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Sanitary Piping System Retrofit for Passenger Ships: A Design Study Based on MARPOL and BKI Rules

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ABSTRACT

This study develops a retrofit sanitary piping system for a passenger vessel operated by an Indonesian inter-island shipping company, following structural damage caused by a tropical cyclone near Bolok Port, Kupang. The vessel, carrying 730 people, previously relied on untreated sewage storage, necessitating an upgraded system aligned with MARPOL Annex IV (MEPC.227(64), 2012) and BKI (2022) requirements. A six-step engineering design methodology was applied, covering regulatory review, data acquisition, system planning, component specification, modelling, and validation. System demand analysis established a sewage flow rate of 4,11 m³/h, guiding the selection of DN40 Schedule 80 carbon steel pipes (JIS G3454) for durability under shipboard conditions. A Jets STP 600 vacuum sewage treatment unit with a 0,60 m³/h capacity was chosen for its compact size and regulatory certification. The discharge system includes a 4 bar pump and SDNR valves to ensure safe, compliant operation. A 2D schematic was developed to illustrate flow paths, tank connections, treatment cycles, and discharge routing. Validation confirmed compliance with international and class society regulations. The retrofit improves safety, environmental protection, and operational flexibility, replacing the vessel's storage-only system with an integrated treatment solution suitable for tropical maritime operations.

INTRODUCTION

Passenger vessels play a vital role in supporting maritime transportation across Indonesia's vast archipelagic regions. Serving as inter-island connectors, these ships are obligated to comply with operational safety and marine environmental protection regulations, particularly in managing domestic wastewater produced by passengers and crew. A key component in this waste management system is the onboard sanitary piping infrastructure, which must be capable of effectively collecting, treating, and discharging sewage (Ketin & Andrejic, 2021). In practice, many vessels particularly aging or non-convention ships still operate with conventional gravity-based sanitary systems that lack modern controls, are prone to clogging, and often use materials susceptible to corrosion. These legacy systems typically have limited capacity, poor separation between grey and black water streams, untreated and outdated discharge mechanisms that do not comply with current regulatory standards.

The increasing volume of passenger and cruise ships has raised serious concerns about marine waste, prompting the need for comprehensive systems that ensure proper collection,

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treatment, and environmentally safe disposal, as highlighted by Sosa (2023). Wastewater discharge from ships is governed under MARPOL 73/78 Annex IV, Regulation 11, which outlines specific requirements for effluent discharge distance, type, and treatment systems. According to classification rules issued by BKI (Part 1, Volume III, Section 11), these apply to vessels over 400 GT or those certified to carry more than 15 people (BKI, 2022; IMO, 2020). Poorly maintained or non-compliant systems significantly elevate the risk of marine contamination. Rompis et al. (2020) demonstrated this risk through a case study at Amurang Port, where several vessels lacked adequate sanitation facilities, despite meeting some waste management requirements.

Wastewater on ships is generally classified as grey water, originating from activities like bathing and washing and black water from toilet systems, which contains harmful bacteria and organic matter (Tilley et al., 2014). MARPOL Annex IV mandates that black water must meet strict pollutant limits, including TSS below 35 mg/L and BOD_5 under 25 mg/L (IMO, 2012; MEPC.227(64)).

Recent findings suggest that untreated wastewater from ships poses serious environmental hazards. For instance, Koboevic et al. (2022) reported that the presence of small cruise ships correlated with increased fecal coliform levels in Croatian coastal waters. Zhang et al. (2024) further revealed that ship-generated sewage often contains high concentrations of microplastics and heavy metals, requiring more advanced treatment technologies such as membrane bioreactors. In addition to routine discharge, ship accidents especially during tropical storms can severely damage onboard piping, including freshwater and wastewater systems. In such scenarios, retrofitting becomes essential. Kolios (2024) describes retrofitting as a structured, risk-based engineering upgrade process intended to restore system functionality while complying with updated environmental standards like MARPOL Annex IV.

Several studies have demonstrated the importance of reliable and regulation-compliant sewage systems. Kusuma et al. (2023) identified that MV. Amarilis Indah discharged untreated sewage within 12 nautical miles due to STP failure. Saleh et al. (2022) proposed the Omnipure 6440 electroflotation STP unit for a non-convention Ro-Ro ferry, ensuring compactness and regulatory compliance. Yanti et al. (2018) addressed similar concerns by developing a tank-based solution for wooden vessels on Lake Toba. Meanwhile, Wibowo (2019) emphasized the need for regular STP maintenance, citing failures in aeration and discharge pumps aboard MT. Gas Eva. In support of engineering accuracy, Budi et al. (2015) used open-source CAD tools to develop sanitary pipe layouts based on BKI standards. Yudanto (2015) and Haryyadi (2022) also underlined the need for optimal pipe sizing and system division, especially on large-capacity vessels. Pramono et al. (2025) stressed the importance of pipe wall thickness based on BKI and JIS classifications.

This study focuses on a passenger vessel operated by an Indonesian inter-island shipping company that sustained structural damage during a tropical cyclone near Bolok Port, Kupang. The incident impaired both freshwater and wastewater systems, making it necessary to retrofit the sanitary discharge network for approximately 730 persons on board. Previously, this vessel did not employ any wastewater treatment and relied solely on storing grey water and black water in a sewage holding tank without processing. Therefore, the retrofit design in this study includes the planning and selection of a suitable Sewage Treatment Plant (STP) to meet operational requirements in accordance with MARPOL Annex IV. The main objective of this engineering study is to redesign the sanitary piping system in accordance with BKI (2022) and MARPOL Annex IV (MEPC.227(64), 2012), involving system demand analysis, pipe dimension calculations, STP and pump specifications, and the development of a compliant schematic diagram using 2D tools. The outcome is expected to improve operational safety, ensure regulatory conformity, and minimize the vessel's environmental footprint (Utomo et al., 2024).

RESEARCH METHODS

This study adopts an engineering design methodology aimed at developing a sanitary discharge piping retrofit for a passenger vessel that experienced damage due to a tropical cyclone.

The method used consists of six main steps, began with literature and regulatory review, data collecting, system design planning, component selection, system modelling, and system design validation.

Figure 1. Research Methodology

Literature and Regulatory Review

A review of relevant literature and regulations established the design foundation. This included analysis of classification rules from BKI (2022) and MARPOL Annex IV specifically Resolution MEPC.159(55), later superseded by MEPC.227(64) in 2012. Furthermore, technical references including those by Munson et al. (2013) and White (2011) were employed to support calculations related to fluid mechanics and piping system design.

Data Collecting

Technical data were obtained from field observations and ship documentation. The vessel's main specifications are shown in **Table 1**.

Table 1. Vessel Specifications

Parameter	Value
Vessel Type	Passenger Ship
Length (LPP)	81 m
Breadth (B)	15,60 m
Draft (T)	3,75 m
Service Speed (Vs)	15,50 knots
Crew	30 persons
Passengers	700 persons

Information on the distribution of toilets and sanitary equipment was sourced from the ship's General Arrangement drawings, while the layout of mechanical components and existing piping infrastructure was based on the Engine Room Layout plans.

System Design Planning

The system planning phase began with the calculation of the minimum required capacity of the sewage holding tank:

$$Q\ sewage\ holding\ tank = Q_{given} \text{ x } N \text{ x } T \qquad (1)$$

Where Q_{given} is the required daily wastewater volume per person according to the rules (in liters/person/day), N is the maximum number of persons on board as per data (persons), and T is the required number of days the waste must be stored onboard.

This informed the network design for both grey and black water. Pipe sizing applied hydraulic principles using the continuity equation (White, 2011):

$$D = \sqrt{\frac{4Q}{\pi v}} \qquad (2)$$

In this equation, D is the internal diameter of the pipe (m), Q is the volumetric flow rate (m^3/h), and v is the assumed flow velocity (m/s).

The design of the sewage treatment plant (STP) was also based on **Equation 1**, adjusted according to the selected flushing system either conventional or vacuum each of which requires different daily waste generation rates.

Component Selection

Component selection considered performance, compliance, and operational context. Pipes followed JIS G3454, sized per hydraulic needs. STP options were reviewed based on capacity, footprint, and IMO MEPC.227(64) certification. The discharge pump was selected using MEPC.164(65) and calculated using:

$$DR_{MAX} = 0{,}00926 \times V \times D \times B \qquad (3)$$

Where:

DR_{MAX} = Maximum permissible discharge rate or capacity (m^3/h)

V = Ship's average speed (knots) over the period

D = Draft (m)

B = Breadth (m)

System Modelling

A schematic of the sanitary discharge system was developed using 2D CAD software. The diagram illustrated the routing of grey and black water from fixtures to holding tanks, through the STP, and finally to discharge outlets.

System Design Validation

Validation ensured compliance with BKI and MARPOL standards, focusing on tank capacity, pipe dimensions, STP performance, and allowable discharge rate. Component placement and system operability were also evaluated.

RESULTS AND DISCUSSION

Based on field datas, the passenger vessel operated by an inter-island shipping company suffered structural damage due to a tropical cyclone near Bolok Port, Kupang. The passenger vessel transported 730 persons, with 700 as passengers and 30 as crew. According to the Lloyd's Register Rules (Part 7, Section 2.10), 2014, the minimum capacity of the sewage holding tank required for untreated grey water and black water is 135 liters per person per day. Hence, the calculation for the minimum tank capacity is using **Equation 1**.

$$Q \textit{ sewage holding tank} = 135 \text{ L/person/day x } 730 \text{ persons}$$

$$= 98{,}55 \text{ L/day} = 4{,}11 \text{ m}^3/\text{h}$$

To ensure effective transfer of sewage to the holding tank, a correctly sized piping infrastructure is required. The inside diameter of the pipe is calculated using the following standard hydraulic **Equation 2**. Where Q is the flow rate = 4,11 m^3/h = 0,00114 m^3/s and v is the design flow velocity = 1 m/s (White, 2011). The resulting minimum inside diameter is approximately 38 mm, which was rounded to the nearest available commercial size, DN40.

In addition to hydraulic sizing, the design approach also involved evaluating the pipe strength based on classification standards to ensure structural integrity under shipboard operational conditions. According to BKI Part 1 Volume 3 Section 11, the sanitary piping system onboard falls under Group M, which governs the minimum allowable wall thickness and pressure

rating for piping in environments subject to mechanical vibration, pressure variation, and corrosion from saline exposure.

Considering these requirements, carbon steel piping standardized under JIS G3454, specifically DN40 Schedule 80 with a wall thickness of 5,10 mm, was selected. This material provides adequate mechanical strength and durability against corrosion when used in conjunction with marine-grade coatings or galvanized protection. The use of welded connections and appropriate pipe supports was also considered to minimize fatigue and potential joint failure due to ship motion and vibration. This design approach ensures not only hydraulic compatibility but also compliance with marine environmental conditions and classification society requirements for safety, longevity, and regulatory conformity.

In addition, the LR Rules (Part 7, Section 2.10) mandate the use of a certified sewage treatment system, originally in line with MEPC Resolution 159(55), 2006, which has since been replaced by MEPC.227(64), 2012. The sewage treatment plant (STP) must be capable of handling the total onboard sanitary waste. For conventional flushing system, the minimum capacity requirement is 115 liters/person/day. If a vacuum system is used, the requirement drops to 15 liters/person/day. The calculated capacity of the sewage treatment plant using **Equation 1** for both configurations is:

- For conventional flushing system:

$$Q_{STP\ conventional} = 115\ \text{L/person/day} \times 730\ \text{persons} = 83{,}95\ \text{L/h} = 3{,}50\ \text{m}^3\text{/h}$$

- For vacuum system:

$$Q_{STP\ vacuum} = 15\ \text{L/person/day} \times 730\ \text{persons} = 10{,}95\ \text{L/h} = 0{,}46\ \text{m}^3\text{/h}$$

The vacuum system was chosen for its compact design and ease of installation in the engine room. The 0,46 m³/h capacity requirement, as indicated by technical data, can be fulfilled by various standard STP models on the market:

Table 2. Selection of STP Units

Brand	Model	Capacity	Certification
HAMANN	HL-CONT PLUS 0125	0,52 m³/h	IMO MEPC.227(64), USCG, MED
Jets	STP 600	0,60 m³/h	IMO MEPC.227(64)
Taiko	SBH-200	0,50 m³/h	IMO MEPC.227(64)

The Jets STP 600 was chosen from the available options for its space-efficient design and adherence to international regulatory standards. In addition to its compact footprint, the system offers ease of installation and maintenance, which is particularly advantageous for retrofit applications in confined engine room spaces. Its proven operational reliability and certification under IMO MEPC.227(64) further reinforce its suitability for long-term use in passenger vessels operating under stringent environmental compliance requirements.

IMO, MARPOL Resolution MEPC.164(65), IMO (2013) provides the maximum permissible discharge rate as per **Equation 3**.

$$DR_{MAX} = 0{,}00926 \times 15{,}50\ \text{knots} \times 3{,}75\ \text{m} \times 15{,}60\ \text{m} = 8{,}40\ \text{m}^3\text{/h}$$

From this, the required discharge flow rate is approximately 8,40 m³/h, and a discharge pump with a minimum pressure of 4 bar (≈ 40 m total head) is required. The discharge pipeline

calculated with **Equation 2** and uses DN25 Schedule 80, which is then upscaled to DN40 using a reducer to improve flow velocity and reduce backpressure before final overboard discharge.

Following the technical analysis conducted in reference to both classification standards and MARPOL regulations, a detailed schematic diagram of the vessel's sanitary discharge system was developed using 2D software, as illustrated in **Figure 2**. The diagram outlines the flow paths for both grey water and black water generated across multiple decks, including the Compass Deck, Navigation Bridge Deck, Executive Class Passenger Deck, and Passenger Deck. Sanitary fixtures such as toilets, lavatories, galley sinks, laundry units, and medical facilities are connected via carbon steel pipes (DS-40-SHC80) to a centralized discharge network. Grey water originating from urinals and non-contaminated fixtures may be discharged directly overboard via lines equipped with SDNR valves (V1, V3), provided effluent quality complies with MARPOL Regulation 11.

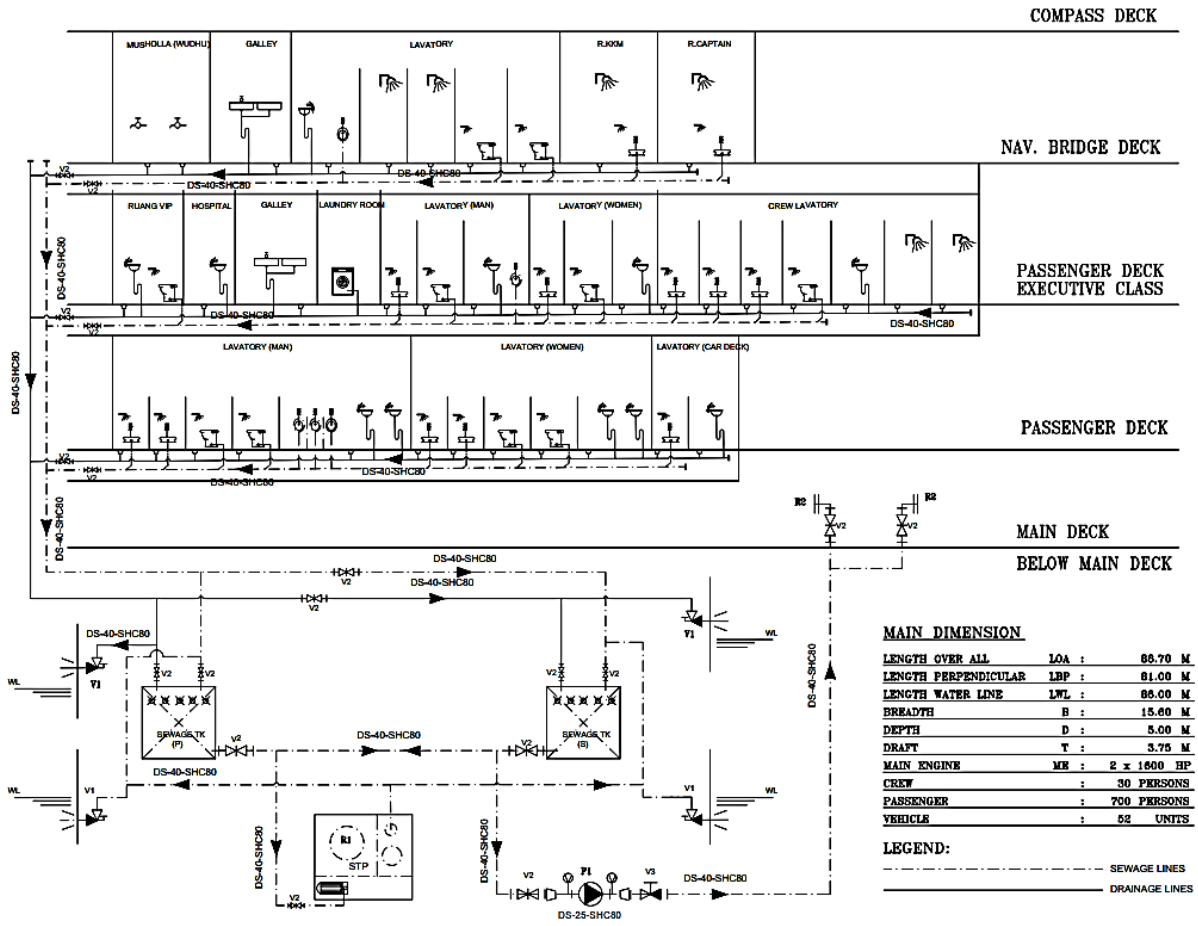

Figure 2. Schematic Diagram of the Sanitary Discharge System

Black water and contaminated grey water are routed to port and starboard sewage holding tanks (Sewage TK P & S) located below the main deck. The effluent from these tanks is directed to the sewage treatment plant (R1), where it undergoes processing in compliance with IMO Resolution MEPC.227(64). The system is designed for a treatment cycle of approximately one day, after which the treated effluent is pumped using discharge pump P1 to either overboard discharge or through International Shore Connections (R2) when docked. The schematic also confirms proper installation of SDNRVs at discharge outlets to prevent backflow, in accordance with BKI Part 1 Vol.3, Sec.11, S 2.7.3.

The development of this schematic diagram enabled a comprehensive review of the retrofit layout, not only for functionality and spatial efficiency but also for compliance with international marine environmental regulations. Key aspects such as pipe size conformity (JIS G3454), component connectivity, flow direction, and safety devices were critically embedded into the

model, serving both as a technical reference for implementation and as validation evidence of system integrity under tropical maritime operating conditions.

Validation results presented in **Table 3**, confirm that the tank capacity, piping specifications, STP capacity, and discharge system meet both BKI and IMO technical requirements in terms of performance, reliability, and safety.

Table 3. Design Validations

No	Reference	Description	Approval Statement
1	BKI 2022 Pt.1, Vol.3, Sec.11, S 1.1, MARPOL 73/78 Annex IV Regulation 11	"Ships of 400 GT and above, or ships under 400 GT that are certified to carry more than 15 persons, shall be equipped with the following systems: 1. A Sewage Treatment Plant approved under MEPC.159(55); or 2. A sewage comminuting and disinfecting system; or 3. A Sewage Collecting Tank."	The sanitary discharge system schematic diagram includes both a Sewage Treatment Plant (R1) and Sewage Collecting Tanks (Sewage TK (P & S)).
2	BKI 2022 Pt.1, Vol.3, Sec.11, S 1.2	The discharge piping system to the reception facility (port) shall be constructed in accordance with the standard discharge connection.	The schematic diagram of the sanitary discharge system shows the discharge piping connected to a standard discharge connection (R2), leading to International Shore Connections.
3	MARPOL 73/78, Resolution MEPC.164(65)	The maximum permissible discharge rate is defined as 1/200,000 of the ship's hull swept volume.	The maximum discharge rate has been calculated in accordance with the regulation's formula. The schematic diagram includes a discharge pump conforming to the regulation, connected to the discharge line (R2) leading to the International Shore Connections.
4	BKI 2022 Pt.1, Vol.3, Sec.11, S 2.7.3	The discharge lines from the sewage tanks and sewage treatment tanks must be equipped with SDNRVs installed on both port and starboard sides of the vessel.	The schematic diagram indicates two sewage tanks installed on both port and starboard sides (Sewage TK (P & S)), with discharge lines to overboard outfitted with SDNRV valves (V1 and V3).

To evaluate the retrofit system's advantages, a comparative analysis was conducted between the vessel's original configuration and the newly proposed sanitary discharge system. Initially, the vessel was only equipped with a sewage holding tank for temporary storage of both grey and black water, with no onboard treatment capability. This configuration relied solely on periodic port discharges, posing environmental risks in the event of operational delays or unauthorized overboard releases.

In contrast, the retrofit introduces a fully integrated sanitary system including an IMO-certified STP (Jets STP 600), a regulated discharge pump, and piping sized according to actual hydraulic demands. The comparative parameters are presented in **Table 4**.

Table 4. Comparison Between Existing and Retrofit Sanitary System

Criteria	Existing System	Retrofit System
Wastewater Handling	Storage only (holding tank)	Storage and onboard treatment
Sewage Treatment	Not available	Jets STP 600 (0,60 m³/h, MEPC.227(64))
Regulatory Compliance	Partial (tank only)	Full (BKI and MARPOL Annex IV compliant)
Pipe Sizing Method	Empirical	Hydraulic-based calculation (Ø 38 mm)
Pipe Material	Not standardized	Carbon steel DN40 Sch. 80 (JIS G3454)
Discharge Method	Manual via port reception	Pumped overboard or via shore connection
Backflow Prevention	Not clearly defined	SDNR valves at discharge points (BKI)
Risk of Marine Pollution	High (in case of overflow)	Minimized (with STP and flow control)
Operational Flexibility	Limited (port-dependent)	High (treatment + dual discharge mode)

This comparison highlights the critical improvements in safety, environmental protection, and compliance achieved through the retrofit. The integration of an STP enables treatment cycles of less than a day, while the inclusion of flow control components like SDNR valves and a properly sized discharge pump allows the vessel to operate autonomously between ports.

Additionally, material selection for marine conditions; such as carbon steel pipes with corrosion-resistant coatings; ensures durability in high-salinity environments, as mandated by BKI Group M criteria based on the location.

CONCLUSION

A sanitary piping retrofit was developed for a passenger vessel operated by an Indonesian inter-island shipping company following structural damage caused by a tropical cyclone near Bolok Port, Kupang. The retrofit design process followed a structured methodology involving regulatory and literature review, data acquisition, system planning, component specification, system modelling, and compliance validation, with reference to BKI (2022) and MARPOL Annex IV (MEPC.227(64), 2012). System requirements for 730 persons onboard were quantified, leading to the calculation of minimum tank and treatment capacities. Hydraulic analysis determined a required flow rate of 4,11 m³/h, with DN40 Schedule 80 carbon steel piping selected in accordance with JIS G3454 and BKI Group M standards. A vacuum-based Jets STP 600 (0,60 m³/h) was selected to provide onboard sewage treatment, supported by a 4 bar discharge pump and SDNR valves to ensure backflow prevention and regulatory conformity. A 2D schematic diagram was developed to depict grey and black water flows from multiple decks to centralized sewage holding tanks, followed by treatment and discharge overboard or via international shore connection. Validation against classification society rules and international regulations confirmed that the system design satisfies technical, operational, and environmental compliance criteria. The retrofit enhances environmental protection by replacing the vessel's previous storage-only system with a treatment-capable configuration. Improvements include compliance with applicable international maritime regulations, reduced pollution risk, and increased operational flexibility during inter-island voyages.

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