APPLICATION OF ORGANIC RANKINE CYCLE POWER PLANT ON COASTER 1000 DWT

Danny Faturachman
Universiti Malaysia Pahang

APPLICATION OF ORGANIC RANKINE CYCLE POWER PLANT ON COASTER 1000 DWT

Ayom Buwono[1*], Muswar Muslim[1], and Danny Faturachman[1]

[1]Faculty of Ocean Technology, Darma Persada University,
Jl. Taman Malaka Selatan, Pondok Kelapa, Jakarta 13450, Indonesia
[*]Email: abuwono.energi@gmail.com
Phone: +628649051, 53; Fax: +628649052

ABSTRACT

The need for electricity is very important for the operation of a ship, especially when the ship is sailing. Inside the ship many auxiliary machines, navigation equipment and lighting are in need of electricity on its operation. The electrical components must be in a running condition. In this research, is aimed to design a model of power plant that may reduce the electrical load generated by the ship generator with concentration only on the electrical load of lighting. As the basic theory for this research is Rankine cycle, with the system is Organic Rankine Cycle (ORC). For the ship data is a 1000 DWT coaster ship with a ship length of 64 meters, width of 12 meters, and 14 knots speed vessel. The required electrical power supply is about 2740 watts.

Keywords: Coaster 1000 DWT, Expander, Heat Exchanger, Organic Rankine Cycle

INTRODUCTION

Every ship on sailing requires electricity as a supporter like a ship in normal conditions. These electrical requirements are used to operate navigation equipment, lighting and turning on other auxiliary machines. Ship electricity is sourced from generator sets powered by diesel fuel in general. This study aimed how to reduce the electrical load generated by the ship generator, so that the fuel needed by the generator is more efficient. To reduce the electrical load by trying to apply the Organic Rankine Cycle (ORC) technology as a power plant that can produce electricity in the ship, especially on 1000 DWT coaster ship. Application of ORC technology has been widely applied as a generator in land, but still little applied on the ship.

LITERATURE REVIEW

The application of ORC technology has been studied by many researchers, for example on the study of Sylvain Quoilin et al. [1] conducting ORC experiments using a scroll compressor as a circulating expander with its working fluid is HCFC-123 refrigerant. The purpose of his research compared the results of predictions with the results of reality. Later research from Mingshan Wei et al. [2] conducting experimental activities using strict ORC rules for small-scale waste heat recovery systems and his research also focuses on which there is a loss of flow, greatly affecting the suction scroll expander. Later investigators from Janette Hogerwaard et al. [3] experimenting on heat engines that control heat at low temperatures aimed at measuring thermal power and effective production for small-scale applications, but the system uses renewable energy such as biomass / biofuel / biogas combustion, geothermal heat, solar and industrial heat radiation throw away, the refrigerant used is R134a with low temperature heat source below 150 ºC. Next researcher Noboru Yamada et al. [4] who conducted experiments using the Pumpless Rankine type cycle tool called (PRC) which also uses expander as the production of electric power as an ORC system. His research uses a pumpless model that uses a scroll compressor as an expander successfully producing 20 watts of electricity. The latter are researchers Jen-Chieh Chang et al. [5] focusing on compressor scroll experiments used as an expander in the application of low-temperature ORC system with working fluid employed is R-245fa refrigerant and the number of compressors used in two pieces by determining the volume of differences in the ratio of each compressor, then the power the maximum outflow of the expander is 1.77 kW and the electrical load delivered to the generator is 1,375 kW. From some of the researchers who have done the research, we will use as materials to design our research.

ORGANIC RANKINE CYCLE (ORC)

The research put forward on the application of basic Rankine cycle theory which ORC theory has been applied to geothermal power plant and power plant in Ocean Thermal Energy Conversion (OTEC).

Support of ORC Component

To carry out this experiment and to fulfill the standard requirements of experiments, it takes some major components and other supporting equipment in conducting the experiment of the power plant in this ORC system. Components include: condenser and evaporator using plate heat exchanger type called Plate Heat Exchanger (PHE) with brand Kaori K70, then working fluid pump with 3 phase specification and 1600 rpm rotation. Expander which is used as turbine with Sanden TRSE09 brand with volume of 97.8 cc / rev and hot water producing tool as heat source which is made to combine heater with heat exchanger with 1200 Watt power. The experimental equipment is shown in the figure below.

Figure 1. Plate Heat Exchanger Kaori K70

Figure 2. Expander Sanden TRSE09

Figure 3. Three Phase Working Fluid Pump

Basic Theory of ORC

ORC work process is explained on a theoretical basis with the given diagrams and P-h cycles shown in Figures 4 and 5 below.

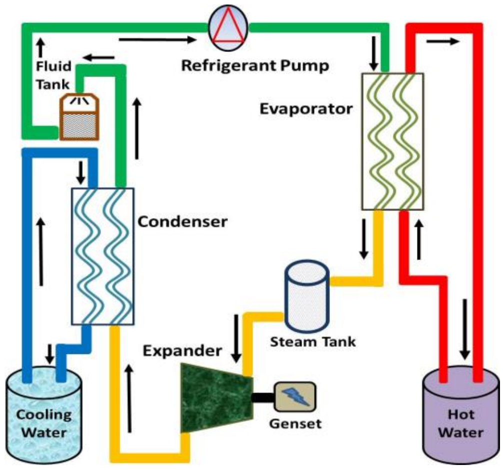

Figure 4. ORC Diagram

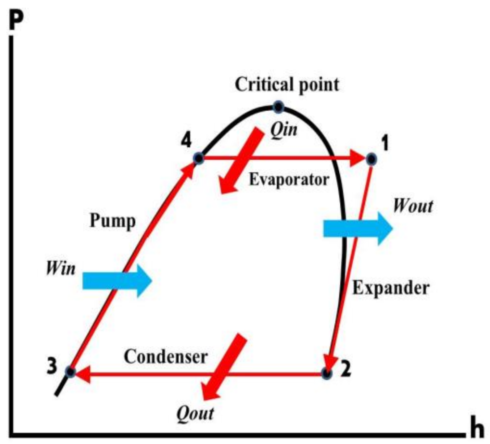

Figure 5. P-h Cycles for ORC

Figure 4 shows that the working fluid flows through the main components, including through condenser and evaporator using Plate Heat Exchanger (PHE) in this case each functioning as heat transfer at low temperature to high temperature or vice versa from high temperature to low temperature. In the evaporator, the working fluid R134a is evaporated by flowing hot water at a predetermined temperature according to the plan. Similarly, on the condenser, the working fluid is liquefied or saturated by cooling system with temperature that has also been planned. The system process refers to the Ph cycle for ORC shown in Figure 5 that the working fluid flows from the condenser from point 3 to point 4 to the evaporator through the refrigerant pump to produce a significant spin in the expander from point 4 to point 1. Further work processes in the expander at point 1 to point 2 and the next process of liquefaction of the working fluid at point 2 to point 3 in the condenser and so the process takes place continuously. Furthermore, in order to be able to feel the actual experiment, we show an experiment equipment as shown in Figure 6 along with the image of heater combination with heat exchanger called Heater and Heat Exchanger (HHE) one package shown in figure 7 below.

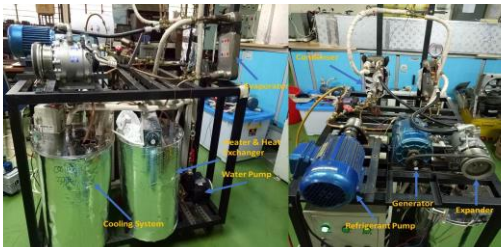

Figure 6. Experiment Equipment of ORC

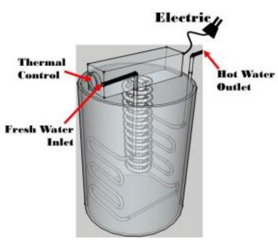

Figure 7. Combination of HHE

For the design dimensions of the HHE combination in figure 7 above, the diameter is 38 cm and 50 cm in height. In this tool, HHE installed temperature controller tool that can raise and lower the temperature of hot water. At the beginning of the operation, the temperature fresh water is equal to the temperature of the boiled environment until it reaches the planned temperature and then the hot water is directly channeled to the evaporator to evaporate the working fluid on the ORC system at a certain pressure and temperature that will be used to operate the expander.

Working Proses on Main Component

For data processing in this experiment used some formula given is as follows:

1. Working Fluid Pump

In the pump process of Figure 5, the working fluid R-134a at condition 3 leaves the condenser sucked and pressed by the refrigerant pump to the evaporator resulting in an increase in pressure. Around the pump is assumed no heat transfer occurs and given the equilibrium equation of mass and energy rate are:

$$Wp = m_f \ . \ (h_{ie} - h_{oc}) \tag{1}$$

and

$$W_p = h_4 - h_3 \tag{2}$$

Where W_p is the incoming power per unit of mass through the pump

2. Heater & Heat Exchanger (HHE)

The evaporation process of refrigerant occurs in a heat exchanger which combines one package with a heater to produce hot water. Hot water will then release heat to the flow of refrigerant pipe in the evaporator at conditions 4 and 1, so that the refrigerant will occur the process of changing the form from liquid to gas and change the process of thermal form is the equilibrium of mass and energy rate given the following equation,

$$Q_{in} = h_1 - h_4 \tag{3}$$

Where Q_{in} is the rate of heat transfer from the energy source into the working fluid per unit of mass through the evaporator and then the refrigerant vapor flows to the expander.

3. Expander

Refrigerant steam 134a out of the evaporator at point 1 with high temperature and pressure conditions will expand to rotate the expander to produce work and then discharged to the condenser at point 2 with a relatively low vapor pressure working fluid. For heat transfer around the expander is not taken into account, then the equilibrium mass energy rate around the expander is given the following equation,

$W_t = h_3 - h_4$ (4)

where *Wt* denotes the rate of work produced per unit of vapor mass through the expander.

4. Condenser

In condenser under 4 - 1 conditions there is heat recovery in the refrigerant flow pipe by a cooling water pipe with a certain temperature and amount of heat. The energy equation in the condenser is given as follows:

$Q_{out} = h_1 - h_2$ (5)

where Q_{out} is the rate of energy transfer from the working fluid to the cooling water per unit of fluid mass working through the condenser. Thermal efficiency is used to measure how much energy goes into the refrigerant given the following equation.

$$\eta_{th} = (w_t - w_p) / Q_{in} = \frac{(h_3 - h_4) - (h_4 - h_3)}{(h_1 - h_4)} \quad (6)$$

Then there is the loss of heat to the environment so that the heat (Q_{in}) is needed in the process of increasing heat transfer, while the thermal efficiency is reduced. This condition can occur due to the irreversibility of the pump and the expander so that the required work (W_{in}) is larger and the expander produces more work (W_{out}).

Working Fluid

The working fluid used in this experiment is R134a with the specifications given as follows:

Table 1. Property of R134a

Characteristics	Conditions
Boiling Point	-14.9 °F or -26.1 °C
Auto-Ignition Temperature	1418 °F or 770 °C
Ozone Depletion Level	0
Solubility In Water	0.11 % by weight at 77 °F or 25 °C
Critical Temperature	252 °F or 122 °C
Cylinder Color Code	Light Blue
Global Warming Potential (GWP)	1200

Room's Light Data on Ship

Table 2 below shows the need for illumination in every room on the vessel with required lamp power between 4 - 100 watts and UF and LLF factor is 0.7 and 0.8.

Table 2. Room's Light

Room's	Area [m²]	E [fx]	Lamp (watt)	Lumen [lm]	N [unit]	Room (Qty)	Power [watt]
Wheel house	51,19	200	20	1400	9	1	180
Captain room	9,19	100	20	1010	2	1	40
Chief Engineer room	9,19	100	20	1010	2	1	40
Owner room	11,4	100	20	1010	2	1	40
Compartment	11,49	200	20	1400	2	1	40
Toilet 1	3,40	50	8	280	2	1	16
Stair room 1	1,92	50	10	410	1	1	10
Crew's room 1	16,08	100	100	1150	3	2	300
Crew's room 2	17,1	100	20	1010	3	1	60
First chief engineer room	16,08	100	20	1010	12	2	40
Toilet 2	8,16	50	20	1400	1	1	20
Kitchen	8,84	50	8	260	2	1	16
Pantry crew room	11,52	50	10	410	3	1	30
Laundry	6,15	50	10	410	1	1	10
Store 1	5,90	50	10	410	1	2	20
Cold storage	4,10	50	10	410	1	1	10
Stair room 2	1,44	50	4	90	2	1	8
Steering gear room and store	22,62	100	100	1150	5	2	500
Crew's room	15,18	100	20	1010	3	1	60
Cadet	12,65	50	20	1400	1	1	20
Clinic	13,05	100	100	1150	1	1	100
Pray room	13,72	50	100	1150	1	1	100
Wudhlu room	4,72	50	10	410	1	1	10
Toilet 3	26,14	50	10	410	5	1	50
Toilet 4	18,84	50	15	780	2	1	30
Economic passenger room 1	129,9	50	15	780	16	1	240
Executive passenger 10 pers.	39,0	50	10	410	8	6	80
Executive passenger 4 pers.	2,72	100	20	1010	1	1	20
Cafeteria	15,6	100	15	710	4	1	60
Outside deck passenger room	13,44	50	10	410	3	2	30
Cargo room	160,3	50	30	1700	5	1	150
Economic passenger room 2	65,52	100	20	1400	8	1	160
Stair room of engine room	1,44	100	10	410	1	4	10
Engine room	107,7	100	20	1010	8	1	160
Control engine room	54,72	200	20	1010	3	1	60
Store 2	9,89	50	20	1010	1	1	20
						Total watt	**2740**

Data of General Arrangement Coaster 1000 DWT

Figure 8 below shows the general arrangement along with the main size of the vessel on a 1000 DWT coaster vessel.

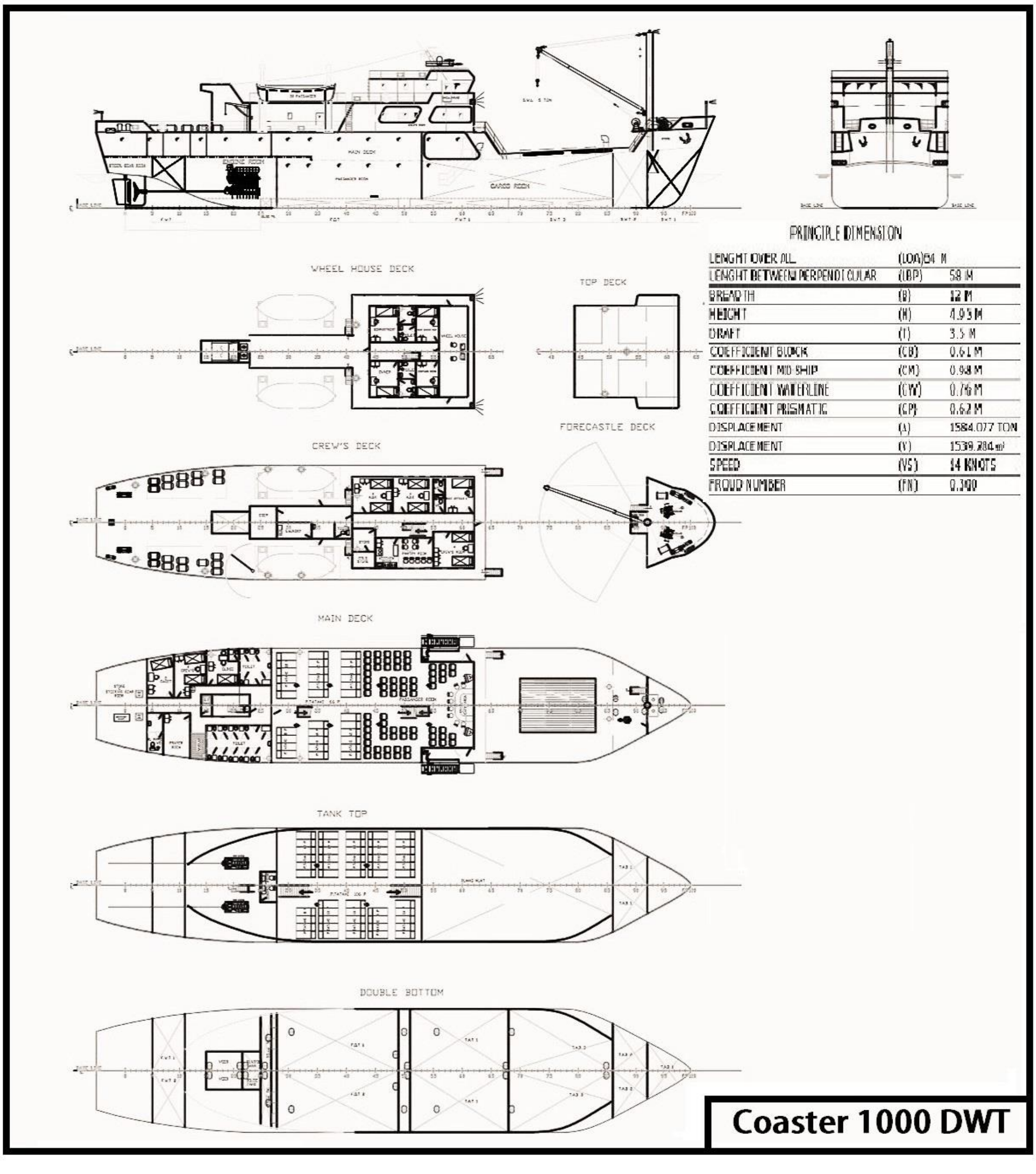

Figure 8. General Arrangement of Coaster 1000 DWT

RESULT AND DISCUSSION

From the experimental results done by setting temperature at HHE that is each setting temperature 40 °C, 50 °C, 60 °C, 70 °C and 80 °C. Figures 9 and 10 show the working fluid temperature variation between 24 0C to 28.5 ^{0}C on the variations of temperature control settings between 40 ^{0}C - 80 ^{0}C and the working fluid pressure entering the expander between 120 psi to 175 psi.

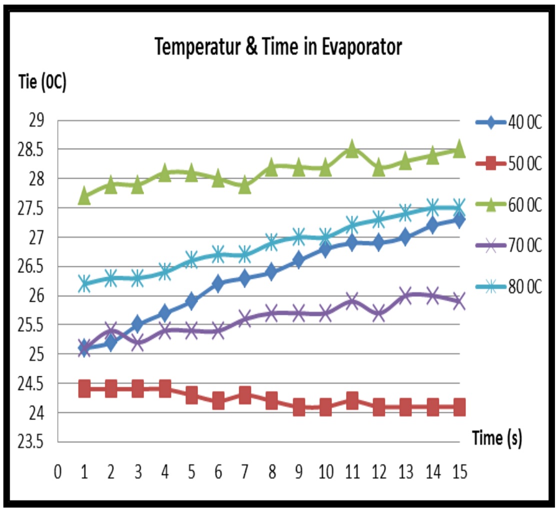

Figure 9. Temperature & time in evaporator

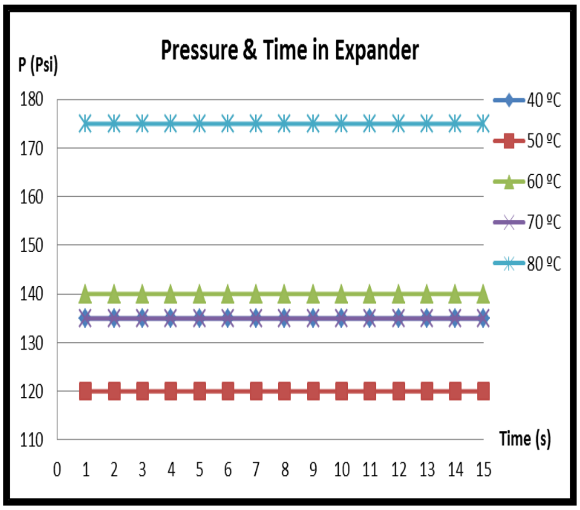

Figure 10. Pressure & time in expander

Figure 11 shows how the rotating expander produces various pressure variations that occur between 316.7 rpm to 377.9 rpm with heater temperature settings between 40 ^{0}C to 80 ^{0}C.

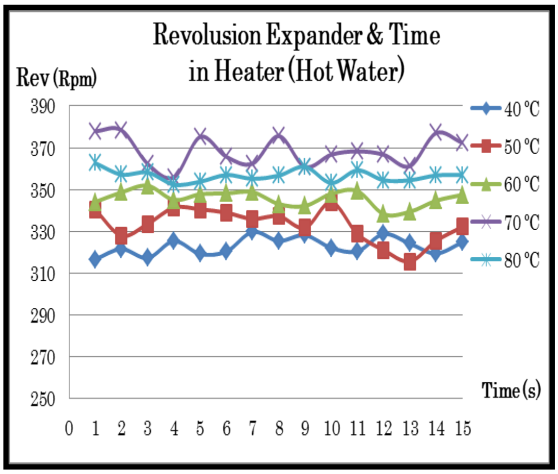

Figure 11. Revolutions & Time in Expander

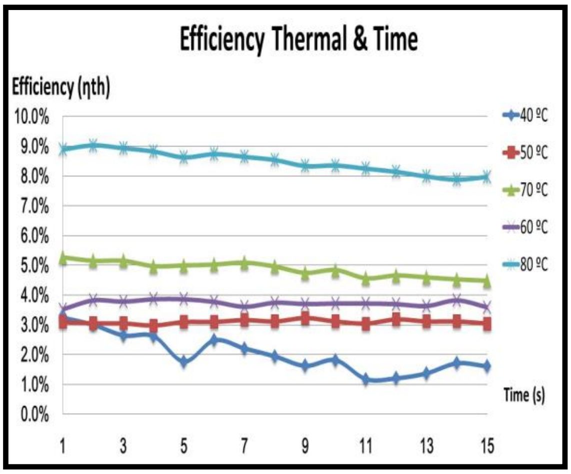

Figure 12. Thermal Efficiency & Time

Figure 12 shows that every temperature setting between 40 ^{0}C and 80 ^{0}C has a very significant increase in thermal efficiency both in the cooling system and in the outlet of the evaporator and condenser. While in Figure 13 and Figure 14 the largest temperature setting is at 80 °C temperatures at expander and gene-set can reach 137.7 Watt and 135 Watt with 16 bars on the expander, and if the ORC system is applied it can reduce the output of gen-set especially on the power on the ship up to 5 %.

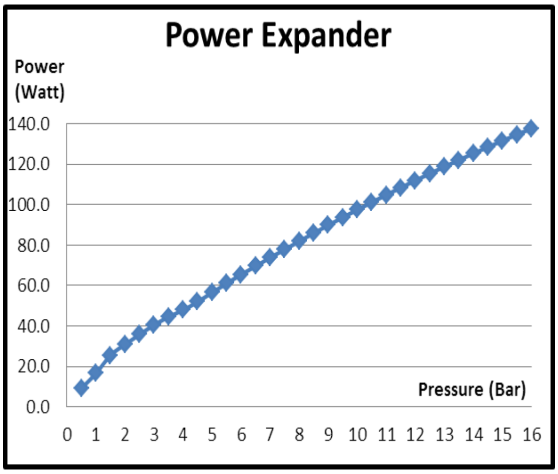

Figure 13. Power and Pressure in Expander

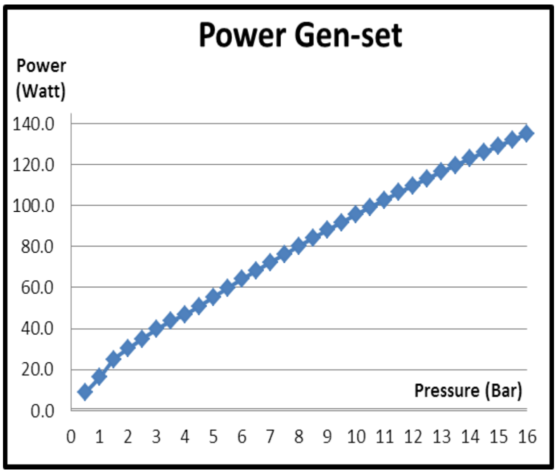

Figure 14. Power and Pressure in Gen-set

CONCLUSION

From the results of the design study on the ORC system by making a heater combination with heat exchanger which setting on 80 ^{0}C indicates that the demand for electricity produced by gene-set vessel can be reduced. The electric power generated by the ORC system is 135 Watt at 16 Bar expander pressure, then the production of the electric power generated on the ORC system can reduce the gear-set load of the vessel and especially for indoor run-of-space lighting up to 5 %.

REFERENCES

Janette Hogerwaard, I. Dincer, C. Zamfirescu 2013; Analysis and assessment of a new organic Rankine based heat engine system with/without cogeneration; Energy 62 300.

Mingshan Wei, Panpan Song, Ben Zhao, Lei Shi, Zhixing Wang, Chaochen Ma 2015; Unsteady flow in the suction process of a scroll expander for an ORC waste heat recovery system; Applied Thermal Engineering 78 460.

Sylvain Quoilin, Vincent Lemort, Jean Lebrun 2010; Experimental study and modeling of an Organic Rankine Cycle using scroll expander; Applied Energy 87 1260.

Noboru Yamada, Masataka Watanabe, Akira Hoshi 2013; Experiment on pumpless Rankine-type cycle with scroll expander; Energy 49 137.

Jen-Chieh Chang, Chao-Wei Chang, Tzu-Chen Hung, Jaw-Ren Lin, Kuo-Chen Huang 2014; Experimental study and CFD approach for scroll type expander used in low temperature organic Rankine cycle; Applied Thermal Engineering 73 1444.

M. Wei, J. Fang, C. Ma, S. Danish 2011, Waste heat recovery from heavy-duty diesel engine exhaust gases by medium temperature ORC system, Sci. China Technol. Sci. 54 2746.

B.F. Tchanche, G. Papadakis, G. Lambrinos, A. Frangoudakis 2009, Fluid selection for a low temperature solar organic Rankine cycle, Appl. Therm. Eng. 29 2476.

ASHRAE Handbook. 2006. Refrigeration System and Applications (SI). American Society of Heating, Refrigerating and Air Conditioning Engineer. Atlanta. Georgia.