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

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Abstract: *The cooling process has a great influence on the dynamic, economic and durability performance of an engine. In the present paper are presented in the first part some theoretical aspects linked by the cooling installation of the engine and the thermal balance; this are preceded in the second part by an calculus example for the determination of energy quantity necessary for cooling a naval engine choused arbitrary, using his technical documentation.*
Keywords**:** *thermal balance, energy quantity, cooling.*

1. THERMAL BALANCE. COOLING 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:

$$\dot{Q}_{disp} = \dot{Q}_e + \dot{Q}_{ge} + \dot{Q}_{rac} + \dot{Q}_{rez} \quad \textbf{(1)}$$

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:

$$\dot{Q}_{disp} = \dot{Q}_e + \dot{Q}_{ge} + \dot{Q}_{rac.cil} + \dot{Q}_{rac.pist} + \dot{Q}_{rac.inj} + \dot{Q}_{rac.ulei}\ \dot{Q}_{rez} \quad \textbf{(2)}$$

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);

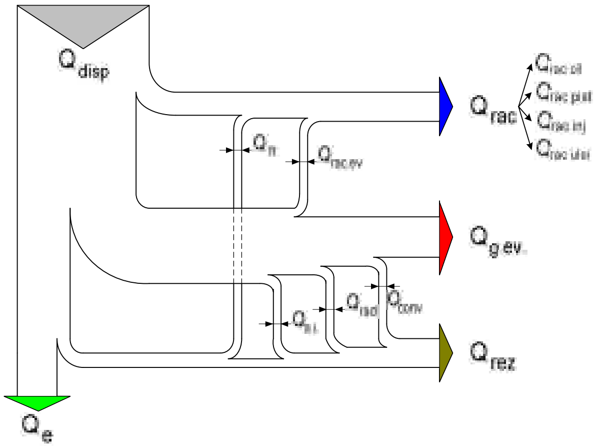

Figure 1: Heat balance diagram.

In percent the energy balance equation becomes:

$$q_e + q_{ge} + q_{rac} + q_{rac.ulei} + q_{rez} = 100[\%] \quad \textbf{(3)}$$

Where:

Table 1:

$q_e = \frac{\dot{Q}_e}{\dot{Q}_{disp}} \cdot 100[\%]$	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]	

Engine cooling is required to provide certain temperatures for mobile and fixed parts, and thus, to create better conditions for lubrication, to maintain normal clearance between piston and cylinder, spindles and bearings.

Marine engine cooling system represents all aggregates and devices that provide forced evacuation through walls for a quantity of heat developed in the engine cylinders, during combustion.

From thermal balance diagram analysis, it follows that the increase of the actual efficiency is possible by reducing the losses or by recovering some energy flows.

For closed circuit cooling system, the cooling water temperature is located between 75…85^{0}C, this fact has a favorable influence in the engine cylinder transformation process and determines the increasing of relative heat flow that can be recovered. The closed cooling circuit water can be used for the following purposes:

- For seawater desalination plant, as a source of heat;

- For air heating or air conditioning plant used for ship cabins and compartments;
- For recovery boilers to preheat water;
- To produce water for social and domestic facilities.

To increase water temperature in closed cooling circuit, sometimes the installation pressurization is used (4…5 bar), so that, at the output of the engine we will have a water temperature between 110…130°C. In this case, the cycle efficiency is rising. Also, the energy flow that can be recovered from the cooling water is increasing, which leads to an increased overall efficiency of the engine cooling installation.

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

We chose for exemplification the following engines: SULZER 5RT-flex 58T-B, K6SZ90/160A şi 6550MC.
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, $Q_{disp.}$

$$\dot{Q}_{disp} = \frac{P_e \cdot c_e \cdot Q_i}{3600} \quad [KW] \tag{4}$$

Where the fuel low calorific power is:

$$Q_i = 42700 \ [kJ/kg] \tag{5}$$

Performing calculation, result:

$$\dot{Q}_{disp} = 21978 \quad [KW] \tag{6}$$

In figure 4 is shown schematically the lubricating oil system with the elements that affect the engine energy balance.

The cylinders cooling degree, and the rational organization of the cooling process has a great influence of the dynamic, economic and durability performance for internal combustion engine. Fresh fluid contact with hot walls of the cylinder reduces the degree of filling, instead, a cylinder walls too low temperature increases heat loss and degreases the indicated efficiency.

Also, the engine parts temperature has an influence on the mechanical losses. If the cooling fluid circuit is not rationally organized, local temperature increases may occur; this leads to cracks in the cylinder head, in the engine block or piston and valves burning. Both high temperature and low temperature, oil film loses its consistency; in the first case by reducing the viscosity, and in the second case because of oil dilution with heavy fuel fractions, condensed on the cylinder mirror. In both cases, the parts wear is increasing due to friction and the engine durability is reduced. Insufficient cooling or misusage organization of the cooling fluid circuit can lead to local temperature increases which will produce local burns, cracks, deformations or excessive wear rates. Also, the excessive cooling has some adverse effects as:

- negative influences on the energy balance;
- increased wear (due to degradation of lubricating oil qualities, especially);
- induction of thermomecanical stress, that generates cracks, in excessively cooled parts.

It is therefore necessary to determine an optimum temperature, for each prticular engine.

Trends regarding the thermal regime, are different. We can mention the experiments on the use of heat-resistant materials (ceramics); reducing the percentage of energy discharged by the cooling fluid. For small and medium power marine engines are used cooling systems consisting of one closed circuit – that provide engine cooling – and an open circuit – which provide the cooling of the close circuit water. For slow engines, with high power, besides the open circuit, more closed circuits are used.

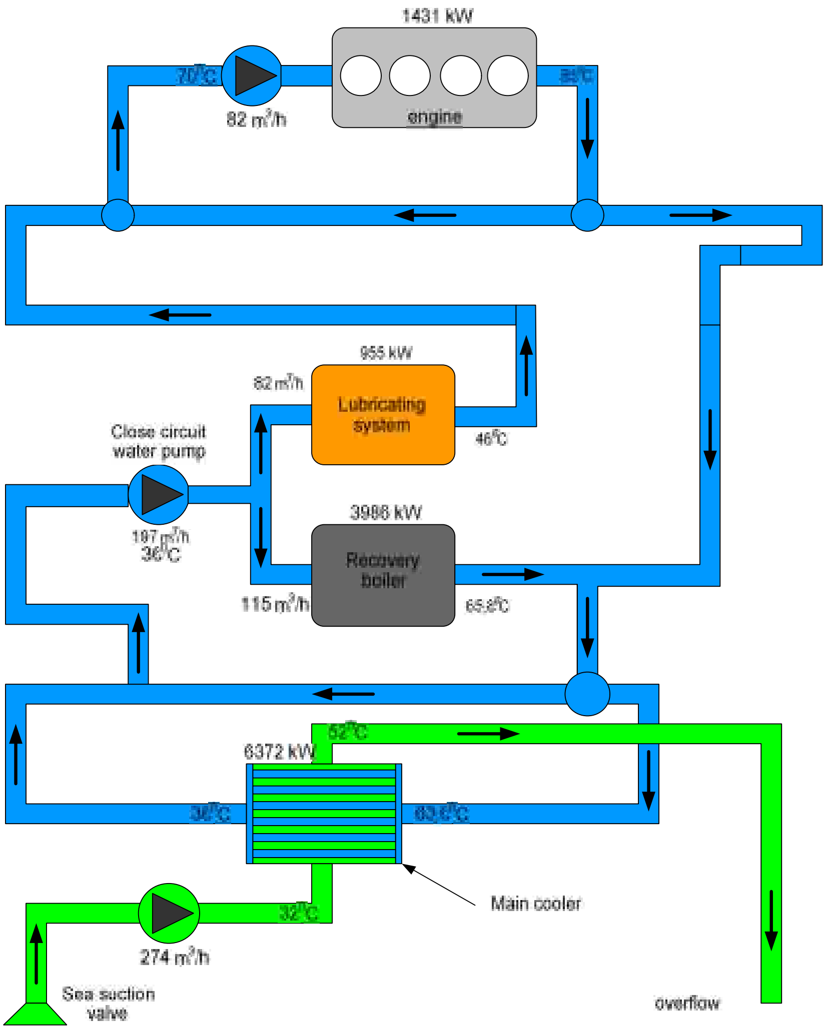

Figure 4: Scheme and functional parameters for cooling system

Energy flow evacuated by cooling water is:

$$\dot{Q}_{rac} = \dot{m}_{am} \cdot c_{am} \cdot \Delta T_{am} \quad \textbf{(7)}$$

where water specific heat is:

$c_{am} = 4{,}186$ [kJ/kg^{0}C] **(8)**

result:

$\dot{Q}_{rac} = 6372$ [kW] **(9)**

Knowing that the energy flow evacuated by lubricating oil is taken by cooling water, we can verify if the calculus results for the energy flow evacuated by cooling water corresponds with the percents of energy balance equation.

We know that:

$q_{ar} = 10 \ldots 25$; [%] **(10)**

$q_u = 3 \ldots 7$; [%] **(11)**

and

$$\frac{\dot{Q}_{rac}}{\dot{Q}_{disp}} \cdot 100\% = 28{,}9\% \quad \textbf{(12)}$$

We can see that the calculated value is between the limits.

Energy flows are influenced by engine load and environment conditions.

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

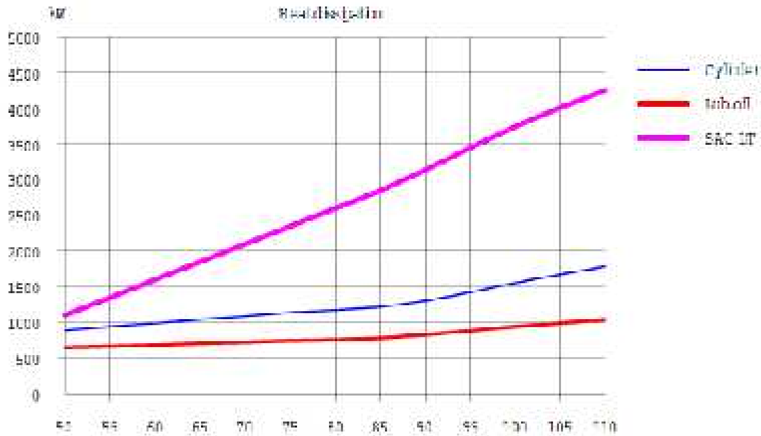

Figure 6. The energy loss by engine cooling, lubrication and recovery boiler for the SULZER 5RT-flex 58T-B engine

The energy flow values evacuated with cooling water are presented further:

- Heat flow introduced into the engine:

$$\dot{Q}_{disp} = C_h \cdot Q_i \qquad \text{[KJ/h]} \tag{13}$$

$$\dot{Q}_{disp} = \frac{C_h \cdot Q_i}{3600} \qquad \text{[KW]} \tag{14}$$

	SULZER 5RT-flex 58T-B	K6SZ90/ 160A	6550MC
$\dot{Q}_{disp}$ [kW]	21978	31751,47	16223,2

- Heat flow evacuated with cylinders cooling water:

$$\dot{Q}_{rac.cil} = \dot{m}_{a.cil} \cdot c_a \cdot \Delta T \qquad \text{[kW]} \tag{15}$$

$\dot{m}_{a.cil}$ - pump water flow rate [kg/s] **(16)**

$c_a = 4{,}186$ - water specific heat [kJ/kg ^{0}C] **(17)**

$\Delta T = 15^0$C – temperature difference [^{0}C] **(18)**

	SULZER 5RT-flex 58T-B	K6SZ90/ 160A	6550MC
$\dot{V}_p$ [m^3/h]	82	275	56
$\dot{m}_{a.cil}$ [kg/s]	22,7	76,39	15,56
$\dot{Q}_{rac.cil}$ [kW]	1431	4796,53	977

- Heat flow evacuated with pistons cooling water:

$$\dot{Q}_{rac.pist} = \dot{m}_{a.pist} \cdot c_a \cdot \Delta T \qquad \text{[kW]} \tag{19}$$

$\dot{m}_{a.pist}$ - Pump water flow rate [kg/s] **(20)**

$c_a = 4{,}186$ - water specific heat [kJ/kg^{0}C]

ΔT = 10^0C - temperature difference [^{0}C] **(21)**

	SULZER 5RT-flex 58T-B	K6SZ90/ 160A	6550MC
$\dot{V}_p$ [m^3/h]	*	200	*
$\dot{m}_{a.pist}$ [kg/s]	*	55,55	*
$\dot{Q}_{rac.pist}$ [kW]	*	2325	*
* - piston cooling is made by lubrication oil			

- Heat flow evacuated with injection nozzles cooling water:

$\dot{Q}_{rac.inj} = \dot{m}_{a.inj} \cdot c_a \cdot \Delta T$ [kW] **(22)**

$\dot{m}_{a.inj} = \rho_a \cdot \dot{V}_{a.inj} \cdot \frac{1}{3600}$ [kg/s] **(23)**

c_a = 4,186- water specific heat [kJ/kg grd]

ρ_u = 1000 [kg/m^3] **(24)**

ΔT = 15^0C - temperature difference [^{0}C] **(25)**

	SULZER 5RT-flex 58T-B	K6SZ90/ 160A	6550MC
$\dot{V}_{a.inj}$ [m^3/h]	-	18	-
$\dot{m}_{a.inj}$ [kg/s]	-	5	-
$Q_{rac.inj}$ [kW]	-	313,95	-

3. CONCLUSION

Engine cooling provides certain temperatures of moving parts, which are made conditions for an optimal lubrication, maintain normal clearances between piston and cylinder, and protect some parts whose temperatures can reach values that affect the engine parts material.

Rational organization of the cooling process has a significantly influence to dynamic, economic and durability performance of the engine.

To prevent insufficient or excessive cooling – having a disastrous impact on engine operation – a great importance is attaches for cooling system design and calculation.

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