Efforts to Prevent Oil Pollution During Loading and Unloading on the MT. Sanana Ship

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Abstract.
Background: Maritime transportation plays a vital role in energy distribution, while tanker loading and unloading operations pose a risk of oil leaks that can damage coastal ecosystems and livelihoods. Objective: This study aims to identify the causes of spills during cargo transfers at MT. Sanana, assess the impact if the leak is not immediately addressed, and formulate practical preventive measures. Method: A qualitative case study was conducted during a 12-month sea practice (August 22, 2024–August 26, 2025). The population included operational personnel and ship documents, with purposive sampling for key informants (master, chief officer, second officer, third officer). Data were collected through participant observation, semi-structured interviews, and documentation studies, analyzed using inductive thematic coding and triangulation. Results: It was found that the implementation of SOPs, the availability of oil spill kits, and routine maintenance were effective in mitigating small leaks; the main obstacles were worn gaskets and valves, procedural omissions, and suboptimal communication. Conclusion: Effective prevention requires synergy between technical maintenance, rigorous pre-operational checks, and ship-terminal coordination; Recommendations include replacing worn fittings, enforcing checklists, and regular simulation training. Limitations: single case study and participatory role of the researcher.
Keywords: *Loading and Unloading, Ship Safety, Pollution Prevention, Tanker Maintenance and Oil Spill.*

I. INTRODUCTION

Maritime transport remains the backbone of global energy distribution, with tankers playing a central role in moving crude oil and refined products between producers, refineries, and end consumers (Cari et al., 2022; Smith & Lee, 2023). In recent years, following the global economic recovery, tanker traffic volumes and the intensity of loading and unloading operations have increased, increasing exposure to the risk of oil leaks and spills, which have broad ecological and economic implications (Anderson et al., 2021; Zhao et al., 2024).

Operationally, tanker loading and unloading activities involve complex technical and procedural systems—pumps, transfer pipelines, valves, Oil Discharge Monitoring Equipment (ODME), and recording in the Oil Record Book—which require tight coordination between the ship's crew and terminal authorities to maintain the integrity of the loading channel and prevent pollution (IMO guidelines; Rahman & Yusuf, 2023). Empirical evidence from field studies and regional incident reports indicates that material failure (e.g., pipeline corrosion), human error (violation of SOPs or poor communication), and lack of inspection and preventive maintenance are often

contributing factors to spills during loading and unloading operations (Wijaya et al., 2024; Santos et al., 2023).

Previous research examining oil spills from tankers has identified a combination of technical, organizational, and environmental factors as key determinants of incidents, and demonstrated the effectiveness of various interventions such as structured maintenance programs (PMS), cathodic protection, and the use of calibrated monitoring equipment (Kumar et al., 2022; Oliveira & Mendes, 2024). However, many studies are general in nature or focus on major incidents, thus underrepresenting daily loading and unloading practices in the field, particularly for vessels operating in regional waters with varying infrastructure and monitoring characteristics (Lim & Hartono, 2023; Garcia et al., 2022).

Comparisons between studies reveal inconsistencies: some studies place material failure as the dominant cause, while others emphasize human factors and operational management weaknesses. Furthermore, methodological limitations such as small sample sizes and a lack of longitudinal data hinder robust assessments of the effectiveness of integrated prevention packages (Lee et al., 2023; Ibrahim & Santoso, 2024). Evaluations of the implementation of international regulations such as MARPOL 73/78 also reveal gaps between formal policies and field practices, particularly regarding documentation compliance and operational monitoring during loading and unloading (Putri & Hidayat, 2022; Noor et al., 2024).

Based on these gaps, this study aims to (1) identify and analyze the causal factors of the oil spill during the loading and unloading process on the MT. Sanana vessel, (2) assess the potential impact if the leak is not immediately addressed, and (3) formulate a package of operational and contextual technical and organizational prevention recommendations for ship crews and terminal managers. The urgency of the study arises from the high long-term ecological and economic consequences and the need to bridge the gap between international regulations such as MARPOL 73/78 and daily practices on local vessels and terminals; the novelty of this study lies in the integrated case-case approach that combines field observations on the MT. Sanana, multidimensional root cause analysis, and an assessment of the implementability of recommendations designed for the Indonesian regional operational context (Rahman & Yusuf, 2023; Oliveira & Mendes, 2024).

II. METHODS

This research uses a qualitative approach with a case study design on the MT. Sanana vessel to understand the phenomenon of oil pollution during loading and unloading activities in a real operational context. A qualitative approach was chosen because the research objective was to gain an in-depth understanding of the processes, practices, and causal factors in a natural setting without experimental treatment, as well as to interpret the meaning of the actions and decisions of the actors (Sugiyono, 2019; Creswell, 2022). By using a case study, this research focuses analysis on a single

representative case unit to obtain rich and flexible contextual data in terms of both collection techniques and interpretation.

Data collection was conducted through a combination of participant observation, semi-structured in-depth interviews, and documentation studies to capture the technical and organizational dimensions of the loading and unloading process. Participatory observation was conducted during the researcher's sea practice on MT. Sanana to record operational procedures, equipment conditions (pumps, pipes, valves), and interactions between the ship's crew and terminal personnel (Bogdan & Biklen, 2014; Emzir, 2021). Semi-structured interviews were conducted with key informants, namely the captain, first officer, second officer, and third officer, to obtain firsthand perspectives on prevention practices, incident experiences, and compliance with MARPOL Annex I, as well as Oil Record Book documentation (Sugiyono, 2019; Sudaryono, 2023). Documentation included examination of the Oil Record Book, maintenance schedules (PMS), inspection records, as well as photographs and field notes to support data triangulation.

The study population comprised all ship operational personnel and operational documents related to loading and unloading activities on MT. Sanana during the sea practice period. The sample was determined using a purposive sampling technique to select informants with direct knowledge and responsibility for the loading and unloading process and oil pollution prevention, namely the captain and officers (I–III). Furthermore, the documents selected as documentary samples were the Oil Record Book, PMS records, and relevant inspection reports during the study period (August 22, 2024–August 26, 2025). This purposive approach aligns with qualitative objectives that emphasize depth of information over statistical generalization (Creswell, 2022; Emzir, 2021).

Fieldwork began with obtaining access permits and explaining the research objectives to shipping company management and crew members. This was followed by routine observations during loading and unloading activities, semi-structured interviews according to the operational schedule, and the collection of operational documents for analysis. All interviews were recorded with the informants' consent and transcribed; observation notes were compiled daily and photographed whenever possible. Data collection was conducted throughout the 12-month sea practice period, allowing for repeated observations of activities, temporal verification, and longitudinal data enrichment.

Data analysis followed an inductive cycle of reduction, presentation, and conclusion drawing as recommended in the qualitative research tradition (Sugiyono, 2019; Sudaryono, 2023). The reduction phase included sorting and initial coding of transcripts and field notes to form thematic categories related to leak causes, prevention practices, and barriers to procedural compliance. The data were then presented in the form of a thematic narrative and a comparison matrix between observational findings, informant statements, and documentary evidence. Conclusion

drawing and verification were carried out iteratively until consistency of findings was achieved. To ensure data validity, this study employed method triangulation (observation, interviews, documentation), source triangulation (various crew roles), and theory triangulation by comparing empirical findings with relevant literature and MARPOL regulations (Denzin & Lincoln, 2018; Emzir, 2021). Furthermore, member checking was conducted by offering a summary of the findings to several key informants to validate interpretations.

The study adhered to the ethical principles of qualitative research: informed consent from all participants, confidentiality of informants' identities, and secure management of recorded data and documents. Acknowledged methodological limitations include the limited generalizability of findings due to the single-case study focus and potential researcher bias due to the participant's role. Mitigation measures implemented included data triangulation, a documentary audit trail, and critical reflection on the researcher's positionality during data collection (Creswell, 2022; Sudaryono, 2023).

III. RESULTS AND DISCUSSION

Data Presentation

1. Observation Results

The data obtained shows that the MT Sanana has consistently implemented Standard Operating Procedures (SOPs) for its loading and unloading processes. These SOPs include checking the condition of manifolds, wilden pumps, valves, and gaskets before loading and unloading. Furthermore, safety meetings are held to ensure all crew members understand their respective duties and responsibilities. The following serves as a basis for understanding the efforts being made to reduce the risk of oil spills:

1) Manifold Condition

Material type :*Casting iron*
Size : 8”ansi x 10” ansi
Last inspection : March 26, 2025
Condition :Ready to use

2) Wilden pump condition

Based on observations, the Wilden pump on the ship performed well and functioned optimally throughout the operation. The pump operated stably without any significant disruptions, such as leaks or pressure drops. Routine maintenance by the ship's crew also contributed to the reliability of this equipment, ensuring smooth and effective loading and unloading operations.

3) Valve and Gasket Inspection

Inspections revealed that the tanker's valves and gaskets were in poor condition. A leak was detected that could have compromised the piping system. The crew responded by halting the unloading process and using absorbent cloth to contain

the spilled oil. These efforts demonstrated that, despite the risk of contamination, the crew's vigilance and adequate equipment prevented the oil from spilling into the sea.

In addition to implementing SOPs, data also shows that MT Sanana possessed equipment to prevent oil pollution, such as oil containment kits, oil absorbent cloths, oil spill containers, and plugging pads. These devices were strategically placed around the manifold and on the cargo deck. This equipment is part of a mandatory pollution prevention system for tankers, in accordance with marine safety and environmental protection regulations.

Interview results

This research conducted interviews with several sources on board the MT. Sanana, including the chief officer, second officer, third officer, and boatswain. The interviews focused on efforts to reduce oil spills during loading and unloading in accordance with environmental safety standards.

Interviews with respondents on the MT. Sanana vessel revealed that efforts to control oil pollution during loading and unloading operations on board were in place, including standard operating procedures (SOPs), SOPEP equipment, and pre-loading/discharging checklists. However, the lack of complete equipment, such as gaskets that were starting to deteriorate, was a challenge.

1. Literature review

Oil pollution at sea is an environmental problem with serious impacts, particularly in the operational activities of tankers such as the MT. Sanana. Oil loading and unloading activities have a significant potential for oil spills, which can have widespread impacts on the marine environment, occupational safety, and ship operations. Therefore, a comprehensive understanding of the causes, impacts, and prevention efforts of oil pollution during the loading and unloading process is necessary.

Based on a literature review, it can be concluded that oil spills during loading and unloading are caused by technical factors, human error, and environmental conditions. The resulting impacts are not only detrimental to the environment but also to operational and occupational safety aspects. Therefore, preventative measures are needed, including the implementation of standard operating procedures (SOPs), improving crew competency, maintaining equipment, and using pollution prevention equipment to minimize the risk of oil spills on the MT. Sanana.

Data analysis

Based on available data, the implementation of standard operating procedures (SOPs) during the loading and unloading process on the MT. Sanana significantly reduced the risk of oil pollution. The crew's discipline in inspecting equipment and monitoring the loading and unloading process successfully prevented a major oil leak. These results align with research by Zhang et al. (2021), which states that compliance with operational procedures is a key factor in controlling the risk of oil pollution.

1. Data reduction

Data reduction shows that the condition and readiness of loading and unloading equipment significantly influence the risk of oil pollution. Equipment that is routinely maintained and inspected before use can reduce the likelihood of leaks. (Fingas, 2018) states that most oil spill incidents on tankers generally occur due to technical problems, which can be minimized through optimal equipment maintenance.

Furthermore, the oil pollution response equipment onboard the MT Sanana proved effective in handling the small oil spill. The promptness of the crew in immediately halting operations and conducting cleanup demonstrated that the pollution response system was functioning effectively. This supports the 2019 ITOPF report, which stated that prompt action at the onset of a spill is crucial in preventing marine pollution.

From a human resources perspective, data analysis shows that human error remains a risk that requires attention. Despite standard operating procedures, drowsiness and lack of focus can lead to operational errors. According to Psarros et al., 2011, increased training, supervision, and crew awareness are needed to minimize the risk of oil pollution caused by human factors.

2. Data presentation

Based on research findings obtained through observations, interviews, and document studies during sea practice on the MT. Sanana, a number of data were obtained relating to the causes of oil spills, their impacts, and prevention efforts during the loading and unloading process.

Table 1. Data presentation

No	Indicator	Observation Results
1	Human factors (human error)	Lack of accuracy was found when monitoring and operating the valve.
	Equipment condition	There are gaskets and valves that are leaking
	Communication and coordination	The communication process is not always optimal when transferring cargo.
2	Environment	Potential oil flows into the sea from the ship's deck
	Work safety	The deck became slippery due to the oil spill
	Ship operations	The loading and unloading process was disrupted when the spill occurred.
3	Implementation of SOP	Checklists, toolbox meetings and supervision are carried out
	Equipment availability	Oil spill kit, drip tray, scupper plug available
	Supervision and action	The ship's crew promptly stopped operations when a leak occurred.
	HR Competence	Still found inexperienced crew

Data shows that the main causes of oil spills during loading and unloading are human error, equipment condition, and lack of coordination. Interviews with ship officers indicate that negligence in installing gaskets, lack of precision when opening and closing valves, and suboptimal communication between the ship and the terminal

are the dominant causes. Furthermore, observations also revealed substandard gaskets and valves, potentially leading to leaks. This is supported by equipment inspection data, which indicates small leaks in the piping system during the loading and unloading process.

IV. DISCUSSION

Based on interviews and observations conducted by the author on board the MT. Sanana, various efforts were made during loading and unloading operations to reduce the risk of oil spills. The problem arose because the gasket connecting the reducer and manifold was already showing signs of damage, which sometimes resulted in oil spills falling onto the ship's deck. Based on the analysis and the issues discussed, the problem formulation is as follows:

Causes of oil spills during loading and unloading processes on ships

1. The main factor causing oil spills is human error.

Such factors include crew members' lack of accuracy in valve operation, incorrect gasket installation, and human error, which remain the dominant causes of operational issues. This is evident in the crew's continued inaccuracy in valve operation and improper gasket installation procedures. Small errors in installation can lead to leaks, which can lead to oil spills. Furthermore, fatigue and lack of focus on duty also increase the likelihood of errors.

2. Lack of supervision during the cargo transfer process

Inadequate monitoring can lead to delays in detecting leaks or pressure mismatches in the piping system. On the other hand, equipment condition is also a significant factor, with some gaskets and valves found to be in suboptimal condition. Worn or unusable equipment has the potential to leak when used under high pressure. Equipment condition is also a significant factor, with some gaskets and valves found to be in suboptimal condition, potentially causing leaks.

3. Ineffective communication between the ship and the terminal

Inaccurate information regarding cargo flow, pressure, and work procedures can trigger operational errors. Overall, the findings indicate that oil spills are not caused by a single factor, but rather by a combination of human factors, technical factors, and suboptimal communication systems, consistent with maritime safety theory.

The impact that occurs if there is an oil spill on a ship

1. From an environmental aspect

Oil spills on ships can have significant impacts if not promptly and properly addressed. Environmentally, oil spills have the potential to pollute marine waters if the oil spills overboard. This pollution can damage marine ecosystems, disrupt environmental balance, and even lead to the death of marine life such as fish and other organisms. Oil spread across the water's surface can block sunlight penetration, disrupting the photosynthesis process of marine organisms.

2. From the aspect of occupational safety

Oil spills on ship decks make surfaces slippery and dangerous for crew members. This increases the risk of workplace accidents such as slips, falls, and other injuries. Furthermore, oil vapors can also impact health if inhaled over a prolonged period.

3. From an operational aspect

Oil spills can disrupt the loading and unloading process because they require temporary stops for handling, resulting in loss of time and operational costs.

Thus, swift action was essential to minimize further impact. The Chief Officer immediately notified the Captain and prepared a report detailing the oil spill, which was caused by worn-out gaskets and valves. This report was issued to ensure the company understood the issues and factors contributing to the spill.

Efforts made to improve prevention of oil pollution on ships

1. Consistent implementation of Standard Operating Procedures (SOP)

Such as pre-operation checklists and toolbox meetings. These activities aim to ensure all crew members understand their duties and the condition of the equipment before loading and unloading begins, thereby minimizing the risk of errors.

2. Routine equipment maintenance and inspection

Regular equipment maintenance and inspections are crucial for prevention. Equipment such as pipes, valves, and gaskets must always be in good working condition to prevent leaks during use. Regular inspections also help detect potential damage early.

3. Provision and use of pollution prevention equipment

This equipment is highly effective in handling small-scale oil spills and preventing them from spreading further. Oil spill kits, scupper plugs, and drip trays should always be kept ready for use.

4. Improving crew competency through training and supervision

Minimizing human error is crucial. Coordination with the terminal must be continuously improved to ensure the loading and unloading process runs safely and under control. The Chief Officer and the officer on duty must continuously supervise the process. This monitoring must be recorded in the port logbook, which records every incident during loading and unloading to prevent oil spills.

V. CONCLUSION

This study found that efforts to prevent oil pollution during the loading and unloading process on the MT. Sanana were generally implemented through the implementation of Standard Operating Procedures, the availability of oil spill kits, and the implementation of routine inspections and maintenance on critical components such as manifolds, pumps, and piping systems. This combination of technical and organizational measures was effective in mitigating small-scale spills and expediting the response when leaks were detected. However, field findings also revealed important weaknesses that increased vulnerability to spills, namely the condition of

gaskets and valves that began to wear, installation practices that were not always meticulous, and several gaps in communication and supervision during cargo transfers. Human error remained a major contributor, along with suboptimal equipment. Triangulative analysis of observations, interviews, and operational documents reinforced the conclusion that effective prevention requires a synergy between systematic technical maintenance, strengthened procedural compliance, and increased capacity of on-deck supervisors, as well as better coordination with the terminal.

Limitations of this study include its focus on a single case study of a vessel, which requires caution in generalizing to other fleets or port conditions. Furthermore, it also highlights the potential for observational bias due to the researcher's participatory role during sea practice. Further research suggests conducting comparative studies across tankers on different routes and using broader longitudinal data to assess the effectiveness of preventive interventions over time, as well as testing simulation-based training interventions to reduce human error. Practically, the study recommends replacing gaskets and valves showing signs of wear before critical operations, implementing a more stringent pre-operational checklist, developing a more robust and verified PMS schedule, and increasing the frequency of toolbox meetings and spill response exercises. Implementation of these recommendations is expected to reduce the frequency of small leaks that have the potential to develop into larger spills and strengthen compliance with MARPOL regulations in the context of regional tanker operations.

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