Factors Affecting the Performance of Fresh Water Generator in Merchant Vessel

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***Abstract* – The research was aimed (1) to analyze the effect of distillate pump performance on the performance of fresh water generator; (2) to analyze the effect of ejector pump performance on the performance of fresh water generator; and (3) to investigate the effect of distillate pumps and ejector pumps joint performance on the performance of fresh water generator. The data were obtained through questionnaire of 67 students who had completed their one year shipboard training on merchant vessels. The data were analyzed using SPSS statistics 16.0 version. The results showed that the variable of distillate pump performance positively affected the performance of fresh water generator reaching 39%. The variable of ejector pump performance also positively affected the performance of fresh water generator reaching 43.5%. The independent variables of this research were the performance of the distillate pump (X_1) and the ejector pump (X_2) which jointly affected the performance of the water generator reaching 60.5%.**

***Keywords* – distillate pump performance, ejector pump performance, fresh water generator performance**

1. Introduction

Fresh water is one of the basic needs on board. As a vessel sails away, a huge amount of fresh water is highly required. However, a huge fresh water tank would be a problem on board as the water tank would automatically reduce the vessel's capacity. Thus, as a solution, a water maker, the so called fresh water generator is required. There are several techniques of seawater desalination including RO (Reverse Osmosis), ED (Electro Dialysis), and evaporation which includes MSF (Multi-Stage Flash), MED (Multi Effect Distillation), and MVC (Mechanical Vapor Compression) [8].

In this research, a low pressure MSF on KT.02 (bulk carrier vessel) was used as the research object. The vaporizer media of the evaporator used the Main Engine's 76-78°C cooling water. 30-33°C seawater was applied as the cooling water input of the condenser, assuming that the vessel sailed in tropical waters. The equipment was functioned after the main engine went full ahead so that the cooling water output temperature was constant and positioned at least 12 miles away from the coastline.

The fresh water generator is a machinery which produces fresh water as the result of seawater's evaporation and condensation [16]. In order to evaporate sea water, a source of heat is required. In this research, the output of the Main Engine cooling water was used to evaporate the seawater.

The fresh water generator consists of several parts (a) the inner parts which consist of evaporator, condenser, ejector, demister/`vessel separator and (b) the outer parts which consist of distillate pump, ejector pump, solenoid valve, and monitoring devices [10]. Evaporator is a heat transfer device which will evaporate seawater using the output of the Main Engine's cooling water. The condenser is used to condense the steam of seawater using seawater cooling media. Ejector is a pipe which functions so as to increase the vacuum level inside the shell. Demister/vessel separator is used to separate water which contains brine from the vapor as a result of the evaporation.

Distillate pump functions so as to pump distilled water into a fresh water tank. Solenoid valve is an automatic valve which manages the fresh water flow. If salt content within the water is still high, the water will be returned to the separator shell. Monitoring devices include flow meter, pressure vacuum gauge,

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and thermometer. Flow meter shows the capacity of fresh water produced in a certain unit of time. Pressure vacuum gauge is used to measure the pressure inside the separator shell. Thermometer is used to measure the temperature of both sea water which goes into the condenser and the fresh water which goes into the evaporator.

The MSF distillation equipment is widely used in most countries in the world. For example, in Qatar, 75% of the total numbers of water maker installations apply MSF due to its reliability. Based on the previous researches which applied life cycle assessments, it was found that the configuration with a higher GR (Gain Ratio) would only produce 7.32 kg of CO_2 for every 1 m^3 of water production. The research objects were assessed based on climate change, eutrophication, fossil fuel depletion, ozone, and human toxicity [9].

Fresh water production performance and gained-output ratio can be improved by using a combination of heating pump and humidification dehumidification desalination system set on 88.34 kg/h and 3.72 at the balance conditions. It could also be done by increasing the compression ratio and decreasing the pinch-point temperature difference of the condenser and the final temperature of the evaporator [5]. The performance of heating pump which was assisted by HDH (Humidification-Dehumidification) system is able to increase fresh water production on condition that SEEC (Specific Electrical Energy Consumption) system is higher reaching 335.4 kW.h/m^3 [2].

The improvement of ejector performance will affect the level of desalination performance. The ejector itself is affected by the amount of crust found in the brine heater pipe, condenser, water box, demister pad, wire mesh, walls, and floors. It will also lead to corrosion on all seawater passages and cooling system pipes [11]. Sulfate scale formation on heat exchangers can be reduced by separating sulfate from seawater using anion-exchange resin, Realite MG 1/P [8]. In order to overcome the corrosion on the plate, DLC (Diamond Like Carbon) made of stainless steel 316 can be applied [4]. Water will only gain 8.57% on 1-D ejectors; it is less than the amount R134a liquid will do [6].

Some researches on correlation of the condensation phenomenon and vapor ejector performance found that droplet liquid on the neck can be evaporated by increasing the superheat level on 35 K on the evaporation input [7].

This research was aimed (1) to analyze the effect of distillate pump performance on the performance of fresh water generator; (2) to analyze the effect of the ejector pump performance on the performance of fresh water generator; and (3) the effect of distillate pumps and ejector pumps joint performance on the performance of fresh water generator.

2. Methodology

In this research, primary and secondary data were used. Primary data were obtained from fresh water generator installed on board of KT.01. Secondary data were obtained through questionnaire. The population included seventh semester students who had completed their one year shipboard training. 67 students were taken as research samples. The numbers of sample were obtained by using Isaac and Michael formula as follows: $s = \frac{\lambda^2.N.P.Q}{d^2\,(N-1)+\lambda^2.PQ}$, where s = number of samples; N = total population; λ^2 = chi-square, with d_k = 1 error level of 1%, 5%, and 10%; d = 0.05; P = Q = 0.5 [14]. The data were then analyzed by using the SPSS statistics 16.0 version [13].

In this research, validity test, reliability test, and classical assumption test were performed. Classical assumption test includes multicollinearity, heteroscedasticity, normality, multiple regression, hypothesis, and coefficient of determination (R^2) tests. Validity test is used to determine the eligibility of the test items in defining a variable. Reliability test is related to the construction of the test items as the dimensions of a variable [15].

Multicollinearity test is aimed to analyze whether independent variables in a regression model are correlated. Heteroscedasticity test aims to test whether in a regression model, an inequality of variance of the residuals is found. The normality test's purpose is to test whether in a regression model, confounding variables or residual variables have a normal distribution. Multiple regression analysis is used to estimate and/predict the population average or the average score of the dependent variable based on the independent variables score. Hypothesis test is applied to prove whether a statement is true or false. The coefficient of determination (R^2) essentially measures the model's ability to explain variations of the dependent variable [3].

Independent variable 1, distillate pump performance (X_1) included the output capacity suitability (1.2 m^3/h), the suitability of pump shaft rotating (3500 Rpm), the suitability of output pressure (6 bar), the suitability of electrical load (1.55 A), and electrical load frequency (60 Hz)

Independent variable 2, ejector pump performance (X_2) included the suitability of distillation water output capacity (18 m^3/h), the suitability of the pump shaft rotating (3500 Rpm), the suitability of output pressure (10 bar), the suitability of the electrical load (9.9 A), and the frequency suitability (9.9 A).

The dependent variable, the performance of fresh water generator (Y) included output capacity (20 tons/day), the suitability of water output salinity (0.2 ppt), the suitability of vacuum level (70 cm Hg), the suitability of heater temperature (76^0C), the suitability of water cooling temperature which goes into the condenser (32^0C).

3. Results and Discussion

Table 1. shows that the coefficients of each indicator for each variable resulted in a significant coefficient. Significance score of each indicator was smaller than 0.05 (α = 5%) which means that the indicators were valid.

Table 1. Validity Test result

No.	Variable	Indicator	Coefficient Correlation	Validity
1.	Distillate pump performance (X_1)	$X_{1.1}$	0.713	Valid
		$X_{1.2}$	0.697	Valid
		$X_{1.3}$	0.612	Valid
		$X_{1.4}$	0.713	Valid
		$X_{1.5}$	0.765	Valid
2.	Ejector pump performance (X_2)	$X_{2.1}$	0.619	Valid
		$X_{2.2}$	0.815	Valid
		$X_{2.3}$	0.642	Valid
		$X_{2.4}$	0.735	Valid
		$X_{2.5}$	0.721	Valid
3.	Fresh water generator performance (Y)	Y_1	0.352	Valid
		Y_2	0.685	Valid
		Y_3	0.400	Valid
		Y_4	0.663	Valid
		Y_5	0.554	Valid

Based on the test on the performance of the distillate pump, ejector pump, and fresh water generator, it was found that the reliability coefficient of Cronbach's Alpha (r) were 0.777; 0.780, and 0.691. The variable's scores were greater than the criteria 0.60, meaning that they were greater than Cronbach's Alpha. Thus, all instruments were stated as reliable; the data were reliable (Table 2.).

In this research, multicollinearity test was conducted to determine correlation between independent variables and multiple correlations which required the condition that there is no correlation between the independent variables. In order to perform the test, the tolerance and the VIF (Variance Inflation Factor) scores were used. If the score is <10, multicollinearity issues exist (Table 3.).

Heteroscedasticity test was aimed to identify whether in the regression model, the inequality of variance from the residuals of one observation to another observation occurred. If the variance of a certain observation residual to another was constant, homoskedacity occurred. On the other hand, if the result varied, heteroscedascity took place. The presence or absence of heteroscedascity could be detected based on the test score [3]. Based on Table 4., it was seen that there was no heteroscedascity since the scores of the variables were $X_1 = 0.336$; $X_2 = 0.332$. Thus, the significance score was > 0.05; heteroscedasticity did not occur.

Table 2. Reliability Test result

No.	Variable	Cronbach Alpha
1.	Distillate pump performance (X_1)	0.777
2.	Ejector pump performance (X_2)	0.780
3.	Fresh water generator performance (Y)	0.691

The normality test was aimed to identify whether the regression model of both independent and dependent variables was normally distributed. One of the easiest ways to check residual normality was by analyzing the histogram which compared the observational data and the normal distribution data. The more reliable method was by analyzing the normal probability plot which compared the cumulative distribution and the normal distribution. The normal distribution would form a diagonal straight line and the plot of the residual data was compared to the diagonal line. Based on Figure 1., it could be seen that the data were spread around the diagonal line on P-Plot of regression standardized residual.

In this research, multiple linear regression analysis was applied in order to identify whether any influence of the independent variables on the dependent variable existed (Table 5.).

Table 3. Multicollinearity Test result

No.	Variable	Tolerance	VIF	Note
1.	Distillate pump performance (X_1)	0.361	2.772	Multicollinearity free
2.	Ejector pump performance (X_2)	0.361	2.772	Multicollinearity free

Based on the results of the linear regression analysis in Table 5., a multiple linear regression equation $Y = 9.849 + 0.390\ X_1 + 0.435\ X_2$ was obtained. The results of the analysis were then interpreted. It was found that a constant reached 9.849. It means that without the presence of X_1 (distillate pump performance) and X_2 (ejector pump performance), fresh water generator performance would be increased reaching 9.849 units. Variable X_1 = 0.390 means that the distillate pump performance variable influenced the performance of fresh water generators reaching 0.390 units or in other words, it had positive effect. It means that one unit increase of spare part availability would improve the performance of fresh water generators reaching 0.390 units. On the other hand, if the performance of the distillate pump was reduced by 1 unit, the performance of fresh water generators would also decrease by 0.390 units with an assumption that the other independent variables were equal to zero. Variable X_2 = 0.435 means that the distillate pump performance variable influenced the performance of fresh water generators by 0.435 units; it led to a positive effect.

Table 4. Heteroskedacity Test result

Model	Unstandardized Coefficients		Standardized Coefficients	T	Significance
	B	Std Error	Beta		
(Constant)	9.849	1.094		9.002	0.000
X_1	0.390	0.074	0.681	5.284	0.336
X_2	0.090	0.092	0.126	0.977	0.332

*Dependent Variable : FWG

Based on Table 5., it was found that the significance score for the influence of X_1 to Y equaled to 0.001 < 0.05 and the score of t-count was 5.284> 1.999. It means that H_1 was accepted; X_1 affected Y. Thus, it can be said that the distillate pump performance variable positively affected the performance of fresh water generator. On the other hand, the low performance of distillate pump would affect the performance of fresh water generator. Thus, it can be concluded that a positive influence on the performance of fresh water generators occurred.

Table 5. Results of Multiple Linear Regression

Model	Unstandardized Coefficients		Standardized Coefficients	t	Significance
	B	Std Error	Beta		
1 (Constant)	9.849	1.094		9.002	0.000
Distillate pump (X_1)	0.390	0.074	0.681	5.284	0.000
Ejector pump (X_2)	0.435	0.092	0.126	3.860	0.030

* Dependent Variable : FWG

Based on Table 5., the significance score for X_2 to Y was 0.007 <0.05 and the t-count was 3.680 > 1.199. It can be said that H_2 was accepted meaning that X_2 had an effect on Y. In other words, the performance of the ejector pump positively affected the performance of fresh water generator. The low performance of the ejector pump would affect the performance of fresh water generator. Thus, it can be concluded that a positive influence on the performance of fresh water generators occurred.

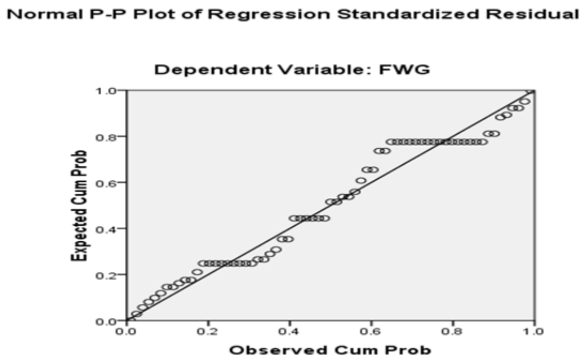

Figure 1. Normality Test result

The percentage of the dependent variable variation on the model could be explained by the independent variables by using the coefficient of determination which was shown in percentage form. Based on Table 6. below, the determinant coefficient or R^2 of the regression model was 0.605 or 60.5%. It can be said that there were 60.5% variations on the dependent variables found. The performance of fresh water generator in the regression model can be explained by the independent variables: distillate pump performance (X_1), ejector pump performance (X_2), and the remaining 39.5% was influenced by other variables.

Table 6. Coefficient of Determination

Model Summary[b]

Model	R	R Square	Adjusted Square	Standard error of the estimate
1	0.785[a]	0.617	0.605	0.72267

a. Predictors : (Constant), X_1, X_2; b. Dependent Variable : FWG

Distillate pump performance affected the performance of fresh water generator. It means that the better the performance of distillation pump in delivering distilled water to fresh water tanks, the more distilled water produced by fresh water generators. In order to increase the distillation water output capacity and a specific cooling capacity, temperature decrease of the condenser was required [18].

The performance of the ejector pump affected the performance of a fresh water generator. The ejector performance was influenced by the ejector driver. The ejector system which was driven by liquid metal had a high vacuum ejecting capacity and a good temperature stability [17].

The research showed that in order to obtain the maximum freshwater production capacity (30 m^3/day), 31.88°C seawater temperature and 72,000 kg/h of mass flow rate of jacket water were needed. When the salinity of seawater increased from 3 g/kg to 41 g/kg (3,000 to 41,000 PPM), the production increased to 2.18% and 5.06% with a constant seawater temperature (23^0C) and a mass flow rate of 58,500 kg/ hour [19].

There are four categories of fouling which can reduce desalination performance: crust, particle fouling, microbial fouling, and organic fouling. There are some fouling control strategies including: feed water treatment, condition setting, and cleaning process. A recommended pre-treatment system for RO desalination plants consists of chlorine, sodium hexametaphosphate, H_2SO_4, ferric chloride, sand filter, 0.5 μm filter cartridge, manganese zeolite filter, activated carbon filter, and sodium metabisulfite [1]. Research showed that the placement of absorbent media such as silicagel between the evaporator and condenser can improve the desalination process on condition that $T_{hot_{in}}$ = 80°C with a performance ratio of 0.6 [12].

4. Conclusion

Based on the results of the linear regression analysis whose data taken from the questionnaire and fresh water specifications on KT.02, a multiple linear regression equation, $Y = 9.849 + 0.390\ X_1 + 0.435\ X_2$ was obtained. Variable $X_1 = 0.390$ means that the distillate pump performance variable positively affected the performance of the fresh water generator reaching 39%. Variable $X_2=0.435$ means that the distillate pump performance variable positively affected the performance of fresh water generators reaching 43.5% units. The independent variable, the joint performance of the distillate pump (X_1) and the performance of the ejector pump (X_2), affected the performance of fresh water generator reaching 60.5% while the remaining 39.5% was influenced by other variables.

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