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THE ENGINE THERMAL BALANCE. DETERMINATION OF ENERGY QUANTITY NECESSARY FOR LUBRICATION OF A NAVAL ENGINE

Florian VASILE[1]
Dumitru CATANĂ[2]
Ion ŞERBĂNESCU[3]
Cătălin Petrişor MIREA[4]
Dorel Dumitru VELCEA[5]
[1]Drd.ing., Military Technical Academy, Bucharest .
[2]Drd.ing., Military Technical Academy, Bucharest .
[3]Drd.ing., Military Technical Academy, Bucharest .
[4]Drd.ing., Military Technical Academy, Bucharest .
[5]Drd.ing., Military Technical Academy, Bucharest .

***Abstract**. To keep the engine parts temperature between some limits, a waste of energy is needed. This paper presents aspects link to the importance of lubrication of engine mechanism and afferent installation and the elements of lubrication installation which influence the thermal balance of the engine. For example were determined the quantity of energy necessary of lubrication of a naval engine, using the technical documentation.*
***Keywords:** thermal balance, energy quantity, lubrication.*

1. THERMAL BALANCE. LUBRICATING OIL SYSTEM.

Energy flow produced by combustion becomes partially effective power and the rest is discharged through various ways out as loss of heat flows. The distribution of these losses depends on engine type, motor cycle, operating conditions and power output.

Thermal balance expresses the equality between the energy flow introduced into the engine by burning fuel in the cylinders and the various energy flows that occur between engine, consumer and environment.

The energy balance represents the distribution of available energy flow, $\dot{Q}_{disp}$, between effective power and different loss. Heat balance equation is :

$$\dot{Q}_{disp} = \dot{Q}_e + \dot{Q}_{ge} + \dot{Q}_{rac} + \dot{Q}_{rez}$$

If lubrication oil cooling is achieved with seawater, in open circuit cooling, in the energy balance equations appear an additional term, $\dot{Q}_{rac.ulei}$, corresponding to the seawater energy flow taken from lube oil.

On the other side, when are used several closed cooling circuits, the term $\dot{Q}_{rac}$ will be divided in corresponding components of each circuit.

In such cases the energy balance equations becomes:

$$\dot{Q}_{disp} = \dot{Q}_e + \dot{Q}_{ge} + \dot{Q}_{rac.cil} + \dot{Q}_{rac.pist} + \dot{Q}_{rac.inj} + \dot{Q}_{rac.ulei} \; \dot{Q}_{rez}$$

where:

- $\dot{Q}_{disp}$ = available energy flow introduced into the engine by combustion;
- $\dot{Q}_e$ = effective power;
- $\dot{Q}_{ge}$ = energy flow exhaust with combustion gases;
- $\dot{Q}_{rac}$ = energy flow evacuated by cooling;
- $\dot{Q}_{rez}$ = residual energy flow (evacuated by radiation);

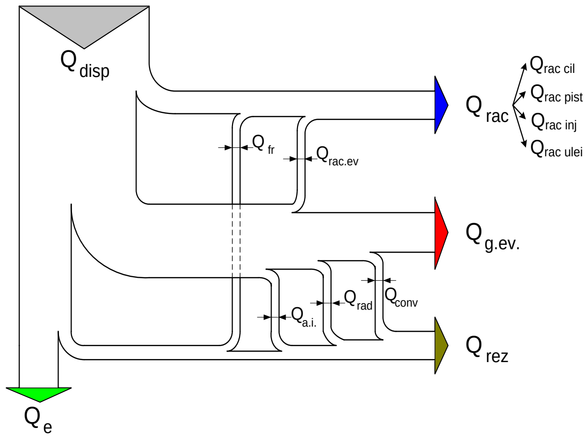

Figure.1. ***Heat balance diagram.***

In percent the energy balance equation becomes:

$$q_e + q_{ge} + q_{rac} + q_{rac.ulei} + q_{rez} = 100[\%]$$

where :

$q_e = \frac{\dot{Q}_e}{\dot{Q}_{disp}} \cdot 100[\%]$	q_e = 34…50 ;
$q_{ge} = \frac{\dot{Q}_{ge}}{\dot{Q}_{disp}} \cdot 100[\%]$	q_{ge} = 25…35 ;
$q_{rac} = \frac{\dot{Q}_{ar}}{\dot{Q}_{disp}} \cdot 100[\%]$	q_{ar} = 10…25 ;
$q_{rac.ulei} = \frac{\dot{Q}_u}{\dot{Q}_{disp}} \cdot 100[\%]$	q_u = 3…7 ;
$q_{rez} = \frac{\dot{Q}_{rez}}{\dot{Q}_{disp}} \cdot 100[\%]$	q_{rez} = 1…5 ;
$\dot{Q}_{disp} = C_h \cdot Q_i \cdot \frac{1}{3600}$ [kW]	
$\dot{Q}_{disp} = \frac{P_e \cdot c_e \cdot Q_i}{3600}$ [kW]	

In the engine mechanism, the oil meets the following function:

- ensures reduction of friction forces by moving surfaces lubrication;
- maintain the temperature of the moving parts;
- provides sealing between cylinder and piston-segment assembly;
- evacuates the impurities produced or accidentally falling inside the moving parts;
- transport and store – inside the filter or in carter – this impurities;
- provides the engine components protection against the corrosive action of environment.

The lubrication intensity of the different engine parts depend on their operating conditions: charge, friction surface and relative displacement speed. All forms of sliding friction exist in the internal combustion engine: dry friction, semi-dry friction, semi-liquid friction and liquid friction.

In the second figure is indicated the oil film formation for translation motion parts (cylinder 2 and piston 1).

The maximum oil pressure is indicated in diagram b; the smallest thickness of oil layer is between 0,001 – 0,007 mm (diagram a).

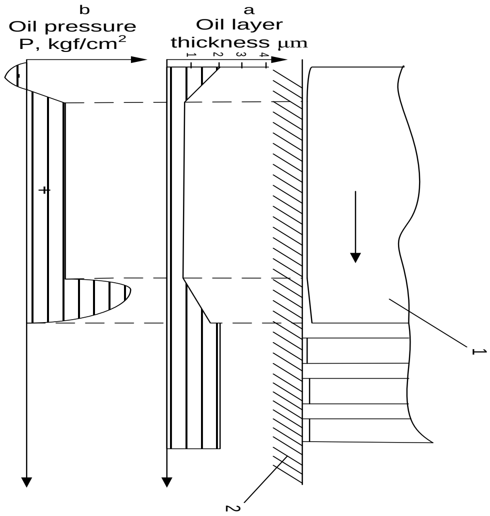

Figure.2. Oil film formation between piston and cylinder.

In the bearing-spindle assembly (figure 3) the spindle 2 rotates with speed "n", being placed eccentric to the bearing 1; the AB gap, filled with oil, will have variable height, which makes the fluid to exert a lifting action.

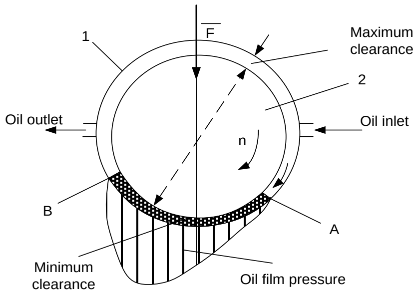

Figure.3. ***Oil film formation between bearing and spindle***

In figure 4 is illustrated the lubricating oil system for a six cylinders Diesel engine, wet crankcase, characterized in that the engine oil is stored in the crankcase. From crankcase, the oil is sucked through a raw filter and is displaced by lubrication pump to the oil strainer. From this strainer, the oil passes through the oil cooler and reaches the lubrication ramp, from where it is distributed to main bearings. From main bearings through crankshaft, the oil reaches the connecting rod bearings and, from here, to the gudgeon pin.

From the same location -lubrication ramp- the lubricating oil is sent to the other mechanical joints of the engine, like camshaft bearings, rockers, etc.

In the fourth figure is indicated, before the oil strainer, a bypass strainer and a manometer; a second manometer is placed in the farthest location from the pump. The dry sump lubrication system has the advantage of reducing the height of the engine; the lubricating oil has a limited contact area with hot gasses, dropped in the crankcase, therefore follows that the oxidation is reduced and allows an efficient cooling of lubricating oil.

Disadvantages of the system:

- large number of oil pumps;
- system complexity;
- large amount of oil needed;

All this leads to higher construction, operation and maintenance costs. This system applies in particular to large engines, because it allows reduction of engine height and an efficient cooling oil.

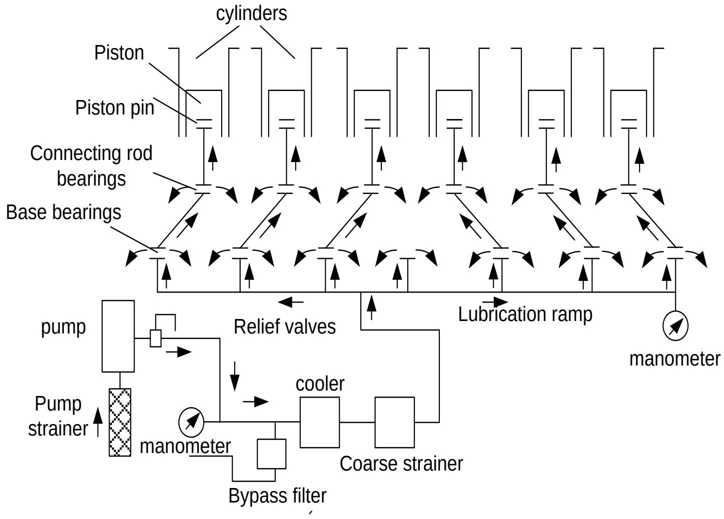

Figure.4. Wet sump lubricating oil system

In figure 5 are presented the components for MAN B&W 5S 50MC main engine lubricating oil system:
1 – crankshaft lubricating oil cooler;
2 – main engine lubricating oil cooler;
3 – bypass strainer;
4 – self-cleaning filter;
5 – cylinder lubricating oil service tank;
6 – cylinder lubricating oil storage tank;
7 – main engine;

8 – filter unit;
9 – drain and circulating tank;
10 – sump tank;
11 – main lubricating oil pumps;
12 – camshaft lubricating oil sump tank;
13 – camshaft lubricating oil pumps.

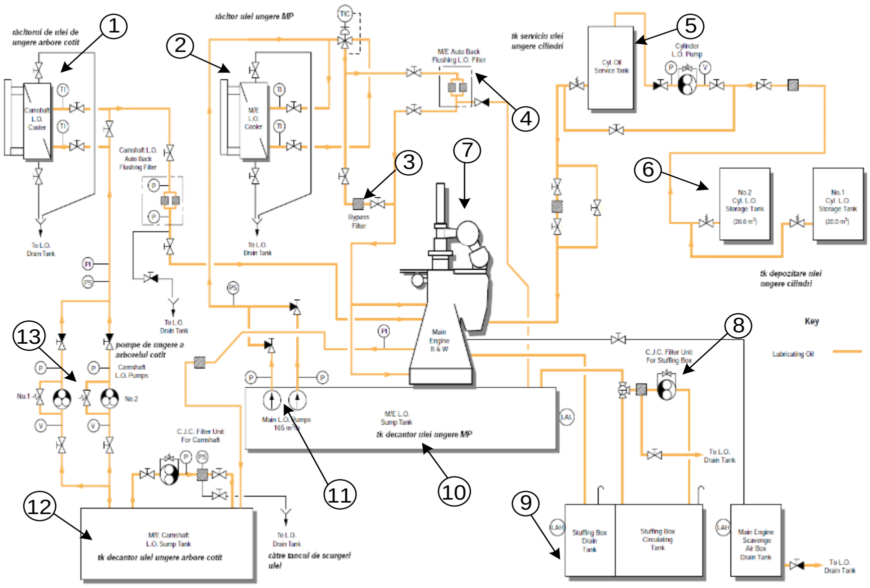

Figure.5. MAN B&W 5S 50 MC lubricating oil system.

2. DETERMINATION OF ENERGY QUANTITY NECESSARY FOR LUBRICATION OF A NAVAL ENGINE

We chose for exemplification the following engines: SULZER 5RT-flex 58T-B, 8550 MCE and RTA 84(4).

Starting from the following SULZER 5RT-flex 58T-B characteristics and measured values:

- Pe = 10900 kW - effective power engine;
- n = 100 rot/min - engine speed;
- c_e = 0,170 kg/kWh - specific fuel consumption;
- $\dot{m}_{am}$ = 274 m^3/h - seawater pump flow;
- $\dot{m}_{cu}$ = 82 m^3/h - required lubricating oil cooling water flow;
- $\dot{m}_{rac.ge}$ = 115 m^3/h - pump water flow rate of recovery boilers;
- $\dot{m}_{p.a.d.}$ = 197 m^3/h - freshwater flow pump(closed circuit);
- $\dot{m}_u$ = 155 m^3/h - circulation pump lubricating oil flow;

we can determine the amount of energy introduced into the engine through combustion, $Q_{disp.}$

$$\dot{Q}_{disp} = \frac{P_e \cdot c_e \cdot Q_i}{3600} \quad \text{[KW]}$$

where the fuel low calorific power is:

$$Q_i = 42700 \text{ [kJ/kg]}$$

Performing calculation result:

$$\dot{Q}_{disp} = 21978 \quad \text{[KW]}$$

Knowing the required lubricating oil cooling water flow,

$$\dot{m}_{cu} = 82 \text{ m}^3\text{/h}$$

and the input and output temperatures at the oil cooler, illustrated in figure 6, is calculated the energy flow evacuated by lubricating oil cooling:

$$\dot{Q}_{ru} = \dot{m}_{cu} \cdot c_a \cdot \Delta T_a$$

$$\dot{Q}_{ru} = 955 \quad \text{[KW]}$$

In figure 6 is shown schematically the lubricating oil system with the elements that affect the engine energy balance.

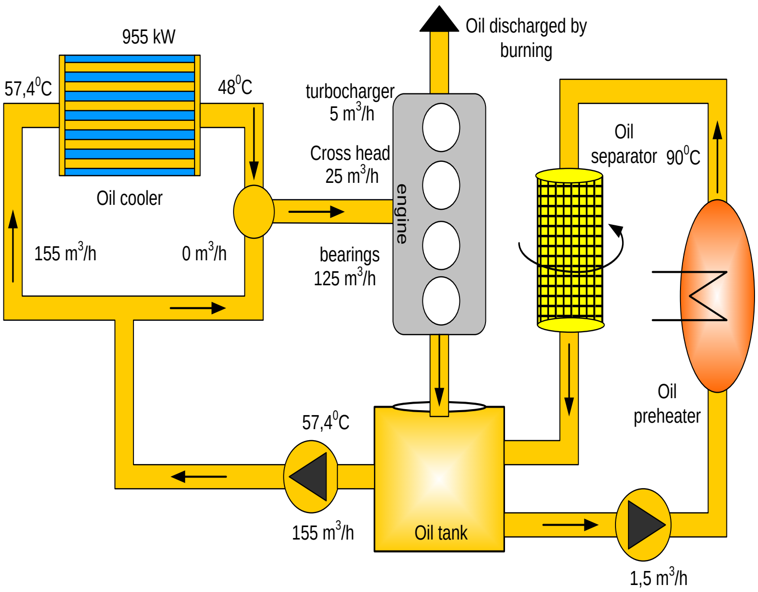

Figure.6. Scheme and functional parameters for lubricating oil system

From technical data of installation, the circulation pump lubricating oil flow is:

$$\dot{m}_u = 155 \quad \text{m}^3\text{/h.;}$$

and the temperature difference between the engine output oil temperature and the engine input oil temperature is ΔT = 10,6 ^{0}C. Therefore follows the energy flow evacuated with lubricating oil.

$$\dot{Q}_u = \dot{m}_u \cdot c_u \cdot \Delta T_u$$

where c_u is the oil specific heat and has the following value: c_u = 2,093 [kJ/kg grd]

$$\dot{Q}_u = 955 \qquad \text{[KW]}$$

Depending on engine power, calculated at certain speeds, exchange of energy between energy consumer and environment can be calculated.

For exemplification, the quantities of energy released by engine cooling, lubrication and recovery boiler were calculated; result are presented graphically in the following figure.

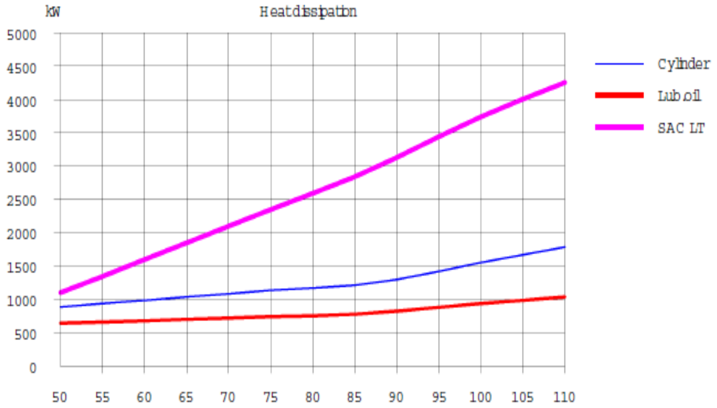

Figure.7. ***The energy loss by engine cooling, lubrication and recovery boiler for the SULZER 5RT-flex 58T-B engine***

The energy flow values evacuated with lubricating oil are presented further:

- Heat flow introduced into the engine:

$$\dot{Q}_{disp} = C_h \cdot Q_i \qquad \text{[KJ/h]}$$

$$\dot{Q}_{disp} = \frac{C_h \cdot Q_i}{3600} \qquad \text{[KW]}$$

	SULZER 5RT-flex 58T-B	8550 MCE	RTA 84(4)
$\dot{Q}_{disp}$ [kW]	21978	17337,74	26854

- Energy flow evacuated with engine mechanism lubricating oil:

$$\dot{Q}_u = \dot{m}_u \cdot c_u \cdot \Delta T \qquad \text{[KW]}$$

$$\rho_u = 900 \qquad \text{[kg/m}^3\text{]}$$

$$\dot{m}_u = \rho_u \cdot \dot{V}_u \cdot \frac{1}{3600} \qquad \text{[Kg/s]}$$

	SULZER 5RT-flex 58T-B	8550 MCE	RTA 84(4)
$\dot{V}_u$ [m^3/h]	155	250	242
$\dot{m}_u$ [kg/s]	43	62,5	60,5
c_u = 2,093 [kJ/kg grd]			
ΔT [^{0}C]	9,4	5,5	4,6
$\dot{Q}_u$ [kW]	955	720	562

- Energy flow evacuated with camshaft lubricating oil:

$$\dot{Q}_{u.ax} = \dot{m}_{u.ax} \cdot c_u \cdot \Delta T \quad \text{[KW]}$$

$$\dot{m}_{u.ax} = \rho_u \cdot \dot{V}_{u.ax} \cdot \frac{1}{3600} \text{ [Kg/s]}$$

$\dot{V}_{u.ax}$ - volume flow of camshaft lubricating oil circulation pump

ρ_u = 900 [kg/m^3]

c_u = 2,093 [kJ/kg degree]

ΔT = 2 [degree]

	SULZER 5RT-flex 58T-B	8550 MCE	RTA 84(4)
$\dot{V}_{u.ax}$ [m^3/h]	-	6,4	-
$\dot{m}_{u.ax}$ [kg/s]	-	1,6	-
$\dot{Q}_{u.ax}$ [kW]	-	6,7	-

3. CONCLUSIONS

To maintain the engine parts temperature within certain limits is necessary to evacuate some energy flows that depend on engine load. Operating characteristics of lubricating oil are influenced by large temperature variations, which require oil cooling and maintaining its low temperature limits.

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