Analysis of the Relationship between *Scrubber Performance* and *Engine Operational Performance* on MV. Sinar Sorong

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Abstract*— The implementation of exhaust gas cleaning systems (scrubbers) has become a critical compliance strategy for maritime vessels following the International Maritime Organization's 2020 Global Sulphur Limit regulation. However, the technical relationship between scrubber performance and main engine operational reliability remains insufficiently documented in empirical maritime research. This study aims to analyze the correlation between scrubber performance and engine operational performance on the container vessel MV. Sinar Sorong through a quantitative approach utilizing technical parameter measurements and structured questionnaires. Data were collected during operational periods from April to December 2025, encompassing chemical performance parameters of coagulant and flocculant agents, engine performance metrics including maximum combustion pressure, compression pressure, exhaust gas temperature, and specific fuel oil consumption. The research employed 29 respondents from the engine department selected through purposive sampling technique, with data analyzed using Pearson correlation and linear regression in SPSS version 26. Results demonstrate a positive and statistically significant correlation (r = 0.587, p = 0.001) between scrubber performance and engine operational performance, with regression analysis indicating that 96.9% of engine performance variance can be explained by scrubber efficiency. The scrubber system maintained optimal technical parameters with nonvolatile solid content of 34.1%, viscosity of 420 cPs, basicity level of 40%, and pH range of 3.5-8.2, effectively reducing sulfur oxide emissions while maintaining engine stability. Main engine parameters remained within optimal design specifications: maximum combustion pressure 145.4 bar, compression pressure 107.2 bar, exhaust gas temperature 333°C, and specific fuel consumption 174.0 g/kWh. This research contributes empirical evidence that scrubber systems function beyond regulatory compliance instruments, serving as technical components that enhance combustion system stability through sulfur residue reduction and corrosive deposit prevention in exhaust pathways. The findings provide practical implications for maritime operators to implement integrated preventive maintenance strategies and real-time monitoring systems to sustain the synergistic relationship between scrubber efficiency and engine reliability, ultimately optimizing operational efficiency and extending critical component lifespan.

Keywords— Engine performance, exhaust gas cleaning system, maritime emissions, scrubber efficiency, ship operations

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I. INTRODUCTION

International regulations governing maritime environmental protection continue to be tightened, especially related to hazardous gas emission standards resulting from shipping activities. Sulfur oxide (SOx) emissions released through the combustion process in ship's diesel engines have a significant impact on human health and the balance of environmental ecosystems [1]. Responding to the urgency of this problem, *International Maritime Organization* (IMO) enforcing IMO 2020 regulations *Global Sulphur Limit* which requires all ships to use fuel with a maximum sulfur content of 0.5% since January 1, 2020 [2]. The Indonesian government has also adopted a similar policy by emphasizing that every ship, both hoisting the Indonesian flag and foreign vessels operating in Indonesian waters, must comply with the sulfur content standard. In the face of these regulations, the shipping industry is faced with two strategic choices: use low-sulfur fuels with higher operating costs, or implement technology *Exhaust Gas Cleaning Systems* (*Scrubber*) that allows the use of conventional fuels with a higher sulfur content but still meets emission standards [3].

Exhaust Gas Cleaning System (EGCS) or *Scrubber* It is an additional device designed to reduce the level of sulfur oxide in the exhaust gases of ship engines through a gradual spraying mechanism using seawater or fresh water that has been mixed with a caustic solution of soda into the exhaust gas stream, so that a chemical reaction occurs between sulfur dioxide pollutants and alkaline water that produces sulfuric acid [4]. System *Scrubber* It is generally operated in two modes: *Open Mode* that takes seawater as a washing medium and disposes of laundry directly into the sea, and *Close Mode* that holds water from deep washing *wash water tank* to be further

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processed or disposed of through receiving facilities at the port [5]. The method of monitoring compliance with SOx regulations is assessed based on the SO_2 (ppm)/CO_2 ratio, with previous research showing that the *Scrubber* able to reduce SO_2 content to reach 97.4% efficiency [6]. To achieve optimal technical feasibility, the system *Scrubber Close Mode* requires several critical components including NaOH pump, freshwater pump, seawater pump, *Water Treatment Unit*, and heat exchanger media [7].

Nonetheless, the implementation of the technology *Scrubber* It is inseparable from various complex operational and regulatory challenges. Based on data *Det Norske Veritas and Germanischer Lloyd* (DNV GL), as many as 2,625 ships or 80.3 percent of the total ships that use *Scrubber* Choosing a system *Open Mode* due to considerations of operational efficiency and lower investment costs. However, there are significant environmental issues where several major maritime countries have imposed bans on the use of *Open mode scrubber* in their territorial waters, including Singapore, the United Arab Emirates, China, Japan, Korea, Belgium, Germany, Latvia, Lithuania, Ireland, Norway, and India. This policy is motivated by concerns about the impact of wastewater discharge from exhaust gas leaching that contains pollutant residues directly into the marine ecosystem without going through an adequate treatment process [8]. This condition requires ship operators to have a comprehensive understanding of the regulations of each country that passes in the shipping route and adaptive capabilities in operating the system *Scrubber* according to the allowed mode.

PT. Samudera Indonesia Tbk. as the owner of the ship and Osaka Asahi Kaiun Co. Ltd of Japan as the lessee of the MV. Sinar Sorong has implemented *a scrubber, exhaust gas cleaning system*, to meet the requirements of IMO 2020 regulations, while still optimizing operational cost efficiency through the use of high-sulfur fuels that have a more economical price than *low sulfur fuel oil*. In its operational practice, *scrubber* systems in both *open and* close *mode* often face various complex technical problems and are interrelated with other mechanical systems on ships. This complexity demands thorough analysis and adequate technical competence from ship *engineers*, especially for those who have not had experience operating *scrubber* systems before.

The urgency of this research lies in the need to build a deep understanding of the correlation between the performance of the *scrubber* and the operational performance of the ship's engines holistically. A literature review indicates that previous research has focused more on the efficiency aspects of *partial scrubber* emission reduction without comprehensively integrating an analysis of its impact on the reliability and operational performance of the motherboard's engines. This knowledge gap poses practical implications where *ship engineers* face difficulties in optimizing *scrubber* maintenance while ensuring the operational continuity of the ship's engines. This study seeks to fill this gap by analyzing the systemic relationship between the technical parameters *of scrubber* performance—including SOx emission reduction efficiency, actual emission levels, and fuel consumption—and engine operational performance indicators measured through *availability* and historical records of engine performance. A comprehensive understanding of the interrelationship between these two variables is fundamental for any *engineer* responsible for the *scrubber system* to be able to maintain the reliability of the ship's engine while ensuring compliance with international emission standards through the implementation of consistent maintenance according to *the instruction manual* and *planned maintenance system* (PMS) determined by the owner and lessee of the ship. Furthermore, the ability to quickly identify any anomalies that occur in the *scrubber* system will minimize the risk of fatal damage that can disrupt ship operations and reduce work productivity.

The contribution of the novelty of this research lies in an integrative approach that examines the performance of *the scrubber* not as an isolated system but as a component that has interdependence with the operational performance of the ship's engine as a whole. This study uses a case study on the MV ship. Sinar Sorong by analyzing measured operational data over a period of time to identify the pattern of relationship between the technical parameters of *the scrubber* and the reliability of the engine. The findings of the study are expected to provide practical recommendations for ship operators in optimizing *scrubber maintenance strategies* that not only meet the aspects of emission regulatory compliance, but also support the sustainability of ship engine operational performance.

Based on the background and gap analysis that has been described, this study aims to: (1) analyze the performance of *scrubber* on MV ships. Sinar Sorong based on measurable technical parameters; (2) optimizing the level of engine operational performance on the MV ship. Sinar Sorong during the use of *the scrubber*; and (3) analyze the relationship between the performance of *the scrubber* and the operational performance of the engine on the MV ship. Sinar Sorong. The results of this study are expected to make a theoretical contribution to the development of the discourse on maritime emission system management as well as a practical contribution to the shipping industry in optimizing the operational efficiency of ships that implement scrubber technology.

II. Method

A. Data Types and Sources

This study adopts a quantitative approach based on the positivism paradigm with an emphasis on objectivity and empirical testing of observed phenomena. The quantitative approach was chosen because it allows researchers to analyze the correlation between the performance of the *scrubber* and the operational performance of the machine in a measurable and systematic manner through the processing of numerical data using statistical techniques. The characteristics of this method meet scientific principles that are concrete, observable, objective, measurable, rational, and systematic, so as to allow the discovery of empirical facts that can be used as a basis for operational decision-making. The research was carried out on the MV. Sinar Sorong, a Singapore-flagged container ship with a capacity of 1,900 TEU operated by PT. Samudera Indonesia Tbk. and chartered by Osaka Asahi Kaiun Co. Ltd. The ship is equipped with a 10,800 BHP HITACHI-MAN B&W 6S60ME-C8.5 main engine and has implemented *an exhaust gas cleaning system* (*scrubber*) system to meet IMO 2020 regulations. The data collection period lasted from April to December 2025 during which the researcher served as *the First Engineer* on the ship.

The data used in this study consisted of primary data and secondary data. Primary data is obtained through two main methods: first, direct measurement of technical parameters *Scrubber* which includes the efficiency of reducing sulfur oxide (SOx), *Emission Factor*, *specific fuel consumption*, exhaust gas pressure, *Flow Rate*, temperature, and pH *wash water* recorded in the *Engine log book* and *Scrubber operation log*; second, the distribution of a structured questionnaire using a Likert scale of 1-5 to the engine crew to assess operational perception of performance *Scrubber* and machine reliability. The study population included 32 crew members serving in the Department of Machinery, with samples determined using techniques *purposive sampling* based on the criteria: serving in the Machinery Department, having a minimum working period of three months, and being directly involved in monitoring activities, *Troubleshooting*or *Maintenance scrubber* and main engine [9]. Based on these criteria, 29 respondents were obtained who met the requirements. Secondary data were collected through a documentation study that included *Instruction Manual*, maintenance records, *Planned Maintenance System* (PMS), as well as scientific literature and maritime regulations relevant to the research topic [10], [11].

The data collection technique is carried out comprehensively through four integrated methods. First, systematic observation of *scrubber* operations in both *open and* close *mode* during the ship's operation at sea and docked in port, with a focus on the identification of technical anomalies and system performance. Second, the filling out of a questionnaire by respondents consisting of *Chief Engineer*, *Second Engineer*, *Third Engineer*, *Fourth Engineer*, *Electro Technical Officer*, and *Oiler* to obtain perceptual data regarding *scrubber* performance and engine operational reliability. Third, visual and written documentation of operational events and *scrubber machine conditions*. Fourth, literature studies to strengthen the theoretical and comparative foundation for similar research. The combination of these techniques ensures data triangulation that increases the validity and reliability of research findings.

B. Data Analysis Methods

Data analysis in this study was carried out through three systematic stages using SPSS software version 26. The first stage is quantitative descriptive analysis to describe the actual conditions and stability of performance *Scrubber* during the operation of the vessel. The parameters analyzed include the efficiency of SOx reduction calculated using the comparison of SOx concentrations before and after the cleaning process, *Emission Factor* expressed in grams per kilogram of fuel, as well as *specific fuel consumption* in grams per kilowatt-hour. The analysis is carried out by calculating the average, maximum, minimum, and standard deviation values which are then visualized in the form of tables and trend graphs to provide a comprehensive understanding of the data distribution patterns of each variable.

The second stage is the quality testing of the instrument through validity and reliability tests. The validity test was carried out by correlating the score of each item of the questionnaire statement with the total score of the variable, where the item was declared valid if the value of the correlation coefficient (r-calculated) was greater than the r-table at a significance level of 5% with a positive direction. The reliability test was conducted using Cronbach's Alpha coefficient, with the instrument considered reliable if the alpha value exceeded 0.70 which indicates adequate internal consistency in measuring the research construct.

The third stage is the Pearson correlation test to identify the relationship between the performance *of the scrubber* as an independent variable (X) and the operational performance of the engine as a dependent variable (Y). The Pearson correlation method was chosen because both variables are in the form of interval data and are numerically scaled (Sugiyono, 2019). The Pearson correlation coefficient (r) ranges from -1 to +1, where values close to +1 indicate a strong positive relationship, values close to -1 indicate a strong negative relationship, and values close to 0 indicate the absence of a linear relationship. Interpretation of correlation strength using guidelines: 0.00-0.199 (very low), 0.20-0.399 (low), 0.40-0.599 (moderate), 0.60-0.799 (strong), and 0.80-1.00 (very strong). The level of significance of the relationship was tested at alpha 5% ($p<0.05$), where if the probability value was less than 0.05, the relationship between variables was statistically significant. The entire analysis process is carried out systematically to ensure the validity of statistical inference and generalization of research findings in the operational context of container ships that implement *scrubber technology* as a solution for compliance with international maritime emission regulations.

III. Results and Discussion

A. Scrubber Performance on MV. Thrust Beam Based on Measurable Technical Parameters

Evaluation of the performance of *the exhaust gas scrubber* system on the MV ship. Sinar Sorong is carried out through the analysis of measurable technical parameters of chemicals used in the exhaust gas cleaning process. *The scrubber* system on this ship operates a *wet scrubbing* mechanism by using a chemical solution that acts as a coagulant and flocculant to bind and precipitate sulfur oxide particles as well as combustion residues before the exhaust gases are released into the atmosphere. The main chemicals implemented in this system are *Coagulant* A-630 and *Flocculant Polyaluminum Chloride* (PAC) with a concentration of 17% produced by Hongwon Co., Ltd., Korea. These two chemical components play a fundamental role in optimizing the absorption efficiency of sulphur and dust particles resulting from the combustion process of the MAN B&W 6S60ME-C8.5 main engine using *heavy fuel oil*.

Based on the results of the *Certificate of Analysis* and *Material Safety Data Sheet* (MSDS) obtained from an independent test laboratory, *Coagulant* A-630 exhibits technical characteristics with *a nonvolatile solid value* of 34.1%, which indicates an effective concentration of solids in the solution that contributes to the formation of particle bonds. The viscosity of the 0.5% solution was recorded at 420 cPs at 25°C, a value that describes the physical stability of the material in forming a homogeneous suspension that is effective for capturing exhaust gas particles under the machine's operational conditions. The *high charge density* of this *coagulant* supports the process of destabilization of colloidal particles in exhaust gases, while the pH of the solution reaching 8.2 provides the ability to neutralize sulfuric acid formed from the SO_2 reaction with water in the *scrubber system*. The alkaline characteristics of this solution are in line with the SOx absorption mechanism which requires the alkaline medium to neutralize the acidic properties of sulfur dioxide.

Meanwhile, the analysis of *Flocculant* PAC 17% shows an Al_2O_3 content of 17.14% with a *Basicity* reaches 40%, a parameter that indicates optimal flocculation ability in binding fine particles into larger aggregates (*FLOC Training*). The pH value of the solution ranges from 3.5 to 5.0, a range that allows for an aluminum polymerization reaction that forms a bridge between particles to facilitate the settling process. A synergistic combination of *Coagulant* and *Flocculant* in the system *Scrubber* MV. Sinar Sorong produces a sulfur removal process that is more efficient than the use of single-agent, with a level of wastewater clarity that meets the criteria *washwater discharge* according to IMO MEPC.259(68) regulations. These findings are consistent with research conducted by [12] that reports that the system *Scrubber* With chemical optimization, it is able to reduce exhaust gas emissions by up to 95% and particulate matter by up to 60%.

From an operational perspective, the performance *of the scrubber* is evaluated through the stability of the process parameters during the monitoring period, including fluid flow, chemical viscosity, and solution regeneration capability during the main engine operating at an economic load with an average speed of 18.3 knots. Test data showed that the *scrubber* system worked in the *range of basicity* 39-41% and viscosity of 410-430 cPs, which signifies the condition of the system is in the optimal range without experiencing significant degradation. In this operational range, there is no indication of a decrease in performance that can affect the combustion pressure of the main engine or an increase in specific fuel consumption. The stability of these parameters indicates that the chemical formulations used have adequate durability for continuous operation without requiring high-frequency replacement or adjustment. The results of the measurement of these technical parameters provide empirical confirmation that the performance *of the scrubber* on the MV. Sinar Sorong is in the stable and efficient category, both in terms of chemical quality and exhaust gas washing effectiveness, which is the foundation for analyzing the relationship with the operational performance of the machine at the next stage.

B. The Level of Engine Operational Performance on the MV Ship. Thrust Beam During Scrubber Use

Evaluation of the operational performance of the main engine on the MV ship. Sinar Sorong is carried out through systematic observation of technical parameters that reflect the stability of the combustion system, energy efficiency, and consistency of engine performance during the *full operation of the scrubber* system. Operational parameter data was obtained from *the engine performance monitoring system* integrated with the MAN B&W 6S60ME-C8.5 engine electronic control system during routine operations in Southeast Asian waters.

Based on the data in Table 1, the maximum combustion pressure parameter (*Pmax*) shows an average value of 145.4 bar which is within the normal limit of engine design between 140-150 bar. This value indicates that the fuel combustion process takes place efficiently with optimal injection timing and fuel chamber conditions that meet specifications. The compression pressure (*Pcomp*) was recorded at 107.2 bar, which indicates the cylinder system and piston rings are working optimally without experiencing significant leakage that can degrade the volumetric efficiency of the engine. An indication pressure (*Pi*) of 13.7 bar indicates that the piston is producing power in accordance with the engine design, where there is no deviation indicating the degradation of the internal components of the engine.

A stable average exhaust gas temperature of 333°C indicates a balanced heat distribution between cylinders, indicating the absence of a phenomenon *fouling* excess in the exhaust system which can inhibit the flow of exhaust gases. This temperature stability also confirms that the exhaust gas cleaning process through *Scrubber* does not cause *back pressure* excessive which can affect the gas extraction process from the combustion chamber. Parameters *Specific Fuel Oil Consumption* (SFOC) recorded a value of 174.0 g/kWh, which is in the high efficiency range between 170-180 g/kWh according to factory specifications. This SFOC value indicates that the use of *Scrubber* does not add significant load to engine fuel consumption, so that the thermal efficiency of the engine is maintained. These findings are in line with the results of the study [13] who find that the installation *Exhaust Gas Scrubber* on ships of the type *Feeder* It actually has a positive impact on fuel efficiency and the stability of the main engine output power when the system is operated and maintained optimally.

TABLE 1.
PARAMETERS OF THE OPERATIONAL PERFORMANCE OF THE MASTER MACHINE DURING THE USE OF THE SCRUBBER

Yes	**Operational Parameters**	**Unit**	**Average Grade (6 Cylinders)**	**Normal Engine Standard MAN B&W 6S60ME-C8.5**	**Technical Description / Interpretation**
1	Maximum Combustion Pressure *(Pmax)*	Bar	**145.4**	140–150	Within normal limits; indicates that fuel combustion is running efficiently.
2	Compressive Pressure *(Pcomp)*	Bar	**107.2**	105–110	Indicates the cylinder system and piston ring work optimally without leakage.
3	Pressure *Indication (Pi)*	Bar	**13.7**	13–14	Stable, indicating the working process of the piston producing power according to the engine design.
4	Average Exhaust Gas Temperature	°C	**333**	320–350	Balanced heat distribution between cylinders; There is no indication of excessive fouling.
5	*Specific Fuel Oil Consumption (SFOC)*	g/kWh	**174.0**	170–180	Fuel efficiency remains high; The use of scrubber does not add significant consumption.
6	*Estimated Load (Engine Load)*	%	**63.0**	60–70	The engine operates at an efficient economic load for medium-distance shipping.
7	Engine *Speed*	Rpm	**95.0**	90–105	As per the optimal range; The vibration and working pressure remain under control.

The engine operates at an *estimated load* of 63.0% which is an efficient economic load range (60-70%) for medium-distance sailing, with a stable engine rotation of 95.0 rpm in the optimal range of 90-105 rpm. These operating conditions at economic loads allow the engine to reach maximum thermal efficiency points while minimizing mechanical stress on internal components. The stability of these operational parameters indicates that the integration of the *scrubber system* with the main engine does not cause interference with the performance characteristics of the engine, and can even be interpreted as a positive contribution in maintaining the cleanliness of the exhaust system which in turn supports the stability of the combustion process.

Overall, the results of the analysis of the machine's operational parameters show that during use *Scrubber,* MV main engine. Sinar Sorong operates with high reliability and stable performance without experiencing a significant decrease in efficiency. Use *Scrubber* Instead, it contributes to the stability of engine work by reducing the accumulation of sulfur residues and maintaining the cleanliness of the combustion system, which strengthens the initial hypothesis of a positive relationship between performance *Scrubber* with the operational performance of the machine. These findings are consistent with research [6] that indicates that the use of *Modern scrubber* on commercial ships able to reduce sulfur emissions by up to 97% without interfering with the performance of the main engine, as well as research [14] which found that the performance of the engines on the ship with the *open-loop scrubber* more stable than ships without *Scrubber* due to the reduction of corrosive deposits in the exhaust gas system.

C. The relationship between the performance of the scrubber and the operational performance of the engine on the MV ship. Sinar Sorong

The analysis of the relationship between *the performance of the scrubber* and the operational performance of the machine began with the characterization of the profiles of the respondents involved in the study. All respondents were male (100%) with the largest age distribution in the range of 31-40 years (44.8%), reflecting the productive age group with adequate operational experience maturity. Based on position, the majority of respondents were technicians at the level of Oiler/Wiper (55.2%) and *Fourth Engineer* (20.7%), while the position of senior technical supervisor was represented by *Chief Engineer* (3.4%) and *Second Engineer* (6.9%). In terms of work experience with *scrubber* systems, most respondents had 1-3 years (37.9%) and 3-5 years (34.5%) experience, indicating that respondents had adequate operational involvement to provide an accurate assessment of the research variables.

Before the correlation analysis is carried out, the quality of the research instrument is tested through validity and reliability tests to ensure that the data collected has a level of accuracy and consistency that can be scientifically accounted for.

TABLE 2.
VALIDITY TEST RESULTS OF SCRUBBER PERFORMANCE VARIABLES (X)

Yes	Statement Items	r count	Sig. (2-tailed)	Information
1	X01	0.871	0.0	Valid
2	X02	0.771	0.0	Valid
3	X03	0.742	0.0	Valid
4	X04	0.686	0.0	Valid
5	X05	0.765	0.0	Valid
6	X06	0.688	0.0	Valid
7	X07	0.788	0.0	Valid
8	X08	0.867	0.0	Valid
9	X09	0.715	0.0	Valid
10	X10	0.665	0.0	Valid
11	X11	0.768	0.0	Valid
12	X12	0.779	0.0	Valid
13	X13	0.716	0.0	Valid
14	X14	0.723	0.0	Valid
15	X15	0.554	0.002	Valid

Source: SPSS Data Processing Results 26, (2025)

TABLE 3.
RESULTS OF THE VALIDITY TEST OF THE ENGINE OPERATIONAL PERFORMANCE VARIABLE (Y)

Yes	Statement Items	r count	Sig. (2-tailed)	Information
1	Y01	0.798	0.0	Valid
2	Y02	0.778	0.0	Valid
3	Y03	0.699	0.0	Valid
4	Y04	0.727	0.0	Valid
5	Y05	0.873	0.0	Valid
6	Y06	0.805	0.0	Valid
7	Y07	0.847	0.0	Valid
8	Y08	0.817	0.0	Valid
9	Y09	0.718	0.0	Valid
10	Y10	0.784	0.0	Valid
11	Y11	0.783	0.0	Valid
12	Y12	0.781	0.0	Valid
13	Y13	0.615	0.0	Valid
14	Y14	0.765	0.0	Valid
15	Y15	0.793	0.0	Valid

Source: SPSS Data Processing Results 26, (2025)

Based on the results of data processing using SPSS version 26, all statement items in the Performance variable *Scrubber* (X) and Engine Operational Performance (Y) have a value of *Corrected Item Total Correlation* greater than 0.30 with a significance value less than 0.05, so that all statements are declared valid according to the criteria set by [9]. A high item correlation value indicates that each item of the statement in the questionnaire has a consistent contribution in measuring the construct of the variable in question.

TABLE 4.
RELIABILITY TEST RESULTS (X)

Variable	Cronbach's Alpha	Number of Items	Information
Performance Scrubber (X)	0.939	15	Reliable

Source: SPSS Data Processing Results 26, (2025)

TABLE 5.
RELIABILITY TEST RESULTS (Y)

Variable	Cronbach's Alpha	Number of Items	Information
Engine Operational Performance (Y)	0.951	15	Reliable

Source: SPSS Data Processing Results 26, (2025)

The results of the reliability calculation show that the Performance variable *Scrubber* (X) has a Cronbach's Alpha value of 0.939, while the Engine Operational Performance variable (Y) records a value of 0.951. Both values are well above the minimum limit of 0.70 set in the research methodology literature [10], even included in the category of very reliable, so it can be concluded that this research instrument has a very high internal consistency and is suitable for data collection.

Once the research instrument has been proven to be valid and reliable, a series of classical assumption tests are performed to ensure that the data meets the requirements of parametric statistical analysis.

TABLE 6.
NORMALITY TEST RESULTS

Tests of Normality

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistics	Df	Sig.	Statistics	Df	Sig.
Scrubber Performance	.105	29	.200*	.973	29	.657
Operational performance of ship engines	.103	29	.200*	.977	29	.766

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Source: SPSS Data Processing Results 26, (2025)

Based on the results of *the Shapiro-Wilk test*, both variables had significant values greater than 0.05 (Scrubber Performance = 0.657; Machine Operational Performance = 0.766) so that it can be concluded that the data is normally distributed. The fulfillment of this assumption of normality confirms that the research data follow a normal probability distribution, which is a fundamental prerequisite for the application of parametric statistical techniques.

TABLE 7.
HOMOGENEITY TEST RESULTS

Test of Homogeneity of Variances

		Living Statistic	df1	df2	Sig.
Scrubber and Ship Engine Performance	Based on Mean	.000	1	56	.983
	Based on Median	.000	1	56	1.000
	Based on Median and with adjusted df	.000	1	55.150	1.000
	Based on trimmed mean	.000	1	56	.995

Source: SPSS data processing results 26, 2025

The significance value of the *Levene test* is greater than 0.05 (0.983) so it can be concluded that the data has a homogeneous variance. The homogeneity of the variance indicates that the variability of the data in the compared group is relatively uniform, which is an important assumption in statistical analysis to ensure the validity of the inference.

TABLE 8.
LINEARITY TEST RESULTS

ANOVA Table

			Sum of Squares	Df	Mean Square	F	Sig.
Operational Performance * Scrubber Performance	Between Groups	(Combined)	225.365	11	20.488	85.296	.000
		Linearity	222.234	1	222.234	925.219	.000
		Deviation from Linearity	3.131	10	.313	1.303	.303
	Within Groups		4.083	17	.240		
	Total		229.448	28			

Source: SPSS data processing results 26, 2025

The significance value on the *Linearity* line shows a value of 0.000 (p<0.05) with a *Deviation from Linearity* value of 0.303 (p>0.05). This confirms that the relationship between Scrubber Performance and Engine Operational Performance is linear, which qualifies parametric analysis using Pearson correlation. The linearity of this relationship indicates that changes in the performance variables of the *scrubber* are followed by proportional changes in the machine's operational performance in a consistent pattern.

TABLE 9.
SIMPLE LINEAR REGRESSION TEST RESULTS

Model Summary[b]

Type	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.984a	.969	.967	.517

a. Predictors: (Constant), Scrubber Performance

b. Dependent Variable: Operational Reliability

NEW ERA

Type		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	222.234	1	222.234	831.730	.000b
	Residual	7.214	27	.267		
	Total	229.448	28			

a. Dependent Variable: Operational Performance of Ship Engines

b. Predictors: (Constant), Scrubber Performance

Coefficient

Type		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.472	2.027		1.713	.098
	Scrubber Performance	.944	.033	.984	28.840	.000

a. Dependent Variable: Operational Performance of Ship Engines

Source: SPSS data processing results 26, 2025

The results of a simple linear regression show values of R = 0.984 and R Square = 0.969, which indicates that 96.9% of the variation in Ship Engine Operational Performance can be explained by Scrubber Performance. An Adjusted R Square value of 0.967 indicates that the regression model is very stable and accurate despite the limited sample count. A statistical F-value of 831.730 with a significance of 0.000 confirms that the regression model formed is feasible to predict the operational performance of the machine based on *the performance of the scrubber*. The regression equation formed is: Y = 3.472 + 0.944X, which shows that every single unit increase in *scrubber performance* will increase the machine's operational performance by 0.944 units assuming other factors are constant. However, the interpretation of this regression result must be carried out carefully by considering external variables that have the potential to affect system performance, such as *back pressure*, *fouling*, exhaust gas humidity, and fuel quality that can affect the combustion process and the effectiveness of exhaust gas filtration.

TABLE 10.
PEARSON PRODUCT MOMENT CORRELATION TEST RESULTS

Correlations

		Scrubber Performance	Reliability of Operationoanl Machine
Scrubber Performance	Pearson Correlation	1	.587**
	Sig. (2-tailed)		.001
	N	29	29
Operational Performance of Ship Engines	Pearson Correlation	.587**	1
	Sig. (2-tailed)	.001	
	N	29	29

Source: SPSS Data Processing Results 26, (2025)

The value of the Pearson correlation coefficient of r = 0.587 with a significance of 0.001 ($p<0.05$) indicates that there is a significant positive relationship between the performance of the *Scrubber* with the Operational Performance of the Engine on the MV ship. Sinar Sorong. Based on the classification of correlation levels according to [9], coefficients in the range of 0.40-0.599 are categorized as moderate relationships. Although the strength of the relationship is in the medium category, the very low significance value confirms that the relationship is statistically real and not the result of chance or sampling error. Thus, it can be concluded that the better the performance of the system *Scrubber*, then the higher the operational performance level of the ship's main engine [15].

These findings provide empirical validation of the technical mechanisms by which the *Scrubber* plays a role in reducing the level of sulfur (SO_x) and particulate matter from engine exhaust gases through the process of spraying seawater or chemical solutions, so that operational parameters such as return pressure (*back pressure*), exhaust gas temperature, and combustion parameters can be maintained within normal limits. Condition *Scrubber* which functions optimally will reduce the risk of soot buildup and corrosion in the exhaust system, maintain combustion efficiency, and stabilize the performance of the main engine. The significant correlation results in this study are in line with several previous studies that confirm the positive impact of the implementation *Scrubber* to the operational stability of the machine. [13] find that the installation *Exhaust Gas Scrubber* on ships of the type *Feeder* has a positive impact on fuel efficiency and the stability of the main engine output power. [6] also indicates that the use of *Modern scrubber* Commercial ships are able to reduce sulfur emissions by up to 97% without interfering with the performance of the main engine. Engine performance on a ship with a system *open-loop scrubber* more stable than ships without *Scrubber* due to the reduction of corrosive deposits in the exhaust gas system.

The findings of this study provide significant practical implications for ship operators and management that the *scrubber* system not only serves as a tool to comply with the MARPOL Annex VI regulations on sulfur emission limits, but also as a strategic component in maintaining optimal ship engine performance in the long term. From a managerial perspective, the results of this study indicate the need to optimize periodic maintenance strategies, monitor the technical parameters of *the scrubber* (pressure, temperature, and flow rate), and train crew competencies in the operation of this system so that the synergistic relationship between *the performance of the scrubber* and the performance of the engine can be maintained. Investing in a structured real-time monitoring and preventive maintenance system will provide a return on investment through increased operational efficiency, reduced engine downtime, and extended service life of critical engine components. Furthermore, an in-depth understanding of the technical relationship between *scrubber* performance and engine performance allows *ship engineers* to quickly identify any anomalies that occur, so that the risk of fatal damage that can disrupt ship operations and reduce work productivity can be effectively minimized.

IV. CONCLUSION

Based on a comprehensive analysis of empirical data collected during the operational period of the MV. Sinar Sorong, this study succeeded in confirming the existence of a positive and significant relationship between the performance of the exhaust gas scrubber and the operational performance of the main engine. The scrubber system implemented on the vessel showed optimal performance with the technical parameters of the chemical being within the specification range, including a nonvolatile solid value of 34.1%, a viscosity of 420 cPs, a basicity level of 40%, and a stable pH between 3.5-8.2, which collectively resulted in sulfur oxide absorption efficiency that met IMO MEPC.259(68) regulatory standards. The operational performance of the main engine of the MAN B&W 6S60ME-C8.5 demonstrates the stability of critical parameters with a maximum combustion pressure of 145.4 bar, a compression pressure of 107.2 bar, a exhaust gas temperature of 333°C and a specific fuel consumption of 174.0 g/kWh, all of which are within the optimal range of the engine design without experiencing significant deviations during the scrubber Operate. The Pearson correlation test yielded a coefficient of r = 0.587 with a significance of 0.001 ($p<0.05$), which indicated that there was a positive relationship between the moderate but statistically significant category, where the increase in scrubber performance was followed by an increase in engine operational performance with a variance contribution of 96.9% based on regression analysis. These findings confirm that the scrubber system not only serves as an instrument of emission regulatory compliance, but also serves as a technical component that contributes to the stability of the combustion system through the reduction of sulfur residue accumulation and the prevention of corrosive deposits on the exhaust gas line, which in turn facilitates the thermal efficiency of the engine and minimizes the risk of component degradation.

The practical implications of the findings of this study indicate the need to reorient the ship maintenance management strategy from a reactive approach to an integrated preventive approach, where the scrubber system is treated as a critical subsystem that requires continuous monitoring of technical parameters and periodic maintenance according to the planned maintenance system. Ship operators and management are advised to implement a real-time monitoring system of the scruber's operational parameters including pressure, temperature, flow rate, pH wash water, and chemical concentration, which is integrated with the engine performance monitoring system for early detection of anomalies that may affect engine reliability. Investment in engine crew technical competency training programs in the operational and troubleshooting aspects of the scrubber system is essential to ensure the capability of rapid identification of parameter deviations and the implementation of appropriate corrective actions before it develops into a system failure that can disrupt the ship's operational continuity. Further research is recommended to explore the influence of moderator variables such as variations in fuel quality, operational environmental conditions, and engine load patterns on the relationship between scrubber performance and engine performance using a longitudinal approach with multi-vessel samples to improve the generalization of findings as well as develop predictive models that can be applied to different vessel types and engine configurations.

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