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ABOUT THE STUDY OF ENERGY'S FLOW FROM ENERGETICALLY NAVAL SYSTEMS

Levent ALI[1]
Anastase PRUIU[2]
Beazit ALI[3]
Daniel MĂRĂŞESCU[4]
[1]PhD attendee Eng. Military Technical Academy
[2]Professor PhD Eng., Marine Engineering and Naval Weapons Department
[3]Professor PhD Eng., Marine Engineering and Naval Weapons Department
[4]PhD attendee Eng., Marine Engineering and Naval Weapons Department

Abstract*: In this paper are analyzed energy's flow in energetically naval systems and their correlation with the effective power of thermal machines. The possibilities for secondary energy flows recovering and their impact on the marine environment with possibilities to reduce pollution*

1. INTRODUCERE

In operating the plant or energy systems, a special attention must be given to mass flows and energy flows because they are main characteristic for a specific physical structure (sections flow of piping, sections of flow through thermal machines and working, sections of energetically exchanges, the components of the energy fluids, etc.).

2. MASS FLOWS

$\dot{m}_{CH}\ [\frac{Kg_{cb}}{h}]$ - fuel consumption
$\dot{m}_{AH}\ [\frac{Kg_{aer}}{h}]$ - air flow
$\dot{m}_{AHSG}\ [\frac{Kg_{aer}}{h}]$ - air flow for gas exchange
$\dot{m}_{AHARD}\ [\frac{Kg_{aer}}{h}]$ - air flow for combustion
$\dot{m}_{GH}\ [\frac{Kg_{gaze}}{h}]$ - gas exhaust flow

$$\dot{m}_{CH} = c_e \cdot P_e\ [\frac{Kg_{cb}}{h}] \quad [1]$$

$c_e\left[\frac{Kg_{cb}}{kWh}\right]$– effective specific fuel consumption
P_e [kW] – effective power

$$\dot{m}_{AH} = \dot{m}_{CH} \cdot \alpha \cdot m_{aert}\ [\frac{Kg_{aer}}{h}] \quad [2]$$

α - excess air coefficient
α_{SG} - excess air coefficient for gas exchange
α_{ARD} - excess air coefficient for combustion

$$\dot{m}_{AHSG} = \dot{m}_{CH} \cdot \alpha_{SG} \cdot m_{aert}\ [\frac{Kg_{aer}}{h}] \quad [3]$$

$$\dot{m}_{AHSG} = \dot{m}_{CH} \cdot \alpha_{ARD} \cdot m_{aert}\ [\frac{Kg_{aer}}{h}] \quad [4]$$

m_{aert} [Kg_{aer}/Kg_{cb}] – minimum theoretical air mass for a full combustion a kilogram of fuel

$$\dot{m}_{GH} = \dot{m}_{CH} + m_{aert}\ [\frac{Kg_{gaze}}{h}] \quad [5]$$

$$\dot{m}_{GH} = \dot{m}_{CH} \cdot [1 + \alpha_{SG} \cdot m_{aert}]\ [\frac{Kg_{gaze}}{h}] \quad [6]$$

Specific units
$c_e\left[\frac{Kg_{cb}}{kWh}\right]$– effective specific fuel consumption
$d_{asg}\left[\frac{Kg_{aer}}{kWh}\right]$– specific air flow for gas exchange

$$d_{asg} = c_e \cdot \alpha_{SG} \cdot m_{aert}\ [\frac{Kg_{aer}}{h}] \quad [7]$$

$d_{aard}\left[\frac{Kg_{aer}}{kWh}\right]$– specific air flow for combustion

$$d_{aard} = c_e \cdot \alpha_{ARD} \cdot m_{aert}\ [\frac{Kg_{aer}}{h}] \quad [8]$$

D_g[Kg_{gaze}/kWh] – specific gas flow

$$d_g = c_e + d_{asg}\ [\frac{Kg_{gazer}}{h}] \quad [9]$$

$$d_g = c_e \cdot [1 + \alpha_{SG} \cdot m_{aert}]\ [\frac{Kg_{gaze}}{h}] \quad [10]$$

3. ENERGY FLOWS

3.1. **Energy flow available**

$$\dot{Q}_d = \frac{\dot{m}_{CH} \cdot Q_i}{3600}\ [kW] \quad [11]$$

Q_i [kJ/Kg_{cb}] - lower calorific power

3.2. **Effective power**

$$P_e = \eta_e \cdot \dot{Q}_d\ [kW] \quad [12]$$

$$\eta_e = \frac{P_e}{\dot{Q}_d} = \eta_i \cdot \eta_e \quad [13]$$

η_e – effective efficiency
η_i – medium indicated efficiency (each cylinder have an indicated efficiency)

$$\eta_m = \frac{P_e}{P_i} = \frac{c_i}{c_e} = \frac{L_e}{L_i} \quad [14]$$

η_m –mechanical efficiency
P_i [kW] – indicated power

$$P_i = \sum P_{icil}\ [kW] \quad [15]$$

P_{icil} [kW] – indicated power for each cylinder
$c_j\left[\frac{Kg_{cb}}{kWh}\right]$ – indicated specific fuel consumption
L_e [kNm] – effectively machine work
L_i [kNm] – indicated machine work

Observations: if the effective operating power is low, or the engine is operating at no-load running must be used indicated specific fuel consumption.

3.3 **Operating Effective Power**

P_{en} [kW] – nominal effective power (the engine have the nominal rpm, in environmental standard condition with fuel Q_i = 42700 [kJ/Kg_{cb}])
P_{eexp} [kW] – operating effective power
P_{eexp} = 0 [kW] – no-load for engine

$$P_{eexpmax} = 1.1 \times P_{en}\ [kW] \quad [16]$$

$P_{eexpmax}$ – maximum operating effective power

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$$K_p = P_{eexp}/P_{en} \qquad [17]$$

K_p - loading factor or power ratio;
$K_p = 0$ – for no-load;
$K_p = 1$ – for nominal load;
$K_p = 1.1$ – for maximum load

According with [B4] for ship propulsion the following engine types are used:

- Slow speed two stroke diesel engines (50 – 300 RPM)
- Medium speed four stroke diesel engines (300 – 1000 RPM)
- Gas turbines (very high RPM > 5000)

Approximate/typical SFOC values for different engine types (at 42.7 MJ/kg oil)

Slow speed engines:	155 – 175 [g/kWh]
Medium speed engines:	175 – 200 [g/kWh]
High speed engines:	195 – 225 [g/kWh]
Gas turbines:	240 – 300[g/kWh]

3.4**Energy flows for turbocharger**

Available energetic flow discharged from cylinders with exhaust gas.

$$\dot{Q}_g = \frac{\dot{m}_{GH} \cdot c_{PG} \cdot (t_{gev} - t_{0ref})}{3600}\ [kW] \qquad [18]$$

c_{PG} [kJ/Kg$_G$·°C] – specific heat of exhaust gas

$$c_{PG} = \sum c_{PGi} \cdot g_i\ \left[\frac{kJ}{Kg_G{\cdot}°C}\right] \qquad [19]$$

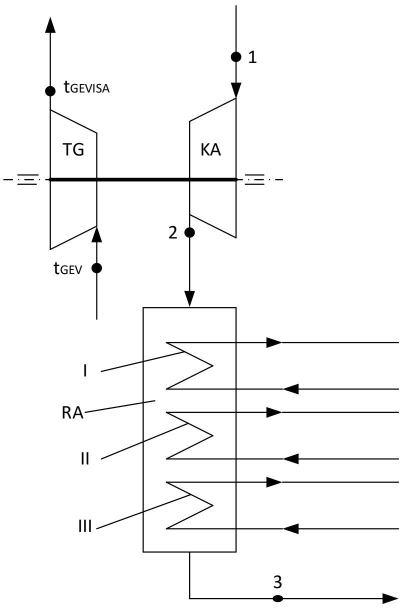
c_{PGj} [kJ/Kg$_G$·°C] – specific heat for each component of exhaust gas

$g_j = \frac{\dot{m}_{gj}}{\dot{m}_g}$ – mass composition of each component of exhaust gas

$\dot{m}_{gj}$ - flow for each component of exhaust gas

t_{gev} [°C] – medium temperature for outlet the cylinder of exhaust gas

t_{0ref} [°C] – standard or reference environmental air temperature



TG – gas turbine from turbocharger
KA – air compressor from turbocharger
RA - air cooler
1 – air compressor suction
2 – air compressor discharge
3 – outlet air from scavenge air cooler
I – cooler with fresh water (preheat system stage from auxiliary boiler)
II - cooler with fresh water (stage from fresh water system)
III – cooler with sea water – oversize cooler - stage adjustment

The ambient reference conditions according to IACS URM28 are the regular machinery space room temperature 45 °C, ambient pressure 1,000 mbar absolute and air humidity 60 %.

	1	2	3
t [°C]	45	150	60
T [K]	318	423	333
p [bar]	1	3	3
p [kN/m^2]	100	300	300
ρ [Kg$_{aer}$/m^3]	1.099	2.48	3.49

$T_2 = T_1 \cdot \left(\frac{p_2}{p_1}\right)^{\frac{n_s-1}{n_s}}$ $[K]$; n_s – politropic coefficient; p_2 - required for turbocharger;

Ex: p_2 = 3 bar; $n_s = 1.35$;

$T_2 = 318 \cdot \left(\frac{3}{1}\right)^{\frac{1.35-1}{1.35}} = 423\ [K]$; T_3 – depended with temperature suction, discharge pressure and relative humidity φ [%]

$T_3 = T_3 + [3 \div 20]\ [K]$ - to avoid a massive condensation of water vapor from air

$\rho = \frac{p}{RT}$; R = 0.286 [kJ/KgK]

Energetic flow discharged from gas turbine

$$\dot{Q}_{gTG} = \frac{\dot{m}_{GH} \cdot c_{PG} \cdot (t_{gev} - t_{GEVSA})}{3600}\ [kW] \qquad [20]$$

$\Delta t_{GTG} = t_{GEV} - t_{GEVSA}\ [°C]$ – temperature decrees in gas turbine

Energetic flow of air receives in air compressor

$$\dot{Q}_{AKA} = \frac{\dot{m}_{AHSC} \cdot c_{PA} \cdot (t_{ref} - t_0)}{3600}\ [kW] \qquad [21]$$

Effective power of gas turbine is equal by compressor driven power

$$P_{eTG} = P_{antKA}\ [kW] \qquad [22]$$

Results:

$$\dot{Q}_{gTG} \cdot \eta_{TG} = \frac{\dot{Q}_{AKA}}{\eta_{KA}}\ [kW] \qquad [23]$$

the resulting:

$$\Delta t_{GTG} = \frac{1}{\eta_{TG} \cdot \eta_{KA}} \cdot \frac{\dot{m}_{AHSG}}{\dot{m}_{GH}} \cdot \frac{c_{PA}}{c_{PG}} \cdot \Delta t_{AKA}\ [°C] \qquad [24]$$

or

$$\Delta t_{GTG} = \frac{1}{\eta_{TG} \cdot \eta_{KA}} \cdot \frac{d_{ASG}}{d_G} \cdot \frac{c_{PA}}{c_{PG}} \cdot \Delta t_{AKA}\ [°C] \qquad [25]$$

Numerical application

$\eta_{TG} = 0.75 \div 0.85$ – gas turbine efficiency
$\eta_{KA} = 0.75 \div 0.85$ – air compressor efficiency

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$d_{ASG} = 0.18 \cdot 3 \cdot 13.5 = 7.29 \left[\frac{Kg_{aer}}{kWh}\right]$;

$d_G = 7.47 \left[\frac{Kg_{gaze}}{kWh}\right]$; $c_{PA} = 1 \left[\frac{kJ}{Kg \cdot {}^\circ C}\right]$; $c_{PG} = 1.2 \left[\frac{kJ}{Kg \cdot {}^\circ C}\right]$;

$\Delta t_{GTG} = \frac{1}{0.8 \cdot 0.85} \cdot \frac{7.29}{7.47} \cdot \frac{1}{1.2} \cdot 10^5 = 126\ [{}^\circ C]$ – this value it is verified with naval diesel engine

Observations: the operating cases in which recovery boiler does not work, the temperature control stage with seawater, must be discharge an energy flow to allows a temperature decrees like $\Delta t_{AR} \cong 90\ {}^\circ C$.

The energy flow that will be transferred to seawater

$$\dot{Q}_{AR} = \frac{m_{AHSC} \cdot c_{PA} \cdot \Delta t_{AR}}{3600}\ [kW] \qquad [26]$$

4. MASS FLOW OF CARBO DIOXIDE

By the elemental analysis of fuel, known carbon content:

$c = 0.85 \div 0.87 \left[\frac{KgC}{Kgcb}\right]$ – for liquid fuel

Combustion:

$$C + O_2 + CO_2 + Q_c \qquad [27]$$

Q_c – the energy obtained by combustion

$$\left\{\begin{array}{c} 1\ Kmol\ C + 1\ Kmol\ O_2 \rightarrow 1\ Kmol\ CO_2 \\ 12\ Kg\ C + 32\ Kg\ O_2 = 44\ Kg\ CO_2 \\ c\ Kg\ C + \frac{32}{12} c\ Kg\ O_2 = \frac{44}{12} c\ Kg\ CO_2 \end{array}\right\} \qquad [28]$$

Results:

$$\dot{m}_{CO2} = \frac{44}{12} \cdot c \cdot \dot{m}_{CH} \left[\frac{Kg_{CO2}}{h}\right] \qquad [29]$$

specific mass of carbo dioxide

or

$$d_{CO2} = \frac{44}{12} \cdot c \cdot c_e \left[\frac{Kg_{CO2}}{kWh}\right] \qquad [30]$$

specific flow of carbo dioxide

Numerical application

$d_{CO2} = \frac{44}{12} \cdot 0.86 \cdot 0.18 = 0.57 \left[\frac{Kg_{CO2}}{kWh}\right]$

For a 35000 [dwt] vessel; $W_n = 15$ [Nd]; P_e=10000 [kW];

$\dot{m}_{CO2} = d_{CO2} \cdot P_e = 0.57 \cdot 10000 = 5700 \left[\frac{Kg_{CO2}}{h}\right]$

$d_{CO2} = \frac{\dot{m}_{CO2}}{T_n \cdot W_n} = \frac{5700}{35000 \cdot 15} = 0.01086 \left[\frac{Kg_{CO2}}{t \cdot Mn}\right] = 10.86 \left[\frac{g_{CO2}}{t \cdot Mn}\right] = 5.86 \left[\frac{g_{CO2}}{t \cdot Km}\right]$

[B1]Based on a HFO fuel saving of 3,555 tons per year (with 3% sulphur content), the installation of a WHRS on a large container ship, will save the environment for the following emission amounts:

CO2 emission saving per year: 11,260 tons
NOx emission saving per year: 319 tons
SOx emission saving per year: 214 tons
Particulates saving per year: 29 tons

[B2]The objective of regulations introduced by the International Maritime Organization (IMO), the European Union (EU), the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) is to reduce the contribution shipping makes to global and local emissions.

Ship designers, owners and operators have three general routes to achieve SOx regulatory compliance:

- Use low sulfur residual or distillate marine fuels in existing machinery,
- Install new machinery (or convert existing machinery where possible) designed to operate on an inherently low sulfur alternative fuel, such as liquefyor natural gas (LNG),
- Install an exhaust gas cleaning (EGC) after treatment system.

Fuel Oils Sulfur Limits

	GLOBAL	ECA
Initial limits	4.5 %	1.5 %
1 July 2010	4.5 %	1,0 %
1 July 2012	3.5 %	1.0 %
1 July 2015	3.5 %	0.1 %
1 July 2020	0.5 %	0.1 %

CONCLUSIONS

a. Determining the mass flows by choosing the flow rate of fluid, allow thepiping designed and circulation sections of thermal machines;

b. On the main flow sections, respectively on the energy flows exchangers must be installed thermometers order to allow proper adjustment of the energy system and performing balance energy;

c. Allows the high rate pollution of ambient environmental components and the rate of ageing for different parts of the thermal machine are determinate by the composition of exhaust gases from thermal machines

d. Operation of energy systems must respect fully statutory provisions concerning for reduction of pollution of the marine environment for the respective navigation areas;

e. Adjusting the energy flows take into account the navigation conditions being imposed by safety crew, vessel and cargo.

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