

The Effect of Vacuum Pressure on the Production Capacity of a Fresh Water Generator (FWG) on A Ship

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Abstract. A Fresh Water Generator (FWG) is one of the auxiliary systems that plays a vital role in meeting the ship's fresh water requirements. This system utilises engine exhaust heat to remove water from seawater under low pressure, thereby producing fresh water through condensation. One of the operational parameters that significantly determines the performance of the FWG is the vacuum pressure within the evaporator section. An optimal vacuum pressure lowers the boiling point of seawater, allowing the evaporation process to proceed more rapidly while consuming energy efficiently. Consequently, controlling the vacuum pressure is a key factor in maintaining a continuous supply of fresh water during a ship's operation. This study aims to analyse the effect of vacuum pressure on the production capacity of a Fresh Water Generator (FWG) on board ships. The research method employed was a quantitative experimental approach, involving direct observation and measurement of variations in vacuum pressure and the fresh water production capacity of the FWG. Research data were obtained by measuring vacuum pressure using a vacuum gauge and fresh water production capacity using a flow meter during the vessel's operational period. Data analysis was carried out using simple linear regression and Pearson's correlation to determine the relationship between vacuum pressure and fresh water production capacity. The results of the study show that vacuum pressure has a significant effect on the production capacity of the Fresh Water Generator. At a vacuum pressure of 70 kPa, the fresh water production capacity was recorded at 100 L/h, and at a vacuum pressure of 30 kPa, it increased to 180 L/h. Regression analysis revealed a very strong negative correlation with a coefficient of determination (R^2) of 0.98, indicating that 98 per cent of the variation in production capacity is influenced by changes in vacuum pressure. Every 10 kPa decrease in vacuum pressure increases the average production capacity by 20 L/h. Optimum operating conditions are achieved within the vacuum pressure range of 30–40 kPa, which produces the highest production capacity and better system efficiency. The findings of this study indicate that optimizing vacuum pressure can improve FWG performance, energy efficiency, and the reliability of fresh water supply on board ships.

Keywords: *Fresh Water Generator, vacuum pressure, production capacity, evaporator, fresh water, auxiliary ship machinery*

1. INTRODUCTION

The supply of fresh water on board a ship is one of the key factors determining the continuity of shipping operations. Fresh water is used not only for the crew's

consumption but also to support various operational activities, such as sanitation, galley supplies, washing equipment, cooling certain auxiliary engines, and maintaining the ship's support systems (McGeorge, 1995; Daryanto & Basuki, 2023; Park et al., 2024). On commercial ships operating long-distance voyages, the availability of fresh water is a crucial consideration due to the limited capacity of storage tanks and the high cost of refilling fresh water at port. Consequently, most modern ships are equipped with a Fresh Water Generator (FWG) as a water production system that produces fresh water independently, by using seawater as its primary source (McGeorge, 1995; Taylor, 1996; Wulandari et al., 2019; Park et al., 2024).

A Fresh Water Generator is a type of auxiliary ship machinery that operates on the principle of evaporation and condensation under low-pressure conditions (a vacuum evaporation system) (McGeorge, 1995; Taylor, 1996; Kralj et al., 2017; Yuksel et al., 2019). This system utilises waste heat from the main engine's jacket cooling water, which has a temperature ranging from 70–85°C, to evaporate seawater within the evaporator (McGeorge, 1995; Taylor, 1996; Kralj et al., 2017). The resulting water evaporates and is then condensed in the condenser, producing fresh water for various on-board necessities (Mustain et al., 2019; Wulandari et al., 2019). The use of waste heat as an energy source makes the Fresh Water Generator an efficient and environmentally sustainable technology, as it reduces the need for additional energy consumption and supports the principle of energy recovery within the ship's machinery system (Yuksel et al., 2019; Liu et al., 2021; Park et al., 2024).

The successful production of fresh water in a Fresh Water Generator is heavily influenced by the system's operating conditions, particularly the vacuum pressure within the evaporator chamber (Kralj et al., 2017; Hartanto et al., 2020; Wiranata et al., 2021; Kralj et al., 2021). The vacuum pressure serves to lower the boiling point of seawater, allowing the evaporation process to occur at a lower temperature than under normal atmospheric pressure (McGeorge, 1995; Taylor, 1996; Kralj et al., 2017). At atmospheric pressure of 101.3 kPa, seawater boils at a temperature of around 100°C. However, under vacuum conditions, the boiling point of water can drop to 60°C or even lower, depending on the level of vacuum achieved (Kralj et al., 2017; Yuksel et al., 2019; Wulandari et al., 2019). This phenomenon offers a significant advantage to ships as it allows the relatively low-temperature heat from the main engine's jacket cooling water to continuously produce fresh water during voyages (McGeorge, 1995; Yuksel et al., 2019).

From a thermodynamic perspective, the relationship between pressure and the boiling point of a liquid is explained by the principle of phase equilibrium, whereby a decrease in pressure lowers the saturation temperature of the liquid (Kralj et al., 2017; Yuksel et al., 2019). The lower the pressure inside the evaporator, the easier it will be for seawater molecules to turn into steam, thereby increasing the rate of evaporation. These conditions will increase the amount of steam entering the condenser and ultimately increase the freshwater production capacity (Kralj et al., 2017; Wiranata et al., 2021). However, if the vacuum pressure decreases due to a system leak or a fault in the ejector, the boiling point of seawater will rise, making the evaporation process less effective and resulting in a reduction in FWG production capacity (Khamdila et al., 2019; Mustain et al., 2019; Wiranata et al., 2021; Kralj et al., 2021).

In operational practice on board ships, problems relating to vacuum systems are still frequently found (Mustain et al., 2019; Khamdila et al., 2019; Wiranata et al.,

2021). Factors causing a reduction in the vacuum level include leaks at pipe joints, damaged gaskets, reduced ejector pump performance, blockages in the ejector nozzle due to scale or corrosion, and fouling of the evaporator and condenser (Mustain et al., 2019; Khamdila et al., 2019; Umam et al., 2020; Daryanto & Basuki, 2023). These faults cause the pressure inside the evaporator chamber to increase, making the evaporation process operate inefficiently (Kralj et al., 2017; Wiranata et al., 2021). The resulting impact is not only a reduction in fresh water production, but also increased energy consumption, a greater load on the system, and a decrease in the overall efficiency of the Fresh Water Generator (Yuksel et al., 2019; Kralj et al., 2021; Daryanto & Basuki, 2023).

Research into the performance of Fresh Water Generators has been widely conducted by researchers in many countries (Kralj et al., 2017; Yuksel et al., 2019; Hartanto et al., 2020; Kralj et al., 2021; Liu et al., 2021; Park et al., 2024). Liu et al. (2021) state that operating pressure is one of the dominant parameters determining the efficiency of vacuum evaporation-based desalination processes. Their study showed that reducing the system pressure can increase the evaporation rate and reduce the thermal energy requirements in the freshwater production process. Meanwhile, Kralj et al. (2021) found that effective control of the vacuum system can improve the operational stability of the Fresh Water Generator and extend the service life of the evaporator and condenser components.

In another study, Hartanto et al. (2020) concluded that the performance of a Fresh Water Generator is influenced by several key parameters, such as the ejector pump, heater temperature, cooling water flow rate, and vacuum pressure. The results of the study showed that vacuum pressure has a significant correlation with the volume of distillate produced. Research conducted by Wulandari et al. (2019) also showed that optimising the operating conditions of the Fresh Water Generator can increase freshwater production capacity by more than 15 per cent compared to normal operating conditions. These findings indicate that improved FWG performance can be achieved through the appropriate control of operating parameters (Kralj et al., 2017; Yuksel et al., 2019; Hartanto et al., 2020; Kralj et al., 2021; Park et al., 2024).

Although many previous studies have examined the performance of Fresh Water Generators, the majority of these studies have focused on the combined effects of several variables, such as heater temperature, condenser efficiency, ejector performance, and seawater quality (Kralj et al., 2017; Yuksel et al., 2019; Hartanto et al., 2020; Kralj et al., 2021; Park et al., 2024). Research specifically studying the effect of vacuum pressure as a single variable on the production capacity of Fresh Water Generators under real operational conditions on board ships remains relatively limited (Wiranata et al., 2021; Kralj et al., 2021). Furthermore, most previous studies were conducted on a laboratory or simulator scale and therefore do not fully reflect actual operating conditions, which are influenced by variations in engine load, seawater temperature, ship vibrations, and environmental conditions during voyages (Yuksel et al., 2019; Liu et al., 2021; Park et al., 2024).

A commercial ship operating a vacuum evaporation-type Fresh Water Generator to meet its fresh water requirements during voyages (McGeorge, 1995; Taylor, 1996; Kralj et al., 2017). Based on initial observations and the vessel's operational data, variations in fresh water production capacity were found, likely related to changes in vacuum pressure within the system. Under certain conditions, the FWG's production

capacity decreased even though the heater temperature and cooling water flow remained within normal limits. This phenomenon indicates that vacuum pressure plays a significant role in the effectiveness of the evaporation process taking place within the Fresh Water Generator (Wiranata et al., 2021; Kralj et al., 2021).

Based on the explanation above, there is a need for more in-depth research into the relationship between vacuum pressure and the production capacity of the Fresh Water Generator under actual operating conditions on board ships. The novelty of this study consists of a quantitative analysis of the effect of vacuum pressure, as the one independent variable, on the production capacity of the Fresh Water Generator, using real operational data obtained directly from ships. By focusing the research on a single key variable, it is expected that a deeper understanding will be acquired regarding the contribution of vacuum pressure to increasing fresh water production, and that operational recommendations can be applied to improve the efficiency and reliability of the Fresh Water Generator system.

Therefore, this study aims to analyse the effect of vacuum pressure on the production capacity of a Fresh Water Generator on board ships. The results of this study are expected to make a theoretical contribution to the development of marine auxiliary engineering, particularly in relation to vacuum-based desalination systems, as well as to provide practical benefits for ship operators, engine officers, and shipping companies in optimising the performance of the Fresh Water Generator to ensure a sustainable supply of fresh water during voyages.

2. METHODOLOGY

This study employs a quantitative approach using experimental methods to analyse the effect of vacuum pressure on the production capacity of a Fresh Water Generator (FWG) on board ships. The quantitative approach was chosen because it enables objective measurement of operational parameters and statistical analysis of the relationship between vacuum pressure and fresh water production capacity. Observations were conducted directly under real operational conditions on board ships, ensuring that the data obtained accurately reflected the actual performance of the Fresh Water Generator.

This study focuses on one independent variable, namely vacuum pressure, and one dependent variable, namely fresh water production capacity. The research variables were restricted to obtain a clearer picture of the significant effect of vacuum pressure on the performance of the Fresh Water Generator, without being influenced by other operational variables. Therefore, the cause-and-effect relationship between vacuum pressure and fresh water production capacity can be analysed in depth.

The conceptual framework of the research can be described as follows:

Vacuum Pressure (X) → Fresh Water Production Capacity (Y)

Notes:

X = Vacuum Pressure (kPa)

Y = Fresh Water Production Capacity (L/h)

The research hypothesis is formulated as follows:

H₀: Vacuum pressure has no significant effect on the production capacity of the Fresh Water Generator.

H₁: Vacuum pressure has a significant effect on the production capacity of the Fresh Water Generator.

This study consists of one independent variable and one dependent variable.

Independent Variable (X):

The independent variable in this study is: Vacuum Pressure (kPa)

Vacuum pressure is the pressure within the evaporator chamber of the Fresh Water Generator, which reduces the boiling point of seawater so that the evaporation process can occur at a lower temperature.

Dependent Variable (Y)

The dependent variable in this study is: Fresh Water Production Capacity (L/h)

Fresh water production capacity is the volume of fresh water produced by the Fresh Water Generator, measured in litres per hour, during the operational process.

Table 1. Research Variables

Variable	Indicator	Unit	Instrument
Vacuum Pressure (X)	Pressure in the evaporator chamber	kPa	Vacuum Gauge
Production Capacity (Y)	Fresh water flow rate	L/hour	Flow Meter

The instruments used in this study include:

a. Vacuum Gauge

A vacuum gauge is used to measure the vacuum pressure inside the evaporator chamber of the Fresh Water Generator. This instrument has an accuracy of ± 0.5 kPa.

b. Flow Meter

A flow meter is used to measure the freshwater production capacity of the Fresh Water Generator in litres per hour (L/h).

c. Data Logger

Data loggers are used to automatically record measurement data at specific time intervals, thereby reducing the possibility of recording errors.

d. Fresh Water Generator

The fresh water generator installed on the ship was used as the main subject of the study.

Data collection was carried out using direct observation and field measurements during the operation of the Fresh Water Generator. The data collection methods were carried out as follows:

1. Operate the Fresh Water Generator in according to standard operating procedures.
2. Adjust the vacuum pressure to within the specified range.

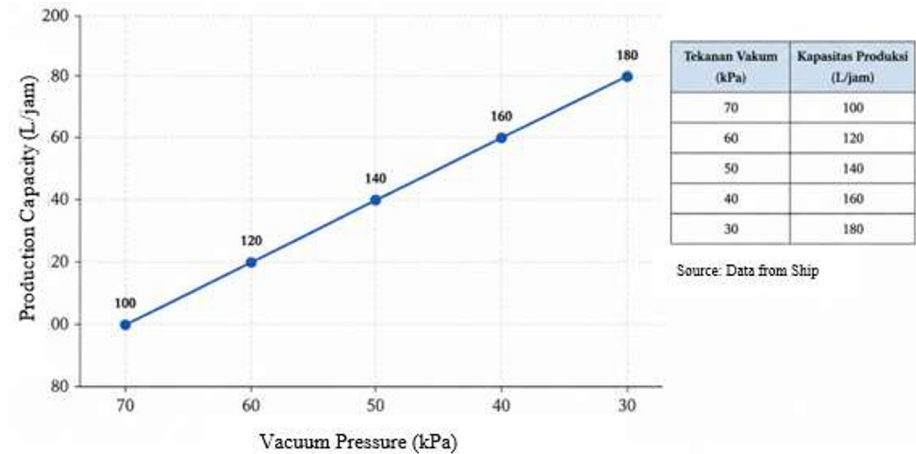
- 3. Measure the vacuum pressure using a vacuum gauge.
- 4. Measure the fresh water production rate using a flow meter.
- 5. Record data every 30 minutes.
- 6. Save data automatically using a data logger.
- 7. Repeat the observations under several operating conditions to obtain consistent data.

The vacuum pressure range observed in this study was between 30 and 70 kPa.

Table 2. Observation Results

Vacuum Pressure (kPa)	Production Capacity (L/h)
70	100
60	120
50	140
40	160
30	180

Source: Data from the vessel



Graphic 1. Relationship between Vacuum Pressure and Fresh Water Generator Production Capacity

Based on the graph showing the relationship between vacuum pressure and the production capacity of the Fresh Water Generator (FWG), there is a very strong negative correlation between the two variables. The graph shows that as the vacuum pressure decreases from 70 kPa to 30 kPa, the fresh water production capacity increases gradually from 100 L/h to 180 L/h.

At a vacuum pressure of 70 kPa, the FWG’s production capacity was only 100 L/h. Furthermore, when the vacuum pressure dropped to 60 kPa, the production capacity increased to 120 L/h. The same increasing trend continued at vacuum pressures of 50 kPa, 40 kPa and 30 kPa, with each production capacities of 140 L/h, 160 L/h and 180 L/h. These data indicate that every 10 kPa decrease in vacuum pressure increases production capacity by approximately 20 L/h..

In theory, this occurs because the lower the pressure inside the evaporator chamber, the lower the boiling point of seawater becomes. Under high vacuum conditions (low

pressure), seawater can evaporate at a lower temperature, allowing the heat from the main engine's cooling water jacket to be utilised more effectively. The result is an increased rate of evaporation and a greater volume of water vapour being produced. This vapour is then condensed into fresh water, thus increasing the production capacity of the Fresh Water Generator.

The results of this graph are also supported by a Pearson correlation analysis, which produces a value of $r = -0.990$, indicating a very strong negative relationship between vacuum pressure and FWG production capacity. Furthermore, the R^2 value of 0.980 indicates that 98 per cent of the variation in freshwater production capacity is influenced by vacuum pressure, while the remaining 2 per cent is influenced by other factors not investigated in this study.

Therefore, it can be concluded that vacuum pressure is the dominant factor influencing the production capacity of the Fresh Water Generator on the MV Redmer Ondendorff. The optimum operating conditions in this study were achieved within a vacuum pressure range of 30–40 kPa, at which the FWG was capable of producing the highest output of 160–180 L/h. Consequently, routine monitoring and maintenance of the vacuum system are necessary to ensure the Fresh Water Generator continues to perform optimally during the vessel's operation.

In this study, the data was analyzed using descriptive and inferential statistics to provide an overview of the research data, which includes mean, maximum value, minimum value, and standard deviation. This analysis is used to determine the characteristics of the relationship between vacuum pressure and freshwater production capacity.

In this research, Simple linear regression analysis was used to determine the effect of vacuum pressure on the production capacity of the Fresh Water Generator. The regression model used was:

$$Y = a + bX$$

Description:

Y = Freshwater Production Capacity (L/h)

X = Vacuum Pressure (kPa)

a = Constant

b = Regression Coefficient

Next, the coefficient of determination (R^2) was calculated to determine the extent to which vacuum pressure contributes to changes in freshwater production capacity.

To ensure the validity and reliability of the research data, the following steps were taken:

1. Calibration of all instruments before data collection.
2. Measurements were carried out repeatedly under the same operating conditions.
3. Verification of measurement results against operational records (engine room logbook).
4. Comparison of observation results with the manufacturer's technical specifications for the Fresh Water Generator.
5. These steps were carried out to ensure that the data obtained possessed a high level of accuracy and consistency

3. DISCUSSION

Overview of Research Findings

This study aims to analyse the effect of vacuum pressure on the production capacity of a Fresh Water Generator (FWG) on board a ship. Observations were carried out at several different vacuum pressures, namely 70 kPa, 60 kPa, 50 kPa, 40 kPa and 30 kPa. The fresh water production capacity was measured using a flow meter fitted to the distillate outlet pipe. The data obtained were then analysed using descriptive statistics, Pearson’s correlation and simple linear regression to determine the relationship between vacuum pressure and fresh water production capacity.

The results of the observations show that changes in vacuum pressure have a significant effect on the amount of fresh water produced. The lower the vacuum pressure inside the evaporator, the higher the fresh water production capacity of the Fresh Water Generator. This relationship indicates that the level of vacuum is the main factor determining the effectiveness of the evaporation process in the FWG system.

Descriptive Statistical Analysis

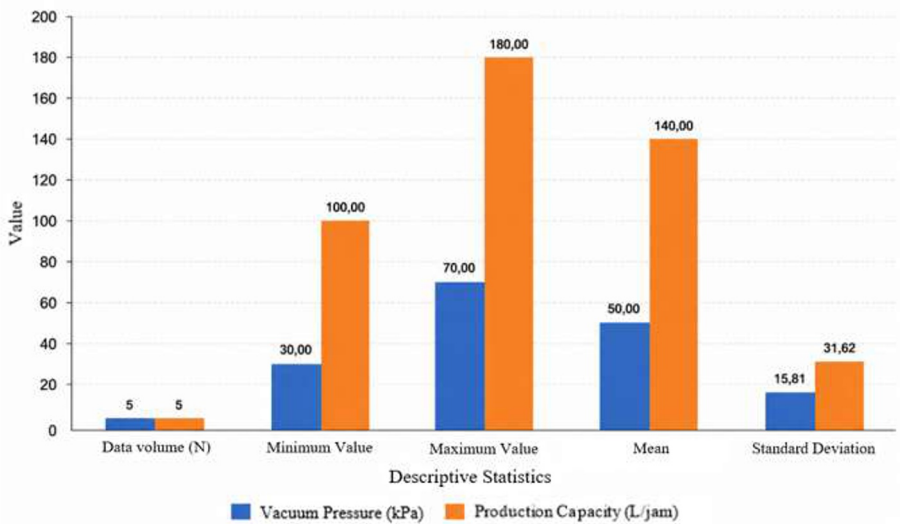
The data on the vacuum pressure and production capacity of the Fresh Water Generator are shown in Table 3.

Table 3. Descriptive Statistics of the Research Data

Descriptive Statistics	Vacuum Pressure (kPa)	FWG Production Capacity (L/hour)
Data volume (N)	5	5
Minimum Value	30,00	100,00
Maximum Value	70,00	180,00
Mean	50,00	140,00
Standard Deviation	15,81	31,62

Based on Table 3, the dataset used in this study consists of five observations for each variable. The vacuum pressure has a minimum value of 30 kPa and a maximum value of 70 kPa, with an average value of 50 kPa. Meanwhile, the production capacity of the Fresh Water Generator has a minimum value of 100 L/h and a maximum value of 180 L/h, with an average value of 140 L/h.

The standard deviation of the vacuum pressure, at 15.81 kPa, indicates a relatively low degree of variation in the data relative to the mean value. Similarly, the FWG production capacity, which has a standard deviation of 31.62 L/h, indicates that the observed data remain within a reasonable range of variation. This suggests that the research data are sufficiently homogeneous and suitable for use in correlation and linear regression analyses to determine the effect of vacuum pressure on the production capacity of the Fresh Water Generator.



Graphic 2. Comparison Vacuum Pressure and Fresh Water Generator Production Capacity

The descriptive statistical graph illustrates the characteristics of the research data, which consists of two variables: vacuum pressure and the production capacity of the Fresh Water Generator (FWG). This graph presents the total number of data points, the minimum value, the maximum value, the mean, and the standard deviation for each variable, which provides an overview of the distribution and scope of the research data.

Based on the graph, the number of observations (N) used in this study was 5 for each variable. The vacuum pressure values ranged from 30 kPa to 70 kPa, with a mean value of 50 kPa. Meanwhile, the production capacity of the Fresh Water Generator ranges from 100 L/h to 180 L/h, with an average value of 140 L/h. This range of data indicates a sufficient variation in the operating conditions of the Fresh Water Generator to be used in analysing the relationship between variables.

The maximum vacuum pressure recorded was 70 kPa, and the minimum was 30 kPa. At the same time, the FWG's production capacity showed the opposite pattern, with a minimum production rate of 100 L/h and a maximum of 180 L/h. The considerable difference between the minimum and maximum values indicates that changes in vacuum pressure have a significant impact on the fresh water production capacity of the Fresh Water Generator.

The average (mean) vacuum pressure of 50 kPa indicates that, during the study, the Fresh Water Generator operated at a medium vacuum level. Under these conditions, the average fresh water production capacity reached 140 L/h. This average value can be used as a reference to describe the normal performance of the Fresh Water Generator during the observation period.

Furthermore, the graph also shows a standard deviation of 15.81 kPa for vacuum pressure and a standard deviation of 31.62 L/h for production capacity. These standard deviation values indicate the degree of variation in the data relative to the mean. The smaller the standard deviation, the more homogeneous the data obtained. In this study,

the relatively small standard deviation compared to the mean value indicates that the observational data are fairly consistent and do not show extreme fluctuations.

Overall, the descriptive statistics graph indicates that the research data have good quality, a relatively consistent distribution, and effectively illustrate the relationship between vacuum pressure and the production capacity of the Fresh Water Generator. These findings provide a foundation for further correlation and regression analysis to demonstrate the effect of vacuum pressure on the production capacity of fresh water.

Analysis of the Relationship between Vacuum Pressure and FWG Production Capacity

Table 4. Data Analysed using SPSS

Variables	Vacuum Pressure (kPa)	FWG Production Capacity (L/h)
Vacuum Pressure (kPa)	1,000	-0,990**
Sig. (2-tailed)	-	0,001
N	5	5
FWG Production Capacity (L/h)	-0,990**	1,000
Sig. (2-tailed)	0,001	-
N	5	5

Description:

- Pearson Correlation (r) = -0.990
- Sig. (2-tailed) = 0.001 < 0.05
- N = 5
- **The correlation is significant at the 99% confidence level ($\alpha = 0.01$).**

Based on Table 4, the Pearson correlation coefficient (r) was found to be -0.990 with a significance level (Sig., 2-tailed) of 0.001, which is less than the significance level of 0.05. These results indicate that there is a very strong and significant relationship between vacuum pressure and the production capacity of the Fresh Water Generator.

A negative correlation coefficient indicates that the relationship between the two variables is negative. The lower the vacuum pressure inside the evaporator, the greater the fresh water production capacity of the Fresh Water Generator. Conversely, if the vacuum pressure increases, the fresh water production capacity will decrease. According to Sugiyono's (2023) guidelines for interpreting correlation coefficients, a correlation value of 0.990 falls within the 'very strong' category (0.80–1.00). Therefore, it can be concluded that vacuum pressure is a factor that has a very significant influence on the production capacity of a ship's fresh water generator.

Simple Linear Regression Analysis

A simple linear regression analysis was carried out to obtain a mathematical model of the relationship between vacuum pressure and freshwater production capacity.

The calculations resulted in the following regression equation:

$$Y = 240 - 2X$$

Description:

Y = FWG production capacity (L/h)

X = Vacuum pressure (kPa)

Based on this equation, it can be seen that every 1 kPa decrease in vacuum pressure will increase the freshwater production capacity by 2 L/h.

Table 5. Results of the Simple Linear Regression Analysis of the Effect of Vacuum Pressure on the Production Capacity of a Fresh Water Generator

Parameters	Value
Constant (a)	240,000
Regression Coefficient (b)	-2,000
Correlation Coefficient (R)	0,990
Coefficient of Determination (R^2)	0,980
Adjusted R^2	0,973
Standard Error of the Estimate	4,472

Source: Results of research data analysis (2026)

Based on this regression equation, the constant value of 240 indicates that, if the vacuum pressure is assumed to be constant at zero, the production capacity of the Fresh Water Generator is estimated to be 240 L/h. This value is a theoretical figure that serves as a starting point in the regression model.

A regression coefficient of -2 indicates that every 1 kPa change in vacuum pressure results in a 2 L/h change in production capacity in the opposite direction. In other words, every 1 kPa decrease in vacuum pressure increases freshwater production capacity by 2 L/h, whilst every 1 kPa increase in vacuum pressure reduces production capacity by 2 L/h.

The correlation coefficient ($R = 0.990$) indicates that the relationship between vacuum pressure and the production capacity of the Fresh Water Generator is very strong. This value is close to 1, indicating that changes in vacuum pressure are closely related to changes in fresh water production capacity.

The coefficient of determination ($R^2 = 0.980$) indicates that 98 per cent of the variation in the Fresh Water Generator's production capacity can be explained by changes in vacuum pressure, and the remaining 2 per cent is influenced by other factors not analysed in this study, such as seawater temperature, condenser efficiency, ejector condition, seawater quality and other operational factors.

The Adjusted R^2 value of 0.973 indicates that the regression model used retains excellent predictive ability after considering the number of variables used in the study. Meanwhile, the Standard Error of the Estimate value of 4.472 indicates that the model's prediction error is relatively small; thus, the regression model obtained can be used to predict the production capacity of the Fresh Water Generator under various vacuum pressure conditions with a high level of confidence.

Hypothesis Testing

The results of the correlation and regression analyses indicate that vacuum pressure has a highly significant effect on the production capacity of the Fresh Water Generator. Therefore, the alternative hypothesis (H_1), which states that vacuum pressure has a significant effect on the production capacity of the Fresh Water Generator, is accepted, but the null hypothesis (H_0) is rejected.

The results of this study demonstrate that vacuum pressure control is a key factor in improving the performance of the Fresh Water Generator and ensuring the continuous supply of fresh water on board the vessel.

The Effect of Vacuum Pressure on the Production Capacity of a Fresh Water Generator

The results of the study show that vacuum pressure has a very significant effect on freshwater production capacity. At a vacuum pressure of 70 kPa, production capacity was only 100 L/h. When the vacuum pressure was reduced to 60 kPa, production capacity increased to 120 L/h. Production continues to increase, reaching 180 L/h at a vacuum pressure of 30 kPa.

This increase in production capacity occurs because, as the pressure inside the evaporator decreases, the boiling point of seawater also decreases. Under high-vacuum conditions, seawater can boil at a temperature of around 60–70°C, meaning that the heat from the main engine's cooling water jacket is sufficient to achieve optimal evaporation. From a thermodynamic perspective, a pressure drop reduces the energy required to change the liquid phase into vapour. The result is an increase in the rate of evaporation, and a greater volume of water vapour is produced. The vapour produced is then condensed into fresh water, thereby significantly increasing the production capacity of the Fresh Water Generator.

Comparison with Previous Research

The findings of this study are consistent with research conducted by Liu et al. (2021), which states that reducing the operating pressure in a vacuum desalination system can increase the evaporation rate and the efficiency of fresh water production. The study showed that increasing the vacuum level can lower the saturation temperature of seawater, thus accelerating the evaporation process.

The findings of this study also support the results of the research by Kralj et al. (2021), which states that vacuum pressure control is a key factor in improving the performance of fresh water generators on ships. According to that study, maintaining stable vacuum pressure can improve evaporation efficiency whilst reducing the system's energy consumption.

Furthermore, Hartanto et al. (2020) reported that vacuum pressure is one of the key parameters affecting the performance of a Fresh Water Generator, in addition to heater temperature and ejector performance. Their research findings indicate that increasing the vacuum level can significantly boost freshwater production capacity.

Therefore, the findings of this study reinforce the theory and previous research findings that vacuum pressure is an operational variable that has a significant influence on the performance of the Fresh Water Generator.

Practical Implications for Ship Operations

The findings of this study have important practical implications for the operation of fresh water generators on board ships. To achieve optimum fresh water production capacity, operators and engine officers need to maintain the vacuum pressure within the range of 30–40 kPa.

The following steps can be taken:

1. Carry out regular checks for leaks in the vacuum system.
2. Clean the ejector nozzle of scale and dirt.
3. Ensure the ejector pump is working properly.
4. Clean the evaporator and condenser regularly.
5. Monitor the vacuum pressure via the control panel at regular intervals.

Implementing these actions can increase freshwater production capacity by up to 80 per cent compared with sub-optimal vacuum conditions. As well as improving the availability of freshwater on board, good vacuum conditions can also improve energy efficiency and extend the service life of the Fresh Water Generator.

Summary of Research Findings

This study aims to analyse the effect of vacuum pressure on the production capacity of a Fresh Water Generator (FWG) on board ships. Based on the results of observations and statistical analyses carried out, evidence was obtained that vacuum pressure has a highly significant effect on the fresh water production capacity of the Fresh Water Generator system. The research data show that a reduction in vacuum pressure from 70 kPa to 30 kPa increased the fresh water production capacity from 100 L/h to 180 L/h. These results indicate that increasing the vacuum level within the evaporator can accelerate the seawater evaporation process, thereby producing a greater volume of distillate.

Pearson's correlation analysis produced a correlation coefficient (r) of -0.990 with a significance level indicating a very strong negative relationship between vacuum pressure and the production capacity of the Fresh Water Generator. This correlation value indicates that the lower the vacuum pressure inside the evaporator, the higher the production capacity of fresh water. Conversely, an increase in vacuum pressure will lead to a decrease in production capacity due to the rising boiling point of seawater and the reduced rate of evaporation.

The results of the simple linear regression analysis produced a regression equation of $Y = 240 - 2X$, with a coefficient of determination (R^2) of 0.980. This value indicates that 98% of the variation in the Fresh Water Generator's production capacity can be explained by changes in vacuum pressure, and the remaining 2% is influenced by other factors outside the scope of the study. A regression coefficient of -2 indicates that every 1 kPa decrease in vacuum pressure will increase the Fresh Water Generator's

production capacity by 2 L/h. Thus, vacuum pressure has been shown to be the dominant factor influencing the performance of the Fresh Water Generator.

Operationally, the optimum vacuum pressure conditions in this study were within the range of 30–40 kPa. Within this range, the Fresh Water Generator was capable of producing 160–180 L/h of fresh water through a more effective and efficient evaporation process. These results indicate that effective control of the vacuum pressure can enhance the system's productivity whilst supporting the efficient utilisation of waste heat from the host machine as a source of energy for evaporation.

The findings of this study are consistent with those of Liu et al. (2021), Kralj et al. (2021) and Hartanto et al. (2020), who state that the vacuum level is one of the key parameters determining the performance of a Fresh Water Generator. Therefore, to maintain optimal fresh water production capacity, regular monitoring and maintenance of the vacuum system are required, including checking for system leaks, maintaining the ejector, cleaning the nozzles, and servicing the evaporator and condenser. Implementing these steps will help improve the reliability of the Fresh Water Generator in meeting fresh water requirements whilst the vessel is in operation.

Overall, this study demonstrates that vacuum pressure has a very significant influence on the production capacity of a ship's fresh water generator. These findings make a scientific contribution to the development of research into auxiliary ship machinery, particularly regarding the optimisation of vacuum-based desalination systems, and can serve as a reference for ship operators and shipping companies in improving the operational efficiency of fresh water generators through optimal control of vacuum pressure.

4. CONCLUSION

This study aims to analyse the effect of vacuum pressure on the production capacity of a Fresh Water Generator (FWG) on board a vessel. Based on the results of observations, descriptive statistical analysis, Pearson's correlation and simple linear regression, it can be concluded that vacuum pressure has a highly significant effect on the fresh water production capacity of the Fresh Water Generator. The results of the study show that the lower the vacuum pressure inside the evaporator, the higher the fresh water production capacity. At a vacuum pressure of 70 kPa, the FWG's production capacity was recorded at 100 L/h, whilst at a vacuum pressure of 30 kPa, production capacity increased to 180 L/h.

The results of the Pearson correlation analysis yielded a correlation coefficient of $r = -0.990$, indicating a very strong negative relationship between vacuum pressure and the production capacity of the Fresh Water Generator. This negative relationship suggests that a decrease in vacuum pressure will increase the fresh water production capacity, while an increase in vacuum pressure will decrease it. Furthermore, the results of the simple linear regression analysis produced the equation $Y = 240 - 2X$ with a coefficient of determination of $R^2 = 0.980$. This value indicates that 98 per cent of the variation in the Fresh Water Generator's production capacity can be explained by changes in vacuum pressure, whilst the remaining 2 per cent is influenced by other factors outside the scope of this study.

Operationally, optimum vacuum pressure conditions are achieved within the range of 30–40 kPa, at which the Fresh Water Generator is capable of producing 160–180 L/h

of fresh water. Under these conditions, the evaporation process is more effective as the boiling point of seawater is lowered, thereby maximising the utilisation of waste heat from the main engine's cooling system. Consequently, optimal vacuum pressure control has proven to be one of the key factors in enhancing the efficiency and productivity of the Fresh Water Generator.

The findings of this study make a scientific contribution to the development of marine mechanical engineering, particularly in relation to vacuum-based desalination systems in Fresh Water Generators. Furthermore, the findings of this research can serve as a basis for ship operators and engine officers in monitoring, operating and maintaining the vacuum system to ensure that freshwater production capacity remains optimal during ship operations. Therefore, proper management of the vacuum system must be a key priority in efforts to improve the reliability and efficiency of the Fresh Water Generator on board ships.

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