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TOLANI MARITIME INSTITUTE'S JOURNAL OF MARITIME FUNDAMENTALS AND APPLIED RESEARCH

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SUBJECTS COVERED

Marine Engineering and Nautical Science

Marine propulsion systems and machinery.

Ship design and hydrodynamics.

Marine refrigeration and air-conditioning systems.

Maritime safety and environmental sustainability.

Navigation systems and nautical charting technologies.

Marine fuel systems and alternative energy sources.

Marine maintenance, diagnostics, and fault detection.

Mechanical Engineering

Thermodynamics and heat transfer applications in maritime systems.

Design and analysis of mechanical components in marine systems.

Fluid dynamics and turbulence modeling for marine applications.

Vibrations and noise control in marine structures.

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General Applied Research

Case studies on complex problem-solving in marine contexts.

Multidisciplinary approaches to maritime innovation.

Emerging technologies and their applications in marine and allied fields.

Research methodologies and experimental techniques in marine sciences.

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ABOUT THE JOURNAL

Tolani Maritime Institute's Journal of Maritime Fundamentals and Applied Research (TMI-JMFAR) is a multidisciplinary platform dedicated to advancing knowledge and fostering innovation in fields related to Marine Engineering, Nautical Science, and allied disciplines. This esteemed journal aims to publish high-quality research encompassing a diverse range of topics, including but not limited to Mechanical Engineering, Electrical and Electronics Engineering, Computer Sciences, Communication Sciences, and Management Sciences. The journal invites contributions that are theoretical, experimental, and numerical in nature, addressing both fundamental and applied aspects of these domains.

TMI-JMFAR emphasizes solving complex real-life problems, making it an ideal platform for researchers, professionals, and academics who aim to make a tangible impact in their respective fields. The scope extends to publishing case studies and literature reviews, alongside original research, thereby providing a holistic approach to knowledge dissemination. This multidisciplinary perspective ensures the journal remains relevant to a wide audience across various technical and management fields.

One of the unique strengths of TMI-JMFAR lies in its rigorous peer review process, which adheres to international standards of scientific publishing. This ensures the credibility, integrity, and quality of every article published. The editorial board, comprising experts from diverse backgrounds, is committed to maintaining the journal's reputation as a hub for excellence in scientific research.

The journal also serves as a platform for the exchange of ideas and information, encouraging cross-disciplinary collaboration and dialogue. Researchers are encouraged to submit work that offers innovative solutions, insights into complex systems, or advances in theoretical understanding. By promoting research that bridges the gap between theory and practice, TMI-JMFAR contributes to the advancement of science and engineering in industries critical to global progress, such as maritime operations and beyond.

With a focus on addressing the challenges of the modern world, TMI-JMFAR invites submissions that explore emerging technologies, sustainable practices, and methodologies that improve operational efficiency and safety. By facilitating the dissemination of cutting-edge research, the journal seeks to inspire and guide future advancements in the fields it represents.

FORMAT OF PUBLICATION

Guidelines for paper submission

- Enter manuscript in MS word, Times New Roman, main text - font 1 subtitle - font 12 and the main title font 12, with main text in the single line spacing double column on A4 sheet.
- Provide every article with an abstract not exceeding 250 words.
- Provide 4-6 keywords.
- Organize paper in smooth flow of title, subtitle and sub-sub title.
- Keep length of the paper to the limit of 12 pages approx.
- Provide 1 inch margin on all sides of the paper
- Provide figures, drawings and graphs in black color on white back ground.
- Submit figures, drawings and graphs in JPEG format with 300 minimum resolution
- Number the figures and tables as per standard practice.
- Provide mathematical equations and functions in suitable equation editor
- List the references at the end of the article with serial number.
- A declaration to the effect that the work is original and has not copied or published earlier elsewhere - needs to be submitted along with the paper.
- On behalf of all the co-authors, the corresponding author shall bear the full responsibility for submission and shall provide his/her full address, contact number and email.
- Follow the suggested order for manuscripts: (In some cases all the points may not come in order as suggested)

Template to Write the Article
• Title, Authors, Affiliations • Abstract • Keywords (provide a maximum of five keywords) Introduction • Main text (may include information based / knowledge based/ theory based/experimental based/model based method) • Data Collection/Data Analysis (if any) • Result and Discussion (If any) • Conclusion References

Technical articles discussing various aspects of science and technology including innovations in the marine field, original research work, experimental investigations with results, industrial practices, case studies are invited for publication. The paper may be please be mailed to jmfar@tmi.tolani.edu

EDITOR's - MESSAGE

Tolani Maritime Institute's Journal of Maritime Fundamentals and Applied Research (TMI-JMFAR) mainly focuses on research related to Marine Engineering and Nautical Science and other disciplines like Mechanical Engineering. Electrical and Electronics Engineering. Computer Sciences, Communication Sciences, and Management Sciences, etc. The scope of the journal covers theoretical. experimental, and numerical research related to basic and applied problems, case studies, and literature reviews from various disciplines mentioned above. We encourage contributions that will be helpful in solving real-life problems which are complex in nature.

TMI-JMFAR also provides a platform for exchanging information on various topics mentioned above. The journal's editorial board members strongly believe in the quality of the research articles, and hence the process of selection of the articles includes a science-driven approach and double-blind peer review process, which conforms to the strict international procedures and editorial standards expected by the scientific community.

I encourage engineering students, research scholars, academicians, industrialists, scientists to contribute their research through publication in TMI-JMFAR. All papers receiving a high degree of enthusiasm in the peer-review process will find a home in TMI-JMFAR. Therefore, we are committed to publishing all discoveries, methods, resources, and reviews that significantly advance the Marine Engineering and Nautical Sciences field.

On behalf of the TMI-JMFAR team, I would like to mention my sincere thanks to the authors, editors, reviewers, technical publication committee members, and bodies who have indirectly supported to achieve the required quality of the research articles and hence the journal. It is with profound pleasure, humility and anticipation that we celebrate the launch of the **Tolani Maritime Institute's Journal of Maritime Fundamentals and Applied Research (TMI-JMFAR)** with this inaugural issue.

At last, I welcome you to contribute to TMI-JMFAR. I see a bright future for TMI-JMFAR with the support of authors, reviewers, and editors. I ensure to serve science and the scientific community even better in the future. Ultimately, we will improve more lives and, consequently, our communities

We would be delighted to hear about your suggestions for improving the quality of TMI-JMFAR on

Thank you. We hope you will find TMI-JMFAR informative and interesting.

Dr. Sanjeet Kanungo
Editor

TECHNICAL TEAM's - MESSAGE

We are pleased to present the first issue of **Tolani Maritime Institute's Journal of Maritime Fundamentals and Applied Research (TMI-JMFAR)**

Tolani Maritime Institute (TMI) has been successful year after year in imparting Marine Education at pre-sea and post sea level because of its strength of faculty members, other resource persons in the organization and the facilities available for the research and industrial project work. TMI has created its benchmark in the Marine Education area.

Tolani Maritime Institute's Journal of Maritime Fundamentals and Applied Research (TMI-JMFAR) provides the platform for the readers, students, academicians, research scholars, industrialists, scientists (authors) to take up the activity of writing and publishing scholarly articles in varied fields of Science, Technology and Management. The TMI-JMFAR Vol. 1, Issue 1 is dedicated to all those who have contributed directly/indirectly in keeping the light of knowledge on.

We are sure that the issue of the journal will keep interest alive of the readers and writers. Enjoy Reading and Writing!!

Technical Team
Tolani Maritime Institute, Pune

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DESIGN AND DEVELOPMENT OF 360 DEGREE FIRE PROTECTION SYSTEM

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***Abstract*:**
History demonstrates that fires on board can result in the loss of ships, including human lives, as the maritime sector has seen in several fire-related tragedies. The crew size of ships is being reduced, and shipping is becoming more autonomous, which presents new difficulties for future ship fire management. This technical paper aims to determine whether the fire safety of unmanned vessels can be guaranteed using advanced fire prevention methods, including the 360-degree Fire Protection System.

The physics of fire and the fundamentals of fire suppression techniques are briefly covered in the theoretical section of this research paper. A number of research publications were examined to learn more about the 360-degree rotating firefighting and fire prevention technology and how they may be applied to guarantee the fire safety of UMS class vessels. The 360-degree fire detection and extinguishing technology, structural fire protection, and possible high-risk sources are all covered in this research paper.

In addition to the research of the whole team, data on the suitability of current systems for unmanned vessels was collected. The data demonstrate that uncrewed ships can be outfitted with an appropriate set of current fire prevention equipment to guarantee fire safety of future ships. But there's still a long way to go, particularly in terms of how reliable alternative technologies for fire management and detection are.

Keywords - Fire, Water Dispersal, Servo Motor, Safety, Hyper mist

I. Introduction

An innovative fire safety initiative called the "360 Degree Fire Protection System" aims to offer complete fire protection from all angles. The device uses clever mechanisms and servo motors to detect and put out fires efficiently. With its capacity to spin and orient towards the fire source and a water dispersal mechanism, this system assures speedy and efficient fire suppression. The 360 Degree Fire Prevention System's main goal is to increase people's and property safety by providing a proactive and automated approach to fire prevention. Conventional fire suppression systems frequently rely on stationary firefighting apparatus, which might not be sufficient to cover all ground or react quickly to fire events.

In contrast, this project overcomes these restrictions by providing a 360-degree coverage with sensors positioned in the north, south, east, and west directions. The primary feature of the system is its capacity to use strategically placed sensors to detect fires. The system turns on the matching servo motor when it detects a fire, allowing it to spin toward the fire. Because of the servo motor's exact and changeable rotation, the system may be precisely positioned to face the fire flame. This feature speeds up response times and increases the likelihood of successful fire suppression by enabling the system to react quickly to fires from any direction.

The system includes a servo motor on the lower side to release the flames. The water dispersal system, which is made up of a pump, valve, and nozzle, is managed by this servo motor. A pressurized water stream is released via the nozzle by the lower servo motor when it aligns with the fire with the directed servo motor. Enough water is directed towards the source of the fire to suppress it properly. An intelligent control unit can be combined with the 360 Degree Fire Protection System to improve its capabilities further. This control unit uses advanced algorithms to maximize servo motor performance and increase the accuracy of fire detection.

The control unit may modify the servo motors' response times and turn on extra safety features like alerts and notifications to notify residents or emergency services by assessing sensor data and environmental factors. Overall, the 360-degree Fire Protection System is a noteworthy development in fire safety technology. The system provides a dependable and efficient fire safety solution in various situations with its accurate location, all-encompassing coverage, and sophisticated management functions.

II. FIRE DETECTION

A. *CNN-based fire detection method using composite channels composed of RGB and IR data*

This seeks to increase fire detection performance by combining RGB and IR data and lower false detection rates; however, picture matching and channel characteristics must be maintained. Furthermore, because the fire detection device functions at all times, it is vital to reduce the load and heat generation of the calculating device by decreasing the amount of calculation and running in real-time.

This study proposes using one-channel IR data and three-channel colour images for the fire detection approach. Data were gathered to use the methodology suggested in this study, and suitable sensors for fire detection were chosen. To monitor a large area at once, the Wide View Lens (M25170H12) and Rpi Camera (G) sensor were combined to create the RGB sensor for obtaining visible light data. In contrast to visible light sensors, infrared sensors are selected based on various application-specific factors. Radiant radiation in the infrared area is scattered and absorbed by components such as smoke, mist, haze, and molecular bulk, resulting in attenuation. As a result, the best fire detection sensor can identify regions with good radiant energy transmittance between 3-5 μm and 8-14 μm. Among these, the long-wavelength infrared is most suited for determining the radiation intensity of a fire located at a distance since it is less impacted by environmental elements such as fog, smoke, and moisture produced during ship operation for the infrared sensor meeting these requirements.

Lepton 3.5 (sensing range 8-14 μm) was selected. It transmits infrared radiation intensity in various situations and can detect the long-wavelength infrared region (lower).

In addition to showing better performance in identifying items that resembled fire or objects with high temperatures, the composite channel model was also helpful in detecting long-distance fires. The project aims to enhance unmanned autonomous vessel fire detection capabilities because fires spread quickly and necessitate prompt identification and suppression. The suggested approach and data consumption across various wavelengths are anticipated to lower false alarms and boost the fire detection system's dependability, making unmanned autonomous operating systems more feasible.

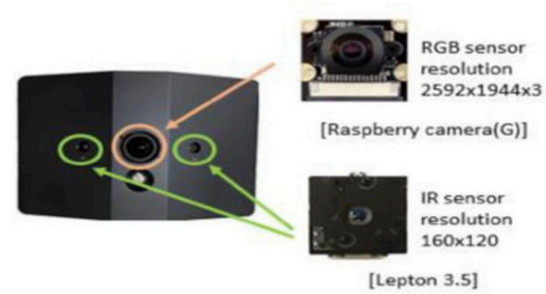

Fig. 1: RGB, IR Modules of Fire detection sensor

Factors and Variables of the dataset.

Factor	Variables			
Materials	Propane, Propane_local_change, Paper, Wood, Power Strip, Grinder, Cooking Oil, kerosene, Welding, Spark, Cigarette, Electric Heater, Radiator, Candle, Lighter, Empty, Electric iron, Frictional Heat, Display (fire video), Tray (Residual heat), kettle, Flashlight, Reflective Images (17)			
Illuminance (lux)	0–151			
Scale		Small	Medium	Large
	Gas (kW)	5	26.5	50
	Fluid (cm)	16	19	22
Distance (m)	5, 8.5, 10, 13, 15, 20, 25			
Height (m)	1, 4.3			

Fig. 2: Factors and Variables of the dataset

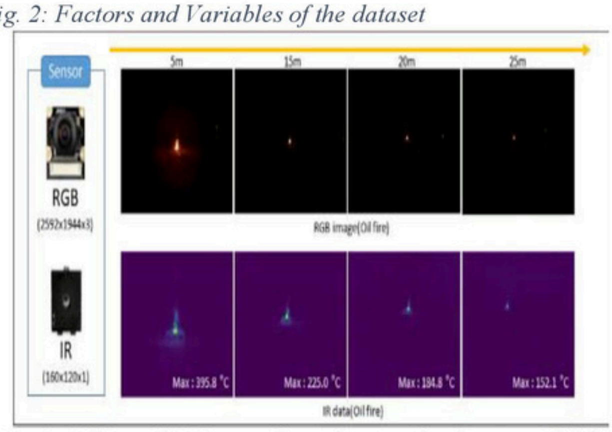

Fig. 3: RGB and IR Image depending on the distance (Oil fire)

B. *Use of AI in fire detection*

The suggested model focuses on a bounding box, colour, and contour-based real-time fire detection system. It uses Google Text-to-Speech Recognition to generate alerts and can distinguish between two flames based on numbers. The system has five masks: Edge Detection, which is free from noisy data, and Bitwise-AND mask for a coloured image of a fire. To ensure precise detection and minimize noisy data, the system incorporates five additional masks.

1) Morphological Transformations

The binary pictures can be subjected to Open CV's morphology operation, represented by morphology Ex (), which only needs two inputs: the kernel image and the original image. Erosion and Dilation are the two fundamental operators; the former calculates the pixel count using the kernel pixel count. An image's erosion weakens the borders between structures, necessitating the opening and shutting of the Dilation process. While closing removes noisy data inside the structure, opening removes noisy data outside.

2) Bitwise AND Operation

Since black is regarded as zero in binary images, Open CV's Bitwise AND operation masks particular channels in images by adding any colour with black. Make an ROI of picture 1 and mask the inverse of image 2 to get a random structure for image 1. With image1 on the white portion and image2 in the foreground, fill the white portion and combine to form a complete ROI. The mask inverse produces black-and-white regions.

3) Edge Detection

As the name suggests, Edge Detection is the automatic detection of an object's edge. Edge detection is the automatic recognition of an object's edge—a location where there is a sudden shift in image intensity. It assists in recognizing abrupt changes in objects and separates them so that semantic and shape information encoded in the edges may be retrieved.

4) RESULTS

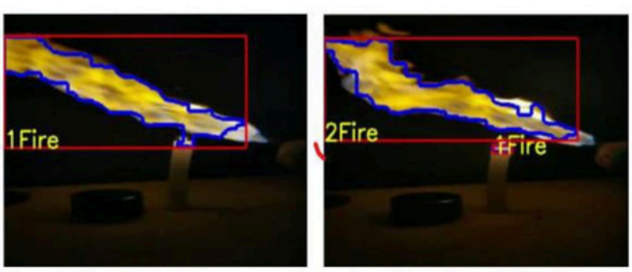

Fig. 4: Fire Detection using Bounding Boxes and Contours

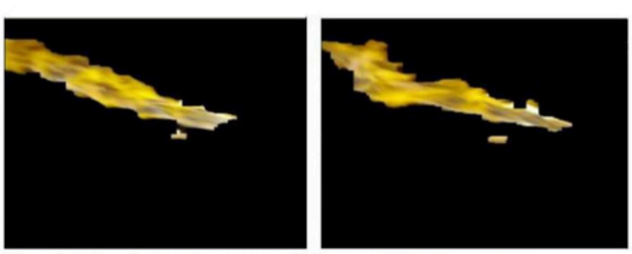

Fig. 5: Fire Detection using Bitwise AND Operation

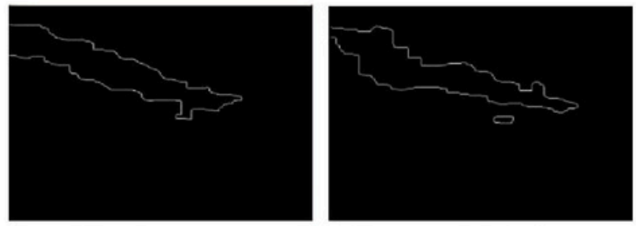

Fig.: 6 Fire Detection using Edge Detection Method

During a real-time test, three masks were formed: the original mask, the BitWise AND mask, and the edge detection mask. The original mask displayed a number representing fire, indicating one object. The system differentiated them as 1 and 2 if two fires were present.

III. LLITERATURE SURVEY

1."A 360-Degree Fire Fighting System using Wireless Sensor Networks," by Min Chen, Zenghua Zhao, and Lingyan Ran, published in the Journal of Network and Computer Applications in 2011.

This study proposes a wireless sensor network-based 360-degree fire-fighting system that utilizes several sensors and actuators to detect and extinguish fires. With sensors placed thoughtfully to detect flames from all directions, the system is built to offer thorough coverage and quick response times. The authors describe the system architecture, sensor location, control algorithms, and experimental findings and also present the system's effectiveness.

2."Development of a 360-Degree Fire Protection System for Smart Buildings," by Hyun-Il Lim, Young Hoon Cho, and Se-Jin Kim, published in the International Journal of Electrical and Computer Engineering in 2018.

This paper presents a 360-degree fire safety system intended for smart buildings. The system combines heat sensors and video cameras to identify fires, and it uses gas suppression and sprinkler systems to put them out. The authors explain the system architecture and algorithms utilized for fire detection and suppression and present experimental findings that corroborate the system's efficacy.

3. "An Intelligent Fire Extinguishing System Based on 360-Degree Coverage," by Yanyan Li, Ming Zhou, and Zhenhua Li, published in the Journal of Computational Information Systems in 2018.

This paper presents an intelligent fire extinguishing system based on 360-degree coverage. The system employs a high-precision servo motor to precisely position the extinguisher nozzle and infrared, ultrasonic, and video cameras for fire detection. The authors offer experimental results showing the system's efficacy and describe the system architecture and the algorithms used for fire detection and suppression.

4."Design and Implementation of a 360-Degree Fire Detection and Suppression System Using Internet of Things," by Yinping Zhang, published in the Journal of Sensors in 2019.

This paper presents a 360-degree Internet of Things (IoT) fire detection and suppression system. The system uses a water mist extinguishing system for suppression and a combination of temperature sensors, smoke detectors, and video cameras for fire detection. The authors explain the system architecture and algorithms utilised for fire detection and suppression and present experimental findings that corroborate the system's efficacy.

5. "A Novel 360-Degree Firefighting Robot System for High-Rise Buildings," by Qi Zhang, Zhihao Wang, and Yan Jin, published in the IEEE Access Journal in 2021.

This paper presents a brand-new 360-degree firefighting robot system intended for use in tall buildings. For precise positioning, the system uses a robotic platform fitted with sensors, extinguishing agents, and a high-precision servo motor. The authors explain the system architecture and algorithms utilized for fire detection and suppression and present experimental findings that corroborate the system's efficacy.

IV. METHODOLOGY

The "360 Degree Fire Protection System" flowchart lists the steps that must be taken for the system to function. It offers a graphic depiction of the entire process, from fire detection to suppression. The system's initialization is shown in the flowchart before the flame sensor's ongoing monitoring. The servo motors on the pump direct the water spray through the nozzle when the system detects a fire. The flowchart depicts the feedback loop, which shows that the system keeps running until the fire is put out or manually reset. The flowchart helps visualize the interactions between various parts and processes and is a guide for comprehending the logical flow of the system's functionality.

I. BLOCK DIAGRAM

The "360 Degree Fire Protection System" block diagram offers a high-level summary of the architecture of the system and the connections between its significant parts. The functional building blocks of the system and their connections are shown graphically. The block diagram usually shows components like the flame sensor, Arduino Nano microcontroller, power supply, voltage regulator, LCD, buzzer, main servo motor, pump servo motor, relay, and pump. The connections between these parts show how information and control signals move through the system. The block diagram facilitates the process of analysis and design by aiding in understanding the system's general structure and organization. It helps with troubleshooting and future development and is a valuable tool for communicating and documenting the system's architecture.

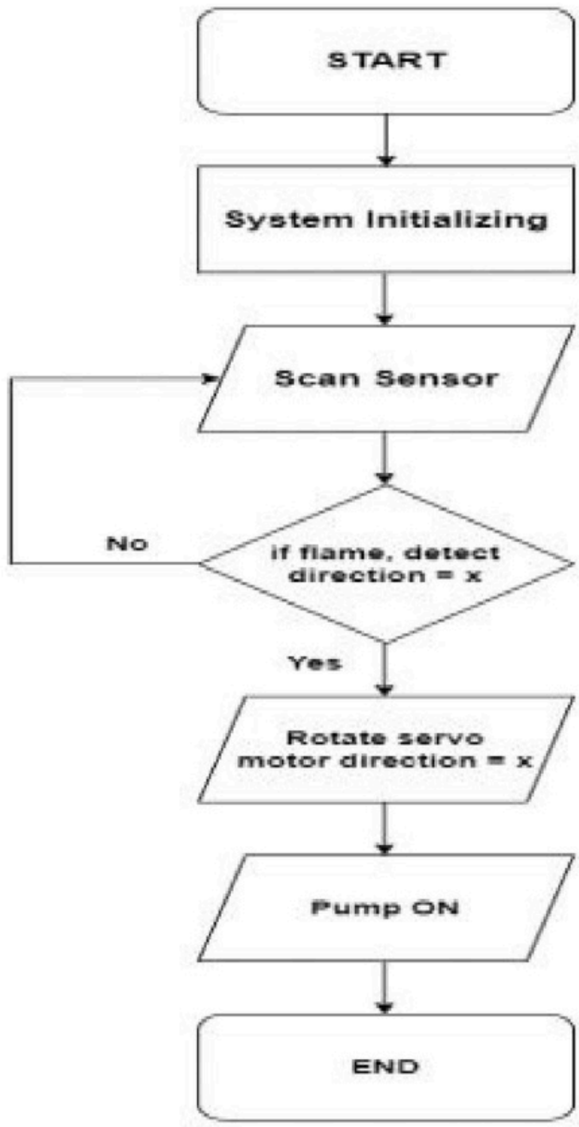

Fig. 7: Flowchart of the System

II. EFFECTS OF WATER MIST

Water mist, composed of tiny droplets (Dv99 < 1000 µm), is environmentally friendly, non-toxic, and easy to clean after extinguishing a fire. The fundamental concept of using water mist for suppressing liquid and solid fuel fires was first explored and documented in the mid-1950s. Over the past two decades, water mist has demonstrated its effectiveness in combating various types of fires. These include Class A fires in shipboard accommodations, office and residential buildings, and historical sites like wooden churches and libraries; Class B fires, such as spray and pool fires in machinery spaces, gas turbines, and bulk conveyors; Class C fires involving electronic and computer equipment; and Class K fires, which commonly occur in commercial kitchens.

Three types of water mist systems can be distinguished based on their intended uses:

- Zoned application (ZA) system
- Local application (LA) system
- Total compartment application (TCA) systems

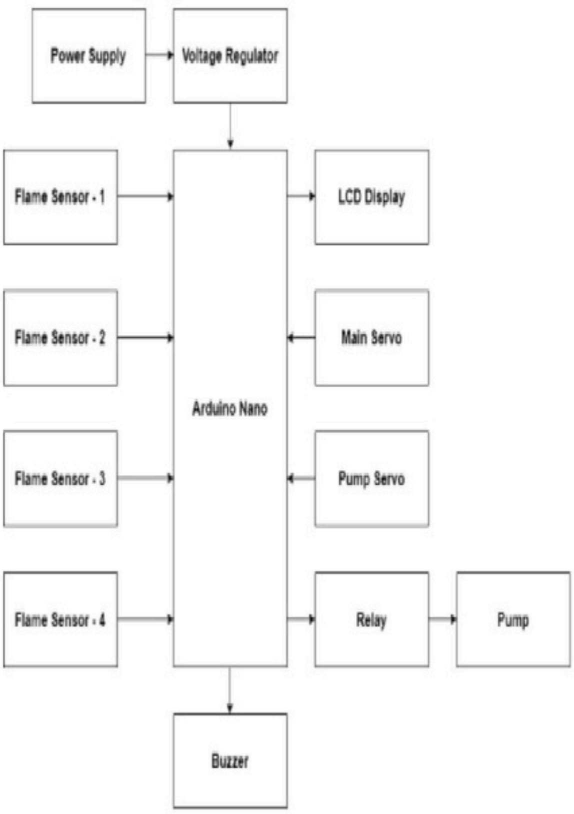

Fig. 8: Block diagram of the system

In a Total Compartment Application (TCA) system, water is dispersed from multiple nozzles positioned throughout the compartment. This system effectively suppresses largely confined fires by rapidly lowering the oxygen concentration due to fire consumption and water vapour displacement. In contrast, a Local Application (LA) water mist system targets a specific hazard or object in enclosed, partially enclosed, or open outdoor spaces. The primary extinguishing mechanism involves cooling either the fuel surface or the flames.

A portable water mist extinguisher is a typical example of a local application. However, it has a smaller spray coverage and a limited water supply than a stationary LA system. Additionally, its pressure declines rapidly during discharge. The effectiveness of water mist in fire suppression depends on factors such as droplet size, water flow density, and spray coverage, which vary depending on the type of fire encountered. Early research on water mist indicates that solid fuel fires are primarily extinguished through fuel surface cooling. In contrast, liquid fuel fires can be suppressed by either cooling the fuel or the flames, depending on the fuel's characteristics. Although both theoretical and experimental studies have helped define the general principles of water mist fire suppression, there remains a lack of precise data on the specific mist properties required for different types of fires. This knowledge gap has slowed the development of optimized water mist fire suppression technologies.

Only one commercially available water mist extinguisher is specifically designed for solid Class A and Class C fires. Studies show that low-temperature liquid pool fires are mainly extinguished by flame cooling, whereas high-temperature pool fires require fuel and flame surface cooling. The interaction between the water mist and the flame enhances heat transfer, causing the fire to grow temporarily during suppression. As the fire plume detaches from the fuel surface, volatile fuel vapours ignite and expand in the air, leading to flare-ups. Fuel surface cooling is the primary extinguishing method for solid fuel fires, such as wood crib fires. However, since wood crib fires are three-dimensional, they require a longer suppression period and a greater water volume to achieve full extinguishment.

III. Prototype Water Mist Extinguishers

Seven different types of commercially available mist nozzles were evaluated for their spray performance, including spray angle, coverage, and flow rate, across various operating conditions. Based on their spray characteristics, two nozzles were selected for use in the prototype portable water mist extinguishers.

The extinguisher comprises four main components: a hose assembly, cylinder, nozzle, and nozzle holder. The cylinder has a maximum capacity of 9.4 litres of water. The accompanying table presents the key water mist properties of the two selected extinguishers.

Table 1: Table: Water mist characteristics of two extinguisher

	Pressure(bar)	2.0	4.0	6.8	10.2	13.6	17.0	20.4
Ext1	Spray angle	120		95		87		75
	Droplet (Dv0.9)				320	290	270	
	Flow rate (Lpm)	6.3	9.3	12	14.6	16.8		
Ext2	Spray angle	60		55		55		50
	Droplet (Dv0.9)					190	180	170
	Flow rate (Lpm)	4.5	6.3	8.2		11.6		

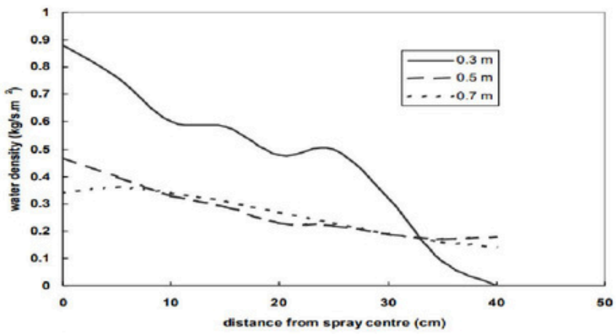

Fig. 9: Changes in the water density of Extinguisher #1 with varying discharge distances during the initial release phase (0–15 s).

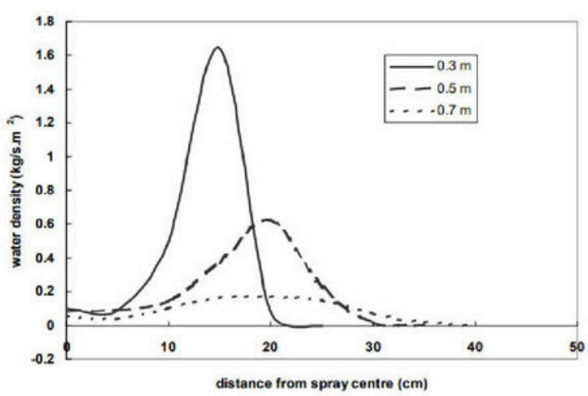

Fig. 10 Changes in the water density of Extinguisher #2 based on discharge location and distance as the discharge time varies from 0 to 15 seconds.

IV. CONCLUSION

For both residential and commercial applications, the "360 Degree Fire Protection System" is a promising fire safety solution. The system's capacity to identify and put out fires employing servo motors, cutting-edge sensor technology, and a modifiable design, making it a dependable and effective solution for increased security and safety.

The project's goals were effectively accomplished, including creating a system that could swiftly put out flames and detect them from all directions. Using a flame sensor, the system could identify flames and then use a water pump, nozzle, and valve to put them out. The system effectively prevented fires since it could turn the main servo motor toward the fire and turn on the pump servo motor to spray water.

The system's features, including 360-degree coverage and an adaptable architecture, make it a flexible option for various settings and uses. To provide increased safety and security, the system can be tailored to meet the particular needs of multiple locations and buildings.

The system's drawbacks must be considered, including its dependence on water as an extinguishing agent and the requirement for ongoing maintenance. For some settings, other extinguishing chemicals might need to be used, and routine electrical system maintenance is required to avert malfunctions that could result in fires.

In conclusion, the "360-degree Fire Protection System" offers a viable way to prevent fires in commercial and residential settings. Its 360-degree coverage, fast fire detection and extinguishment, and adaptable design make it a dependable and practical option for increased safety and security. Addressing the system's limits is imperative to guarantee that it successfully prevents fires.

IX REFERENCES

[1] M Outinen, Kansa, Fire protection of steel structures using water sprinklers, ASFE conference, Prague, 2009.

[2] Ciucă, Dragoș. "Fire Protection of Steel Structures." Scribd. Accessed February 26, 2025. https://www.scribd.com/document/150589357/Fire-Protection-of-steel-structures.

[4] Majid Bahrepour, Berend Jan van der Zwaag, Nirvana Meratnia and Paul Havinga, "Fire Data Analysis and Feature Reduction Using Computational Intelligence Methods", Advances in Intelligent Decision Technologies. Smart Innovation, Systems and Technologies, vol 4. Springer, 2010.

[5] R. Divya and D. Mageshwari, "A Novel Fire Detection System using Image Processing and Artificial Intelligence Techniques", IJCA Proceedings on Emerging Technology Trends on Advanced Engineering Research-2012, ICETT (2):15-18, 2013.

[6] Braidech, M.M., Neale, J.A., Matson, A.F. and Dufour, R.E., "The Mechanisms of Extinguishment of Fire by Finely Divided Water," Underwriters Laboratories Inc. for the National Board of Fire Underwriters, NY, p.73, 1955.

[7] Rasbash, D.J. and Rogowski, Z.W., "Extinction of Fires in Liquids by Cooling with Water Sprays," Combustion and Flame, Vol. 1, 1957.

[8] Rasbash, D.J., Rogowski, Z.W. and Stark, G.W.V., "Mechanisms of Extinction of Liquid Fuel Fires with Water Sprays," J. of Combustion and Flame, Vol. 4, 1960, pp. 223-234.
[9] Liu, Z. and Kim, A. K, "A Review of Water Mist Fire Suppression Systems – Fundamental Studies," J. of Fire Protection. Engineering, 10 (3), 2000, pp 32-50
[10] Liu, Z. and Kim, A. K., "A Review of Water Mist Fire Suppression Systems – Application Studies," J. of Fire Protection. Engineering, 11 (1), 2001 22
[11] D. Kim and Won-Sun Ruy, "CNN-based fire detection method on autonomous ships using composite channels composed of RGB and IR data," vol. 14, pp. 100489–100489, Oct. 2022, doi: https://doi.org/10.1016/j.ijnaoe.2022.100489.
[12] T. N. Khoon, P. Sebastian, and A. B. S. Saman, "Autonomous Fire Fighting Mobile Platform," *Procedia Engineering*, vol. 41, pp. 1145–1153, 2012, doi: https://doi.org/10.1016/j.proeng.2012.07.294.

A DETAILED REVIEW OF MARINE POLLUTION; ITS SOURCES, EFFECTS AND REMEDIES

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***Abstract*:**
Marine ecosystems, biodiversity, and human well-being are significantly impacted by marine pollution, making it a critical worldwide concern. This disturbs marine life and the marine ecosystem, thus disrupting the food chain and leading to the downfall of natural habitats or niches. The current research paper presents data on the different sources of marine pollution, its effects on marine life, country-wise data on the contaminants in seawater, remedies, different projects used to control marine pollution, and its role in economic development. This review examines the causes, consequences, and possible solutions related to marine pollution. The sources include ship pollution, chemical runoff, oil spills, plastic pollution, and heavy metal contamination. Every source affects human health, habitats, and biodiversity by causing the degradation of marine environments. Loss of biodiversity, devastation of habitats, dangers to human health, negative economic implications, and contributions to climate change are all consequences of marine pollution. Several solutions are addressed, focusing on public awareness, education, inventive technologies, international cooperation, regulatory frameworks, and promoting alternative materials. Combining these components is essential for creating policies that effectively reduce marine pollution, encourage sustainable activities, and preserve the resilience and health of marine ecosystems for future generations. The findings from each section are also briefly mentioned at the end of the section. This research paper also includes the scope for future work.

Keywords: *Marine pollution, sources of pollution, remedies*

I. INTRODUCTION

Marine pollution is a critical issue that needs to be addressed to protect the environment. Current trends show that the different sources of marine pollution are toxic chemicals, sewage and fertilisers, plastics, and discarded fishing nets [1]. Water treatment, which includes other sources of pollution, is essential, and researchers need to address different ways to tackle this issue.

Marine pollution, caused by various human activities, seriously threatens the sustainability and overall health of our oceans and seas. The influx of contaminants, including heavy metals, oils, plastics, and chemicals, has significantly impacted marine ecosystems. This review examines the causes, effects, and potential remedies for this growing worldwide issue.

Marine Pollution Sources:

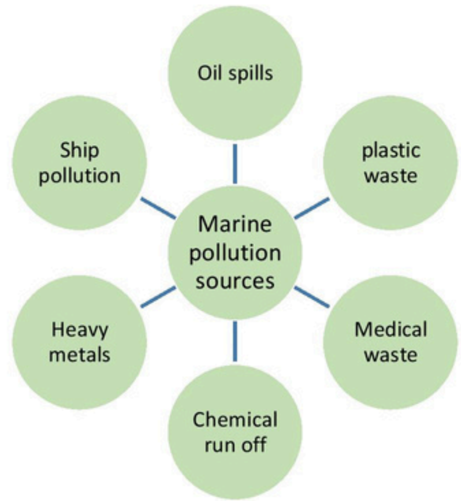

Fig. 1 Sources of Marine Pollution

Oil spills, plastic waste, chemical runoff, heavy metals, and ship pollution are the leading causes of marine pollution. These contaminants upset the sensitive equilibrium of aquatic ecosystems, frequently resulting from industrial operations, inappropriate waste disposal, and the release of untreated effluents.

Table 1: Representing pollutants, its sources and effects

S. No.	POLLUTANT	SOURCES	EFFECTS
1	Microorganism	Domestic waste, dung	Undrinkable water
2	Organic waste	Animal excreta, food waste, detergents, decayed animal	Increased number of bacteria, decreased oxygen levels, death of aquatic life
3	Plant nutrients	Chemical fertilisers	Algae blooms
4	Heavy materials	Metals from factories	Acute and chronic illness.
5	Heat	Water used for cooling purposes in industries	Decrease in oxygen levels, death of fishes and plants.
6	Pesticides	Chemicals used for killing insects, fungi	It kills aquatic life and can enter the human food chain.

Repercussions of Ocean Pollution: Marine pollution has various negative effects, including habitat damage, biodiversity loss, dangers to human health, economic disruption, and a significant contribution to climate change. These consequences highlight how urgent it is to implement policies to lessen and prevent future harm to marine habitats.

Means of Combating Marine Pollution: Marine contamination requires a multifaceted approach to address. Strict regulatory frameworks like the MARPOL Convention must promote international collaboration. Innovative technology for water treatment, plastic waste disposal, and oil spill cleaning can provide promising answers. Education and public awareness campaigns can modify behaviour and promote waste management and responsible consumption. Pollution can also be prevented by supporting recycling, using substitute materials, and requiring sustainable business practices.

II. REMEDIES

Bioplastics: Bioplastics are an effective solution to lessen the environmental impact of traditional plastics, which is essential in the fight against marine pollution. The following are some significant ways that bioplastics support this endeavor

Biodegradability: Many bioplastics are made to be biodegradable, which allows microorganisms to break them down organically over time. In comparison, conventional plastics have a long environmental half-life—they can last for hundreds of years. In marine ecosystems, using biodegradable bioplastics can reduce the buildup of plastic trash.

Renewable Resources: Plant-based materials, such as corn, sugarcane, and potato starch, are familiar sources of bioplastics. Because bioplastics rely on renewable resources instead of finite fossil fuels, they are a more sustainable option for plastics than traditional ones.

Reduced Carbon Footprint: Compared to traditional plastics, the manufacture of bioplastics may have a smaller carbon footprint. This is especially true for bioplastics made from plants since plants take up carbon dioxide during growth, which helps offset emissions from the production process.

Non-toxic Breakdown: Bioplastics typically do not emit hazardous chemicals into the environment during their breakdown. This is not the case with traditional plastics, which can poison marine life by releasing harmful compounds during their degradation.

Innovation in Material Design: Continuous bioplastics research and development enable the development of materials with particular features and functions. Thanks to this breakthrough, biodegradable plastics with customised properties that work well for various applications can now be produced.

Closed-loop Systems: Certain bioplastics can be included in closed-loop systems, allowing for more effective recycling or reuse. This lessens the need for new plastics to be produced overall and reduces the environmental damage that comes with the polymer's life cycle.

Consumer Awareness: Using bioplastics can help increase consumer knowledge of how plastics affect the environment. Goods with biodegradable or renewable resource labels may promote more conscientious consumption patterns and trash disposal procedures.

Although bioplastics present several benefits in mitigating marine pollution, some obstacles must be considered. For example, many bioplastics need particular circumstances to biodegrade efficiently, and industrial composting facilities aren't always accessible. Furthermore, there are worries regarding land use and possible effects on food security due to the competition between food and non-food crops to manufacture bioplastics.

In conclusion, bioplastics have a significant impact on lowering marine pollution. Still, this contribution should be made as part of a larger plan addressing sustainable consumption practices, trash reduction, and improved recycling infrastructure.

Table 2: *Table representing causes of marine pollution*

S No.	Main Causes Of Water Pollution
1	Sewage
2	Industrial Waste
3	Medical Waste
4	Household Waste
5	Oil Pollution
6	Thermal Pollution
7	Plastic And Garbage

III. MAJOR OIL SPILLS IN HUMAN HISTORY

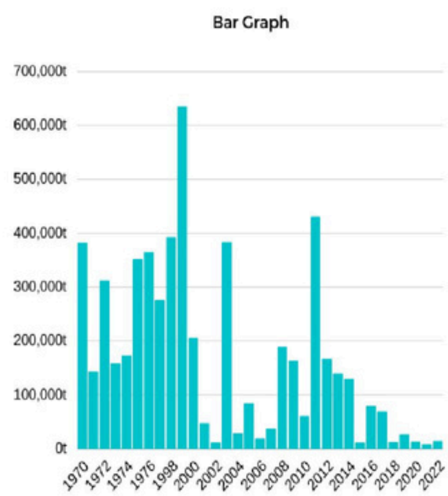

Fig.2 Major Oil Spills in Human History

Throughout history, there have been several oil spills that have seriously harmed the ecosystem and marine there are a few oil spills that have occurred in human history:

The 1989 Exxon Valdez:

Place: Prince William Sound, United States of America

Cause: About 11 million gallons (41,640 cubic metres) of crude oil spilt into Prince William Sound after the Exxon Valdez oil tanker ran aground. It is among the most notorious oil spills, seriously harming ecosystems and marine life.

The 2010 Deepwater Horizon:

Location: USA's Gulf of Mexico

Cause: A blowout on a BP-operated offshore drilling rig resulted in a significant oil leak. During the 87-day disaster, the largest accidental maritime oil spill occurred, releasing an estimated 4.9 million barrels (210 million gallons) of oil into the Gulf of Mexico.

Ixtoc I (1979–1980):

Location: Bay of Campeche, Mexico

Cause: A blowout in a Pemex-operated oil well resulted in an uncontrollable oil leak. 140,000 tonnes or approximately 3.3 million barrels of oil were spilt into the Gulf of Mexico throughout the roughly ten-month well-capping process.

The 1967 film Torrey Canyon:

Approximately 25,000 tonnes of crude oil were released into the English Channel after the oil tanker Torrey Canyon ran aground in Southwest England and the Scilly Isles. It was among the first large-scale oil spills and caused serious harm to coastal ecosystems and marine life.

1991's Gulf War:

Location: Persian Gulf

Cause: One of the most significant oil spills in history was caused by Iraqi forces purposefully releasing enormous amounts of oil into the Persian Gulf during the Gulf War. Although estimates of the oil spilt vary, it is thought to have been around 240 million gallons, or roughly 6 million barrels.

The 1978 Amoco Cadiz:

Location: In French Brittany, off the coast

Cause: During a storm, the oil ship Amoco Cadiz ran aground, releasing nearly 1.6 million barrels, or 68 million gallons, of crude oil into the atmosphere. It seriously harmed coastal ecosystems and marine life.

These oil spills have harmed fish and wildlife, contaminated shorelines, and caused long-term ecological harm, all of which have had a profound and long-lasting effect on marine ecosystems. However, there has been a significant increase in the effort to prevent and respond to oil spills, and the likelihood of such events persists, underscoring the significance of sustainable practices and emergency response readiness.

IV. LATEST STRATEGIES FOR COMBATING MARINE POLLUTION

It takes a variety of creative strategies, cutting-edge technologies, and legislative initiatives to address the complicated issue of marine pollution. According to my most recent knowledge update from January 2022, the following are some novel and perhaps cutting-edge solutions to address marine pollution:

Ocean Cleanup Technologies:

Projects such as "The Ocean Cleanup" utilise cutting-edge technologies, like passive floating barriers, to gather plastic debris from surrounding waters. These devices concentrate and collect trash using the natural ocean currents.

Bioremediation and Biofilters:

The application of biological processes to degrade water contaminants is still being studied. This involves using specific microbes and plants that can absorb or metabolise toxins, helping to clean up contaminated environments naturally.

Autonomous Vehicles for Monitoring and Cleanup:

Autonomous surface vessels and unmanned aerial vehicles (UAVs) outfitted with sensors are used to monitor and gather information on marine pollution. Additionally, some prototypes have systems for collecting and clearing trash out of the water.

Enzymes That Eat Plastic:

Researchers are investigating using enzymes to degrade specific kinds of plastic. Scientists have found microorganisms naturally generating enzymes that can degrade polymers like PET. These enzymes may be employed to break down environmental plastic waste.

Waste Management and the Circular Economy:

Encouraging resource reuse and developing goods with recycling in mind are key components of promoting a circular economy. Better waste management and recycling facilities keep plastic and other pollutants from entering maritime habitats to a minimum.

Policy and Regulatory Measures:

Stricter enforcement of laws about industrial discharges, single-use plastics, and other sources of pollution can have a significant effect. Several nations and areas are enacting prohibitions on specific kinds of single-use plastics and tightening regulations on industrial trash disposal.

Underwater Drones for Monitoring and Cleanup:

To monitor and remove marine pollution in underwater habitats, including the seabed, autonomous underwater vehicles (AUVs) with sensors and manipulators are being developed.

Innovative Materials and Packaging:

Scientists are trying to create substitute materials that are easier to recycle, biodegrade, or more suited to the environment. One way to do this is to investigate materials made of fungus, algae, or other sustainable sources.

Public Awareness and Education

Raising public awareness of the harms caused by marine pollution can influence people's actions. Education programmes can promote correct waste disposal, minimisation, and responsible consumption.

It's important to remember that these therapies' efficacy varies and that considerations like technological viability, economic viability, and international cooperation often affect how widely they are implemented. Furthermore, since my last update in January 2022, there might have been fresh advancements in the dynamic field of environmental solutions.

V. ADVANTAGES OF MARINE POLLUTION

It's critical to make clear that ecosystems, marine life, and human activity are all deemed negatively impacted by marine pollution. However, unforeseen effects or apparent benefits in particular situations or places might exist. It's important to remember that these alleged "advantages" are frequently fleeting and hurt the planet's and marine ecosystems' general health. Here are a few examples where some might see benefits:

Oil exploration and economic activity:

In places where oil exploration and extraction are significant industries, the presence of oil in the marine environment may encourage economic activity and the creation of jobs. Oil spills can have significant and long-lasting consequences on marine ecosystems. Therefore, it is important to weigh the economic benefits against the substantial biological and environmental risks.

Nutrient Runoff's Fertilisation Effect:

Nutrients from agriculture, such as nitrogen and phosphorus, can cause eutrophication in coastal waters. While algal blooms and "dead zones" caused by excessive nitrogen discharge can be detrimental to marine ecosystems, in other circumstances, the higher nutrient levels may increase the productivity of some species. Though the long-term effects are frequently detrimental, this can result in short-term gains in fishery yields in particular places.

It is imperative to underscore that the broader adverse effects of marine pollution surpass these ostensible benefits. These detrimental effects consist of:

- Disturbance of Ecosystem: Marine pollution can disturb ecosystems, resulting in biodiversity losses and changes to natural habitats.
- Dangers to Health: Human health may be threatened by marine environment contaminants such as heavy metals and hazardous chemicals if contaminated seafood is consumed or if exposure occurs directly.
- Economic Losses: Any short-term economic gains are greatly outweighed by the long-term financial consequences of marine pollution, which include losses to fisheries, tourism, and infrastructure damage.
- Changing Climate: Pollutants have an additional effect on marine ecosystems due to factors like ocean acidification and temperature fluctuations, which are factors in climate change.

  The long-term survival of marine ecosystems and the welfare of aquatic and human populations depend on the fight against marine pollution. Sustainable practices, efficient waste management, and international cooperation are crucial to addressing and mitigating its effects.

VI. NUMERICAL EVALUATION OF MARINE POLLUTANTS

Different components of marine pollution are measured and quantified using a variety of indices and equations. Here are a few instances:

WQI (Water Quality Index) :

$$WQI=(wi*li)/wi \quad ---- \quad 1$$

Ii denotes each parameter's sub-index, and the weight allocated to each water quality parameter is Wi. The Water Quality Index (WQI) comprehensively evaluates water quality by considering factors such as dissolved oxygen, biochemical oxygen demand, nutrients, and heavy metals.

Biochemical Oxygen Demand (BOD):

$$BOD = (DOi - Dof)*P \quad --- \quad 2$$

DOi represents the starting concentration of dissolved oxygen, DOf represents the end concentration, and P is a dilution factor. The amount of dissolved oxygen used by microbes in the breakdown of organic matter in water is measured by BOD, which indicates the level of organic pollution

Index of Pollution Load (PLI):

$$PLI = (C1/S1)*(C2/S2)*\ldots*(Cn/Sn) \quad ---- 3$$

Si is the standard or allowable limit for that pollutant, and Ci is the concentration of that particular pollutant. PLI evaluates an area's total pollution level by taking into account a variety of pollutants

Heavy Metal Pollution Index (HPI) :

$$HPI= (Ci/Si)/n* 100 \quad --- \quad 4$$

Si is the standard or allowable limit, and Ci is the concentration of a heavy metal. HPI is specifically designed to evaluate the degree of water pollution caused by heavy metals.

The Sediment Quality Index (SQI)

$$SQI = (Ci/ERLi)/n*100 \quad --- \quad 5$$

ERLi is the effects range-low value for that pollutant, and Ci is the contaminant concentration in the sediment. SQI assesses sediment quality based on possible ecological danger.

To effectively manage and remediate marine pollution, scientists, environmentalists, and politicians use these equations and indices as instruments to analyse and monitor the contamination objectively.

Let's look at a little illustration for each of the values stated above:

1. The WQI (Water Quality Index):

Assume the following parameters for water quality, together with the corresponding sub-indices:

Oxygen Dissolved (DO): Ido = 80

Oxygen Demand (BOD) biochemical(BOD):Ibod=60

Levels of Nutrients (N): In=70

Each parameter has the following weights set to it: -

Wdo = 0.5

Wbod = 0.3

Wn = 0.2

One can compute the WQI as follows:

WQI = (0.5 * 80) + (0.3 * 60) + (0.2 * 70)

2.Oxygen Demand by Biochemistry (BOD):

Assume that there are eight milligrammes of dissolved oxygen at the beginning DOi, two milligrammes at the end DOf, and five milligrammes at the dilution factor P. One way to calculate the BOD is:

BOD = (8 - 2) * 5.

3. Environmental Load Index (ELI)

Assume the following three pollutants have standard limits Si and concentrations Ci:

The first pollutant is C1 = 20, S1 = 10.

S2 = 5 and C2 = 15 are the values for Pollutant 2.

The third pollutant is C3 = 30, S3 = 25.

PLI =(20/10)*(15/5)*(30/25) is one way to calculate the PLI.

4. The (HPI) Heavy Metal Pollution Index:

Let us examine two heavy metals that have standard limits Si and concentrations Ci:

The first metal is C1 = 2, S1 = 1.

The second metal is C2 = 1.5, S2 = 0.5.

One way to compute the HPI is: \[HPI = (1.5/0.5)2 + (2/1) *100

5. SQI, or Sediment Quality Index:

Assume two pollutants with range-low values ERLi and concentrations Ci in the sediment:

The first contaminant is C1 = 8, ERL1 = 5.

Contaminant 2: ERL2 = 10, C2 = 12

The formula for calculating the SQI is: (8/5) + (12/10)(2)* 100 is SQI.

These examples offer a condensed representation of the computations required for each index. Real-world situations could call for more variables and intricate computations based on particular information and guidelines.

VII. CONCLUSION

To sum up, marine pollution is a serious worldwide problem that needs to be addressed right now and requires cooperation from all sectors of society, including governments, businesses, and communities. Pollutants severely negatively influence marine ecosystems, impacting not only the wide variety of aquatic life but also human health and welfare. To prevent more harm to our seas, immediate action is needed to address the causes of marine pollution, implement efficient waste management plans, and encourage environmentally friendly behaviours.

Since marine pollution crosses national borders, international cooperation is essential to developing and implementing strict rules. Public awareness and education are also critical to creating a sense of accountability and encouraging behavioural changes that support a better marine environment. Long-term efforts to combat marine pollution depend on developing eco-friendly alternatives and innovative waste reduction technology.

In the end, maintaining the health of our seas is both a moral duty for present and future generations and an environmental need. By taking a comprehensive and proactive approach, we can work towards healthier and cleaner waters while protecting the priceless biodiversity and ecosystem services that our oceans offer.

VIII. ACKNOWLEDGEMENT

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IX. REFERENCES

[1]. Clark, R. B. (2015), Marine Pollution. Oxford University Press.

[2]. Derraik, J. G. (2002), The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin, 44(9), 842-852.

[3]. Thompson, R. C., Moore, C. J., vom Saal, F. S., & Swan, S. H. (2009). Plastics, the environment and human health: current consensus and future trends. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2153-2166.

[4]. Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015), Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

[5]. United Nations Environment Programme (UNEP). (2016), Marine Plastic Debris and Microplastics: Global lessons and research to inspire action and guide policy change.

[6]. International Maritime Organization (IMO), (2018), Action Against Marine Plastic Litter. MEPC 72/INF.12.

[7]. NOAA Marine Debris Program: (https://marinedebris.noaa.gov/)

[8]. https://theoceancleanup.com

[9]. Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., ... & Watson,R (2008), A global map of human impact on marine ecosystems. Science, 319 (5865), 948-952.

[10]. Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., ... & Taylor, W. W. (2007). Complexity of coupled human and natural systems. Science, 317(5844), 1513-1516.

INTEGRATED APPROACHES FOR EFFECTIVE HULL CORROSION AND BIO-FOULING CONTROL IN MARINE ENVIRONMENTS- A COMPREHENSIVE REVIEW

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***Abstract*:**

The shipping industry faces problems in physical and operational management due to bio-fouling and corrosion of hulls. This technical paper explores innovative hull protection and anti-fouling techniques to address these challenges in maritime applications. This study explores new research in materials science, coating technology and sustainability strategies to extend the life of marine structures and improve fuel efficiency. The report also explores new concepts for product design using advanced materials. The paper examines traditional anti-fouling methods, such as biocidal coatings and sacrificial anodes, and highlights their limitations, including environmental concerns and reduced effectiveness over time. These findings contribute to the maritime industry's ongoing efforts to develop cost-effective, environmentally friendly and economical ship protection and solutions.

This article first reviews bio-fouling analysis methods, including visual inspection and manual cleaning time, and highlights their limitations in terms of quality of performance.

This report also discusses the environmental impact of bio-fouling and evaluates the effectiveness of different anti-fouling techniques and strategies to reduce fouling adhesion. It discusses the development of environmentally friendly anti-pollution solutions and their integration into fleet management, including efficiency and environmental sustainability.

Keywords: ***Shipping industry, bio-fouling, hull corrosion, hull protection, anti-fouling techniques***

I. Introduction

Hull Corrosion and Biofouling are major issues for ships. The Maritime industry plays a significant role in the transportation of goods. Trade depends on the efficiency and reliability of ships. The study of corrosion and anti-fouling protection technique development began in the 19th century and continues today. The submerged surfaces of ship hulls are constantly exposed to harsh marine environments, leading to two significant challenges: hull corrosion and bio-fouling. These issues compromise the vessels' structural integrity and have far-reaching economic and environmental implications.

Corrosion is the chemical or electrochemical effect of a corrosive environment that damages the product. Corrosion is, therefore,, a permanent problem for humans; as marine science creates and creates, the technology uses and advances, and humans find ways to achieve this and more space as they find space. Generally speaking, we can say that a corrosion attack can bring many costs, including environmental pollution, affecting equipment safety and causing serious damage. Problems with ocean corrosion have been studied for many years, but despite published data on the behavior of materials in the ocean, failures still occur.

Hull Corrosion involves the gradual deterioration of a ship's metal structure due to electrochemical reactions with seawater. Various factors, including the composition of the hull material, water salinity, temperature, and the presence of impurities influence this phenomenon. Corrosion not only compromises the vessel's structural integrity but also increases maintenance costs and poses environmental risks by releasing corroded materials into marine ecosystems.

On the other hand, bio-fouling is the accumulation of marine organisms, such as barnacles, algae, and molluscs, on the submerged surfaces of a ship's hull. This process is accelerated by the conducive environment created by combining warm seawater and nutrient-rich particles. As bio-fouling progresses, it significantly increases drag, decreasing fuel efficiency and increased greenhouse gas emissions. Moreover, the transportation of invasive species through bio-fouling threatens marine ecosystems globally.

This article aims to provide a detailed overview of shell corrosion and biofouling processes and demonstrate the positive interaction between these two phenomena. It will discuss various corrosion protection coatings, anti-fouling coatings, and new technologies developed to prevent physical corrosion and biofouling.

II. CORROSION: STUDY

Corrosion is defined as the deterioration of material by chemical or electrochemical actions of a corrosive medium. Hull corrosion on ships is the deterioration of a ship's hull structure due to electrochemical reactions between the metallic surface and its surrounding environment. The primary factors contributing to hull corrosion include the corrosive nature of seawater and microbial activity. This paper details the mechanisms behind hull corrosion and its implications for the maritime industry.

$$\text{Metal} \underset{\text{Metal Extraction}}{\overset{\text{Corrosion}}{\rightleftarrows}} \text{Metal Oxides} + \text{Energy}$$

A. *Causes Of Corrosion*

Seawater Corrosion:

Seawater corrosion is a complex electrochemical process involving degrading metallic structures exposed to marine environments. Seawater contains chloride ions, which accelerate the corrosion process. A ship's hull is susceptible to degradation over time due to constant exposure to seawater.

Microbial Corrosion:

Microbial corrosion is induced by the activities of microorganisms, including bacteria, algae, and fungi, on ship hulls. It can accelerate the corrosion rate and create localized damage on the ship's hull.

Galvanic Corrosion:

When dissimilar metals come into contact with an electrolyte, galvanic corrosion occurs. Metals with different electrochemical potentials are in electrical contact; an electrochemical cell is formed. This leads to the flow of electrons and ions between the metals, accelerating corrosion of the less noble metal. Ships, with their diverse metal components, are susceptible to galvanic effects, especially if proper preventive measures are not in place.

B. *Effects Of Corrosion*

Effects of Corrosion Are:

- Sea-worthiness of ships
- On the pollution of seas and marine environment (aquatic life)
- On the economic status

III. HULL CORROSION

Hull corrosion refers to material degradation inside the hull due to an electrochemical reaction between the metal structure and its environment (seawater only). Most hull corrosion is galvanic corrosion, which occurs when dissimilar metals come into contact with an electrolyte such as seawater. This phenomenon causes an electric current to flow between metals, causing one metal to rust faster than the other.

Ship hulls are generally made of metal, usually iron or aluminium, and are affected by seawater.

A. *How Does Corrosion Occurs on Our Ships?*

Vessels are frequently subject to atmospheric corrosion caused by a combination of moisture and salty sea fog; Both directly affect the metal at the worst moment of the painful process.

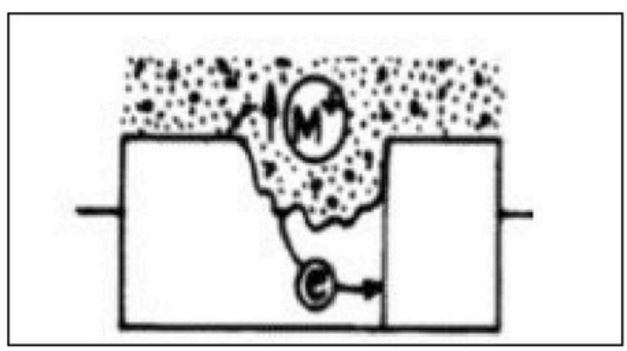

Fig. 1. Corrosion on ship

Ships can be subject to fretting corrosion due to the relative movement of the metal cargo surface, mainly caused by vibrations (caused by all causes) and distorted patterns (caused by waves and wind). As with all dissimilar metals, galvanic corrosion occurs at contact points between dissimilar metals. The two metals form a galvanic cell using seawater as the electrolyte.

This movement of the battery causes one of the metals (usually iron) to oxidize. Poor or bad soil on a docked ship and port equipment can cause water on board (usually from the hull or sharp edges) to be released into the water, which then goes to the bottom of the hull. It's like the ocean. The world is like a power plant.

Stray flow corrosion usually occurs when water leaves the system. The ocean can cause water to enter the cavity through soil, sand, marine life, depressions, or sealants. This creates a permanent spot on the metal that is always wet, creating invisible corrosion pits that slowly erode the metal and allow water to enter the internal structure. This is called crevice corrosion.

Microbial corrosion occurs when marine organisms adhere to the shell or collect in the cavity. Their activities produce acids that alter local chemistry and, therefore, exacerbate corrosion. Internal corrosion occurs in tankers' tanks, pipes, and pumps.

Ships are made of steel, and iron is their main product. Metal is an electrochemically good element; it tends to lose electrons and become free ions.

1) The resulting anode reaction is $2Fe \rightarrow 2Fe^{++} + 4e^-$

2) Seawater combines oxygen and hydrogen to form an electrochemical reaction with good hydroxyl ions $H_2O + O_2 + 4e^- \rightarrow 4(OH)^-$—which can accept free electrons from the metal.

3) Iron ions and hydroxyl groups combine with the ions in seawater to form iron hydroxide. $2Fe^{++} + 2(OH)^- \rightarrow 2Fe(OH)_2$. This is called the oxidation of iron.

4) This iron hydroxide oxidizes in excess oxygen in water, forming iron oxide and water, which we call rust. $2Fe(OH)_2 + O_2 \rightarrow Fe_2O_3 + 2H_2O$ (rust)

B. *Why Do Ship's Hull Rust?*

When two metals come into contact with each other in a corrosive environment (electrolyte), the active metal in the first cell acts as the anode, and corrosion occurs. This means that most of the active iron in the galvanic iron series will act as the anode and be subject to corrosion, while most active iron will act as the cathode and shield.

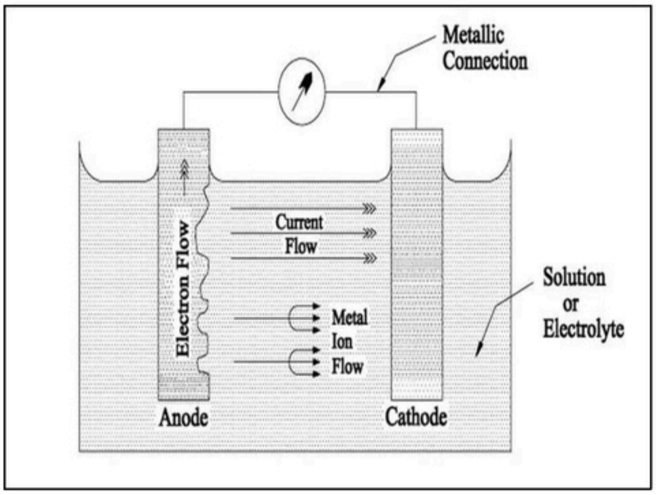

Fig. 2. Impressed current cathodic protection

If these two metals are placed in water and direct electrical contact, electricity will flow from the strong metal(anode) to the low-power metal (cathode) through the electrolyte.

This current is called corrosion current and is nothing but the transfer of metal ions and electrons dissolved in the solution from the anode. A simple cell in which the corrosion occurs is called a galvanic cell.

C. *Hull Corrosion Prevention Techniques*

The hull of a ship or boat is usually made of metals like steel or aluminum, and it is constantly exposed to harsh marine environmental conditions. Hull corrosion prevention techniques are important for several reasons, particularly in the context of marine vessels. Corrosion, which is the deterioration of metal due to chemical reactions with the surrounding environment, can significantly negatively impact the structural integrity, safety, and overall performance of a vessel.

Material Selection

Depending on the material of the boat and tank, corrosion can cause serious damage. Since many metals are more susceptible to corrosion than others, this needs to be considered when replacing and designing products. Stainless steel and plastic are more corrosion-resistant, and some nickel and titanium alloys are specifically designed to resist corrosion, making them the best materials to ensure good protection and durability of your volume. Corrosion-resistant materials are used throughout the shipbuilding industry, especially in critical areas such as pipes, storage tanks and construction materials. For special applications, consider stainless steel, aluminium or other corrosion-resistant alloys.

The shell consists of a keel, hull, rope, deck and beam. These elements ensure the water resistance, safety and durability of the boat. The most commonly used metals are iron and aluminium alloys. Choose equipment according to its usage area. These materials include special metals. It is important in the construction of heavy cargo ships, large cargo ships and trucks, trucks, ships, ships, special cargo ships, cargo ships, and dredgers and are also used in construction. barges, and floating docks. The main materials we use in the shipbuilding industry are as follows.

- Steel
- Aluminum Alloys
- Composite Materials

Steel material consists of a small amount of carbon. Steel is the most commonly used material in the shipbuilding industry. Rolled structural steel is used to increase the durability of plates and profiles. Since high-strength steel is required for the main components of the ship, this steel is normalized and heat-treated. The choice of metal and its physical and chemical structure is limited by the distribution of the community to which it belongs. Aluminum Alloys: Commercially pure aluminum contains at least 99% pure metal.

Different special grades with higher purity are also available for some special applications. Products containing metal and two or more elements, at least one of which is metal, are called aluminium alloys. Most aluminium alloys have different aspects that give them their special properties, such as 90% to 96% aluminium. In some special productions and products, some metal is often added to the main alloy content. Composite Materials Composite Materials are materials made from two or more materials. Composite data can be labelled as "data created by combining two or more different parts of different parts.

The information that makes the most of it protects your belongings. General information: Metals, ceramics and organic materials are divided into three groups. Each of these three materials has advantages and disadvantages. As technology develops, new materials resulting from combining two or more materials into a single product are considered composite products.

Protective Coating

Preventing corrosion on boat hulls is one of the most excellent strategies to stop and manage boat corrosion. This section of the ship is more vulnerable to salt and rotten food because it is at the bottom of the river. It can be protected by applying a vinyl tar coating and coal tar epoxy in two parts. Corrosion can also affect support, particularly during extreme weather. Seawater can surge onto the deck during storms or high waves, damaging the surface. Repairing the damage to your deck may involve repainting it, but for optimal protection against seawater and normal wear and tear, use alkyd and chlorinated rubber coatings. Cargo tanks are prone to corrosion.

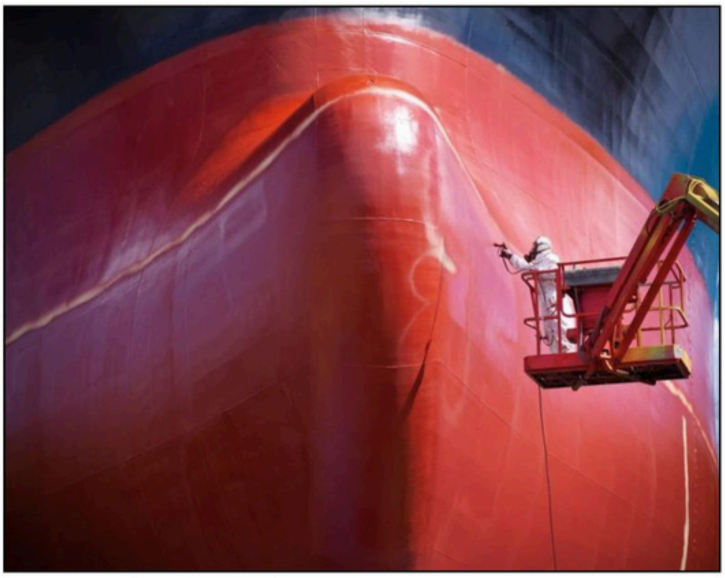

Fig. 3. Hull protection from corrosion

This happens when the water and sulfur in crude oil are mixed with water vapor. Bacteria may potentially harm the tank's protective layer. Numerous people have noted that new coating processes can help protect and maintain the integrity of containers.

Fig. 4. Protective coatings

Impressed Current Cathodic Protection (ICCP)

Marine ICCP systems have sacrificial anodes connected to external power. This electrical energy provides electric current, causing the electrochemical reaction required for cathodic protection to occur. The main advantage of the ship's ICCP system is that many monitoring and control options are directly aimed at the ship's control system. This provides continuous monitoring and troubleshooting from shore. Moreover, the system adjusts even when the water changes, providing maximum protection in all conditions.

In Ships, select the contact point of the body and connect it to the reference electrode. This electrode is completely non-toxic. The electrode material measures the natural corrosion current, which is the difference between the body and the material at hand. To obtain a DC current equal to or slightly more significant (the reverse direction) than the current affected by this anode, we need to measure the corrosion current in the body. This provides a protective current to the body and turns it into a cathode against corrosion.

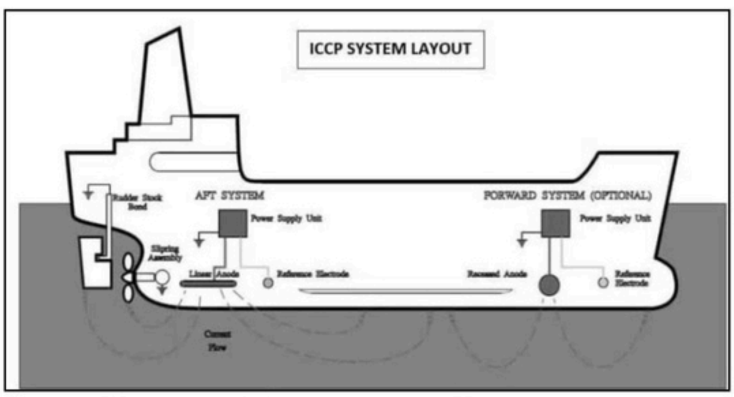

Fig. 5. ICCP system layout

It is a technologically advanced, long-term corrosion solution to meet existing cathodic protection systems and is considered a better alternative to sacrificial anode systems. In ICCP, the metal to be protected is connected to an insoluble anode and a current is sent from a DC source in the corrosion current if it corrodes the metal.

Switch from anode to cathode and prevent corrosion. This insoluble anode may be platinum, platinized titanium, or other materials. The picture above is a similar galvanic cell containing an anode (a more active metal) and a cathode (a less active metal) but with some modifications. Here, an insoluble impregnated flow anode is added to the system.

Under normal conditions, if there is no insoluble anode, a corrosion current will occur and corrode the anode. Still, in this case, we emit a direct current in the opposite direction of the natural corrosion current of the anode and cathode.

The engine control room includes a remote control center that monitors and records ICCP faults daily. Make sure the ICCP power supply is off when the ship is docking. Otherwise, the water flow in the ship's ICCP system may be interrupted, causing damage to the ship's paint. Too much current entering the chamber may cause the paint to peel.

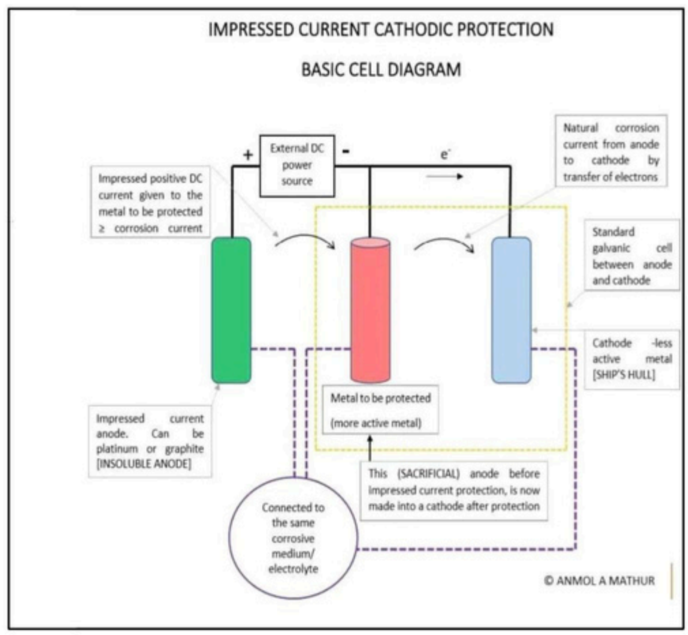

Fig. 6. Cell Diagram

Environmental Aspects

Ship hull corrosion has many environmental factors that will affect the water in the water and harm the environment. These conditions highlight the importance of using effective corrosion protection. Some important environmental considerations are:

Release of metals into water: Corroding ship hulls can release metal ions into the water, containing substances such as iron, copper, and zinc. In high concentrations, these metals can be harmful to marine life, affecting fish, plankton, and other aquatic life. High levels of metals can disrupt biological processes, harm sensitive ecosystems, and harm marine life.

Sedimentary Pollution: Corrosion particles (such as rust) from the hull can enter the soil at the bottom of the water body. These organisms can affect benthic organisms and disrupt soil ecosystems. Infectious diseases can also affect the nutrition and growth of some marine species.

Biofouling and Antifouling Coating: Ships often use antifouling chemicals to prevent biofouling (the growth of marine life on the hull). These dyes contain biocides that are toxic to marine life. Although they are effective preventive measures, they can cause environmental pollution. To reduce these effects, efforts are being made to develop environmentally friendly antifouling technologies.

Eutrophication: Boat runoff due to corrosion will increase nutrients in the water. When metals such as iron enter water, they can act as nutrients and cause eutrophication and enrichment of nutrients in the water, which can lead to algal blooms, oxygen depletion, and damage to water bodies.

Effects on Coral Reefs: Metals released from corroded ships can be particularly problematic in areas with coral reefs. Coral reefs are sensitive ecosystems, and exposure to metal ions can harm polyps and other coral organisms. Corrosion protection is essential to protecting fragile marine environments.

Long-term persistence: Contaminants due to corrosion can remain in the environment long. At the same time, integrated metal products can affect the health of marine ecosystems and have long-term ecological impacts.

IV. Bio-Fouling

Marine biofouling refers to accumulating various marine organisms on submerged surfaces in aquatic environments. These organisms include bacteria, algae, barnacles, molluscs, and other small invertebrates. Biofouling is a natural process that occurs when organisms attach and grow on submerged structures such as ship hulls, buoys, pipelines, and underwater infrastructure. The accumulation of marine life on these surfaces can have several adverse effects, leading to increased maintenance costs, reduced operational efficiency, and environmental concerns.

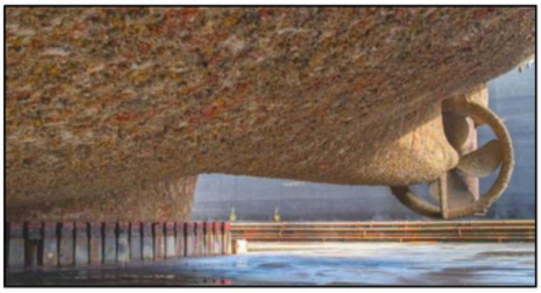

Fig. 7. Impact of biofouling and niche areas

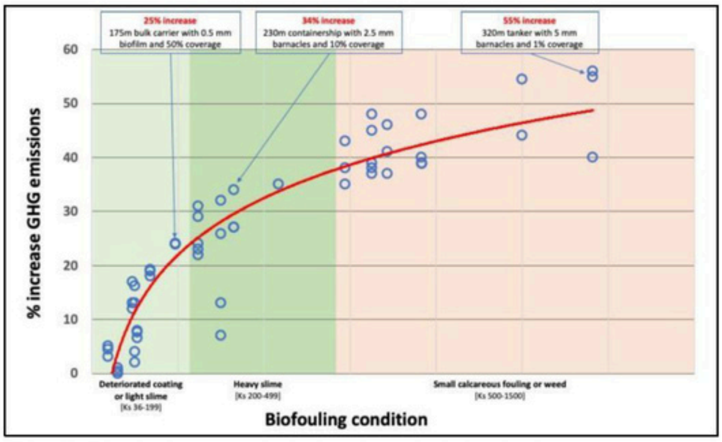

Fig. 8. Biofouling on ships leads to higher fuel consumption.

Key Aspects of Biofouling:

Attachment and Growth: Marine organisms begin to grow by attaching to the bottom of the water. The release of adhesives from the bacteria facilitates this binding, allowing the organisms to stabilize the substrate.

Fig. 9. Fouling of ship and marine infrastructure

Biofilm Formation: Organisms such as bacteria and algae generally form a thin layer called biofilm on the substrate's surface. This biofilm provides the material necessary for the attachment and growth of large organisms such as mussels and molluscs.

More Friction: When marine organisms accumulate on the surface, they create roughness and irregularities. The increase in surface roughness leads to higher pressure, which affects the ship's hydrodynamics, resulting in more oil and less performance.

Corrosion Risk: Biological contamination can promote corrosion by creating a micro-environment that encourages corrosion. metal surface. The presence of bacteria, their metabolic activities and biofilm formation can accelerate the corrosion process and further affect the integrity of underwater structures.

Transportation of Invasive Species: Biological contamination can facilitate the transportation of animals to new areas. Attached to the boat from a single location, the animals will be transported to remote waters where they can reproduce themselves and potentially impact local ecosystems.

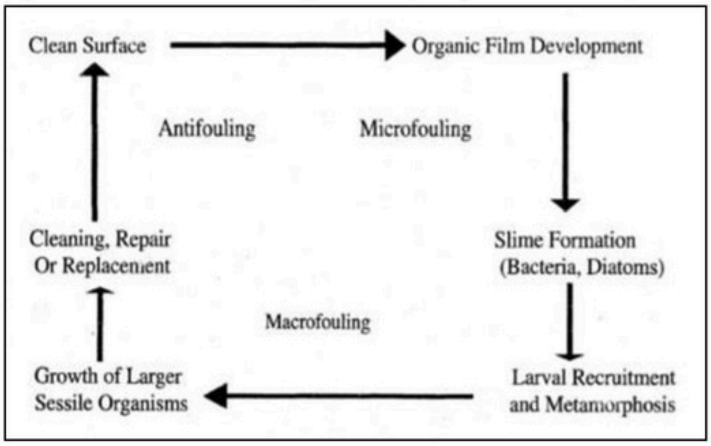

Fig. 10. Biofouling cycle

ANTI-FOULING TECHNIQUES

The main types of protection used on ships are:

1. Electrolysis systems
2. Chemical dosing
3. Ultrasonic systems
4. Electrolytic chlorination

1. Electrolysis System

It is one of the most used systems to prevent biological contamination on ships.

An electrolysis machine consists of anodes, usually copper and aluminium (or iron). The anode is attached to the marine tank or filter. Direct current passes through the copper anode, creating ions carried with the ocean through the network. The copper ions in this seawater prevent marine organisms from settling and balancing in the pipe.

The second anode prevents corrosion of the metal surface. The metal anode helps prevent damage to the metal oxide film from corrosive substances (sulfur) in the sea. The system also provides protection for valves, condensers, engine cooling systems, and auxiliary equipment.

The control panel measures and monitors the output of each anode.

2. Chemical dosage

The use of chemicals is also a way to prevent the growth of marine organisms in the pipe. Antifouling chemicals such as ferric chloride are used for injection into seawater. Pipe paints with a metal coating to prevent rust.

3. Ultrasound

High frequency waves are also used to prevent the growth of marine life in the pipe. Ultrasonic systems are considered one of the best ways to prevent biofouling. This method is claimed to reduce biofouling by up to 80%.

According to research, ultrasound should have two effects in preventing contamination.

Fig. 11. Ultrasonic testing

There are destructive effects due to high usage, such as high-frequency waves that make the habitat unacceptable and Interference with bacteria trying to release adhesives. It helps prevent clotting and ensures that existing bacteria remain dormant within 4-5 months.

In the ultrasonic method, the electric wave generator creates and transmits the electric frequency. These waves are transmitted via a coaxial cable to a transducer mounted outside the marine tank or filter. The transducer has a piezoelectric ceramic crystal that produces an ultrasound beam when excited by an electrical pulse.

The transducer has a piezoelectric ceramic crystal that produces an ultrasound beam when excited by an electrical pulse. This system's biggest advantage is that it does not interfere with the ocean and does not produce chemicals.

4. Electro-chlorination

Electro-chlorination produces chlorine gas to produce sodium hypochlorite, which is used to prevent scaling. While titanium is used as the cathode material, titanium coated with 100 micro inch platinum is used as the anode. Titanium is electrochemically inert at positive voltages below 9 volts. The anode/cathode voltage was maintained at 7 volts.

The anode produces chlorine gas and other products to form sodium hypochlorite. Large amounts of hydrogen are also produced, and they need to be handled safely.

The anode layer is depleted at a rate of 6 mg/amp per year. However, this depends on the unit's voltage and current source. All chlorine released is a function of the current not flowing through the device. Therefore, sufficient water is needed to cool down and prevent calcium buildup.
10 ppm chlorine in the ocean will quickly kill all marine life, while 1 PPM will prevent calcification. This can be checked on board.

It is worth noting that this system is designed for use only in sea water, not fresh water.

Biofouling has plagued the maritime industry since its inception. Programs such as AMBIO are used to find a solution to this problem. Progress has been made in the field of antifouling coatings and anti-marine development systems. Some new technologies that may be used to prevent biofouling in the future are floating seeds and anti-fouling techniques caused by certain types of bacteria.

V. Effect of Hull Corrosion On Seaworthiness of Ship

Hull corrosion can seriously affect a ship's seaworthiness. Seaworthiness refers to the suitability and ability of a ship to navigate safely and efficiently at sea. When the ship is not properly impacted, it can affect its structural integrity and overall performance, causing many safety and operational issues. Some of the main effects of corrosion on a ship's seaworthiness include:

Structural Weaknesses:
Corrosion can weaken a ship's hull, including plating, framing, and bracing. This affects the boat's ability to withstand stress from waves, wind and other forces.

Reduced load-carrying capacity:
Metal loss due to corrosion reduces the thickness and strength of the hull. Loss of these items can reduce the ship's carrying capacity, limit its ability to carry cargo and affect its operational performance.

Leaks and flooding:
Corrosion can cause holes, cracks, or punctures in the hull. This affects the water content of the can, making it easier for water to enter. Continued hull corrosion can lead to leaks and water ingress, posing a threat to the ship's stability.

Increased fuel consumption:
The worn hull surface creates more resistance in the water, making the boat more efficient and reducing water efficiency. This can lead to higher fuel and operating costs as the ship requires more power to meet its speed requirements.

Safety Risks:
Corrosion-related weaknesses and defects can pose safety hazards to crew, passengers, and the environment. In extreme cases, ship failure due to corrosion can lead to serious damage, such as water or land damage.

Navigation Challenges:
Service hull corrosion can affect a ship's stability, maneuverability, and response to navigation controls. This can make it difficult for employees to travel safely, especially in bad weather.

Compliance with Classification Society and Legislation:
Hull corrosion problems may lead to non-compliance with classification society and international maritime regulations and rules. Failure to comply may result in a fine, imprisonment or refusal of entry.

More Costly:
The continued development of corrosion will require more frequent maintenance, resulting in loss of time and operating costs for ship owners.

VI. Sustainable Ideas

The hydrophobic layer mainly forms the amphiphilic hydrogel/organic matrix interface; this improves the underwater adhesion of the hydrogel through the assembly and assembly of lipophilic structural units in the amphiphilic hydrogel. However, hydrophobic interactions weaken water absorption and prevent the formation of a stable water layer at the hydrogel/water interface, reducing amphiphilic hydrogels' capacity.

The invention prepares a composite amphiphilic hydrogel antifouling product by mixing amphiphilic hydrogel prepolymer and pure water as the structure of the hydrogel prepolymer. In particular, the lipophilic structural units of amphiphilic hydrogels enhance the adhesion of the hydrogel, and the hydrophilic structural units of pure water-based hydrogels form a stable hydration layer at the hydrogel/water interface. Therefore, its anti-fouling performance is incredibly good. developed. As a result, the composite amphiphilic hydrogel maintains very good adhesion, and its resistance to falling is seen in the test results after immersion in static seawater (60 days) and swirling seawater (30 days); In addition, the water absorption capacity and antifouling effect are better than amphiphilic hydrogel products; for example, the water absorption of mixed hydrogel BSH60T (%S = 324.2%) is 6.7 times that of amphiphilic hydrogel polymer hydrogel BS60T (S). % = 48.3%). Protein and Nitzschia crescentus f. The adhesion of Minutissima to the surface of the mixed amphiphilic hydrogel is very poor, and the tested material is very effective in antifouling areas in the marine environment. This research provides a creative way to improve the adhesion and antifouling properties of hydrogel antifouling materials.

VII. CONCLUSION

The technical document "Hull Corrosion and Biofouling Prevention" emphasizes how crucial it is to deal with the various issues raised by ship hull degradation in maritime conditions. The study explores the economic, safety, and environmental implications of biofouling and hull corrosion, highlighting the necessity of all-encompassing preventative measures. Hull corrosion's effects on the environment are a significant concern since they include using antifouling coatings, sediment contamination, and releasing metal ions into aquatic ecosystems. Adopting ecologically friendly and sustainable corrosion prevention solutions is imperative due to the potential harm that corrosion may do to ecosystems and marine life.

Hull corrosion poses a risk to the structural integrity of boats, which could result in accidents, leaks, and decreased seaworthiness. Safety considerations are therefore of the utmost importance. The significance of protective coatings, routine maintenance, and inspections are stressed as essential procedures to guarantee the security of maritime operations.

The study emphasizes the importance of corrosion prevention in maintaining the operating effectiveness of vessels from an economic standpoint. Reduced service life, higher fuel consumption, and maintenance expenses can all be caused by corroded hulls. Investing in corrosion prevention technologies is considered essential for maximizing the longevity and financial performance of marine assets.

The development of environmentally friendly antifouling treatments, cathodic protection systems, and protective coatings are just a few of the corrosion prevention strategies covered in this tech paper. The necessity of continual research and development to improve corrosion prevention technology is emphasized, with an emphasis on reducing environmental effect while preserving safety and financial feasibility.

This study emphasizes the significance of environmental stewardship and compliance in light of international rules and industry standards. The necessity for integrated and sustainable methods of preventing hull corrosion and biofouling is becoming more and more apparent as the maritime sector develops.

In the end, the technical paper thoroughly examines the issues and remedies related to hull corrosion and biofouling avoidance. Researchers, industry stakeholders, and regulatory organizations are encouraged to work together to promote technological improvements, promote best practices, and guarantee a more robust and sustainable future for marine operations.

VIII. Acknowledgement

It would be self-seeking to claim all the credit for this technical report, so we would like to acknowledge the support of those without whom this would not have been possible.

We are grateful to Dr. Ajaj Attar, who has been a constant support in preparing this report. They guided us at every step and also made it possible for us to reach various other sources whose insights were indispensable for this technical report. Developing a technical report requires a substantial amount of technical information. We are greatly thankful to Mr. Abdul Raheem (PVD Coordinator).

IX. References

[1] Xiao Wu, Chao Yang, Lingli Wu, Chuchu Zhang , Gan Cui , Yanping Xin "Self-repairing and anti-fouling performance of anticorrosive coating in marine environment", Science direct, 2023, Volume 124,Page no: 1-18.

[2] Chandra Sekhar Mishra, Fanar Ali, Samson Adam "A brief survey of the procedure of hull corrosion and biofouling prevention technique in Eritrea and its effect on environment due to biofouling and improper way of biofouling preview", IJCRR , 2017, Volume 08,Page no: 20242-20251.

[3] M.R. Enikeev , D.I. Potemkin , L.V. Enikeeva , A.R. Enikeev , M.A. Maleeva , P.V. Snytnikov , I.M. Gubaydullin ",Analysis of corrosion processes kinetics on the surface of metals" ,2020,science direct , Volume 383.

[4] S. Harsimran, K. Santosh, K. Rakesh "Overview of corrosion and its control: a critical review", research gate, 2021, Vol. 03, Page no :13-24.

[5] T. Munk, D. Kane, D.M. Yebra "The effects of corrosion and fouling on the performance of ocean-going vessels: a naval architectural perspective", Science direct, Pages 148-176.

[6] Limei Tian, Yue Yin, Wei Bing, E Jin, "Antifouling Technology Trends in Marine Environmental Protection", Springer,2021,Volume 18, pages 239–263.

[7] Iliya Valchev, Andrea Coraddu , Miltiadis Kalikatzarakis, Rinze Geertsma, Luca Oneto, "Numerical methods for monitoring and evaluating the biofouling state and effects on vessels' hull and propeller performance: A review", Science direct, 2022 , Volume 251.

ZERO EMISSION TECHNOLOGIES

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***Abstract*:**

To effectively reduce ship emissions, it is crucial to consider climate, human well-being, and environmental impacts while implementing solutions that integrate seamlessly with existing ship engines and infrastructure. Various options allow for optimal selection based on ship type, routes, and regional requirements. Carbon-neutral fuels, including low-carbon and carbon-negative alternatives, are emerging as viable successors to conventional marine fuels such as diesel, methane, and methanol. The carbon neutrality of these fuels is assessed based on well-to-wake greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Harmful substances in exhaust gases, such as NO_x, SO_x, CO_2, and particulate matter (PM), pose significant threats to both the environment and human health. To mitigate the adverse effects of ship emissions and comply with increasingly stringent regulations set by the IMO and national governments, the maritime industry is adopting clean energy solutions and advanced exhaust gas cleaning technologies. Exhaust emissions, which are hazardous to health and the environment, must be effectively treated through fuel modifications, engine improvements, or post-combustion exhaust treatment technologies.

Particulate matter emissions, which contain hazardous substances like polycyclic aromatic hydrocarbons (PAHs) and heavy metals, pose severe health risks. Carbon-neutral fuels generally do not contain sulfur, thereby minimizing SO_x emissions. Advanced exhaust after-treatment technologies, such as particulate filtration, further enhance emission control. The substantial reduction in external costs to society caused by ship emissions justifies the regulations, policies, and investments necessary to support this transition. Additionally, specialized water-based scrubbing systems, equipped with perforated pipes submerged in water, are used to purify exhaust gases before their release into the atmosphere, ensuring cleaner emissions.

Keywords: ***Carbon-neutral fuels, exhaust gas cleaning, ship emissions reduction, maritime sustainability***

1. INTRODUCTION

In the past few years, laws intended to lessen pollution have been implemented in the shipping industry. Measures to improve ship energy efficiency and lower CO_2 emissions are under discussion. Large zero-emission vessels are also being considered; however, new or improved energy-saving devices and alternative propulsion systems will be needed to make these a reality. When applied to current ship designs using conventional propulsion solutions, the combination of technologies could result in fuel savings as well as a significant reduction in the emission of harmful gases like sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM). Such a ship would also have a lower carbon intensity per kilowatt than ships in service today. Additional enhancements in energy efficiency could potentially be attained through operational strategies such as weather-based voyage planning, routine hull cleaning, and gradual steaming.

Emissions will be kept below target levels shortly by using exhaust after-treatment systems and low-sulfur fuels like marine gas oil (MGO), which is produced by blending with residual fuels in refineries that have 0 point 1 per cent m/m sulfur or less. Alternately, sulfur oxide and particulate matter levels in exhaust gas can be decreased by using exhaust gas cleaning systems (EGCS) (scrubber) systems. Sulfur oxide and exhaust gas with a lower particulate matter content are released into the atmosphere following the washing process. Cleaning the exhaust gas in open loop scrubbers is best done with seawater. The ship's operation in a particular body of water determines its effectiveness. Meanwhile, sodium

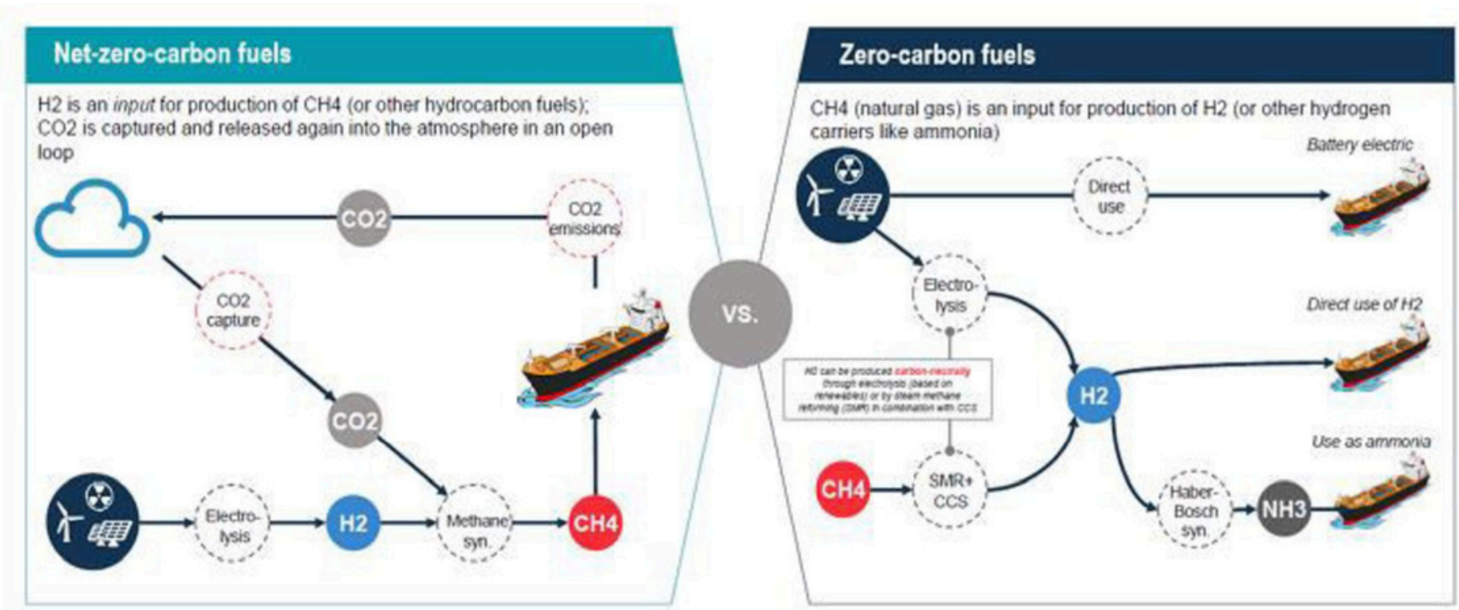


Fig. 1 Zero emissions technology options

hydroxide (NaOH) is used in closed-loop scrubbers to clean exhaust gas before it is fed back into the cleaning system.

Need for cleaner emissions:

A global framework for limiting the severity and impact of climate change is outlined in the 2015 Paris Agreement by world governments. A rapid and sustained decline in emissions in the upcoming decades is necessary to reach net-zero emissions between 2050 and 2070 to meet the Agreement's stated ambition of keeping global warming well below 2°C above preindustrial levels and pursuing efforts to limit the increase to 1.5°C. In other words, by pledging to reach net zero, people will eventually remove as much anthropogenic greenhouse gas emissions as they produce annually. This is necessary to ensure that the 1°C target is not overshot. Global net anthropogenic CO_2 emissions will need to decline by roughly 45% from 2010 levels by 2030, reaching net zero around 2050. One way to achieve this goal is to reduce emissions; however, for hard-to-abate sources of emissions, it might be more economical to extract emissions from the atmosphere or capture them during the energy production process from biomass sources and then store them underground. For instance, creating decarbonized shipping fuels from fossil fuels along with 100% carbon capture and storage would be a workable solution in line with the goals of zero-emissions shipping. Given the alternative technologies available, it is unlikely that this will be the most economical route for shipping with zero emissions (discussed further in Section 3). The power sector produces and has received the majority of global decarbonisation efforts to date.

Batteries:

Batteries are electrochemical frameworks that store electric control with exceptionally high responsiveness. They are appealing both since they talk about a coordinated utilization of power, which is more effective in terms of a drive than other advances. Since in case the power source is renewable, they have the potential to be zero-carbon. Battery control is a built-up, commercially reasonable innovation, and as of now, it is moderately cheap with still-declining costs. For short-distance vessels, battery-electric control has already illustrated a positive commerce case. Certain countries are in speciality markets, such as short-distance ships, pull, and work water crafts. Close full-electric vessels are increasingly being used within the Scandinavian short-haul ship showcase. In any case, battery impetus has its restrictions: Lithium-Ion batteries have around 1/30th of the volumetric vitality thickness of MGO, viably administering out any full-battery framework on deep-sea vessels based on weight and space necessities. Since most shipping outflows come from deep-sea vessel boats and they are the centre of this report, batteries are not talked about are the centre of this report; batteries are not discussed in advance as a decarbonisation option.

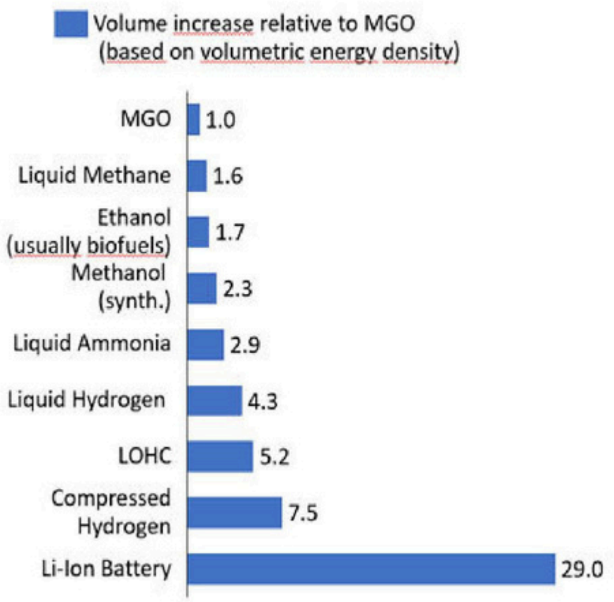


Fig. 2 Synthetic carbon-based electrofuels

1. Synthetic carbon-based electrofuels

Manufactured electro fuels ("synfuels" from now on) can be carbon—or hydrogen-based. Carbon-based synfuels incorporate a wide range of manufactured hydrocarbons from hydrogen and carbon oxides and utilise a few diverse chemical forms. These include engineered methane, methanol, and diesel (regularly alluded to as e-methane, e-methanol, etc.). "Green" synfuels customarily allude to powers delivered utilizing renewable power, whereby sufficient CO2 is captured from the air to balance outflows from combustion.

The major impediment to synfuels' utilise part utilization for large-scale shipping decarbonisation is that carbon-based synfuels, for the most part, ought to incorporate coordinate discussion capture to be carbon unbiased, which is as of now as it was given at tall fetched by a modest bunch of companies. Subsequently, methane and methanol synfuels and coordinate discuss the capture of CO2 are not, however, accessible in sufficient commercial amounts or at competitive costs.

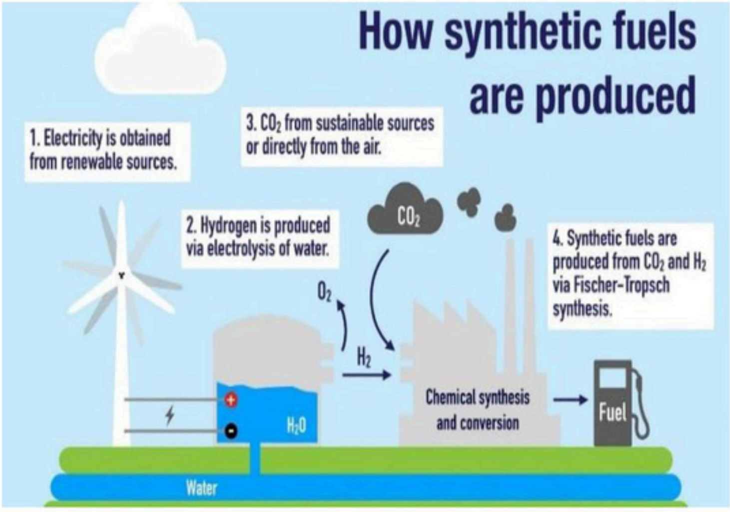


Fig. 3 Production of synthetic fuels

2.Green Ammonia

In the long run, green ammonia will be a viable net-zero carbon fuel for the shipping industry. The energy-demanding Haber-Bosch process turns hydrogen and atmospheric nitrogen into ammonia. Grey ammonia, primarily produced using hydrogen derived from fossil fuels, is traded and produced widely for fertiliser and other industrial applications. Compared to hydrogen and hydrocarbon fuels, ammonia presents a significantly lower fire risk and can be stored in liquid form at atmospheric pressures and relatively normal temperatures. It also has a volumetric energy density that is more than twice that of liquid hydrogen. Ammonia is highly toxic and corrosive, but for safely handling, storing, and transporting bulk ammonia. Because ammonia supply chains already exist, they can be stored and transported with less energy and expense than hydrogen, and an established global logistical infrastructure backs them. Therefore, even though it requires two stages to produce, ammonia offers a potentially quicker path to decarbonisation than hydrogen. According to one interviewee, ammonia is the most effective vector for exporting hydrogen and the most promising because of the market's scalability. Many of the interviewees agreed with the conclusion made by another shipping industry representative: "The hydrogen future we see is an ammonia future.". Ammonia does not mix well with the current bunkering infrastructure.

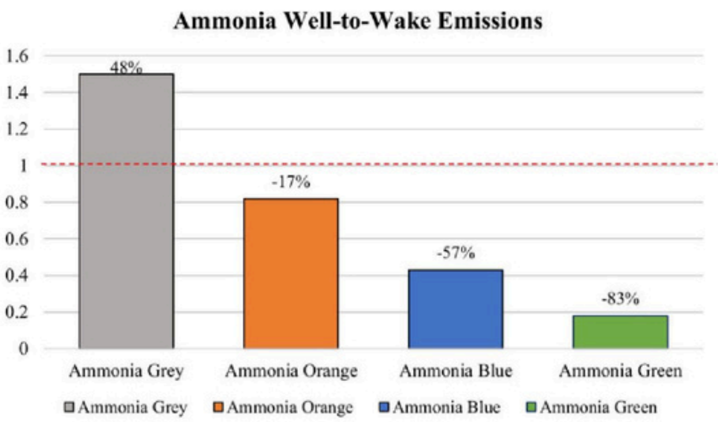


Fig. 4 Ammonia Well to wake emissions

3.Wind and Sail

Wind propulsion technologies have also been suggested and used on a small scale to increase energy efficiency and lower emissions in the shipping industry. Nuclear power is not the only option. Based on their characteristics, wind technologies are expected to reduce fuel consumption by 10–30% and CO2 emissions by 10–60%.

Different wind technologies are available, each fulfilling a different purpose and being at various stages of development and maturity. Rigid and soft sails, kites, and rotors provide an erratic propulsion source that needs to be paired with other technologies, but turbines and rotors facilitate electric propulsion or battery recharging. The costs associated with development and installation vary significantly depending on the type of technology. To meet the energy demands of modern shipping vessels, alternative net-zero carbon fuel solutions will need to be repaired.

Environmental and safety barriers

Safety and the environment are two critical concerns with marine fuels. In addition to fires, explosions, and exposure to toxins, oil spills, leaks, and hazardous and noxious substances (HNS) present potentially disastrous environmental risks with long-term effects.

There have been ten marine fuel spills over 700 tons in the past ten years. There are well-established ways to lessen the likelihood of these incidents, such as double-hulling ships. In contrast, even though the amounts of accidents that can be attributed to chemicals like cargo and oil-based fuels are comparable, there is a relative lack of development in safety standards for other HNS, even ammonia. All net-zero-carbon fuels under consideration have standards for transportation and handling, but each has unique safety and environmental risks (for more details, see Technical Appendix A2). All gaseous and low-flashpoint fuels are covered by the IMO's International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF) and International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC). The IGF contains comprehensive regulations for compressed or liquid natural gas (LNG and CNG), while rules for low-flashpoint diesel fuels and methanol are still being developed. Ships installing additional low-flashpoint fuel systems must prove they abide by the IGF Code. The IGF does not currently cover the use or storage of hydrogen or ammonia, but regulations are being developed and should be included in the following amendment.

Treatment of exhaust gas technologies

Systems are currently available for selective catalytic reduction (SCR), exhaust gas recirculation (EGR), exhaust gas cleaning (EGCS), NOx and SOX emissions, and particulate matter control.

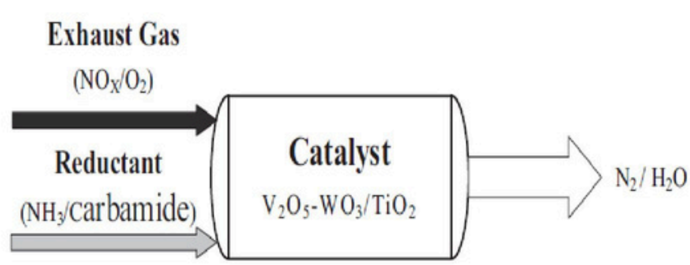
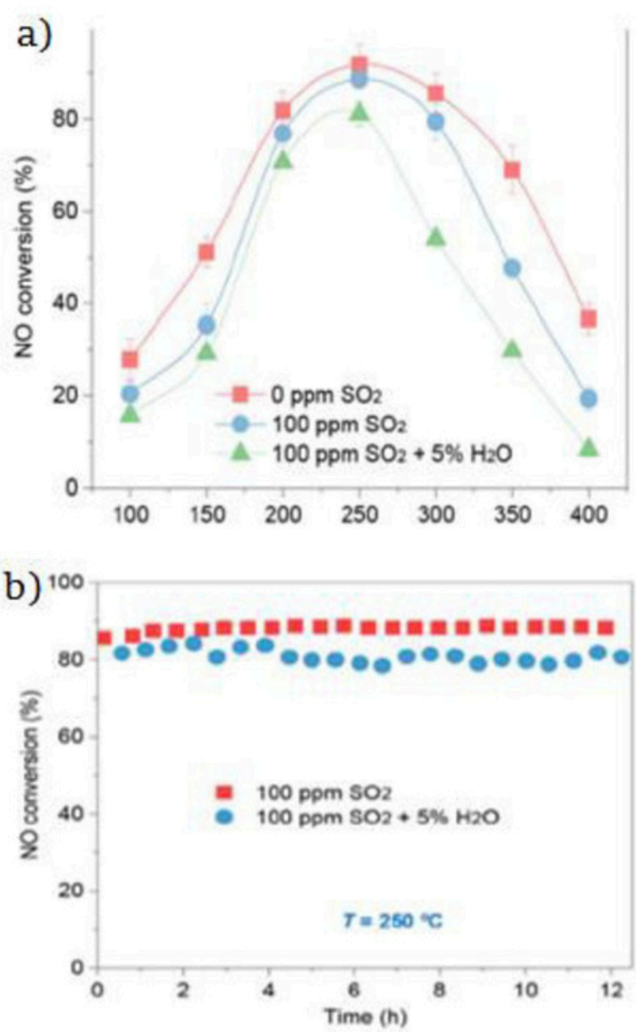


Fig. 5 Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR)

One method of reducing emissions to meet the Tier III NOx emission limits set by the International Maritime Organization (IMO) is to install an SCR system. Using urea as a reducing agent and vanadium pentoxide, V_2O_5 supported on titanium dioxide (TiO_2) as the main component of the catalysts lowers the amount of NOx in the exhaust gas [8]. Using urea as a reducing agent and vanadium pentoxide, V_2O_5 supported on titanium dioxide (TiO2) as the catalytic converter's primary component, the exhaust's NOx content was reduced. The catalyst undergoes a reduction reaction, and its move rate depends on the NOx ratio. Carbon dioxide (CO_2) and ammonia

(NH_3) are the end products of this reaction. Nitrogen (N_2) and water (H_2O) are produced when nitrogen oxides (NOx) released from the exhaust gas react with ammonia (NH_3) on the catalyst surface. The exhaust pipe's metal structure houses the catalytic element. Numerous variables, including the reductant dosage, the number of catalytic elements, and the exhaust gas temperature, affect how catalytic elements and the exhaust gas temperature affect how effective catalytic reduction is. Usually, NOx emissions can be decreased by 90%. A comparatively advanced technique for reducing NOx emissions, selective catalytic reduction (SCR) offers a broad operating temperature range, excellent selectivity, and a more than 90% conversion rate. Utilised catalysts demonstrate that NH3 or urea (CO $(NH_2)_2$) is used as a reductant, and metal oxides like V_2O_5-WO_3 and TiO_2 are used as catalysts.



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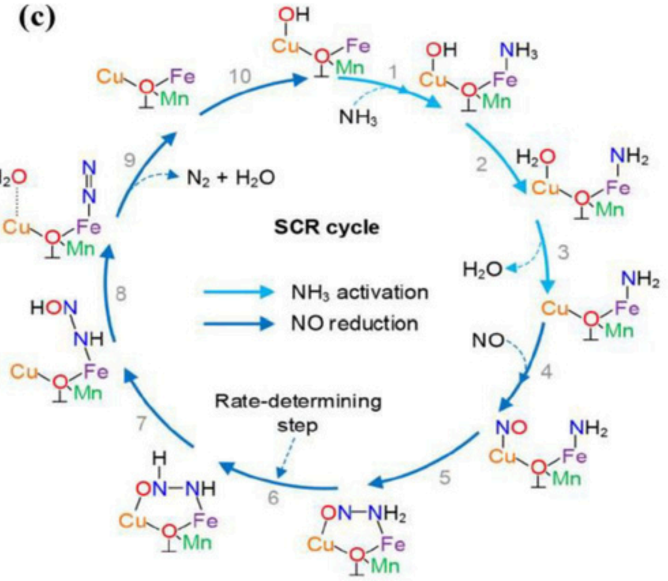

Fig. 6 Selective catalytic reduction cycle

The SCR catalyst system offers high selective catalyst capacity and requires minimal modifications to existing marine diesel engines to comply with IMO's Tier III emission standards. However, installing twin engines on most large ocean-going vessels with twin engines may be challenging. Furthermore, there are still some unresolved issues with the ship's SCR catalyst system, such as its large footprint and high HC and CO emissions levels.

Exhaust Gas Recirculation

Large two-stroke marine diesel engines are the primary applications for exhaust gas recirculation (EGR), an efficient technology to reduce NO_X emissions. The EGR system comprises an exhaust gas wet scrubber, cooler, water mist catcher, high-pressure blower, etc. The device lowers the peak temperature of the gas in the cylinder by recycling the burned gas back into the cylinder, thereby reducing the formation of NO_X dots. The following are the functions of each component: (1) Exhaust gas wet scrubber: This unit consists of a buffer tank with a freshwater supply, a sodium hydroxide quantitative unit, a circulating pump, and water treatment equipment with sludge collection. Its purpose is to remove particulate matter and Sulphur oxides from recycled exhaust gas, preventing corrosion and reducing fouling in the engine and system; (2) Cooler: This unit lowers the temperature of the recycled exhaust gas even more; (3) Water Mist Catcher: This unit removes condensed and entrained water droplets from the purified exhaust gas; (4)

High-pressure blower: This unit raises the pressure of recirculated exhaust gas before it is reintroduced.

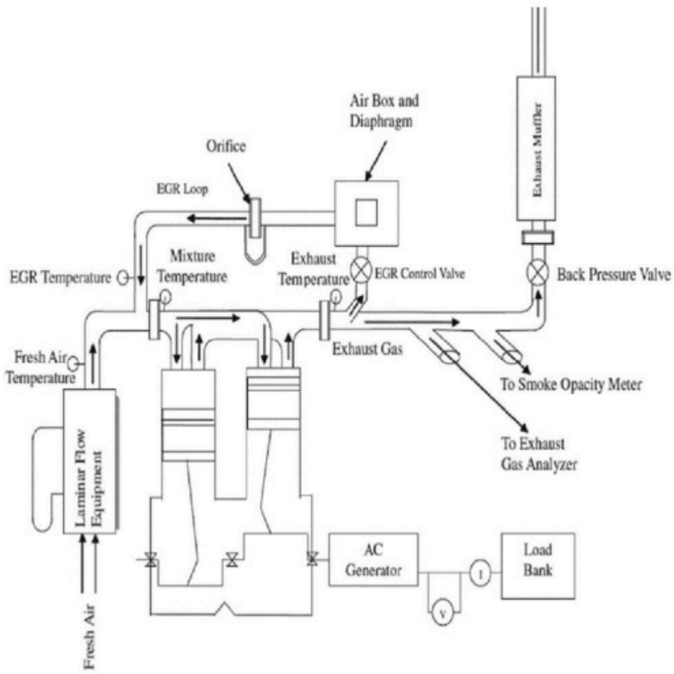

Fig. 7 EGR system

Researchers have recently looked into marine diesel engines' EGR technology. We combined low-pressure EGR with seawater washing to study the discharge performance of an LPG tanker using high-sulfur fuel oil. According to the results, the engine runs consistently and reduces NO_X emissions by about 70% by Tier III regulations at EGR rates of 25–35 per cent. There has been a 98% decrease in SOX emissions. This is the same as using fuel emissions with a Sulphur content of 0 point04 per cent (m/m) lower than ECA. Requirements for emissions.

Methane emissions have also been cut by more than half, and wastewater's pH, turbidity, and nitrate levels are significantly below IMO regulations. Nevertheless, this gadget has shortcomings call for more investigation and improvement, including significant CO and PM emissions and an extra 2-3% fuel loss. The EGR system can efficiently cut NO_X emissions and, in contrast to the SCR, is not constrained by the fuel's sulfur content or reaction temperature. However, oxygen in the combustion chamber decreases when the burned exhaust gas is returned to the cylinder. This leads to incomplete fuel burning, which increases fuel consumption and releases more smoke, carbon monoxide, and particulates into the air. It needs to be paired with other technological advancements because there's a chance of accelerated engine wear and higher maintenance requirements.

Scrubbing Tower

With the help of SOX in ship exhaust fumes and the natural alkaline content of seawater, seawater scrubbing desulphurisation creates sulfates released into the ocean. Seawater scrubbing desulphurisation has the following benefits over other wet desulphurisation techniques: (1) It is a simple process with dependable, mature technology—preservation of freshwater assets. (3) No equipment or pipes shall be obstructed or contaminated. However, natural seawater is only appropriate for low-sulfur marine emissions because of its low alkalinity and restricted ability to buffer acids and bases. In the event of a high Sulphur content, low desulphurisation efficiency makes it challenging to meet current emission standards, and desulphurisation efficiency requires constant replenishment of seawater. The wash water's pH is also low and contains many sulfates. Direct releases harm marine life and devastate the aquatic ecosystem. Ships will no longer use cleaning water for open-loop waste gas cleaning systems in China's air pollution as of January 1, 2020, according to the "Implementation Plan for the 2020 Global Marine Fuel Sulphur Limit Order" published by the China Maritime Safety Administration in 2019. It was explicitly stated that discharge was prohibited—an area of ship control.

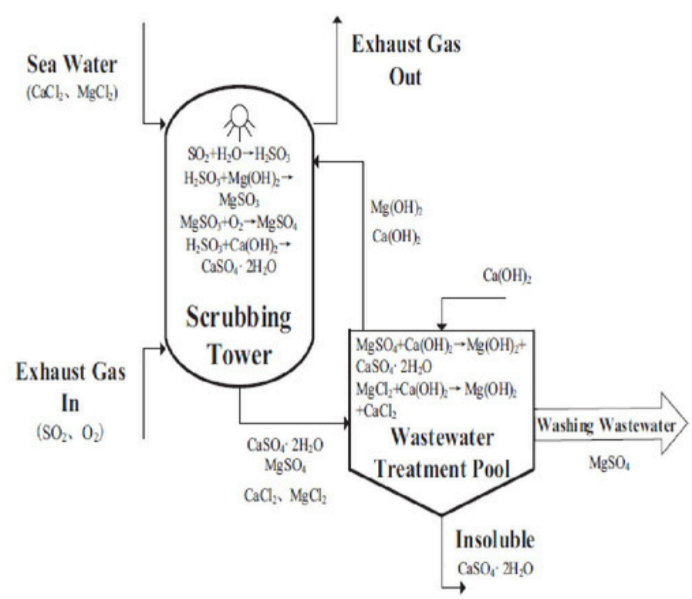

Fig. 8 Scrubber tower

Water Bath Method

This work aims to create an affordable, easy-to-use, and effective diesel emissions control method that could be applied to lower emissions from diesel engines used in the private sector to generate electricity. Before being released into the atmosphere, the exhaust from diesel engines is supposed to be submerged in water as part of an emission control technique.

An especially made water bath was created, air-cooled, and equipped with the required emissions measurement apparatus to confirm the viability of employing this technique to lower emissions from diesel engines. Conducted tests on a 4-stroke diesel engine with a single chamber. Along with other factors like exhaust noise, temperature, unburned HC, CO, and NOx. Exhaust noise is slightly reduced, and NOx, HC, CO, and exhaust gas temperature are significantly decreased when diesel engine emissions are regulated with a water bath, according to experimental findings. Figure 7 illustrates how using a water bath decreased NOx emissions by 62–73 per cent in the diesel engine power range (0–4 to 2 kW) investigated in this study. In comparison to Raman et al.'s findings, this is far superior. [18] With an EGR ratio of 5–20 per cent, he decreased his NOx content by 3–38–6–17 per cent by using exhaust gas recirculation (EGR). EGR use also increased CO and HC emissions by 8–14 points and 27–28 points, respectively. Roy and associates. Showed reductions in NOx of 24%, 47%, and 77% at his respective EGR ratios of 10%, 20%, and 30%.

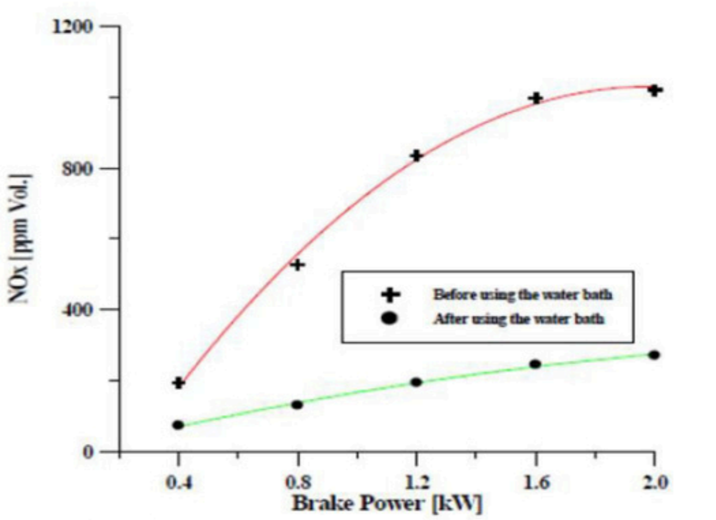

Fig. 9 Effect of using water bath on NOx

These findings show that, compared to conventional methods, using a water bath can significantly reduce diesel engine emissions at a minimal cost. Furthermore, no technique currently in use can cut emissions from diesel engines. Conversely, as previously stated, technology can decrease some types of pollution while increasing others. Several technologies have been used simultaneously to get around this restriction, raising the price of already pricey solutions. Furthermore, as was previously mentioned, a few of these technologies affect engine performance, including fuel economy and engine thermal efficiency.

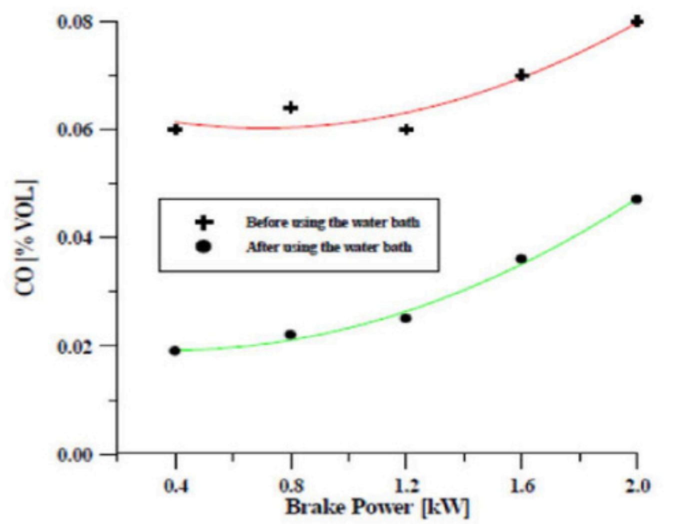

Fig. 10 Effect of using water bath on emission CO

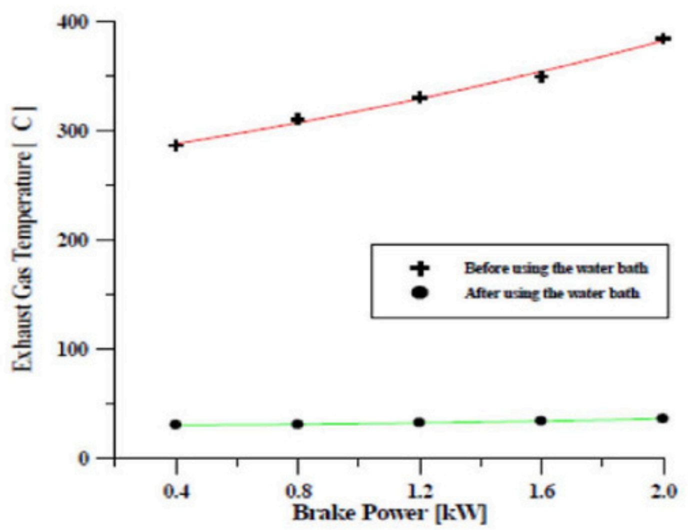

Fig. 11 Effect of using water bath on exhaust temperature

Varying Engine Loads

Compared to older engines, incomplete combustion's load dependence and total emissions are less noticeable in contemporary marine engines. Emission levels and load dependence of emissions are impacted by fleet age. Compared to the medium and small ship fleets (16–22 per cent aged 15+ years and 24-28 per cent built within 0–4 years), the large ship fleet is younger.). 15 years or more). Sixty-one per cent of small boats have operated for at least fifteen years. It is reasonable to anticipate non-optimized engine use, energy efficiency goals, hybridisation, and restricted operation in port areas like B. The EU's proposed zero emissions at sea at berth and California's "At-Berth Regulation" will continue to decline. As a result, the literature reviewed here is restricted to engine loads higher than 40%.

Diesel Particulate Filter (DPF)

When needed, a DPF can be placed before or after the catalytic converter to direct exhaust gases from the engine's combustion chamber. Porous pores in the filter allow exhaust gases to pass through. The size of the soot particles exceeds that of the filter's perforations. The DPF outlet releases the cleaned exhaust gases into the atmosphere. Up to a specific point, soot particles gradually build up in the filter as the back pressure decreases. Next, a differential pressure sensor sends a signal to the electronic control unit (ECU). To initiate the regeneration process, the ECU signals the burner. In one of the methods, accumulated soot is burned during the regeneration process: Active regeneration, where particle accumulation reaches a certain point and exhaust gas temperature rises above 600 degrees. Temperature increases by using upstream burners, electrical regeneration, and engine derating. • The engine becomes leaner as the throttle is applied, which increases the amount of oxygen that can be burned. Soot buildup can burn off due to the increased temperature of exhaust gases. • A burner that has accumulated soot around the filter can be activated when the ECU signals it to be done so. For situations where metal fibers must pass through filters, electrical regeneration is especially appropriate. An electric current flows through the filter by heating and burning the undesirable soot.

Passive regeneration is using a catalyst to lower the total oxidation temperature of soot particles to the exhaust gas temperature. Reduced oxidation temperature facilitates easy regeneration of soot at low temperatures. After installing the engine with the DPF + EGR system, a DPF system was installed to collect soot particles. The DPF has a 200 CPSI construction with 0 points 30 mm thick walls. Ensuring that EGR and DPF systems are installed guarantees that no particulate matter is delivered into the combustion chamber during exhaust gas recirculation. It utilises cordierite wall flow DPF, which is not catalytic. No chemical reactions take place in this cordierite wall stream. It only holds on to soot. EGR and DPF schemes are displayed.

II. CONCLUSION

Ship exhaust fumes need to be controlled because they are becoming more and more detrimental to the environment and public health. Governments and international environmental protection agencies have imposed stricter emission limits since the IMO published MARPOL Annex VI in 1997. As a result, ship emission reduction technology has grown to be a significant concern. It presents substantial difficulties. The technologies discussed in this article for clean energy and exhaust gas cleaning can significantly lower ship pollution emissions. The methodologies for methodically estimating exhaust emissions from merchant ships, their environmental costs, and emission reduction strategies were compared in this study. During her one-year operation on a bulk carrier vessel, this methodology was tested through a cost-benefit analysis of various emission reduction scenarios. New systems must be integrated to lower ship-related emissions in line with technological advancements. As was previously mentioned, however, certain types of emissions can be reduced by using specific auxiliary systems or by changing the fuel type; on the other hand, adding more systems will result in a slight increase in fuel consumption. CO_2 output. Open-circuit scrubber systems are the best option when installing scrubbers. Still, they are already divisive because many nations have outlawed their use, and the wash water from these systems returns to the ocean—systems of hybrid scrubbers.

Because LNG is less expensive than MGO, it is typically recommended when adhering to the IMO2020 sulfur regulation. LNG is a practical substitute for meeting emissions standards for both new construction and existing vessels. The primary benefit is almost zero emissions of PM and SOx. This eliminates the need for an emission control system and enables vessels to meet the IMO Tier III limit for NOx emissions. The drawbacks in this case are the pricey dual-fuel engine and uneven gas station distribution. MGO is the best option for reducing emissions when considering costs exclusively. MGO is free to install and provides extra benefits to ships that operate in ECA. Conversely, vessels operating outside of the ECA are

known as VLSFOs. Aside from switching to dual-fuel engines, investment PBP indicates that recovery is achievable in two to three years globally. Sensible. The goal of future research should be to expand the test to a wide range of vessels that differ in type, size, age, and range. Additionally, reliable Energy Efficiency Design Index (EEDI) calculations must be addressed. This could provide additional benefits to LNG use and qualify the vessel's value when sold on the second-hand market.
,
Through margin recovery, especially at low freight rates and volatile fuel prices. In addition, customers, shipowners and charterers are increasingly aware of the negative environmental impacts of shipping.

The exhaust gas temperatures, unburned HC, CO, and NOx were significantly reduced when the water bath was used. Exhaust noise was only slightly reduced. Water baths lowered all of the emissions considered in this work, in contrast to other methods of reducing diesel engine emissions that increase some pollutants while decreasing others. Thanks to its affordability and ease of use, the suggested technique of using water baths to reduce emissions from diesel engines used in the private sector for power generation looks very promising.

III. ACKNOWLEDGEMENT

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IV. REFERENCES

[1] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[3] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[4] K. Elissa, "Title of paper if known," unpublished.

[5] R. Nicole, "Title of paper with only first word capitalised," J. Name Stand. Abbrev., in press.

[6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Trans. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[7] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[8] Reducing Exhaust Gas Emissions of Stationary

[9] Diesel Engines Using Water Bath; To cite this article: Waleed Majeed et al. 2019 IOP Conf. Ser.: Mater. Sci. Eng. 518 032019

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MARINE ACCIDENTS AND PREVENTION

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Abstract— **Maritime safety is a critical concern in the shipping industry, aiming to protect lives, cargo, and the marine environment. Accident prevention on board ships involves a comprehensive approach that includes risk assessment, adherence to international regulations, regular training, and maintenance. The International Maritime Organization (IMO) sets global safety and environmental performance standards, which are implemented through various safety management systems. These systems help identify potential hazards, implement control measures, and ensure continuous improvement in safety practices. Additionally, technological advancements such as automation and improved communication systems contribute to the prevention of accidents at sea and in port. Despite these measures, human factors remain a significant cause of maritime accidents, highlighting the need for ongoing training and awareness programs to mitigate risks. Overall, a proactive and integrated approach to safety management is essential for preventing accidents on board ships.**

I. INTRODUCTION

The vast expanses of our world's oceans have long been vital arteries of global trade, commerce, and transportation. However, in the busy activity of these shipping lanes, there is a great spectre of accidents that threaten the safety of sailors and passengers and the delicate marine ecosystems. Understanding the dynamics of marine accidents and implementing effective prevention tools are paramount in safeguarding lives, preserving the environment, and ensuring the sustainability of marine industries.

This article explores the diversity of marine accidents and examines their causes, consequences and, most importantly, the preventive tools available to mitigate their occurrence. By examining historical data, case studies, and scholarly research, we aim to illuminate the complex interplay of factors contributing to marine accidents, ranging from human error and technical failures to environmental hazards and regulatory deficiencies.

The consequences of marine accidents extend far beyond the immediate impact on vessels and infrastructure. Oil and hazardous chemical spills can inflict lasting damage on aquatic ecosystems, threatening biodiversity and the livelihoods of coastal communities. Collisions, groundings, and sinkings not only result in tragic loss of life but also incur significant economic costs through vessel damage, salvage operations, and legal liabilities.

In response to these challenges, various prevention tools and strategies have been developed, spanning technological innovations, regulatory frameworks, and educational initiatives.

From advanced navigation systems and vessel monitoring technologies to international conventions and industry best practices, these tools constitute a comprehensive arsenal to enhance maritime safety and resilience.

However, despite the progress made in recent decades, marine accidents continue to pose a persistent threat, underscoring the need for ongoing research, collaboration, and innovation in maritime safety. This paper seeks to contribute to this endeavor by critically evaluating existing prevention tools, identifying gaps and challenges, and proposing recommendations for future action.

In the following pages, we will delve into the intricate tapestry of marine accidents and prevention, examining case studies from around the world, analyzing emerging trends and technologies, and offering insights into effective risk management strategies. Doing so, we aspire to foster a deeper understanding of this critical issue and empower stakeholders to work towards a safer, more sustainable maritime future.

II. METHODOLOGY

A successful investigation after a maritime accident will find the root causes contributing to the accident. This would provide valuable lessons for maritime safety. For these reasons, the investigation team must be methodical and insightful and must use all the necessary and possible means to efficiently use data. We use the Text Mining Method for our research paper, which consists of extracting important information from documents, reports and case studies to establish causal links to corresponding concepts. This method allows for the concentration of the data and puts them on significant accident concepts. The materials consulted and used for this research were obtained through the library, the Internet and other publicly accessed sources. We have done content analysis and discussion based on the established literature and database.

Due to the limitation of the length of this paper and other limitations, it is impossible to compare all aspects of accident investigation. In this research paper, we have focused solely on marine accidents from 2000 to the present day. Due to the vast number of incidents in maritime history, we acknowledge that it is not feasible to cover all accidents within the scope of this study. Therefore, by limiting our research to the specified time frame, we aim to provide a more comprehensive analysis of recent maritime incidents.

The main objectives were identifying the underlying causes and exploring their possible association with inspection practices. It also aims to identify the consequences to human health, the environment, and property. This analysis considered the following ship types: general cargo ships, container ships, passenger ships and cruise ships. In addition, the subsequent accident categories, failure of equipment, structural failure, fire and explosion, are considered in the analysis. These were selected because, as derived from the study of the accident reports, they may be safely correlated to omissions during the inspection process.

We have attempted to accurately and efficiently incorporate all the different causes that lead to accidents and all the different consequence paths that follow. The in-depth analysis of the accident reports also led to the identification of main and intermediate causes attributed to the human element (e.g., inexperienced personnel, untrained personnel and inappropriate actions). The role of inspections and maintenance is also covered in research.

The conclusion and recommendations will be made at the end of this paper.

III. RESEARCH ON MARINE INCIDENTS

This research paper aims to analyze marine incidents between 2000 and the present day, focusing on their causes, consequences, and measures taken to prevent future occurrences. This study provides valuable insights into the patterns, trends, and lessons learned from these events by examining a range of incidents, including oil spills, ship collisions, and maritime disasters. Here are some
Examples of major marine incidents that happened after the year 2000

- **Bahamas-flagged tanker Prestige split in two -**

Fig. 1 Structural Failure of the Prestige Tanker

The 26-year-old Bahamian-registered tanker Prestige (Details of which are provided in Appendix A) broke in two and sank on Tuesday, November 19, 2002, with a large amount of her original cargo of 76,972 tons of fuel oil still on board. The ship was some 130 miles off the Northwestern coast of Spain at the time.

During a storm, it burst a tank on 13 November, and the French, Spanish, and Portuguese governments refused to allow the ship to dock. The vessel subsequently sank on 19 November, about 210 kilometers (130 mi) from the coast of Galicia. It is estimated to spilt 60,000 tons or a volume of 67,000 m3 (17.8 million US gal) of heavy fuel oil.

The oil spill polluted 2300 kilometers (1429 miles) of coastline and more than one thousand beaches on the Spanish, French, and Portuguese coasts, causing great harm to the local fishing industry. It is the most significant environmental disaster in the history of both Spain and Portugal. The amount of oil spilled was more than that in the Exxon Valdez incident, and the toxicity was considered higher because of the higher water temperatures.

- **Collision of Cargo ship Eastern Challenger in Tokyo -**

The Philippine-registered cargo ship Eastern Challenger is seen sinking at the entrance of Tokyo Bay, 13 April 2006.

Fig. 2 Structural Failure of the Eastern Challenger

The Eastern Challenger collided with another cargo ship in foggy conditions at the entrance of Tokyo Bay, with all 30 Filipino and Japanese crew members being rescued, the Coast Guard said.

- **Cargo ship 'New Flame' collided with oil tanker in Spain -**

Fig. 3 Structural Failure of the New Flame

MV New Flame was a Panamanian bulk-carrier cargo ship. It collided with an oil tanker off Europa Point, the southernmost tip of Gibraltar, on 12 August 2007 and ended up partially submerged in the Strait of Gibraltar. The vessel broke into two in December 2007 amid numerous unsuccessful recovery efforts. The cargo was salvaged, and the stern section was removed for scrap. Following the crew's rescue, the captain was arrested for departing without authorization. Charges of endangering shipping were later dropped.

- **Costa Concordia disaster in Italy -**

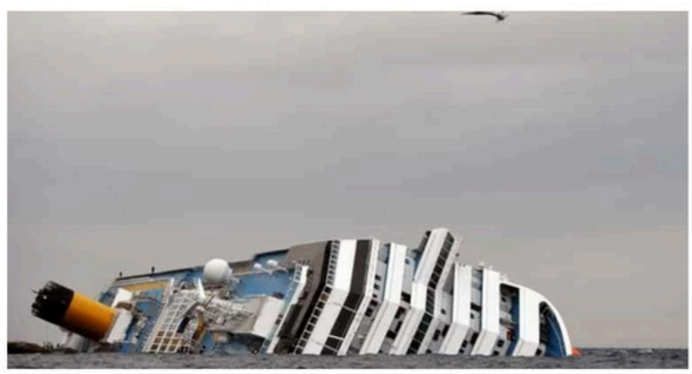

Fig. 4 Capsizing of Costa Concordia

An Italian cruise ship, Costa Concordia, ran aground and overturned on January 14, 2012, after striking an underwater rock off Isola del Giglio, Tuscany.

The cruise ship accommodated more than 4,000 people on board. The owner of the luxury liner that ran aground off the coast of Italy, killing at least six people, said its captain had made 'errors of judgment' as the search continued for the missing.

- **Sanchi oil tanker blaze -**

Fig. 5 Fire on Sanchi oil tanker

On January 6, 2018, the Sanchi, an Iranian oil tanker carrying 136,000 tons of highly toxic light crude oil, collided with a Hong Kong-registered bulk freighter, setting the ship ablaze and killing all 32 Iranian crew members on board. Efforts to contain the fire and locate crew members took over a week, but the boat eventually drifted towards Japan and sank on January 14.

The accident caused an oil slick covering an area of 100 square kilometers – roughly the size of Paris – in one of China's richest fishing grounds.

IV. TYPES OF MARINE ACCIDENTS

Marine mishaps can be roughly divided into multiple categories:

1: Collision: This happens when two or more ships collide. It is often the result of bad navigation, unclear communication, or poor visibility.

2: Groundings: A vessel runs aground when lodged on the ocean floor or the coastline. Mistakes in navigation, malfunctioning equipment, or unfavorable weather can all cause this.

3: Sinking: A vessel that sinks partially or completely submerges in water frequently results in property loss, environmental harm, and, in extreme situations, fatalities. The reasons could be anything from equipment malfunctions to harsh weather to hull breaches.

4: Fires and explosions: Fires and explosions onboard a vessel can cause serious dangers to human safety and the environment. Numerous things, including engine problems, fuel leaks, electrical problems, and dangerous cargo, might cause them.

5: Capsizing: A vessel can capsize if it overturns, rolls onto its side, or even topples over entirely. Severe variations in weight distribution, unbalanced loads, or severe weather can all cause this.

6: Pollution Incidents: These incidents occur when dangerous materials, such as oil spills, chemical leaks, or sewage discharges, are released into the maritime environment. The ecological and economic effects of these incidents may be long-lasting.

7: Structural Failures: These include various problems, such as component malfunctions, fatigue in the structure, and hull breaches. These malfunctions can potentially cause mishaps and jeopardize the vessel's integrity.

8: Human error: Many maritime mishaps are caused by people, including poor decision-making, insufficient training, exhaustion, or drunkenness. Human error's interaction with other causes frequently increases accident severity.

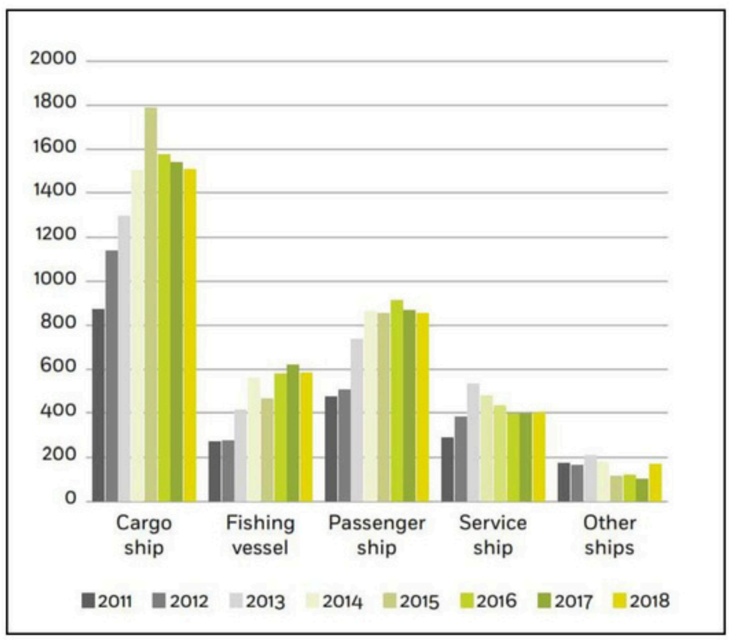

Fig. 6 Annual Distribution of Ship Types (2011-2018)

To reduce risks and guarantee the safety of maritime activities, it is essential to comprehend the different kinds of maritime accidents and implement appropriate safety measures, training procedures, and regulatory frameworks.

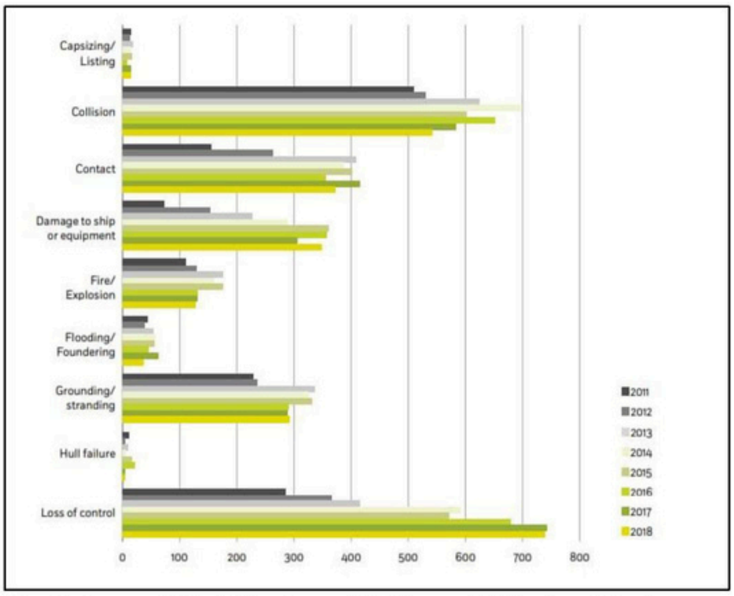

Fig. 7 Annual Distribution of Different Ship Accidents

V. RISK FACTORS AND CAUSES

Risk factors and reasons, such as the following, can result in marine accidents:

1: Human Error: One of the main reasons why marine accidents occur is human error. It can involve crew member errors, navigational blunders, poor maintenance, exhaustion, and insufficient training.

2: Weather: Unfavorable weather can raise the chance of collisions, groundings, and capsizing. These weather conditions include storms, strong winds, fog, and choppy seas.

3: Equipment Failure: Mishaps can result from mechanical breakdowns or faults of vital onboard equipment, including engines, propulsion systems, navigational aids, and communication systems.

4: Navigational errors can lead to crashes, groundings, or running aground on subsurface hazards. Examples of navigational errors include misreading charts, failing to take current or tide conditions into account, and misusing nautical aids.

5: Collision dangers: There are a lot of dangers associated with collisions in marine operations, whether they include other vessels, fixed structures like piers or bridges, or floating things like garbage or icebergs.

6: Fire and Explosions: Fuel leaks, electrical problems, improper cargo handling, and other causes can result in fires and explosions on board ships, which can cause significant damage, casualties, and fatalities.

7: Cargo Incidents: When cargo is loaded, secured, or mishandled, it can lead to mishaps like cargo shifts, container collapses, or hazardous substance spills, putting the crew and ship in danger.

8: Environmental conditions: Several environmental conditions might cause an accident, including strong currents, shoaling, undersea hazards, icebergs, and limited visibility from fog or darkness.

9: Adherence to Regulations: Vessels may be subject to financial and legal risks and an increased chance of accidents if maritime legislation, safety standards, and best practices are broken.

10: Security Risks: Terrorism, sabotage, and pirate activities put ships, crew members, and cargo at risk and constitute security risks to maritime operations.

Comprehensive risk management techniques, such as efficient training programs, routine equipment maintenance, adherence to safety procedures and laws, constant observation of weather and navigational conditions, and encouraging a safety culture among crew members are necessary to prevent maritime accidents. Furthermore, continuous accident investigation and analysis aid in determining the underlying causes and putting preventative measures in place to improve marine safety.

VI. IMPACT OF MARINE ACCIDENTS

Marine accidents have far-reaching consequences across several critical domains. Let's delve into each aspect:

1: Environmental Impact:

- Ecosystem Disruption: A single incident, such as an oil spill from a large tanker, can wreak havoc on marine ecosystems. These spills contaminate water, soil, and habitats, affecting marine life, birds, and coastal vegetation.
- Biodiversity Loss: Toxic substances harm aquatic organisms, leading to biodiversity loss. Sensitive species may face extinction, disrupting the natural balance.
- Long-Term Effects: The environmental repercussions can persist for years, affecting the immediate accident site and neighboring regions.

2: Economic Implications:

- Direct Costs: Maritime accidents incur immediate financial burdens. These include rescue operations, salvage efforts, and emergency responses.
- Indirect Costs: There are long-term economic consequences beyond immediate expenses. These include:

Resource Loss: Damage to fisheries, aquaculture, and other marine resources.

- Tourism Impact: Coastal tourism suffers from polluted beaches and damaged ecosystems. Trade Disruptions: Accidents disrupt shipping routes, affecting global trade and supply chains.
- Insurance Claims: Payouts for vessel damage, cargo loss, and liability claims. Legal Proceedings: Legal costs related to investigations and compensation.

3: Human Cost:

- Loss of Life: Maritime accidents result in fatalities among crew members, passengers, and rescue personnel.
- Injuries: Survivors may suffer physical injuries, trauma, and long-term health issues.
- Psychological Toll: Witnessing accidents or losing colleagues takes a toll on mental health.
- Livelihood Impact: Families of victims face emotional distress and financial instability.

Efforts to prevent maritime accidents should focus on addressing human error, improving safety practices, and minimizing the impact on both the environment and society

VII. PREVENTION STRATEGIES

Prevention techniques for maritime accidents encompass a range of measures aimed at mitigating risks and ensuring the safety of vessels, crew, and the environment:

- Crew Training: It is crucial for crew members to receive regular training on safety procedures, emergency responses, and the use of safety equipment.
- Adherence to Safety Protocols: Strict adherence to established safety protocols, including procedures for navigation, collision avoidance, and handling hazardous materials, helps minimize the likelihood of accidents.
- Vessel Maintenance: Regular inspection and maintenance of vessels, machinery, and equipment ensure they are in optimal working condition, reducing the risk of mechanical failures and malfunctions.
- Effective Communication: Clear communication among crew members and other vessels and shore authorities helps prevent misunderstandings and coordinate responses during emergencies.
- Use of Navigational Aids: Advanced navigational aids such as GPS, radar, and AIS (Automatic Identification System) enhance situational awareness and assist in safe navigation, especially in busy or hazardous waters.
- Safety Management Systems (SMS): Implementing SMS, which includes risk assessment, incident reporting, and continuous improvement processes, helps identify potential hazards and mitigate risks proactively.
- Risk Assessments: Conduct regular risk assessments to identify and evaluate potential hazards and implement measures to reduce or eliminate risks accordingly.
- Compliance with Regulations: Ensuring compliance with international maritime regulations, such as those set by the International Maritime Organization (IMO), national maritime authorities, and industry standards, is essential for maintaining safety standards.
- Emergency Preparedness: Developing and practising emergency response plans for various scenarios, including fire, collision, grounding, and pollution incidents, enhances the ability to respond effectively to emergencies.
- Environmental Protection Measures: Implementing measures to prevent pollution, such as proper waste handling and disposal, use of environmentally friendly practices, and adherence to ballast water management regulations, helps protect marine ecosystems.

VIII. CONCLUSION

In conclusion, this research has shed light on the critical issue of marine accidents and the effectiveness of preventive measures. Based on a thorough analysis of past cases and current prevention efforts, it is clear that effective risk reduction requires a multifaceted approach. While technological advances and regulatory frameworks are crucial, the emphasis remains on the continuous training and awareness of maritime personnel. In terms of progress, concerted efforts in research, innovation and collaboration between different industries are needed to improve maritime safety and prevent future accidents.

Maritime safety is crucial in the shipping industry to protect lives, cargo, and the environment. Accident prevention involves a comprehensive approach, including risk assessment, adherence to regulations, training, and maintenance. Despite technological advancements, human factors remain a significant cause of accidents, emphasizing the need for ongoing training and awareness programs. A proactive and integrated safety management approach is essential to prevent onboard ship accidents.

IX. REFERENCES

1] A. Smith et al., "Analyzing Marine Accident Data: Trends and Patterns," Maritime Safety Journal, vol. 25, no. 2, pp. 45-58, Apr. 2022.
2] B. Johnson and C. Lee, "Evaluation of Navigation Systems for Preventing Marine Collisions," IEEE Transactions on Marine Engineering, vol. 15, no. 3, pp. 112-125, Jul. 2020.
3] C. Garcia and D. Patel, "A Review of Human Factors Contributing to Marine Accidents," Journal of Maritime Safety, vol. 8, no. 4, pp. 321-335, Oct. 2019.
4] D. Wang, "Development and Application of Artificial Intelligence in Marine Accident Prevention," in Proceedings of the International Conference on Maritime Technology, Singapore, 2023, pp. 87-94.
5] E. Brown, "Use of Simulation Tools for Training and Preparedness in Marine Accident Response," Journal of Maritime Technology Education, vol. 12, no. 1, pp. 55-68, Mar. 2021.
6] K. Johnson and R. Patel, "Risk Assessment Techniques for Marine Vessels," in Proceedings of the International Conference on Maritime Safety, London, UK, 2021, pp. 112-120.
7] M. Garcia and S. Lee, "Application of Artificial Intelligence in Maritime Safety Systems," IEEE Transactions on Marine Engineering, vol. 10, no. 2, pp. 78-89, May 2019.

A BRIEF REVIEW ON EXTENDED SURFACES

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***Abstract*-This research investigates how a notched fin array can improve heat transmission. In real-world applications, we frequently need to accelerate the pace of heat moves from smaller regions. We must employ several fin types in these situations. The system's temperature-driven forces are likewise reduced when fins are used. This study examined several notched fin array combinations and types based on the notches' shapes, including circular, triangular, and rectangular ones. Furthermore, it has been noted that the inverted notch fin arrays outperform notched fin arrays in terms of performance.**
Keywords: Nusselt number, notched fin, and heat transfer increase.

I. INTRODUCTION

Concerns regarding methods to increase heat transfer rates have arisen with the development of effective thermal procedures. Improved thermal execution research refers to heat transfer strengthening, expansion, or upgrading. Heat transfer enhancement can enhance the performance of a heat transfer network. For scholars, this topic is exciting because it encourages cost and energy conservation. Due to the massive increase in power demand worldwide, plan and task engineers are constantly faced with the challenge of reducing energy loss caused by insufficient use and intensification of energy and the importance of heat in numerous real-world applications.

Since eliminating heat from a system is crucial, heat sinks are used in systems to do just that. They do this by exchanging the heat extracted with another fluid or the surrounding air. The two ways to accomplish this are from Newton's law of cooling.

1) Increasing the heat sink's surface area
2) Raising the heat transfer coefficient ok

According to a literature review, experimental studies have been conducted to improve heat exchange using notched fin arrays, which include square, triangular, circular, and inverted fin arrays. In natural convection, changes in the finned array's geometry and orientation affect the rate of heat transmission. This research is significant for developing novel types of small heat sinks.

II. REVIEW

Suneeta Sane et.al [1]

This article investigates heat transmission via natural convection from horizontal rectangular notched fin arrays experimentally. The primary regulating factors for the increase in heat transfer were the influence of the fin array's geometry and orientation. Experimental testing is done on four fin configurations with aluminium fins (17, 13, 11, 9, and 12) that have a thickness of 2 mm and an aluminium base plate that measures 150, 100, and 50 mm at different input powers (20, 40, 60, 80, and 100 watts). Two-fin separation measured in millimetres 6 mm, 8 mm, 10 mm, and 12 mm—is another criterion. Slot decrement is 20%, 30%, and 40% of the un-slotted fin's surface area. From this investigation, we deduced that the convective heat transfer coefficient increases with fin spacing. The convective heat transfer coefficient increases with the slot region. For the specified

N. A. NAWALE AND A. S. PAWAR [2]

This study explores experiments on heat exchange through fins with different notches. The flat fin's core piece is removed by creating various notches. The study uses five aluminium fins fixed to the base plate, each measuring three millimetres thick. Several fin configurations are considered to investigate the impact on heat transfer rate, including unnotched, triangular notched, circular notched, and rectangular notched. The experiments were conducted at two base temperatures: 600°C and 800°C. According to the study, the fin arrangement with the triangular indent has the most remarkable coefficient of convective heat transmission. Further research was conducted by altering the fin's triangular notch height. The investigation found that the set of fins for the triangle notch with the maximum height had the highest convective heat transfer coefficient.

S. SADRABADI HAGHIGHI ET.AL. [3]

This paper examines the natural convection enhancement of heat transfer in newly designed plate-fin heat sinks. The convective heat exchange coefficient and the heat execution of plate fins and plate cubic heat sinks under free convection were the main points of examination. The setup has six different fin arrangement possibilities made of aluminium alloy 6061 material. Rectangular plane fins spaced 12, 8.5, and 5 mm apart are employed in three configurations. The final three variants feature cubic pin-fin fins alternately spaced appropriately. The range of input was 10W to 120W. The findings showed that the thermal resistance of the plate cubic pin fin heat sink is 12% less than that of the plate pin fin. Moreover, increasing fin spacing causes a drop in thermal resistance, which raises the heat transmission rate.

ABBAS JASSEM JUBEAR AND ALI A. F. AL-HAMADANI [4]

This paper investigates the heat exchange through free convection from a group of vertically oriented rectangular fins. The group comprises six aluminium fins measuring 4 mm thick and spaced 10 mm apart. The fins are 300 mm long and have heights of 10 mm, 25 mm, and 45 mm. The primary focus of the study is to analyse the impact of varying fin heights on the heat exchange process. The study considers heights of 10 mm, 25 mm, and 45 mm. The Rayleigh number used in the study ranges from 7.6 × 10^-5 to 1.5 × 10^-5, and the power input for each fin configuration ranges from 68 W to 716 W. The study measured several heat generation values, namely 413, 930, 1680, 2630, and 3792 W/m2. The results indicate that the length, height, and base of the temperature difference influence the high heat exchange rate from fin clusters on perpendicular plates. The heat transfer rate increases as the fin height increases from 10 mm to 45 mm.

SANJEEV SURYAVANSHI AND NARAYAN SANE [5]

The two main factors that regulate the heat transfer process are the geometry and orientation of the system. This experiment removes a middle section to create an inverted indent. The parameters considered for the analysis include the percentage of the region expelled as changed indent, power input, and fin separation. CFD is used to verify the results.

The findings of the experiment show that,

The heat transfer coefficient gradually increases as the fin spacing rises to 9 mm.

The heat exchange coefficient estimation also increases with an increase in power input.

Indented fins' average heat exchange coefficient is 40-50% higher than un-indented fins.

The coefficient of heat transfer estimation also increases as the excluded region's level increases.

The Nusselt number values decrease with a decrease in fin separation, reaching a maximum of approximately 6mm before the nub begins to shrink.

Inverted fins provide a faster heat exchange rate than conventional fins at a specific temperature.

Moreover, 40% of the inverted fin arrays offer a better heat exchange rate for a given temperature difference.

Higher power input values correspond to higher nub values.

MD. SHAMIM HOSSAIN ET.AL. [6]

This study focuses on the functionality and design of leg fins used in heat transfer examinations. The fin and base plate were made of aluminium. Seven fins, with a periphery of 8.2 mm and a length of 70 mm, were employed and deposited in a line. The study was erected on the following criteria dimension of heat exchange with natural convection (h = 31.6, 35.39, and 38) and forced convection (h = 54.14, 58.85, and 64.78) prognostications.

Fin forms' effectiveness concerning natural convection (η = 52.87,60.16,55.88) and forced convection (η = 23.6,20.84,16.17).

The following are the issues that followed: When forced convection occurs,

The heat exchange rate through the fins increases as the addict's speed increases, but the fins' efficacity decreases as the forced convection heat exchange measure increases.

The logic is that as the speed increases, less time will be spent in contact with the fin and air, reducing the fins' effectiveness.
On the other hand, as the heat transfer rate rises, the efficacity of free convection will also rise.

ANANT JOSHI AND D.G. KUMBHAR [7]

The study of heat exchange by free convection from a vertical blockish (square-depressed) cluster is examined in this exploration. The air sluice over the fin cluster and heat exchange from natural convection is prognosticated by this trial. Nine fins with a 9 mm fin distance were used in the arrangement used for the trial. The aluminium fin and base plate measures are measured independently: 70 mm x 40 mm x1.1 mm and 101 mm x 70 mm x 25 mm. In addition to 10, 20, and 30 reductions in the square notched area, heat input of 40W, 60W, and 80W was supplied. According to the result, the absolute heat inflow and the convective heat exchange measure increase as the indent depth increases.

SHYY-WOEI CHANG ET.AL [8]

This work examines the heat exchange upgrade of a vertically dimpled fin cluster in free convection. We experimented with and examined separately four fin designs with the same base area: a plane rectangular thirteen-fin cluster, a plane rectangular nine-fin cluster, a dimpled nine-fin cluster, and a dimpled seven-fin cluster. Using a fixed Prandtl number of 0.71, the Rayleigh numbers (Ra) of 108, 7.75 ×107, 5.5 ×107, and 3.25 ×107 were examined for the analysis of free convective flow. The comparison of heat transfer between a dimpled nine-fin array and a plain thirteen-fin array is used to achieve the purpose. The results showed that for each type of fin surface used, the average and local Nusselt numbers increase as the Rayleigh number increases. Every fin segment experiences accelerated flow because the air stream rate at the tip is higher than the air stream rate at the fin base passage due to the lower fluid densities at the tip. A high Nusselt number is achieved with a dimpled layout because the upward convective flows are more substantial.

AKSHENDRA SONI [9]

Using natural convection, this experiment compares the thermal performance of three types of heat sinks—plate-fin, pin-fin, and elliptical. Here, the fin height and base plate dimensions remain unchanged. A comparison is made between heat sinks with rectangular fins and pin fins positioned vertically. Thermal impacts and relentless-state-free convection heat exchange are used to compare them. Additionally, continuous fins are studied, and their analytical outcomes are discovered. Elliptical fin effects were then discovered. The 3-D model created using ANSYS and SolidWorks software is used to study the unique effects of fin geometry. The whole heat dissipation under constant volumetric circumstances is the basis for the results. The research and testing revealed that plate fins outperform pin fins in terms of performance. Based on creating a region map, plate-fin heat sinks exhibit good thermal execution in most testing locations. Elliptical fins are also better than pin fins in free convection, although they lack the exposed area that plate fins have. Finally, it can be said that although elliptical fins can be used instead of pin fins, they are not yet strong enough to compete with plate fins since plate fins have a larger surface area subject to convection.

ENCHAOYU AND YOGENDRA JOSHI [10]

This work examines leg-fin heat sinks to grease heat transfer from enclosed separate factors. colourful flux patterns and temperature readings were made to enhance heat exchange. The vessel measures 25.4 x 25.4 mm and 127 x 127 x 41.3 mm. An arrangement with a leg fin and heat source was made. The parameters are considered: element length, quad length, quad height, element viscosity, quad wall viscosity, leg fin size, and porosity. The quad's perpendicular and vertical configurations were made with certain boundary conditions in mind. Aluminium fin array material was named in sizes nine by 9 and 12 by 12. A single thermo-counter heater is employed for heating. To measure temperature, T-type thermocouples with a0.076 mm fringe are connected.
The following are the results of the trial
Because of shrouding, the quadrangle walls lower overall heat transfer.
An unrestricted terrain with the thermal prosecution of a heat source performs better than an open space with a finned array.
A rise in leg fin number reduces the improvement of heat exchange.
Vertical alignment results in reduced thermal opposition in the whole quadrangle. Pin-fin arrays give fresh advancements in heat exchange for straight enclosures.

QIE SHEN, DAMING SUN, YA XU, TAO JIN, XU ZHAO [11]

This experimental disquisition of Gomorrah, a skinny heat source used in LEDs, is conducted. A computational and experimental disquisition occurs on the fluid inflow under natural convection and exposure goods. All eight exposures are made, and Gomorrah's skinny fin heat is estimated for each. For LEDs to produce enhanced illumination intensity, heat exodus is pivotal. There are two orders of cooling technologies: unresistant cooling and active cooling. The skinny fit is the most successful heat cesspool that advocates conservation and zero energy use. Exposure causes considerable changes in thick fins. The vast fin distance exhibits minimum variation in thermal performance between zero and 135 degrees of exposure. heat Gomorrah, but changes in heat sinks with narrow fin distances are substantial. still, the worst script for both kinds of heat sinks is exposure to 260 degrees. The trial issues, current prospects, and preliminarily unexplored data are substantially relative. Between the heat exchange area and the free convection flux, there's an imbalance between the two supervising rudiments that reverse heat exchange through skinny fin heat sinks.

MAO-YU WEN AND CHING-YEN HO [12]

The primary objective of this experiment is to investigate the components of a fin-and-tube heat exchanger. Three distinct types of fins—the plate fin, wavy fin, and compound fin—are mainly examined. The pressure drop, Reynolds number, airspeed, Fanning friction factor (f), Colburn factor (j), and heat exchange coefficient (c) have all been discussed with each other. To further analyse the fluid stream properties, stream perception was also performed. The pressure drop, heat exchange coefficient, j, and f variables increase due to the wavy fin transitioning to a flat fin display pattern. The results of compounded fins compared to flat fins likewise demonstrate the increase. The best way to increase the efficiency of round tube and plate-fin heat exchangers is to develop improved fin designs. Compact heat exchangers have complex air flow due to the intricate relationship between the fin design and the air stream. During experiments, compact heat exchangers are employed to enhance heat transfer and pressure drop. The best of these three distinct types of fins is the compound fin.

Y. JOO AND S. J. KIM [13]

The thermal efficiency of optimized plate-fin and leg-fin heat sinks with a vertically oriented base plate is analyzed under natural convection. A novel correlation for heat transfer assessment is introduced and experimentally validated for optimizing leg-fin heat sinks. In contrast, an existing correlation from previous studies is applied to plate-fin heat sinks. The analysis is conducted under identical base plate dimensions and fin height conditions. Two key performance criteria are considered: total heat dissipation and heat dissipation per unit mass for a given base-to-ambient temperature difference. When total heat dissipation is the primary criterion, the optimized plate-fin heat sinks release more heat than optimized leg-fin heat sinks in most practical scenarios. Conversely, when heat dissipation per unit mass is emphasized, optimized leg-fin heat sinks exhibit superior performance over plate-fin heat sinks in most real-world applications.

G. J. HUANG, S. C. WONG, AND C. P. LIN [14]

The convective heat transfer efficiency in long vertical rectangular fin arrays is generally low due to inadequate airflow in the inner regions. This study introduces perforations at the fin base to enhance ventilation by allowing cold air to enter from below. Numerical analysis is conducted on Aluminium fin arrays with lengths of 380 mm and 104 mm, a fin height of 38 mm, a thickness of 1 mm, and a spacing of 10 mm, considering a temperature difference of 55 K between the fin base and its surroundings. An unsteady model is adopted since airflow instability occurs in fin arrays exceeding 100 mm. The study primarily examines a single-channel design with multiple evenly spaced rectangular perforations, covering either L/2 or L/4 of the fin spacing. Additionally, a multi-channel analysis is performed on a specific fin array configuration where uniform heat is applied at the base's center, and longitudinal perforations are positioned outside the heated region. The perforations, particularly those in the inner section, significantly improve ventilation and heat dissipation. Designs with smaller, more widely distributed perforations demonstrate greater enhancements. The overall heat transfer efficiency in long fin arrays with perforations can more than double compared to non-perforated configurations. The study also analyzes airflow patterns and the longitudinal distribution of surface heat flux to assess the effects of fin-base perforations.

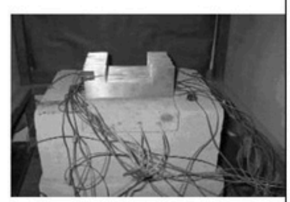
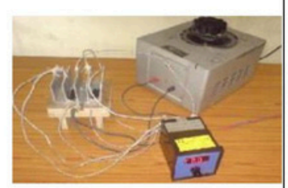
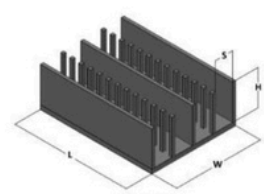
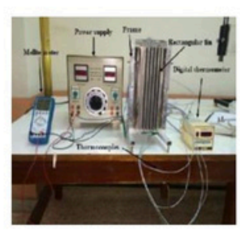
V. S. KORADA, M. OVINIS, AND S. B. HASSAN [15]

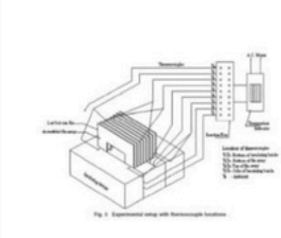
Trials have been conducted to determine the emissivity for black chrome carpeted and uncoated aluminium shells. The emissivity of the shells is estimated considering concerted convection radiation heat transfer and observed to be a constant in the range of 60 to 110 °C. The concerted heat transfer portions from a black chrome carpeted perpendicular base perpendicular fin array of size 70 x 70 mm conforming 22 aluminium fins with a fin distance of 10 mm by natural convection and radiation have been determined at different heat inputs.

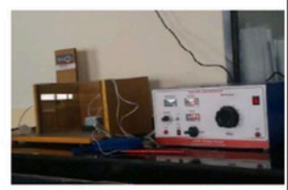
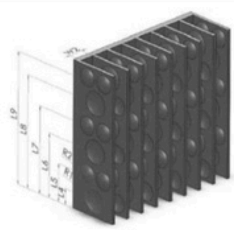
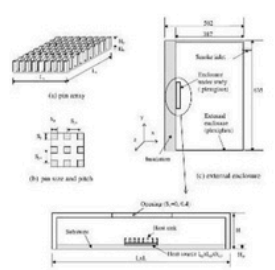
Theoretical analysis of a single fin figure of constant consistency, considering both convection and radiation, has been used to prognosticate temperature distribution and heat inflow.

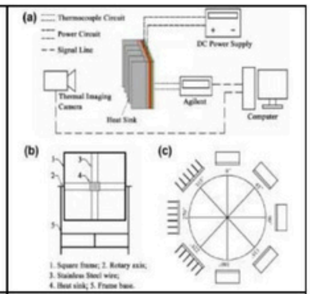
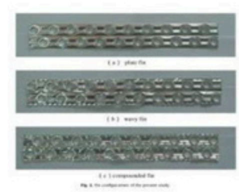
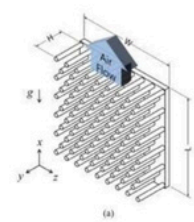
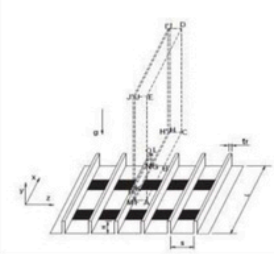
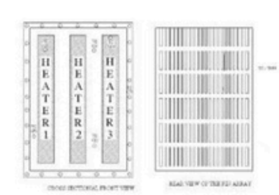
The theoretical values of heat inflow estimated for a fin array are in good agreement with the experimental compliances validating the emissivity of the face. The experimental data is further validated with the Nusselt equations presented by Churchill and Chu.

TABLE 1. SUMMARY OF LITERATURE REVIEW RESULTS

NAME OF AUTHOR	MODIFICATIONS	PARAMETERS STUDIED	ENHANCEMENT ACHIEVED	GEOMETRY
SuneetaSen [1]	• Horizontal rectangular notched fin array. • Number of fins- 17, 13,11,9. • Thickness- 2mm.	• Fin spacing- 6, 8, 10, 12 mm. • Notch area reduced- 20%, 30%, 40%.	• Fin spacing increases, heat transfer rate increases. • Coefficient of heat exchange of indented array is 30%-40% more than corresponding un-indented array.	
N.A Nawale [2]	• Fins having different notches (circular, triangular, rectangular). • Number of fin- 5. • Thickness – 3mm.	• Height of triangular notch is varied.	• Heat transfer rate is maximum for triangular notch. • A set of the fin with a maximum height of triangular notch has the highest heat transfer coefficient.	
S. SaDr Abadi Haghighi [3]	• Cubic pin fins are used alternatively with plain rectangular fins.	• Number of fins- 5, 7 and 9. • Spacing between fins – 12mm, 8.5mm, 5mm.	• The thermal opposition of the plate pin fin is 12% more than that of the plate cubic pin fin. • Rate of heat exchange increments with increment in separation among fins.	
Abbas Jassem Jubear [4]	• Vertical rectangular fin array. • Number of fins- 6. • Thickness- 4mm. • Fin spacing- 10mm.	• Height considered are – 10mm, 25mm, and 45mm.	• When fin height increases from 10mm to 45mm, there is enhancement in heat transfer coefficient and Nusselt Number.	

Sanjeev D. Suryavanshi [5]	• Horizontal rectangular inverted notched fin array.	• Fin spacing varied up to 9mm. • Percentage of region expelled in the form of inverted indentation.	• With the increase in fin spacing, the rate of heat exchange increases. • Average heat transfer coefficient for the indented fin is 40% - 50% higher than un-indented. • Qinverted> Qnormal	

Md. Shamim Hossain [6]	• Pin fin array. • Number of fins -7 • Diameter of pin fin- 8.2mm. • Length – 70mm	• Heat transfer rate • Fin efficiency of Pin fin shapes	• Fins efficiency decreases with the increment of the heat exchange coefficient for forced convection. In contrast, in the case of free convection, efficiency increases with the increment of the heat exchange coefficient.	
Anant Joshi [7]	• Horizontal rectangular (square notched) fin array. • Number of fins – 9. • Spacing – 9mm	• Reduction in the square notched area by 10%, 20%, 30%.	• Total heat variability and convective heat exchange coefficient increments with indentation depth.	
Shyy-WoeiChang [8]	• Vertical dimpled fin array. • Four fin configurations, plane and dimpled, are used.	• Rayleigh number (Ra) of 108, 7.7 ×107 , 5.5×107 and 3.25×107 are used • Prandtl number (Pr) of 0.71 is considered.	• Local and average Nusselt number increments with augmentation in Rayleigh number over each fin surface. • By using a dimpled configuration, a high Nusselt number is obtained.	 (a)
AkshendraSo ni [9]	• Pin fin, Plate fin and elliptical fin heat sinks (vertically orientated base plate).	• Type of fIn.	• Heat exchange rate of, • Pin fin < elliptical fin < plate-fin heat sink.	
EnchaoYu [10]	• Pin fin array configurations of 9×9 and 12×12 are considered	• Length and thickness of component. • Length and height of enclosure. • Thickness of enclosure wall.	• The thermal effects of heat sinks in closed surroundings are superior to those in open surroundings. • For horizontal enclosure, there was more enhancement in heat transfer using pin-fin arrays	

Qie Shen [11]	• Rectangular fin heat sink mounted on LEDs	• Orientation (Angle variation from 00 to 2600)	• For wide fin spacing heat sink, thermal performance varies a little for orientation from 00 to 1350, whereas, for narrow fin spacing heat sink, fluctuation is quite significant • 260 260-degree orientation is the worst scenario for both heat sinks.	
Mao Yu Van [12]	• Fin and tube heat exchanger with improved fin design (plate-fin, wavy fin and compounded fin)	• Pressure drops of airside • Colburn factor • Fanning friction factor.	• Enhanced fin design is a key to increasing the round fin's effectiveness.	
Younghwan Zoo [13]	• Plate-fin and pin-fin heat sink	• Total heat rejection. • Heat rejection per unit mass	• Thermal resistance of plate-fin heat sinks is higher than pin-fin heat sinks by 40% • Enhanced plate fin accomplishes better results than enhanced pin fin heat sink.	
Gui Jang Huang [14]	• Horizontal rectangular fin array with perforations on the base of fins. • Perforation lengths- L/2 or L/4.	• Low flow velocity. • Temperature of airflow in fin channel and fin spacing.	• Perforations in the inner portion provide more ventilation, giving more heat transfer. • If uniform heat is supplied at the middle of the fins base, heat transfer is enhanced by a factor of 1.77.	
Vishwanath Sharma Korada [15]	• Vertical base fin array. • Number of fins – 22. • Fin spacing – 10mm.	• Temperature range – 600C to 1100C. • Radiation (which contributes more than 20% of total heat dissipation)	• An increase in the radiation parameter increases heat dissipation, which results in a higher value of the heat transfer coefficient. • An increase in temperature ratio gives a high value of heat exchange.	 Figure 1. Schematic diagram of the experimental setup

The comparison table analyses various fin configurations, highlighting their modifications, studied parameters, and enhancements achieved. Notably, inverted notched fin arrays demonstrate 40%- 50% higher heat transfer efficiency compared to regular fin arrays, suggesting a significant advantage in heat dissipation. Similarly, triangular notched fins achieve the highest convective heat transfer coefficients among the tested geometries, indicating superior performance in natural convection applications.

Additionally, fin spacing and height variations play a crucial role in heat transfer efficiency. For instance, increasing fin spacing (up to 9mm) enhances convective heat transfer, while perforations in rectangular fin arrays can more than double overall heat transfer performance. These findings reinforce the importance of optimized fin geometry for maximizing cooling efficiency in heat sink applications.

III.CONCLUSION

From the below, it's presumed that in structuring the heat, Gomorrah bone can get the introductory understanding of the different parameters similar to the figure and exposure of fin. The rate of heat transfer supplements with proliferation in fin separation and fin height. It's also observed that an 8 to 10 mm distance gives the optimum heat transfer rate. Also, it's completely justified that a reversed notched fin gives further heat transfer than a standard fin. A triangular, notched fin gives a higher heat transfer rate than a blockish and indirect fin array. The performance of notched fin arrays is competitive compared to regular fin arrays. Hence, the literature review substantiates plate-fin heat Gomorrah being most espoused compared to leg fin and elliptical-fin heat Gomorrah regarding real-life heat transfer operations. This expansive study is helpful for the unborn exploration of the design of heat sinks.

IV. REFERENCES

V.

1] S. Sane, "Experimental Analysis of Natural Convection Heat Transfer from Horizontal Rectangular Notched Fin Arrays," vol. 4, no. 1, 2014.
2] N. A. Nawale and A. S. Pawar, "Experiment on Heat Transfer Through Fins Having Different Notches," pp. 46–49, 2015.
3] S. S. Haghighi, H. R. Goshayeshi, and M. R. Safaei, "Natural convection heat transfer enhancement in new designs of plate-fin based heat sinks," Int. J. Heat Mass Transf., vol. 125, pp. 640–647, 2018.
4] A. J. Jubear and A. A. F. A.- Hamadani, "Research Article The Effect of Fin Height on Free Convection Heat Transfer from Rectangular Fin Array," vol. 6, pp. 5318–5323, 2015.
5] S. D. Suryawanshi and N. K. Sane, "Natural Convection Heat Transfer from Horizontal Rectangular Inverted Notched Fin Arrays," J. Heat Transfer, vol. 131, no. 8, p. 082501, 2009.
6] Md. Shamim Hossain, J. U. Ahamed, Farzana Akter, Debdatta Das, Santoshi Saha, "5/26/2017 Heat Transfer Analysis of Pin Fin Array," no. November, pp. 1–8, 2017.
7] Anant Joshi, D GKumbhar, "Analysis of Heat Transfer from Horizontal Rectangular (Square Notched) Fin Arrays by Natural Convection, "Volume 4, Issue 1, ISSN: 2277 – 5668, 2014.
8] S. W. Chang, H. W. Wu, D. Y. Guo, J. Jie Shi, and T. H. Chen, "Heat transfer enhancement of vertical dimpled fin array in natural convection," Int. J. Heat Mass Transf., vol. 106, pp. 781–792, 2017.
9] A. Soni, "Study of Thermal Performance between Plate-fin, Pin-fin and Elliptical Fin Heat Sinks in Closed Enclosure under Natural Convection," vol. 3, no. 11, pp. 133–139, 2016.
10] E. Yu and Y. Joshi, "Heat transfer enhancement from enclosed discrete components using pin-fin heat sinks," Int. J. Heat Mass Transf., vol. 45, no. 25, pp. 4957–4966, 2002.
11] X. Zhao, Y. Xu, T. Jin, D. Sun, and Q. Shen, "Orientation effects on natural convection heat dissipation of rectangular fin heat sinks mounted on LEDs," Int. J. Heat Mass Transf., vol. 75, pp. 462–469, 2014.
12] M. Y. Wen and C. Y. Ho, "Heat-transfer enhancement in fin-and-tube heat exchanger with improved fin design," Appl. Therm. Eng., vol. 29, no. 5–6, pp. 1050–1057, 2009.
13] Y. Joo and S. J. Kim, "Comparison of thermal performance between plate-fin and pin-fin heat sinks in natural convection," Int. J. Heat Mass Transf., vol. 83, pp. 345–356, 2015.
14] G. J. Huang, S. C. Wong, and C. P. Lin, "Enhancement of natural convection heat transfer from horizontal rectangular fin arrays with perforations in fin base," Int. J. Therm. Sci., vol. 84, pp. 164–174, 2014.
15] V. S. Korada, M. Ovinis, and S. B. Hassan, "Natural Convection-Radiation from a Vertical Base-Fin Array with Emissivity Determination," MATEC Web Conf., vol. 13, p. 02018, 2014.

PERFORMANCE ANALYSIS OF A VARIABLE PITCH SPIRAL TUBE-IN-TUBE HEAT EXCHANGER WITH AL_2O_3 NANOFLUIDS

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***Abstract*—This study investigates the performance enhancement of a novel tube-in-tube spiral heat exchanger (STSHE) with variable pitch using Al_2O_3 nanofluids. The research evaluates the exchanger's heat transfer coefficient (HTC), thermal conductivity, pressure drop, temperature distribution, and energy efficiency. The impact of variable pitch on these parameters is analysed to optimise heat transfer performance. Al_2O_3 nanofluids are employed to express their potential for further enhancing thermal conductivity and heat transfer.**

Keywords— Tube-in-tube spiral heat exchanger, Variable pitch, Thermal conductivity, Al_2O_3 nanofluids, Heat transfer coefficient, Pressure drop, Temperature distribution, Energy efficiency.

I. INTRODUCTION

Heat exchangers play a significant role in various industrial processes, where effective heat transfer is required for maintaining optimal operational conditions and energy conservation. The quest for enhancing heat exchanger performance has led to the exploration of innovative designs and advanced fluid mediums. Tube-in-tube spiral heat exchangers have garnered considerable attention for their compactness, enhanced heat transfer rates, and suitability for diverse applications.

Integrating variable pitch mechanisms within tube-in-tube spiral heat exchangers introduces a dynamic dimension to heat transfer optimization. By adjusting the pitch of the spiral coils, the heat transfer characteristics can be finely tuned to match specific operating conditions, thus offering enhanced flexibility and efficiency.

Choi et al. **[1]** from Argonne National Laboratory of the United States of America first developed the concept of nanofluids in the year 1995 and discovered their enhanced thermal characteristics. In parallel, utilising nanofluids, such as Al_2O_3 nanofluids (aluminium oxide), presents a promising avenue for augmenting heat transfer properties. These nanofluids, comprising nanoparticles dispersed within conventional heat transfer fluids, exhibit unique thermal conductivity and convective heat transfer enhancements, which can significantly improve the overall performance of heat exchangers.

Against this backdrop, this paper aims to calculate the performance of a Variable Pitch Tube-in-Tube Spiral Heat Exchanger utilizing Al_2O_3 nanofluids. The research objectives encompass a comprehensive assessment and comparison of heat transfer rates, pressure drop characteristics, and overall efficiency when employing nanofluids in conjunction with the variable pitch mechanism. Through meticulous experimentation and analysis, this study seeks to provide insights into the feasibility and potential benefits of this innovative approach, thereby contributing to the advancement of heat exchanger technology.

By exploring the synergistic effects of variable pitch design and Al_2O_3 nanofluids, this research endeavours to unlock new avenues for enhancing heat exchanger performance, addressing the growing demand for energy-efficient solutions in diverse industrial sectors. Below are the images of Al_2O_3 Nano powder.

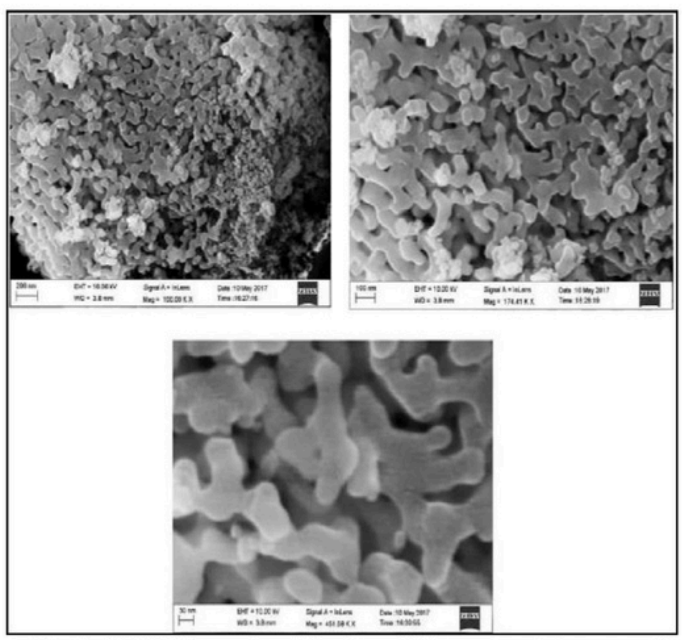

Fig.1: SEM (Scanning Electron Microscope) images of Al_2O_3 Nano powder.

II. CLASSIFICATION OF NANOPARTICLES

A. TYPES OF NANOPARTICLES

Nanoparticles come in different types, each one with unique properties and uses and are listed below **[2]**:

Carbon-based nanoparticles: These include Carbon Nanotubes (CNTs) and Fullerenes. Fullerenes are like tiny soccer balls of carbon atoms arranged in hexagons and pentagons. Carbon Nanotubes are tube-shaped and can be either semiconducting or metallic, depending on their size. They're rolled-up graphite sheets and can be single-walled (one layer), double-walled, or multi-walled (many layers).

Metal nanoparticles: These are made from metals like copper (Cu), silver (Ag), and gold (Au). They have special properties related to light absorption called Localized Surface Plasmon Resonance, which makes them useful in various applications.

Ceramic nanoparticles: These are non-metallic solids made through heating and cooling. They come in different forms, like amorphous or crystalline, and are used in things like catalysis and imaging.

Semiconductor nanoparticles: These materials have properties between metals and non-metals and wide band gaps. Changing the bandgap can vary their properties, making them essential in electronics and optics.

Polymeric nanoparticles: These are made from organic materials and are usually spherical. They have a solid core with other molecules attached to the surface.

Lipid-based nanoparticles: These contain lipids and are used in biomedical applications. They're typically spherical and have a solid core surrounded by a matrix containing other molecules. They're essential for things like drug delivery and cancer therapy.

B. APPLICATIONS OF NANOFLUID

Nanofluids have numerous applications across different industries due to their ability to transfer heat and other characteristics efficiently **[3]:**

Automobile Engine Cooling: Nanofluids can also cool car engines, improving their efficiency and performance.

Electronic Component Cooling: They're also helpful in cooling electronic components, preventing overheating and prolonging their lifespan.

Welding Equipment Cooling: Nanofluids help cool welding equipment, ensuring optimal performance during welding processes.

Cooling of High Heat Flux Devices: Nanofluids are effective in cooling high heat flux devices like high-power microwave tubes and laser diode arrays, where traditional cooling methods may struggle.

Other Common Applications: Nanofluids are used in various other applications, such as engine transmission oil, boiler exhaust flue gas recovery, solar water heating, nuclear cooling systems, refrigeration, defence, space applications, thermal storage, biomedical applications, drilling, and lubrication.

III. LITERATURE REVIEW

In their study, **Mohammad Sikindar Baba and colleagues [4]** investigated how well a double tube counter flow heat exchanger with multiple internal longitudinal fins performed when using Fe3O4/water nanofluid for forced convective heat transfer. They found that, specifically, with higher concentrations of nanofluid, heat transfer rates were 80-90% higher in finned tube heat exchangers. For a nanofluid concentration of 0.4% Fe3O4-water, the heat transfer rate in finned tube heat exchangers surpassed plain tube heat exchangers by 90-98%.

Additionally, they observed that the friction factor in finned tubes was 3.75 times greater than in plain tubes when the nanofluid flowed at 2 litres per minute.

Overall, their findings suggest that employing Fe_3O_4/water nanofluid in double-tube counterflow heat exchangers with multiple internal longitudinal fins can significantly enhance heat transfer efficiency, making them a promising option for various industrial applications.

In their study, Han and colleagues [5] examined how Al_2O_3/water nanofluids impact heat transfer inside a double tube heat exchanger with changing inlet temperatures. They used Al_2O_3 nanoparticles at 0.25% and 0.5% in volume, testing them at various inlet temperatures.

Their findings revealed that as temperature and nanoparticle concentration increased, so did heat transfer. They noted a significant improvement compared to water, with the Nusselt number, a measure of heat transfer, increasing by up to 24.5% at a 50°C-inlet temperature.

Moreover, they calculated that the convective heat transfer coefficient increased by approximately 9.7% and 19.6% for 0.25% and 0.5% volume concentrations, respectively. Their study employed a schematic diagram **Fig.2** of the experimental apparatus, providing a visual aid for understanding their setup.

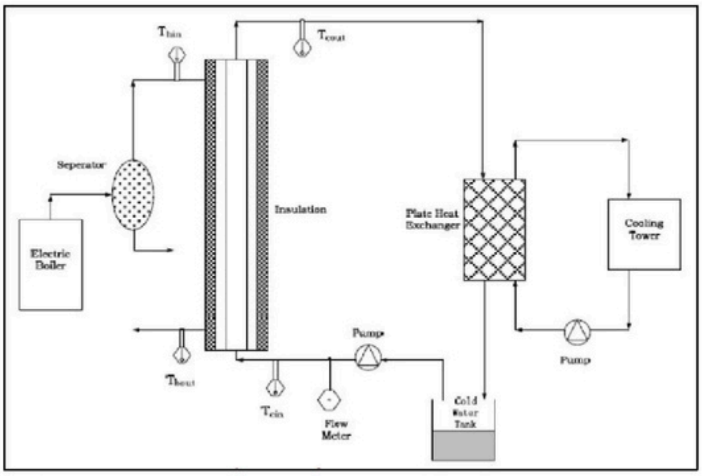

Fig.2: Schematic diagram of experimental Apparatus.

In their research, **Palanisamy and team [6]** delved into the heat transfer and pressure drop of a cone helically coiled tube heat exchanger using Multi-Wall Carbon Nanotube (MWCNT)/water nanofluids. Their experiments revealed significant enhancements in heat transfer compared to water. Specifically, they observed Nusselt numbers, indicating heat transfer rates were 28%, 52%, and 68% higher for nanofluid volume concentrations of 0.1%, 0.3%, and 0.5%, respectively. However, they also noticed increased pressure drops with nanofluids: 16%, 30%, and 42% higher for concentrations of 0.1%, 0.3%, and 0.5%, respectively, compared to water.
A measure of how well heat transfers (The heat transfer coefficient) showed improvements of 14%, 30%, and 41% for 0.1%, 0.3%, and 0.5% MWCNT/water nanofluids, respectively, compared to water. Their study utilized a model for numerical analysis, depicted in Figure 3, aiding in understanding their experimental setup.

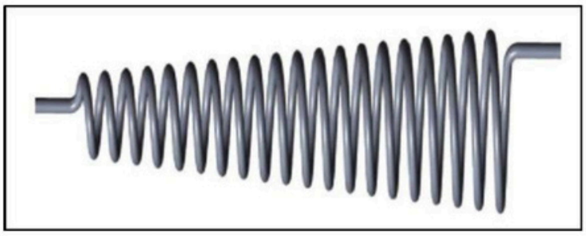

Fig.3: Model used for numerical analysis.

Mohammad Hussein Bahmani et al. [7] In this study, the researchers explored heat transfer rate and turbulent flow using water/alumina nanofluid in a double pipe heat exchanger in parallel and counter flow configurations. They had solved governing equations using a FORTRAN code based on the finite volume method. Results show that increasing nanoparticle volume fraction or Reynolds number improved the Nusselt number and convection heat transfer coefficient. The highest enhancements were 32.7% for the average Nusselt number and 30% for thermal efficiency, particularly in the counterflow regime.

Salman. K et al. [8] This study focused on thermal analysis using titanium dioxide (TiO_2) nanofluid in a double pipe heat exchanger, varying nanoparticle concentration (0-3 vol%). 3-Dimensional simulations showed an 18% increase in heat transfer coefficient at 0.3% volume concentration of TiO2 nanofluid. Nusselt number increased significantly with higher TiO_2 percentages. The friction factor increased proportionally with volume concentration but showed less enhancement compared to heat transfer, as depicted in Figure 4.

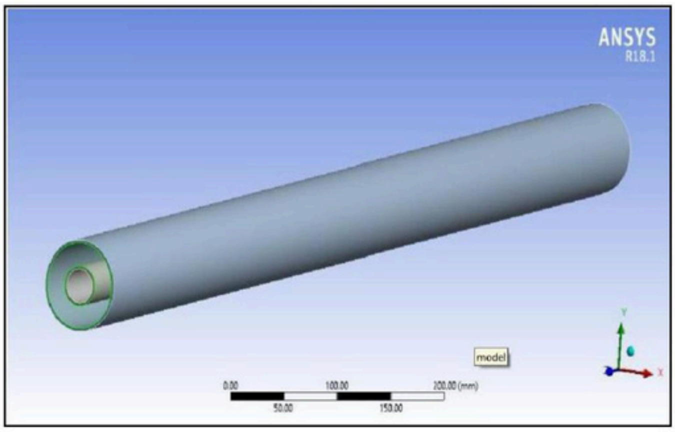

Fig.4: Model used for CFD analysis

P.J. Fule et al. [9] This work investigated heat transfer enhancement using water-based copper oxide (CuO) nanofluids in a helical coil heat exchanger. Various volume percentages of CuO nanoparticles and flow rates were considered. At 0.1 vol% concentration, the heat transfer coefficient increased by 37.3% compared to the base fluid, while at 0.5 vol%, it reached 77.7%. The experimental setup schematic is shown in Figure 5.

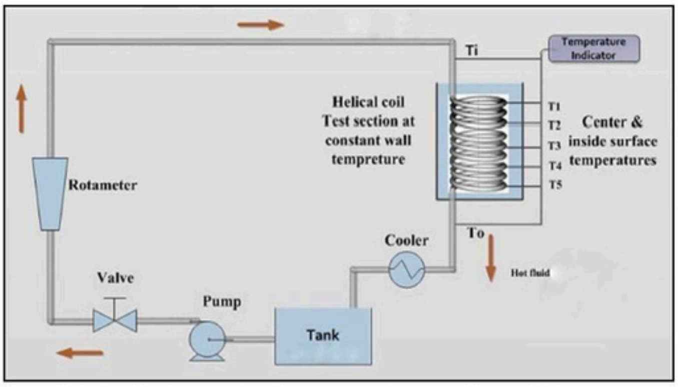

Fig.5: Schematic diagram of experimental set-up

A few other experiments were conducted, and a table based on the relevant data was presented.

S. N.	Researcher (s)	Year	Set-up	Nano-Parti c-les	Base-Fluid	Work-Type	Flow-Regimes	Finding(s)
1	N.T. Ravi Kumar et al.	2016	Double pipe U-bend heat exchanger	Fe_3O_4	Water	Num.	Turb.	1. Heat transfer enhancement of 34.93% is observed at 0.4% volume concentration. 2. There is a maximum friction penalty of 1.26 times at 0.4% volume concentration.
2	Dr. M Sakthivel et al.	2018	Shell and Tube heat exchanger	Al_2O_3 SiO2	Water	Num.	Turb.	1. With the increase in Reynolds number and volume concentration of nanofluid thermal performance of heat exchanger is increased.
3	Bharat B. Bhosle et al.	2017	Double pipe heat exchanger	Al_2O_3	Water	Num. and Exp.	Lam. and Turb.	1. For CFD analysis 11.5% enhancement in heat transfer rate observed at 0.1% concentration. 2. For Experimentally analysis 9.5% enhancement in heat transfer rate is observed at 0.1% concentration.
4	S. Nallusamy et al	2017	Shell and Tube Heat Exchange-r	Al_2O_3	Water	Exp.	Turb.	1. 10% enhancement in nusselt observed at 1.25% nanofluid concentration in counter flow arrangement of heat exchanger. 2. 8.9 % enhancement in nusselt observed at 1.25% nanofluid concentration in parallel flow arrangement of heat exchanger.
5	Ganesh Kumar Poongavanam et al	2019	Peened double pipe heat exchanger	carbon (AC) -	Solar Glycol	Num. and Exp.	Lam. and Turb.	1. 26.25%, 40.79%, and 57.06% enhancement of overall heat transfer coefficient is observed for 0.2, 0.4 and 0.6% volume concentrations nanoflud respectively.
6	Cong Qia et al.	2019	Double-tube heat exchanger	TiO_2	Water	Exp.	Turb.	1. 10.8%, 13.4% and 14.8% improvement in heat transfer rate observed for 0.1%, 0.3% and 0.5% volume concentration of nanofluid respectively as compared with deionized water. 2. pressure drop of nanofluids increased by 2.77%, 4.38% and 6.5% for 0.1%, 0.3% and 0.5% volume concentration of nanofluid respectively.
7	N.T. Ravi et al.	2018	Double pipe U-bend heat exchanger	fe3O4/	Water	Exp.	Turb.	1. The Nusselt number is enhanced to 14.76% (no insert) and it is further increased to 38.75% (with twisted tape inserts of H/D=10) at 0.06% volume concentration and at Reynolds number of 30000 compare to water. 2. The friction factor penalty of 1.092 times for no insert and penalty of 1.251-times for twist ratio of H/D=10 at 0.06% volume concentration of nanofluid and at Reynolds number of 30000 compared to water.
8	P. C. Mukesh et al.	2015	Helically coiled heat exchanger	Al_2O_3	Water	Num.	Turb.	1. The coiled tube side Nusselt number (Nu) is found to be 30% higher with nanofluid compare to water. 2. The maximum pressure drop is found to be 9% higher with nanofluid compare to water.
9	Mojtaba Shirzad et al.	2019	Pillow plate heat exchanger	Al_2O_3, CuO and TiO_2	Water	Num.	Lam. and Turb.	1. At 5% volume concentration the maximum and minimum thermal performance improvements in comparison with the water are belong to Al_2O_3(43.38%) and CuO (15.62%) respectively.

Table 1. Some other nanofluids used in heat exchangers

IV. RESULTS AND DISCUSSION

COMPARISON BETWEEN RESULTS OF NANOFLUID AND WATER:

Figures 6, 7, and 8 illustrate the variation of heat transfer across the tube wall temperature for both nanofluid and water. It's evident that Al_2O_3 nanofluid consistently achieved higher heat transfer than water at various flow rates and tube wall temperatures. For instance, at a tube wall temperature of 60°C and a flow rate of 60 LPH, heat transfer using nanofluid exceeded 1100 W, while with water, it was only around 900 W. Similarly, at tube wall temperatures of 60°C, 61°C, and 61°C, with flow rates of 75 LPH, 90 LPH, and 90 LPH, respectively, nanofluid consistently outperformed water in terms of heat transfer, achieving maximum values of 1350 W, 1620 W, and 1571.30 W, compared to the respective values of 1300 W, 1400 W, and 1085.023 W for water.

Overall, the results indicate that heat transfer with nanofluid was consistently higher than water across various flow rates and temperatures, with a notable increase of approximately 30%, as shown in **Table 2**. This suggests that the heat transfer coefficient likely significantly enhanced heat transfer rates with nanofluid **[10].**

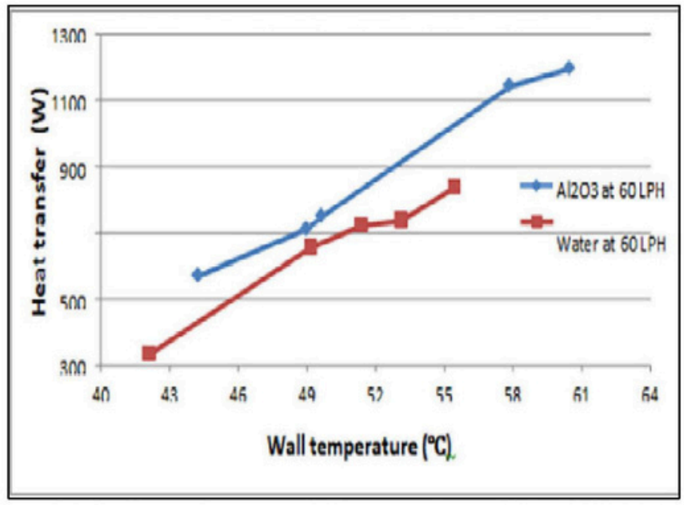

Fig. 6. Heat transfer vs. wall temperature (°C) at 60 LPH

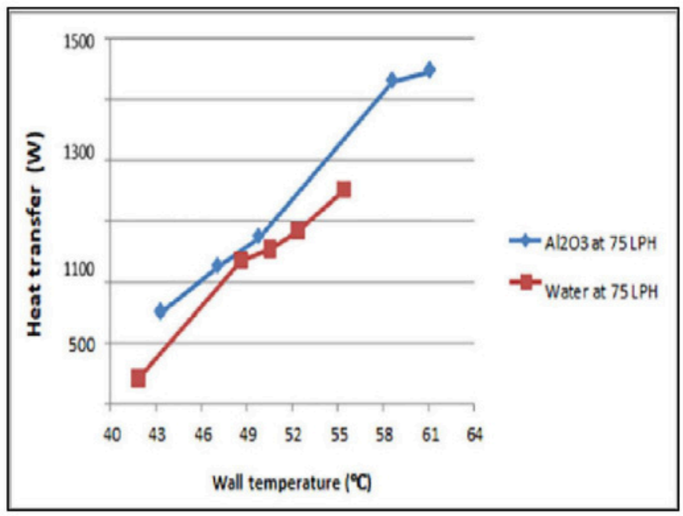

Fig. 7. Heat transfer vs. wall temperature (°C) at 75 LPH

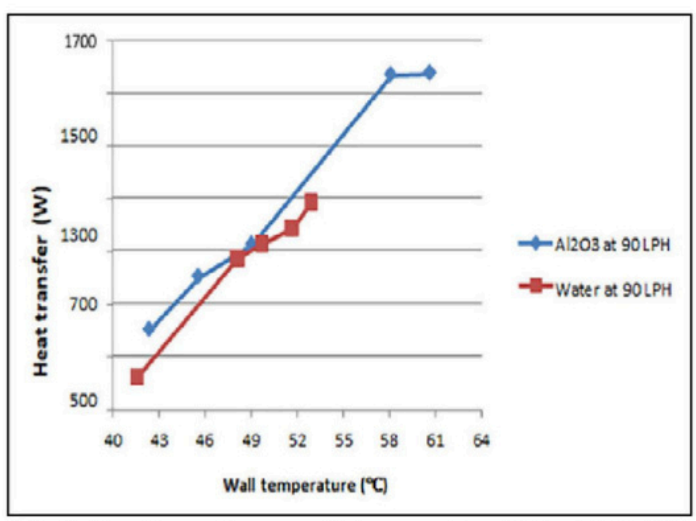

Fig. 8. Heat transfer vs. wall temperature (°C) at 90 LPH

Volt (V)	Mass Flow Rate (LPH)	Heat Transfer Of Water Q_{water} (W)	Heat Transfer Of Nano Fluid Q_{nf} (W)
60	60	335.8686	568.69
	75	382.0672	599.21
	90	419.584	600.11
100	60	657.9229	710.11
	75	769.6179	770.11
	90	871.0286	820.12
110	60	723.479	747.71
	75	806.2979	845.25
	90	865.359	922.13
130	60	738.4415	1142.21
	75	866.9506	1359.39
	90	984.9547	1565.97
140	60	838.784	1196.61
	75	1091.935	1394.22
	90	1085.023	1571.30

Table 2. Comparison of heat transfer (Water vs. nano fluid)

V.CONCLUSION

The study examined how changing the coil pitch in a heat exchanger affects heat transfer, measured by the Nusselt number. They found that adjusting the pitch significantly influenced heat transfer by altering fluid flow patterns and turbulence inside the exchanger. This suggests that optimizing the pitch design can boost heat transfer efficiency.

They also explored how the concentration of Al_2O_3 nanofluid affects heat transfer. Increasing the nanofluid concentration improved heat transfer performance due to its superior thermal conductivity and convective properties compared to regular fluids.

Additionally, the study examined the pressure drop and pumping power associated with different pitch configurations and nanofluid concentrations. Results showed that changing the pitch enhanced heat transfer and affected pressure drop and pumping power. Similarly, varying the nanofluid concentration influenced these factors due to changes in fluid viscosity and flow behaviour. Comparing their results with previous studies validated their findings and highlighted the reliability of their experimental setup and computational models.

Lastly, the study delved into the mechanisms behind the observed trends, analysing fluid dynamics, boundary layer behaviour, and nanoparticle dispersion. This deeper understanding provided valuable insights into optimizing heat transfer and hydraulic performance in heat exchangers using Al2O3 nanofluids and variable pitch configurations.

VI. ACKNOWLEDGMENT

We want to express our sincere gratitude to Mr. Sangram Puhan for his invaluable assistance and support throughout the research process. His guidance and expertise were instrumental in completing this study on the performance evaluation of a Variable Pitch Tube-in-Tube Spiral Heat Exchanger with Al2O3 Nanofluids.

VII. REFERENCES

[1] Stephen U.S. Choi, J.A. Eastman, "Enhancing thermal conductivity of fluids with nanoparticles", ASME International Mechanical Engineering Congress and Exposition, San Francisco, CA (1995).

[2] Ibrahim Khan, Khalid Saeed, Idrees Khan, "Nanoparticles: properties applications and toxicities", Arabian Journal of Chemistry (2017).

[3] B. Kirubadurai, P. Selvan, V. Vijayakumar, M. Karthik, "Heat transfer enhancement of nanofluids: A review", IJRET (2014) 2319-2335.

[4] Mohammad Sikindar Baba, A.V. Sita Rama Raju, M. Bhagvanth, "Heat transfer enhancement and pressure drop of Fe3O4 -water nanofluid in a double tube counter flow heat exchanger with internal longitudinal fins", Case Studies in Thermal Engineering, 12 (2018), 600–607.

[5] D. Han, W.F. He, "Experimental study of heat transfer enhancement using nanofluid in double tube heat exchanger", UK Energy Procedia, 142 (2017), 2547–2553.

[6] K. Palanisamy, P.C. Mukesh Kumar, "Experimental investigation on convective heat transfer and pressure drop of cone helically coiled tube heat exchanger using carbon nanotubes/water nanofluids", Heliyon 5 (2019),1146-1154.

[7] Mohammad Hussein Bahmani, Ghanbarali Sheikhzadeh, Majid Zarringhalam, Omid Ali Akbari, "Investigation of turbulent heat transfer and nanofluid flow in a double pipe

heat exchanger", Advanced Powder Technology, (2017), 415-420.

[8] Salman. K, Prasidh E Prakash, "CFD analysis of TiO2/water nanofluid flow in a double pipe heat exchanger", International Journal of Advanced Information in Engineering Technology (IJAIET) Vol.5, No.5, (2018), ISSN: 2454-6933.

[9] P.J. Fule, B.A. Bhanvase S.H. Sonawane, "Experimental investigation of heat transfer enhancement in helical coil heat exchangers using water-based CuO nanofluid", Advanced Powder Technology, (2017),530-545.

[10] Veeramanikandan K., Vignesh S., Pitchia Krishnan B., Mathanbabu
M., Ashokkumar M. "Investigation of Al2O3-water nanofluid flow through the circular tube" Received 27 January 2021 Received in revised form 24 February 2021 Accepted 9 March 2021.

WASTE HEAT RECOVERY OF MARINE MACHINERIES

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Abstract—
Waste Heat Recovery systems harness exhaust heat from engines and industrial processes to generate additional power or heat, enhancing energy efficiency and reducing environmental impact. There are different waste heat recovery systems and technologies used onboard ships have been discussed from the perspective of technical principles and application feasibility. The study of basic principles, novel methods, and existing designs are discussed in this paper. The primary focus of this paper is to provide basic available ways for waste heat recovery and use in various applications onboard ocean-going ships to improve fuel economy and environmental compliance.

Keywords— WHR, Turbocharger, Power Turbine, Rankine Cycle, Desalination, Thermoelectric Generation

I. INTRODUCTION

The shipping industry is at a very important point where it needs to seriously reduce the gases it emits that contribute to global warming. The International Maritime Organization (IMO) knows this is crucial and has devised an ambitious plan. IMO, I want to see the industry's greenhouse gas emissions go down by half by 2050 compared to what they were in 2008. To reach such a hard goal, we need new ideas and technologies that make ships run better and smarter. The IMO is looking closely at many ways to do this, but they're especially interested in making ship engines—which mostly run on diesel and are used by all kinds of ships—work more efficiently. These engines create a lot of waste heat, which, until now, has mostly been ignored. This paper takes a deep dive into Waste Heat Recovery Systems (WHRS), which focus on taking advantage of this otherwise unused energy. By taking the extra heat from the ship's exhaust and using it again, these systems can cut down on how much fuel ships need, which means fewer pollutants get into the air, and it costs less to run the ships. The success of thermoacoustic waste heat recovery systems (WHRS) in making money depends on such things as how much they cost to buy, how much they save during use, and their impact on the environment.

II. THERMOELECTRIC GENERATION

in the maritime industry, decreasing the fuel eaten up within the delivery engine is a priority. Many solutions exist to improve vessel energy performance, reduce gasoline intake, minimise emissions, such as energy-saving gadgets and new machinery technology, and improve the gas efficiency of ships in service. furthermore, optimizing gas consumption and implementing innovative solutions are also possible options. these answers can be categorized as altering the design (including hull form optimization, structural optimization, and light-weight creation), modernizing present propulsion structures (exhaust gasoline cleaning systems (EGCS), air lubrication, waste heat recuperation), the use of alternative marine fuels (Liquefied natural gasoline (LNG), Methanol, Ammonia) and imparting alternative electricity assets. The established order of new technologies to reduce air pollutants, mainly from ships, results in high funding charges. current diesel engines, analysed in terms of gas efficiency, have been discovered to be about 50% green, while the ultimate amount of energy is misplaced as waste heat. As this strength is misplaced as waste heat, it can become a waste-warmth recuperation machine onboard, improving strength efficiency and lowering emissions. Specific locations, specifically on ships, have a high-temperature capacity. The principle engine exhaust temperature ranges from 300–350 °C for 2-stroke systems to 400–500 °C for four-stroke engines in these regions. because of the rising difficulty for environmental safety, the preference to use waste warmness in diesel engines has grown, as has interest in the thermoelectric era, which investigates the relationship between temperature and strength. consequently, the Seebeck, Peltier, and Thomson impacts are all useful. Thermoelectric generator (TEG) packages can facilitate electricity conversion reliably, and TEGs appear as one of the most promising strength technologies of the twenty-first century. to maximize the thermoelectric price of a material, it should have a high thermopower, excessive electrical conductivity, low thermal conductivity, and the usual parameters for thermoelectric materials. Thermoelectric mills can feature with excessive efficiency on diverse surfaces on ships. the primary engine, auxiliary generators, boilers, and the locations where the ship's waste warmth is eliminated are specific surfaces that may create the temperature distinction needed for Peltier to supply electric electricity.

A. *Working principle of thermoelectric generation*

Thermoelectric substances for power technology are to be had as modules. those gadgets are generally products of stable-nation materials and comprise more than one layer. because of their structure, thermoelectric couples are constructed of semiconductor materials (n-type and p-kind) connected electrically in a chain simultaneously as thermally related in parallel. The switch of electron flow to the section in which the temperature is low, with the assistance of temperature variations, generates electrical power in thermoelectric mills. To reap high power from thermoelectric mills, the voltage has to be increased, and for this reason, it's vital to boost the Seebeck coefficient. To generate the Seebeck voltage, each detail of the thermoelectric couple ought to have a monotype fee provider. The ZT coefficient expresses the suitability of a substance for thermoelectric strength production. The Seebeck impact, also known as the Seebeck regulation, is a fundamental principle in thermoelectricity that describes the generation of an electromotive pressure (EMF) or voltage between two various conductors.

The Seebeck impact takes place because of the distinct fees of electrons that go with the flow in materials with various electric conductivities when they may be subjected to a temperature gradient. while one quit of a conductive fabric is heated even as the other give-up is stored cooler, the free electrons within the fabric tend to emigrate from the hotter give-up to the cooler quit. This electron flow creates a difference in electric capacity among the 2 ends of the fabric, resulting in voltage generation. The significance of the voltage produced via the Seebeck effect is proportional to the temperature distinction (ΔT) between the two ends of the fabric. It is characterized by a material-unique asset called the Seebeck coefficient (α). The Seebeck coefficient represents the voltage generated in step with unit temperature distinction and is typically expressed in devices of microvolts in step with Kelvin (µV/ok).

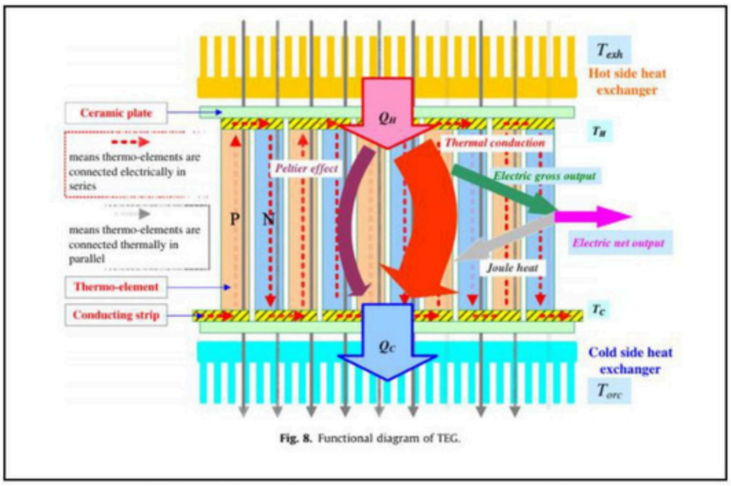

Fig. 1 Functional diagram of TEG

B. *Application*

Thermoelectric power generation holds considerable potential for various applications on ships, offering a range of benefits that contribute to enhanced energy efficiency, sustainability, and operational flexibility. One primary application of thermoelectric power generation on ships is waste heat recovery from the vessel's propulsion system. Ships typically use internal combustion engines, such as diesel or gas turbines, to drive propulsion systems. However, a significant portion of the energy produced by these engines is lost as waste heat through the exhaust gases. Thermoelectric modules integrated into the exhaust system can capture this waste heat and convert it into usable electrical power, thereby increasing the overall efficiency of the propulsion system and reducing fuel consumption. Another important application of thermoelectric power generation on ships is providing supplementary power generation for onboard electrical systems. Ships require electricity to operate various critical systems, including navigation, communication, lighting, and auxiliary equipment. By installing thermoelectric modules in strategic locations, such as engine exhausts or hot surfaces within the ship's infrastructure, excess heat can be harvested and converted into electrical energy to supplement the power supply. This approach reduces the reliance on traditional power generation methods, such as diesel generators, leading to fuel savings and decreased emissions. Thermoelectric power generation also offers opportunities for improving the thermal management of ships' onboard systems. In addition to generating electricity, thermoelectric modules can be employed for temperature control and heat dissipation in various compartments and equipment onboard. By strategically placing thermoelectric coolers or heaters, thermal gradients within the ship can be regulated, ensuring optimal operating conditions for sensitive equipment and enhancing overall system reliability. Moreover, thermoelectric modules can be integrated into refrigeration and air conditioning systems to improve energy efficiency and reduce environmental impact. Thermoelectric power generation can contribute to developing hybrid propulsion systems for ships. By combining traditional propulsion methods with thermoelectric generators, ships can achieve greater flexibility in power management and optimize energy utilization. For instance, in hybrid propulsion configurations, thermoelectric modules can complement the primary power source, such as diesel engines or fuel cells, by generating additional electrical power from waste heat. This hybrid outlook enhances overall energy efficiency and improves the vessel's ability to adapt to varying operating conditions and power demands. Additionally, thermoelectric power generation can play a critical role in enhancing the sustainability credentials of ships and aligning with regulatory requirements and environmental standards. By capturing and utilizing waste heat, thermoelectric systems help reduce greenhouse gas emissions and mitigate the environmental impact of maritime transportation. This aligns with global efforts to combat climate change and promote cleaner, more sustainable energy solutions in the shipping industry.

C. Economic Feasibility

The economic feasibility of implementing thermoelectric power generation on ships involves assessing the costs and benefits of installing and operating thermoelectric systems relative to traditional power generation methods. While thermoelectric technology offers promising energy efficiency and sustainability advantages, its economic viability hinges on various factors, including initial capital investment, operational expenses, fuel savings, and potential revenue streams. One significant aspect of the economic feasibility of thermoelectric power generation on ships is the initial capital investment required for installing the necessary equipment and infrastructure. Thermoelectric modules, the core components of thermoelectric systems, can be costly to manufacture and integrate into existing ship systems. Additionally, retrofitting ships with thermoelectric generators or modules may involve significant labour and engineering expenses, adding to the upfront costs. However, advancements in thermoelectric materials and manufacturing processes could lead to cost reductions over time, improving the economic feasibility of implementation. The operational expenses associated with thermoelectric power generation on ships must be considered. While thermoelectric systems require minimal maintenance compared to traditional power generation methods like diesel generators, ongoing operational costs are still associated with monitoring, servicing, and optimizing the thermoelectric module's performance. Additionally, the efficiency of thermoelectric systems may vary depending on factors such as temperature gradients, environmental conditions, and system design, which could impact overall operational costs. The primary economic benefits of thermoelectric power generation on ships lie in fuel savings and operational efficiency gains. By capturing waste heat from the ship's engines and converting it into electrical power, thermoelectric systems reduce the requirement for traditional fuel-based power generation methods, such as diesel generators. This can result in significant fuel cost savings over the operational lifespan of the thermoelectric system, especially considering the high fuel consumption rates of marine vessels. Additionally, the improved energy efficiency offered by thermoelectric systems can contribute to lower overall operating expenses and increased profitability for ship operators. The economic feasibility of thermoelectric power generation on ships may be enhanced by probable revenue streams associated with energy efficiency and sustainability initiatives. In a progressively environmentally conscious world, there is growing pressure on the maritime industry to reduce emissions and adopt cleaner energy technologies. Ships equipped with thermoelectric power generation systems may be eligible for carbon credits, incentives, or subsidies to promote sustainable practices and mitigate climate change. Additionally, market differentiation and competitive advantages could be achieved by positioning ships as environmentally friendly and energy-efficient, potentially attracting environmentally conscious customers and improving the marketability of the vessel. Technological advancements, economies of scale, and regulatory developments may influence the long-term economic viability of thermoelectric power generation on ships. As thermoelectric technology evolves and matures, economies of scale may drive down production costs and improve cost-effectiveness. Furthermore, regulatory initiatives to reduce emissions and promote sustainable energy solutions could create additional incentives for ship operators to invest in thermoelectric power generation. By staying abreast of technological advancements and regulatory changes, ship operators can assess the economic feasibility of implementing thermoelectric systems and make informed decisions regarding investment and adoption. In conclusion, the economic feasibility of thermoelectric power generation on ships involves a comprehensive analysis of costs, benefits, and potential revenue streams associated with implementing and operating thermoelectric systems. While initial investment costs and operational expenses may present challenges, the potential for fuel savings, operational efficiency gains, and revenue generation from sustainability initiatives can enhance the economic viability of thermoelectric technology in the maritime industry. By carefully evaluating these factors and considering technological advancements and regulatory developments, ship operators can assess the economic feasibility of integrating thermoelectric power generation into their vessels and capitalize on the opportunities presented by these innovative energy solutions

III. Rankine Cycle

The Rankine cycle is nothing but a cycle that converts heat into work. A simple Rankine cycle consists of four main components: steam turbine, circulation pump, condenser, and evaporator. The working fluid is usually circulated in a closed loop. First, the working liquid is pumped from the condenser outlet to the evaporator. The turbine uses waste heat from the exhaust gas. The energy is then transmitted from the boiler to the high-pressure steam turbine. The energy generated by the steam turbine is transferred to the generator or output. Finally, the energy from the turbine turns into liquid again in the condenser and starts a new cycle. How the Rankine Cycle Works Examining the elements in the cycle allows us to understand how the cycle works in a closed loop where water is recycled.

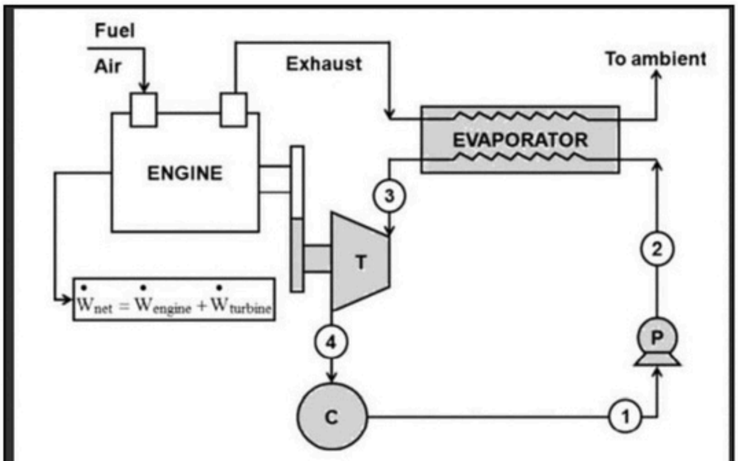

Fig. 9. Schematic of a basic Rankine cycle driven by exhaust of engine.

Fig. 2 The basic Rankine cycle is driven by the exhaust of the engine

A. *Working principle*

The typical Rankine cycle consists of four thermodynamic processes, described below with each diagram. We assume that the cycle operates in the temperature range of 0°C to 400°C. Process 1-2: The working fluid enters the pump and transfers from high to low. This is also called isentropic compression. This stage requires a power input. Process 2-3: The liquid pressure entering the boiler is heated at constant pressure by an external electrical source. The liquid is converted into dry saturated steam thanks to the high temperature in the boiler. Process 3-4: Dry saturated steam leaving the boiler expands when it enters the turbine. This is also called isentropic expansion. Therefore, the temperature and pressure of the steam decreases. Process 4-1: At this stage, the wet steam entering the condenser is condensed under constant pressure. This is then converted into a saturated liquid. This process is also called constant temperature in the condenser. This saturated liquid returns to the pump, and the cycle continues. It is shown as the heat removed after the final stage or as waste heat.

Real Rankine Cycle

True Rankine Cycle The true Rankine or negative cycle used in real power plants does not undergo isentropic compression and expansion by the pump and turbine, respectively. Compared to the ideal cycle, this process is irreversible and increases entropy, as shown in the figure below. As can be seen from the picture above, compared to the actual cycle, there is a pressure drop in the condenser and boiler and an irreversible process in the pump and turbine. These conditions increase energy demand and reduce energy production.

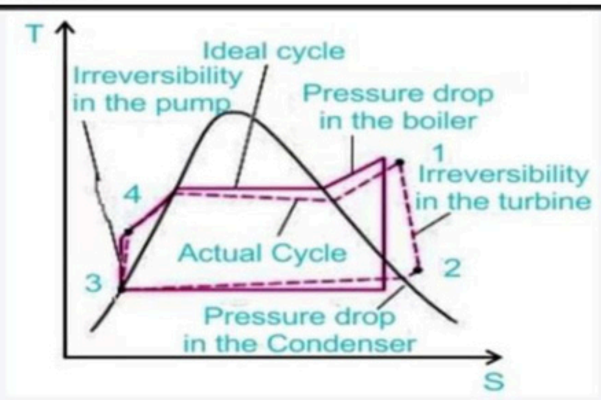

Fig 3: Real Rankine Cycle T-s Diagram

Fig. 3 Real Rankine Cycle

B. Applications

Use of Rankine Cycle Understanding its advantages and disadvantages makes us curious about these different cycles. Let's understand the concept of using these loops.

1. The reheated Rankine cycle is used in power plants that produce electricity from fluids at supercritical pressure.
2. Today, thermal power plants, such as nuclear power plants, use the regenerative Rankine cycle with minor modifications.
3. ORC is used in waste heat recovery facilities, biomass power plants, geothermal power plants, solar power plants, wind thermal energy consumption, and other industries.
4. The supercritical Rankine cycle is used in medium power applications such as supercritical power plants

C. Economic feasibility

Both investment and maintenance should be considered when evaluating the cost of an RC system. Additionally, an RC system should be evaluated by its output power, which is the power produced by the generator minus the power used by the pump. Gewald introduced the measurement method of RC systems. Ringler performed an economic analysis of a steam turbine with a top turbine and found that the essential oil was profitable for investment. Leibowitz examined the possibility of generating 20-50 kW of electricity by reusing low-energy materials. Using a screw expander instead of a turbine gives better results because the installation cost is lower than a normal ORC system, and the net power output is in the range of $1200-2000/kW. Low-temperature waste-to-energy plants with a capacity below 5 MW are generally not economically viable. For this purpose, Brasz et al. The application of ORC power plant equipment supplied by air conditioning equipment overcomes the problem of high cost because the cost of air conditioning equipment is almost one order of magnitude higher than that of static electricity. For example, air conditioning costs about $200-300 per kilowatt. A multi-megawatt power plant costs around $1,200 to $1,500 per kilowatt of generator output and even more for small power plants. Studies have shown that organic liquids have potential as working fluids in waste-to-energy applications. If the leakage problem can be solved entirely, the development as well as use of organic liquid in waste heat recovery boilers will become popular.

IV. DESALINATION

Desalination in cargo ships refers to converting seawater into potable water suitable for human consumption and other onboard uses. This technology is crucial for long sea voyages where access to freshwater sources may be limited or unavailable. Here's an introduction to desalination in cargo ships: The primary purpose of desalination on cargo ships is to ensure a sustainable and reliable freshwater supply for crew members and various operational needs throughout the voyage

Working Principle

Desalination Methods are

Reverse Osmosis (RO): This is the most common method of maritime desalination. It involves pushing seawater through a semi-permeable membrane to separate salt and impurities from water molecules, producing freshwater.

- Multi-Stage Flash (MSF): Seawater is heated to generate steam, which is then condensed into freshwater. MSF was historically used but mainly replaced by RO due to its higher energy consumption.

The desalination plant consists of

Pre-treatment System that Removes larger particles, sediments, and biological contaminants from seawater before it enters the desalination unit.

Desalination Unit: This unit includes the RO or MSF system, which processes seawater to extract fresh water.

Post-treatment System: This system ensures the quality of desalinated water by adjusting pH levels, adding minerals, and removing any remaining impurities.

Some of the significant challenges are

Energy Consumption: Desalination requires significant energy, impacting the ship's fuel consumption and operational costs.

Maintenance: Desalination units require regular maintenance to ensure efficient performance and longevity.

Brine Disposal: The concentrated salt solution (brine) generated during desalination must be carefully disposed of to minimise environmental impact.

Major benefits are

Water Security provides a reliable source of fresh water, reducing dependency on port facilities or natural freshwater sources. Independence allows cargo ships to operate in remote or extended voyage areas without concerns about freshwater availability.

Environmental Impact: While energy-intensive, modern desalination technologies aim to minimize environmental impact through efficient processes and waste management.

Future Trends are Advancements in Efficiency: Research focuses on improving desalination efficiency, reducing energy consumption, and exploring alternative energy sources such as solar power. Innovative Designs Integrate desalination systems into ship designs to optimise space utilisation and operational efficiency. Overall, desalination plays an essential role in ensuring the sustainability and self-sufficiency of cargo ships during their voyages, contributing to enhanced water management practices in maritime operations.

Application

Desalination is critical in ensuring a reliable freshwater supply aboard cargo ships during long voyages or when freshwater sources are limited. Here are the key applications of desalination in cargo ships. Potable Water Supply is the primary application of desalination, providing potable water for the crew members' drinking, cooking, and other human consumption necessities. Desalinated water meets drinking water standards and ensures the health and well-being of everyone on board. Operational Water Needs: Cargo ships require water for various operational purposes such as cleaning, laundry, and maintenance. Desalination provides a steady supply of fresh water for these non-potable uses, reducing dependency on external water sources. Desalination systems can be integrated with ballast water treatment systems on cargo ships. This helps treat and purify ballast water, essential for maintaining stability and trimming the vessel during loading and unloading operations. Desalination is a vital backup during emergencies, such as mechanical failures or unexpected delays that might prevent access to freshwater resupply points. It ensures the ship can continue operations and sustain the crew until regular services are restored. Environmental Considerations: By producing freshwater onboard, cargo ships reduce their environmental footprint by minimizing the need to take on fresh water from coastal areas or ports. This helps in preserving local freshwater resources and ecosystems. Remote Operations: Desalination enables cargo ships to operate in remote or offshore areas where access to freshwater sources is limited or unavailable. This independence enhances the ship's capability to undertake long-distance voyages efficiently.

A desalination system onboard reduces the logistical burden of transporting large quantities of freshwater for extended voyages. This can lead to cost savings and increased operational efficiency for cargo shipping companies. Overall, desalination technology plays a crucial role in enhancing cargo ships' self-sufficiency, sustainability, and operational capabilities, making them more resilient and adaptable to varying environmental and operational conditions at sea.

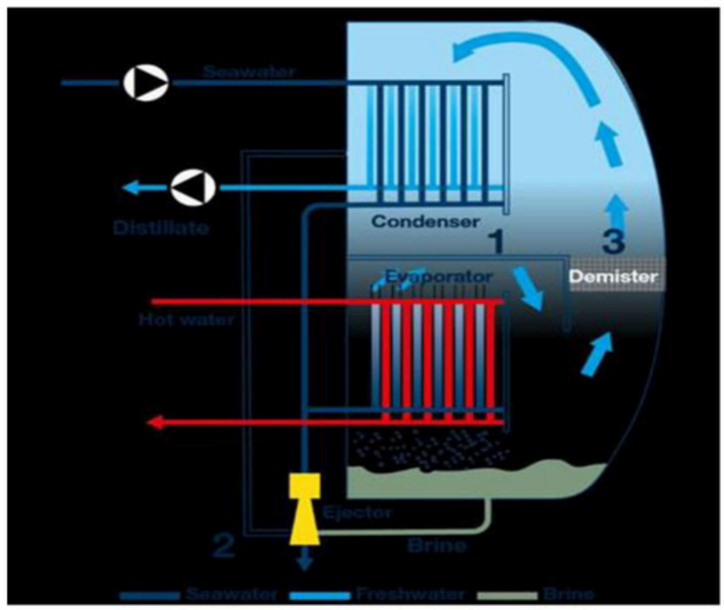

Fig. 4 Fresh water generator

A. Economic feasibility

The economic feasibility of desalination in cargo ships depends on various factors, including initial capital investment, operational expenses, energy efficiency, and the availability of alternative freshwater sources. Here are key considerations regarding the economic viability of desalination on cargo ships:

Initial Capital Investment of Desalination The cost of installing a desalination system, whether a Reverse Osmosis (RO) or Multi-Stage Flash (MSF) unit, can be significant. It includes the purchase of equipment, installation, and integration into the ship's infrastructure.

Operational Expenses are Energy Consumption: Desalination processes, especially RO, require substantial energy. The energy cost from onboard generators or external sources contributes significantly to operational expenses.

Maintenance and Upkeep: Regular maintenance, membrane replacement (in RO systems), and operational monitoring are essential for efficient and reliable desalination. These maintenance costs add to the overall operational expenses.

Water Demand and Consumption—The volume of freshwater required on a cargo ship directly impacts the economic feasibility of desalination. Ships with higher water demands due to larger crews or extended voyages may find desalination more economically viable than smaller vessels with lower water needs.

Alternative Freshwater Sources - The availability and cost of alternative freshwater sources at ports or along the voyage route can influence the decision to invest in desalination. If reliable and cost-effective freshwater resupply points are accessible, the requirement for onboard desalination may be reduced.
Energy Efficiency and Innovation - Advancements in desalination technology, such as improved membrane efficiency, energy recovery systems, and integration with renewable energy sources like solar power, can enhance the energy efficiency of desalination. This, in turn, can improve the economic feasibility by reducing energy costs over the system's lifespan.

Long-term Considerations - The economic analysis of desalination in cargo ships often involves long-term projections and cost-benefit assessments. Factors such as the expected lifespan of the desalination system, fuel prices, regulatory compliance costs, and potential savings from reduced logistics (transporting freshwater) are considered.

Environmental Impact and Regulations - Environmental considerations, including regulations related to brine discharge and environmental impact assessments, can influence economic feasibility. Compliance with environmental standards may incur additional costs but can also enhance the ship's sustainability and reputation

V. POWER TURBINE

A power turbine is used in a waste heat recovery (WHR) system on ships to improve the fuel efficiency of the main engine. A WHR system uses waste heat from ship engines to generate power, which can be used as additional propulsion power or for shipboard services. The power turbine in the system combines heat from sources like steam or hot output gases with other engine processes to save energy and increase the ship's engine energy efficiency. WHR systems can recover up to 10% of the main engine shaft power as electrical power, which can cut exhaust gas emissions and deliver fuel savings

A. Working principle

The principle behind power turbines in WHR systems is rooted in the efficient utilization of exhaust heat generated by heavy-duty engines. A turbocharger that can only access a small portion of the exhaust gas is sufficient to secure the power to compress the charging air. To utilize untapped energy in exhaust gas, the application of a power turbine is appreciated in a WHR system. Power turbines can exhaust heat utilization for heavy-duty engines, especially aboard large tonnage ships. Power turbines are employed in WHR systems as thermal propulsion devices to increase the main engine's fuel efficiency. Compared to steam power plants, power turbines have relatively low capital costs. It also has environmental advantages.

There are two types based on the arrangements and location of the power turbine. In the first arrangement, the diesel engine feeds in parallel with the turbocharger and the power turbine with the exhaust gas from the main exhaust gas manifold. In the second arrangement, the turbocharger and the power turbine are fed in series from the diesel engine exhaust gas manifold, and the power turbine is located downstream of the turbocharger. Both arrangements have bypass valves to direct the distribution of the exhaust gas flux.

Application

Fig. 5 shows a combined propulsion system for a ship with a marine engine. The system harnesses the energy in the main engine exhaust gas. Some of the exhaust gas that leaves particular cylinders is collected in the exhaust gas manifold and then flows to a constant-pressure turbocharger. Some of the exhaust gas is used to provide the power required to compress the charging air; the remaining gas can be expanded in a second power turbine that is supplied in parallel—the power turbine drives, as an additional drive, the propeller screw via a gear. During partial loads, the exhaust gas flow from the main engine is insufficient to secure the power turbine's additional operation. In this case, a control valve closes the exhaust gas inflow to the power turbine. The charging air pressure signal and the propeller shaft angular speed or torque signal can operate this valve. The exhaust gas flows from the power turbine and the supercharger to the waste-heat boiler installed in the main engine exhaust gas duct in front of the silencer. The steam generated by the waste-heat boiler is used to meet shipboard requirements as well as power the steam turbine, which turns the propeller screw. The system also allows for independent operation of the piston internal combustion engine, with the power turbine in off condition. The adopted control system also helps control the supercharging system's operation at partial loads.

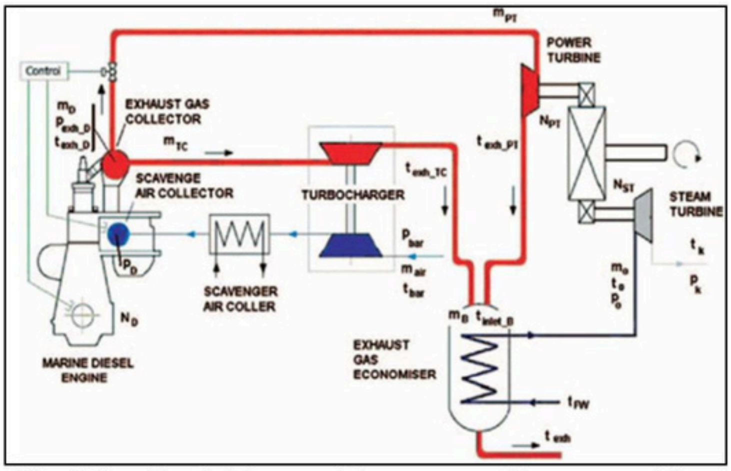

Fig. 5 Combined ship propulsion system with power turbine

In conclusion, incorporating power turbines within waste heat recovery (WHR) systems signifies a significant leap forward in maritime engineering, particularly for large ships aiming to bolster fuel efficiency and minimize emissions. By tapping into exhaust heat that would otherwise be wasted, these turbines are pivotal in maximising the energy output of leading engines. Their operation revolves around effectively utilising exhaust heat, a resource previously overlooked in conventional turbocharger systems. Power turbines offer a cost-effective alternative with notable environmental advantages compared to steam power plants, making them an appealing choice for ship propulsion systems.

Two primary arrangements exist for integrating power turbines within WHR systems, each offering distinct advantages. Whether operating in parallel or series with turbochargers, these arrangements optimise energy extraction from exhaust gases while maintaining flexibility through bypass valves. This adaptability ensures efficient distribution of exhaust gas flux, optimizing performance across various operational scenarios.

Practically, the combined propulsion system illustrated in Fig. 5 exemplifies the seamless integration of power turbines within the ship's engine layout. The system maximises energy recovery by capturing exhaust gas heat through a constant-pressure turbocharger and directing it to turbocharging and power turbine functions. Furthermore, including a control valve ensures optimal operation, particularly during partial loads, by regulating exhaust gas inflow to the power turbine based on dynamic signals such as charging air pressure and propeller shaft speed or torque.

Moreover, the system's utilization of waste-heat boilers enhances efficiency by producing steam for additional propulsion via steam turbines and meeting general ship demands. This comprehensive approach improves fuel efficiency and allows for independent operation of internal combustion engines when the power turbine is disengaged. The sophisticated control system depicted in Fig. 2 underscores the system's adaptability, facilitating precise management of supercharging operations across varying load conditions.

In summary, integrating power turbines within WHR systems represents a transformative innovation in maritime technology, offering tangible benefits in fuel savings, emissions reduction, and operational flexibility. As the maritime industry continues to prioritize sustainability and efficiency, power turbines are poised to play an increasingly integral role in shaping the future of ship propulsion systems. Through ongoing research and development, further refinements in design and implementation hold the promise of even greater advancements in maritime energy efficiency and environmental stewardship.

VI. Turbocharger

A turbocharger is used in internal combustion engines to increase engine efficiency and power output by compressing air entering the combustion chamber. It is made up of a shaft connecting a compressor and a turbine. The engine's exhaust gasses power the turbine, which in turn powers the compressor, adding more air to the engine. This compressed air allows more fuel to be burned, resulting in increased power output without a proportional increase in fuel consumption. Turbochargers are commonly used in automotive, marine, and aerospace applications to improve engine performance.

Variable Geometry Turbochargers (VGTs) have become helpful in giving precise control over the air-to-fuel ratio across different engine speeds and loads. They help control the intake air volume ratio to the fuel injected, resulting in improved combustion, better engine performance, and lower emissions. VGTs have introduced extra flexibility in engine control systems by allowing independent engine speed adjustment and air-to-fuel ratio. This provides significant benefits in terms of performance and efficiency, especially in steady-state operation, where fine-tuning the air-to-fuel ratio independent of engine speed optimizes overall efficiency.

Multi-entry turbines are an advanced technology in turbochargers that improves energy conversion. They are designed to isolate overlapping exhaust pulses from different engine cylinders, which prevents interference that can reduce energy transfer. This separation ensures the turbine receives maximum energy, increasing efficiency and engine performance. It's especially beneficial when exhaust flow is intermittent, such as in some engine designs.

Electric Turbo-Compound Systems (ETC) are more advanced turbocharger systems that generate electricity from exhaust gas energy. Old turbo-compound systems were used for only mechanical extraction; however, ETCs have an electric generator driven by a turbine in the exhaust stream. This electricity can power the compressor or a generator, enhancing fuel efficiency and simplifying the system. While ETCs can significantly reduce fuel consumption, they also require complex control systems to manage the interactions between the turbocharger and the electric generator.

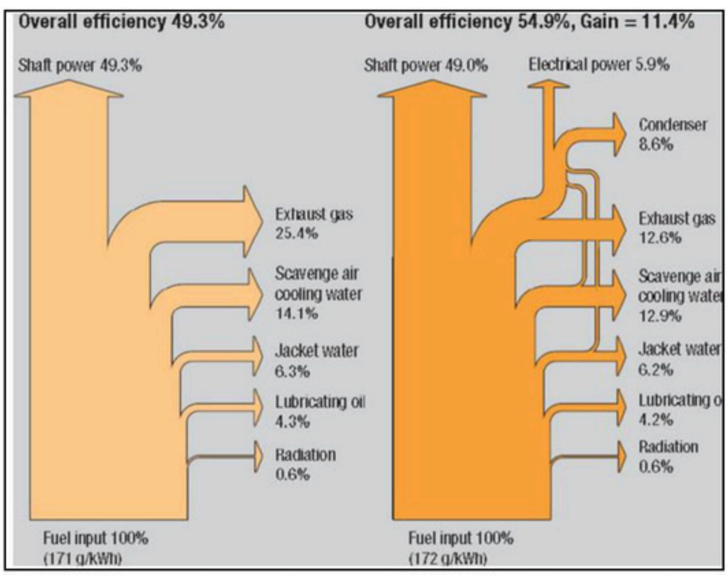

Fig. 6 Comparisons of energy flux and fuel consumption between engines with and without WHR system

VII. CONCLUSION

An extensive review of the literature on WHR technology, based on board ships, used waste heat. The goal is to give thorough knowledge about WHR to enable better emissions and fuel consumption development. These technologies include mixed cycle systems that use more than two WHR technologies: turbine, desalination, and the Rankine cycle. On ships, turbine technology has been authorized and extensively used. The desalination and Rankine cycle are established technologies that offer a handy means of obtaining both cooling and heat sources. Despite their limited use, combined cycle systems are expected to get greater attention due to their substantial development potential in achieving increased thermal efficiency and mitigating the issue of atmospheric pollution. It will be the primary focus of WHR technology research.

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REFERENCES

[1] A review of waste heat recovery on two-stroke IC engine aboard ships. Clerk Maxwell,

[2] Stefanopoulou A, Smith R. Maneuverability and smoke emission constraints in marine diesel propulsion. Control Engineering Practice 2000;8:1023–31.

[3] Galindo J, Serrano JR, Climent H, Varnier O. Impact of two-stage turbocharging architectures on pumping losses of automotive engines based on an analytical model. Energy Conversion and Management 2010;51: 1958–1969.

[4] Copeland CD, Newton P, Martinez-Botas R, Seiler M. The effect of unequal admission on the performance and loss generation in a double-entry turbocharger turbine. Journal of Turbo Machinery 2012;134:021004–15

[5] Dzida Marek, Mucharski Janusz. There is a possible increase in efficiency of the ship power plant with the system combined with marine diesel engines, gas turbines, and steam turbines if the main engine cooperates with the gas turbine fed in parallel with the steam turbine. Polish Maritime Research 2009;1(59)(vol. 16):47–52.

[6] MAN diesel & turbo LTD. MAN diesel & turbo technology boosts efficiency. MAN diesel & turbo SE Teglholmsgade 41 DK-2450 Copenhagen SV DENMARK; June 2011. /www.mandieselturbo.com

[7] Hopmann Ulrich, Marcelo C. Algrain diesel engine electric turbo compound technology. SAE paper 2003-01-2294

[8] Heywood JB. Internal combustion engine fundamentals. New York: McGraw-Hill; 1988 p. 248–70

[9] Buros OK. The U.S.A.I.D. desalination manual. Gainesville, Florida: International Desalination and Environmental Association; 1980.

[10] Ghirardo Federico, Santin Marco, Trave rso Alberto, Massardo Aristide. Heat recovery options for onboard fuel cell systems. International Journal of Hydrogen Energy 2011;36:8134–42

[11] Sommariva C, Venkatesh R. MSF desalination. MEDRC Newsletter 2002;18:1–3.

[12] Vlachos GTh, Kaldellis JK. Application of gas-turbine exhaust gases for brackish water desalination: a techno-economic evaluation. Applied Thermal Engineering 2004;24:2487–500.

[13] Bidini G, Maria F, Generosi M. Micro-cogeneration system for a small passenger vessel operating in a nature reserve. Applied Thermal Engineering 2005;25:851–65

[14] Tien W-K, Yeh R-H, Hong J-M. Theoretical analysis of cogeneration system for ships. Energy Conversion and Management 2007;48:1965–74

[15] Rigby GR, Hallegraeff GM, Sutton C. Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. Marine Ecology Progress Series 1999;191:289–93.

LOAD FREQUENCY CONTROL OF GENERATOR IN POWER SYSTEM

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***Abstract*— This paper comprehensively reviews key research areas in various Load Frequency Control (LFC) techniques, focusing on achieving zero steady-state error in frequency and bus-bar power deviations. Power system stability refers to the ability of a power system to maintain load levels within predefined limits while ensuring a steady-state transfer of electrical power. With the increasing complexity of modern electrical grids due to growing interconnections and power exchanges, robust control mechanisms are essential to mitigate deviations caused by external disturbances. Load Frequency Control (LFC) plays a crucial role in power systems by regulating generator output to balance fluctuations in demand and maintain system frequency. Generators respond to load variations, ensuring a stable power supply. Control mechanisms regulate inputs based on frequency changes, preventing grid instability. A notable power supply quality issue in ship electric networks is 'frequency modulation. 'Frequency control is a complex yet critical function in modern power systems. LFC is crucial for stable power system operations, ensuring generators respond to demand fluctuations and preventing frequency deviations that can cause grid instability and blackouts. The conclusion highlights research gaps and proposes new directions in LFC systems.**

Keywords*— Load frequency control, Frequency modulation, Steady State Error, Power System, Grid Instability

I. Introduction

The regulation of frequency and bus bar frequency presents significant challenges in interconnected power systems (PS), where manual control is impractical. Another critical issue is ensuring that the generated power accurately matches the load under nominal conditions. The primary objective of Load Frequency Control (LFC) is to restore frequency to its nominal value while minimizing unintended tie-line power exchanges between interconnected control areas. As modern power systems expand in size and complexity, system oscillations can propagate over large areas, potentially leading to widespread blackouts. Advanced control techniques have been implemented in LFC to address these challenges.

II. Various Optimization Techniques Related to LFC Studies

i. This mismatch is mitigated by the operation of anti-windup schemes for Governor demand (GDB) and Generation rate constraint (GRC), which demonstrate their compensation effects through simulation results. The paper highlights that it does not focus on LFC design but rather on maintaining control performance in the presence of nonlinearities through anti-windup schemes while eliminating linarites.[1]

ii. Wind turbines, solar generation, and sea wave energy can also be integrated into marine vessel power systems to make them more energy efficient.

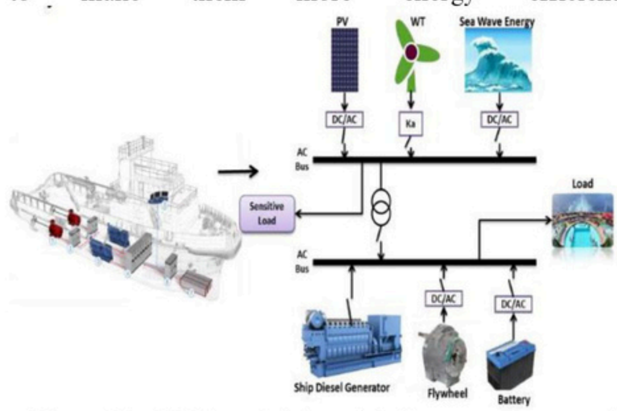

Fig.1. The LFC in a shipboard Grid system case study

The author discusses a new time-varying method using a modified optimization approach for tuning a fractional order fuzzy proportional derivative +

integral controller for load frequency control in shipboard microgrids.

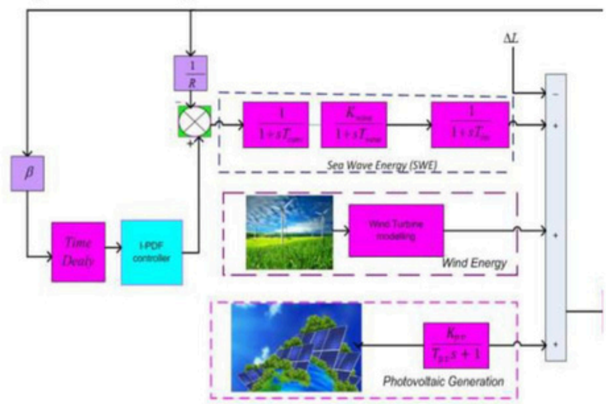

Fig. 2. Marine microgrid system modelling

The proposed optimal tuning scheme is effective and less complex for practical applications.[2]

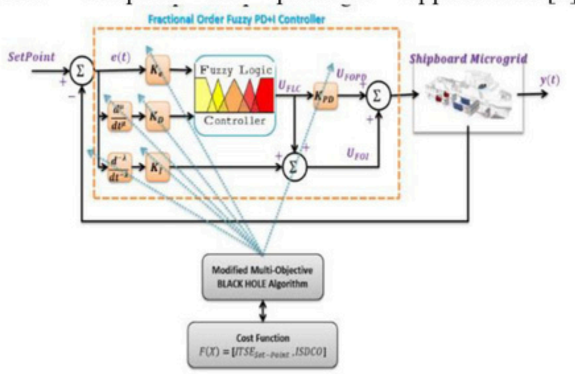

Fig. 3. The overall design of the recommended LFC controller

iii. The PID controller remains widely utilized in ship power stations despite the introduction of numerous advanced control techniques. Our focus is on parallel synchronous generators. Taking an ocean-going ship power system as an example, the system consists of three identical diesel engines (DE) and synchronous generators (G) of the same capacity, the novel control system design shown in Fig. The ship power control system mainly consists of a PC, auto-tuning neurons and a parallel PID controller; the control strategy applies constant-frequency and power-equalization methods. The parallel PID gains are not fixed but can be automatically adjusted by the steepest descent method. According to the Δe-size, PWM is automatically selected. The simulation result shows that the frequency-load adjustment process will not produce a fast and overshoot phenomenon.[3]

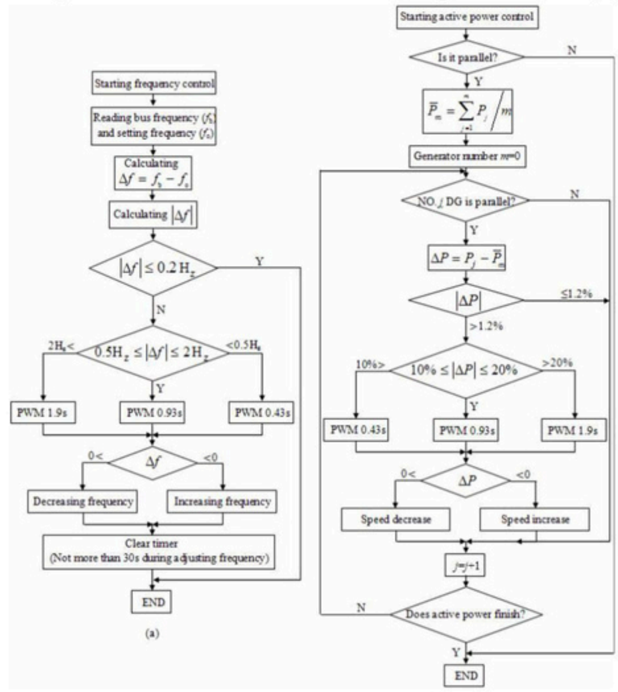

Fig. 4. a) The automatic control flow charts for bus frequency; b) The generator active power automatic control flow charts

iv. The structure and complexity of deregulated power systems are increasing due to the growing integration of renewable energy sources. This expansion raises the risk of large-scale blackouts. In such a scenario, the conventional Load Frequency Control (LFC) approach may become impractical due to the system's unregulated and complex nature. To overcome this challenge, intelligent control schemes combined with soft computing techniques, such as artificial neural networks (ANN), fuzzy logic, genetic algorithms (GA), bacterial foraging optimization algorithm (BFOA), particle swarm optimization (PSO), and firefly algorithm, are being explored. These advanced techniques offer effective solutions for mitigating LFC issues in deregulated power systems, making them a viable alternative to traditional controllers.[4]

v. The literature survey indicates that integrating active energy storage devices or techniques to support Load Frequency Control (LFC) in deregulated power systems enhances performance. Various energy storage technologies, such as battery energy storage systems (BESS), pumped storage hydroelectric systems, supercapacitors, and superconducting magnetic energy storage (SMES), are examined in the context of interconnected power systems. Their respective advantages and disadvantages are also discussed in detail. [5]

vi. The optimization objective function integrates economic and stability indices, each with its own physical significance. This approach formulates the market-based optimal Load Frequency Control (LFC) problem as a functional extremum optimization problem. A structure-preserving power system model is used to account for load characteristics, constraining the optimization problem with differential algebraic equations (DAEs). A quasi-Newton algorithm is then proposed to solve the formulated DAEs-constrained optimization problem. The IEEE 30-bus system is simulated under various market arrangements, demonstrating that the proposed framework and corresponding algorithm effectively achieve optimal power system performance in both economy and security.[6]

Flexible AC Transmission Systems (FACTS) Devices

vii. FACTS devices regulate electricity flow across interconnected transmission lines. They enhance both the system's dynamic stability and transmission lines' power transfer capacity, thereby improving overall network stability. Over the past decades, various FACTS devices have been developed, including the Unified Power Flow Controller (UPFC), Static Synchronous Series Compensator (SSSC), Thyristor-Controlled Phase Shifter (TCPS), Static Synchronous Compensator (STATCOM), Thyristor-Controlled Series Capacitor (TCSC), and Interline Power Flow Controller (IPFC). These devices contribute significantly to optimizing power system performance and reliability.[7]

viii. The paper addresses electric power supply quality(PSQ) challenges in ship electric networks, focusing on voltage and frequency modulation from pulsed loads. Highlighting gaps in existing standards, the authors aim to formulate a theoretical analysis of frequency modulation. This analysis considers factors such as modulation periodicity, pulsed load duration, and the operational characteristics of the generator. The findings aim to contribute to setting standards for power supply quality in ship electric networks. The parameters examined can be sorted in decreasing order of criticality as:

† frequency droop, Rf ;
† pulsed load period, T;
† rotor inertia constant, J′;
† integral gain of frequency controller, Ki[8]

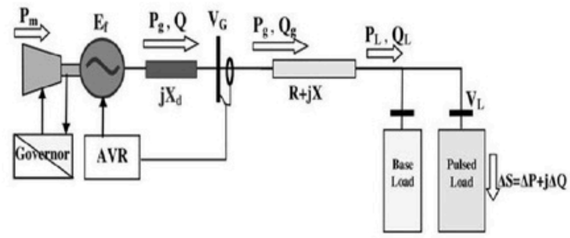

Fig. 5. Ship electrical network's simplified electrical circuit

III. Control Objectives

1. The primary control objective is to maintain frequency within protection relay limits in a marine power plant; Section 3.1 mentions class rules on frequency deviation. DNV (2012) states that the frequency shall stay between 90% and 110% of the rated frequency during transients and between 95% and 105% for steady state. preventing blackout escalation from failures. The frequency does not need to match the rated values precisely; however, it must remain within specified limits to maintain system stability.

2. To reduce wear, minimise rapid load changes on generator sets, focusing on minimising variations in no-load frequency, as this directly impacts fuel consumption.
3. The final objective is achieving desired load sharing, allowing the plant to operate efficiently for a genset combination or facilitating soot burn-off.

IV. Discussion And Recommendation

1. Further Research on RES Integration: Encourage continued research on the integration of RES in LFC, exploring innovative models and technologies to enhance the reliability and efficiency of power systems.
2. Optimization of Control Techniques: Advocate for research into advanced control techniques, including optimising auto-tuning neurons, parallel PID controllers, and other modern approaches to refine LFC strategies.
3. **Enhanced Integration of FACTS and ESD:** Advancing the development and implementation of cutting-edge Flexible AC Transmission Systems (FACTS) and Energy Storage Devices (ESD) can significantly enhance the robustness of Load Frequency Control (LFC) by effectively managing frequency fluctuations and improving overall system stability.

4. **Focus on Hybrid Power Systems:** Prioritize research on the unique challenges associated with hybrid power systems, particularly in addressing

frequency regulation issues resulting from the increased integration of renewable energy sources (RES). Develop advanced control mechanisms specifically designed to accommodate the dynamic nature of hybrid power systems, ensuring stability and reliability.

5. **Collaborative Industry-Research Initiatives:** Promote joint efforts between academia, industry, and research institutions to drive innovation and facilitate the practical implementation of Load Frequency Control (LFC) strategies. These collaborations should address real-world challenges and system requirements, ensuring the development of effective and scalable solutions for modern power systems.

6. By addressing these recommendations, the power industry can continue to enhance the effectiveness of

Active energy storage solutions in deregulated power systems are examined, and promising results are demonstrated. As the power sector transitions toward hybrid power systems with greater RES penetration, the need for advanced control mechanisms and optimization techniques incorporating Load Frequency Control, ensuring the reliability and sustainability of power systems in the face of evolving energy landscapes.

V. Conclusion

This work provides a critical review of contemporary advancements in Load Frequency Control (LFC), focusing on emerging technologies such as realistic Renewable Energy Resource (RES) models, anti-windup schemes, and a novel time-varying approach utilizing a fractional-order fuzzy proportional-derivative plus integral (FO-FPD+I) controller for shipboard microgrids. The integration of Flexible AC Transmission Systems (FACTS) and Energy Storage Devices (ESD) in LFC is gaining significance, with a detailed analysis of various LFC strategies and their characteristics.

The study explores advancements in conventional and deregulated LFC with RES integration, emphasizing enhanced system dynamics. The application of modern control techniques, soft computing optimisation, and FACTS and ESD becomes crucial to addressing future LFC challenges.

Furthermore, the study highlights significant research opportunities in integrating RES into deregulated power systems and concludes with a comprehensive roadmap for future research directions.

VI. References

[1] W. Tan, S. Chang, and R. Zhou, "Load frequency control of power systems with non-linearities," *IET Generation, Transmission and Distribution*, vol. 11, no. 17, pp. 4307–4313, Nov. 2017, doi: 10.1049/iet-gtd.2017.0599.

[2] M. H. Khooban, T. Dragicevic, F. Blaabjerg, and M. Delimar, "Shipboard Microgrids: A Novel Approach to Load Frequency Control," *IEEE Trans Sustain Energy*, vol. 9, no. 2, pp. 843–852, Apr. 2018, doi: 10.1109/TSTE.2017.2763605.

[3] G. Zhang, "Frequency-load control based on auto-tuning neurons for ship power station," in *Procedia Engineering*, 2011, pp. 1196–1202. doi: 10.1016/j.proeng.2011.08.221.

[4] A. Pappachen and A. Peer Fathima, "Critical research areas on load frequency control issues in a deregulated power system: A state-of-the-art-of-review," *Renewable and Sustainable* doi: 10.1016/j.rser.2017.01.053.

[5] Bhatt SP, Ghoshal, Roy R. Coordinated control of TCPS and SMES for frequency regulation of interconnected restructured power systems with dynamic participation from DFIG-based wind farm. Renew Energy 2012;40:40–50.

[6] L. Feng *et al.*, "Article in IEE Proceedings-Generation Transmission and Distribution," 2003, doi: 10.1049/ip-gid:20020683.

[7] N. Ram Babu, S. K. Bhagat, L. C. Saikia, T. Chiranjeevi, R. Devarapalli, and F. P. García Márquez, "A Comprehensive Review of Recent Strategies on Automatic Generation Control/Load Frequency Control in Power Systems," *Archives of Computational Methods in Engineering*, vol. 30, no. 1. Springer Science and Business Media B.V., pp. 543–572, Jan. 01, 2023. doi: 10.1007/s11831-022-09810-y.

[8] F. D. Kanellos, G. J. Tsekouras, J. Prousalidis, and I. K. Hatzilau, "An effort to formulate frequency modulation constraints in ship-electrical systems with pulsed loads," *IET Electrical Systems in Transportation*, vol. 1, no. 1, pp. 11–23, Mar. 2011, doi: 10.1049/iet-est.2010.0050.

ELECTRIC PROPULSION FOR LIFEBOAT

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Abstract

This paper presents the integration of electric propulsion technology in the lifeboat manoeuvring system to enhance efficiency, reliability and sustainability. The present lifeboat propulsion system often relies on the internal combustion engine, which requires fuel to propel and also has various challenges to face, such as emissions, maintenance, and overall environmental impact. This paper delves into the design, economics, ergonomics, engineering challenges and performance assessments associated with successfully implementing electric propulsion for lifeboats. Special emphasis is given to the research and development of lightweight, high-capacity energy storage systems and efficient electric motors suitable for maritime emergency evacuation applications. Electric propulsion (EP) features, such as reduced harmful emissions, lowered maintenance requirements and improved manoeuvrability, draw more attention to this research field. The paper also explores the integration of green energy sources, such as solar and wind, that can be used to supplement the electric propulsion system, enhancing the lifeboat's autonomy and sustainability during emergencies. This work focuses on the overall advancement of maritime emergency safety equipment. It will also help make maritime services more eco-friendly by offering a comprehensive analysis of electric propulsion integration in lifeboats, providing insights for future developments.

Keywords—Electric propulsion, Emergency, Energy saving, Lifeboat, Renewable energy

I. Introduction

The rise of electric propulsion technology has brought about a pivotal shift in lifeboat manoeuvring systems, bringing in a new era of heightened efficiency, reliability, and environmental sustainability. Departing from conventional methods, the electric propulsion system uses battery-powered electric motors, granting higher precision in control and manoeuvrability. This comprehensive paper dives into the undisputed role of electric propulsion within lifeboat systems, providing an in-depth analysis of its components, advantages, and diverse applications. By integrating cutting-edge technology, electric propulsion ensures the safety and responsiveness of lifeboat operations and stands as a tremendous advancement in maritime safety and rescue. By avoiding the limitations inherent in traditional propulsion systems, we delve into the transformative potential brought by this innovative technology.

The seamless integration of EP promises heightened reliability, efficiency, and manoeuvrability in lifeboat operations, thus significantly enhancing safety and performance at sea. This study undertakes the challenge of addressing technical intricacies and refining control strategies, ultimately striving for a seamless transition that amplifies safety, efficiency, and environmental sustainability in maritime rescue operations. In contributing to the ongoing evolution of propulsion technologies, this research is a pivotal step towards fostering a greener and more resilient maritime future.

It is feasible to run a power system with fewer generators by incorporating an ESS [1]. The different ways that engine manufacturers can reduce emissions of SOx and NOx are explained in [2] while also elucidating the primary factors they consider when selecting the best technology. The historical development of electricity use in naval boats is presented in [3]. In addition to other relevant ideas, [4] provides an overview of the state of the art in the scientific community on the application of transactive energy, market-based control, and peer-to-peer energy trading. In [5], conventional technologies for electric propulsion and generation for various ship types have been examined. It then highlights the key features of novel architectures designed to generate electric energy for powering electric propulsion systems and onboard auxiliaries. The introduction of EP drives, which paved the way for the development of all-electric ships, is discussed in [6]. Next, technologies for producing and controlling electricity are included, allowing the integrated electrical power system to be utilised. In the Split port area, a thorough examination of the electrification requirements for one hull type and ferry route has been conducted [7]. The possibility of a hybrid power system for medium-sized oceangoing ships is illustrated in [8]. Several criteria are used in the decision-making process, and various opportunities are evaluated about multiple elements and sub-factors, as explained in [9]. The key enabling technology for the electrification of large ships has been shown in [10]. Improved controllability of the vessel when manoeuvring and docking is another benefit of electric ships [11]. A detailed discussion is held in [12] regarding how new conversion technologies, including power electronics, battery energy storage, and the DC power system, may affect this development. An analysis of technology to mitigate emissions from marine engines is given in [13]. The characteristics of some of the main motor classes that could be employed in ship propulsion are described in [14]. Electric propulsion on passenger cruise ships in the commercial domain is explained in [15].

A. ELECTRICAL PROPULSION SYSTEM

A typical EP system layout often involves several key components, as shown in Fig. 1:

1. **Power Source**: Batteries, fuel cells, or a combination. The power source provides electricity to drive the propulsion system.
2. **Electric Motors**: These main parts transform electrical energy into mechanical energy to produce thrust. Electric motors come in various types, including brushed, brushless, and induction motors.
3. **Motor Controller**: The motor controller regulates the power supplied to the electric motors, controlling their speed and direction of rotation. It ensures efficient operation and protects the motors from overloading.
4. **Propellers or Thrusters**: These elements generate thrust to propel the vehicle forward (or in any desired direction). The choice between propellers and thrusters depends on the specific application, with propellers being more common in aerial vehicles and thrusters in underwater or space applications.
5. **Power Distribution System**: This system manages the distribution of electrical power from the source to the motors and other components of the propulsion system. It includes wiring, switches, circuit breakers, and sometimes power conditioning units to ensure stable voltage and current levels.
6. **Control System**: The control system includes sensors, actuators, and software that regulate the operation of the propulsion system. It monitors parameters such as motor speed, temperature, and battery voltage and adjusts the system's operation accordingly.
7. **Cooling System**: Electric motors and power electronics generate heat during operation, so a cooling system is often required to maintain optimal temperatures and prevent overheating. This can involve air or liquid cooling methods.
8. **Auxiliary Systems**: Depending on the specific application, additional components such as battery management systems, power converters (for converting between AC and DC power), and energy storage systems may be included in the layout.

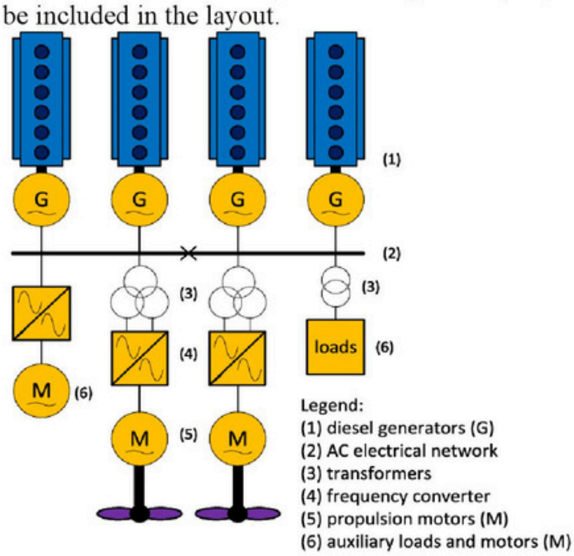

Fig. 1. Typical electrical propulsion system layout

II. WORKING ON EP OF LIFEBOAT

The electric propulsion system (EPS) facilitates a lifeboat's propulsion and navigation system. This technology is popular regarding efficiency, reliability, and environmental friendliness. EPS for lifeboats includes the following components:

Electric Motor:

Power provided to EPS for lifeboats is mainly by electric motors. Based on the design and requirements of the system, these motors can be either AC (alternating current) or DC (direct current)

Power Source:

The power source for the EPS depends upon standard options such as batteries, fuel cells, or a combination of both. Batteries store electrical energy, which is used during propulsion, whereas fuel cells generate electricity based on the chemical reaction of oxygen and fuel. When lifeboats are mainly made of EPS, they are primarily equipped with batteries. The batteries are charged and store electrical energy, which supplies power during emergencies when conventional propulsion systems are not feasible.

In some cases, electricity is generated by fuel cells upon burning the fuel through chemical oxidation. This provides a continuous and reliable source for electric propulsion.

Control System:

An advanced control system is required to manage the effect of the control system. It includes a sensor, data, software, and controller to control and regulate the power output, ensuring the propulsion system's safe operation.

Thrust Propulsion:

A thrust is generated upon propelling the lifeboat, which can be used as a propeller for an air jet. So, it is monitored for efficient operation.

TABLE 1 CO_2 EMISSIONS

		CO_2 EMISSION			
		SCENARIO 1		SCENARIO 2	
VOYAGE TYPE	NO. OF VESSELS IN THE WORLD FLEET	60% LOAD	40% BALLAST	60% LOAD	40% BALLAST
HANDYSIZE	1774	1.8	3.5	0.07	2.8
HANDYMAX	1732	0.23	0.095	0	0
PANAMAX	1383	4.1	2.9	2.3	1.7
POST PANAMAX	98	0.51	0.25	0.33	0.14
CAPESIZE	722	1.6	1	0	0

Electric propulsion systems are valuable in lifeboats, providing reliable power during emergencies. This is crucial for ensuring the lifeboat can operate effectively when needed to rescue the life of seafarers.

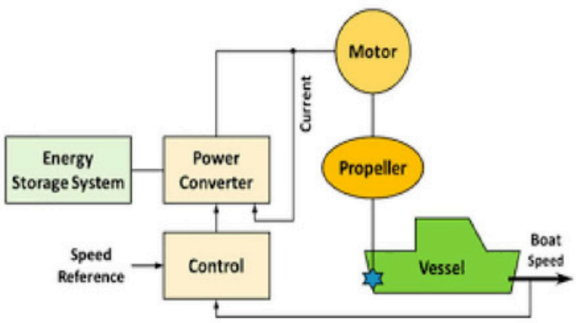

Fig. 2. Electric propulsion system components

III. THE POTENTIAL OF THE EPS FOR CO2 EMISSION

EPS have the potential to significantly reduce CO_2 emissions compared to traditional combustion-based propulsion systems, particularly in transportation sectors such as automotive, aviation, and maritime. EPS are inherently more energy-efficient than internal combustion engines (ICEs). Electric motors can convert more electrical energy into mechanical energy, resulting in less energy waste and lower overall energy consumption. This efficiency reduces CO_2 emissions, especially when coupled with renewable energy sources. Electric propulsion systems can be powered by electricity from renewable energy sources such as solar, wind, hydroelectric, and geothermal. By utilising clean energy sources, the CO_2 emissions associated with electricity generation are significantly reduced compared to fossil fuel-based power generation. electric propulsion systems offer a promising pathway to decarbonise transportation and mitigate the impacts of climate change by reducing CO_2 emissions and promoting sustainable energy use.

In the maritime sector, ships account for 3% of the world's greenhouse gas emissions. If the economy grows by 2050, greenhouse gas emissions will increase by 150 per cent to 250 per cent. This means that the world's greenhouse gas emissions triple economic growth. At the same time, to achieve the target of increasing global temperature by 1.5 to 2 degrees Celsius by 2050, all economic zones must have zero greenhouse gas emissions. The international shipping industry, therefore, faces a major challenge in reducing carbon monoxide emissions as it aims to reduce the impact of climate change. There are many studies on measures to reduce CO_2 emissions in maritime. The solutions include improving design, economies of scale, architecture of electrical power and propulsion systems, building a fast ship, using other fuels and renewable energy, and optimising extraction plans. This can be taken into consideration.

Hull design covers the boat's size, shape and weight. This helps improve hydrodynamic performance and reduce drag. Economies of scale are another way to reduce emissions, as larger ships and cargo will produce more energy per cargo unit.

When the payload capacity doubles, the need for electricity and fuel consumption also increases. Approximately two-thirds reduce fuel consumption per unit. Energy and propulsion include the design of electric motors, hybrid solutions, increased energy efficiency, waste energy recovery and the reduction of onboard power required by energy-saving equipment such as kites and sails. Hybrid systems can use many energy sources, such as combining the battery with the internal generator.

To get the best results from all technologies, the battery can be used negatively to meet high energy needs. Power is required to prevent the internal combustion engine from running at low power. Speed is related to the ship's operating speed and design speed. Traditionally, ships are designed to operate at the hydrodynamic speed limit; This is the speed at which the resistance curve for a body increases with increasing speed.

Since power must be directly proportional to the product of speed and resistance, fuel consumption will also decrease when the boat reduces its speed. The maximum fuel consumption will decrease when the ship reduces its speed in the boundary zone. Fuel savings are achieved. Fuel and Alternative Energy covers replacing or supplementing the marine fuel HFO-MGO with other energy products. By moving to fuels with lower overall emissions, CO_2 emissions can be decreased immediately and throughout the fuel cycle, including distribution, refinement, and production.

Like LNG and biofuels, hydrogen is attracting increasing attention due to its use in combination with renewable energy sources such as wind and solar energy. Weather routing and planning will consider the current tides and weather, find the best sailing route and speed, and deliver according to the contract or published schedule, thus consuming less fuel and using less fuel.

IV. ADVANTAGES

A. Environmental Impact:
Reduced emissions: Electric propulsion systems in lifeboats produce fewer greenhouse gas emissions than conventional engines, contributing to a cleaner maritime environment.
B. Operational Efficiency:
Electric motors provide instantaneous torque, enabling rapid acceleration and response in critical life-saving scenarios.
C. Simplified control:
EPS in lifeboats often have fewer moving parts, leading to simplified control systems and potentially lower maintenance requirements.
D. Maintenance:
EPS in lifeboats typically have fewer components prone to wear and tear, resulting in lower maintenance costs.
E. Longer lifespan:
Electric motors in lifeboats often have a longer lifespan than traditional engines, contributing to their overall reliability.

V. DIS-ADVANTAGES

A. Limited Range:
Range limitations: Electric lifeboats may be constrained by range, particularly in situations where extended operation is required.
B. Battery technology:
The current state of battery technology poses challenges related to energy density, weight, and charging times, potentially limiting the operational capabilities of electric lifeboats.
C. Initial Cost:

The initial investment for electric propulsion systems in lifeboats can be higher than that for traditional counterparts, potentially impacting the overall affordability of lifesaving vessels.

D. Infrastructure:
Infrastructure requirements: Charging infrastructure for electric lifeboats may be limited, especially in remote or emergency scenarios, posing challenges to their adoption.
E. Reliability Concerns:
Electric propulsion systems in lifeboats rely heavily on a stable power supply, raising concerns about reliability in situations with power outages or system failures.

V. CONCLUSION

Throughout this study, we explored the intricate design considerations, engineering challenges, and performance evaluations associated with integrating electric propulsion into lifeboats. Special attention was directed towards developing lightweight, high-capacity energy storage systems and efficient electric motors tailored for maritime applications. The advantages of electric propulsion, including reduced emissions, lower maintenance requirements, and improved manoeuvrability, have been thoroughly discussed.
Moreover, exploring renewable energy sources, such as solar and wind, as complementary components to the electric propulsion system has been presented as a means to bolster autonomy and resilience during emergency scenarios. Real-world case studies and simulations have substantiated electric propulsion's feasibility and manifold benefits in lifeboat contexts.
In sum, this research contributes significantly to advancing maritime safety, environmental stewardship, and the efficacy of emergency response systems, paving the way for integrating electric propulsion as a cornerstone in the evolution of lifeboat technology.

REFERENCES

[1] Kim K, Park K, Lee J, Chun K, Lee SH. Analysis of battery/generator hybrid container ship for CO2 reduction. IEEE Access. 2018;6:14537-14543.

[2] Wik C, Niemi S. Low emission engine technologies for future Tier 3 legislations—options and case studies. J Shipp Trade. 2016;1;3.https://doi.org/10.1186/s41072-016-0009-z.

[3] Skjong E, Rødskar E, Molinas M, Johansen TA, Cunningham J. The Marine Vessel's electrical power system: from its birth to today. Proc IEEE. 2015;103(12):2410-2424.

[4] Küster KK, Aoki AR, Lambert-Torres G. Transaction-based operation of electric distribution systems: a review. Int Trans Electr Energy Syst. Dec 2019; e12194. https://doi.org/10.1002/2050-7038.12194.

[5] O. Veneri, F. Migliardini, C. Capasso, and P. Corbo, "Overview of electric propulsion and generation architectures for naval applications," Electron Syst Aircraft, Railw Sh Propulsion, ESARS, 2012.

[6] Sulligoi G, Vicenzutti A, Menis R. All-electric ship design: from electrical propulsion to integrated electrical and electronic power systems. IEEE Trans Trans Electrif. 2016;2(4):507-521.

[7] G. Gašparovic and B. Klarin, "Techno-economic analysis of replacing Diesel propulsion with hybrid electric-wind propulsion on ferries in the Adriatic. In: 2016 International Multidisciplinary Conference on Computer and Energy Science (SpliTech), 2016, pp. 1–6.

[8] Kim K, Park K, Lee J, Chun K, Lee SH. Analysis of battery/generator hybrid container ship for CO2 reduction. IEEE Access. 2018;6:

14537-14543.

[9] K. Q. Bui and L. P. Perera, "The compliance challenges in emissions control regulations to reduce air pollution from shipping". In:

OCEANS 2019-Marseille, 2019, pp. 1–8.

[10] Sulligoi G, Vicenzutti A, Menis R. All-electric ship design: from electrical propulsion to integrated electrical and electronic power systems. IEEE Trans Trans Electrif. 2016;2(4):507-521.

[11] Dale SJ, Hebner RE, Sulligoi G. Electric ship technologies. Proc IEEE. 2015;103(12):2225-2228.

[12] Skjong E, Rødskar E, Molinas M, Johansen TA, Cunningham J. The Marine Vessel's electrical power system: from its birth to today. Proc IEEE. 2015;103(12):2410-2424.

[13] Pham VV, Hoang AT. Technological perspective for reducing emissions from marine engines. Int J Adv Sci Eng Inf Technol. 2019;9(6): 1989-2000.

[14] Kirtley JL, Banerjee A, Englebretson S. Motors for Ship Propulsion. Proc IEEE. 2015;103(12):2320-2332.

[15] Vie R. Commercial experience with electric propulsion on passenger cruise vessels. Trans Mar Eng C. 1998; 110:1-10.

REVIEW PAPER ON PIEZOELECTRIC GENERATOR ON BOARD SHIP

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***Abstract*— This paper provides a concise overview of piezoelectricity and its applications in energy harvesting, focusing on converting mechanical vibrations into electrical energy using piezoelectric materials and highlighting the growing interest in renewable energy sources for maritime applications and reviewing case studies where piezoelectric generators have been successfully implemented and discuss ongoing research in different fields and potential future developments.**

***Keywords*— renewable energy, piezoelectric, crystal**

I. Introduction

The maritime industry is transforming towards sustainable and environmentally friendly practices, driven by the increasing global focus on reducing carbon emissions and adopting green technologies. In this context, exploring alternative energy sources becomes imperative, and one promising avenue is the integration of piezoelectric generators on board ships. Piezoelectricity, the ability of certain materials to generate an electric charge in response to mechanical stress, offers a unique and innovative approach for harnessing energy in the dynamic environment of the open sea.

Traditional power sources for ships have predominantly relied on fossil fuels, presenting challenges related to emissions, fuel availability, and the volatility of oil prices. The maritime sector seeks viable alternatives to enhance energy efficiency and minimize its ecological footprint. Piezoelectric generators, capable of converting mechanical vibrations into electrical energy, emerge as a sustainable solution with the potential to contribute significantly to the maritime industry's energy landscape.

Understanding the fundamental principles of piezoelectricity is crucial to appreciating its application on ships. When subjected to mechanical stress or vibrations, Piezoelectric materials generate electric charges that can be harnessed for power generation. This direct transformation of mechanical energy into electrical energy offers a compelling opportunity to harness ambient vibrations and movements naturally occurring in the maritime environment.

This comprehensive review explores the current research and application of piezoelectric generators on board ships. This paper examines the principles, materials, technologies, and case studies to offer insights into this innovative energy harvesting method's benefits, challenges, and future prospects. Incorporating piezoelectric generators can improve energy efficiency while supporting the industry's dedication to sustainability and environmentally friendly practices.

The subsequent sections of this review will research the principles of piezoelectricity, the materials and technologies employed, specific applications in maritime settings, advantages, challenges, comparisons with other energy harvesting methods, regulatory considerations, and prospects for future research. By examining these aspects comprehensively, this review aims to fully understand the current landscape and future potential of piezoelectric generators on board ships.

II. Literature review

Radha D and Sayed Zahid Ali R presented a paper that gives us an insight into piezoelectric materials, their workings, and their potential use in various industries [1].
Piezoelectric materials generate electricity when subjected to mechanical strain and vibrations.

This phenomenon occurs due to the internal displacement of molecules caused by the applied force, leading to electron movement and the subsequent production of electricity. The figure below shows the same.

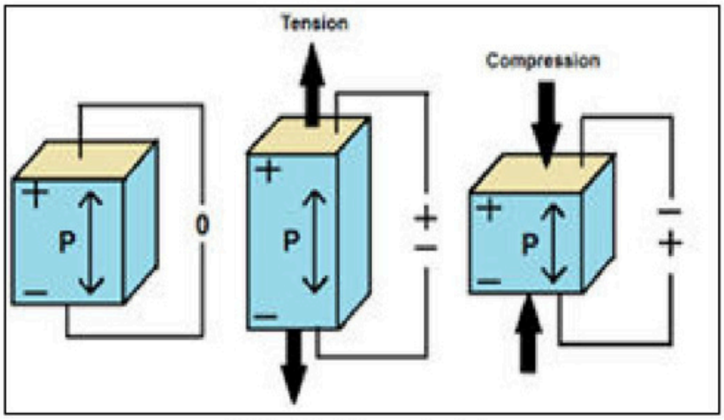

Fig1: Working principle

Denis O. Urroz-Montoya and Jeffrey R. Alverto-Suazo explored diverse applications of piezoelectricity across various fields, including [2]:

- **Piezoelectric Pavement as an Energy Collector from Traffic:**

Piezoelectric materials are used in the pathways and speed breakers, which generate electricity from forces applied by moving vehicles and the people moving on the pathways

- **Railway Integration of Piezoelectric Devices:**

The electricity generation from train tracks can be achieved by integrating piezoelectric material into the railway tracks. The advantage of this is efficient power generation due to the uniform pressure exerted on the railway tracks. The block diagram shows the stepwise generation of electricity from railway tracks.

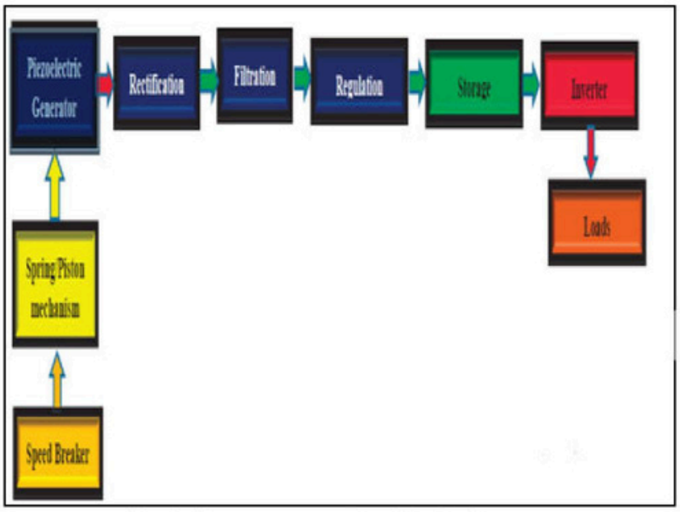

Fig 2: Power generation block diagram

- **PIEZOELECTRIC BREAKWATER**

By tapping into the immense potential of wave energy, piezoelectric devices can be utilized to generate electricity from ocean waves. This can be achieved by mounting these devices on offshore buoys or floating structures. Moreover, these systems are cost-effective and, despite their compact size, have little to no impact on the marine environment while also functioning as valuable navigation sensors. The figure below shows the working mechanism of piezoelectric breakwater.

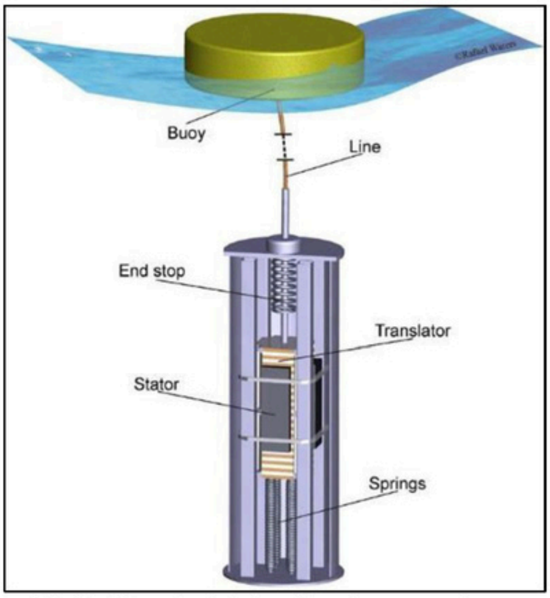

Fig 3. Piezoelectric breakwater generator

Fernando Cunha Pimentel UlhOa and Pedro Americo Almeida Magalhaes Junior presented electricity generation using piezoelectric sensors.[3]

It explains that a ship undergoes various motions, including rolling, pitching, and heaving, which can potentially cause it to capsize on the water's surface. In certain conditions, the oscillation periods may align with the natural frequency of these movements, leading to resonance and resulting in significant vibrations and amplified motion. The diagram below shows the vibrations caused by a change in stability due to a change in metacentric height.

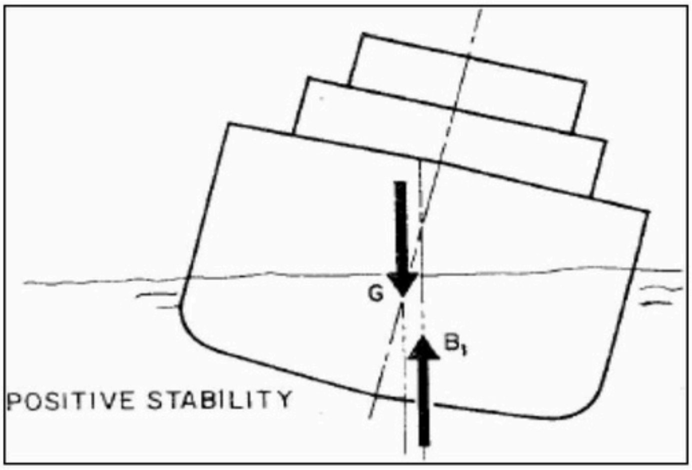

Fig 4. Stability of ship i

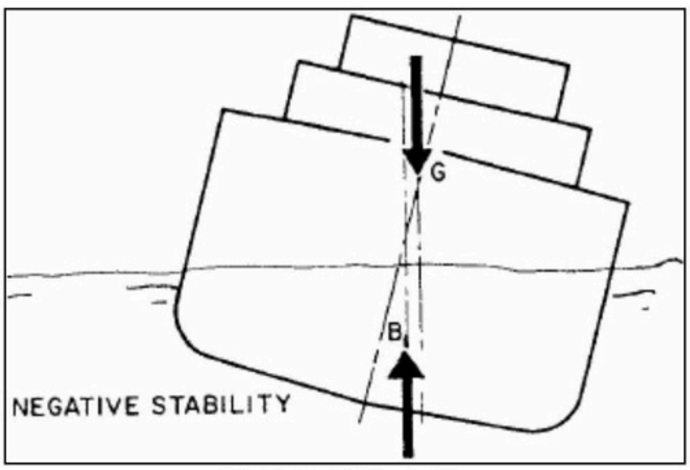

Fig 5. Stability of ship

- Hydrodynamic Resistance: As the ship moves, it experiences vibrations caused by the frequency of its interaction with the crests and troughs of sea waves. These vibration frequencies are generated due to the randomness of the waves and the hydroelectricity of the ship's hull.
- The propellor continuously rotates during a voyage where the propellor encounters irregular water flows. These generate vibrations, and the maximum is generated at the stern of the ship. So, electricity can be generated from the propellor of the vessel.

III. RESULTS AND DISCUSSION

Souza Floriano and Victor Nogueira analysed that Vibratory phenomena arise due to dynamic forces that change over time and act on the hull, specific appendages, or structural components of the ship. The system's response to these vibrations depends on the magnitude of the excitation forces and their inherent properties, including inertia, damping, and stiffness. The most common sources of vibration excitation in a ship are:

• Forces and external moments induced in the line of shafts by the propeller to rotate in the wake of the ship;
• Surface forces induced in the hull by the propeller;
• Internal forces and moments of imbalances produced by the action of the gases and the rotational organs of the propulsion engines (pistons, crankshafts) and auxiliary equipment;
• Forces caused by the dynamic action of the sea waves.

The excitation energy is transmitted from the sources to the structure (hull and superstructures) of the vessel, and the responses of these elements can be analysed separately or integrally, depending on the existence of coupling between the reactions of that system or equipment and the ship's hull.

IV. CONCLUSION

Piezoelectric transducers emerge as a promising method for generating power on ships.

This technology is recognized for its reliability, cost-effectiveness, and environmentally friendly characteristics, offering an efficient alternative for power generation.

By adopting this innovation, reliance on traditional petroleum derivatives could be lessened, prompting expanded functional productivity in transport works, all while aligning with ecologically supportable practices.

In the future, advancements and refinements in this technology may enhance its efficiency and cost-effectiveness, paving the way for more sustainable and effective electricity generation on ships.

Such progress has the potential to contribute to a more sustainable and efficient future for the shipping industry. Piezo ceramic material can be retrofitted on the forward portion of the vessel as it is a potential location for electricity generation.

Thus, it can reduce the generator loads by power sharing, which will help reduce pollution. The figure below shows the same.

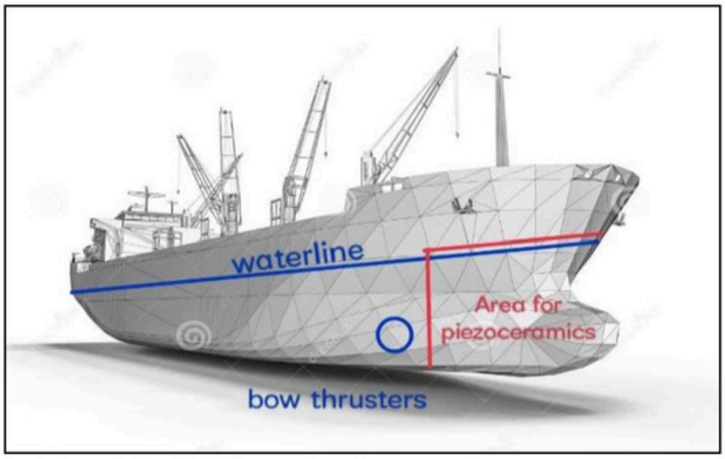

Fig 6. Positioning of piezoceramics

Piezoelectric materials can be installed on the port and starboard sides of the ship to harness energy from ocean waves while sailing. The figure below illustrates this concept.

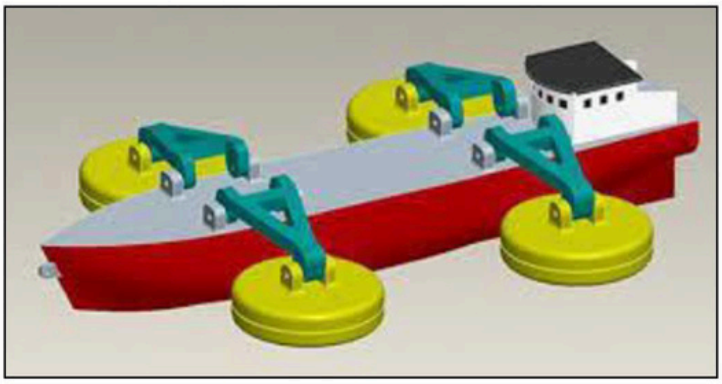

Fig 7. Positioning of piezoelectric material on ship

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REFERENCE

[1] "Generation of Electricity from Vibration of Vehicles" technical paper conducted by Radha D, Syed Zahid Ali R, Yuvaraja T.

[2] Denis O. Urroz-Montoya1, a Jeffrey R. Alverto-Suazo1, b, Julio R. García-Cabrera1, c and Cesar H Ortega-Jiménez1, "Piezoelectricity: a literature review for power generation support."

[3] Fernando Cunha Pimentel UlhOa, Pedro Americo Almeida Magalhaes Junior, Rafael Augusto de Souza Floriano, and Victor Nogueira Coutinho, "Electric Power Generation with Piezoelectricity for Cargo Ships"

[4] W. S. Vorus, Principals of Naval Architecture - Vibration, 3aed, New Jersey, USA, 1988

MARITIME SECURITY IN THE 21st CENTURY (CASE STUDY)

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***Abstract*—As international waters become a playground for geopolitics, maritime security in the 21st century has become very important. It covers multiple topics of international importance that can glorify or destroy the history of our future generations as it binds or breaks relationships between nations and communities, balances trades, and transports relief material.**

However, as feelings of competition and envy rise amongst the global powers, the oceans experience big tides, not of water but of problems like terrorism, piracy, cybercrime, illegal fishing, trade wars, and territorial disputes. This paper presents in-depth research about the cases that started a series of reactions shaping the current maritime security situation.

The paper attempts to provide solutions in the case study to fill in the lacunae causing the problem. It even includes additional information about the steps that have already been taken.

Keywords- terrorism, piracy, trade war and territorial dispute

I. INTRODUCTION

The 21st century has brought many challenges to maritime security that require a comprehensive understanding of the various threats that invade the world's oceans. Covering more than 70% of the Earth's surface, the maritime domain is an important conduit for global trade, transport and communication networks. However, this vast body of water has become increasingly vulnerable to various illegal activities, including piracy, terrorism, cybercrime and illegal fishing, which can disrupt maritime activities and threaten the safety of maritime stakeholders, which this paper aims to counter. Examining various case studies from different world regions, this study aims to provide a nuanced understanding of the evolving threats to shipping and explore possible strategies to address these challenges effectively. Piracy, a constant threat. to maritime security, continues to plague shipping lanes worldwide, endangering ships, crew and cargo. The resurgence of piracy in certain regions underlines the need for strong countermeasures and international cooperation to combat this perennial threat effectively. Similarly, terrorism has become a significant problem in the maritime sector, with terrorist organizations exploiting the marine environment to their advantage—illegal activity, including arms smuggling, human trafficking, and attacks on critical infrastructure. The asymmetric nature of maritime terrorism presents unique challenges that require a coordinated and intelligence-led response from maritime security agencies. In cybercrime, the growing digitization of maritime transport has exposed vulnerabilities that malicious actors can exploit to disrupt. maritime operations, compromise sensitive information and jeopardize the integrity of maritime systems. The growing development of cyber threats requires a proactive approach to cyber security to protect marine assets and infrastructure against cyber-attacks. Illegal, Unreported and Unregulated (IUU) fishing is a significant threat to marine ecosystems and sustainable fisheries management, with economic consequences. losses, environmental degradation and food security. The prevalence of illegal, unreported and unregulated fishing underscores the importance of strengthening marine governance frameworks, improving monitoring and enforcement capabilities, and fostering international cooperation to combat this illegal practice. The purpose of this research paper is to analyze actual events and there. consequences of the complex dynamics of maritime security challenges and emphasize the need for cooperation between governments, international organizations, and maritime stakeholders to strengthen security measures and ensure the safety of the seas. Through an in-depth review of case studies, this study aims to provide valuable insights that can help inform policy, shape maritime security strategies and contribute to maintaining a safe maritime environment in the 21st century.

II. TERRORISM

The Attacks Of 26/11

The Start

A total of 10 terrorists heavily armed with AK-47s, grenades and IEDs started their journey on the 23rd of November 2008 from the city of Karachi in the Sindh province of Pakistan.

They carried essentials like food in the form of dry fruits, biscuits and water. The food was limited, and a Pakistani vessel could not complete the journey. It will surely come under the notice of the coastguard, and navigation routes for the first time towards Mumbai shall, too, be challenging.

The method

To counter the problems, a fishing vessel named 'The Kuber' was hijacked. This vessel had a crew of 4, and the captain had previously been detained for illegal fishing by the Pakistani authorities. After the hijacking, the captain, along with another crew member, was killed, threatening the other two with the same consequence if they did not navigate to Mumbai. This gave them a mask to hide their ill wills under an innocent passage.

The result

After reaching a nearby place, the 10 of them, using a rubber tube raft, travelled as near as the gateway of India. The above went all unnoticed by the India coast guards for the following reasons

1. No daylight
2. Inadequate Surveillance
3. Intelligence failure

The paper suggests that there should be a formation of dedicated harbors under the jurisdiction of the CISF, which help out the fishermen and keep the area sanitized too, and that after sunset, the vessels shall be regulated when coming towards the crowded places, especially the markets as this opens the door to another sector of a problem called smuggling. Smuggling peaked at 2022-23 in India with around 4000 kgs of gold infiltration. Just like gold comes arms and drugs.

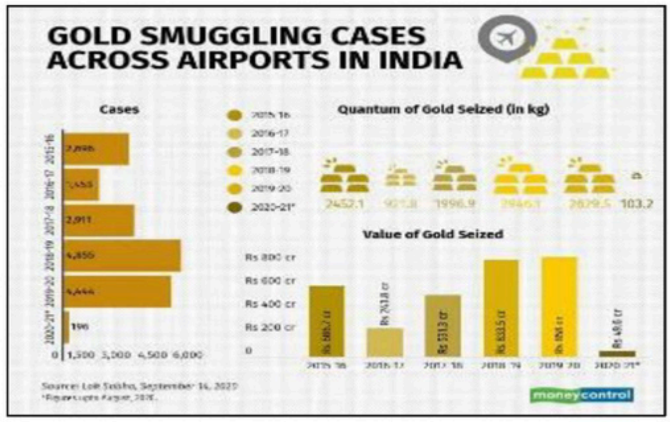

Fig. 1.Gold smuggling: More than 11,000 kg of gold worth Rs 3,122 crore seized over five years across Indian airports

The String of Pearls

In 2004, the United States Department of State published a theory about the rise of multiple ports, both civil and military, in China but outside its mainland. This mapped port route, when interconnected, created the largest and most lethal naval blockade, paralyzing the entire length of the Indian Ocean in general and India in particular.

Merchant navy of ages has been used as a lethal weapon for destruction. Though it has sailors without any arms, it, when used, can make enemies kneel and accept defeat. This is achieved by a simple naval blockade, which will stop all the supplies (including food and arms), forcing the enemy to talk. The Dutch did the first blockade against the Flemish port in 1584, and has continued till the Morden era. A close blockade entails placing warships within sight of the blockaded coast or port to ensure the immediate interception of any ship entering or leaving. It is both the most effective and the most challenging form of blockade to implement.

In a distant blockade, the blockaders stay well away from the blockaded coast and try to intercept any ships going in or out. This may require more ships on station, but they can usually operate closer to their bases and are at much less risk from enemy raids. A loose blockade is a close blockade where the blockading ships are withdrawn out of sight from the coast (behind the horizon) but no farther. The object of the loose blockade is to lure the enemy into venturing out but to stay close enough to strike. British admiral Horatio Nelson applied a loose blockade at Cádiz in 1805.

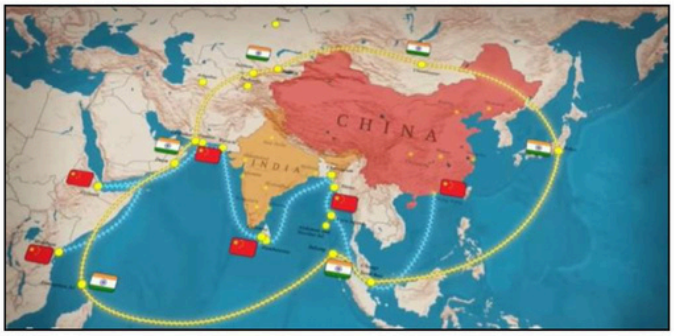

Fig. 2. String of Pearls in the Indian Ocean

III. PIRACY

Fig. 3.Yemen's Houthis hijack cargo ship in the Red Sea

On November 19, 2023,[1] Yemen's Iran-backed Houthi rebels carried out a daring hijacking operation in the Red Sea, seizing an Israeli-linked cargo ship named the Galaxy Leader. This incident has raised concerns as it occurred on a crucial shipping route and involved the taking of 25 crew members as hostages.
The key details are:

Hijacking and Motivation: The Houthi rebels claimed that they hijacked the ship due to its connection to Israel. They vowed to target any vessel in international waters linked to or owned by Israelis until the end of Israel's campaign against Gaza's Hamas rulers. Their statement emphasised that "all ships belonging to the Israeli enemy" would become legitimate targets.

Crew and Nationalities: The 25 crew [2] members held hostage on the Galaxy Leader come from various nationalities, including Bulgarian, Filipino, Mexican, and Ukrainian. Notably, no Israelis were on board the ship.

Response and Condemnation: Israeli Prime Minister Benjamin Netanyahu's office attributed the attack to the Houthis and labelled it an "Iranian act of terror." The Israeli military considered the hijacking a "very grave incident of global consequence".

Ownership and Affiliation: While Israeli officials insisted that the ship was British-owned and Japanese-operated, public shipping databases associated the ship's owners with Ray Car Carriers, founded by Israeli billionaire Abraham "Rami" Ungar. Ungar, one of the wealthiest individuals in Israel [3], refrained from commenting on the incident.

Video Evidence: A video released by the Houthis showed the helicopter-borne operation as they swiftly approached the Galaxy Leader and landed on the vessel. The rebels rappelled down from the helicopter, securing control of the ship.

This incident underscores the ongoing tensions in the region and highlights how maritime routes can become new battlegrounds for geopolitical conflicts. The fate of the crew members remains uncertain, and the international community closely monitors developments in this high-stakes situation.

Fig. 4. NYK Lines car carrier Galaxy Leader hijacked

The hijacking of the Galaxy Leader [4] by Yemen's Houthi rebels in the Red Sea carries significant implications on multiple fronts:

1. Geopolitical Tensions:
The hijacking underscores the ongoing regional tensions between Iran-backed Houthi rebels and Israel. It signifies that maritime routes are becoming new battlegrounds for geopolitical conflicts.
The rebels' targeting of an Israeli-linked ship reflects the broader Israel-Hamas war dynamics and the involvement of external actors in the Yemeni conflict.

2. Maritime Security and Trade Routes:

The Red Sea is a crucial shipping route connecting Europe, Asia, and Africa. The hijacking disrupts maritime security and raises concerns for international trade and commerce.
While navigating this strategic waterway, shipowners and operators may face increased risks and uncertainties.

3. Crew Safety and Diplomatic Efforts:
The 25 crew members held hostage are caught in the crossfire. Their safety and well-being are at stake. Diplomatic efforts will be crucial to secure their release. International actors, including the United Nations and concerned nations, may negotiate with the Houthis.
4. Israel-Iran Relations:
The hijacking is seen as an "Iranian act of terror" by Israeli Prime Minister Benjamin Netanyahu's office. It further strains relations between Israel and Iran.
Israel's response and potential retaliation could escalate tensions in the region.
5. Ownership and Accountability:
The ship's ownership complexities highlight the challenges in tracing ownership and affiliations in international shipping.
The involvement of Israeli billionaire Abraham "Rami" Ungar's company adds another layer of intrigue. Ungar's previous ship also experienced an explosion in 2021, which was attributed to Iran.
6. Global Consequences:
The hijacking is labelled a "very grave incident of global consequence" by the Israeli military. It draws international attention and may prompt responses from other nations.
The situation could impact regional stability and security dynamics in the Red Sea area.
In summary, the hijacking of the Galaxy Leader has far-reaching implications, affecting regional stability, trade, crew safety, and diplomatic efforts. The international community closely monitors developments in this high-stakes situation.

WHO WERE HOUTHIS?

Fig. 5. A Surge in Attacks: Houthi Rebels

The Houthi rebels [5], also known as Ansar Allah, are a Yemen-based armed group with a significant presence in the country's northern regions.

Origins and Ideology:
The Houthis emerged in the early 2000s as a Zaidi Shia Muslim movement advocating for greater autonomy and social justice.
Their ideology combines Zaidi's religious beliefs with anti-imperialist and anti-Western sentiments.

Conflict with the Yemeni Government:
The Houthis have conflicted with successive Yemeni governments, accusing them of marginalizing their community.
Their grievances include economic disparities, political exclusion, and social inequality.

Iranian Backing:
The Houthis receive support from Iran, which has fueled allegations of them being an Iranian proxy.
However, the extent of direct Iranian control remains a subject of debate.

Control of Territory:
The Houthis gained control over Yemen's capital, Sana'a, in 2014, leading to the ousting of President Abdrabbuh Mansur Hadi.
Since then, they have expanded their influence in northern Yemen.

Recent Piracy in the Red Sea Chronological Order: Here are some notable incidents of Houthi piracy in the Red Sea:

Mid-November 2023:
The Houthis began attacking commercial ships in the Red Sea, asserting that their actions aimed to end the war in Gaza. These assaults disrupted global shipping, prompting firms to reroute vessels around southern Africa.

January 2024:
In retaliation for Houthi offensives, the United States and the United Kingdom struck Houthi infrastructure and weaponry to degrade their military capability.
The Houthis vowed to target ships associated with the US, UK, and Israel.

Rubymar Incident:
The Rubymar, a cargo ship transiting the Red Sea from the UAE to Bulgaria, was hit by an anti-ship ballistic missile on February 18, 2024.
The ship sank on March 2nd after taking on water for nearly two weeks. It was carrying 21,000 metric tons of hazardous fertilizer.

This marked the first ship to sink in the Gulf of Aden due to Houthi strikes, with severe environmental consequences.

Ongoing Threat:
Reports confirm that the Houthis engage in extortion activities in the Red Sea, contradicting their claim of solidarity with Palestinians during the Israel-Hamas war.
The attacks pose a significant threat to commercial shipping and may continue even after the Gaza war ends.

In summary, the Houthi rebels' piracy in the Red Sea disrupts global commerce, raises security concerns, and highlights the complex dynamics of regional conflicts and maritime security.

The Red Sea region has a long history of maritime conflicts shaped by geopolitical tensions, territorial disputes, and security challenges. Here are some key points:

1. Houthi Attacks and Somali Piracy:
Since November 2023, Yemen's Houthi militia has been involved in a series of attacks on shipping in the Red Sea. These incidents include missile and armed drone strikes on vessels and hijackings by Somali pirates.
One hundred thirty-three reported incidents have occurred, with 14 vessels struck by missiles or drones and 18 vessels hijacked. These nonstate actors operate outside international law and have access to standoff armaments, posing fundamental challenges to regional security and economic development.

2. Impact on Maritime Stability:
The attacks have disrupted shipping from the Red Sea through the Gulf of Aden to the Western Indian Ocean—a route through which 25% of global shipping traffic flows.
Due to these incidents, African citizens face delays, higher consumer goods prices, disruptions to local economies, and polluted waterways.
Global shipping companies have diverted routes from the Red Sea, affecting trade between Asia and Europe.

3. Economic Fallout:
Insurance premiums for shipping have surged, raising costs for consumers worldwide.
Diversions of ships around South Africa can add up to 2 weeks and 6,000 extra nautical miles to a vessel's journey.
Uncertainty over energy flows and freight impacts countries dependent on imports, affecting business environments.
Egypt's annual revenues from tolls on vessels using the Suez Canal are also at risk.

Figure. 6. Piracy regions

4. Environmental Consequences:
Debris generated by attacks and responses has polluted the waters and marine ecosystems along Africa's Red Sea coastline.
The 57 million East Africans facing acute food insecurity, including refugees and internally displaced people, are directly affected as food supplies flow via the Red Sea.

5. Geopolitical Tensions:
The Red Sea region grapples with territorial claims, maritime boundaries, and regional dominance disputes.
These issues pose a significant risk to maritime stability, potentially leading to blockades and restrictions.
Due to ongoing maritime conflicts, the Red Sea region faces complex security, trade, and environmental challenges. The international community closely monitors developments in this critical area.

Measures should be taken to enhance security:

1. International Cooperation and Surveillance:
International organizations, including the International Maritime Organization (IMO), closely monitor incidents in the Red Sea area. They collaborate with regional governments and naval forces to enhance surveillance and response capabilities.
Joint patrols by naval forces from different countries help deter piracy and monitor shipping routes.

2. Naval Presence and Escort Services:
Naval vessels from various nations patrol critical areas to safeguard commercial ships. These patrols provide a visible deterrent against piracy and other threats.
Some countries offer escort services for merchant vessels through high-risk zones, ensuring safe passage.

3. Information Sharing and Reporting:
Shipping companies and vessel operators receive regular updates on security threats and incidents in the Red Sea. As a

result, they can adjust their routes and take necessary precautions.
Reporting mechanisms allow ships to share information about suspicious activities or potential threats.

4. Best Management Practices (BMP):
The BMP guidelines advise shipowners, operators, and crews on preventing piracy attacks. These include increasing vigilance, enhancing onboard security, and maintaining communication with naval authorities.

5. Armed Security Teams:
Many commercial vessels employ armed security teams to protect against piracy. These teams deter attackers and respond if necessary.
However, using armed guards is complex, and regulations vary by country.

6. Regional Cooperation and Capacity Building:
Countries in the Red Sea region collaborate to strengthen their maritime security capabilities.
Training programs enhance the skills of Coast Guard personnel, improve surveillance systems, and promote information sharing.

7. Legal Frameworks and Prosecution:
Establishing clear legal frameworks allows for the prosecution of pirates and hijackers.
International agreements facilitate the transfer of arrested pirates to countries where they can face trial.

8. Infrastructure Development:
Developing port facilities and coastal infrastructure improves security and response times.
Enhanced communication networks enable faster coordination during emergencies.

9. Public Awareness and Education:
Raising awareness among seafarers about security risks and preventive measures is crucial.
Crew training programs emphasize situational awareness and emergency protocols.

10. Regional Stability and Conflict Resolution:
Addressing underlying conflicts and political tensions in the region contributes to long-term stability.
Diplomatic efforts to resolve disputes can reduce security risks.
In summary, a combination of international cooperation, naval presence, information sharing, legal frameworks, and capacity building enhances maritime security in the Red Sea area. However, ongoing vigilance and adaptability are essential to address evolving threats.

IV. CYBERSECURITY

The Maersk Shipping Company's NotPetya Ransomware Nightmare

Fig. 7-A.P. Møller - Mærsk A/S — cyber-attack update

In the fast-paced world of global shipping, where massive vessels transport goods across oceans, the last thing anyone expects is a cyberattack capable of crippling an entire logistics giant. Yet, that's precisely what happened to Moller-Maersk[6], the world's largest container shipping firm, on June 27, 2017.

The Unintended Victim
Maersk was caught in the crossfire of the NotPetya ransomware attack. NotPetya, initially designed by the Russian military as a disk-wiping cyber weapon, quickly spiraled out of control. It leveraged the leaked Eternal Blue hacking tool (the same exploit behind the infamous WannaCry outbreak) and targeted businesses in Ukraine. But its impact extended far beyond Ukrainian borders.

The Devastating Impact
Headquartered in Denmark, Maersk operates hundreds of sites worldwide. Its massive ships, each carrying up to 20,000 containers, arrive at ports worldwide every 15 minutes. When NotPetya struck, Maersk found itself with nearly 50,000 infected endpoints and thousands of compromised applications and servers across 600 sites in 130 countries.
The severity of the attack became apparent as banks of screens in Maersk offices turned black. The company faced a dual challenge: maintaining normal business operations despite lacking IT infrastructure and rebuilding networks. The recovery process was a manual, labour-intensive effort spanned approximately 10 days. During this time, Maersk's resilience was tested as it balanced the need to continue operating with the urgent task of rebuilding.

The Human Resilience Factor

Lewis Woodcock, head of cybersecurity compliance at Maersk, vividly recalls the chaos: "There was a moment of disbelief, initially, at the sheer ferocity and the speed and scale of the attack and the impact it had." The financial toll was staggering, estimated at up to $300 million [7] in losses due to the serious business interruption.

Maersk's recovery operation heavily relied on human resilience. Employees worked tirelessly to rebuild the IT infrastructure, piece by piece. The company's commitment to maintaining normal business operations during this crisis was unwavering.

Fig. 8-Cyberattack cost Maersk as much as $300 million and disrupted operations for 2 weeks

Key Lessons Learned

1. Protection and Recovery: Maersk learned that robust protection measures are essential, but equally critical is a strong recovery process. Having a well-defined plan for rebuilding after an attack is crucial.
2. Global Impact: NotPetya demonstrated how interconnected our world is. An attack targeting one region can quickly spread globally, affecting organizations far beyond the intended victims.
3. Human Resilience: Amid the chaos, the determination and resilience of Maersk's employees kept the company afloat. Technology alone cannot save the day; human adaptability and determination are vital.

Conclusion

The NotPetya attack was a wake-up call for Maersk and the shipping industry. It highlighted the need for continuous vigilance, robust cybersecurity practices, and a strong recovery strategy. Maersk's experience is a cautionary tale, reminding us that even the mightiest vessels can be brought to their knees by lines of malicious code.

During the NotPetya ransomware attack, Maersk's shipping operations faced severe disruptions and challenges:

1. Operational Halts:
Maersk's IT infrastructure was compromised, leading to widespread system outages [8].
Critical operations, including cargo tracking, booking, and vessel scheduling, stopped.

2. Manual Processes:
With digital systems down, Maersk had to resort to manual processes.
Employees manually tracked shipments, communicated with ports, and managed logistics.

3. Port Delays and Backlogs:
Ports worldwide experienced delays due to Maersk's inability to process cargo efficiently.
Containers piled up at terminals, causing congestion and logistical challenges.

4. Customer Impact:
Customers faced uncertainty as shipments were delayed or rerouted.
Maersk's reputation took a hit, and customer trust was tested.

5. Financial Losses:
The attack resulted in significant financial losses, estimated at up to $300 million.[9]
Revenue streams were disrupted, and recovery costs were substantial.

6. Supply Chain Disruptions:
Maersk's supply chain partners were affected, including trucking companies and warehouses.
The ripple effect impacted global trade and supply chains.

7. Rebuilding Efforts:
Maersk's resilience was evident as employees worked tirelessly to rebuild networks.
The recovery process involved reinstalling thousands of servers and endpoints.
In summary, the NotPetya attack severely impacted Maersk's shipping operations, highlighting the vulnerability of critical infrastructure to cyber threats.

The maritime industry faced a series of cyberattacks during the same period. Notably, all four of the world's largest shipping companies were hit by significant cyber incidents:

1. Maersk:
Maersk suffered a devastating NotPetya ransomware attack in 2017.
The attack disrupted operations, led to substantial financial losses, and highlighted vulnerabilities in the shipping industry.

2. Mediterranean Shipping Company (MSC):
MSC, another major shipping conglomerate, faced cyber threats during this period.

Specific details about the attack on MSC were not provided, but it underscores the industry's vulnerability.

3. CMA CGM:
CMA CGM, a global shipping giant, experienced cyber incidents.
While details are not specified, the company's operations were likely affected.

4. COSCO (China Ocean Shipping Company):
COSCO Group, a major Chinese shipping company, was also hit by cyberattacks.
The incident demonstrates that the entire industry needs to bolster its cybersecurity defenses.
In summary, the maritime industry faced a wave of cyber threats during this period, emphasizing the need for better protection and resilience against digital disruptions.
Collaboration among shipping companies to address cybersecurity challenges has become increasingly crucial in the face of growing threats. These companies have worked together in various ways:

1. Industry Forums and Associations:
Shipping companies participate in industry forums, conferences, and associations focused on cybersecurity.
These platforms allow them to share best practices, discuss emerging threats, and collaborate on solutions.

2. Information Sharing and Threat Intelligence:
Companies exchange threat intelligence and share insights about cyber incidents.
Collaborative efforts help identify common attack patterns and vulnerabilities.

3. Joint Exercises and Drills:
Shipping companies conduct joint cybersecurity exercises and drills.
These simulations test incident response capabilities and enhance coordination during real-world incidents.

4. Standardization and Guidelines:
Industry bodies develop cybersecurity standards and guidelines.
Companies adopt these frameworks to align their security practices and improve overall resilience.

5. Supply Chain Security:
Companies collaborate with suppliers, vendors, and partners to enhance supply chain security.
Ensuring third-party compliance with cybersecurity measures is critical.

6. Incident Response Coordination:
In case of a cyber incident, companies coordinate response efforts.
Sharing lessons learned helps prevent similar attacks in the future.

7. Government and International Cooperation:
Shipping companies engage with government agencies and international bodies.
Collaborative efforts address cross-border threats and regulatory compliance.

8. Threat-Sharing Platforms:
Companies use threat-sharing platforms to report incidents and receive timely alerts.
These platforms foster collective defenses against cyber threats.

9. Education and Training:
Companies invest in employee training and awareness programs.
Educated staff are better equipped to recognize and mitigate cyber risks.

10. Mutual Assistance Agreements:
Some companies establish mutual assistance agreements. They pledge to support each other during crises, including cyber incidents.
In summary, shipping companies collaborate through various channels to enhance cybersecurity resilience. Collective efforts strengthen the industry's ability to combat evolving threats and protect critical infrastructure.[10]

V. ILLEGAL FISHING

IUU Fishing: A Maritime Security Threat Requiring Unique Solutions

Fig.9. Illegal fishing

Illegal, unregulated, and unreported (IUU) fishing poses a significant risk to maritime security. This clandestine activity has far-reaching consequences, impacting not only the health of our oceans but also global stability. Here's why IUU fishing demands unique solutions:

1. Complex Impacts:
IUU fishing is linked to a range of issues, including overfishing, coastal destabilization, piracy, food insecurity, environmental degradation, labor violations, drug smuggling, and transnational criminal organizations.[11]
Its multifaceted impact requires a comprehensive approach.

2. Whole-of-Government Approach:
The U.S. government recognizes IUU fishing as one of the greatest threats to ocean health.
A whole-of-government approach involves maritime law enforcement agencies taking the lead in combating IUU fishing.

3. Lessons from the War on Drugs:
While IUU fishing shares similarities with drug smuggling (tracking bad actors, intelligence sharing, and cooperation with partner nations), it requires tailored solutions.
Fish and illegal drugs are vastly different commodities, and their business models differ significantly.

4. Unique Business Model:
IUU fishing ventures can be disrupted more easily than cocaine smuggling operations.
The pressure needed to stop an illegal fishing venture is much lower than that required for a drug smuggler.
IUU fishing court cases are challenging due to jurisdictional restrictions and legal complexities.

5. Taking Advantage of Weaknesses:
IUU Fishing's unique business model allows for targeted interventions.
Exploiting its weaknesses can lead to more effective outcomes.
Unlike drugs, fish lose value rapidly, disrupting illegal fishing ventures easier.

6. Defining Success:
Success in counter-IUU fishing activities may not always involve convictions.
Stopping illegal activity and deterring bad actors can be considered successful outcomes.

7. Building Court Cases:
Building IUU fishing court cases is notoriously tricky.
Jurisdictional limitations and legal complexities make convictions challenging.
However, dealing with fish (not drugs) provides advantages in this fight.

In summary, IUU fishing demands tailored solutions that leverage its unique vulnerabilities. By understanding its distinct business model, we can protect our oceans and enhance maritime security.

(IUU) fishing has significant implications for the merchant navy sector.:

1. Navigational Hazards:
IUU fishing vessels often operate without proper navigation lights or AIS (Automatic Identification System) signals.
Merchant ships encounter these unmarked vessels, leading to navigational risks and potential collisions.

2. Interference with Shipping Routes:
IUU fishing vessels may drift into established shipping lanes.
This disrupts the smooth flow of maritime traffic and poses safety hazards.

3. Increased Surveillance and Reporting Burden:
Merchant navy vessels are increasingly tasked with monitoring and reporting IUU fishing activities.
This diverts attention from their primary responsibilities and adds to operational challenges.

4. Resource Depletion and Food Security:
IUU fishing depletes fish stocks, affecting the availability of seafood.
Reduced fish populations impact food security for seafarers and coastal communities.

5. Economic Impact:
IUU fishing undermines legitimate fishing operations.
It affects the livelihoods of legal fishermen and the economic viability of the fishing industry.

6. Environmental Consequences:
IUU fishing contributes to overfishing and ecosystem degradation.
Merchant ships witness firsthand the impact on marine biodiversity and habitats.

In summary, IUU fishing affects the merchant navy sector by posing navigational risks, increasing surveillance burdens, and impacting food security and economic stability.

Merchant navy vessels are crucial in collaborating with maritime law enforcement agencies to combat IUU fishing. Here are several ways they can enhance cooperation:

1. Information Sharing and Reporting:
Merchant navy vessels should promptly report any suspicious activities related to IUU fishing to relevant authorities.
Sharing real-time information on vessel sightings, locations, and suspicious behavior helps law enforcement agencies take swift action
.
2. AIS Monitoring and Verification:
Merchant ships can assist by monitoring Automatic Identification System (AIS) signals from nearby vessels.
Verifying the legitimacy of AIS data helps identify IUU fishing vessels.

3. Collaborative Patrols and Surveillance:
Joint patrols involving merchant navy vessels and law enforcement agencies enhance surveillance capabilities.
Coordinated efforts increase the chances of detecting and intercepting IUU fishing vessels.

4. Training and Awareness:
Merchant navy crews should receive training on recognizing signs of IUU fishing.
Awareness programs help seafarers understand the importance of reporting suspicious activities.

5. Leveraging Technology:
Merchant ships equipped with radar, infrared cameras, and satellite communication can contribute to IUU fishing detection.
Sharing data from onboard technology enhances overall situational awareness.[12]

6. Participating in Regional Agreements:
Merchant navy vessels should adhere to regional agreements and protocols related to IUU fishing.
Cooperation within established frameworks strengthens enforcement efforts.

7. Supporting Port State Measures:
When merchant ships dock at ports, they can assist in verifying catch documentation and inspecting vessels suspected of IUU fishing.
Compliance with port state measures contributes to global efforts.

8. Advocacy and Public Awareness:
Merchant navy companies can advocate for stronger regulations and enforcement against IUU fishing.
Raising public awareness about the impact of IUU fishing encourages collective action.
In summary, merchant navy vessels, as eyes and ears on the seas, can collaborate effectively with law enforcement agencies to combat IUU fishing. Their active participation contributes to ocean conservation and sustainable fisheries.

Success stories where merchant navy vessels helped apprehend IUU fishing operators

Here are some success stories where merchant navy vessels collaborated with maritime law enforcement agencies to apprehend IUU fishing operators:

1. ScanEagle's Role in Identifying Chinese Vessels:
The U.S. Coast Guard (USCG) employs ScanEagle unmanned aircraft systems (SUAS) equipped with advanced optical and AI payloads.
In 2020, ScanEagle played a crucial role in identifying over 35 Chinese vessels illegally fishing off the coast of the Galapagos Islands, a UNESCO World Heritage Site.
These unmanned systems helped locate, surveil, and track otherwise undetectable fishing vessels during day and night, even in austere conditions.

2. Indo-Pacific Maritime Security Exchange:
The 2021 Indo-Pacific Maritime Security Exchange, conducted virtually from Hawaii, focused on IUU fishing.
Participants discussed global IUU fishing challenges and shared strategies to combat illegal fishing activities.
Such exchanges foster collaboration among maritime stakeholders.

3. Indian Navy Monitoring Chinese Fishing Vessels:
The Indian Navy closely monitored more than 200 Chinese fishing vessels in the Indian Ocean.
Despite growing IUU fishing beyond the Exclusive Economic Zone (EEZ), the Indian Navy actively tracked and reported these vessels.
Their vigilance helps protect marine resources and enforce regulations.

In summary, these success stories demonstrate how merchant navy vessels, in collaboration with law enforcement agencies, contribute to combating IUU fishing. Their vigilance, technology adoption, and reporting play a vital role in protecting our oceans and ensuring sustainable fisheries.

Legal Measures to Combat IUU Fishing

IUU fishing is a global challenge that depletes fish stocks, harms marine ecosystems, and undermines local communities.[13] To address this issue, governments and international bodies have implemented legal actions against IUU fishing operators.
Here are some key measures:

1. Denying Support Services:
Governments should make the provision of support services (such as vessel maintenance, fuel bunkering, insurance, and

satellite communication) to any IUU fishing vessel illegal, regardless of flag or location.
By cutting off critical resources, IUU fishing operations become less viable.

2. Information Sharing and Cooperation:
Governments must share information on IUU fishing vessels with other nations, relevant entities, and businesses providing services to fishing vessels.
Enhanced cooperation ensures a coordinated response against IUU fishing.

3. Due Diligence by Businesses:
Businesses that provide services to fishing vessels should improve due diligence.
Ensuring they do not support any IUU fishing vessels is crucial.
Starting with vessels listed on the Combined IUU Fishing Vessel List helps prevent inadvertent support.

4. Penalizing Service Providers:
Governments should penalize service providers who support vessels confirmed to have engaged in IUU fishing.
Sufficient penalties act as a deterrent against supporting illegal fishing operations.

5. Beneficial Ownership Disclosure:
Requiring vessels flying their flag or accessing their waters to state their beneficial owners enhances transparency.
Knowing the true owners helps track IUU fishing operators.

In summary, these legal actions aim to disrupt IUU fishing operations by targeting their access to critical services, improving transparency, and enforcing penalties. By implementing these measures, we can protect marine resources and promote sustainable fishing practices.

References

[1] Ap, "Yemen's Houthi rebels hijack India-bound, Israeli-linked ship in the Red Sea; 25 crew members held hostage," The Hindu, https://www.thehindu.com/news/international/yemens-houthi-rebels-hijack-india-bound-israeli-linked-ship-in-the-red-sea-25-crew-members-held-hostage/article67553187.ece. (accessed Apr. 18, 2024).

[2] "Houthi rebels hijack India-bound ship in the Red Sea, crew taken hostage," English.Mathrubhumi, https://english.mathrubhumi.com/news/world/houthi-rebels-hijack-india-bound-ship-in-the-red-sea-crew-taken-hostage-1.9088473. (accessed Apr. 18, 2024).

[3] Ap, "Yemen's Houthi rebels hijack Israeli-linked India-bound ship in Red Sea, take 25 crew members hostage," hijack | Yemen's Houthi rebels hijack Israeli-linked India-bound ship in Red Sea, take 25 crew members hostage - Telegraph India, https://www.telegraphindia.com/world/yemens-houthi-rebels-hijack-israeli-linked-india-bound-ship-in-red-sea-take-25-crew-members-hostage/cid/1981202 (accessed Apr. 15, 2024).

[4] "Yemen's Houthis release video of hijacking India-bound ship, threatening crew," India Today, https://www.indiatoday.in/world/story/yemen-houthis-rebels-india-bound-cargo-ship-turkey-hijacked-crew-threatened-iran-israel-hamas-war-2465550-2023-11-21. (accessed Apr. 15, 2024).

[5] A. Banerjee, "Yemen's Houthi rebels hijack India-bound cargo ship on Red Sea, confirm US officials," English, https://www.indiatvnews.com/news/world/yemen-s-houthi-rebels-hijack-india-bound-cargo-ship-on-red-sea-confirm-us-officials-israel-hamas-war-idf-netanyahu-latest-updates-2023-11-20-903524 (accessed Apr. 14, 2024).

[6] "Cyber-attack update," A.P. Møller - Mærsk A/S, https://investor.maersk.com/news-releases/news-release-details/cyber-attack-update (accessed Apr. 15, 2024).

[7] D. E. Capano, "Throwback attack: How notpetya ransomware took down Maersk," Industrial Cybersecurity Pulse, https://www.industrialcybersecuritypulse.com/threats-vulnerabilities/throwback-attack-how-notpetya-accidentally-took-down-global-shipping-giant-maersk/ (accessed Apr. 15, 2024).

[8] "Cyberattack cost Maersk as much as $300 million and disrupted operations for 2 weeks," Los Angeles Times, https://www.latimes.com/business/la-fi-maersk-cyberattack-20170817-story.html (accessed Apr. 17, 2024).

[9] P. J. 28, "Maersk's cargo operations hit hard by Cyberattack," The Maritime Executive, https://maritime-executive.com/article/maersks-cargo-operations-hit-hard-by-cyberattack (accessed Apr. 12, 2024).

[10] "US accuses Russians for malware linked to cyber-attack on Maersk," Lloyd's List, https://lloydslist.com/LL1134337/US-accuses-Russians-for-malware-linked-to-cyber-attack-on-Maersk (accessed Apr. 14, 2024).

[11] Illegal fishing " world ocean review (no date) World Ocean Review. Available at: https://worldoceanreview.com/en/wor-2/fisheries/illegal-fishing/#:~:text=ILLEGAL%20FISHING%20refers%20to%20fishing,of%20the%20state's%20protected%20areas. (Accessed: 11 April 2024).

[12] Illegal fishing and transparency (2024) Oceana USA. Available at: https://usa.oceana.org/our-campaigns/illegal-fishing-and-transparency/ (Accessed: 12 April 2024).

[13] Fisheries, N. (no date) Understanding illegal, unreported, and unregulated fishing, NOAA. Available at: https://www.fisheries.noaa.gov/insight/understanding-illegal-unreported-and-unregulated-fishing (Accessed: 15 April 2024).

A REVIEW OF GLOBAL SANCTION AND THEIR IMPACTS ON MARINE INDUSTRIES

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***Abstract*:**

Global sanctions, a tool employed by governments and international bodies like OSCE (Organization for Security and Cooperation in Europe), UN (United Nations), SDN (Specially Designated Nationals), EU (European Union), etc. to influence or penalize specific nations, entities, or individuals, have a profound impact on various sectors of the global economy. This paper delves into the intricate relationship between global sanctions and the shipping industry, analyzing the multifaceted consequences faced by shipping companies, seafarers, and international trade. By examining case studies, policy frameworks, and RWE (Real World Examples), this paper sheds light on the challenges and opportunities that emerge in the wake of sanctions, emphasizing the need for adaptive strategies and international cooperation within the shipping sector. In the subsequent sections, the paper will dissect specific case studies, assess the challenges faced by the shipping industry, explore potential strategies for mitigating sanctions-related risks, and advocate for collaborative efforts on a global scale. Through this comprehensive analysis, the paper aims to contribute valuable insights to policymakers, industry stakeholders, and researchers, fostering a deeper understanding of the intricate relationship between sanctions and the global shipping landscape.

Keywords— *Sanction, shipping companies, seafarers, international trade and RWE*

ABBREVATION

Automatic Identification System	AIS
European Union	EU
International Maritime Organisation	IMO
Organization for Security and Cooperation in Europe	OSCE
Real World Examples	RWE
Specially Designated Nationals	SDN
United Nations	UN
United Nations Security Council	UNSC

I. INTRODUCTION

The intricate web of international relations is often woven with threads of sanctions, a powerful instrument employed by nations and international bodies to exert influence, address security concerns, or promote diplomatic agendas [1]. Among the various sectors affected by these measures, the shipping industry stands as a crucial linchpin in the global economy [2-3]. Ships, the backbone of international trade, ferry goods, resources, and people across oceans, connecting nations and fueling economic growth. However, when sanctions are imposed, the ripples extend far beyond the targeted entities, creating challenges and complexities for the entire maritime ecosystem [3-5].

The modern shipping industry forms the cornerstone of globalization, enabling the seamless exchange of goods and services across continents. From consumer goods to raw materials, nearly every product traverses the seas, underscoring the interdependence of nations in the global marketplace [6-7]. In this interconnected network, disruptions caused by sanctions resonate far beyond the specific regions or entities targeted, affecting supply chains, economies, and the livelihoods of millions of people involved in the shipping industry [7-10].

This paper is divided into six Sections. In Section II, global sanction is introduced with League of Nations, United Nations and Bilateral Sanctions, Proliferation of Sanctions, and Targeted Sanctions and International Cooperation. In Section III and IV, Types and Objectives of Global Sanctions and Case Studies are presented. In Section V, International Cooperation and Policy Frameworks are highlighted. Lastly, this paper provides concluding remarks in Section VI.

II. Background of Global Sanctions: A Historical Perspective

Global sanctions, as a diplomatic and economic tool, have deep historical roots, evolving alongside the development of international relations and the establishment of modern nation-states. The concept of sanctions can be traced back to ancient civilizations, where city-states and empires-imposed trade embargoes, blockades, and other forms of economic restrictions on rival entities. However, the systematic and widespread use of sanctions as a tool of statecraft gained prominence in the 20th century [9-12].

A. Post-World War I Era: League of Nations

After World War I, the League of Nations, the precursor to the United Nations, emerged as the first international organization tasked with maintaining peace and preventing conflicts. The League imposed economic sanctions against aggressor nations, most notably Italy after its invasion of Ethiopia in 1935. These early attempts at collective security laid the groundwork for future international sanctions regimes [13-15].

B. Cold War Era: United Nations and Bilateral Sanctions

During the Cold War, both the United States and the Soviet Union utilized economic sanctions to exert influence over other nations. The United Nations Security Council, established after World War II, became a key platform for implementing multilateral sanctions. For instance, sanctions were imposed on Rhodesia (now Zimbabwe) in the 1960s and South Africa in the 1980s due to apartheid policies [14-16].

C. Post-Cold War Era: Proliferation of Sanctions

With the end of the Cold War, the use of sanctions became more frequent and complex. The UN Security Council imposed sanctions on Iraq in the 1990s following its invasion of Kuwait, leading to significant humanitarian consequences. In the same period, the United States and the European Union imposed sanctions on countries like Cuba and Iran, reflecting both geopolitical tensions and human rights concerns [15-17].

D. 21st Century: Targeted Sanctions and International Cooperation

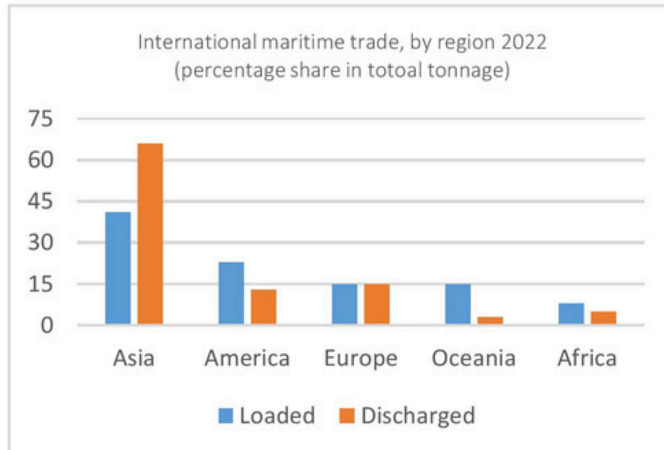

Fig.1 International maritime trade

In the 21st century, there was a shift towards targeted sanctions aimed at specific individuals, entities, or sectors, rather than entire nations. This approach was designed to minimize adverse humanitarian effects on civilian populations. The United Nations, regional organizations, and individual countries have used targeted sanctions in response to various issues, including terrorism, nuclear proliferation, human rights abuses, and cyber-attacks [16-18]. The international maritime trade by region 2022 is represented in Fig.1.

III. Types and Objectives of Global Sanctions

A. Economic Sanctions

Economic sanctions, a cornerstone of modern diplomacy, are punitive measures imposed by one or more countries or international organizations to coerce a targeted nation, entity, or individual into changing specific behaviors. These sanctions are multifaceted, ranging from trade restrictions and asset freezes to financial penalties. While their primary purpose is to influence political decisions, economic sanctions have far-reaching implications that extend to economic, social, and geopolitical realms [17-20].

B. Trade Sanctions:

Trade sanctions are punitive measures imposed by one or more countries to limit or completely halt the import and/or export of goods and services to and from a targeted nation. These sanctions are often imposed for various reasons, such as human rights violations, national security concerns, or violations of international law. Trade sanctions can include tariffs, import quotas, or outright bans on specific goods and can significantly impact the economy of the targeted country. They aim to weaken the targeted nation's economic stability, thereby coercing it into changing its behavior in line with international norms [14-15].

C. Arms Embargoes and Dual-Use Goods:

Arms embargoes and restrictions on dual-use goods serve as critical components of international sanctions, especially in cases where nations are involved in armed conflicts, aggressive military actions, or human rights abuses. Arms embargoes prohibit the sale, supply, transfer, or export of military equipment and related services to the targeted country. Dual-use goods are items that have both civilian and military applications [16-18]. Restricting these goods prevents the targeted nation from acquiring technologies that could be used for military purposes, ensuring regional and international security.

D. Targeted Sanctions against Individuals and Entities:

Targeted sanctions zero in on specific individuals, organizations, or entities rather than entire nations. These measures can include freezing assets, travel bans, and arms embargoes imposed on individuals, companies, or government entities involved in activities that violate international law, threaten peace, or undermine human rights. By pinpointing key actors responsible for objectionable actions, targeted sanctions aim to apply pressure precisely where it is needed, without causing unnecessary harm to the broader population [19-21]. This approach reflects a nuanced strategy in the realm of international diplomacy, allowing for tailored responses to specific incidents or behaviors. The World's most sanctioned countries data as per December 2023 is shown in Fig.2.

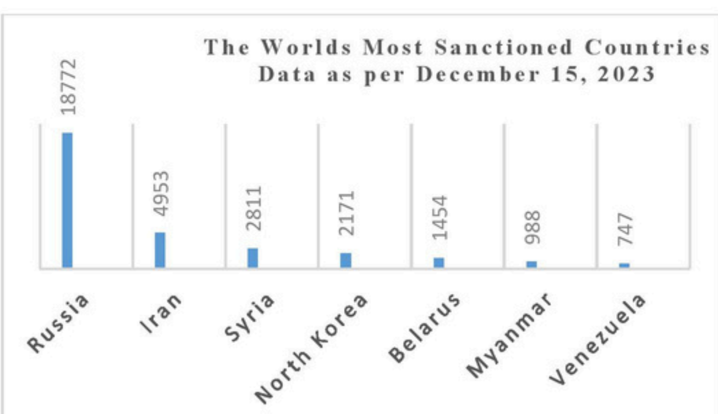

Fig.2 World most sanctioned countries

IV. Case Studies: Impact of Sanctions on Shipping

A. Iran Sanctions and Maritime Trade in the Persian Gulf

Iran, a prominent player in the Middle East, has long been a subject of international sanctions due to concerns over its nuclear program, regional influence, and human rights practices. These sanctions have had a significant impact on maritime trade in the Persian Gulf region, a vital hub for global energy supplies and trade routes. The intersection of Iran's strategic location, the importance of the Persian Gulf, and the imposition of sanctions has created a complex geopolitical challenge with far-reaching consequences for international trade and regional stability [14-20].

A.I. Historical Context:

- Nuclear Program Sanctions: International sanctions, particularly from the United Nations Security Council and the United States, targeted Iran's nuclear program, restricting its economic activities and international trade.
- Impact on Maritime Trade: Sanctions led to disruptions in maritime trade, affecting Iranian shipping companies, oil exports, and the flow of goods through the Persian Gulf.

A.2. Oil Exports and Tanker Traffic:

- Strategic Chokepoint: The Persian Gulf is a crucial chokepoint for global oil supplies, with a significant portion of the world's oil passing through the Strait of Hormuz, which is bordered by Iran.
- Sanctions and Oil Exports: Sanctions limited Iran's ability to export oil, reducing tanker traffic in the region and impacting the economies of neighboring countries dependent on energy exports.

A.3. Economic Challenges and Responses:

- Economic Strain: Sanctions resulted in economic challenges, including inflation, unemployment, and a depreciating currency, affecting the overall stability of the region.
- Diversification Efforts: In response to sanctions, Iran pursued efforts to diversify its economy, focusing on non-oil sectors and seeking trade partnerships with countries less affected by sanctions.

In conclusion, the impact of Iran sanctions on maritime trade in the Persian Gulf underscores the intricate interplay between geopolitics, economics, and global energy security. As negotiations and diplomatic efforts continue, the future of maritime trade in this region remains uncertain, necessitating careful analysis and strategic planning for international stakeholders involved in trade and energy transit through these vital waters.

B. North Korea Sanctions: Curbing Illicit Ship-to-Ship Transfers

North Korea, due to its nuclear ambitions and international tensions, has faced a series of sanctions imposed by the United Nations Security Council (UNSC) and individual nations. One challenge addressed by these sanctions is the issue of illicit ship-to-ship transfers. These clandestine operations involve North Korean vessels transferring goods, including oil and coal, to other ships on the high seas, bypassing sanctions and generating revenue for the regime. Efforts to curb these transfers have become a focal point in international efforts to enforce sanctions and maintain regional stability.

B.1. UNSC Resolutions and Sanctions:

- Targeted Measures: UNSC resolutions have imposed specific sanctions on North Korean vessels involved in illicit activities, including asset freezes and travel bans on individuals associated with these ships.
- Prohibition of Transfers: Resolutions have explicitly prohibited member states from facilitating ship-to-ship transfers to or from North Korean-flagged vessels, aiming to cut off this revenue stream.

B.2. Challenges in Enforcement:

- Detection and Identification: Illicit ship-to-ship transfers are conducted covertly, making detection challenging. North Korean vessels often disguise their identity, using false flags or turning off their Automatic Identification System (AIS) transponders.
- Regional Cooperation: Cooperation between regional states, international organizations, and naval forces is essential to effectively monitor and interdict suspicious vessels.

B.3. Technological Solutions and Surveillance:

- Satellite Surveillance: Satellite imagery and aerial surveillance are crucial tools in monitoring ship movements. These technologies can identify suspicious activities and track vessels engaged in illicit transfers.
- AIS Monitoring: Enhancing AIS monitoring capabilities and ensuring vessels comply with international regulations regarding AIS usage can help improve transparency in maritime activities.

C. Russian Sanctions and the Black Sea Shipping Routes

Western sanctions punishing Russia for its invasion of Ukraine are reorganizing global trade along political lines, defying geography and efficiency. This new reality is creating a windfall for merchant shipping, but risks creating higher prices for European consumers and hunger for Africa.

The imposition of sanctions on Russia by various countries and international organizations has significantly impacted shipping routes in the Black Sea region, a critical area for global trade and energy transportation. These sanctions, driven by geopolitical tensions and concerns over Russia's actions in neighboring countries, have led to challenges and complexities for maritime trade, affecting not only Russia but also the countries bordering the Black Sea and those relying on its strategic maritime routes. Fig.3 represents the percentage of global seaborne trade from Russia by cargo quantity by 2021 and Fig.4 represents the global seaborne trade growth by2022.

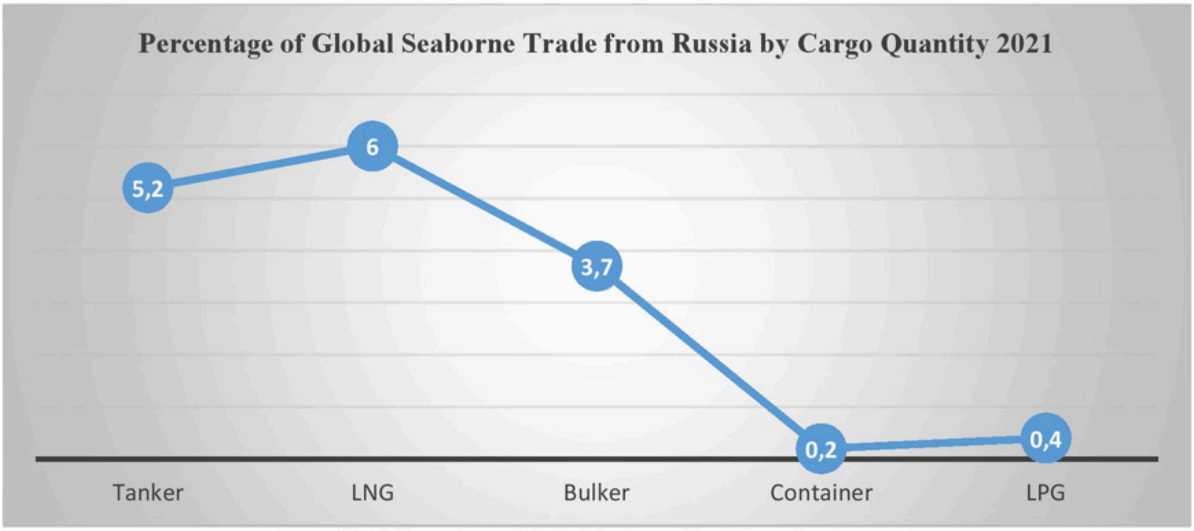

Fig.3 Percentage of Global Seaborne Trade from Russia

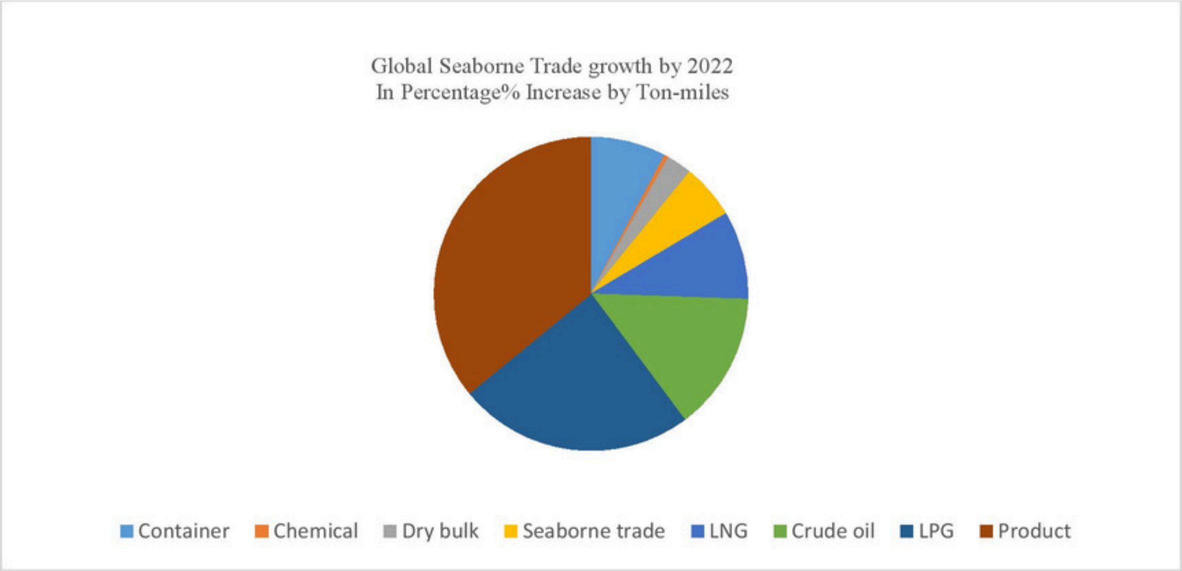

Fig.4 Percentage of Global Seaborne Trade growth by 2022

C.1. Impact on Russian Ports and Shipping Companies:

- Economic Strain: Russian ports and shipping companies faced economic strain due to sanctions, limiting their access to international financial markets, technology, and investments necessary for modernizing infrastructure and vessels.
- Operational Challenges: Sanctions led to operational challenges for Russian ships, including higher insurance premiums, difficulties in obtaining necessary certifications, and restrictions on access to certain ports.

C.2. Challenges for Neighboring Countries:

- Trade Disruptions: Countries bordering the Black Sea, such as Ukraine and Georgia, faced disruptions in their trade activities due to sanctions affecting transit routes and the flow of goods.
- Energy Transport: The Black Sea is a crucial route for transporting energy resources, and disruptions in this region affected the energy security of European countries reliant on natural gas and oil supplies from Russia.

C.3. Impact on International Shipping Companies:

- Navigational Challenges: International shipping companies faced navigational challenges, as sanctions led to increased scrutiny and changing regulations in the Black Sea. Compliance with evolving sanctions measures required constant monitoring and adjustment of shipping routes.
- Diversification Efforts: Shipping companies sought to diversify their routes, reducing dependency on the Black Sea region to mitigate the risks associated with sanctions-related uncertainties.

V. International Cooperation and Policy Frameworks:

Navigating the complexities of global sanctions in the shipping industry requires a collaborative and coordinated approach at the international level. International maritime organizations, United Nations Security Council resolutions, and bilateral/multilateral agreements play pivotal roles in shaping policy frameworks, ensuring compliance, and fostering cooperation among nations and industry stakeholders [17-21].

A. Role of International Maritime Organizations (IMO):

The International Maritime Organization (IMO) serves as the linchpin for international cooperation in the maritime sector. Its role in the context of sanctions includes:

- **Setting Standards:** IMO establishes global standards for the safety, security, and environmental performance of international shipping. These standards ensure uniformity and compliance, even in the face of sanctions-related challenges.
- **Capacity Building:** The IMO provides technical assistance and capacity-building programs to member states, aiding them in enhancing their regulatory frameworks and enforcement capabilities concerning sanctions compliance.
- **Information Exchange:** Facilitating the exchange of information among member states and shipping companies regarding sanctioned entities and best practices in sanctions compliance. This information sharing enhances the industry's

ability to adapt to changing sanctions landscapes.

B. United Nations Security Council Resolutions and Maritime Sanctions:

The United Nations Security Council (UNSC) plays a crucial role in enforcing international law through resolutions. Specifically, in maritime sanctions:

Imposing Measures: The UNSC can impose sanctions, including arms embargoes and trade restrictions, against states, entities, and individuals involved in activities detrimental to international peace and security.

Monitoring and Enforcement: UNSC resolutions provide a framework for monitoring sanctioned activities. Member states are obligated to enforce these sanctions, ensuring compliance with the established measures.

Global Consensus: UNSC resolutions represent a global consensus on sanctions. They provide a unified stance against specific actions or behaviors, guiding member states and the shipping industry in their compliance efforts.

C. Bilateral and Multilateral Agreements:

Bilateral and multilateral agreements between nations and regional organizations are instrumental in enhancing cooperation and facilitating trade even in the face of sanctions:

Promoting Dialogue: Bilateral agreements foster open dialogue between nations, allowing them to address concerns and find mutually beneficial solutions. These agreements can create avenues for exemptions or waivers in specific cases, easing trade disruptions.

Regional Collaborations: Multilateral agreements among neighboring countries or within regional blocs facilitate trade by harmonizing regulations and procedures. By promoting regional stability and cooperation, these agreements can mitigate the impact of global sanctions on local economies and shipping routes.

Leveraging Diplomacy: Diplomatic negotiations can lead to agreements that allow for the continuation of essential goods and humanitarian aid, even during sanctions. Skillful diplomacy can ensure that critical supplies reach affected populations without violating sanctions.

VI. CONCLUSION

The shipping industry, as a vital component of global trade, faces significant complexities due to these sanctions. However, opportunities arise from diversifying trade routes, investing in technology, collaborating with regulatory bodies, and upholding ethical business practices. Additionally, international cooperation through organizations like the IMO, adherence to UNSC resolutions, and bilateral/multilateral agreements are essential in navigating the intricate web of sanctions-related challenges. In conclusion, the global shipping industry stands at a crossroads, where challenges and opportunities coexist. By embracing adaptation, fostering collaboration, and investing in research, the industry can not only overcome the hurdles posed by global sanctions but also emerge stronger, more resilient, and better prepared to navigate the complex waters of international trade in the 21st century.

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REFERENCES

[1] United Nations Department of Economic and Social Affairs. Available online: https://sdgs.un.org/topics/sustainable-transport (accessed on 20 June 2023).

[2] Qiushi Web Page. Available online: https://en.qstheory.cn/2023-03/21/c_870899.htm (accessed on 10 April 2023). Sustainability 2023, 15, 12554 10 of 11

[3] Y.C. Chang, On Legal Implementation Approaches toward A Maritime Community with A Shared Future. China Leg. Sci. 2020, 8, 3–31.

[4] W.B. Zhang, Y.C. Chang, L.F. Zhang, An ocean community with a shared future: Conference report. Mar. Policy 2020, 116, 103888.

[5] X.Y. Duan, Y.C. Chang, The Relationship between the General Principles of International Law and UNCLOS: Conference report. Mar. Policy 2023, 150, 105552.

[6] H.M Tian, M.I. Khan, Y.C. Chang, Maritime Traffic Law of the People's Republic of China and its implications in international law. Mar. Policy 2023, 151, 105570.

[7] Available online: https://sputniknews.cn/20220421/1041039065.html (accessed on 10 April 2023).

[8] Y.C. Chang, Accelerating domestic and international dual circulation in the Chinese shipping industry—An assessment from the aspect of participating RCEP. Mar. Policy 2022, 135, 104862.

[9] G. Desalegn, A Tangl, Fekete-Farkas, M. From Short-Term Risk to Long-Term Strategic Challenges: Reviewing the Consequences of Geopolitics and COVID-19 on Economic Performance. Sustainability 2022, 14, 14455.

[10] N. Haber, M. Fargnoli, Product-Service Systems for Circular Supply Chain Management: A Functional Approach. Sustainability 2022, 14, 14953.

[11] The Biden-Harris Plan to Revitalize American Manufacturing and Secure Critical Supply Chains in 2022. Available online: https://www.whitehouse.gov/briefingroom/statementsreleases/2022/02/24/the-biden-harris-plan-to-revitalize-americanmanufacturing-and-secure-critical-supply-chains-in-2022/ (accessed on 10 April 2023).

[12] P.C. Earle, De-dollarization Has Begun. Available online: Aier.org/article/de-dollarization-has-begun/ (accessed on 10 April 2023). Sustainability 2023, 15, 12554 11 of 11

[13] S.A. Altman, C.R. Bastian, Harvard Business Review. Available online: https://hbr.org/2022/04/the-state-of-globalization-in2022 (accessed on 10 April 2023).

[14] Z. Wang, Y.Q. Li, F. Jiang, The Russia-Ukraine Conflict, Global Political and Economic Transition, and Its Impact on China. Russ. Res. 2022, 235, 20–54.

[15] N. Mulder, The Economic Weapon: The Rise of Sanctions as a Tool of Modern War; Yale University Press: New Haven, CT, USA, 2022.

[16] The World Bank. Available online: https://www.worldbank.org/en/news/press-release/2022/04/26/food-and-energy-priceshocks-from-ukraine-war (accessed on 10 April 2023).

[17] The EU Moves to Bar Insurance on Ships Carrying Russian Oil. It'd Be a Big Blow. Available online: https://www.npr.org/2022/06/03/1102990015/the-eu-will-likely-bar-insurance-on-ships-carrying-russian-oil-itd-be-a-big-blow (accessed on 10 April 2023).

[18] Available online: https://news.un.org/zh/story/2022/06/1105232 (accessed on 10 April 2023). 55. Michail, N.A.; Melas, K.D. Geopolitical risk and the LNG-LPG trade. Peace Econ. Peace Sci. Public Policy 2022, 28, 243–265.

[19] Karlsson, L.; Hedberg, P. War and trade in the peaceful century: The impact of interstate wars on bilateral trade flows during the first wave of globalization. Econ. Hist. Rev. 2021, 74, 809–830. [CrossRef]

[20] Wedemeier, J.; Wolf, L. Navigating Rough Waters: Global Shipping and Challenges for the North Range Ports. Intereconomics 2022, 57, 192–198.

[21] Available online: https://world.gmw.cn/2023-03/02/content_36402220.htm (accessed on 10 April 2023).

DECENTRALIZED AUTONOMOUS ORGANIZATIONS (DAOS) IN EDUCATION

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***Abstract*— This research paper explores the potential of Decentralized Autonomous Organizations (DAOs) to revolutionise the educational sector by decentralizing governance, management, and decision-making processes. DAOs are blockchain-based entities governed by smart contracts and community consensus, offering transparency, autonomy, and inclusivity. This study investigates how DAOs could be applied in educational institutions for curriculum development, faculty hiring, student governance, and resource allocation. By decentralising traditional hierarchical structures, DAOs enable stakeholders—students, teachers, and administrators—to participate equally in decision-making, thus promoting democratic participation and accountability. The paper evaluates case studies of early DAO implementations in educational settings and assesses their impact on institutional flexibility, cost-effectiveness, and stakeholder engagement. Furthermore, it examines potential challenges, including legal and regulatory issues, technical limitations, and the digital divide. The findings suggest that while DAOs offer promising solutions to problems of centralization and inefficiency in education, their widespread adoption will require overcoming significant technological, cultural, and policy hurdles. Ultimately, this research highlights the transformative potential of DAOs in reshaping educational governance and fostering decentralised, community-driven institutions that prioritise innovation, equity, and inclusivity.**

The paper evaluates case studies of early DAO implementations in educational settings and assesses their impact on institutional flexibility, cost-effectiveness, and stakeholder engagement. The Web's evolution has created nearly unprecedented possibilities and obstacles in web-based learning and education. For example, the standard internet version Web 1.0 began as a read-only channel; Web 2.0, on the other hand, developed its position as a read-and-write medium. Web 3.0 is described as a technically sophisticated medium that empowers consumers to execute along with reading and writing and also enables devices to undertake a portion of the cognition that was originally expected mostly from humans. Web 3.0 is about decentralization, stripping institutions of consolidated power and transferring it to individuals. A decentralized Internet could weaken the power of educational institutions but provide more opportunities for students to learn. Web 2.0, & Web 3.0 have rapidly developed new methods and technologies for aiding Internet learning and education. More radical visions of Web 3.0 include schools acting like businesses and selling cryptocurrency and NFTs to raise money. But schools are entrenched, conservative institutions and any changes will be slow and difficult. To date, school administrators and teachers have been wary of decentralized online learning environments where they might be unable to supervise student activity. They have been inclined to opt for online "walled gardens" — such as Google for Education — providing a suite of online tools accessed through easily monitored school accounts. To initiate, this paper will talk about Web 3.0 and its characteristics. Following that, we talked about the application of Web 3.0 in education & research.

Keywords*— *Decentralized governance, Blockchain in education, Smart contracts, Educational DAOs, Peer-to-peer learning, Decentralized decision-making

I. Introduction

Since its establishment in the nineties, the World Wide Web has progressed from older iterations, such as Web 1.0 to Web 2.0, and is now evolving into the most recent version, Web 3.0. Web 1.0 is only readable, non-manipulative information with simplistic markups for word recognition. Web 2.0 is described as reading and writing information in real-time via internet services to customize sites on the internet and maintain things. Web 3.0 is now used to read, write, and execute. In Web 2.0, the consumer gets to read data retrieved from the internet and offers data to exchange with everyone via the web. Compared to Web 2.0, there is no specific definition of Web 3.0. Web 3.0 is a term that refers to the future of the World Wide Web.

II. Characteristics of Web 3.0

A. Decentralization

Unlike traditional centralized educational systems, Web 3.0 enables decentralized governance through technologies like blockchain. In education, DAOs allow institutions to be run without a central authority, distributing power among students, faculty, and administrators.

B. Transparency and Trust

Web 3.0 operates on blockchain technology, ensuring that all transactions and decisions within a DAO are transparent and immutable. This fosters trust in educational governance, as stakeholders can verify decisions and records.

C. User Control and Data Sovereignty

Web 3.0 emphasizes user ownership of data. In education, DAOs can empower students and educators to control their personal academic records, learning history, and other data without relying on a central authority.

D. Automation with Smart Contracts

Smart contracts, a key feature of Web 3.0, can automate tasks within educational DAOs, such as course enrollment, certification, or even payments. This reduces administrative overhead and ensures conditions are executed fairly without human intervention.

E. Peer-to-Peer Interactions

Web 3.0 promotes direct interactions between users without intermediaries. Students, teachers, and administrators can collaborate and make decisions directly within a DAO, bypassing traditional top-down hierarchies.

F. Incentive Structures and Tokenization

DAOs often use token-based systems for governance and incentives. In education, tokens could be used to reward participation in decision-making, peer review, or even for achievements in learning and teaching.

G. Interoperability and Open Access

Web 3.0 facilitates the seamless sharing of resources and information across platforms. Educational DAOs can create interoperable learning environments where students can transfer credits, achievements, and credentials across different institutions or platforms.

H. Collaborative Governance

DAOs in education foster a collaborative approach where all stakeholders—students, educators, and administrators—can propose and vote on changes, such as curriculum updates or institutional policies. This increases engagement and democratizes governance.

Literature review

The rise of Decentralized Autonomous Organizations (DAOs) has created new opportunities for governance and management across various sectors, including education. DAOs, which operate on blockchain technology and use smart contracts to execute organizational processes without central control, promise greater transparency, autonomy, and collaboration. This literature review explores foundational concepts, benefits, and challenges of implementing DAOs within educational settings, drawing from research on Web 3.0 technologies, blockchain applications, and educational decentralization.

1) Foundational Concepts of DAOs in Education

Researchers emphasise that DAOs shift from traditional, hierarchical governance models toward decentralized, participatory structures. In educational settings, DAOs could support the administration of schools, universities, and online learning platforms by giving stakeholders equal voting rights (De Filippi & Hassan, 2016). According to Buterin (2014), DAOs use smart contracts to automate decision-making, which can reduce administrative costs, minimise human error, and increase accountability in educational institutions.

2) Benefits of DAOs in Educational Governance

DAOs offer a range of benefits in educational governance, including enhanced transparency, stakeholder participation, and operational efficiency. Tapscott and Tapscott (2018) discuss how DAOs foster trust by recording all transactions on the blockchain, allowing stakeholders to verify decisions and processes. With DAOs, students, educators, and administrators can propose and vote on institutional decisions, such as curriculum changes or budget allocation, fostering a more democratic and inclusive educational environment (Friedman et al., 2019). Moreover, the decentralized nature of DAOs can help reduce administrative bottlenecks and streamline routine tasks such as enrollment and credential verification (Zhao & Ren, 2021).

3) Decentralized Credentialing and Identity Management

Blockchain-based DAOs enable decentralized credentialing, allowing students to own and control their academic records. Research by Sharples and Domingue (2016) highlights the potential of blockchain to store secure, verifiable credentials, thus enabling students to transfer credits seamlessly across institutions. This decentralized credentialing system aligns with Self-Sovereign Identity (SSI), where students can share verifiable credentials without involving third-party institutions (Mikroyannidis et al., 2020). The literature suggests that using DAOs for credentialing can streamline verification processes, improve privacy, and support lifelong learning.

4) Challenges in DAO Implementation for Education

Despite the benefits, several challenges exist in implementing DAOs within educational institutions. Legal and regulatory concerns present significant obstacles, as centralised authorities and compliance standards govern most educational systems. According to Reijers and Wuisman (2018), the ambiguity in DAO regulations and legal frameworks limits their application in formal education. Furthermore, technical barriers such as the high cost of blockchain infrastructure, limited scalability, and data storage and retrieval issues complicate the practical application of DAOs (Zyskind et al., 2015). Additionally, researchers highlight a "digital divide," where students and educators in low-resource settings may struggle to access the required technology, risking unequal participation (Jiang & Wu, 2020).

5) Case Studies of DAOs in Educational Settings

Early implementations of DAOs in education provide insights into their practical potential and limitations. For instance, MIT's Digital Certificates project uses blockchain to issue verifiable credentials, marking one of the first steps toward decentralized credentialing (Massachusetts Institute of Technology, 2017). Another example is ODEM (On-Demand Education Marketplace), which leverages blockchain to create a decentralized marketplace for educational content and services, allowing students and educators to interact without intermediaries (ODEM, 2018). These case studies indicate that while DAOs can enhance transparency and decentralization, their success depends on technical feasibility, user acceptance, and alignment with existing educational policies.

6) Future Directions in DAO-Based Education Systems

Researchers propose several directions for further exploration of DAOs in education. These include developing standardized frameworks for DAO governance, creating incentive structures to encourage participation, and improving interoperability between educational institutions (Davidson et al., 2018). Additionally, integrating artificial intelligence in DAOs could support adaptive learning environments, where AI-driven algorithms personalize learning experiences based on student data within decentralized systems (Pan et al., 2021).

The literature on DAOs in education underscores their potential to transform traditional governance structures, promoting transparency, equity, and autonomy. While DAOs hold promise for decentralizing various educational processes, their practical application is still in its early stages. Future research should address regulatory concerns, scalability issues, and equitable access to ensure that DAOs contribute meaningfully to a more inclusive and decentralized educational landscape.

The above explanations and characterisations can summarise four Web_3.0 characteristics listed below.

1) Intelligence

According to experts, a smart web, also known as a web with intelligence, is among Web 3.0's greatest desirable attributes. Human-computer interaction and intellectual prowess will be used to make applications operate intelligently. Various machine learning (AI) tools and techniques (such as rough set theory, fuzzy rules, neural nets, deep learning, etc.) will be integrated so that the applications can function intelligently. This implies that a Web 3.0 application can instantly perform insightful analysis and produce the best results even with minimal user input. In the Web 3.0 era, documents in numerous languages can be smartly transcribed into certain language families. We should be able to communicate using human language with Web 3.0. As a result, users can communicate with others nearby in their native language.

2) Personalization

Personalisation is another hallmark of Web 3.0. Various activities, such as information processing, searching, and other specific or individual preferences, create a personal web interface. The semantic web would indeed be the foundational technique for personalisation in Web 3.0 [7] [8].

3) Interoperability

Interconnection, collaborative effort, and reusability are related concepts in the frame of reference of Web 3.0. Reusability, which is also a type of collaboration, is implied by interoperability. A communication tool for exchanging data and expertise will be offered by Web 3.0. A novel form of data or expertise is created when an individual or a system software creates content on the Web, and this data is used by others [24]. Applications for Web 3.0 would be simple to customise and self-reliant on device type. A Web 3.0 application would be capable of running on various computers, microwaves, hand-held devices, mobile phones, TVs, cars, and other gadgets.

4) Virtualization

Web 3.0 will indeed feature fast internet bandwidths. Additionally, high-end 3D graphics that are better suited for virtualization. Future web trends include the development of virtual three-dimensional settings. Second Life is a perfect example of the most well-liked Web 3.0 3-D application [7].

III. Application of Web 3.0 in Education & Research

Web 3.0 offers many tools and services for different kinds of web applications on the Internet, as shown in the figure below.

A. Learning with 3D-Wikis / Virtual 3D Encyclopedia

A Wiki is a tool that enables one or even more people to amass a knowledge base through the procedure of creating and formatting web pages that are linked together. Wikis play a big part in producing content, publicizing it, formatting it, adjusting it, and working together to create new knowledge. Wiki pages are being employed to construct and maintain repositories of information and materials. Pupils can post substantial objects and collaborate on projects. The wiki system's simplicity makes it easy for an editor (professor) to remove, edit, or modify content. Research teams and technologists have already been focusing on developing projects to add a new aspect to the universe of wikis and encyclopedias due to the development of the 3D web.

You can find some instances of this new tech on applications like The webcam will move to that specific location on the spinning globe to transfer the appropriate audio and visual information, assuming that a student conducted the search and selected one of the results in relation to data about a particular geographic location. For learners, 3-dimensional Wikis would've offered a rich and efficient environment that contains all media and visual effects, allowing for greater knowledge acquisition and retention.

B. Learning with 3D Virtual worlds & Avatars

As was already discussed, a three-dimensional virtual world is a hybrid of 3-dimensional gaming technology, ar / vr, and a computer-generated atmosphere supported by the Internet, where users interact using adjustable personas. On the Internet, people create personas and permit them to live in digital environments. Students can create their own personas online and live in these virtual worlds. Just like they enable students to participate actively and creatively in role-playing, 3D modelling, simulations, and other learning activities, virtual worlds can be seen as the start of a new era in e-learning. Studying the didactical advantages of education and learning in 3-dimensional virtual worlds has much-untapped potential.

Teachers can conduct lessons in a wide range of settings inside a 3-dimensional digital world, where students can communicate in a setup that closely resembles a classroom. In a sharable 3D computer area, educators and students can work together to conduct classes from remote locations.

Holding a meeting, training, lectures, and virtual expos, they can enable teachers and students to interact just as they would in real life. A diverse variety of fields of study, such as education, healthcare, corporate, marketing, biology, connectivity, mainstream press, craft, building and design, legislation, computer programming, multilingualism, heritage, and geography, to name a few, will find 3-dimensional virtual realms to be of great use in the coming years.

How will Web 3.0 impact education?

Web 3.0 is about decentralization, stripping institutions of consolidated power and transferring it to individuals. A decentralized Internet could weaken the power of educational institutions but provide more opportunities for students to learn. The power to learn and impart knowledge does not belong to a single institution. Still, the current educational system puts the institution — school, university, etc — at the forefront of the student learning experience. The institution decides what content students should learn, how they learn it, and for how long.

Students who study in a traditional brick-and-mortar school limit their opportunities to learn in other environments and from other experts. In a decentralized learning environment, students are no longer bound by the formal constraints imposed by school or university administrators. As Web 3.0 and the Metaverse develop, the Internet will increasingly enable students to access valuable resources and instructional experts and learn in fully immersive and multimedia environments that leverage the physical and digital worlds.

As such, more immersive speciality programs or "micro-schools" (small learning communities) will emerge. One example is the STEM metaverse for children aged 6-14, which leverages live virtual multiplayer gaming to teach science topics. Homeschooling will also become more common as parents have an increasingly robust series of learning resources and experts to draw on.

Fig. 1.Representative diagram showing technology interface

C. Intelligent Search Engines

Learning activities have profited recently from the internet's technological advances. The spread of the internet has made it possible to introduce new instructional methods that allow for more adaptable learning resources. The Web is by far the most effective and practical source of knowledge. Sophisticated internet search engines have indeed been created to retrieve meaningful data in multimedia format so that their customers can efficiently handle the enormous amount of data on the web [21]. A conventional Web search engine can't fully comprehend your search if you use one of those. It searches for websites that include the key phrases you entered in your search.

The web browser cannot determine the Website page's relevance to your search. Only the word or phrase on the website page can be inferred. A search engine built for the Web 3.0 Agencies period could comprehend your query's context and the key phrases you entered.

It would provide pertinent results and recommend additional content based on your search queries. According to experts, Web 3.0 will offer users wealthier and more specific content. Web 3.0 will give each user a distinct online identity based on their online activity. This account will be used by Web 3.0 to customize each user's user experience.

In other words, if 2 distinct students used that service to conduct a keyword-based online search, they each would get distinct findings based on their unique profiles [22]. Knowledge construction fueled by the Semantic Web will also assist learners. Instead of just returning a results list, a Semantic Web Advisor search tool will also return an audiovisual report. A clever operator can recommend local lectures, pertinent articles, journals, and TV programs to the learning process.

IV. Conclusion

The techniques and services that comprise Web 3.0 are not just innovative and beneficial. Web 3.0 technology solutions provide many features that enable a real online school. Considering how Nature Services from Web 3.0 will benefit learning and education. The advantages of Web 3.0 technology solutions include 3-dimensional wikis, 3-dimensional labs, smart agent-based search engines, virtual worlds like Avatar, and semantic digital archives, among others. In our vision of Web 3.0, we anticipate a situation in which such pervasive techniques will combine physical and virtual surroundings, allowing users to communicate virtually and physically with people and machines. Integrating Web 3.0 technology provides a revolutionary opportunity for Indian higher education, expanding the various aspects of the education sector. These advantages can align with the current best practices in online learning, making them even more credible and efficient in academic settings.

References

[1] Jinhong Cui, "Capability Sharing Architecture and Implementation in IM or SNS",2008,978-1-4244-2013-1/08,2008 IEEE.

[2] Juan M. Silva, "Web 3.0: A Vision for Bridging the Gap between Real and Virtual", ACM,2008, ACM 978-1-60558-319-8/08/10.

[3] Victoria Shannon, "A 'more revolutionary' Web". International Herald Tribune. Published: Wednesday, May 24, 2006. http://www.iht.com/articles/2006/05/23/business/Web.php (visited on 2/04/11).

[4] Dan Farber & Larry Dignan, "TechNet Summit: The new era of innovation". ZDNet blog. Posted November15th,2006 http://blogs.zdnet.com/BTL/?p=3959.

[5] Web 3.0 Wikipedia Definitions. http://en.wikipedia.org/wiki/Web_3.0 (visited on 4/08/10).

[6] Han Xiaoting, Niu Li," Subject Information Integration of Higher Education Institutions in the Context of Web3.0", 2nd International Conference on Industrial Mechatronics and Automation, 978-1-4244-7656-5/10, 2010, IEEE.

[7] Russell K, "Semantic Web", Computer World, 2006(9):32.

[8] Zhang Yang, "The Development of Web and Library Reference Service-from Web 1.0 to Web 3.0," Sci-TechInformation Development & Economy, vol.18, 2009.

[9] Radar Networks http://www.radarnetworks.com/, http://www.evri.com (visited on 08/03/11).

[10] Red Light Official Website: http://redlightcenter.com (visited on 12/03/11).

[11] Buterin, V. (2014). "DAOs, DACs, DAs, and More: An Incomplete Terminology Guide." Ethereum Blog.

[12] De Filippi, P., & Hassan, S. (2016). "Blockchain technology as a regulatory technology: From code is law to law is code." First Monday.

[13] Friedman, A., et al. (2019). "Decentralized Education: Blockchain and DAOs in the Educational Sector".

[14] Jiang, H., & Wu, L. (2020). "Barriers to Implementing DAOs in Education: A Critical Analysis." Journal of Emerging Technologies.

[15] Massachusetts Institute of Technology (MIT). (2017). "Digital Certificates Project".

[16] Mikroyannidis, A., et al. (2020). "Self-Sovereign Identity and Blockchain for Education: Concepts and Implications." IEEE Transactions on Learning Technologies.

[17] ODEM. (2018). "The On-Demand Education Marketplace: A Decentralized Platform for Learning".

[18] Pan, X., et al. (2021). "The Role of AI in Decentralized Learning Ecosystems." AI and Education Journal.

[19] Reijers, W., & Wuisman, I. (2018). "DAOs and Legal Frameworks: Exploring New Regulatory Models." Journal of Blockchain Studies.

[20] Sharples, M., & Domingue, J. (2016). "The Blockchain and Knowledge Sharing: From Distributed Databases to Digital Certificates." Journal of Digital Learning.

A COMPREHENSIVE REVIEW ON CCUS: KEY TO MITIGATING GLOBAL CARBON DIOXIDE EMISSIONS

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***Abstract*: In 2019, global carbon dioxide (CO_2) emissions from human activities reached a record high of approximately 43.1 billion tons, underscoring the ongoing reliance on fossil fuels and the critical need for Carbon Capture, Utilization, and Storage (CCUS) technologies. CCUS plays a pivotal role in addressing climate change by capturing CO_2 emissions before their release into the atmosphere, recycling CO_2 for various uses, and ensuring its safe storage. As global warming threatens ecosystems and communities through rising sea levels, warming oceans, shrinking ice caps, and increasing extreme weather events, the urgency for effective climate change mitigation and adaptation strategies intensifies. Experts advocate for limiting the global surface temperature to below 2°C compared to pre-industrial levels, aiming for a CO_2 equivalent of approximately 450 parts per million by 2100. Achieving this requires a significant reduction in greenhouse gas (GHG) emissions—by 40% to 70% below 2010 levels by 2050, with a goal of net-zero emissions by the century's end. This abstract highlights the critical importance of combining adaptation and mitigation strategies, including CCUS, to combat the adverse effects of climate change and meet international emissions targets.**

Keywords—component, formatting, style, styling, insert (keywords)

I. Introduction

Reducing greenhouse gas concentrations necessitates innovative solutions, and CCUS has emerged as a promising strategy [1-4]. The yearly global carbon dioxide (CO_2) emission was about 43.1 billion tons 2019 from human activities, which was an all-time high, breaking the previous record from 2018. The dependence on fossil fuels will continue to exist for the foreseeable future as renewable energy sources cannot meet the energy demands independently. Thus, we need to use Carbon capture, utilization, and storage (CCUS) to preserve the environment, designed to combat climate change [7]

Human activities have caused long-term climate change by causing greenhouse gas (GHG) emissions to reach levels unprecedented in human history. Its primary purpose is to capture carbon dioxide before it is released into the atmosphere, recycle it for various uses, and store it safely against its impact on climate change. Global warming affects ecosystems and communities, causing sea levels to rise, oceans to warm, ice caps to shrink and temperatures to rise. Control and adaptation of the settlement structure are important. It is essential to prevent extreme weather events such as heat waves, fires, floods, droughts, and storms. These conditions are affecting ecosystems and disrupting global well-being. Experts agree to limit surface temperature increase to below 2 °C compared to pre-industrial levels; Emission target of approximately 450 parts per million (ppm) CO_2 equivalent by 2100 (RCP2 .6, most severe) IPCC 's). It is essential to use adaptation and mitigation strategies to prevent global warming. The plan calls for greenhouse gas (GHG) emissions to be reduced by 40% to 70% below 2010 levels by 2050.

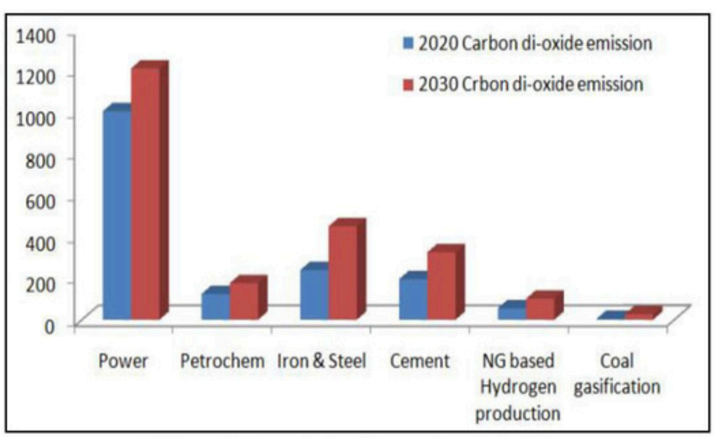

Figure 1 CO_2 emission from various industries

To guide action and provide weather forecasts, we create custom changes and mitigations that indicate actions and measures needed to achieve desired goals. [18]. Fig. 1 depicts CO2 emissions from various industries as of 2020 and predicts the same in 2030. Fig. 2 represents an overview of the entire CCUS process, providing a glimpse of various methods used in the process.

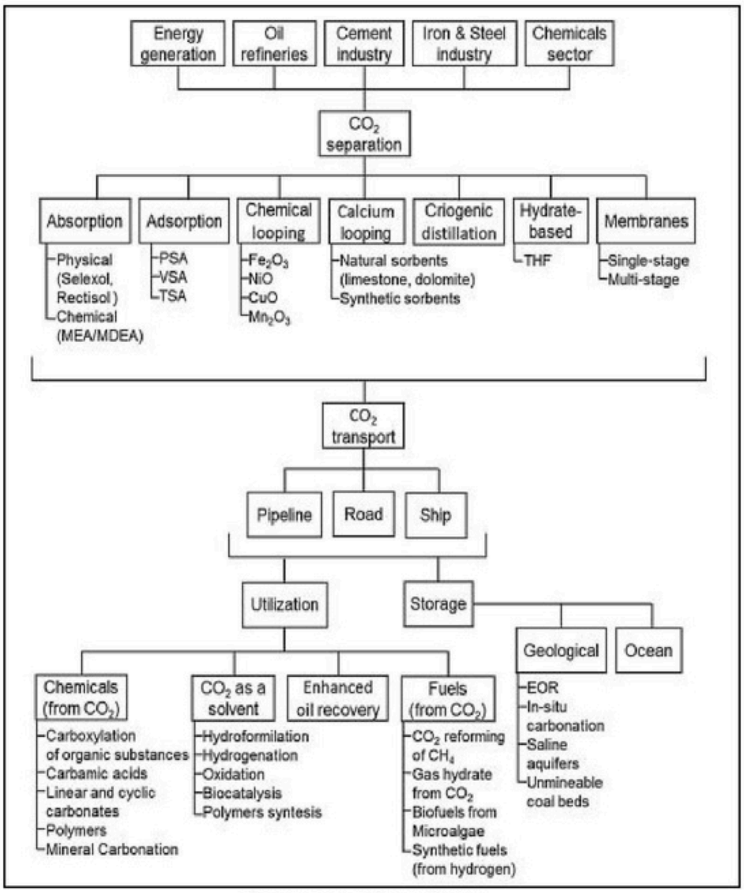

Fig 2 An overview of CUS

II. CARBON CAPTURE

Carbon capture is a crucial technology in the fight against climate change, aiming to reduce the amount of carbon dioxide (CO_2) emitted into the atmosphere from various sources, primarily industrial processes like power generation and manufacturing. The process involves capturing CO_2 emissions produced from burning fossil fuels or other industrial activities before they are released into the air and then storing or repurposing the captured CO_2 to prevent it from contributing to global warming. [7] There are three main methods of carbon capture: post-combustion capture, pre-combustion capture, and oxyfuel combustion.

TABLE 1 VARIOUS CARBON CAPTURE METHODS

Pre combustion	**Post combustion**	**Oxy-fuel combustion**
involves converting fossil fuels into a mixture of hydrogen and CO_2 before combustion	involves capturing CO_2 from flue gases after fossil fuels have been burned.	Involves burning fossil fuels in pure oxygen, producing a concentrated CO_2 stream for capture
This technology is often employed in integrated gasification combined cycle (IGCC) power plants	Post-combustion capture is particularly relevant for existing infrastructure	Oxy-fuel combustion is particularly suitable for new power plants and industries, offering pure CO_2 streams for efficient capture

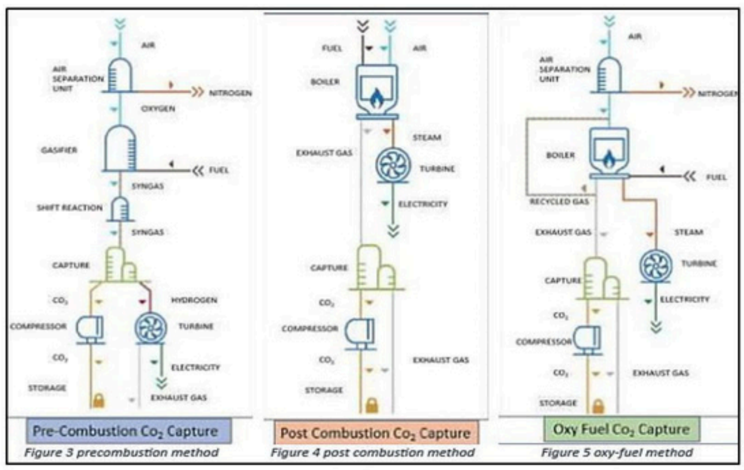

Figure 3 precombustion method
Figure 4 post combustion method
Figure 5 oxy-fuel method
Fig 3 Methods of carbon capture

The above fig. 3 to fig. 5 represent the various methods of carbon capture commonly used in industries [18]. While carbon capture technologies have the potential to reduce greenhouse gas emissions significantly, they face challenges such as high costs, energy requirements, and concerns regarding the long-term storage of CO_2. Additionally, economic factors, regulatory frameworks, and public acceptance have hindered widespread deployment of carbon capture technologies.

Despite these challenges, carbon capture remains a critical tool in mitigating climate change, especially in industries where emissions reduction is particularly challenging. Continued research, development, and investment in carbon capture technologies are essential for achieving global climate goals and transitioning to a sustainable, low-carbon future. [8] The fig. 2 represents the state-wise emission of CO_2 from India in 2020 from the power and industrial sectors.

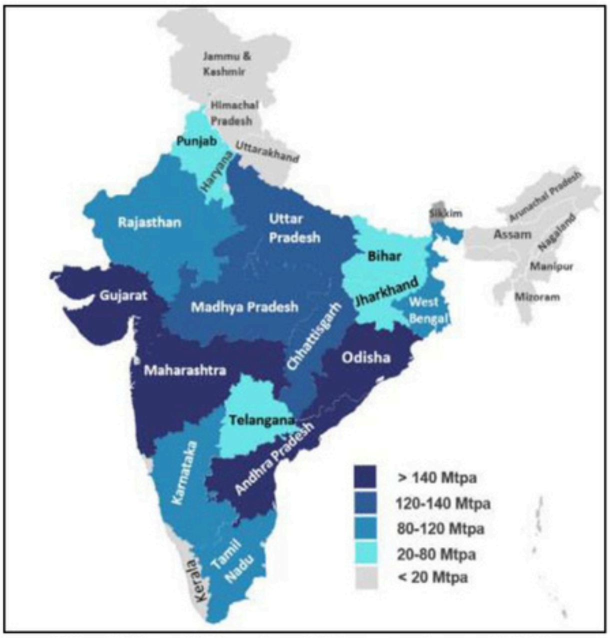

Fig. 4 CO_2 emissions from India state-wise as of 2020

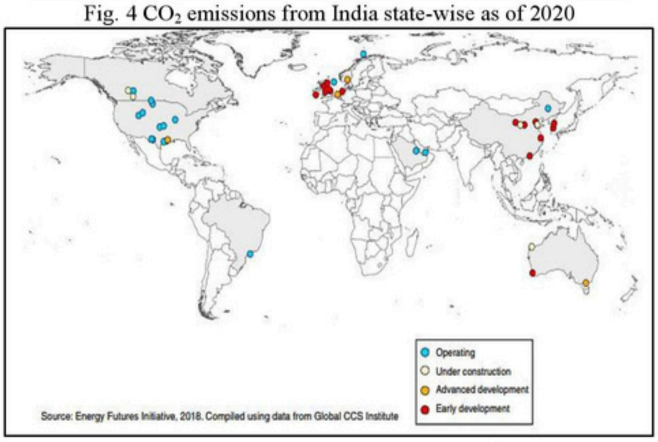

Fig. 5 large scale CCUS projects worldwide

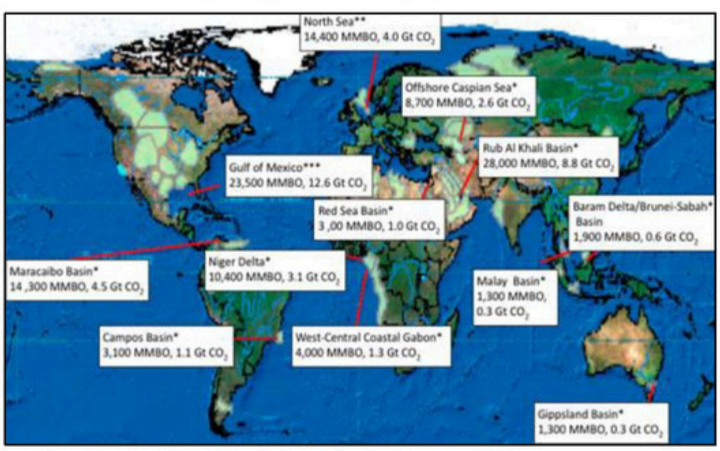

Fig. 6 Basins for which the potential for incremental oil production and CO_2 storage has been assessed

Fig. 3 depicts the location of existing CCUS projects. Figure 4 Basins for which the potential for incremental oil production and CO_2 storage has been assessed

III. TRANSPORTATION

Transportation plays a crucial role in Carbon Capture, Utilization, and Storage (CCUS) initiatives, facilitating the movement of captured carbon dioxide (CO_2) from emission sources to storage or utilization sites. Here's how transportation is managed in the context of CCUS:

Pipeline Transportation: Pipeline transportation is the most common method for transporting captured CO_2 over long distances from capture sites to storage or utilization sites. Dedicated CO_2 pipelines transport compressed CO_2 in liquid or dense-phase form, typically at high pressure, to ensure efficient and safe delivery. These pipelines may traverse multiple or even hundreds of kilometers to reach suitable storage or utilization facilities. Pipeline transportation offers a cost-effective and environmentally friendly option for large-scale CO_2 transport.

Shipping: In some cases, captured CO_2 may be transported via ships, particularly for offshore storage or utilization projects. Specialized tankers are used to transport compressed or liquefied CO_2 across oceans or waterways to storage facilities or industrial sites. Shipping can be a viable option for regions where pipeline infrastructure is limited or impractical, although it may incur higher costs and logistical challenges compared to pipeline transportation.

Trucking: For shorter distances or remote locations where pipelines or ships are not feasible, captured CO_2 may be transported by trucks or tankers. CO_2 is compressed and loaded onto trucks for delivery to nearby storage or utilization sites. While trucking offers flexibility and accessibility, it is generally less cost-effective and efficient than pipeline or shipping transportation, particularly for large-scale CCUS projects.

Rail Transportation: In some cases, rail transportation may be used to transport captured CO_2, although it is less common than other modes of transport. CO_2 can be compressed and loaded onto rail cars for delivery to storage or utilization sites, particularly for projects located near rail lines. Rail transportation may offer advantages in terms of capacity and efficiency for certain CCUS projects but may also face logistical challenges and higher costs compared to pipelines or trucks.

Effective transportation infrastructure is essential for the success of CCUS projects, ensuring the reliable and safe delivery of captured CO_2 to storage or utilization sites. The choice of transportation method depends on various factors, including distance, volume, cost, regulatory considerations, and local infrastructure availability. By facilitating the movement of CO_2 from emission sources to storage or utilization sites, transportation plays a critical role in realizing the potential of CCUS technologies to mitigate carbon emissions and combat climate change [10-13].

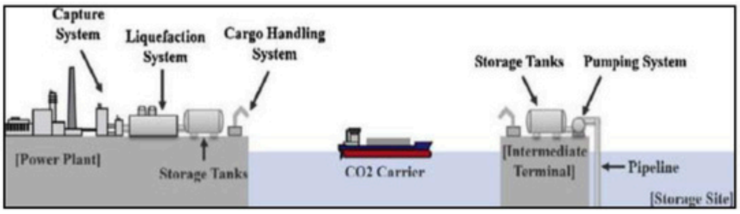

Fig. 7 Role of shipping in CCUS

The above figure depicts the role of ships in the transportation of CO2 and, thus, in CCUS.

IV. UTILISATION

Carbon Capture, Utilization, and Storage (CCUS) technologies offer a versatile approach to reducing carbon dioxide (CO_2) emissions across various sectors of the economy. Here are some key uses of CCUS in different sectors:

1. **Power Generation**: CCUS can be applied to fossil fuel-fired power plants, including coal, natural gas, and oil-fired plants, to capture CO_2 emissions from combustion processes. This allows for the continued use of fossil fuels for electricity generation while significantly reducing greenhouse gas emissions. CCUS can also enable bioenergy deployment with carbon capture and storage (BECCS), where CO_2 emissions from biomass combustion are captured and stored underground, resulting in harmful emissions.

2. **Industrial Processes**: CCUS can be integrated into various industrial processes to capture CO_2 emissions generated from cement production, steel manufacturing, chemical processing, and refining. These sectors account for significant global CO_2 emissions and can benefit from CCUS technologies to reduce their carbon footprint.

3. **Enhanced Oil Recovery (EOR):** Captured CO_2 can be utilised for enhanced oil recovery (EOR) operations, where CO_2 is injected into depleted oil reservoirs to increase oil production. This extends the lifespan of existing oil fields and facilitates the capture and storage of CO_2 underground, effectively sequestering it from the atmosphere.

4. **Bioenergy and Biofuels**: CCUS can be coupled with bioenergy production processes to capture CO_2 emissions from biomass combustion or biofuel production. By capturing and storing CO_2 from biomass-based energy generation or biofuel production, CCUS can achieve harmful emissions and contribute to carbon neutrality.

5. **Chemical and Manufacturing Industries**: CCUS technologies can be applied in chemical and manufacturing industries to capture CO_2 emissions from various processes, such as hydrogen production, ammonia synthesis, and ethanol production. Captured CO_2 can be utilized as a feedstock for producing chemicals, fuels, plastics, and other materials, contributing to the circular economy and reducing reliance on fossil resources.

6. **Direct Air Capture (DAC):** CCUS technologies, specifically direct air capture (DAC), can capture CO_2 directly from the atmosphere. DAC systems can be deployed in various sectors or locations to remove CO_2 emissions from the atmosphere, providing a pathway to achieve harmful emissions and offset hard-to-abate emissions from sectors such as aviation, shipping, and agriculture.

Overall, CCUS technologies offer a versatile and scalable approach to reducing CO_2 emissions across multiple sectors of the economy, contributing to global efforts to mitigate climate change and transition to a low-carbon future. Continued research, development, and deployment of CCUS technologies are essential to unlocking their full potential and achieving climate goals. [2,8]

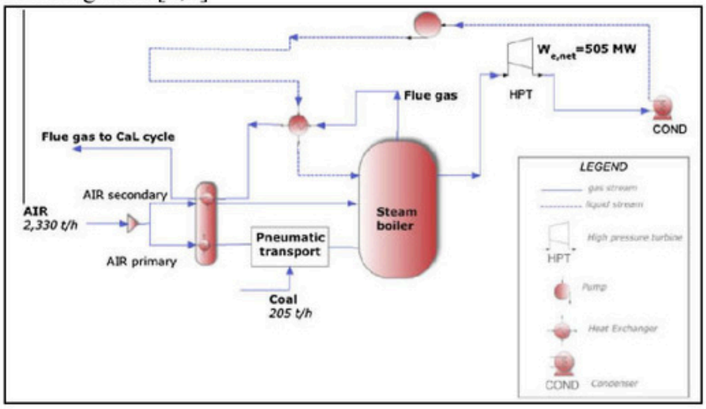

Fig. 8 Schematic representation of the coal-fired power plant (CFPP) used as reference for the integration of the CaL cycle

The above fig 10 depicts a schematic representation of coal fired plant used for calcium looping. The fig 11 represents the process of enhanced oil recovery process, this is a utilization of CO_2.

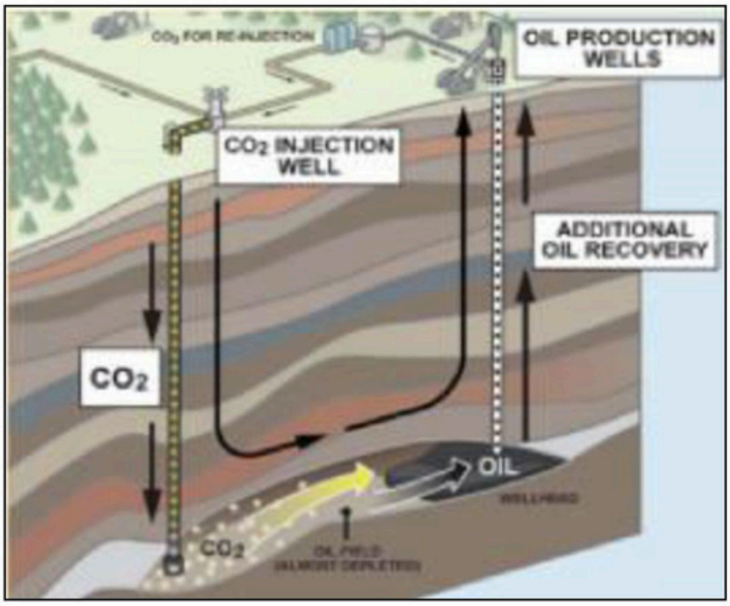

Fig.9 EOR

V. STORAGE

Carbon Capture, Utilization, and Storage (CCUS) technologies involve capturing carbon dioxide (CO_2) emissions from industrial processes and power plants and storing them underground to prevent their release into the atmosphere. Several storage methods are employed for storing captured CO_2 safely and securely underground. Here are the main storage methods used in CCUS:

Geological Storage: Geological storage involves injecting captured CO_2 into underground geological formations, where it is permanently stored and prevented from entering the atmosphere. The most common geological storage formations include:

Depleted Oil and Gas Reservoirs: Oil and gas reservoirs that have been depleted of their hydrocarbon resources can serve as suitable storage sites for CO_2. The injected CO_2 displaces residual oil or gas, enhancing oil recovery while storing CO_2 underground.

Deep Saline Aquifers: Deep saline aquifers, porous and permeable rock formations filled with salty water, provide ample storage capacities for CO_2. The injected CO_2 is stored in the rock formations' pore spaces, trapped by impermeable layers above.

Unmineable Coal Seams: Unmineable coal seams are deposits that cannot be economically extracted. They can also serve as CO_2 storage sites. The injected CO_2 adsorbs onto the coal surfaces, trapping it underground.

Enhanced Oil Recovery (EOR): Enhanced Oil Recovery (EOR) involves injecting captured CO_2 into depleted oil reservoirs to increase production. While EOR primarily aims to enhance oil recovery, it also provides a means of storing CO_2 underground. The injected CO_2 displaces residual oil, improving oil flow, while the oil reservoir acts as a storage reservoir for CO_2.

Mineral Carbonation: Mineral carbonation is a natural process where CO_2 reacts with certain minerals to form stable carbonates. This method, captured CO_2 is injected into geological formations containing magnesium or calcium-rich minerals, such as olivine or serpentine. CO2 is converted into solid carbonate minerals through a series of chemical reactions, permanently storing it underground.

Ocean Storage: Ocean storage involves injecting captured CO_2 into the deep ocean for long-term storage. While the deep sea has vast storage potential, concerns about environmental impacts, including ocean acidification and ecosystem disruption, have limited the practical application of this method.

Each storage method has its advantages and challenges, and the suitability of a particular method depends on geological, technical, economic, and regulatory factors. Ensuring the safe and effective storage of CO_2 is essential for the success of CCUS projects and climate change mitigation. Ongoing research, monitoring, and regulation are necessary to address potential risks and optimize CO_2 storage methods. [2-10]

In addition to the primary storage methods mentioned earlier, there are a few more methods of storing carbon dioxide (CO_2) as part of Carbon Capture, Utilization, and Storage (CCUS) initiatives:

Hydrate Formation: CO_2 can be stored as solid hydrates as CO_2 hydrate crystals, which are stable at low temperatures and high pressures. This method involves injecting CO_2 into subsea sediments or deep permafrost regions where low temperatures and high pressures exist naturally or can be induced. The injected CO_2 reacts with water and forms solid hydrate crystals, trapping the CO_2 underground.

Carbonation of Industrial Wastes: Industrial wastes, such as steel slag, fly ash, and other alkaline materials, can be utilized for carbonation reactions to store CO2 permanently. By reacting CO_2 with alkaline materials, carbonates are formed, which can be stable and safely stored. This approach not only sequesters CO_2 but also provides a beneficial reuse of industrial waste materials.

Bioenergy with Carbon Capture and Storage (BECCS): BECCS combines bioenergy production with CO_2 capture and storage. Biomass, such as agricultural residues, forestry waste, or dedicated energy crops, is used as feedstock for energy production through combustion or gasification. The resulting CO_2 emissions are captured and stored underground, resulting in net negative emissions due to the carbon sequestration potential of biomass.[10]

Ocean Alkalinity Enhancement: This method involves enhancing the alkalinity of seawater by adding alkaline substances, such as crushed limestone or calcium hydroxide, to increase its capacity to absorb CO_2 from the atmosphere. The dissolved CO_2 reacts with the alkaline substances to form bicarbonate ions, which are stable in seawater. While not a direct storage method, it can enhance the ocean's natural capacity to absorb and store CO2.

Direct Air Capture (DAC) and Mineralization: DAC technologies directly capture CO_2 from the atmosphere and subsequently mineralize it into stable carbonates. This involves capturing atmospheric CO_2 using chemical sorbents or solvents, followed by mineralization reactions where CO_2 is reacted with mineral-rich materials to form stable carbonates. The resulting carbonates can be safely stored or utilized in various applications.

VI. CONCLUSION

Carbon Capture, Utilization, and Storage (CCUS) technologies are critical in mitigating carbon emissions and combating climate change. By capturing carbon dioxide (CO_2) from industrial and power generation sources, utilizing it in various applications, and securely storing it underground, CCUS promotes a sustainable, low-carbon future. Continued research, investment, and global cooperation needs to enhance and broaden the implementation of CCUS for effective climate mitigation. CCUS is crucial for reducing CO_2 emissions, enabling the use of fossil fuels with minimal environmental impact, and facilitating a transition to cleaner energy. Additionally, the utilization aspect of CCUS transforms CO_2 into a valuable resource, contributing to a circular carbon economy. Despite challenges such as costs and the need for secure storage, collaborative efforts are essential to overcome these barriers and advance CCUS technologies.

REFERENCES

[1] The development of Carbon Capture Utilization and Storage (CCUS) research in China: A bibliometric perspective Kai Jiang a,*, Peta Ashworth

[2] Life cycle assessment of carbon capture and storage/utilization: From current state to future research directions and opportunities Tatiane Tobias da Cruz a, *, Jos´e A. Perrella Balestieri a, Joao ˜ M. de Toledo Silva a, Mateus R. N. Vilanova b, Otavio ´ J. Oliveira c, Ivonete Avila ´ a

[3] The grand challenges in carbon capture, utilization, and storage Berend Smit 1,2*, Ah-Hyung Alissa Park 3,4 and Greeshma Gadikota3,4

[4] Enabling Large-Scale Carbon Capture, Utilisation, and Storage (CCUS) Using Offshore Carbon Dioxide (CO2) Infrastructure Developments—A Review Lars Ingolf Eide 1,*, Melissa Batum 2, Tim Dixon 3, Zabia Elamin 4, Arne Graue 5, Sveinung Hagen 6, Susan Hovorka 7, Bamshad Nazarian 6, Pål Helge Nøkleby 4, Geir Inge Olsen 4, Philip Ringrose 6 and Raphael Augusto Mello Vieira 8

[5] Calcium Carbonate Cement: A Carbon Capture, Utilization, and Storage (CCUS) Technique Craig W. Hargis 1,*, Irvin A. Chen 2, Martin Devenney 2 , Miguel J. Fernandez 2 , Ryan J. Gilliam 1 and Ryan P. Thatcher

[6] Decarbonizing the Atmosphere Using Carbon Capture, Utilization, and Sequestration: Challenges, Opportunities, and Policy Implications in India Abhishek Gupta 1 , Akshoy Ranjan Paul 1 and Suvash C. Saha 2,*

[7] Opportunities for a Low Carbon Transition-Deploying Carbon Capture, Utilization, and Storage in Northeast India Aparajita Datta1† and Ramanan Krishnamoorti 2,3 *

[8] Harnessing the power of machine learning for carbon capture, utilisation, and storage (CCUS) – a state-of-the-art review Yongliang Yan, *ab Tohid N. Borhani, c Sai Gokul Subraveti,d Kasturi Nagesh Pai,d Vinay Prasad, d Arvind Rajendran,d Paula Nkulikiyinka, a Jude Odianosen Asibor, a Zhien Zhang,e Ding Shao, f Lijuan Wang, g Wenbiao Zhang, f Yong Yan, g William Ampomah,h Junyu You,hi Meihong Wang, j Edward J. Anthony, a Vasilije Manovic a and Peter T. Clough * a

[9] Potential matching of carbon capture storage and utilization (CCSU) as enhanced oil recovery in perspective to Indian oil refneries Narendra N. Dalei1 · Jignesh Josh

[10] Carbon capture and storage opportunities in the west coast of India Harsha Kumar Bokka, Kai Zhang, Hon Chung Lau *

[11] Carbon capture utilization and storage in review: Sociotechnical implications for a carbon reliant world Hope McLaughlin a , Anna A. Littlefield a,b,* , Maia Menefee a,h , Austin Kinzer a , Tobias Hull a , Benjamin K. Sovacool c,d,e,f , Morgan D. Bazilian a,b , Jinsoo Kim g , Steven Griffiths h

[12] A review of large-scale CO2 shipping and marine emissions management for carbon capture, utilisation and storage Hisham Al Baroudi, Adeola Awoyomi, Kumar Patchigolla * , Kranthi Jonnalagadda, E.J. Anthony

[13] The calcium looping cycle for large-scale CO2 capture J. Blamey a , E.J. Anthony b , J. Wang b , P.S. Fennell

[14] Techno-economic comparison of coal plants in India with conventional and advanced power generation technologies integrated with calcium looping based CO2 capture Srinath Haran1,* Anand B Rao1, 2 Rangan Banerjee1, 3

[15] Calcium looping cycle for CO2 capture: Performance, cost and feasibility analysis Hari C. Mantripragadaa * andEdward S. Rubina

[16] Integration of calcium looping technology in existing cement plant for CO2 capture: Process modeling and technical considerations K. Atsonios a,b,⇑ , P. Grammelis a , S.K. Antiohos c , N. Nikolopoulos a , Em. Kakaras

[17] A new integration model of the calcium looping technology into coal-fired power plants for CO2 capture C. Ortiz a,⇑ , R. Chacartegui a , J.M. Valverde b , J.A. Becerra

[18] A Comprehensive Review on Carbon Capture, Utilization, and Storage (CCUS) Prateek Kumar Tiwari , Vaishali Pendse , Debabrata Mukhopadhyay

THE BULGE OF GEOPOLITICS: NAVIGATING THE SOUNDS OF 21ST CENTURY FOR SHIPPING

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Abstract— **The shipping industry operates within a tumultuous global landscape of geopolitical tensions, economic fluctuations, and environmental concerns. Strategic chokepoints like the South China Sea and the Suez Canal are focal points of contention, impacting shipping routes and trade flows. Events such as the COVID-19 pandemic and conflicts like the Russia-Ukraine war disrupt global trade, leading to significant repercussions for the shipping sector. These geopolitical shifts highlight the industry's vulnerability to external factors beyond its control. Regional alliances and trade agreements play a crucial role in shaping the dynamics of the shipping industry. Free Trade Agreements (FTA) aim to promote international trade by reducing barriers, but trade wars can disrupt established relationships, causing economic uncertainty. The interplay between geopolitical alignments and trade agreements underscores the complexity of the global shipping landscape. The global shipping industry is a complex interplay between economics and geopolitics, where events and agreements at both the global and regional levels influence its trajectory. While economic factors drive trade and shipping demand, geopolitical tensions and trade policies can introduce volatility and disruption. Navigating these challenges requires adaptability and foresight from industry stakeholders as they chart their course through the ever-changing currents of global affairs.**

***Keywords*— Geopolitical tensions, strategic chokepoints, global trade, tariff structures, economic fluctuations, shipping route.**

I. Introduction

In today's complex geopolitical landscape, the shipping industry plays a crucial role in global trade, navigating the world's oceans and intricate webs of international politics. As trade routes evolve and geopolitical dynamics shift, maritime transportation faces innumerable challenges and opportunities. Each factor significantly impacts global commerce, from strategic chokepoints to economic sanctions and climate change to technological advancements.

As shown in Figure 1, geopolitical considerations heavily influence decisions in shipping, from route planning and security measures to market strategies and regulatory compliance. In this dynamic environment, stakeholders must skillfully navigate geopolitical tensions while balancing economic imperatives. This passage explores the diverse facets of navigating 21st-century geopolitics within the shipping industry, emphasising adaptability and strategic foresight to ensure smooth operations in a volatile world.

Fig. 1. Geopolitics and Global Trade

II. HISTORICAL CONTEXT

The history of geopolitics and the shipping industry is deeply intertwined, spanning centuries of exploration, trade, conflict, and cooperation. Geopolitics, the study of the influence of geographical factors on politics and international relations, has always been closely linked to maritime trade due to the strategic importance of sea routes and ports [1].

Maritime trade routes date back to ancient civilisations such as the Phoenicians, Greeks, and Romans. They played a pivotal role in economic prosperity and cultural exchange.

World War I and World War II underscored the critical role of maritime transportation and naval superiority in global conflicts. The Cold War era saw the emergence of containerisation, revolutionising the efficiency of marine trade. Ports and shipping routes became vital nodes in the international supply chain, influencing geopolitical alliances and economic strategies during the East-West divide, as shown in Fig. 2

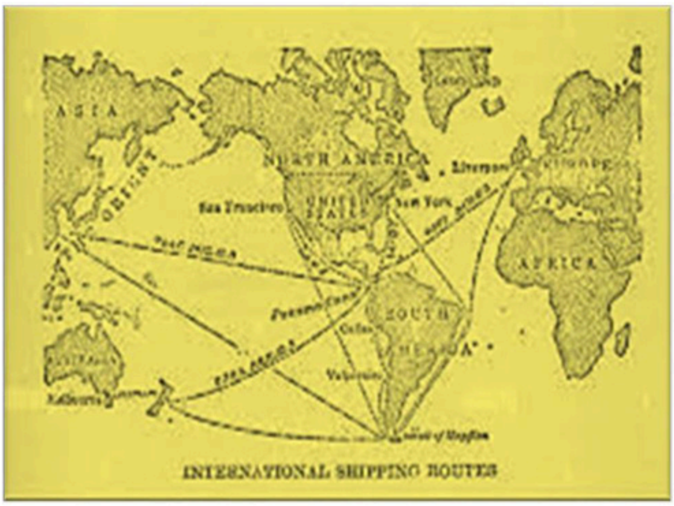

Fig. 2. International Shipping Routes

MAJOR GEOPOLITICAL PLAYERS

The major geopolitical players in the shipping industry include the United States, China, the European Union, Russia, Japan, and Middle Eastern countries like Saudi Arabia, the UAE, and India.

- *United States of America:* As the world's largest economy and a significant maritime power, the United States plays a pivotal role in shaping international maritime policies, ensuring freedom of navigation, and promoting its strategic interests through alliances and naval presence in key regions such as the Asia-Pacific and the Middle East [2].
- *European Union:* The EU member states collectively constitute a significant market and trading bloc. The EU shapes maritime regulations, environmental standards, and trade policies that affect global shipping. European ports and naval logistics networks are crucial hubs for international trade flows.
- *Middle Eastern Countries:* Saudi Arabia, Qatar, and the United Arab Emirates (UAE) play crucial roles in global shipping as major oil exporters and strategic maritime hubs. The region's geopolitical stability influences energy prices, maritime security, and trade flows.
- *Russia:* Russia's vast coastline along the Arctic Ocean and its control over critical maritime chokepoints such as the Bosporus and Dardanelles Straits gives it geopolitical leverage in global shipping.
- *India:* With its growing economy and strategic location along major sea lanes, India is evolving as a key player in global shipping. Indian ports are critical nodes in international trade networks, and India's maritime strategy focuses on enhancing connectivity, security, and trade relations with Southeast Asia, Africa, and the Middle East.

III. Strategic Checkpoints

Strategic choke points are narrow passages connecting more significant regions, often straits or canals. Due to their considerable traffic, these choke points are susceptible to blockades or intentional disruptions during political instability [3]. The level and type of risk can vary based on their specific geographic location, as illustrated in Figure 3.

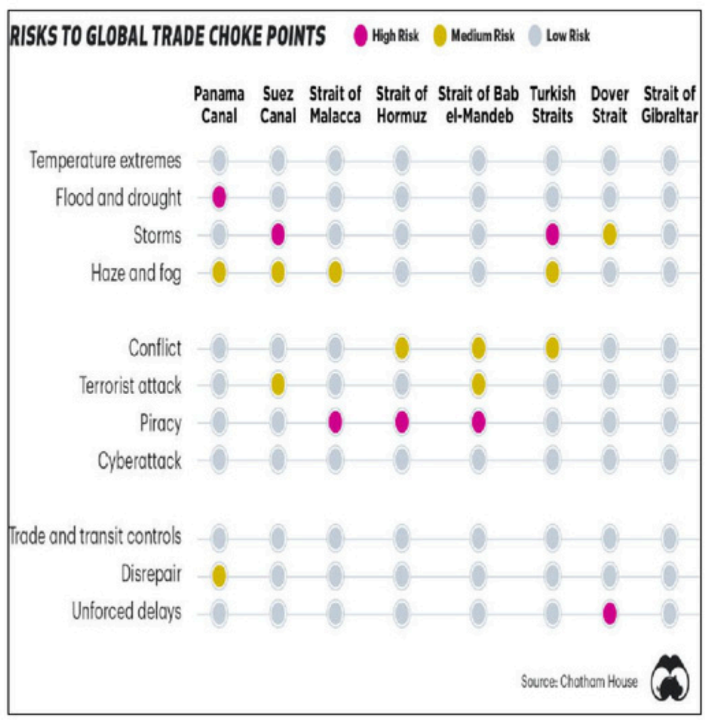

Fig. 3. Risks to Global Trade Choke Points

KEY MARITIME CHOKE POINTS

- *The Panama Canal:* The Panama Canal is a lock-type waterway that offers a shortcut for ships travelling between the Pacific and Atlantic oceans. Ships sailing between the eastern and western coasts of the United States save more than 8,000 nautical miles by using the canal, reducing their journey by approximately 21 days.

- *The Suez Canal:* The Suez Canal, located in Egypt, is a crucial maritime route connecting Europe to Asia. Without this passage, ships would need to circumnavigate Africa, adding around seven days to their voyages. In 2019, nearly 19,000 vessels and 1 billion tons of cargo transited through the Suez Canal [4].
- *The Strait of Malacca:* The Strait of Malacca measures about 1.5 nautical miles at its narrowest point, ranking it among the world's narrowest choke points. Despite its size, it plays a crucial role as one of Asia's most vital waterways, facilitating essential connections between China, India, and Southeast Asia. This choke point poses significant risks for the approximately 130,000 ships that visit the Port of Singapore annually.

IV. Impacts of Geopolitics on Shipping

The international shipping industry has faced significant challenges in recent years, including problems of overcapacity, fluctuating fuel prices, stringent environmental regulations, and the complexities of digitalisation.

- *The US-China tariff stand-off:* The ongoing tariff dispute between the United States and China is escalating towards a potential trade war. Both countries have imposed higher tariffs on billions of dollars of imports, raising concerns among experts about the impact on container shipping lines [5]. According to geopolitical analysts at Stratfor, the imposition Sof $50 billion in tariffs by the US and China's retaliatory measures have placed nearly 7% of US-China container trade in jeopardy, as depicted in Fig. 4.

Fig. 4. The US-China tariff stand-off

- *US Sanctions on Iran:* The recent wave of sanctions imposed on Iran focuses heavily on its shipping industry. Companies such as the Islamic Republic of Iran Shipping Lines (IRISL), South Shipping Line Iran, and their affiliates will bear the brunt of these measures. These sanctions include restrictions on providing insurance across various Iranian sectors, including shipping, besides sanctions on Iran's port operators, shipbuilders, shipping lines, and transactions involving the National Iranian Oil Company. Additionally, Iran's energy and financial sectors are also being targeted.

South China Sea Dispute: The South China Sea, situated at a critical juncture involving Hong Kong, the Philippines, and Vietnam, is a vital shipping route rich in oil and natural gas resources. However, the region is also a focal point of an intense international territorial dispute. China asserts its claim over approximately 90% of the South China Sea using the controversial 'Nine-Dash Line,' contested by countries such as the Philippines, Brunei, Malaysia, Taiwan, and Vietnam. This dispute is compounded by nearly half of the world's oil tanker shipments passing through these waters. [15]

The Iran-backed Houthi rebels' rebellious attack on commercial vessels: The Yemen-based Houthi rebels, supported by Iran, have launched attacks on commercial ships, claiming they were targeting vessels headed to Israel. However, it remains uncertain whether all the targeted ships were indeed bound for Israel. The Houthis have utilised rockets and drones to target foreign-owned cargo vessels passing through the Bab al-Mandeb strait—a narrow channel separating Eritrea and Djibouti from Yemen. These actions have disrupted maritime traffic in the region, impacting global trade routes that rely heavily on the Suez Canal. [6].

- *Impact of Alternative Routing:* As billions of pounds worth of cargo are diverted around the Cape of Good Hope, extending transit times for container shipments on the Asia-Europe route, the disruption caused by Houthi activities in the Red Sea will have enduring effects on supply chains reliant on safe and reliable maritime transportation, as depicted in Figure 5. [7].

Fig. 5. Impact of Alternative Routing

Russia-Ukraine war: global impact on Logistics: The conflict between Russia and Ukraine has resulted in price hikes for various commodities, including fertilisers, food products, and oil and gas. Supply chain disruptions have led to increased freight costs, container shortages, and warehouse space availability. Numerous ports have faced closures, and delayed shipments and congestion have prompted many orders to be withdrawn. Russia's blockade of the Black Sea and Azov Sea, along with incidents of Ukrainian grain shipments being intercepted, aggravated the situation. Despite a United Nations agreement between Russia and Ukraine to resume Ukrainian grain exports from three Black Sea ports to alleviate shortages, tensions escalated as Russia launched cruise missiles at Odesa's seaport shortly after the deal was signed.

A. ECONOMIC IMPLICATIONS OF GEOPOLITICS ON THE SHIPPING INDUSTRY

Certain factors significantly disrupt global supply chains and hinder operations amidst various geopolitical tensions. These disruptions can arise from both natural occurrences and human-induced events, such as trade wars, pandemics, the Global Recession, Power dynamics, Military activities, Terrorist activities, etc. [8].

The shipping industry faces challenges from supply chain disruptions caused by geopolitical tensions between countries. These crises create a ripple effect, impacting the industry in the following ways:

- *Escalating shipping rates:* Trade tariffs rise, reducing international trade and decreasing shipping orders. To cope with decreased demand, shipping companies lower their rates.
- *Fluctuating container availability:* During the pandemic, the surge in e-commerce led to heightened demand for shipping containers, while many retail stores closed. This resulted in a shortage of containers, prompting manufacturers to ramp up production to meet the increased demand.
- *Baltic Dry Index (BDI):* To establish a reference point for the cost of transporting primary raw materials by sea, the Baltic Dry Index (BDI) is utilised. This index is published monthly by the Baltic Exchange in London and comprises three sub-indices that gauge different sizes of dry bulk carriers: Capsize vessels, which typically transport iron ore or coal loads weighing around 150,000 tons; Panamax vessels, which generally carry coal or grain cargoes of approximately 60,000 to 70,000 tons; and Supramax vessels, with capacities ranging from 48,000 to 60,000 tons. The BDI encompasses 23 shipping routes handling coal, iron ore, grain, and other commodities, as depicted in Fig. 6 [9].

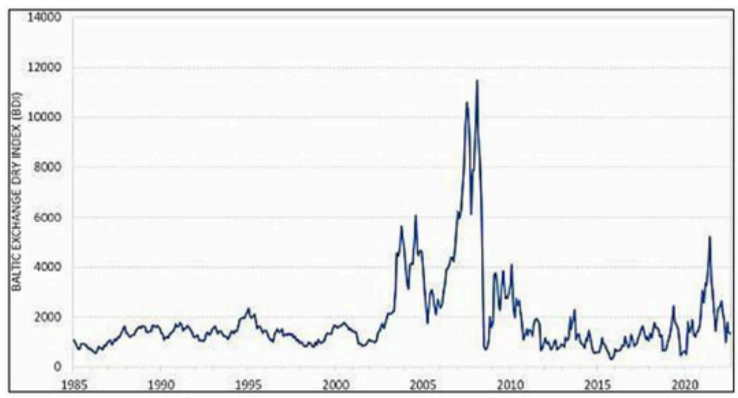

Fig. 6. Baltic Dry Index (BDI) from 1985 to 2022

B. GEOPOLITICS AND TECHNOLOGICAL INNOVATION

Geopolitical Dynamics Shaping Innovation: Geopolitical factors can significantly influence the direction and pace of technological innovation. Government policies, international relations, and regional conflicts often determine the allocation of resources, research priorities, and the flow of information and technology across borders.

Technology as a Geopolitical Tool: Technology itself is becoming a key player in the geopolitical arena. Countries leading in technological capabilities can exert considerable influence on the global stage. The US-China tech race, particularly in areas like 5G and AI, is a prime example of how the technological process is tangled with national power and influence.

Digital Divide and Geopolitical Implications: The uneven distribution of technological advancements, known as the digital divide, also has geopolitical implications. Countries that lag in digital capabilities may find themselves at a disadvantage economically, in terms of security, and in terms of international standing. This divide can lead to shifts in alliances and power balances as nations seek to bridge their technological gaps, as shown in Fig. 7 [11].

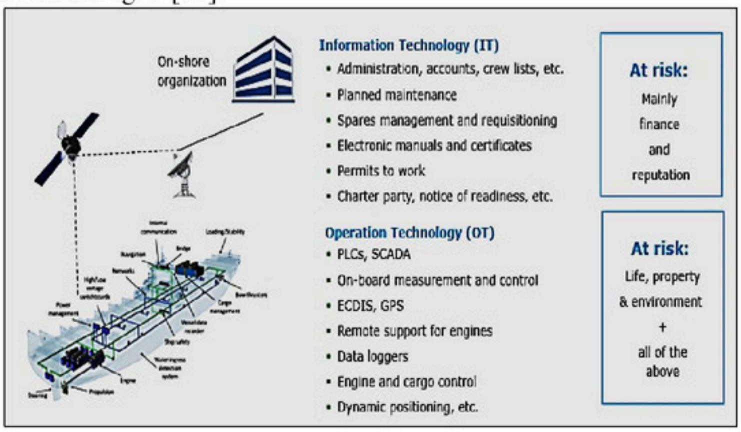

Fig. 7. Operational Technology (OT) and Information Technology (IT)

C. THE ROLE OF THE INTERNATIONAL MARITIME ORGANIZATION (IMO) IN RESOLVING GEO-POLITICAL DISPUTES

Establishing International Regulations: IMO develops and implements international regulations and standards for shipping, including safety, security, environmental protection, and navigational practices [16]. IMO helps mitigate conflicts arising from differing national regulations or interpretations, as shown in Figure 8, by providing a universal framework that member states adhere to.

Conflict Prevention through Legal Frameworks: International Maritime Organization (IMO) conventions and treaties, including SOLAS (Safety of Life at Sea), MARPOL (Prevention of Pollution from Ships), and UNCLOS (United Nations Convention on the Law of the Sea), establish definitive rules and protocols for maritime operations. These regulatory frameworks play a crucial role in averting disputes by outlining rights and obligations concerning navigation, pollution prevention, and the consumption of oceanic resources.

Facilitating Dispute Resolution: IMO provides mechanisms for resolving disputes related to maritime issues. This includes facilitating arbitration, mediation, and negotiation processes when disagreements arise about interpreting or implementing international maritime laws and regulations.

Enhancing Maritime Security: IMO initiatives bolster maritime security, exemplified by the International Ship and Port Facility Security (ISPS) Code. This code strives to thwart acts of terrorism targeting ships and ports. IMO plays a pivotal role in fortifying stability and bolstering trust in global shipping routes by fostering a safe maritime environment.

Resolution of Maritime Boundary Disputes: Disputes over maritime boundaries are intricate and necessitate a thorough examination of legal, historical, and economic aspects. Resolving these disputes can carry substantial political, commercial, and security ramifications for the countries in question.

Fig. 8. The Role of IMO In Resolving Geo-Political Disputes

D. NOTABLE EVENTS IN MARITIME GEOPOLITICS

One of the pivotal events in the maritime industry's geopolitical history was the opening of the Suez Canal in 1869. This artificial waterway, connecting the Mediterranean Sea to the Red Sea, revolutionised global trade by providing a significantly shorter route between Europe and Asia. It reduced the journey from Europe to India by several thousand kilometres, saving time and costs for shipping goods.

The 2016 ruling by the Permanent Court of Arbitration (PCA) regarding the South China Sea dispute is a modern event of significant importance in the maritime industry.

The collapse of the Soviet Union and the end of the Cold War (1989-1991) reshaped global geopolitics, including maritime strategies and alliances. Reducing naval tensions and opening new maritime routes in the Arctic contributed to shifts in maritime policies and economic opportunities.

The United Nations Convention on the Law of the Sea (UNCLOS) (1982) established a comprehensive legal framework for maritime disputes, exclusive economic zones (EEZs), and freedom of navigation [13]. It has promoted stability in maritime affairs by providing guidelines for resolving territorial disputes and managing ocean resources, as shown in Figure 9.

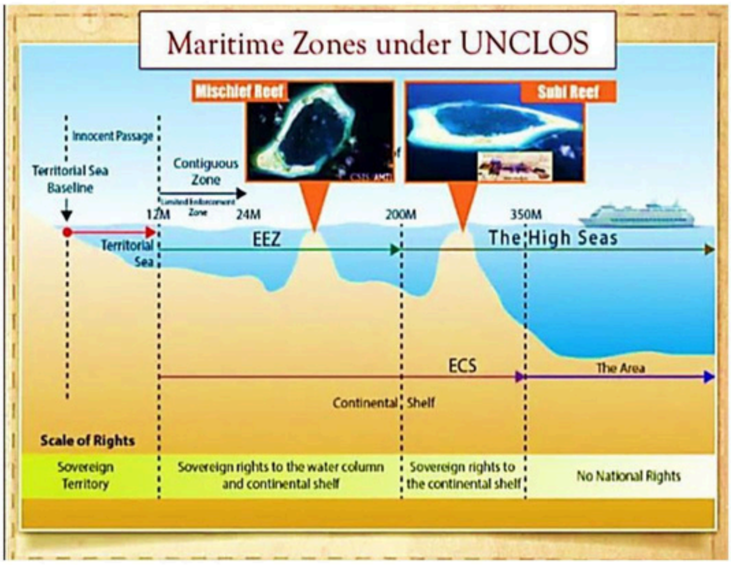

Fig. 9. The Maritime Zones under UNCLOS

E. RECOMMENDATIONS FOR SHAPING THE FUTURE

- *Arctic Navigation:* The melting of Arctic ice due to climate change introduces new maritime routes, potentially transforming global trade patterns. Arctic nations, including Russia, Canada, and the Nordic countries, are positioning themselves to capitalise on these routes, leading to increased geopolitical competition and cooperation over resource extraction, environmental protection, and security, as shown in Figure 10[14].

Fig. 10. Arctic Navigation

Geopolitical Competition in the Indo-Pacific: The Indo-Pacific region is a focal point for maritime geopolitics due to its strategic sea lanes, contested maritime territories (e.g. South China Sea), and economic importance. The rivalry between major powers (China, the United States, India, and others) will influence maritime security arrangements, infrastructure investments, and regional trade dynamics.

Environmental Regulations: The continued emphasis on eco-friendly sustainability will drive stricter regulations in maritime operations, particularly concerning emissions, ballast water management, and marine litter. Geopolitical discussions will focus on balancing environmental protection with economic interests and influencing global shipping practices and policies.

CONCLUSIONS

In conclusion, the realm of maritime geopolitics presents a dynamic landscape marked by both opportunities and challenges. The maritime sector faces significant transformations from the opening of new Arctic routes to the strategic rivalries in the Indo-Pacific and the impact of technological advancements and environmental regulations.

Moving forward, international cooperation, adherence to established legal frameworks like UNCLOS, and sustainable practices will be essential in fostering stability, security, and prosperity in global maritime affairs. Continued collaboration among nations, supported by organisations such as the International Maritime Organization (IMO), will play a crucial role in shaping a sustainable maritime future.

By navigating these complexities with foresight and collective action, we can harness the potential of maritime trade, preserve marine environments, and ensure that the benefits of global maritime connectivity benefit all nations and communities equitably. Together, we can steer towards a future where the seas unite us in prosperity, security, and shared responsibility for the oceans that sustain our planet.

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[1] https://openai.com/index/chatgpt/

[2] Burak Sakir Seker, Transnational Press London, ISBN:978-1-80135-116-4, Global Maritime Geopolitics.

[3] https://www.visualcapitalist.com/mapping-the-worlds-key-maritime-choke-points/

[4] https://srilankatwo.wordpress.com/2021/04/01/mapping-the-worlds-key-maritime-choke-points/

[5] https://www.freightwaves.com/news/global-trade-at-crossroads-geopolitical-risks-loom-inflation-abounds

[6] DH Web Desk, www.deccanherald.com

[7] https://www.linkedin.com/posts/andyyakulis_geopolitics-globaleconomy-globalbusiness-activity 7147927021115904000-xfrD

[8] https://www.lotus-containers.com/en/geopolitical-events-affect-shipping-rates/

[9] https://www.isquareintelligence.com/guides/baltic-dry-index

[10] https://www.dnv.com/maritime/insights/topics/maritime-cyber-security/

[11] Chris Weaver, CISSP, CC www.linkedin.com

[12] https://www.imo.org/en/MediaCentre/SecretaryGeneral/Pages/Global-shipping-and-geopolitics-roundtable-speech.aspx

[13] https://iilss.net/difference-between-islands-and-rocks-in-law-of-the-sea/

[14] https://www.researchgate.net/figure/Arctic-Shipping-Routes-Eurasian-Geopolitics-2021-With-the-increasingly-diminishing-of_fig2_354375446https://www.researchgate.net/figure/Arctic-Shipping-Routes-Eurasian-Geopolitics-2021-With-the-increasingly-diminishing-of_fig2_354375446 Shipping-Routes-Eurasian-Geopolitics-2021-With-the-increasingly-diminishing-of_fig2_354375446

[15] By Ralf Emmers, Geopolitics and Maritime Territorial Disputes in East Asia Edition 1st Edition First Published 2009, London, ISBN9780203875018.

[16] Arsenio Dominguez, https://www.un.org/en/un-chronicle/applying-law-sea-protect-international-shipping

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