International Journal of Engineering and Advanced Technology Studies
Vol.4, No.3, pp.1-17, July 2016
Published by European Centre for Research Training and Development UK (www.eajournals.org)

DESIGN AND CONSTRUCTION OF A TUBE TYPE LUBRICATING OIL HEAT EXCHANGER

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ABSTRACT: *A heat exchanger is a device used to transfer thermal energy (enthalpy) between two or more fluids, at different temperatures. This tube type lubricating oil heat exchanger is used to extract heat from lubricating oil circulating in the main engine of a vessel. Its operation is based on the principle of heat balance, given as:* $Q=M_hC_{ph}\Delta T_h = M_cC_{pc}\Delta Tc$. *This heat exchanger was designed using the Logarithmic Mean Temperature Difference method and it takes up sea water at 27 degree celsius and exits it at a temperature of 68 degree celsius. The exchanger has 96 tubes and a shell area of 0.0239 square meter, with an overall heat transfer coefficient of* $172.3W/m^oc$ *and effectiveness of 50.41 percent. The paper shows standard steps to design and analyze the working and performance of a Tube type heat exchanger. By plotting a graph of effectiveness against lubricating oil temperature difference, using the energy balance equation and analyzing same, the maximum possible effectiveness is obtained. The uniqueness of this design is essentially in its mode of operation, simplicity and construction.*

KEYWORD: Design, Construction, Tube Type Lubricating Oil, Heat Exchanger

INTRODUCTION

Heat exchangers are specialized devices used to transfer thermal energy between two or more fluids, at different temperatures. It is a device in which energy is transferred from one fluid to another across a solid surface (Roetzel and Nicole, 2005). The possibility of applying tube type heat exchangers in a wide range of heat transfer surface, temperature, mass flow rate, and pressure has made them the most common heat exchanger type in industries (Navarro and Cabezas, 2007). Also the tube type heat exchanger is the most common type of heat exchanger used in the process of petroleum, chemical and marine industries intended for heat exchange processes in fluids (Kottket and Li, 1998).

The application of heat transfer is in designing heat transfer equipment for exchanging heat from one fluid to another (Kara and Guraras, 2008). Tube type heat exchangers are used when a process requires large amounts of fluids to be heated or cooled. Due to their design, they offer a large heat transfer area and provide high heat transfer efficiency (Sakariya et al, 2014). They consist of tubes and shells. The tubes act as the flow channels for one of the fluids in the heat exchanger, these exchangers are often parallel in order to provide a large surface area for the heat transfer. The shell on the other hand holds the tube bundle and acts as the conduit for the fluid. The shell assembly houses the shell side connections and is the actual structure in which the tube bundle is placed (Guo et al, 2009).

Heat exchangers are widely used for various purposes having limitation to be designed for maximum pressure and temperature up to $15000N/m^2$ and 523.6^OC (Niak and Matawala, 2012).

It is important to note that the design of tube type heat exchanger usually involves iteration, trial and error procedure. Where for a certain combination of the design variables the heat transfer area is calculated and then another combination is tried to check if there is any possibility of reducing the heat transfer area (Kara and Guraras, 2004). A primary objective in the Heat Exchanger Design is the estimation of the minimum heat transfer area required for a given heat duty, as it governs the overall cost of the heat exchanger (GopiChand and Srividya, 2014).

This tube type lubricating oil heat exchanger adopts the Logarithmic Mean Temperature Difference (LMTD) method which utilizes the principles of Tinkers model for hand calculation to determine the parameters of this exchanger. It is design to take up sea water at 27 degree celsius and exit temperature of 68 degree Celsius. With 96 tubes and a shell area of 0.0239 square meter, the exchanger gives an overall heat transfer coefficient of 172.3W/m^{o}c and effectiveness of 50.41 percent.

Purpose of the Research Design and Construction

The purpose of this research design was to design heat exchanger device that is economical and suitable enough to enhance the process of exchanging heat between two fields at different temperature variations at minimal cost capable of preventing overheating, engine failure and marine engine knocking.

Significance of the Design and Construction

The design and construction of heat exchanger is expected to be of benefit to Engineering and Technology students, teachers, researchers, seafarers, ship designers and ship builders on heat exchanger strategies and modalities. The study will serve as a reference to researchers interested for further research as well as teams and sub teams in seminar and conferences. Findings from the study can enhance academic empirical framework.

METHODOLOGY AND MATERIAL SELECTION

Due to the many variables involved, selecting optimal heat exchangers is challenging. Hand calculations are possible, but much iteration, trial and error are typically needed (Kara and Guraras, 2008). As such, heat exchangers are most often selected via computer programs, either by system designers, who are typically engineers, or by equipment vendors.

Design Methodology

The design of this dump type shell and tube lubricating oil heat exchanger will adopt the logarithmic mean temperature difference (LMTD) method which utilizes the principles of Tinkers model for hand calculation to determine the parameters of the exchanger. The design processes include the following steps:

1. To determine the areas and length of the tubes of the heat exchanger
2. To determine the number of tubes for the heat exchanger
3. To determine the number of baffles required by the heat exchanger
4. To analyze the overall heat transfer coefficient of the heat exchanger
5. To determine the area of the shell
6. To determine both shell side and tube side pressure drop of the heat exchanger
7. To analyze the design of the heat exchanger using the Logarithmic

Mean Temperature Difference method

8. To analyze the effectiveness of the heat exchanger
9. Evaluation of design results and adjustment to meet process specification with respect to heat transfer and pressure drop

Ensure that the final design and consideration meet process requirement at lowest possible cost. The lowest cost should include both operational and capital cost

Design Analysis and Calculation of Tube Type Heat Exchanger

Design producers:

A heat exchanger can be design by the LMTD when the inlet and out let conditions are specified. When the problem is to determine the inlet and outlet temperature for a particular heat exchanger, the analysis is performed more easily by using a method based on effectiveness of the heat exchanger and Number of Transfer Unit (NTU) (Navarro and Cabezas, 2007).

Design specification 1

Process fluid	lubricating oil
Cooling fluid	sea water
Specific heat capacity of hot fluid, Cp_h	$4198 j/kg^oC$
Specific heat capacity of cold fluid, Cp_c	$2135 J/kg^oC$
Inlet temp. of hot fluid, Th_1	110^0c
Outlet temp. of hot fluid ,T_{h2}	98^0c
Inlet temp. of cold fluid, Tc_1	27^0c
Shell diameter, D_s	0.387m
Pitch size, P_t	0.031m
Clearance, c	0.0063
Thermal conductivity of copper, k	$335 W/m^0c$

Design specification 2

Length of tubes	2.15m
Internal diameter of tube, D_i	0.022m
External diameter of tube, D_o	0.025m

Source: Authors, 2015

Properties of lubricating oil at 110^{0}c

Density of lub oil, L_{lo}	$850 kg/m^3$
Specific heat capacity of lub oil ,Cp_{L0}	$4198 j/kg^oC$
Absolute viscosity of lub oil, μ_{L0}	0.0006537 kg /ms
Kinematic viscosity of lub oil , v_{Lo}	$0.000338\ m^2/s$
Pradtle number, Pr_{Lo}	4.340
Thermal conductivity of lub oil, k_{Lo}	0.6280 w/m k

Source: standards

Properties of salt water at 27^{0}c

Density of salt water, ℓ_{sw}	$1025 kg/ m^3$
Specific heat capacity, Cp_{sw}	$2135 j/kg^oC$
Absolute viscosity, μ_{sw}	1.196×10^{-5}kg/ms
Kinematic viscosity, v_{sw}	$0.48\ m^2/s$
Prandtl number, Pr_{sw}	1.08
Thermal conductivity of salt water, K_{sw}	0.0610w/mk

Source: standards

Numerical Solution Procedure

Area of tube:

From equation stated below, the area of the tube can be calculated as follows;

$$\text{At} = \frac{\pi Di^2}{4}$$
$$= \frac{3.142\ x\ (0.022)^2}{4}$$
$$= 0.00038m^2$$

Numbers of tubes

The number of tubes of the heat exchanger is calculated using the relation below.

$$N_t = \frac{\text{mh}}{\text{A}_t \text{ x } u_t \text{ x } \ell}$$
$$= \frac{27.5}{0.00038\ x\ 0.8823\ x\ 850}$$
$$= 96\ tubes.$$

Tube side Reynolds number

The tubes side Reynolds number is given by:

$$R_{et} = \frac{U_t\ \ell \text{Di}}{\mu}$$

$$Ret = \frac{Ut\ \ell\ Di}{\mu}$$
$$= \frac{0.890\ x\ 850\ x\ 0.0220}{0.0006537}$$
$$= 25{,}459.7$$

$$A_{tp} = \frac{N_t\ A_t}{no\ of\ passes}$$
$$= \frac{96\ x\ 0.00038}{1}$$
$$= 0.0365m^2$$

$$G_t = \frac{m_h}{A_{tp}}$$
$$= \frac{27.5}{0.0365}$$
$$= 753kgm^2s$$

$$U_t = \frac{G_t}{\ell}$$
$$= \frac{753}{850}$$
$$= 0.8858\ m/s$$

Tube Side Nusselt Number.

From the value of the Reynolds number above, the tube side flow is turbulent, Using Petukhov and Kirillov correlation, the Nusselt number calculated as follows ;

$$N_{ut} = \frac{(\frac{f}{2})R_eP_r}{1.07+12.7(\frac{f}{2})^{1/2}\ (Pr\ 2/3 - 1)}$$

Where :

$$f = (1.58\ In\ R_e - 3.28)^{-2}$$

$$= [1.58 \, x \, In(25459.7) - 3.28]^{-2}$$

$$= (12.748)^{-2}$$

$$= 0.006153$$

$$N_{ut} = \frac{(0.006153/2) \text{ x } 25459.7 \text{ x } 4.34}{1.07 + 12.7\,(0.006153/2)\wedge 1/2 \text{ x } 4.34\wedge (2/3) - 1}$$

$$= \frac{339.938169}{2.239819751}$$

$$= 151$$

Tube side heat transfer coefficient

The heat transfer coefficient is calculated using the equation:

$$\mathrm{h_t} = \frac{Nu \, \mathrm{k}}{\mathrm{Di}}$$

$$= \frac{151 \, x \, 0.6280}{0.022}$$

$$= 4310 \, w/m^2 k$$

Tube Side Pressure Drop

Equation below is used to calculate the tube side pressure drop

$$\Delta P_t = \left[4f\left(\frac{LN_p}{d_i}\right) + \ 4N_b\right]\frac{\ell_{lo}\mu_{lo}^2}{2}$$

$$= \frac{4 \, x \, 0.006153 \, x \, 1.816x10^{-4}}{0.022}$$

$$= \frac{4.4695392x10^{-6}}{0.022}$$

$$= 0.203KN/m^2$$

Number of baffle;

$$Nb = \frac{L}{B}$$

But;

Baffle spacing, B = $0.4D_s$

$$B = 0.4 \text{ x } 0.387$$

$$= 0.20m$$

$$Nb = \frac{L}{B}$$

$$= \frac{2.15}{0.20}$$

$$= 10\, baffles$$

Shell Side Area

The shell side area can be calculated using the equation below:

$$A_s = \frac{\mathrm{Ds\ x\ C\ x\ B}}{Pt}$$

$$= \frac{0.387\ x\ 0.0063\ x\ 0.304}{0.031}$$

$$= 0.0239m^2$$

Shell side Reynolds number

The shell side Reynolds number is calculated using the relations

using Equation below;

$$R_{es} = \frac{De\ Gs}{\mu}$$

$$mass\ velocity\ , G_s = \frac{\mathrm{m_c}}{\mathrm{As}}$$

$$= \frac{4}{0.0239}$$

$$= 167.36kg/m^2s$$

Equivalent diameter,

$$\mathrm{D_e} = \frac{4\ (\mathrm{P_t^2} - \frac{\pi \mathrm{d_o^2}}{4})}{\pi \mathrm{d_o}}$$

$$\mathrm{D_e} = \frac{4\ (0.0312\ \ -\ \pi\ x\ 0.0252/4\ )}{\pi\ \ x\ 0.0252\mathrm{m}}$$

$$= 0.0235m$$

$$Re_s = \frac{D_e G_s}{\mu_{sw}}$$

$$= \frac{0.0235\ x\ 167.36}{1.196\ x\ 10^{-5}}$$

$$= 328{,}842.8$$

Shell Side Nusselt

Using Mc Adam’s correlation, the Nusselt number is computed using;

$$N_{us} = 0.36[\frac{D_e G_s}{\mu_{sw}}]^{0.55}[\frac{C_p \mu_{sw}}{k}]^{0.33}[\frac{\mu_{sw}}{\mu_{lo}}]^{0.14}$$

$$N_{us} = 0.36[\frac{0.0235\ x\ 167.36}{1.196\ x\ 10^{-5}}]^{0.55}[\frac{2135\ x\ 1.196\ x\ 10^{-5}}{0.022}]^{0.33}[\frac{1.196x\ 10^{-5}}{6.537\ x\ 10^{-5}}]^{0.14}$$

$$= 389.62\ x 1.050\ x\ 0.1829$$

$$N_{us} = 75$$

Shell side heat transfer coefficient

Using the equation below, the shell side heat transfer coefficient is

Calculated as follows;

$$h_S = \frac{N_{us}\ K_{sw}}{\mathrm{do}}$$

$$= \frac{75\ x\ 0.0610}{0.025}$$

$$= 183\ w/m^2\ k$$

Shell side pressure drop:

The equation below is use in calculating the shell side pressure drop;

$$\mathrm{P_s} = \frac{f \mathrm{G_s}^2(\mathrm{Nb} + 1)\ \mathrm{Ds}}{2\ell\ \mathrm{De}\ \text{Ø}\mathrm{s}}$$

$$= \frac{0.006153\ x 167.36^2(10 + 1)\ x\ 0.387}{2\ x\ 1025\ x\ 0.0235\ x\ 0.5713}$$

$$= \frac{733.658}{27.522}$$

$$= 26.66\ N/m^2$$

Overall heat transfer coefficient

The overall heat transfer coefficient can be calculated using the relation of equation below

$$\frac{1}{U} = \frac{1}{h_t} + \frac{1}{h_s} + \frac{d_0\ in(\frac{d_0}{d_i})}{2k} + f_t$$

Where:

h_t = tube side heat transfer

h_s = shell side heat transfer

f_t = fouling factor = 0.1m^{0}c/km

k = thermal conductivity of copper = 0.355kw/m^{0}c

$$\frac{1}{U} = \frac{1}{0.183} + \frac{1}{4.310} + \frac{0.025\ in\ (\frac{0.025}{0.022})}{2\ x\ 0.355} + 0.1$$

$$\frac{1}{U} = 5.464 + 0.2320 + 4.50x10^{-3}\ +\ 0.1$$

$$\frac{1}{U} = 5.8005$$

$$U = \frac{1}{5.8005}$$

$$U = 172.3w/m^{o}c$$

Logarithmic mean temperature difference (LTMD)

For counter flow heat exchanger, the LTMD is calculated using the relation below:

$$\Delta \mathrm{TLMTD}\ = \frac{\Delta \mathrm{TI} - \Delta \mathrm{T2}}{\mathrm{In}\ (\Delta \mathrm{Ti}/\Delta \mathrm{T2})}$$

Where;

$$\Delta T = T_{h1} - T_{c2}$$

$$\Delta T = T_{h2} - T_{c2}$$

But outlet temperature of cold fluid is calculated from the energy balance equation.

Q = heat given by the cold fluid = heat lost by the hot fluid

$$Q = m_c c_{pc} \Delta T_c = m_h c_{pc} \Delta T_h$$

$$4\ x\ 4198\ x(T_{c2} - 27) = 27.5\ x\ 2135\ x\ (110 - 98)$$

$$16{,}792\ x\ (T_{c2} - 27) = 704{,}550$$

$$T_{c2} = \frac{704{,}550\ +\ 27}{16{,}792}$$

$$T_{c2}\ = 68.95^{0}C = 69^{0}C$$

$$\Delta TLMTD\ = \frac{(110- 68) - (98 - 27)}{In\ (110 - 68)/\ (98 - 27)}$$

$$= \frac{29}{0.5250}$$

$$\Delta T_{LMTD} = 55.23^{0}C$$

Effectiveness

The equation below is used to find the effectiveness of the heat exchanger as shown below;

$$\epsilon = \frac{C_{mar}(T_{h1}-T_{h2})}{C_{min}(T_{h1}-T_{c1})}$$

$$C_{min} = m_c C_{pc}$$
$$= 4 \times 4.2$$
$$= 16.8$$
$$C_{max} = m_h C_{ph}$$
$$= 27.5 \times 2.13$$
$$= 58.575$$
$$\epsilon = \frac{58.575\,x\,(\,110-98)}{16.8\,x\,(110-27)}$$
$$= \frac{702.9}{1{,}394.4}$$
$$= 0.5041$$
$$= 50.41\%$$

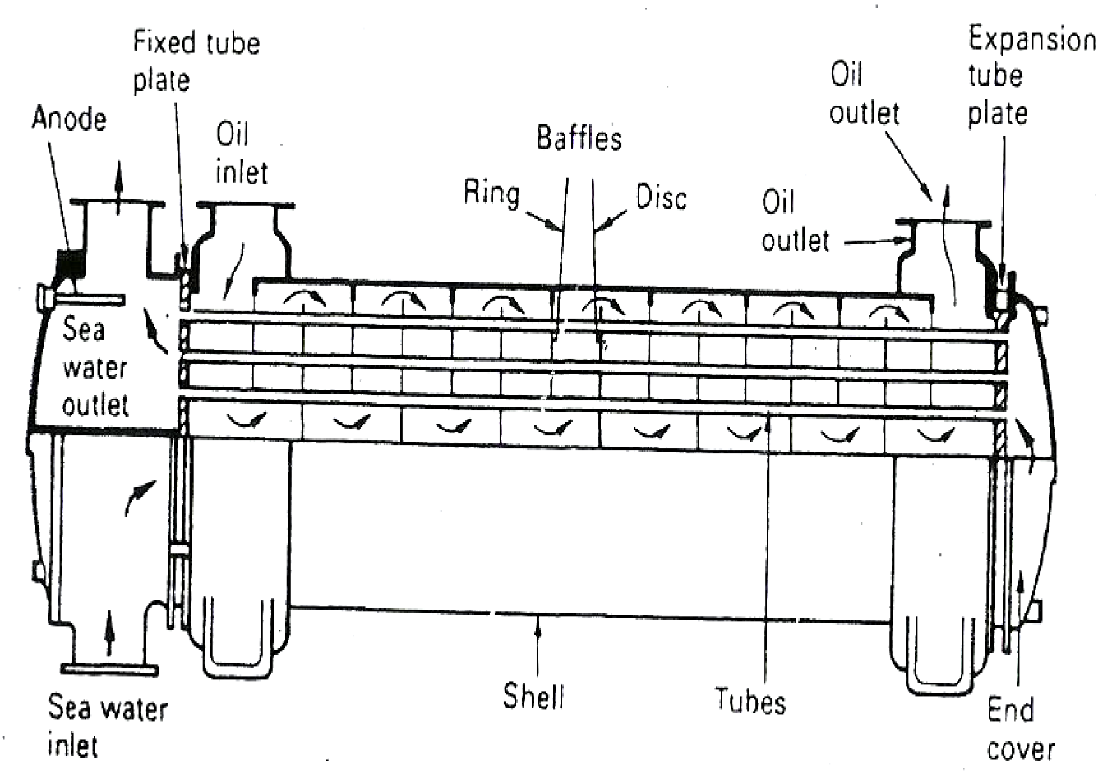


Figure 1.2 *Tube type cooler*

Tube Type Lubricating Oil Heat Exchanger

RESULT PRESENTATION

Results obtained from theoretical calculations of design parameters are as presented in table 1. While other data obtained from the heat exchanger is showed in table 2 and is computed using the heat balance equation. The data includes: a set of values for fresh water temperature in degree Celsius, heat exchanger effectiveness in percentage, seawater mass flow rate in kilogram per second and heat gained by the seawater in kilowatt.

Table 1: Result from theoretical calculation

Logarithmic mean temperature difference	55.23^{0}C
Shell side Area	0.0239m^2
Area of table	0.0038m^2
Number of tubers	96
Number of baffles	10
Tube side heat transfer coefficient	4.310kw/m^{o}C
Shell side heat transfer coefficient	0.183kw/m^{o}C
Tuber side pressure drop	203N/m^2
Shell side pressure drop	26.66N/m^2
Overall heat transfer coefficient	172.3w/m^{O}C
Tube side Nusselt number	151
Shell side Nusselt number	75
Effectiveness	0.5041

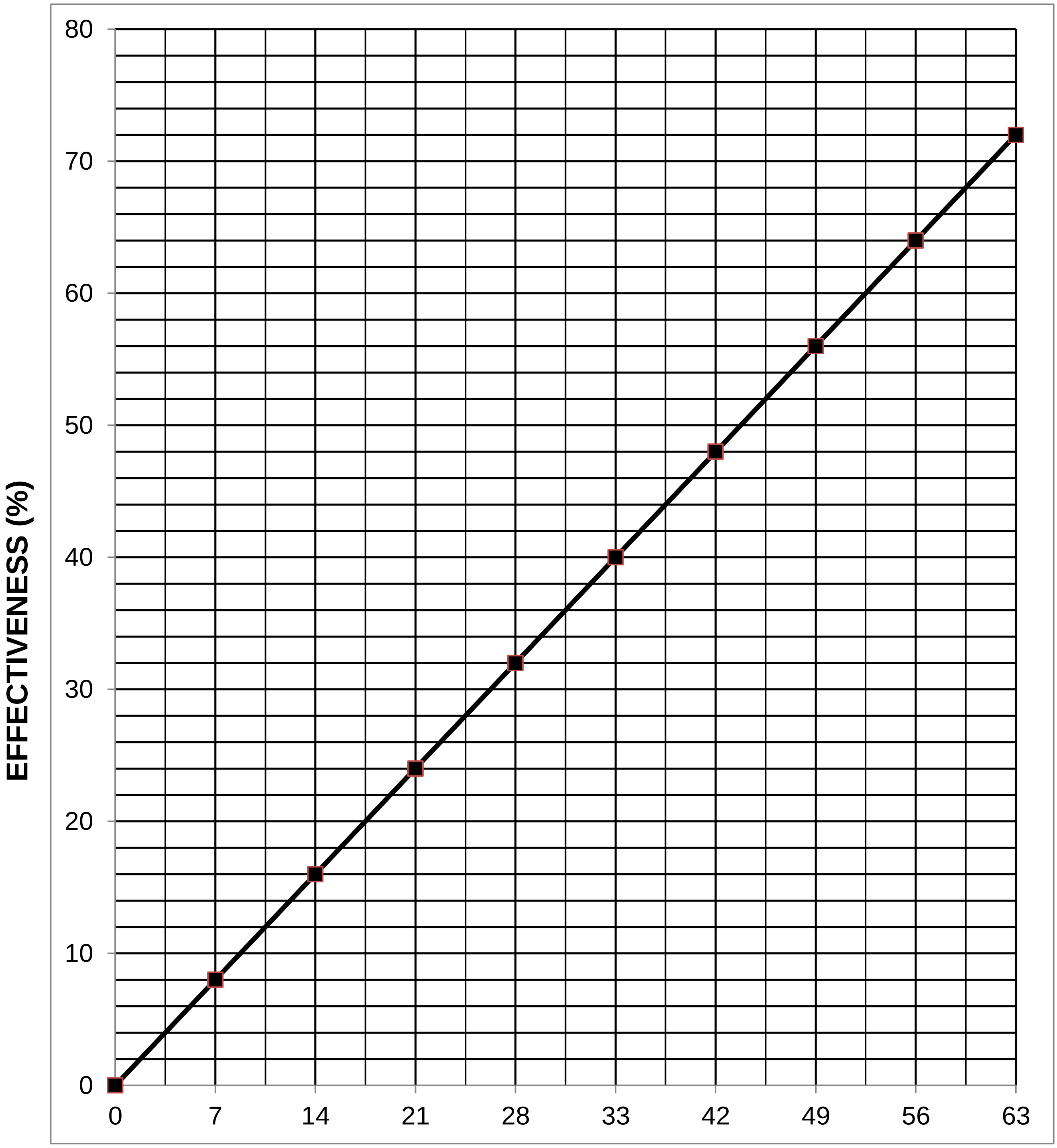
Source: Authors, 2015

This table 2 is computed using the heat balance equation. $m_c C_{pc}(t_1 - 32) = m_h C_{ph}(110 - t_2)$

Table 2: Data from existing heat exchanger for comparism

Lub. Oil temp. diff (^{0}C)	Effectiveness	Lub. Oil mass flow rate,m$_h$ (kg/s)	Heat loss from lub. Oil, Q$_2$ (kw)	Sea water mass flow rate, m$_c$ (kg/s)	Heat gain by sea water, Qs (kw)
O	O	0	0	0	0
7	8	18.2	1.75	11.5	0.41
14	16.0	19.2	1.84	12.5	0.45
21	24.0	20.2	1.94	13.5	0.48
28	32.0	21.2	2.04	14.5	0.52
35	40.0	22.2	2.14	15.5	0.56
42	48.0	23.2	2.22	16.5	0.59
49	56.0	24.2	2.34	17.5	0.63
56	64.0	25.2	2.44	18.5	0.67
63	72.0	26.2	2.60	19.5	0.74

Source: Authors, 2015


EFFECTIVENESS (%)
80
70
60
50
40
30
20
10
0
0
7
14
21
28
33
42
49
56
63

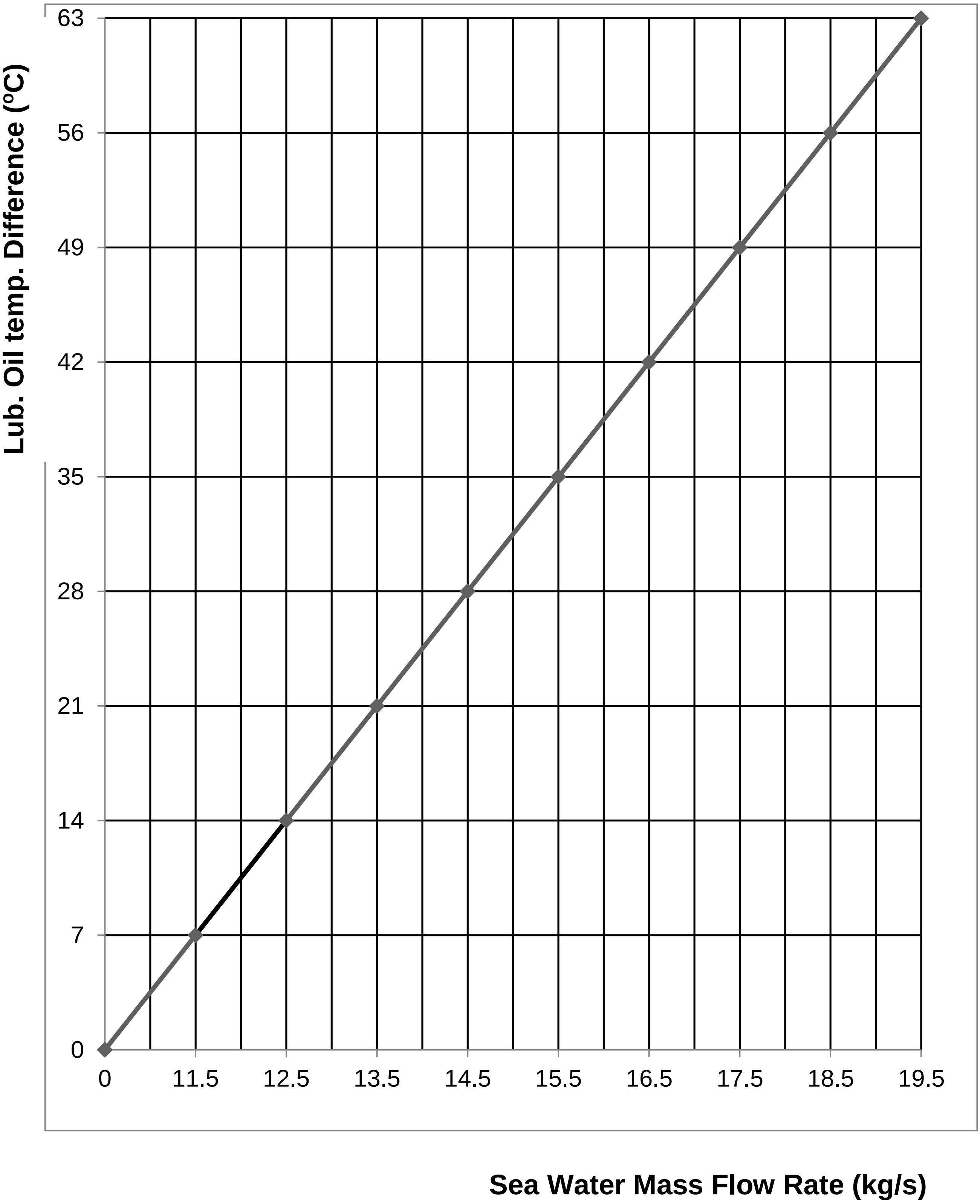


Fig. 2: Lubricating Oil Temp. Difference Versus Sea Water Mass Flow Rate (kg/s)

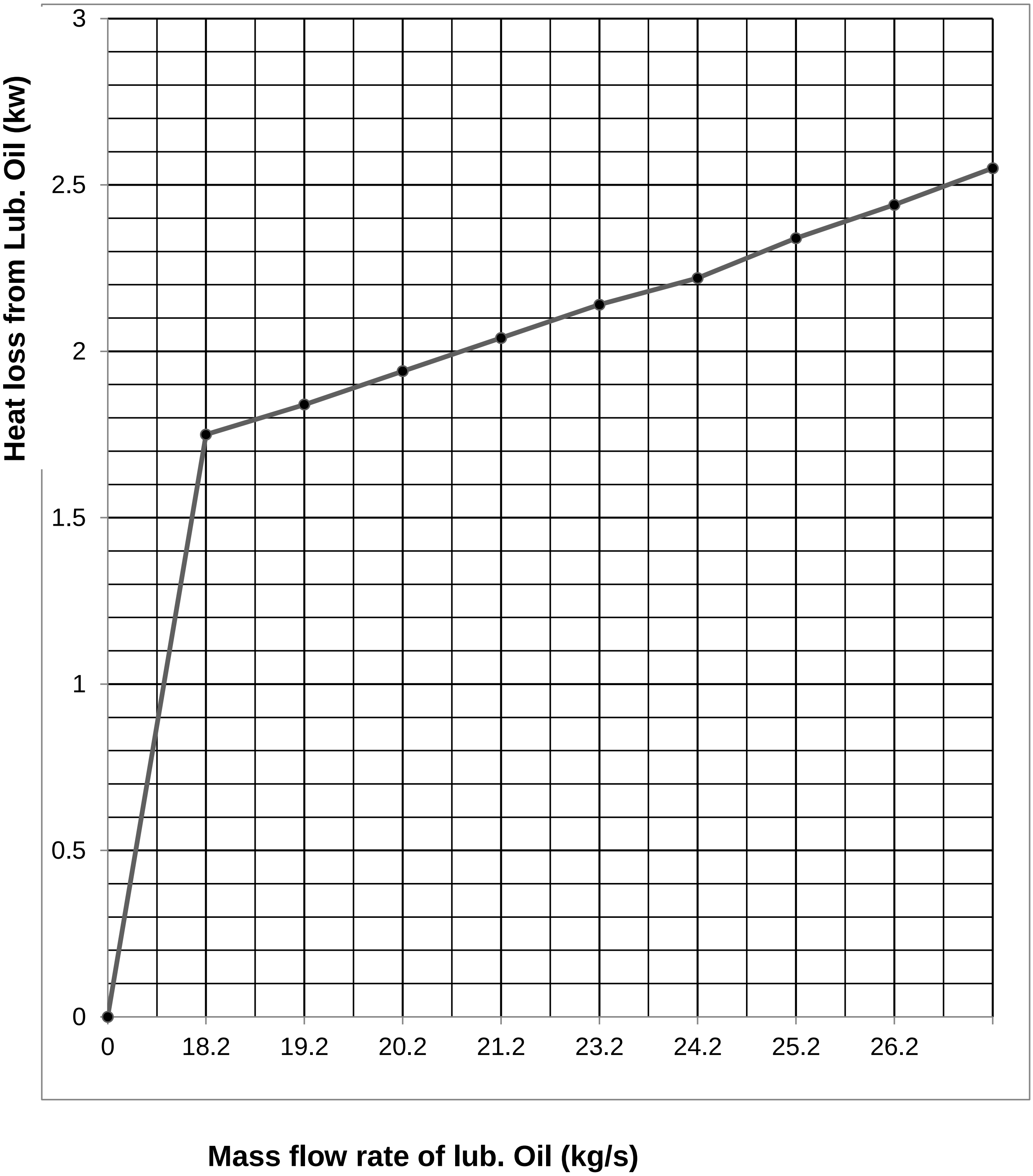
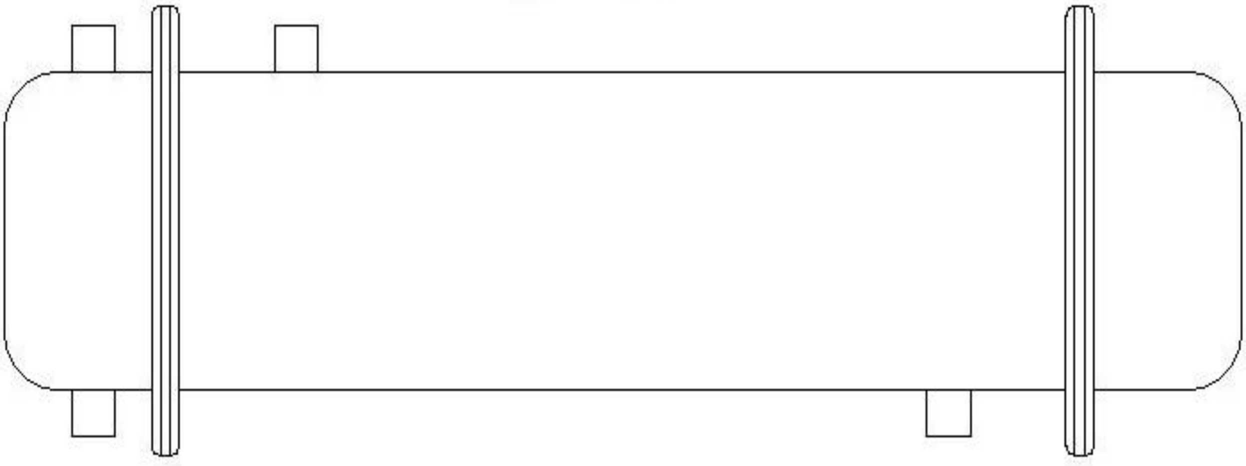


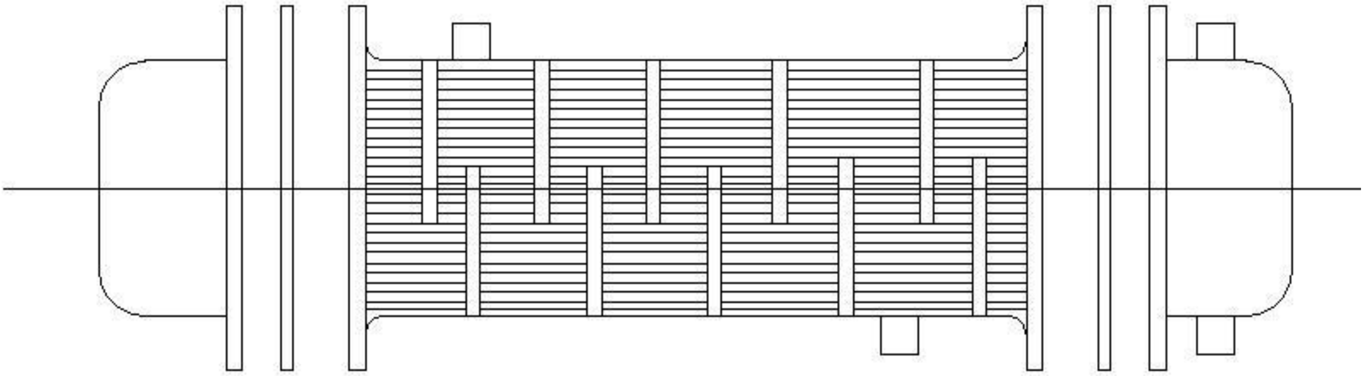
Fig. 3: Heat Loss from Lub. Oil Vs Mass Flow Rate of Lub. Oil

Appendix B1



Coupled Heat Exchanger

Appendix B2



Assembled Heat Exchanger
Showing Baffle Arrangement

DISCUSSION OF RESULTS

The overall heat transfer coefficient of this Tube type Heat Exchanger obtained from the design calculation is 172.3w/m^{o}c.

There is a direct proportional relationship between effectiveness of a heat exchanger and the lubricating oil temperature difference (difference between the lubricating oil inlet and outlet temperature). This is deduced from fig 1(graph of effectiveness versus lubricating oil temperature difference). It was observed that the effectiveness increases as the lubricating oil temperature difference increases. A balance must be strike between the effectiveness and the difference between the inlet and outlet temperature of the lubricating oil. This is important because excessive lubricating oil temperature difference which will give a higher effectiveness can lead to sub cooling of the lubricating Oil resulting to creating thermal stress in the engine components. This can lead to engine failure.

Figure 2 (graph of lubricating oil temperature difference versus mass flow rate of seawater) also shows a direct proportional relationship between the mass flow rates of seawater and the lubricating oil temperature difference.

From figure 3 the heat loss from lubricating oil rises rapidly to about 1.75kw before it then increases as the mass flow rate of the lubricating oil increases. All this translates to increase in the overall heat transfer coefficient. Which invariably means an increase in effectiveness of a heat exchanger can be seen from figure 1.

Educational Implications

The design will enhance academic outcomes and empirical reference study in engineering applications. This means that it is imperative for government, school, administrators and stakeholders to provide functional workshops, laboratories for experimental and empirical studies which foster rapid technological development for economic growth.

CONCLUSION

The following conclusions were drawn:

1. The general design process can be summarized in the calculation of the required area to transfer heat from one fluid to the other, through the actual design parameters used.
2. The works lucidly discuss the tube type heat exchanger for lubricating oil with moderate's area to volume ratio.
3. The design consideration were to ensure suitability of the calculated area of heat transfer with regards to important parameters like baffle arrangement, number of tubes, shell and tube diameter to meet with the maximum pressure loss requirement in tube type heat exchanger.
4. The effectiveness of heat exchanger is increased by increasing the sea water inlet and outlet temperature difference and mass flow rate. However care must be taken, as excessive increment may result in thermal stress in the plant components.
5. It was discovered that all power plants on board vessels that generate heat from combustion, requires a heat exchange, in order to avoid plant failure.
6. From figure 1. it was discovered that the efficiency increases with increase in temperature difference between the lubricating oil inlet and outlet temperatures.
7. Figure 2. (graph of Lubricating oil temperature difference versus mass flow rate of seawater) shows that the lubricating oil temperature difference increases as the seawater mass flow rate increases.
8. Figure 3. shows that the heat loss from lubricating oil rises rapidly to about 1.75kw when the mass flow rate of the lubricating oil is 18.2kg/s, before it then increases proportionally as the mass flow rate of the lubricating increases.
9. Excessive increase in temperature difference between the lubricating oil inlet and outlet temperature difference, may lead to thermal stress in the power plant component

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