

THERMAL BALANCE ANALYSIS OF THE MAN B&W 6S50ME-C MARINE DIESEL ENGINE

Andrei Răzvan TUDOR¹, Bogdan Mihai VÂRLAN¹

¹Constanta Maritime University, Faculty of Naval Electro-Mechanics, 104 Mircea cel Batran Street, 900663, Constanta, Romania, ORCID ID 0009-0004-3328-3825, e-mail address: trazvan72@gmail.com

Abstract : This study investigates the thermal balance of a MAN B&W 6S50ME-C two-stroke marine engine operating as the main propulsion system of a 40,000 DWT Oil/Chemical Tanker. Within the current maritime context, where fuel efficiency and emission reduction have become major priorities, a clear understanding of how thermal energy is distributed inside large marine engines is essential for performance optimization and energy recovery solutions. The objective of the paper is to determine how the energy released during fuel combustion is converted into useful mechanical work and how it is dissipated through various loss mechanisms. The analysis is based on a detailed thermal balance calculation using real operational data, such as effective engine power, specific fuel consumption, cooling fluid flow rates, lubrication oil parameters, and exhaust gas temperatures. The applied methodology consists of thermal balance calculations based on established thermodynamic relations, expressed in absolute, relative and percentage terms. The results indicate that approximately 40.98% of total thermal energy supplied by the fuel is transformed into effective mechanical output. A significant part of the remaining energy is lost through exhaust gases, accounting for about 29.37%, while cooling systems represent approximately 22.32% of total losses. Additional minor losses, including radiation and mechanical friction represent around 7.04%. The analysis confirms that exhaust gas losses constitute the dominant source of recoverable thermal energy. Consequently, the study highlights the importance of exhaust heat recovery systems as an effective means to improve overall engine efficiency, reduce fuel consumption, and support more sustainable marine propulsion operations.

Key words : Exhaust gas losses, Marine diesel engine, MAN B&W 6S50ME-C, Thermal balance, Waste heat recovery.

1. INTRODUCTION

Internal combustion engines convert the energy released during fuel combustion into mechanical work. In practice, only part of this energy is effectively transformed into useful output, while the remaining amount is dissipated toward the cold source. For this reason, engine operation is characterized by a specific thermal efficiency. The distribution of energy within an internal combustion engine can be described in a comprehensive manner by means of the thermal balance, which is obtained through thermal calculations and is commonly used to evaluate energy losses and the potential for residual heat recovery.

Depending on the form of expression, the thermal balance can be presented as:

- hourly, when the energy terms are expressed in [kJ/h];

- energetic, when the terms are given in [kJ/kWh];
- percentage, when the results are expressed as percentages.

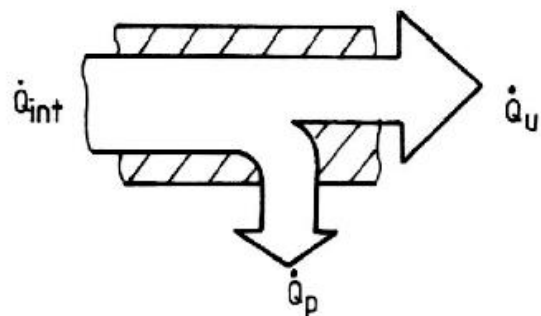


Figure 1 Energy distribution within a transformation process

2. ENGINE DESCRIPTION AND MAIN TECHNICAL DATA

The engine analysed in this study is a DOOSAN–MAN B&W 6S50ME-C9.5-TII, manufactured by DOOSAN ENGINE Co., Ltd., in compliance with the requirements of the Registro Italiano Navale (RINA) classification society, applicable at the time of contract conclusion between MAN Diesel & Turbo and the Korean engine builder.

- Engine application: Main propulsion engine for a 40,000 DWT oil tanker;
- Engine type: Two-stroke, medium-speed, turbocharged, reversible marine diesel engine, coupled to a fixed-pitch propeller;
- Number of cylinders: $i = 6$, in-line configuration;
- Cylinder bore: $D = 0.500$ m;
- Piston stroke: $S = 2.214$ m;
- Engine power: $P_{en} = 6,480$ kW (8,812 BHP).

3. THERMAL BALANCE METHODOLOGY

To describe the distribution of energy resulting from the combustion process, the energy balance of the marine engine is expressed in mathematical form by accounting for the useful mechanical output and the main heat loss components.

In absolute terms, the energy balance relation of a marine engine is given by:

$$Q_{tot} = Q_u + Q_{cl} + Q_{gl} + Q_{dl} \text{ [kJ/h]}, \quad (1)$$

where:

1. Q_{tot} - the energy flow resulting from fuel combustion and calculated using the following relation:

$$Q_{tot} = c_e \cdot P_e \cdot Q_i \text{ kJ/h} \quad (2)$$

$$Q_{tot} = 5.692 \cdot 10^7 \text{ kJ/h}$$

where: $c_e = 0.208 \text{ kg/kWh}$ - effective hourly fuel consumption

$Q_i = 4.229 \cdot 10^4 \text{ kJ}$ - lower heating value of the fuel

$P_e = 6480 \text{ KW}$ - effective engine power

2. Q_u - the useful heat flow (corresponding to the useful mechanical work) and calculated using the following relation:

$$Q_u = 3600 \cdot P_e \quad (3)$$

$$Q_u = 2.333 \cdot 10^7 \text{ kJ/h}$$

3. Q_{pr} - heat flow lost through the cooling fluids of the engine components
4. Q_{pg} - heat flow lost through the exhaust gases discharged from the engine
5. Q_{pd} - miscellaneous heat losses that cannot be directly evaluated

By relating equation (1) to the effective engine power, the energy balance expressed in relative terms is obtained:

$$q_{tot} = q_u + q_{pr} + q_{pg} + q_{pd} \text{ [kJ/kWh]} \quad (4)$$

From this relation, the percentage form of the thermal balance can be derived:

$$100 = q_u + q_{pr} + q_{pg} + q_{pd} \quad (5)$$

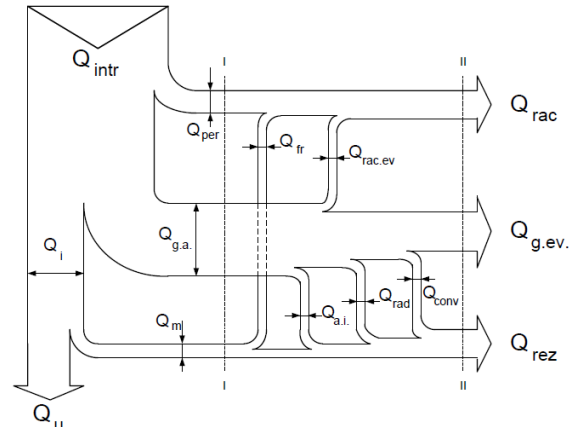


Figure 2 Energy balance diagram of the MAN B&W 6S50ME-C engine

A clear graphical representation of the energy balance of a marine engine is provided by the diagram shown in Figure 2. Within this energy balance diagram, the following energy flows cross the balance boundary:

- ✓ the total thermal energy input supplied by the fuel;
- ✓ the useful energy flow corresponding to the effective power developed by the engine;
- ✓ the heat flow lost through the cooling fluids, which is given by:

$$Q_{pr} = Q_{cc} + Q_{pc} + Q_{ras} + Q_{injc} + Q_{oc} \quad (6)$$

Where:

1. Q_{cc} - the heat flow removed from the engine through the cooling water of the cylinders and the turbocharger, which depends on the cooling water flow rate \dot{m}_{rc} and on the temperature difference between the outlet cooling water temperature t_{rc2} and the inlet cooling water temperature t_{rc1} , and is calculated using the following relation:

$$Q_{cc} = \dot{m}_{rc} \cdot c_a \cdot (t_{rc2} - t_{rc1}) \quad (7)$$

$$Q_{cc} = 8.19 \cdot 10^6 \text{ kJ/h}$$

$$\text{Where: } \dot{m}_{cc} = \rho_{rc} \cdot G_{rc} \quad (8)$$

$$\dot{m}_{cc} = 150000 \text{ kg/h}$$

$$c_a = 4.2 \text{ kJ/kW} \cdot K$$

$$t_{cc2} = 83 \text{ C}$$

$$t_{cc1} = 75 \text{ C}$$

2. Q_{cp} - the heat flow removed through piston cooling water:

$$Q_{cp} = \dot{m}_{cp} \cdot c_{cp} \cdot (t_{cp2} - t_{cp1}) \quad (8)$$

$$Q_{cp} = 8.239 \cdot 10^5 \text{ [kJ/h]}$$

$$\text{Where: } \dot{m}_{cp} = \rho_{cp} \cdot G_{cp} \quad (10)$$

$$\dot{m}_{cp} = 422500 \text{ kg/h}$$

$$c_a = 4.2 \text{ kJ/kW} \cdot K$$

$$t_{cp2} = 55 \text{ C}$$

$$t_{cp1} = 45 \text{ C}$$

3. Q_{injc} - the heat flow removed from the engine through the injector cooling fluid (diesel fuel), which depends on the cooling fluid flow rate \dot{m}_{rinjc} , its specific heat c_{fl} , and the temperature difference between the inlet and outlet of the cooling fluid Δt_{inj} , and is calculated using the following relation:

$$Q_{injc} = \dot{m}_{injc} \cdot c_{fl} \cdot \Delta t_{inj} \quad (11)$$

$$Q_{injc} = 1.68 \cdot 10^5 \text{ kJ/h}$$

$$\text{Where: } \dot{m}_{injc} = \rho_{injc} \cdot G_{injc} \quad (12)$$

$$\dot{m}_{injc} = 4200 \text{ kg/h}$$

$$c_{fl} = 2 \text{ kJ/kW} \cdot K$$

$$\Delta t_{inj} = 20 \text{ C.}$$

4. Q_{oc} - the heat flow removed from the engine through the lubricating oil, depending on the oil flow rate \dot{m}_{ulei} and the oil temperatures at the inlet t_{u1} and outlet t_{u2} , and calculated using the following relation:

$$Q_{oc} = \dot{m}_o \cdot c_o \cdot (t_{o2} - t_{o1}) \quad (13)$$

$$Q_{oc} = 3.69 \cdot 10^6 \text{ kJ/h}$$

where:

$$\dot{m}_o = \rho_o \cdot G_o \quad (14)$$

$$\dot{m}_o = 4200 \text{ kg/h}$$

$$c_{fl} = 2 \text{ kJ/kW} \cdot K$$

$$t_{o2} = 55 \text{ C}$$

$$t_{o1} = 45 \text{ C}$$

5. Q_{egl} - the heat flow lost through the exhaust gases discharged from the engine, which can be expressed by the following relation:

$$Q_{egl} = c_e \cdot P_e \cdot [v''_{ga} \cdot (a'_{am} + b'_{am} \cdot T_{ev}) \cdot T_{ev} - L \cdot (a_{aer} + b_{aer} \cdot T_{aer}) \cdot T_{aer}] \quad (15)$$

$$Q_{egl} = 1.672 \cdot 10^7 \text{ kJ/h}$$

$$T_{eg} = T_b \cdot \left(\frac{p_a}{p_b}\right)^{\frac{\kappa-1}{\kappa}} \quad (16)$$

$$T_{eg} = 791.367 \text{ K.}$$

6. Q_{rez} - the heat flow associated with miscellaneous losses that cannot be evaluated by measurements.

$$Q_{rez} = Q_{tot} - (Q_u + Q_{cc} + Q_{cp} + Q_{injc} + Q_{oc} + Q_{egl}) \quad (17)$$

$$Q_{rez} = 4.006 \cdot 10^6 \text{ kJ/h.}$$

As can be observed from the energy balance diagram of the marine engine, the heat flow equivalent to mechanical losses, Q_{mec} , which includes friction losses and the mechanical consumption of the engine auxiliary mechanisms, is partly transferred to the cylinder cooling

water due to piston ring friction, Q_{frs} . Another part, corresponding to bearing friction losses, Q_{fr1} , is transferred to the lubricating oil, while the remaining portion contributes to the miscellaneous loss flow. This includes heat lost by radiation to the surrounding environment, Q_{rad} , heat associated with incomplete combustion, Q_{ain} , as well as the heat equivalent to the kinetic energy of the exhaust gases discharged from the engine, Q_{gcin} .

Relative thermal balance:

$$q'_u = 100 \cdot \frac{Q_u}{Q_{tot}} \quad (18)$$

$$q'_u = 40.981 \%$$

$$q'_{cooling} = 100 \cdot \left(\frac{Q_{cc}}{Q_{tot}} + \frac{Q_{cp}}{Q_{tot}} + \frac{Q_{injc}}{Q_{tot}} + \frac{Q_{oc}}{Q_{tot}}\right) \quad (19)$$

$$q'_{cooling} = 22.32\%$$

$$q'_{egl} = 100 \cdot \frac{Q_{pgev}}{Q_{tot}} \quad (20)$$

$$q'_{egl} = 29.37\%$$

$$q'_{rez} = 100 \cdot \frac{Q_{rez}}{Q_{tot}} \quad (21)$$

$$q'_{rez} = 7.037\%$$

It can be observed that, among the thermal energy losses, the largest share is represented by the losses through the exhaust gases discharged from the engine, which constitute the most significant source of thermal energy and should therefore be the primary target for recovery efforts.

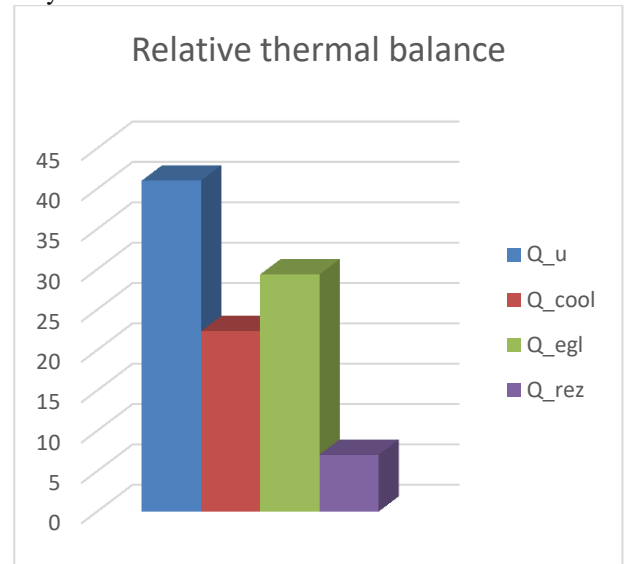


Figure 3. Graphical representation of the relative thermal balance

The graphical representation of the thermal balance highlights the manner in which energy flows are distributed throughout the engine system.



4. CONCLUSIONS

The analysis shows that exhaust gases represent the dominant source of thermal losses, followed by losses

associated with the cooling water and lubricating oil systems. These findings indicate that exhaust gas heat recovery and improved cooling system management offer significant potential for increasing the overall efficiency of marine propulsion plants.

In the context of the ongoing decarbonisation of the maritime industry, a detailed assessment of the thermal balance becomes essential, as it provides a solid basis for identifying energy-saving measures and supporting the development of more efficient and environmentally sustainable propulsion systems.

6. FUNDING

This paper received no external funding.

8. CREDIT authors statement

Conceptualization: T.A.R.

Data curation: T.A.R.

Formal analysis: V.B.M.

Funding acquisition: -

Investigation: T.A.R.

Methodology: T.A.R.

Project administration: T.A.R.

Resources: T.A.R.

Software: T.A.R.

Supervision: V.B.M.

Validation: V.B.M.

Visualization: V.B.M.

Writing – original draft: T.A.R.

Writing – review & editing: V.B.M.

8. REFERENCES

- [1] Buzbuchi, N., Sabău, A., 2006, Procese, caracteristici și supraalimentarea motoarelor navale, Editura Nautica, Constanța.
- [2] MAN Diesel & Turbo, Technical Documentation: MAN B&W ME/ME-C, Copenhagen SV, Denmark, www.mandieselturbo.com.
- [3] MAN Diesel, 2006, Operation Manual – 50-108ME/ME-C, Volume I, Edition 0003, MAN Diesel A/S.
- [4] MAN Energy Solutions, 2021, ME-C Engines Technical Manual – Operation and Maintenance, Copenhagen.
- [5] Ciucur, V.V., Increasing the efficiency of marine energy conversion, *Journal of Marine Technology and Environment*, vol. 2, 2021, 7-10, Nautica publish House, Constanta, Romania.
- [6] LEO TERESA J., NAVARRO EMILIO, RASO MIGUEL A., RODRIGUEZ-CORTIJO JOSE M., COBO JUAN M., The dead state choice in exergy calculations for marine and naval applications, *Journal of Marine Technology and Environment*, vol. 1, 2012, 67-74, Nautica publish House, Constanta, Romania.

