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Evaluating the Implementation of Waste Management Practices on Ships: A Study of Compliance and Effectiveness at the Port of Jeddah, KSA

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Abstract: Ship waste management is essential to ensuring compliance with laws of international maritime mainly MARPOL Annex V which mandates effective waste management practices to avoid marine pollution. This study emphasizes assessing waste management compliance among ships operating at Jeddah Port, estimating waste segregation and dumping practices, recognizing challenges faced by ship crews, and suggesting recommendations for improvement. A descriptive and cross-sectional research design was implemented, using an online survey targeting crew members from various ships at Jeddah Port. Data collection included both open-ended and closed-ended questions to access quantitative and qualitative insights on MARPOL compliance and waste handling practices. 30 Participants were selected through convenience sampling. The findings showed notable gaps in compliance with MARPOL Annex V, with deficiencies in waste segregation, disposal methods, and crew training. Challenges such as insufficient port reception facilities, inadequate waste storage capacity, and unsatisfactory crew awareness of MARPOL protocols were identified as significant barriers. Despite the occurrence of regulatory frameworks, execution and implementation remain inconsistent. The study concludes that increasing crew training programs, refining port infrastructure, and ensuring stricter enforcement of waste management regulations are critical to highlighting these challenges. These actions will show to better compliance, better waste handling practices, and the advancement of environmental sustainability at Jeddah Port.

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I. INTRODUCTION

Waste management on ships is an important factor for proper compliance with international maritime law and the protection of the ocean environment. Based on IMO's guidelines, ship waste disposal is guided by regulatory frameworks like MARPOL Annex V, which requires the adoption and practice of sound waste management procedures, including shipboard marine pollution emergency announcement plans (IMO, 2017). Such frameworks highlight the universal obligation of players in the shipping industry to prevent different environmental risks posed by wastes emitted by ships.

The management of waste and waste disposal cannot be over-emphasized in handling challenges that affect port and coastal areas. Kalomo (2018) and others establish inadequacies of existing port reception facilities, for instance, the Port of Walvis Bay for absorbing the growing volumes of SGWs. In the same way, Ülker et al. (2023) have also described that ports like Istanbul are struggling with waste reception performance problems and need a better method for higher compliance. Thus, the results of this study suggest that there is a need for ports currently facing waste management issues such as ports in Jeddah to rise to these rising environmental demands.

Crew management and competency of employees involved by training is also another significant factor in shipboard waste management. For instance, Kim and Seo (2019) showed that effective maritime training ensures that individuals on a crew are better aware and develop better practices concerning the MARPOL regulation on waste management. Kamis et al. (2020) have reinforced this notion pointing out how through basic training seafarers develop a safety-oriented mindset that can include environmental management as well.

- *Problem Statement*

The shipping industry engulfs a lot of waste which if not properly addressed pollutes the marine environment. Discouraging decision-making is not easy, even with strict legal measures like MARPOL Annex V in place, many ports and ship operators do not always adhere to it. Jeddah Port is

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one of the large sea ports in the Kingdom of Saudi Arabia experiencing pressure in compliance of its wastes with international standards. Consequently, this research aims to assess the levels of compliance as well as efficiency of these practices at Jeddah Port.

Research has shown that ports across the globe are struggling with waste management structures and efficiency. According to Kalomo (2018), the infrastructure at the Port of Walvis Bay lacks effectiveness in the management of waste whereby occasional environmental hazards are observed. Likewise, Ülker et al. (2023) pointed out deficiencies in the subject of performance concerning ports in Istanbul and recommended the imperative of implementing innovations in the waste reception and processing system. Constraints such as limited ability to pare down waste and insufficient disposal techniques show that these ports such as the port of Jeddah need to upgrade their conventional methods to meet MARPOL stipulations and the best practices in the market.

The level of training and experience of a crew is another important determinative factor concerning the extent of adherence to waste management standards. However, many of these ports, including Jeddah, still have milestones in training and knowledge that hinder the realization of compliance.

➢ *Objectives*

- To assess the level of compliance with MARPOL Annex V waste management regulations among ships at the Port of Jeddah.
- To evaluate the effectiveness of waste segregation, disposal, and record-keeping practices on board ships.
- To identify challenges faced by ship crews in implementing waste management procedures.
- To propose recommendations for improving waste management practices to ensure better compliance and environmental sustainability.

II. RESEARCH METHOD

This study employs descriptive and cross-sectional research design. Exploratory research seeks to give an account of the qualitative and quantitative status of marine waste management and MARPOL V compliance by crews. Cross sectional design enables collection of information at one time from a given population regarding their perception, behavior and experience in handling wastes on ships. The research mainly concentrates on crew proficiency, waste control and compliance and also the analysis of areas of effectiveness and inefficiency in waste control procedures.

➢ *Data Collection Methods*

Survey was conducted online with target participants being crew members from different ships at Jeddah port. The survey adopted a number of questions aimed at determining qualitative and quantitative information on MARPOL compliance and waste management. As a result of the nature of research and the need to compare results across multiple participants, a survey was the most appropriate way of data collection. The open-ended and closed-ended questions were used in the survey facilitated measurable answers, this made it easier to use statistical analyzing to compare the data.

➢ *Participant Selection*

The target population for this research is crew members from ships from different zones of international waters involved in waste disposal and enforcement of MARPOL protocols. The participants were randomly recruited through the non-probability sampling technique known as convenience sampling. This approach was used given the challenge of obtaining the list the crew members and the logistics of researching on different boats. The sample of the study was derived from 30 respondents; every participant was administered the questionnaires according to their encounter and perception on waste management aboard their vessels.

➢ *Survey Design*

The survey was designed after assessing the literature on the MARPOL Annex V compliance, waste management and training of the crews. The questions in the survey include basic questions about backgrounds of crew, ship operational experience, their understanding of waste management, waste segregation on board including type of wastes generated, management of wastes, whether they are compliant with MARPOL requirements or otherwise and satisfaction levels with regards to existing port reception facilities. The survey was therefore divided into segments, each segment focusing on a particular subject/area of waste management and legal compliance.

This survey also used multiple choices questions as well as the questions that employed Likert scale specifications. For the collection of attitudinal and perception data, five Likert-scale questions related to compliance with MARPOL regulation, waste management and issues faced by the crew were included. Potential response options were equal to 1 to 3 for questions that addressed: Crew proficiency, waste management, and areas for improvement were categorized as 1: poor, 2: average, and 3: excellent. To measure MARPOL knowledge, questions were posed with a Likert rating scale of 1 to 5, where 1 equal ‘I strongly disagree’ and 5 equals ‘I strongly agree.”

- *Key Areas Covered in the Survey Included:*

✓ Crew Proficiency: Assessing the crew's theoretical and practical understanding of MARPOL waste management regulations.
✓ Waste Management Practices: Evaluating the effectiveness of onboard waste segregation, waste disposal methods, and waste management plans (WMP).
✓ MARPOL Compliance: Assessing the crew's adherence to MARPOL Annex V regulations, including waste segregation and disposal procedures.
✓ Challenges in Compliance: Identifying the barriers to full compliance with MARPOL regulations, such as limited storage capacity, training deficiencies, and access to port reception facilities.

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✓ Satisfaction with Port Reception Facilities: Gauging the crew's satisfaction with the availability and effectiveness of port reception facilities at various ports.

➢ *Data Analysis*

The survey responses were then reviewed to complete the survey where descriptive statistics was used as a method to analyze the data and summarize the results. Quantitative data specified below were employed to analyze the results of each survey based on means and standard deviations. This enabled estimation of the mean and standard deviation of the responses which in turn exposed general proficiency of crew, waste disposal and MARPOL regulation adherence levels.

For categorical data, the response frequency rate for each option was computed in order to examine the Crews' practices as well as their attitudes towards waste management. To enhance comprehension of the results, data was presented in forms of pie charts, bar charts, and tables.

- Mean: The average score for each question was obtained using mean whereby the latter gave a general summary of the crew's response. A mean above the benchmark was interpreted to mean that the practices being measured were good, or the levels of compliance with the standards being expected were high.
- Standard Deviation: The measure of variability or dispersion was done by standard deviation. A low standard deviation value meant that answers submitted were homogeneous while high standard deviation meant that answers were heterogenic.
- Frequency Distribution: For categorical data, the use of a frequency distribution allowed understanding the pattern of response and determine areas of agreement or disagreement among the majority of the crew members.

III. RESULT AND FINDING

Table 1 shows demographic analysis in this survey data, presents there were sample size of 30 participants, highlights the distribution of job roles, experience levels, and vessel types. Among the respondents, the majority (52.8%) were Second Engineers, followed by Chief Officers (32.3%) and Environmental Compliance Officers (12.9%). Regarding years of experience, over half of the participants (56.5%) had 6–10 years of experience, 34.4% had 11–20 years, and a smaller proportion (9.4%) reported more than 21 years of experience. In terms of vessel operation, the majority (78.8%) worked on tanker ships, while the remaining 21.2% operated container ships. As shown in following figures:

Table 1 Demographic Analysis (N=30)

Variables	Options	Frequencies	Percentage %
Job	Environmental Compliance Officer	4	12.9
	Second Engineer	16	52.8
	Chief officer	10	32.3
Experience years	6-10 years	18	56.5
	11–20 years	9	34.4
	21+ years	3	9.4
Vessel Operated	Tanker Ship	23	78.8
	Container Ship	7	21.2

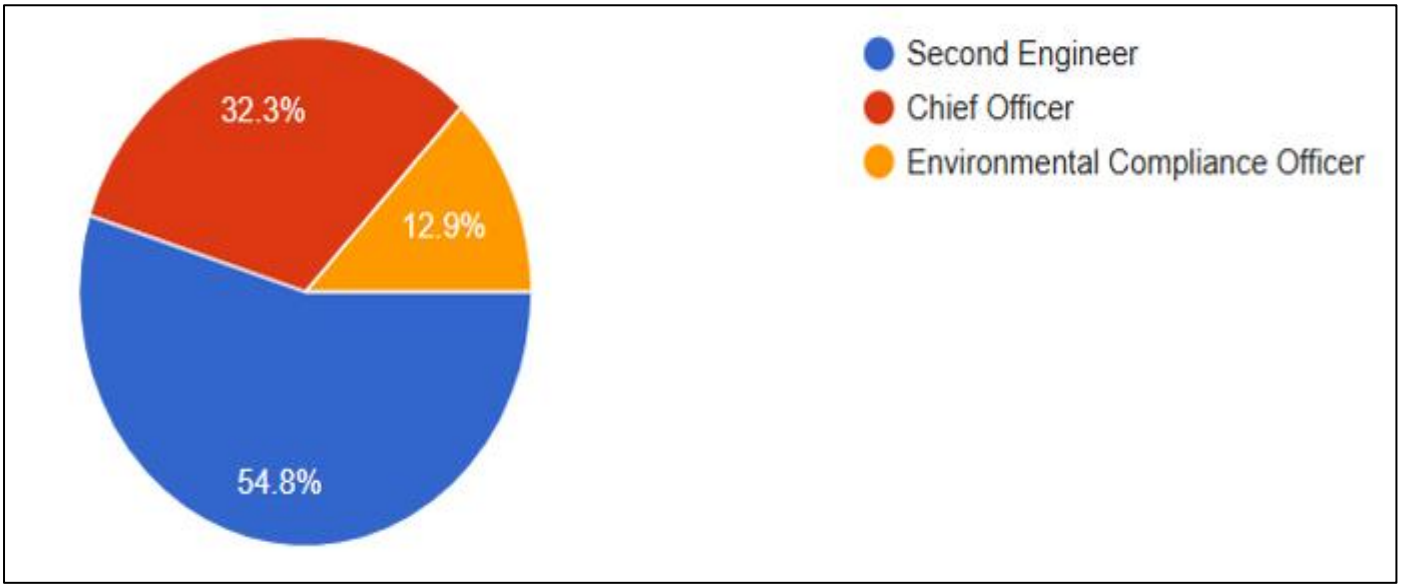

Fig 1 Job Ranks of Participants

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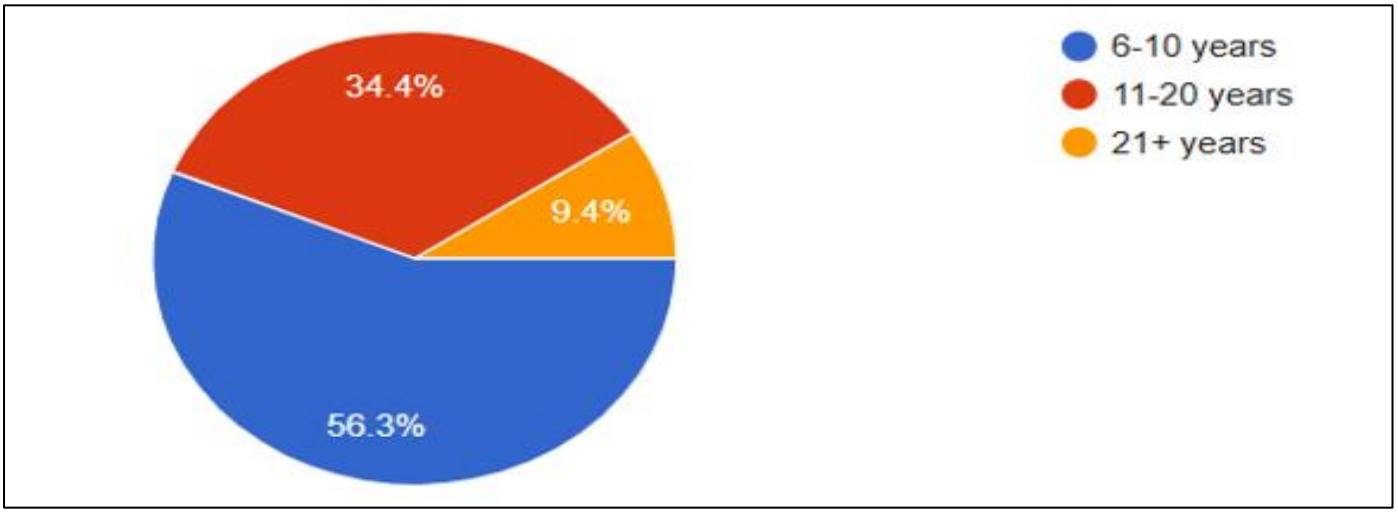

Fig 2 Job Experiences of Participants

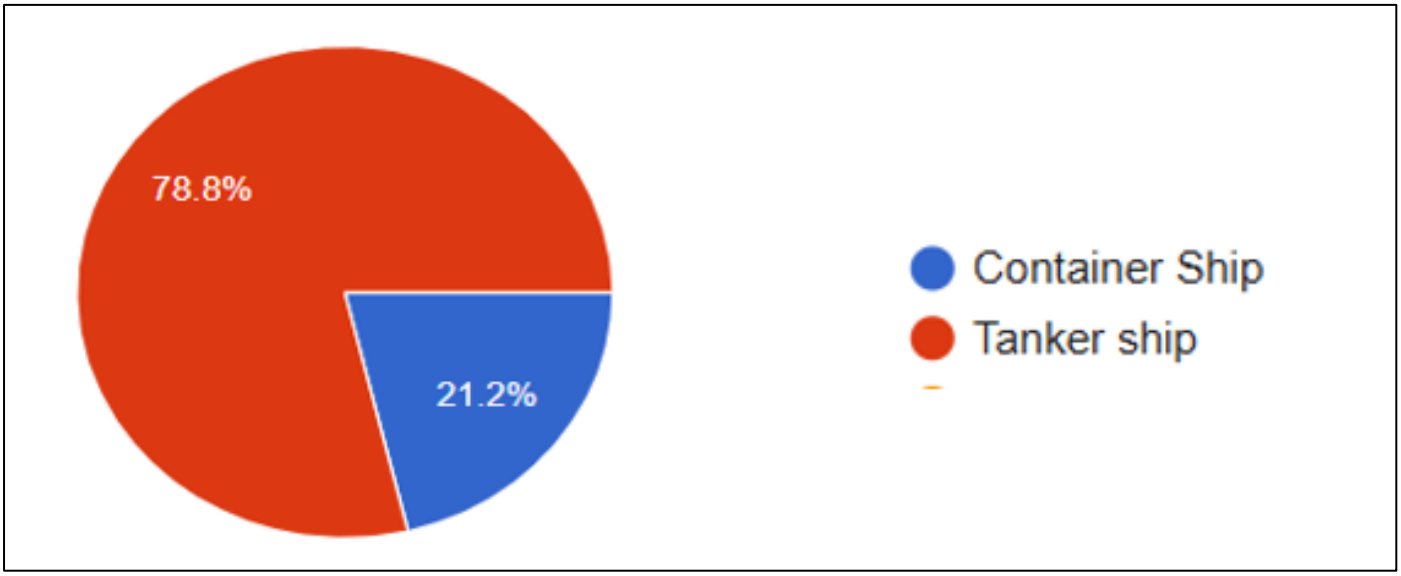

Fig 3 Vessel Operated by Participants

➢ *Mean and Standard Deviation*

The mean is thus a measure of central tendency that gives average of a set of values that is obtained by adding all values together and then dividing by the number of observations (McGrath et al., 2020). It gives one figure that gives the overall picture of the data an analyst or anyone using the media has to interpret. The standard deviation, however, measures range or variability of the datasets, which shows how much each element differs from the average of all the values in a given set (Pramanik et al., 2023). An analysis of the identified factors also gives a statistical inclination concerning the proficiency level of crew and the manner in which they manage wastes as well as their compliance level with the MARPOL regulations as well as the areas that can benefit from the improvements. As 20 questions were given to the participants, the following table represents the frequencies of response of 30 participants. All questions asked were multiple choice questions and all of the questions had number responses that ranged from 1 to a maximum of 3 numbers in Compliance with MARPOL Regulations it recorded the least number of 5. The achieve mean response scores in response to each question were also different Only one item 'Crew proficiency' received a mean response score of 2.87 on 1-3 scale, and there was a little variation around the mean, assessed by standard deviation of 0.216 This indicates that most of the respondent had high Crew proficiency levels. Waste management practices had a mean of 2.46 (scale 1 – 3) and SD of 1.008 demonstrating moderate practices but with a great range. The highest mean results regarding MARPOL regulation were observed and amounted to 4.17 points (scale 1-5) with a minimum standard deviation of 0.930, which shows a high level of adherence to regulations but with less variability. The measure termed standard deviation indicates the amount of scatter of the responses; the larger that figure the more spread out the repsonces are. On the other hand, improvement areas averaged a score of 2.44 (1–3) with a standard deviation of 1.050 with Table 4 but is also indicative of areas that can still be enhanced with an indication of a wider range of responses. Collectively, these analyses indicate high levels of compliance, but also show that there are significant variations within waste management and the degree of improvement required.

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Table 2 Descriptive Statistics of Variables

Descriptive Statistics						
	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Crew Proficiency	30	1	3	2.87	.100	.216
Waste Management Practices	30	1	3	2.46	.089	1.008
Compliance with MARPOL Regulations	30	1	5	4.17	.092	.930
Improvement Areas	30	1	3	2.44	.099	1.050
Valid N (listwise)	30					

➢ *Assessment of Crew Proficiency in Adhering to MARPOL Regulations*

From the responses received during the survey, highlights two key aspects of crew proficiency in adhering to MARPOL regulations regarding waste management: Of the thirty respondents, the majority of them (78.8%) gave the highest perception score of 3; regarding their understanding of MARPOL waste management regulations. This suggests a very good understanding of the regulations in theory, among the crew. Conversely, 15.2% rated their understanding in levels 2 and 6.1% in level 1, evidencing some level of variation of comprehension that could be enhanced by further ethnographic training.

An amazing 87.9% of the respondents associated actual compliance to the established MARPOL waste management procedures at a high level (level 3). A few of them quantified their adherence at lower levels: 6.1% for both level 1 and level 2. This shows that although a large majority of the crew members apply the procedures properly, there could be a sector of suboptimal respondents who could possibly make improved compliance if they were given specific individualized attention. Overall, participants demonstrated a high level of knowledge and compliance with the MARPOL regulations, it is also important to notice potential for increasing its effectiveness.

➢ *Frequency of Wastes Segregation*

An aspect measured by the 30 participants in this survey includes the segregation of waste on ships as presented on the pie chart in figure four. 87.9% stated that they segregate wastes generated by ships on daily basis, which suggests that most of respondents have developed high standard of daily waste management. Even less, 12.1%, dispose off waste by segregation weekly while none of the respondents mentioned of doing so monthly or not at all. This data paints a picture of good concordance with the requirements for MARPOL waste management as displayed by daily segregation of wastes. The lack of “monthly” or “never” responses indicates that the crew considers routine waste sorting as their operational axiom.

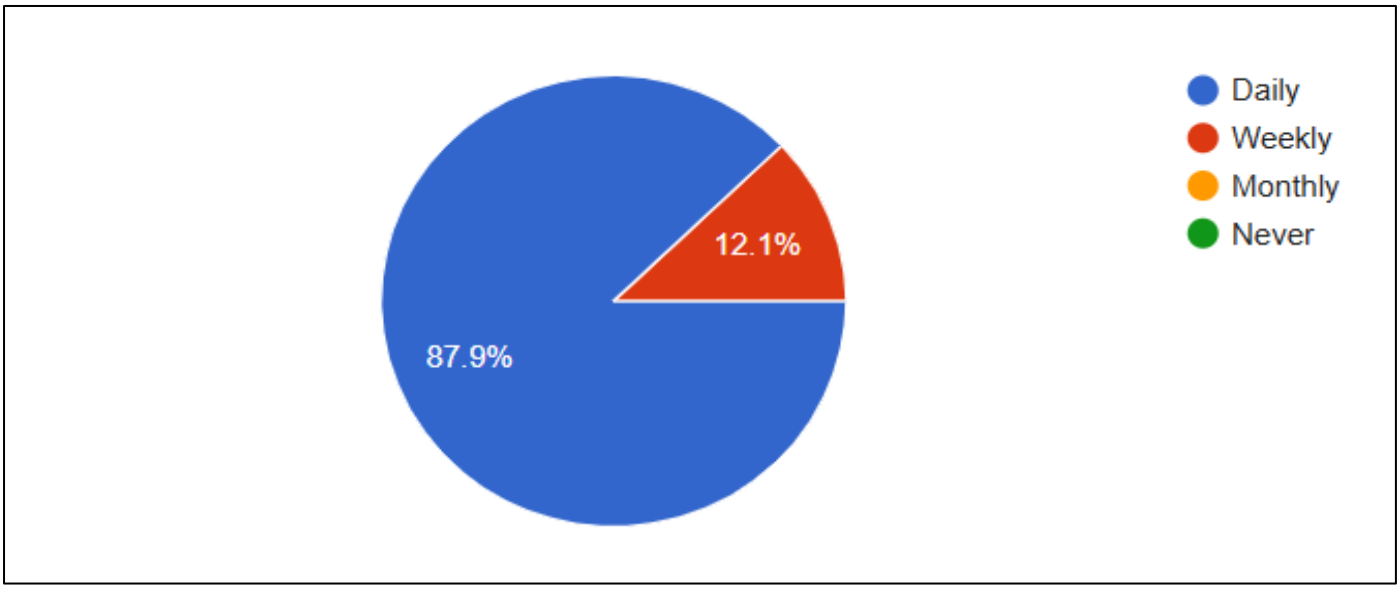

Fig 4 Ship Generated Waste Segregation

Figure 5 bar chart highlights the various types of waste generated on ships, based on survey responses. Plastics are the most commonly reported waste type, with 97% of respondents indicating its presence, followed closely by oil residues (sludge), which 93.9% of respondents identified as a significant waste category. Food waste is also highly prevalent, with 90.9% of participants acknowledging it as a common issue on ships. In contrast, chemical or hazardous waste is less frequently reported, with 54.5% of respondents mentioning it. These findings underscore the widespread generation of plastics, oil residues, and food waste on ships, emphasizing the need for robust waste management systems to address these issues, while also highlighting the challenges posed by hazardous waste, which requires specialized handling.

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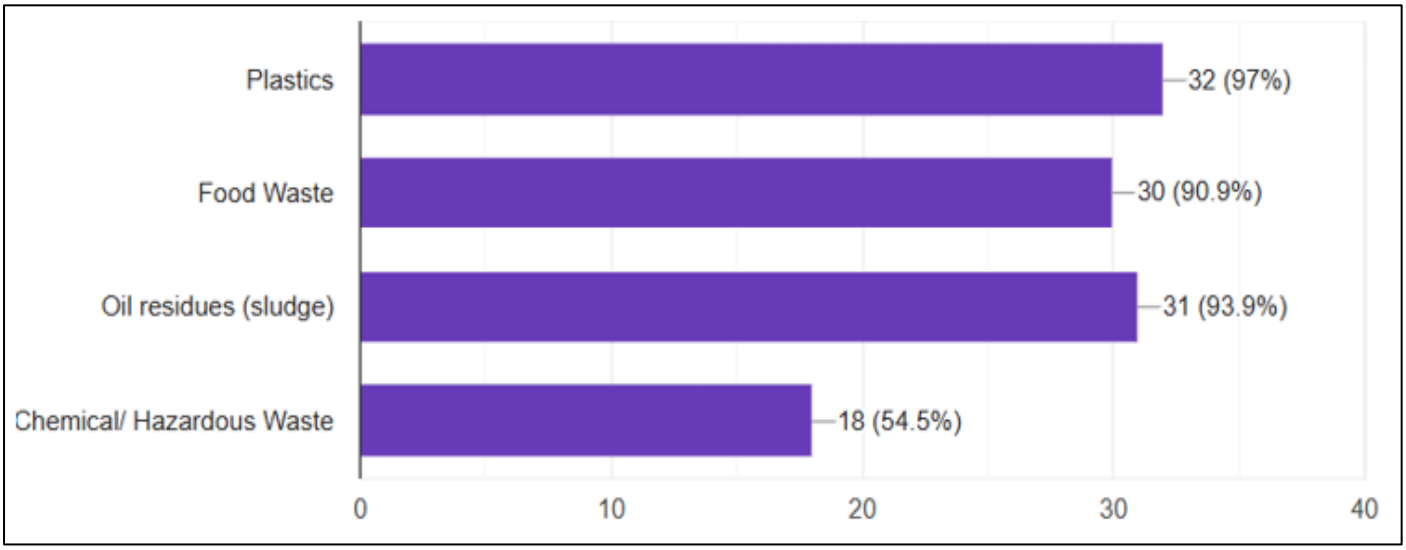

Fig 5 Types of Waste Generated on Ship

➢ *Waste Management Practices*

In surveys, it gives information about the WMP concerning the management of waste on the ships and the ability of onshore waste disposal.

In the first chart, the mean score for onshore waste disposal was 4; 81.8% of the participants gave the onshore waste disposal a rating of '4' meaning that most participants think that it is effective to a great extent. A fewer number said it was "3" (9.1%), and 6.1% and 3% labelled it "1" not effective and "2" less effective, respectively. This is further improved by the fact that the onshore waste disposal has been deemed efficient by most while a section of the people details inefficiencies.

Second it measures the level of WMP being embraced. Of those, 78.8% responses were pointing to value "4", which means 'fully implemented', thus indicating that the majority of shipping companies have an instituted and followed through proper waste management strategy. Whereas, at "3" percent, only 12.1% said it was "3" percent, 6.1% said it was "1" whereas 3% said it was "2". Results indicate that although the handling and management of wastes and pronounced by WMP implementation is mostly effective across the fleets, there may be instances that warrant improved WMP among certain vessels. The data highlights the methods used for treating waste before disposal on ships. Incineration is the most commonly used method, with 81% of respondents indicating its practice, reflecting its efficiency in reducing waste volume and eliminating hazardous materials onboard. Crushing or compacting waste is used by 69.7% of respondents, likely as a means to minimize the space occupied by waste before further handling or disposal. Meanwhile, 72% of respondents reported discharging waste at port reception facilities, emphasizing the importance of ports in supporting waste management efforts. These findings suggest a preference for onboard waste reduction methods, such as incineration, while also relying on port facilities for waste disposal, shown in figure 6.

Fig 6 Waste Management Practices

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- *MARPOL Annex V Compliance and Satisfaction*

The interpretation highlights the compliance with the regulation in MARPOL Annex V; the frequency of inspections; and perceived efficiency of reception facilities of ports. When asked about the last one year's MARPOL Annex V related inspection, 18.2% respondents said that their ships indeed have been inspected, 15.6% said no, 9.4% respondents were uncertain and opted for "maybe". Despite, the number of inspections being relatively low, 97% of the respondents were fully confident that their ship fully complies with the MARPOL Annex V, showing high level of confidence in compliance with rules to prevent pollution by garbage from ships. This remaining difference could also be suggesting self-regulating instruments or internal assurance in waste management programs.

Regarding the satisfaction level of port reception facilities at the Port of Jeddah, the response obtained from 30 participants reflected a general but mixed satisfaction mind set where 54.4% are satisfied and 18.2% very satisfied this could mean that the reception facilities was found adequate by the majority of the shippers. Slightly under a quarter, 27.4%, said it was 'neutral' but this still leaves mutual understanding open to improvement. The lack of actual percentage as to dissatisfactions categorically connives to insignificantly or no large dissatisfaction given which also translates to an overall positive perception of these facilities. These findings imply that although MARPOL Annex V compliance self-evaluation is high, continual assessment/monitoring of MARPOL Annex V compliance and eventual improvement to the port reception services for ship-generated waste can contribute to better waste management satisfaction.

- *Challenges in Achieving Full Compliance with MARPOL Waste Regulations*

The responses to this survey provide the following insights for challenges that ships may encounter in meeting the MARPOL waste requirements. The foremost impairment is the low amount of space onboard a ship, reported by 58 percent of participants. This implies that where there is small storage capacity of waste onboard, it becomes difficult to observe the MARPOL regulations with regard to segregation and disposal of waste. Further, 39% of the respondents pointed to lack of adequate training as an issue which means that some of the crew members don't even posses the knowledge let alone the skills that nature dictates must be employed when discharging and managing wastes.

Other issues affecting disposal include the admission of having a challenging time in getting access to port reception facilities reported by 13% of the respondents which could practically slow or complicate the disposal process. Also, the survey revealed that 16% of the respondents observed high costs of waste management as a limitation to the proper management of wastes. These outcomes informed the need to consider enhancing the storage capacities, besides training the crew on MARPOL waste regulations, and the availability as well as affordability of efficient waste disposal services.

- *Crew Training on MARPOL Waste Management Requirements*

The survey shows that overall, 93% of the respondents agree that adequate training programs can be provided to the crew pertaining to the MARPOL waste management regulations. This means that most of the firms possess effective training measures for its crew to embrace MARPOL provisions and prevent pollution of the seas. At the same time, 3% of the respondents noted that training was insufficient, and 4% could not decide on the availability of training programs. In general, a vast majority of the respondents expressed a high degree of dedication to crew education on MARPOL waste management with a minority of the responses suggesting that the information provided was insufficient or ambiguous.

IV. RESEARCH DISCUSSION

The data collected from the research can be of great importance in unraveling the current practices on ships with special reference to compliance or lack thereof to MARPOL Annex V which deals with prohibition of pollution of the surrounding environment by garbage from ships. The responses from 30 survey participants indicate various problems, assets, and opportunities for further evolution of the crews' competence, efficiency in waste management, and conformity with the existing international standards.

The assessment of crew competency reveals excellent knowledge of the MARPOL regulations on the theoretical level, with the average score of 2.87 on the scale of 1 – 3. This means most of the crew members are conversant with the standard waste management practices expected of them. However, there is the small scope of development, which is proved by standard deviation 0.216, though it pointing rather low and shows variation in skill's degree. Specifically, MARPOL waste management procedures were assessed in practical terms; the respondents' overall score of compliance was as high as 87.9 %. This high level of compliance can be attributed to the fact that the majority of the respondents, that is 87.9% reported that they disposed wastes according to the daily basis and as it has been agreed in MARPOL, wastes are supposed to be disposed frequently.

These notwithstanding, the survey exposes large variations in the management of wastes, especially in the types of wastes and the methods used for their disposal. , however, out of all ships, a significant proportion produces plastics, oil residues and food waste however there is a major issue in the disposal of hazardous waste since it is reported less frequently but due to the fact that it poses a serious problem it must be handled in a special way. The uptake of incineration with 81% note to be using it in the treatment of waste onboard shows a good means of minimizing waste onboard but there is still the problem with limited space to store such waste onboard, only 42% note to be committing to the full implementation of the MARPOL regulations. Inability to contain storage space underlines the need to expand shelving area and enhance the waste compression techniques.

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Respondents showed a high level of confidence in the compliance of their ships with MARPOL Annex V regulation with 97% of the respondent ships believing to be fully compliant despite an evidently low level of inspections; only 18.2% of the respondents reported having been inspected in the past 12 months. This divergence indicates that, whereas organizations may report high levels of compliance, there is potentially a divergence between belief and practice regarding current regulation compliance, thus the need for external auditing to check for compliance lapses much later. In addition, the level of satisfaction with port reception facilities at the Port of Jeddah show overall positive attitudes with 54.4% of the respondents satisfied with a further 18.2% very satisfied. However, there is potential for improvement since 27,4% of the participants were neutral, thus, the improvement of such facilities may help to enhance the efficiency of waste disposal.

It is also apparent that training continues to be an important element of achieving the type of compliance that meets the objectives of the MARPOL convention. According to the survey most of the respondents agreed on option "yes" that there is adequate training programs to be made for the crew.; The given below figure of percentage indicates that about 93% of the respondents agreed that there are enough training programs for the crew in most of the ships for learning the waste management Information. The 3% that dissented and another 4 percent who are still not sure that constant subsequent and assurance ought to be incorporated in the training programs. Crew training and the augmentation of feedback, especially for the junior operators, along with an enhancement of knowledge regarding the disposal of waste content and regulations are important factors for maintaining uniformity of procedure.

The response received by the respondents in this regard is as follows: Cabin on board space/deck space was considered to be inadequate onboard by 58% of the respondents which affected efficient waste management. This is coupled with the fact that the standard deviation scores suggested that the randomness of waste management measures that were taken by organizations needed improved solutions for improving on waste management practices. Another important problem is access to port reception facilities indicated by 13 of the respondents. This limitation underlines the demand for increased affordable approaches.

Some of the recommendations of the survey relate to the need to enhance waste management practices at sea as described below. These are such measures as increasing the number of waste compaction instruments, assigning individual tasks for discharge of wastes to the crew, and introducing more frequent inspections to check their observance. In addition, improved methods of waste disposal, rubbish sorting that could be applied in shared working spaces could as well promote high standards in waste disposal. Some of the suggestions include uptake of large storage facility, enhancement of waste disposal services, and bringing down of the extraordinarily costly shore-based disposal facilities.

Pre-sea and regular onboard training and raising awareness level should be improved to guarantee all the crew members' understanding of MARPOL Annex V and new amendments like those introduced by SIRE 2.0. Moreover, understanding of zero-pollution goals, along with the usage of beneficial actions and stimulus for adherences, would greatly help in attaining of environmental objectives set by MARPOL.

In the survey data indicate a relatively high degree of MARPOL awareness and a clear willingness among ships' personnel to adhere to MARPOL requirements on the management of waste. Nevertheless, there are issues to do with storage space, trainings and the costs and availability of waste management services, which should be addressed. Hence, the need to fix these problems through enhancing infrastructure, recurrent training, and access to port reception facilities, ships should increase their compliance with the regulation of the MARPOL ANNEX V, and actively reduce marine pollution to the environment.

V. CONCLUSION

This study provides valuable insights into waste management practices on ships and their compliance with MARPOL Annex V. Findings indicate a high level of awareness and implementation among crew members, with 78.8% rating their understanding of MARPOL regulations as excellent, and 87.9% confirming adherence to waste segregation protocols. This aligns with the impact of online training programs aimed at improving crew knowledge.

Despite this, several challenges remain. Waste management inconsistencies, particularly in segregation policies, were identified. While plastics, oil residues, and food waste are well-managed, hazardous waste disposal remains a challenge. Additionally, 58% of respondents cited limited onboard storage as a key issue, affecting proper waste segregation. The availability of port reception facilities was rated positively by 54.4% of respondents, yet 27.4% remained neutral, suggesting room for improvement.

Another concern is the low frequency of MARPOL inspections, with only 18.2% of crew members experiencing an inspection in the past year. This may reduce external motivation for compliance. Furthermore, 16% of respondents indicated that high waste disposal costs at shore facilities deter compliance. Addressing these issues is critical to ensuring sustainable and effective waste management practices.

RECOMMENDATIONS

- *Enhanced Training & Awareness*

While most crew members possess adequate knowledge, some still require additional training. Specific courses for junior personnel and those unfamiliar with MARPOL nuances should be introduced. Regular refresher training, drills, and exercises will reinforce compliance.

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- *Stronger Waste Segregation Policies*

Ships should implement standardized waste collection and segregation procedures, particularly in public and high-traffic areas. Assigning responsibility for waste management among designated crew members will ensure better compliance.

- *Regular MARPOL Inspections & Audits*

Increasing the frequency of MARPOL compliance checks will reinforce adherence. Stricter enforcement will discourage non-compliance and ensure industry-wide accountability.

- *Incentives for Compliance*

Implementing reward-based systems for crew members who excel in waste management can further encourage compliance. Recognizing and incentivizing best practices will help build a culture of environmental responsibility.

FUTURE IMPLICATIONS

The study underscores the need for ongoing advancements in waste management systems aboard ships. Future efforts should focus on developing smart waste segregation technologies that minimize manual sorting and increase efficiency. Innovations such as automated sorting and waste-to-energy conversion systems will help reduce onboard waste volumes. Further investment in sustainable disposal methods, including biodegradable packaging and circular economy strategies, could revolutionize maritime waste management.

Enhancing port reception facilities will be crucial as shipping activities continue to grow. Future policies should focus on reducing disposal costs, increasing waste-handling efficiency, and incorporating environmentally friendly disposal technologies. These improvements will encourage compliance and support the broader goals of MARPOL Annex V.

Regulatory bodies should consider integrated compliance tracking through centralized databases that monitor waste management practices globally. This would improve transparency and allow regulators to identify and address non-compliance more effectively.

Lastly, fostering a zero-pollution culture within the maritime industry is essential. Encouraging sustainable practices, such as green shipping initiatives and reduced waste production, will support global environmental conservation efforts. As shipping remains a major contributor to marine pollution, continuous improvements in waste management, policy enforcement, and technological innovation will be critical in mitigating its impact.

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