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Energy analysis of ship energy systems – the case of a chemical tanker

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Abstract

Improved understanding of ship energy use can be a crucial part of the process of increasing ship energy efficiency. In this paper, the methodology of energy analysis is applied to ship energy systems in order to showcase the benefits of such methodology. Data from one year of operations of a case study ship were used, together with mechanistic knowledge of ship systems, in order to evaluate the different energy flows. The identification of main producers, consumers and waste flows, allowed by the application of the method, leads to the suggestion of a number of possible improvements guided by the improved knowledge of the ship's energy system.

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Keywords: Shipping; energy analysis; energy efficiency; energy flows; propulsion system

1. Introduction

The shipping industry is currently facing a big challenge. Bunker fuel prices are today 3 to 4 times as high as they were in the 80's [1] and fuel costs are today estimated to account for 43% to 67% of total operating costs depending on vessel type [2], where this figure only accounted for 13% in the 70's [3]. Additionally, stricter environmental regulations will exert an additional leverage to fuel costs [4]. Several solutions have been proposed for addressing this issue [5]. However, it has also been acknowledged that the world fleet is very heterogeneous [6]: what could be cost efficient for a certain series of ships will not be for another. Therefore, a decision-maker who wants to determine a cost effective pathway to increased energy efficiency for his or her fleet needs assessment tools.

This issue has partially been addressed in literature. Thomas et al. [7] and Basurko et al. [8] presented the energy audit of fishing vessels; Shi et al. proposed models for predicting ship fuel consumption in design and off-design conditions [9].

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The aim of this paper is to propose and to apply a methodology to analyze the energy flows of an entire ship with the goal of providing a better understanding of how energy is used on board and where the largest potential for improvement is located.

2. Methodology

This paper presents an application of energy analysis to ship energy systems. A pure analysis and aggregation of measured data (top-down approach), would not provide enough insight of the system under study in this case because of the lack of information about many flows; on the other hand, a pure mechanistic modelling of ship energy system (bottom-up approach) would not allow making use of the large amount of measured data [10],[11] that is available for the ship under study. Therefore, a combined top-down and bottom-up approach was employed in which mechanistic knowledge of the system is used to estimate the energy flows that are not directly measured on board. This method was applied to a case study ship, for which extensive measurements were available, whose main features are provided in Table 1.

Table 1. Ship main features

Ship feature	Value	Unit
Deadweight	47 000	ton
Installed power (Main Engines)	7 700	kW
Installed power (Auxiliary Engines)	1 400	kW
Shaft generator design power	3 200	kW
Exhaust boilers design steam gen.	1 400	kg/h
Auxiliary boilers design steam gen.	28 000	kg/h

Energy demand on board of the case-study vessel is fulfilled by: the main engines (MEs), the auxiliary engines (AEs), and the auxiliary boilers (ABs). In addition, a shaft generator (S/G) is used to convert mechanical energy generated by the MEs to electrical energy, while an exhaust gas boiler (EGB) is used to provide auxiliary heat when the MEs are running. Since providing mobility at sea is the main function of the ship, propulsion is the first, principal energy demand; heating of the high viscosity residual fuel, accommodation and operations of cargo-tank cleaning between one load and another require auxiliary heat; operation of all auxiliary machinery onboard, such as pumps, compressors, navigation equipment and electric motors, finally requires auxiliary power.

Most input data was derived from an on board data logging system. Additional operational data from manual loggings and knowledge of the system based on design information and technical documentation was used for the derivation of the remaining information (see Table 2).

Table 2: Summary of the calculation procedure for the different energy flows

Energy flow	Input	Method
Fuel input to the system	Data Logging	Aggregation of measurements
Propulsion and total auxiliary power need	Data Logging	Aggregation of measurements
Auxiliary heat demand	Data Logging + Design Data	Calculated
Auxiliary power demand (per operational mode)	Data Logging + Design Data	Calculated
Waste heat flows	Data Logging + Design Data	Calculated

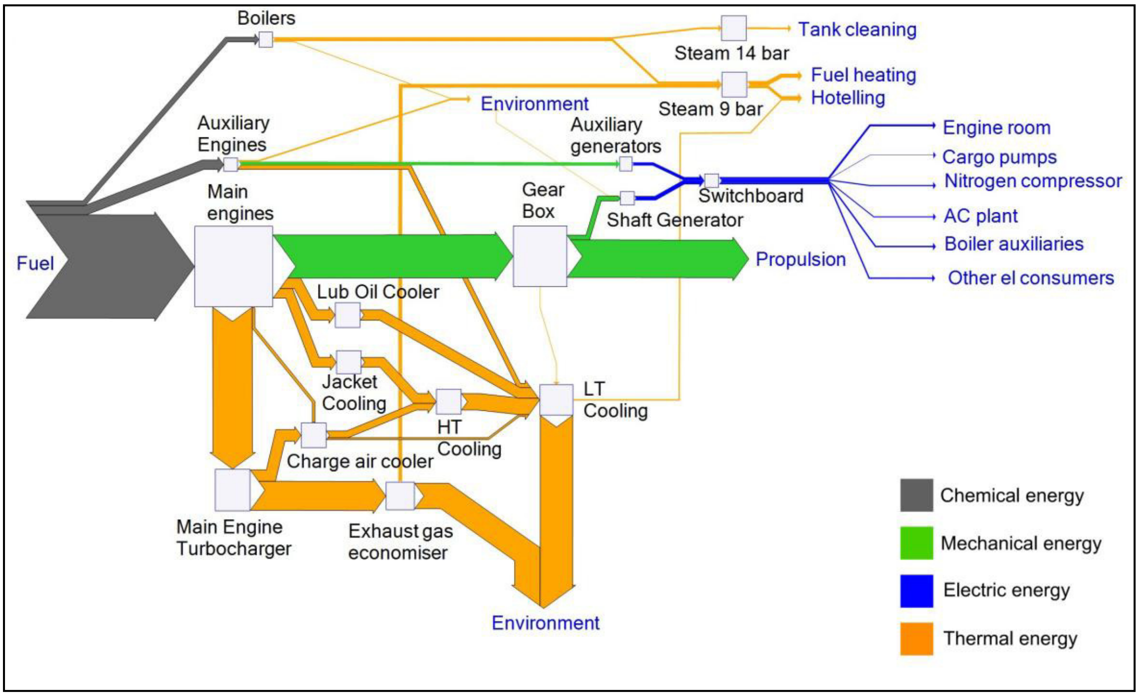

Fig. 1: Sankey diagram of ship energy systems

The analysis is based on one year of ship operations and represents the consumption through all ship operations (sailing, maneuvering, loading/unloading, and waiting in port). Separated analysis for each operational mode could be easily obtained and is here omitted for space limitations. Further details on the specific assumptions employed for the calculation of each individual flow can be found in [12].

3. Results and Discussion

Figure 1 represents the Sankey diagram of the ship energy systems, while Table 3 summarises input, output and waste energy flows.

Results of the analysis confirm the usual assumption that propulsion and main engines are the main components to focus on. However, the relatively high need of auxiliary power (14% of total) and heat (16% of total) suggest that the focus should be put also on these categories. Finally, the large amount of energy wasted to the environment, of which only a relatively small amount is recovered (7%), suggests that there is room for improvement of the system energy's efficiency.

The results of the analysis can be used in order to guide the decision making process by providing insight on ship energy use. The relevant needs of both auxiliary power and heat can suggest the optimization of the interaction between engine, propeller, auxiliary heat and power needs, as proposed in [10]. In addition, when compared to energy audits presented by Thomas et al.[7] and Basurko et al. [8], waste heat flows were included in the analysis. The availability of large amounts of waste heat, especially in the exhaust gas, also suggests possibilities for system improvement. The use of ABs could be reduced through the storage of waste heat from the MEs to be used while the ship is at berth. Alternatively, waste heat recovery systems could be used for the generation of auxiliary power. Estimations also based on energy quality, as well as the feasibility of such systems, should be evaluated in order to understand their potential in relation to the auxiliary needs, as proposed in [12].

Table 3: Summary of main energy flows

Producers	%	Consumers	%	Waste flows	%
Main engines	88.4	Propulsion	70	Exhaust gas	38
Auxiliary engines	8.0	Auxiliary power	14	Charge air cooler	19
Boilers	2.6	Auxiliary heat	16	Jacket water	21
				Lubricating. Oil	22

4. Conclusion

A detailed analysis of ship energy flows was performed in this study. A mixed bottom-up and top-down approach was used in order to obtain the main energy flows for one year of operation. The results allow identifying and quantifying the main consumers and the main sources of waste heat, and can be used as the basis for further analysis on the improvement on ship energy systems based on the knowledge of the system.

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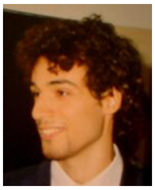

Biography

Francesco Baldi is a doctorate student at the department of Shipping and Marine Technology at Chalmers University of Technology, in Gothenburg. Educated at the University of Bologna in Energy Technology, his main focus lies in the analysis and modeling of ship energy systems.