Design of Air Ventilation System for Cargo Hold Vessels using Solar Desiccant

Alam Baheramsyah[1],Taufik Fajar Nugroho[2], Prasetyo Adi Wibowo[3]

***Abstract*—one of the facilities and infrastructure of the vessel is the ventilation system in the cargo hold to maintain the quality. One attempt to avoid high moisture ratios is to provide a dry air supply by using desiccants. The purpose of this thesis is to design the system of air ventilation with solar desiccant by analysis the calculation with decrease air humidity ratio after passing desiccant rotor as well as fulfillment needs of heater and cooling system using heat of exhaust gas and seawater as well as fulfillment of electricity need using solar energy. From the result of analysis obtain to provide air supply in the cargo hold of 437.5 m^3 / hour, the specification of rotor desiccant has a diameter of 550 mm with thickness 200 mm to decrease ratio of outside air humidity equal to 83.1% become 46.5%. Dehumidification air temperature of 47.7^{o}C will be lowered to 35^{o}C by using the sea water cooling media. As for the reactivation air heater requirement of 24.292 kW would be to fulfilled by utilizing the exhaust power of 498.12 kW. And for the electric power needs of the syetm is 34,488 wp will be supplied from the total solar module is 33 units with 345 wp per-capacity.**

Keywords: air ventilation, cargo hold, pelayaran rakyat vessel, solar desiccant.

I. INTRODUCTION

Vessels used as a logistics transport from a small port, to a port hub-port, the above function is a function of the people's voyage to ensure the availability of national logistics system to inland areas. The role of the people's sail in “Sea Highway” also plays an important role in safeguarding the stability and availability of logistics, especially in areas that are difficult to reach by land transport rice, cement, fertilizer, food are some of the freight carried by Pelayaran Rakyat vessels. In addition, Pelayaran Rakyat vessels are also used for river transport such as in Kalimantan, and Sumatra. One of the facilities and infrastructures of the Pelayaran Rakyat vessels is the air ventilation system in cargo hold which is useful to keep the cargo quality in good condition.

Natural air ventilation systems for cargo hold Pelayaran Rakyat vessels are considered less effective for some items such as rice, flour or other foods. This is because the system is heavily dependent on the surrounding air condition especially for its temperature and humidity [1-5], so that when the outside air condition has high temperature and humidity which is too high can cause the quality of the cargo brought mainly to the unsuitable quality of the existing standard because of excess moisture in the cargo hold [2-11].

The region of Indonesia is in tropical climate with a range of temperatures in waters of 27^{o}C with a humidity level of 80%, while the normal temperature recommended for the charge is 43^{o}C with a relative humidity value of 65%. With the difference in environmental conditions, the charge will be affected by micro-climate elements, especially air humidity [12-18].

In addition to the use of renewable energy for the fulfillment of the heating system needs of the dehumidification system will use exhaust gas from the engine and the fulfillment of the electrical power needs used for the fulfillment of electrical power from the rotary desiccants system using solar thermal energy which is then converted through the system from photovoltaic [13].

Air ventilation system is the process of providing fresh air into the room or out of the dirty air of a room naturally and mechanically. The air venting system on the vessel has the function of maintaining chemical composition and humidity or keeping it as requirment in the vessel's room, by regulating the flow of air into out of the vessel in order to perform the process of replacing the already dirty air with fresh air and Adjust the temperature, pressure and chemical composition of the air inside the vessel [2]. With the occurrence of the process will be able to fulfill the purpose of ventilation in the vessel.

Desiccant is one of the hygroscopic substances that can absorb moisture by put away water inside the capillary or surface of an item while maintaining the presence of water

Alam Baheramsyah, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : alam@its.ac.id
Taufik Fajar Nugroho, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : taufikfajar@its.ac.id
Prasetyo Adi Wibowo, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : Prasetyo.Wibowo@mhs.ne.its.ac.id

molecules. The most common substance used as a desiccant compiler is silica gel which is a form of silica dioxide (SiO2). The use of desiccants in dehumidifier is used to attract moisture from the air by creating low vapor pressure areas on the surface of the material [3].

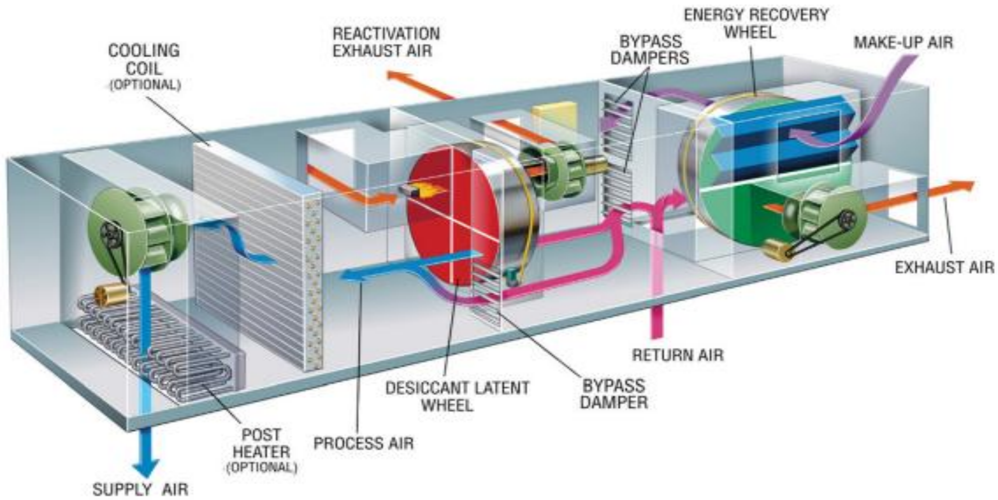


Figure. 1. Configuration wheel desiccant[3]

Calculation of exhaust heat is determined by estimating the mass of exhaust gas obtained through correction of optimation point on engine load curve and correction to ambient condition and exhaust gas pressure according to engine maker rules [4]. The economizer that to transfer of exhaust gas heating is uses to supply hetaer of reactivation energi. The power generated by exhaust gas heat can be known by the following equation:

$$Q_{exh} = \rho \cdot C_p \cdot \Delta T \cdot V_{exh} \quad (1)$$

Where:
Qexh =The power generated by exhaust gas (kW)
ρ = Density of exhaust gas (kg/m^3)
C_p = Specific heat (kJ/kg.K)
ΔT = Temperature difference (^{o}C)
V_{exh} = Exhaust gas flow capacity (m^3/s)

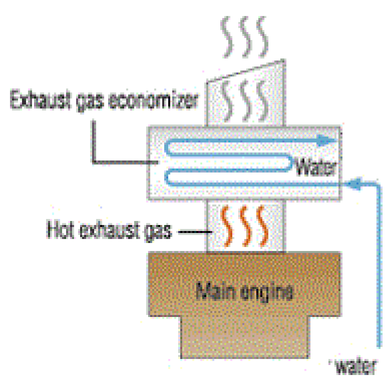


Figure. 2. Exhust Gas Economizer[5]

Calculation of heat load is performed by calculating the heat source of the ship's load space, which is the heat of solar radiation (Øs). Estimation of parameter values in determining heat load refers to ISO 7574 : *Ship and Marine Technology – Air Conditioning and Ventilation of Accomodation Spaces*[6]. The solar heat burden (Øtotal) can be calculated based on the equation:

$$\emptyset_s = \Sigma A_V K . T_r + \Sigma \dot{A}_g G_s \quad (2)$$

In determining the design of the cooling system can be done using calculations of energy equilibrium ie$Q = m.c.\Delta T$. [4]. In the type of cooling use seawater as medium of cooling system. The system need to calculate flowrate the sewater is fulfill requirmnent of cooling capacity [14]. The cooling capacity that uses to decrease the temperature is result for procces dehumidification of rotary desiccant. The flowrate of sewater that uses as medium of cooling system is to select the seawater pump with the requirment of system [15-17]. The seawater pump have function to circulating supply cooling fluid.

Mass equilibrium

Early + Procces = End

$m_{da}.W_2 + m_w = m_{da}.W_1$

$m_w = m_{da}.(W_1 - W_2)$ (3)

Calculation Flowrate

Flowrate = Mass flowrate/density

$$q = \frac{\dot{m}_c}{\rho} \quad (4)$$

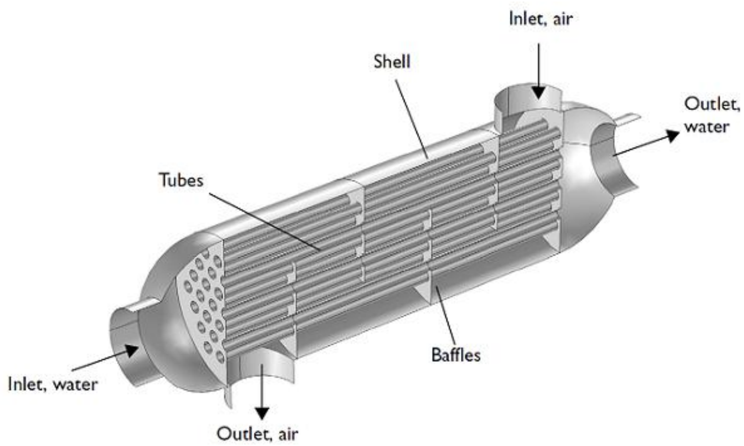


Figure. 3. Type Cooling [7]

Solar energy is energy derived from the process of converting solar heat through certain equipment into a resource in anotherenergi. Solar energy is one source of power generation other than water, steam, wind, biogas, coal, and petroleum [13].

The development of the use of solar energy reappeared in 1958. Silicon cells used to convert solar energy into resources began to be taken into calculation as a new method, since it could be used as a resource for space satellites [8].

The equation used to determine the capacity of the solar system:

$$P_{\text{solar panel}} = \frac{ET}{sun\ insulationi} \times f \quad (5)$$

Where :

ET =Total energy power (Wh)

f =Correction factor (1,1)

II. METHOD

In supporting to make this research it is needed a sequence of methods that become the framework of reference in the completion of this research. The methodology of this thesis contains steps to solve the problem in the work of this thesis. Starting from the formulation of the problem until later concludes the conclusion on the work of this thesis. The methodology used in this thesis is through the four main stages, the first is to design the dehumidification system using rotary desiccants, the second phase is to design the heating and cooling needs, the third is to design the electricity needs fulfillment system, and the last stage is to do the design condition suitability analysis.

The first step in this thesis is to determine the design schema and initial condition as a reference in determining the calculation parameters. Furthermore, it calculates the volume of vessel loading space and determines the value of air changes per hour in accordance with the recommendation of BKI, to obtain the air capacity to be supplied as well as the technical specifications of the rotor desiccant.

The next step is to design the need for reactivation air heaters for the desiccant rotor and the dehumidification air conditioning system requirements. Heating needs planning is done by calculating the required power from the heaters to be designed. Next is the calculation of the power generated by the heat from exhaust gas from the main engine. To determine the cooling system is done by calculating the cooling load from the dehumidified air desiccant dehumidifying process adjusted to the initial design temperature for cargo hold. In the cooling system can be determined the estimation of the compressive capacity that can be produced by utilizing sea water as a cooling medium.

The next step is the designing of the electrical system. The electrical system on this system uses modul photovoltaic that utilize solar energy as a source of energy. In determining the solar panel to be installed it needs to calculate the power load on the solar desiccant system. After that it is necessary to estimate the selection of equipment specification to be used in the system.

The final step is to analyze the suitability of design conditions. The analysis is conducted to determine is the design of designed to maintain the cargo hold condition based on the type of cargo transported. The suitability of the cargo hold condition is determined by considering the air dehumidification parameters of the dehumidification process. And its relation to the cooling ability before being supplied into the cargo hold.

III. RESULTS AND DISCUSSION

A. Design Desiccant System

Here is the flow diagram design of the solar desiccant system used:

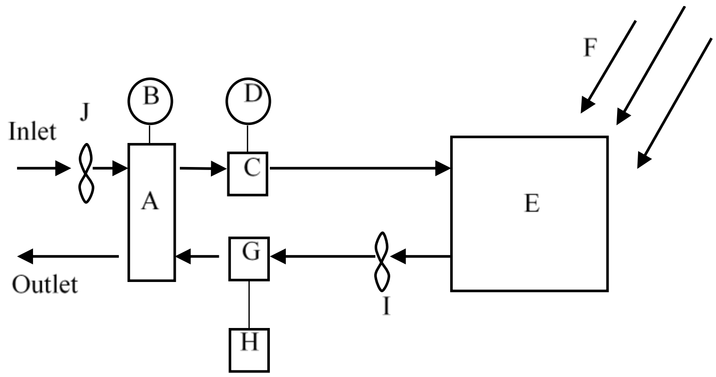


Figure. 4. Flow diagramsolar Desiccant SYSTEM
(A: *Desiccant wheel*; B: *Electric Motro* C: Cooling; D: Sea Water Pump; E: Cargo Hold; F: Solar Radiation; G: *Heater* ; H: *Thermal Oil Pump;* I: *Exhaust Fan;* J:*Supply Fan)*

B. Design Condition Determination

The outside air at 38.5^{o}C with 83.1% RH will be conditioned at 35^{o}C with 65% RH. That according from the table 1 obtained which cargo handbook.From the table 1 obtained the initial design conditions of the system.

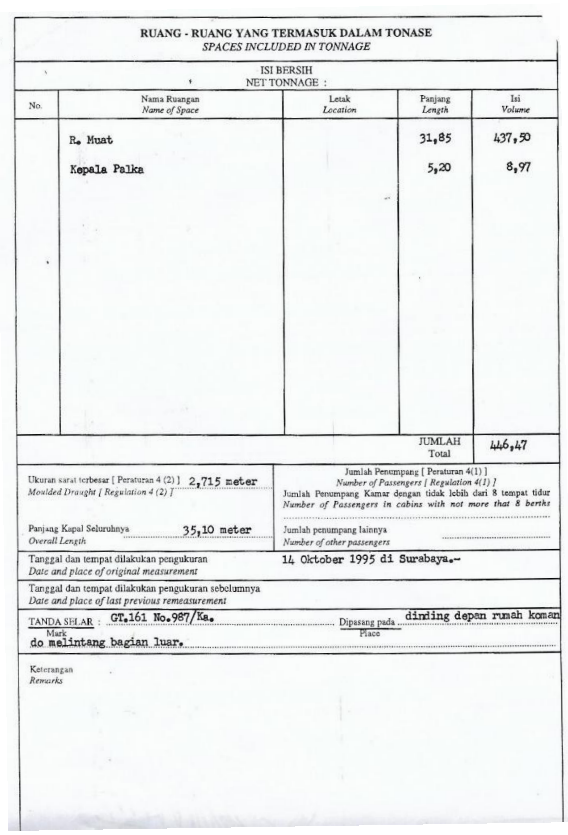
TABLE 1.
STANDARD TEMPERATURE AND RELATIVE HUMIDITY STORAGE OF STAPLES LOAD

No.	Materials	Temperature Max (^{o}C)	RH Max (%)
1	Sugar	43	65
2	Rice	43	70
3	Flour	-	65

Figure. 5. KLM Pesona Bahari

General Arrangement :

Length overall (Loa)	: 35.1 meter
Length of waterline (Lwl)	: 31.85 meter
Length between perpendiculars (Lpp)	: 30.05 meter
Breadth moulded (B)	: 9.5 meter
Draught Design (T)	: 3.62 meter
Service speed (Vs)	: 10.2 knot



RUANG - RUANG YANG TERMASUK DALAM TONASE
SPACES INCLUDED IN TONNAGE

ISI BERSIH
NET TONNAGE :

No.	Nama Ruangan *Name of Space*	Letak *Location*	Panjang *Length*	Isi *Volume*
	R. Muat		31,85	437,50
	Kepala Palka		5,20	8,97
			JUMLAH Total	446,47

Ukuran sarat terbesar [Peraturan 4 (2)] 2,715 meter
Moulded Draught [Regulation 4 (2)]

Panjang Kapal Seluruhnya 35,10 meter
Overall Length

Jumlah Penumpang [Peraturan 4(1)]
Number of Passengers [Regulation 4(1)]
Jumlah Penumpang Kamar dengan tidak lebih dari 8 tempat tidur
Number of Passengers in cabins with not more that 8 berths

Jumlah penumpang lainnya
Number of other passengers

Tanggal dan tempat dilakukan pengukuran 14 Oktober 1995 di Surabaya.-
Date and place of original measurement

Tanggal dan tempat dilakukan pengukuran sebelumnya
Date and place of last previous remeasurement

TANDA SELAR : GT.161 No.987/Ka. Dipasang pada dinding depan rumah koman
Mark Place
do melintang bagian luar.

Keterangan
Remarks

Figure. 6. Intenational Ship Surveying Letter of KLM. Pesona Bahari

The total volume of cargo hold ship (vol.) Based on data capacity plan is 437.5 m^3. While the value of air changes per hour (n) based on BKI Ventilation is 6 air changes per hour. The calculation from that obtained of requirment capacity to fulfill the system. Capacity is the air of quantity that must be in the supply into the system. So the air capacity (Q_{air}):

$$Q_{air} = n \; x \; vol. \tag{2}$$
$$= 6x437.5$$
$$= 2625 \; m^3/h$$

C. Dehumidification Procces

Determination of specification from rotor desiccant is done with the assisted of the Desiccant Wheel Simulation Program. The desiccant diameters are selected based on the availability of space in the accommodation space and the ability to lower the humidity ratio [16]. To selected desiccant rotor need to known quantity of air flow, temperature, reactivation of temperature and humiduty rasio. Input parameters to determine the desiccant specification are shown in Table 2.

TABLE 2
INPUTS PARAMETERS FOR THE DESICCANT PROCCES

Parameter	Value
Process Air Inlet	
Air flow	2625 m^3/h
DB Temperature	38.5^{o}C
Humidity Ratio	83.1
Regen Air	
T react	66^{o}C
R/P Ratio	0.333

The result of dehumidification process using desiccant wheel with size of 550 mm x 200 mm in air temperature of 47.7^{o}C with relative humidity of 46.5%. It has been corresponding with the relative humidity condition of the initial design of 65%. However, for the initial temperature design conditions are still too high at 43^{o}C. So, we need to cooling to reduce the air temperature into the outside air temperature of 35 ° C.The specification of rotor desiccant can be supply the system. The spesicification of rotor desiccant are shown in Table 3.

TABLE 3
SPECIFICATION SILICIA GEL DESICCANT [9]

Model No.	Wheel diameter (mm)	Wheel depth (mm)	Cassette Height/Width (inches) A	Cassette depth (inches) B	Approx. total Wt. (pounds)
550	550	200	35.8	12	180

D. Design *Heater Requirment*

Based on the result of dehumidification procces, is the requirment of temperature heater for *rotary desiccant*is 66^{o}C. The air flow for the regeneration process starts from the air of cargo hold to the desiccant wheel. Input parameters to determine the design heater of energi reactivation system shown in Table 4.

As a fulfillment of requirment heater is used heat from main engine exhaust gas as amedia reactivation air heater with a heat transfer medium therma oil.The power generated by exhaust gas heat is obtained through estimation calculation of the mass and the exhaust gas temperature by engine exhaust gas data from your project Nissan NKC-RH10C used.To determine the temperature and mass flowrate exhaust gas of main engine shown in Table 5.

TABLE 4.
INDICATORS DESIGN HEATER

Parameters	**Value**
Outside air temperature (T_1)	35^{o}C
Reactivation air temperature (T_2)	66^{o}C
Average temperature	85.5^{o}C
Heat specific (C_p)	1.00636 kJ/kg.K
Density (ρ)	1.14152 kg/m^3
Mass flowrate (m)	0.832 kg/s
Energi heater ($q_{heater\ 1}$)	24.292 kW

TABLE5.
MASS FLOWRATE AND TEMPERATURE EXHAUST GAS MAIN ENGINE [10]

At % Power	Flow Rate (kg/s)	Temperature (^{o}C)
100 % Power	1.55	370
85 % Power	1.39	340
75 % Power	1.2	350
50 % Power	0.8	385

Thus, the capacity of the exhaust gas flow($\dot{m}E$), the heat power of the exhaust gas is calculated by equation 1 so thatis :

$$Q_{exh} = 1.39x1.054 \text{ x } 340$$
$$= 498.12 \text{ kW}$$

Power generated by exhaust gasof 498.12 kW can be used to supply the heater requirement of 24,292 kW.

E. Calculation Cooling Capacity

Based on the dehumidification process that has been done, the air temperature after passing the desiccant wheel increased to 47.7°C. This air temperature will be let off to 35°C before entering into the loading space. The first step is to find the value of cooling power needs with parameters that can be seen in Table 6.

TABLE 6.
PARAMETERS OF DESIGN COOLING

Parameter	Value
Outside air temperature (T_1)	47.7°C
Intial air temperature (T_2)	35°C
Heat specific (C_p)	1.00735 kJ/kg.K
Density (ρ)	1.1051 kg/m^3
Mass flowrate (m)	0.832 kg/s
Energy cooler ($q_{heater\ 1}$)	10.306 kW

From the Table 6 it was found that the cooling requirement of 10.306 kW will be supplied with a cooler that uses the medium of sea water as a heat transfer.

F. Design Cooling System

Cooling system design begins by calculating the flow capacity of the cooling system with the sea water medium.Then we calculate the temperature change in the cargo hold due to the heat load from the solar radiation.

$$\dot{m}_c C_c \Delta T_c = \dot{m}_h C_h \Delta T_h$$

$$\dot{m}_c \times 4001.88 \times 12.7 = 0.6239 \times 1007.35 \times 12.7$$

$$\dot{m}_c = 0.1571 \text{ kg/s}$$

So the flow capacity needed to supply the water cooling from seawater is

$$q = \frac{\dot{m}_c}{\rho}$$

$$q = \frac{0.151}{1022.64}$$

$$= 0.553 \text{ m}^3/\text{h}$$

Obtained from calculating the cooling system seawater flow rate requirements to supply the cooling system amounted to 0.553 m^3 / h. The flow rate of seawater will be used for the selection of seawater supply pump as a coolant from the solarsystem dehumidification.

G. Heat Load Calculation

The heat load that affects the cargo hold conditions comes from the heat generated by solar radiation (Øs). In this calculation process in accordance with ISO 7574 regarding : *Ship and Marine Technology – Air Conditioning and* Ventilation *of Accomodation Spaces*. With these calculations can be observed the results of the cooling system's ability to keep the condition of the cargo hold according to the initial design of the heat load caused by solar radiation. To calculate the value of the solar radiation heat load used equation 2..

$$\emptyset_s = (133,.2x1.1306x32) + (0x240)$$

$$\emptyset_s = 4816.365\ watt$$

From the above calculations obtained heat generated from solar radiation of 4.816365 kW. This heat causes temperature changes in the cargo hold vessel to conditioned by the system. The calculation of temperature changes due to solar radiation heat can use the formula:

$$Q = m.\,C_p \Delta T$$

$$4.8163 = 0.8373x1.0062x\Delta T$$

$$\Delta T = 0.5717\,^{o}\text{C}$$

$$T_2 = 35 + 0.5717$$

$$T_2 = 35.5717^{o}\text{C}$$

From the above calculation of temperature changes due to the present of heat energy from solar radiation of 0.5717°C. So the final temperature of the cargo hold is 35.5717°C. With these results can be observed that the ability of existing cooling system in the solar dehumidification system is able to fulfill a requirment of the system and heat load from solar radiation..

H. Electrical System Design

In the design of solar desiccant electrical system there are several considerations that needsto be considered such as insolation of the sun in an area. For electrical system design parameters using solar panels on the system required a process of changes from solar energy to the distribution of electrical energy generated. Here is the process of solar panel distribution for theneeds of the required power load solar desiccant system.

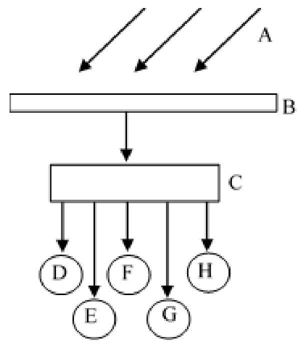


Figure. 7. Scheme of Electrical Energy Distribution of Solar Panels
(A: *Solar Radiation*; B: *Photovoltaic;* C:*Battery*; D: *Electric Motor*; E: *Exhaust Fan*; F: *Supply Fan*; G: *Thermal Oil Pump*; H: *Sea Water Pump)*

From the above scheme can be determined needs of the power load required by the system by looking for specifications of each equipment required for each system. Specification of equipment used can be seen in Table7.

TABLE 7.
SPECIFICATIONS OF DESICCANT SOLAR SYSTEM EQUIPMENT

No.	Equipment	Power (Watt)	Time (Jam)	Energy (Wh)
1	*Electric Motor*	83	24	1992
2	*Exhaust Fan*	342	24	8208
3	*Supply Fan*	342	24	8208
4	*Thermal Oil Pump*	300	24	7200
5	*Sea Water Pump*	370	24	8880

From the Table 7 it is found that the total energy required by the system is 34488 Wh..

ET = EA+(15%EA) losses equipment 15%
ET = 34488 + (15%x34488)
ET = 39661.2 Wh

Energy requirements of the calculated system, which amounted to 39661.2 WH. The lowest monthly solar insolation was in January 2015 ie 3.91. For the adjustment factor the installation is 1.1.

$$\text{Power module capacity} = \frac{39661,2}{3,91} x1,1$$

= 11157,88 wp

The photovoltaic module to be used has the following specifications:

Power capacity =345 WP
Maximum current = 6.02 Ampere
Maximum voltage = 57.3 Volt
Dimensions = 1.6 x 1.05 m

Because the solar power module capacity is 11157.88 Wp and the power capacity of 1 unit of photovoltaic 345 WP can be made equation:

$$\sum m = \frac{power\ capacity}{power\ capacity/unit}$$

= 33 unit.

Of the total solar module of 33 units then the required area required for 55.44 m^2. While the extent of existing solar module placement on the vessel of 9.5x8.5 = 80.75 m^2, then the extent that still exists.

IV. CONCLUSION

From the calculation and analysis of data that has been done to design air ventilation system using solar desiccant, it can be concluded that:

1. From result of calculation analysis to dehumidification process of cargo hold volume equal to 437.5 m^3 at 6 air changes / hour got desiccant wheel specification which best compatible with diameter 550 mm and thickness 200 mm.
2. The ratio of outside air humidity at 38,5^{o}C temperature of 83.1% can be decreased to 46.5% at 35.6^{o}Ca cargo hold temperature after passing the desiccant wheel.
3. To requirment desiccant heating requirement of 24.292 kW, heat exhaust gas from main engine with temperature of 350^{o}C and produce power equal to 498.12 kW. Therefore, it is requirfor the economizer to transfer heat energy from the exhaust gas meter. With the requirement of 24.292

heater energy, economizer with thermal oil fluid as heat transfer medium. The required cross-sectional area is 0.1828 m^2. While the use of sea water as a cooling medium can reduce the temperature of 12.7^{o}C with the flow of sea water flow of 0.553 m^3/h.

4. To fulfill the electric power requirement of solar desiccant system 34.488 Wh with 1 day storage capacity obtained amount of module power requirement equal to 11.157,88 wp. From the module's power capacity requirement, the solar module is required for 33 units with a capacity of 345 wp each.

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