DESIGN CALCULATION FOR EQUIPMENT AND COMPONENTS SPECIFICATION OF LUBRICATING OIL SYSTEM OF A TUG BOAT

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ABSTRACT

The lubricating oil system is primarily used to lubricate wear surfaces to minimize friction losses, it cools internal engine parts which cannot be directly cooled by the engines' water cooling system and it cleans the engine by flushing away wear particles amongst others. Adequate lubrications require lubricant (oil) with sufficient film strength to withstand bearing pressure and viscosity index low enough to allow adequate flow when subjected to heat. The system consist of the tanks (storage, settling, sump and head), lube-oil pumps, strainers, oil coolers, piping, valves, and fittings, lubricating oil purifier, sub system and condition monitoring devices amongst others. The lubricating oil system for a tug boat whose transmitting power is about 955KW was calculated mathematically to obtain the flow rate of the shaft line bearing cooling oil, stern tube bearing cooling oil, main engine camshaft bearing cooling oil and main engine camshaft bearing cooling oil. Modelled equations were employed to obtain the camshaft lube-oil pump capacity, surface area and storage tank. The cylinder lube-oil storage and density tanks were estimated to be 1m^3 while the transfer pump is calculated to be approximately 0.4m^3/hr. The various suction and discharge diameters and velocities of pumps in the lubricating oil system were determined; it was observed the suction pipe diameter is always bigger than the discharge pipe diameter while the discharge velocity is higher than the suction velocity for all the pumps including the camshaft lube-oil pump, cylinder oil transfer pump and main lube-oil transfer pump. This is a clear indication that the said design process met the international standard for the design of such a tug boat. Similarly the shaft line bearing cooling oil pipe, piston bearing cooling oil pipe and main engine lube-oil pipe discharge velocities were seen to be at the acceptable limits obeying the classification rules. All designs were done in accordance to the Lloyd's specification rules and regulations for a sea going tug boat.

KEYWORDS: *tug boat, pumps, lube-oil, valves, piping, fittings and condition monitoring device*.

I. INTRODUCTION

The lubricating oil system is primarily used to lubricate wear surfaces to minimize friction losses, it cools internal engine parts which cannot be directly cooled by the engines' water cooling system and it cleans the engine by flushing away wear particles amongst others. Adequate lubrications require lubricant (oil) with sufficient film strength to withstand bearing pressure and viscosity index low enough to allow adequate flow when subjected to heat. In addition, the lubricant must be capable of neutralizing harmful combination combustion products and holding them in suspension for the duration of the oil change period [1].
Practically, consideration is given to amount of contamination such as water and dirt which can enter the lubricant, time between the lubricant changes, variation of service requirement, as well as the chemical nature of the lubricant. Solid particles are removed from the oil by mechanical filtration. The size of the mesh is determined by the maximum particle size that can be circulated without notable abrasive action. The standard oil filter system on every engine must meet these requirements [2].
The lubrication system selection is determined in part by the prime mover selected and in part the layout of the machinery space. There are two basic types of lubricating system; the gravity system and

the pressure system. In addition, there are two types of sub-lubricating system; these are high-head pressure/gravity system and the low-head pressure/gravity system. The gravity system uses one or more head tanks to supply oil to the propulsion plant which requires a high head room. The pressure system supply is direct from the lubricating oil pump [3].
The lubricating oil system consist of the tanks (storage, settling, sump and head), lube-oil pumps, strainers, oil coolers, piping, valves, and fittings, lubricating oil purifier, sub system and condition monitoring devices. Most importantly, a lubricant must have different properties and be able to provide; high temperature and oxidation stability, corrosion protection to prevent rusting and chemical attack on the non-ferrous components and to neutralize acids generated during combustion. Similarly it provides load caring capacity, low water for prolonged ring and cylinder liner life and overall engine cleanness and consequently has good detergency property [4]. In this work I looked at the Lubricating oil system of a diesel engine in details, highlighted some classification rules for the system, used mathematical models to design the components and equipment of the system and did a general discussion with the results obtained.

II. THE LUBRICATION OIL SYSTEM

Lube-oil for an engine is stored in the bottom of the crankcase, known as the sump, or in a drain tank located beneath the engine. The oil is drawn from this tank through a strainer, one of a pair of pumps, into one of a pair of fine filters. It is then passed through a cooler before entering the engine and being distributed to the various branch pipes. The branch pipe for a particular cylinder may feed the main bearing. Some of this oil will pass along a drilled passage in the crankshaft to the bottom end bearing and then up a drilling passage in the connecting rod to the gudgeon pin or crosshead bearing [5].
An alarm at the end of the distribution pipe ensures that adequate pressure is maintained by the pump. Pumps and fine filters are arranged in duplicate with one as standby. The fine filters will be arranged so that one can be cleaned while the other is operating. After use in the engine the lubricating oil drains back to the sump or drain tank for re-use. A level gauge gives a local read-out of the drain tank contents. A centrifuge is arranged for cleaning the lubricating oil in the system and clean oil can be provided from a storage tank.
The oil cooler is circulated by the sea water, which is at a lower pressure than the oil. As a result any leak in the cooler will mean a loss of oil and contamination of the oil by the sea. Where the engine has oil-cooled pistons they will be supplied from the lubricating oil system, possibly at a higher pressure produced by booster pumps. An appropriate type of lubricating oil must be used for oil-lubricated pistons in order to avoid carbon deposits on the hotter parts of the system.

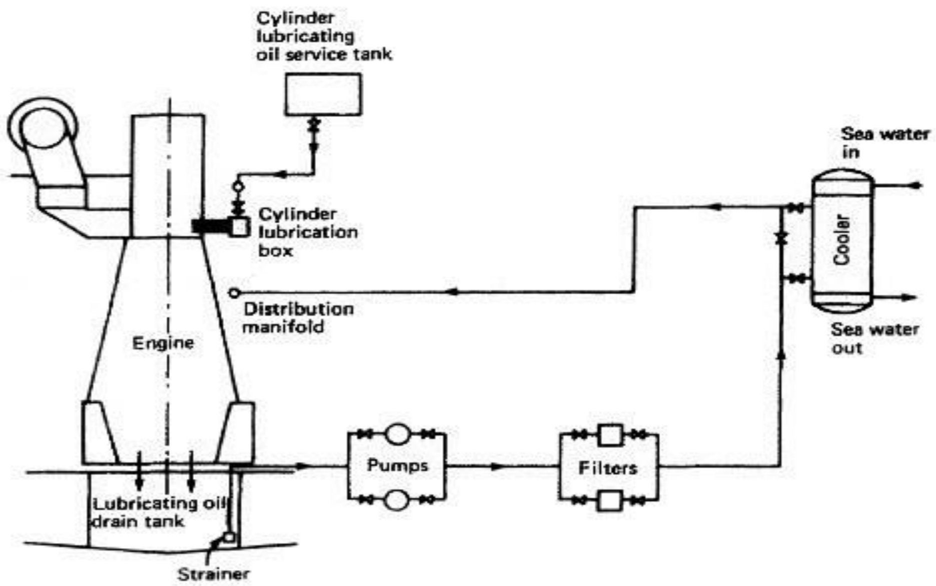

Figure 1: Lubricating oil System of a Diesel Engine (source – Machinery Spaces.com)

2.1. Relevant Classification Regulation and Requirement for Lubricating oil System

The classification rules and regulations must be adhered to in order to enhance the prospective or required effect for design calculation of the capacity and flow piping. These rules will also ensure that every component in the system is suitable for the intended purpose and duty when they are obeyed strictly. The lube-oil system consist of tanks, pumps, strainers, oil coolers, piping, valves and fittings, lube-oil purifier sub-system and condition monitoring device, each of these must have regulations guiding them [6]

In the design of tanks for the lubricating oil systems, all tanks which are pumped up are to be fitted with overflow pipes and the overflow pipes is led to an overflow tank of adequate capacity. Similarly, suction intake in lubricating oil tank should maintain a minimum of 4-inch above the tank bottom to avoid picking up solid contaminant from the bottom. Every tank should be provided with a drain system. Furthermore, tanks should be designed with the necessity of mutually cleaning the lube-oil system and the possibility subsequent cleaning taken into account. Tank capacity must be based on the maximum oil requirement per unit time and on the minimum allowable residence time in oil return line and tanks. Another consideration in the design of tanks for the lube-oil system, a sight glass is to be provided in the overflow pipe to indicate when the tanks are overflowing or alternatively an alarm device to warn when oil reached a pre-determined level in tank [7].

The power supply to all independent driven lube-oil transfer and pressure pumps is to be capable of being stopped from a position outside the space. All pumps which are capable of developing a pressure exceeding the design pressure of the system are to be provided with a relief valve. Valves or corks should be interposed between pumps (at the suction and discharge pipes), in order that any pump may be shut off for opening up and overhauling. For the considerations of piping and fittings in the lubricating oil system, external care is to be taken to ensure that pipe and fittings, before installation, are free from scale sand, metal particles and other foreign matters. All valves are to be arranged to shut with a right hand motion of the wheels and are to be provided with indicators showing whether they are open or shut unless this is readily obvious [8].

Generally, filters and alarm systems will be fitted in the lubricating oil system to ensure the smooth running of the system. The material selection is based on many factors such as; the ability to resist general and localized corrosion such as pitting, impingement attack and cavitations throughout all the flow velocity likely to be encountered, compatibility with the other materials in the system such as valve bodies and casing (in order to minimize bimetallic corrosion). Other factors include ability to resist selection and stress corrosion and corrosion fatigue. The design pressure and temperature must be maintained for all components and equipment in the lubricating oil system.

2.2. Special considerations in the design of the lube-oil system of a tug boat

To enhance the working condition of the tug boat at full load and other sea conditions we must take a critical account of the stability of the vessel during any operation [9] and [10].

III. MATERIALS AND METHODS

The lubricating oil system design calculations for equipment, component, piping and fittings for the Tug boat engines and generators.

The capacity of the engines for the design of the lubrication oil system included

The Starboard side Main Engine	- 955KW and 1800 rpm
The Port side Main Engine	- 955KW and 1800 rpm
The Starboard side Aux-Engine	- 82KW and 1500 rpm
The Port side Aux-Engine	- 82KW and 1500 rpm
FI-FI pump set	- 133KW and 1800 rpm [11]

General Data for Diesel Fuel Oil (D.F.O)

Net Calorific value of D.F.O.	= 42700 KJ/kg
Mean overall heat transfer coefficient of fuel	= 760 KJ/M^2 deg hr
Specific gravity of .D.F.0.	= 900 kg/m^3
Specific heat of D.F.O.	= 1.82KJ/kg°C

Viscosity of diesel fuel oil -5-15 cst at 20°C

Other parameters of the tug boat

Length of Boat	-	28m
Breadth of Boat	-	9m
Moulded depth of Boat	-	4.5m
Gross Tonnage	-	180
Net Tonnage	-	55

3.1. Total energy (Heat) input in Engine (Q_F)

The total energy input in main engine can be obtained from the relation

$$Q_F = \frac{SFC\ x\ LCV\ x\ MCR}{3600} \tag{1}$$

Where:-
SFC – Specific fuel consumption = 0.2 Kg/KWhr
LCV – Lower calorific value = 41,399
MCR – Maximum continuous rating = 1800 rpm
By simple substitution into equation 1

$$Q_F = 4140\ KW$$

Shaft Power Output (SPO)
The shaft power output could be obtained from the brake power and the gear efficiency

$$SPO = B_P\ x\ \eta_G \tag{2}$$

Where:-
SPO - Shaft Power Output
B_P – Brake Power output = 995 KW
η_G – Gear efficiency = 0.96 – 0.98
By Simple substitution into equation 2

$$SPO = 955\ KW$$

3.2. Shaft Line bearing cooling oil flow rate (M_{SL})

The shaft line bearing cooling oil flow rate could be determined by the relation of the volumetric flow rate of sea water.

$$M_{SL} = \frac{Q_{SL}}{C_{PLO}\ x\ \Delta T} \tag{3}$$

Where:-
C_{PLO} = Specific heat capacity of lube oil at constant pressure = 1.913 KJ/Kg (SAE 30 at 30^0C)

ΔT – Temperature difference between inlet and out of the lube oil = $T_{LO(out)} - T_{LO(in)}$ = 50-30 = 20

We know that the capacity of lube oil shaft line bearing pump Q_{SL} is approximately equal to 1.5% of the shaft power output

$$Q_{SL} = 14.325KW$$

By Simple substitution into equation 3

$$M_{SL} = 0.375\ kg/s$$

3.3. Stern tube bearing cooling oil flow rate (M_{ST})

This can be obtained from the formula

$$M_{SL} = \frac{Q_{ST}\ x\ i_c}{C_{PLO}\ x\ \Delta T} \quad (4)$$

Where:-
C_{PLO} = Specific heat capacity of lube oil at constant pressure = 1.913 KJ/Kg (SAE 30 at 30^{0}C)

ΔT – Temperature difference between inlet and out of the lube oil = $T_{LO(out)} - T_{LO(in)}$ = 55-35 = 20
i_c - Filling coefficient = 20/hrs
MCR – Maximum continuous rating = 1800 rpm

We know that the capacity of lube oil stern tube bearing pump Q_{ST} is approximately equal to 1.5% of the SPO

$$Q_{ST} = 14.325KW$$

By Simple substitution into equation 4

$$M_{ST} = 0.125\ kg/s$$

3.4. Stern tube lube-oil gravity capacity (V_{STT})

This capacity is chosen from experience on similar system

$$V_{STT} \geq \frac{M_{ST}}{\rho_{LO}\ x\ i_c} \quad (5)$$

Where:-
M_{ST} = Mass flow of stern tube oil = 0.125 Kg /s = 450 Kg/hr
ρ_{LO} – Density of lube oil = 863.9 Kg/m (at 40
i_c - Filling coefficient = 10/hrs

By Simple substitution into equation 5

$$V_{STT} \geq 0.052m$$

3.5. Main Engine Camshaft bearing cooling oil flow rate (M_{CS})

The engine camshaft bearing cooling oil flow rate can be determined with the relation

$$M_{CS} = \frac{Q_{CS}}{C_{PLO}\ x\ \Delta T} \quad (6)$$

Where:-
C_{PLO} = Specific heat capacity of lube oil at constant pressure = 1.942 KJ/Kg (SAE 30 at 40^{0}C)
ΔT – Temperature difference between inlet and out of the lube oil = $T_{LO(out)} - T_{LO(in)}$ = 60-40 = 20

We know that the capacity of lube oil camshaft bearing pump Q_{CS} is approximately equal to 0.8% of the SPO

$$Q_{CS} = 7.64KW$$

By Simple substitution into equation 6

$$M_{CS} = 0.2\ kg/s$$

3.6. Capacity of Camshaft lube-oil pump (Q_{SCP})

The capacity is selected using the maximum mass flow rate of cooling oil required

$$Q_{CSP} = \frac{M_{CS}}{\rho_{LO}} \quad (7)$$

M_{CS} – Mass flow rate of camshaft lube oil pump = 0.2 Kg/s
ρ_{LO} = Density of oil = 863.9 (SAE 30 at 40^{0}C)

By Simple substitution into equation 7

$$Q_{CSP} = 0.833m^3/\text{hr}$$

3.7. Camshaft lube-oil cooler surface area (A_{CS})

This can be obtained from the formula

$$A_{CS} = \frac{Q_{CS}}{K\ x\ F\ x\ LMTD} \quad (8)$$

Q_{CS} - Capacity of lube oil camshaft bearing pump = 7.64KW = 27504 KJ/hr
K - Mean overall heat transfer coefficient (for shell and tube heat exchanger) = 2600KJ/m hr ^{0}C
F – Correction factor for heat exchanger tube = 1.0
ΔT_1- Temperature difference between lube oil (in) and sea water (out) = 60 – 42 =18^{0}C
ΔT_2- Temperature difference between lube oil (out) and sea water (in) = 40 – 32 =8^{0}C

$$\Delta T_m = LMTD = \frac{\Delta T_1 - \Delta T_2}{In\frac{\Delta T_1}{\Delta T_2}} \quad (9)$$

By simple substitution into equation 9

$$\Delta T_m = LMTD = 12.8$$

By Simple substitution into equation 8

$$A_{CS} = 0.83m^2 \approx 1.0\ m^2$$

3.8. Camshaft lube-oil storage tank (V_{CST})

The camshaft lube oil storage tank V_{CST} capacity could be obtained from the relationship

$$V_{CST} = \frac{Q_{CSP}}{i_c} \quad (10)$$

Q_{CSP} – Capacity camshaft lube-oil pump flow = $0.833m^3/\text{hr}$
i_c = Filling coefficient = 10/hr

By Simple substitution into equation 10

$$V_{CST} = 0.0833m^3 \approx 0.1m^3$$

3.9. Main Engine Piston cooling oil flow rate (M_P)

The main engine piston cooling flow rate could be determined by the formula

$$M_P = \frac{Q_P}{C_{PLO}\ x\ \Delta T} \quad (11)$$

Where:-
C_{PLO} = Specific heat capacity of lube oil = 1.942 KJ/Kg (SAE 30 at 40^{0}C)
ΔT – Temperature difference between inlet and out of the lube oil = $T_{LO(out)} - T_{LO(in)}$ = 55-40 = 15

We know that the capacity of piston cooling oil pump Q_P is approximately equal to 4.5% of the Q_F

$$Q_P = 186.30KW$$

By Simple substitution into equation 11

$$M_P = 0.395\ kg/s$$

3.10. Capacity of Cylinder Lube-oil storage tank (V_{COS})

This can be obtained from the relation

$$V_{COS} = \frac{b_{CO}\ x\ MCR\ x\ t\ x\ i}{\rho_{LO}} \tag{12}$$

b_{CO} - Total specific cylinder oil consumption = 0.7 x 10 Kg/KW hr
MCR – Maximum continuous rating = 1800 rpm
ρ_{LO} - Density of lube-oil = 863.9 Kg/m (SAE 30 at 32^{0}C)
t – 3 times duration of voyage (hr) = 21 x 24 = 504 hrs
i – Correction factor = 1.1

By Simple substitution into equation 12

$$V_{COS} = 0.81\ m^3$$

3.11. Capacity of Cylinder Lube-oil density tank (V_{COD})

This can be obtained from the relation

$$V_{COD} = \frac{b_{CO}\ x\ MCR\ x\ t\ x\ i}{\rho_{LO}} \tag{13}$$

b_{CO} - Total specific cylinder oil consumption = 0.7 x 10 Kg/KW hr
MCR – Maximum continuous rating = 1800 rpm
ρ_{LO} - Density of lube-oil = 863.9 Kg/m (SAE 30 at 32^{0}C)
t = 2 x 24 = 48 hrs
i – Correction factor = 1.1

By Simple substitution into equation 13

$$V_{COD} = 0.8\ m^3$$

Hence the capacity of cylinder oil transfer pump (Q_{COP})

$$Q_{COP} = \frac{V_{COD}}{t} \tag{14}$$

By Simple substitution into equation 14

$$Q_{COP} = 0.385 m^3/\text{hr}$$

3.12. Main Engine Lube-oil cooler surface area (A_{LO})

This can be obtained from the formula

$$A_{LO} = \frac{Q_{LO}}{K\ x\ F\ x\ MLTD} \tag{15}$$

Q_{LO} – Total heat loss to lube-oil = $Q_{ML} + Q_P + Q_{SL}$
Q_{ML} = 3% of Q_F = 124.2 KW = 447109.2 KJ/hr
Q_P = 186.3KW (KJ/s) = 670680 KJ/hr
Q_{SL} = 14.328 KW = 515608 KJ/hr
Q_{LO} = (124.2 + 186.3 + 14.328) KW = 1169370 KJ/hr

K - Mean overall heat transfer coefficient (for shell and tube heat exchanger) = 2600KJ/m h ^{0}C
F – Correction factor for heat exchanger tube = 1.0

ΔT_1- Temperature difference between lube oil (in) and sea water (out) = 60 – 42 =18^{0}C
ΔT_2- Temperature difference between lube oil (out) and sea water (in) = 40 – 32 =8^{0}C

$$\Delta T_m = LMTD = \frac{\Delta T_1 - \Delta T_2}{In\frac{\Delta T_1}{\Delta T_2}} \tag{16}$$

By simple substitution into equation 16

$$\Delta T_m = LMTD = 12.8$$

By Simple substitution into equation 15

$$A_{LO} = 35.14m^2$$

3.13. Main Engine Lube-oil mass flow rate (M_{LO})

The main engine lube-oil mass flow rate could be determined by the formula

$$M_{LO} = \frac{Q_{LO}}{C_{PLO}\ x\ \Delta T} \tag{17}$$

Where:-
C_{PLO} = Specific heat capacity of lube oil = 1.942 KJ/Kg (SAE 30 at 40^0C)
ΔT – Temperature difference between inlet and out of the lube oil = $T_{LO(out)} - T_{LO(in)}$ = 20^0C

$$Q_{LO} = 324.825 \text{ KW}$$

By Simple substitution into equation 17

$$M_{LO} = 8.4\ kg/s$$

≫ Amount of lube-oil requires for one cylinder = $\frac{M_{LO}}{z} = \frac{8.3632}{16}$ = 0.523Kg/s

3.14. Capacity of Main Engine Lube-oil service pump (M_{TLO})

$$M_{TLO} = M_{LO} + M_P + M_{SL} = 8.3632 + 0.395 + 0.3745 = 9.133 \text{ Kg/s}$$

This can be obtained from the relation

$$Q_{LOP} = \frac{M_{TLO}\ x\ i}{\rho_{LO}}\ x\ 3600 \tag{18}$$

ρ_{LO} - Density of lube-oil = 863.9 Kg/m (SAE 30 at 32^0C)
i – Correction factor = 1.1

By Simple substitution into equation 18

$$Q_{LOP} = 41.86\ m^3/\text{hr}$$

M_{TLO} is the minimum total lube-oil mass flow rate required

3.15. Capacity of Lube-oil sump tank (V_{ST})

The camshaft lube oil storage tank V_{CST} capacity could be obtained from the relationship

$$V_{ST} = \frac{Q_{LOP}}{i_c} \tag{19}$$

$Q_{LOP} = 41.86m^3/\text{hr}$
i_c = Filling coefficient = 10/hr

By Simple substitution into equation 19

$$V_{ST} = 4.2m^3$$

Quality of lube oil in service system (V_{SS})

The lube oil in service system V_{SS} is 10% of V_{ST}
$V_{SS} = 0.1\ x\ 4.2$

$$V_{SS} = 0.42m^3$$

Quality of lube oil Drain Tank (V_{DT})

The lube oil drain tank V_{DT} capacity could be obtained from the relationship

$$V_{DT} = t\left(\frac{Q_{LOP}}{10} + V_{ST} + V_{SS}\right) \quad (20)$$

By simple substitution into equation 20

$V_{DT} = 1.1\ (4.186 + 4.2 + 0.42) = 8.806\ m^3$

3.16. Capacity of Lube-oil storage (min-reserve) tank (V_{ST})

This can be obtained from the relation

$$V_{RST} = \frac{b_{CO}\ x\ MCR\ x\ t\ x\ i}{\rho_{LO}} \quad (21)$$

b_{CO} - Total specific cylinder oil consumption = 0.7 x 10 Kg/KW hr
MCR – Maximum continuous rating = 1800 rpm
ρ_{LO} - Density of lube-oil = 863.9 Kg/m (SAE 30 at 32^{0}C)
t = 504 hrs
i – Correction factor = 1.0

By Simple substitution into equation 21

$$V_{RST} = 0.81\ m^3$$

Note that the capacity of the lube-oil settling tank is the same as the storage (service) tank

IV. Piping Calculation and Specification of Pipe Diameter and Fluid Velocity

The life span of the pipe depends largely on the adherence to critical design velocity. Suggested fluid velocities which serve as guides in pipe selection are as shown in tables below.

Table 1: Guides for Lubricating oil pipe selection

S/No	SERVICES	Fluid Velocity $C = V\sqrt{D_L}$ (m/s)	V_{max} (m/s)
1	Lube-oil service suction Pumping	$1.9\sqrt{D_L}$	1.2
2	Lube-oil service discharge Pumping	$3.8\sqrt{D_L}$	1.8
3	Hydraulic oil service suction Pumping	$2.85\sqrt{D_L}$	2.4
4	Hydraulic oil service discharge Pumping	$15.2\sqrt{D_L}$	6.0

The calculation velocity (V) must not exceed the limit velocity (V_{MAX}) in any condition. From the equation of continuity

$$Q = AV = \pi\frac{D_L}{4}\ x\ V \quad (22)$$
$$= \pi\frac{D_L}{4}\ x\ C\sqrt{D_L}$$
$$\therefore\ D_L = \left[\frac{Q}{0.745\ C}\right]^{0.4} \quad (23)$$

Where

Q – Fluid flow rate (m^2/s)
A – Area of Pipe (m^2)
D_L – Diameter of Fluid flow (m)

V – Velocity of fluid flow (m/s)
V_{MAX} – Maximum allowable velocity of flow (m/s)
C – Flow coefficient

4.1. Camshaft lube-oil pump pipe diameter and flow velocity

$$\therefore\ D_{LOP(SUCTION)} = \left[\frac{Q}{0.745\ X\ C}\right]^{0.4} \quad (24)$$

Where
$Q_{CSP} = 1.5652 m^3/hr$
$C = 1.9$

By Simple substitution into equation 24

$D_{LOP(SUCTION)} = 39.2\ mm$
Selected pipe for $D_{CSP(Suction)}$ = 40mm

$$D_{LOP(Discharge)} = \left[\frac{Q}{0.745\ X\ C}\right]^{0.4} \quad (25)$$

By Simple substitution into equation 25

$D_{LOP(Discharge)} = 26.7\ mm$

Selected pipe for $D_{CSP(Discharge)}$ = 30mm

Hence to obtain the velocity of the fluid flowing

$D_{LOP(Sunction)} = 1.9\ D_{Suction}{}^{0.5}$
= 0.38m/s ≤ V_{MAX}1.2m/s
$D_{LOP(Discharge)} = 3.8\ D_{Suction}{}^{0.5}$
= 0.66m/s ≤ V_{MAX}1.8m/s

4.2. Cylinder oil transfer pump pipe diameter and flow velocity

$$\therefore\ D_{LOP(SUCTION)} = \left[\frac{Q_{COP}}{0.745\ X\ C}\right]^{0.4} \quad (26)$$

Where
$Q_{COP} = 0.385 m^3/hr = 0.000107 m^3/s$
$C = 1.9$

By Simple substitution into equation 26
$D_{LOP(SUCTION)} = 22.5\ mm$

Selected pipe for $D_{COP(Suction)}$ = 25mm

$$D_{LOP(Discharge)} = \left[\frac{Q}{0.745\ X\ C}\right]^{0.4} \quad (27)$$

By Simple substitution into equation 27
$D_{LOP(Discharge)} = 17.02\ mm$
Selected pipe for $D_{COP(Discharge)}$ = 20mm

Hence to obtain the velocity of the fluid flowing

$D_{LOP(Sunction)} = 1.9\ (D_{Suction})^{0.5}$
= 0.30m/s ≤ V_{MAX}1.2m/s

$D_{LOP(Discharge)} = 3.8\, D_{Suction}{}^{0.5}$
$= 0.56\text{m/s} \leq V_{MAX} 1.8\text{m/s}$

4.3. Main lube-oil service pump pipes diameter and flow velocity

$$\therefore\ D_{LOP(SUCTION)} = \left[\frac{Q_{LOP}}{0.745\ X\ C}\right]^{0.4} \quad (28)$$

Where
$Q_{LOP} = 69.37 m^3/hr$
$C = 1.9$

By Simple substitution into equation 28
$D_{LOP(SUCTION)} = 179.3\ mm$
Selected pipe for $D_{COP(Suction)}$ = 200mm

$$D_{LOP(Discharge)} = \left[\frac{Q}{0.745\ X\ C}\right]^{0.4} \quad (29)$$

By Simple substitution into equation 29
$D_{LOP(Discharge)} = 136\ mm$
Selected pipe for $D_{CSP(Discharge)}$ = 150mm

Hence to obtain the velocity of the fluid flowing

$D_{LOP(Sunction)} = 1.9\ (D_{Suction})^{0.5}$
$= 0.85\text{m/s} \leq V_{MAX}\ 1.2\text{m/s}$
$D_{LOP(Discharge)} = 3.8\, D_{Suction}{}^{0.5}$
$= 1.5\text{m/s} \leq V_{MAX}\ 1.8\text{m/s}$

4.4. Shaft line bearing cooling oil pipe diameter and flow velocity

$$D_{SL} = \left[\frac{M_{SL}}{M_{LO} + M_P + M_{SL}}\right] D_{LOP(Discharge)} \quad (30)$$

$M_{SL} = 0.3745\ Kg/s$
$M_{LO} = 8.3632\ Kg/s$
$M_P = 0.395\ Kg/s$
$D_{LOP(Discharge)} = 0.133m$

By Simple substitution into equation 30
$D_{SL} = 5.5\ mm$
Selected pipe for D_{SL} = 10mm

Hence to obtain the velocity of the fluid flowing
$V_{SL} = 3.8\ (D_{Discharge})^{0.5}$
$= 0.3\text{m/s} \leq V_{MAX}\ 1.8\text{m/s}$
$D_{LOP(Discharge)} = 3.8\, D_{Suction}{}^{0.5}$
$= 1.5\text{m/s} \leq V_{MAX}\ 1.8\text{m/s}$

4.5. Piston cooling oil pipe diameter and flow velocity

$$D_P = \left[\frac{M_P}{M_{LO} + M_P + M_{SL}}\right] D_{LOP(Discharge)} \quad (31)$$

$M_{SL} = 0.3745\ Kg/s$

$M_{LO} = 8.3632\ Kg/s$
$M_P = 0.395\ Kg/s$
$D_{LOP(Discharge)} = 0.133m$

By Simple substitution into equation 31
$D_P = 57.5\ mm$
Selected pipe for D_P = 100mm

Hence to obtain the velocity of the fluid flowing
$V_P = 3.8\ (D_{Discharge})^{0.5}$
$= 1.2\text{m/s} \leq V_{MAX}\ 1.8\text{m/s}$

4.6. Main Engine lube-oil service pipe diameter and flow velocity

$$D_{LO} = \left[\frac{M_{LO}}{M_{LO} + M_P + M_{SL}}\right] D_{LOP(Discharge)} \tag{32}$$

$M_{SL} = 0.3745\ Kg/s$
$M_{LO} = 8.3632\ Kg/s$
$M_P = 0.395\ Kg/s$
$D_{LOP(Discharge)} = 0.133m$

By Simple substitution into equation 32
$D_{LO} = 121.8\ mm$
Selected pipe for D_{LO} = 150mm

Hence to obtain the velocity of the fluid flowing
$V_{LO} = 3.8\ (D_{Discharge})^{0.5}$
$= 1.2\text{m/s} \leq V_{MAX}\ 1.8\text{m/s}$

V. RESULTS DISCUSSION

The lubricating oil system is designed to lubricate wear surfaces to minimize friction losses, it cools internal engine parts which cannot be directly cooled by the engines' water cooling system and it cleans the engine by flushing away wear particles The design of the lubricating oil system for a tug boat whose transmitting power is about 955KW the flow rate of the shaft line bearing cooling oil, stern tube bearing cooling oil, main engine camshaft bearing cooling oil and main engine camshaft bearing cooling oil is modelled to be approximately 0.4kg/s, 0.14kg/s, 0.37kg/s and 0.4kg/s respectively. The camshaft lube-oil pump capacity, surface area and storage tank were calculated to be 1.55m^3/hr, 1.56m^2 and 0.155m^3 respectively. It was also discovered that if the power increase there will be also an increase in camshaft lube-oil pump capacity, surface area and storage tank. The cylinder lube-oil storage and density tanks were estimated to be 1m^3 while the transfer pump is calculated to be approximately 0.4m^3/hr. In the calculations of diameters and velocities of various pipes in the lubricating oil system, it was observed the suction pipe diameter is bigger than the discharge pipe diameter while the discharge velocity is higher than the suction velocity for all the pumps including the camshaft lube-oil pump, cylinder oil transfer pump and main lube-oil transfer pump. Similarly the shaft line bearing cooling oil pipe, piston bearing cooling oil pipe and main engine lube-oil pipe discharge velocities were seen to be at the acceptable limits obeying the classification rules. All designs were done in accordance to the Lloyd's specification rules and regulations for a sea going tug boat.

VI. CONCLUSION

The lubricating oil system and the cooling water system work hand in hand together to ensure that the temperature of the main engine is kept within the acceptable limit. The lube-oil is primarily used to lubricate wear surfaces to minimize friction losses, it cools internal engine parts which cannot be directly cooled by the engines' water cooling system and it cleans the engine by flushing away wear particles amongst others. The system consist of the tanks (storage, settling, sump and head), lube-oil pumps, strainers, oil coolers, piping, valves, and fittings, lubricating oil purifier, sub system and condition monitoring devices amongst others. The lubricating oil system for a tug boat with 955KW power is designed to have flow rate of the shaft line bearing cooling oil, stern tube bearing cooling oil, main engine camshaft bearing cooling oil and main engine camshaft bearing cooling oil as 0.4kg/s, 0.14kg/s, 0.37kg/s and 0.4kg/s respectively. The camshaft lube-oil pump capacity, surface area and storage tank were calculated to be 1.55m^3/hr, 1.56m^2 and 0.155m^3 respectively. It was also discovered that if the power increase there will be also an increase in camshaft lube-oil pump capacity, surface area and storage tank. The cylinder lube-oil storage and density tanks were estimated to be 1m^3 while the transfer pump is calculated to be approximately 0.4m^3/hr. The cylinder lube-oil storage and density tanks being 1m^3 and the transfer pump 0.4m^3/hr shows a good design work for the lubricating oil system. The observation that showed that the suction pipe diameter is always bigger than the discharge pipe diameter while the discharge velocity is higher than the suction velocity for the camshaft lube-oil pump, cylinder oil transfer pump and main lube-oil transfer pump is a clear indication that the said design process met the international standard for the design of such a tug boat. Similarly the shaft line bearing cooling oil pipe, piston bearing cooling oil pipe and main engine lube-oil pipe discharge velocities were seen to be at the acceptable limits obeying the classification rules. All designs were done in accordance to the Lloyd's specification rules and regulations for a sea going tug boat. Future work that could be looked at on the subject is to be on board the vessel and ascertain the performance of the lube-oil system at a full operating (loading) condition, condition monitoring of the system with respect to the efficiency and reliability at sea.

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