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Change in Steam Generators Main and Auxiliary Energy Flow Streams During the Load Increase of LNG Carrier Steam Propulsion System

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ABSTRACT

In this paper is presented an analysis of main and auxiliary steam energy flow streams from steam generators during the increase in steam system load at conventional LNG carrier. During the steam system load increase was presented differences in steam pressure and temperature between main and auxiliary steam flow streams. Energy power of the auxiliary flow stream is higher than energy power of the main flow stream only at the lowest steam system loads after which main flow stream takes over primacy at middle and high steam system loads. Cumulative auxiliary energy flow stream was divided on energy flow streams to each auxiliary device and energy power consumption of each auxiliary device was also investigated throughout number steam system loads. Analysis of steam production from marine steam generators presented in this paper provides insight into the operation dynamics of the entire steam propulsion system.

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Abbreviations:		**Subscripts:**	
DWT	Deadweight Tonnage	AD	Auxiliary device
		AH	Air heaters
LNG	Liquefied Natural Gas	AUX	Auxiliary
Latin Symbols:		CU	Cumulative
$\dot{E}$	stream flow power, kW	DEA	Deaerator
		DES	Desuperheater
h	specific enthalpy, kJ/kg	DU	Dump
		en	energy
$\dot{m}$	mass flow rate, kg/h	IN	inlet (input)
P	power, kW	MA	Main
$\dot{Q}$	heat transfer, kW	OUT	outlet (output)
SH	share, %	SS	Splash steam

1 Introduction

Internal combustion diesel engines in general (mostly slow speed diesel engines) have a leading role in ship propulsion nowadays [1,2]. The wide presence of diesel engines in ship propulsion enabled the development of different numerical models for investigation of their operating parameters [3,4] and for optimization of their processes [5].

Steam propulsion is slightly present on ships, but is still the dominant propulsion of LNG (Liquefied Natural Gas) carriers [6] due to the specificity of their operation and the transported cargo. Any steam system as well as the steam propulsion system is very complex because it is assembled from a large number of components [7]. The marine steam propulsion system in comparison with any conventional land-based steam power system is much more dynamic in its operation.

The marine steam propulsion system consists of two steam generators [8] due to safety and reliable operation and two parallel operating turbo-generators [9] to ensure electricity supply at any time. Propulsion propeller (or more of them) drive is ensured with main propulsion turbine [10]. Steam after expansion in turbo-generators and main propulsion turbine goes to the main condenser [11] on liquefaction.

On water return channel to steam generators there are several devices which provide condensate and feed water heating. The first of such devices is evaporator (fresh water generator) [12]. The evaporator is a steam propulsion system component which is not required in conventional land-based steam power systems. After evaporator is usually located sealing steam condenser [13] and two or more feed water heaters [14,15]. Between feed water heaters is located deaerator [16] with its dual function – feed water heating and removal of gaseous components from feed water. The water return channel also consists of hot well [17] for collecting all the condensate from the steam propulsion system and desuperheater. Desuperheater is a heat exchanger which is used for steam cooling and preparation for the cargo and auxiliary systems heating [18]. General LNG carrier steam propulsion system scheme can be found in [9].

New systems for the propulsion of LNG carrier's are currently under development [19]. The main goal of such propulsion systems is greenhouse gas emissions reducing [20,21]. For these complex systems is necessary to provide the economic and profitability analysis [22] as well as operational risk assessment [23] with the aim to minimize possible harmful consequences.

In this paper were analyzed changes in main and auxiliary energy steam flow streams from steam generators in marine propulsion system of one conventional LNG carrier. Each energy flow stream was investigated during the steam propulsion system load increase (from the lowest to the highest system loads). It was compared differences in steam pressure and temperature between main and auxiliary steam energy flow streams. Cumulative auxiliary energy flow stream was divided on flow streams to each auxiliary device. Energy flow stream consumption of each auxiliary device was also investigated throughout all steam system loads.

2 Description of Main and Auxiliary Energy Flow Streams in the Marine Steam Propulsion System

A marine steam propulsion system which main and auxiliary energy flows were analyzed in this paper is mounted on conventional LNG carrier. The essential parts of this propulsion system are two mirror-oriented marine steam generators, one propulsion turbine (with two turbine cylinders), two identical turbo-generators for electrical power production and low power steam turbine with one Curtis stage for main feed water pump drive. Another characteristics and specifications of the analyzed LNG carrier are presented in Table 1.

Steam energy flow streams which exits both steam generators are divided to two different flows: main flow stream and auxiliary flow stream. Both flow streams from steam generators are required and necessary for proper operation of analyzed marine steam propulsion system.

Table 1 Analyzed LNG carrier main characteristics

Dead weight tonnage	84812 DWT
Overall length	288 m
Max breadth	44 m
Design draft	9.3 m
Steam generators	2 × Mitsubishi MB-4E-KS
Propulsion turbine	Mitsubishi MS40-2 (max. power 29420 kW)
Turbo-generators	2 × Shinko RGA 92-2 (max. power 3850 kW each)
MFP steam turbine	Shinko DMG 125-3 (max. power 570 kW)

The main steam flow stream has a maximum pressure and temperature, which are dependable on steam generator specifications. Main steam flow stream in the observed propulsion system has a pressure of around 6 MPa and a temperature of around 515 °C. The main steam flow stream is used for operation of all steam turbines (main propulsion turbine, both turbo-generators and MFP steam turbine). Each steam turbine, regardless of turbine developed power, requires steam with maximum possible parameters (pressure and temperature) in any steam propulsion system.

The auxiliary steam flow stream is produced from the main flow stream. One part of produced main steam stream, which was not led to steam turbines, was sent back to the steam generators. That steam passes through steam drums and transferred one part of its heat content to feed water. Due to heat transfer, steam temperature significantly decreases while steam pressure also decreases, but not as significantly as the temperature. Such steam stream with lower temperature and pressure in comparison with main steam stream is called an auxiliary steam flow stream. After heat transfer is steam drums, auxiliary steam flow stream exits from steam generators. The auxiliary steam flow stream is used for the operation of auxiliary system devices which required steam with lower temperature and pressure in comparison with the main flow stream.

In the analyzed marine steam propulsion system, the auxiliary steam flow stream was used for the operation of five auxiliary devices: splash steam system, dump line, deaerator, desuperheater and steam generators air heaters, Fig. 1. Operation principle of each auxiliary device is explained as follows:

- **Splash steam system:** Splash steam system takes a small amount of auxiliary steam from steam generators for water preparation in order to use such prepared water for cooling purposes. Water prepared in the splash steam system is usually used for cooling of the main condenser or for cooling of a steam at the turbines outlet. In some operating regimes of marine steam propulsion system, steam which enters into the main condenser can still be superheated. Cooling of that superheated steam enables its liq-

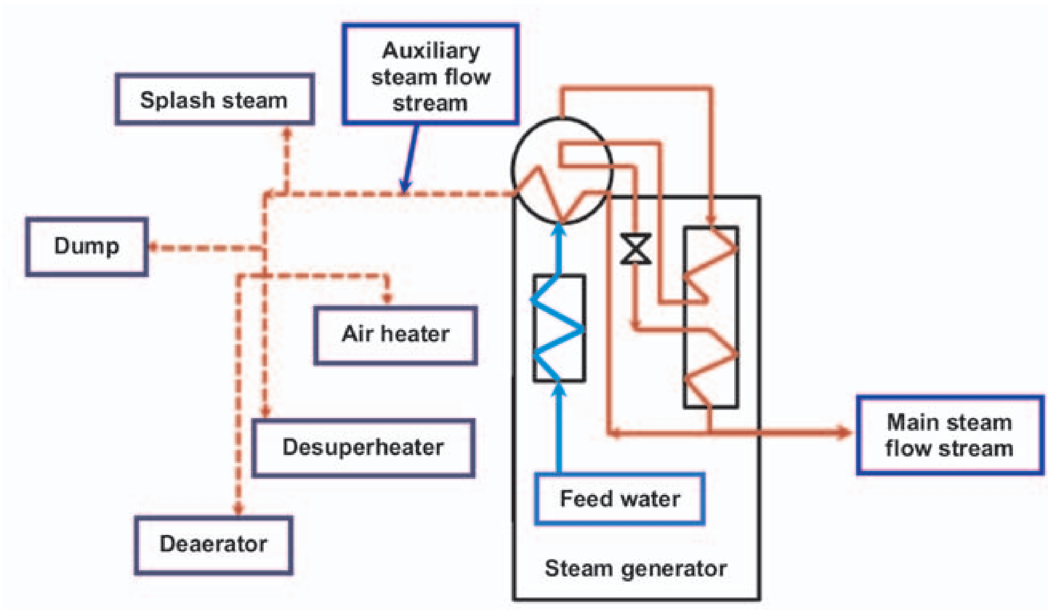

Figure 1 Scheme of one marine steam generator with main and auxiliary steam flow streams

uefaction. Water prepared in the splash steam system can also be used for the other cooling purposes in the steam propulsion system.

- **Dump line:** At low steam propulsion system loads, steam generators produce much more steam than an entire system requires. Steam surplus was led directly to the main condenser through the steam system dump line. This amount of heat represents a direct heat loss, because a high amount of produced steam can not be used anywhere in the steam propulsion system. As propulsion system load increases, steam system components (main and auxiliary) require more and more steam and at the middle steam system loads all produced steam will be used by system components, so from that moment on dump line is closed.
- **Deaerator:** Deaerator is a steam propulsion system component which has two important functions. First is feed water heating (the deaerator is open feed water heater) and the second is oxygen and other gases removal from feed water to avoid corrosion and cavitations in a feed water pipeline. For both of its functions deaerator requires auxiliary steam.
- **Desuperheater:** Desuperheater is used in the marine steam propulsion system to prepare auxiliary steam for additional heating purposes. In desuperheater, one small part of feed water is taken from the feed water pipeline and injected in auxiliary steam. On such way auxiliary steam temperature additionally decreases and steam is adequately prepared for additional heating purposes.
- **Steam generators air heaters:** Before entrance in each steam generator combustion chamber, air is heated in air heater. Heating medium is auxiliary steam. Each steam generator has one air heater. Air heaters are identical ones. Usually, in land-based steam power systems, air is heated with flue gases which exit from the steam generator. In marine steam systems, flue gases temperature is not sufficient for air heating purposes, so air heating is obtained with auxiliary steam.

In analyzed marine steam propulsion system, it should be noted that only the splash steam system is constantly supplied with auxiliary steam flow from steam generators (from the lowest to the highest steam system load). Other auxiliary devices are supplied with steam from steam generators at low and middle steam system loads. At high steam system loads, auxiliary steam flow from steam generators significantly decreases, because the majority of auxiliary devices (all auxiliary devices except splash steam system) get a steam required for their operation from main steam turbine subtractions. This fact will be clearly seen from measurement results, Table 3 and Table 4.

3 Equations for Energy Flow Streams Analysis

3.1 Energy Analysis – Governing Equations

Energy analysis is defined by the first law of thermodynamics [24]. Mass and energy balance equations for a standard volume in steady state disregarding potential and kinetic energy are defined according to [25] and [26]:

$$\Sigma \dot{m}_{IN} = \Sigma \dot{m}_{OUT} \tag{1}$$

$$\dot{Q} - P = \Sigma \dot{m}_{OUT} \cdot h_{OUT} - \Sigma \dot{m}_{IN} \cdot h_{IN} \tag{2}$$

Energy power of a flow for any fluid stream can be calculated according to [9] by using the equation:

$$\dot{E}_{en} = \dot{m} \cdot h \tag{3}$$

3.2 Calculation of Main and Auxiliary Energy Flow Streams from Marine Steam Generators

Energy power of each steam flow stream (main and auxiliary) was calculated by using measured steam pressures, temperatures and mass flow rates, according to equation (3). Steam specific enthalpies were calculated from measured steam pressures and temperatures by using NIST REFPROP software [27].

Energy power values were presented for both steam generators throughout this paper, so it was investigated cumulative streams from the propulsion system. A steam flow stream which enters to each system device was produced by both steam generators, so only the cumulative flow streams can be relevant in energy analysis.

Auxiliary steam pressure and temperature (and consequentially auxiliary steam specific enthalpy) is not the same at the steam generator's outlet when compared to flow streams to each auxiliary device due to losses through the pipeline. On the other side, decrease in auxiliary steam pressure and temperature in the pipeline is small and in this paper is neglected. Auxiliary steam flow streams to each auxiliary device were calculated with the same specific enthalpy as at the steam generator's outlet, but with corresponding and measured steam mass flow rates.

Cumulative steam mass flow rate, which exits from both steam generators, is defined as:

$$\dot{m}_{CU} = \dot{m}_{MA} + \dot{m}_{AUX} \tag{4}$$

Cumulative steam energy power is:

$$\dot{E}_{en,CU} = \dot{E}_{en,MA} + \dot{E}_{en,AUX} \tag{5}$$

where main and auxiliary steam energy power are defined as:

$$\dot{E}_{en,MA} = \dot{m}_{MA} \cdot h_{MA} \tag{6}$$

$$\dot{E}_{en,AUX} = \dot{m}_{AUX} \cdot h_{AUX} \tag{7}$$

The share of main steam energy power in cumulative energy power is:

$$SH_{MA} = \frac{\dot{E}_{en,MA}}{\dot{E}_{en,CU}} \cdot 100 \tag{8}$$

The share of auxiliary steam energy power in cumulative energy power is:

$$SH_{AUX} = \frac{\dot{E}_{en,AUX}}{\dot{E}_{en,CU}} \cdot 100 \tag{9}$$

The auxiliary steam flow stream is divided on flow streams to each auxiliary device (auxiliary devices are splash steam system, dump line, deaerator, desuperheater and air heaters).

Mass flow rate balance for auxiliary steam flow stream is:

$$\dot{m}_{AUX} = \dot{m}_{SS} + \dot{m}_{DU} + \dot{m}_{DEA} + \dot{m}_{DES} + \dot{m}_{AH} \tag{10}$$

As the change in auxiliary steam pressure and temperature through the pipeline is neglected, auxiliary steam energy power divided to each auxiliary device is:

$$\begin{aligned} \dot{E}_{en,AUX} &= \dot{m}_{AUX} \cdot h_{AUX} = \\ &= (\dot{m}_{SS} + \dot{m}_{DU} + \dot{m}_{DEA} + \dot{m}_{DES} + \dot{m}_{AH}) \cdot h_{AUX} \end{aligned} \tag{11}$$

Steam energy power to each auxiliary device is then:

$$\dot{E}_{en,AD} = \dot{m}_{AD} \cdot h_{AUX} \tag{12}$$

The share of each auxiliary device energy power in the cumulative auxiliary energy power is:

$$SH_{AD} = \frac{\dot{E}_{en,AD}}{\dot{E}_{en,AUX}} \cdot 100 \tag{13}$$

4 Measurement Results of Main and Auxiliary Steam Flow Streams

Measurements were performed in twenty four different LNG carrier steam system loads. Measurements of steam temperature, pressure and mass flow rate at each steam system load were obtained with measurement equipment already mounted on the steam system pipeline. That equipment is used for control and regulation of the entire steam system during LNG carrier exploitation.

The list of used measurement equipment is presented in Table 2.

Table 2 Used measurement equipment

Main steam flow stream	
Steam temperature	Greisinger GTF 601-Pt100 – immersion probe [28]
Steam pressure	Yamatake JTG980A – pressure transmitter [29]
Steam mass flow rate	Yamatake JTD960A – differential pressure transmitter [30]
Auxiliary steam flow stream	
Steam temperature	Greisinger GTF 601-Pt100 – immersion probe [28]
Steam pressure	Yamatake JTG980A – pressure transmitter [29]
Steam mass flow rate	Yamatake JTD960A – differential pressure transmitter [30]
Auxiliary steam flow stream to each auxiliary device	
Steam mass flow rate	Yamatake JTD960A – differential pressure transmitter [30]

All required steam operating parameters were presented in relation to propulsion propeller speed. Increase in propulsion propeller speed is directly proportional to increase in steam system load and vice versa.

Table 3 present measurement results of the main and cumulative auxiliary steam flow streams. Based on these data, it was performed calculation and comparison of steam energy power for each observed stream.

Table 3 Measurement results for the main and cumulative auxiliary steam flow streams

Propulsion propeller speed (rpm)	Main steam flow stream			Auxiliary steam flow stream-cumulative		
	Steam temperature (°C)	Steam pressure (MPa)	Steam mass flow rate (kg/h)	Steam temperature (°C)	Steam pressure (MPa)	Steam mass flow rate (kg/h)
25.00	501	6.20	16744	313	6.01	29876
34.33	500	6.20	22696	309	6.08	27710
41.78	500	6.19	29394	304	6.11	17708
53.50	509	6.10	47985	297	6.07	12170
56.65	498	5.98	40363	297	5.94	17038
61.45	500	5.98	49438	297	5.94	14486
62.52	499	5.99	48977	299	5.95	14528
63.55	500	5.99	52080	298	5.95	14915
65.10	504	6.10	54438	299	6.10	15633
66.08	515	6.08	56078	300	6.04	16133
67.68	515	6.08	59201	301	6.04	16756
68.66	516	6.09	61300	302	6.05	13618
69.49	515	6.09	62723	302	6.05	14039
70.37	516	6.09	64366	302	6.05	14150
71.03	516	6.10	65019	302	6.06	13954
73.09	515	6.10	70515	301	6.07	14690
74.59	515	6.07	77211	299	6.04	10641
76.56	515	6.07	82881	299	6.04	10848
78.41	515	6.09	89907	299	6.06	10744
79.46	498	5.94	95990	298	5.92	3273
80.44	502	6.00	100540	297	5.94	3384
81.49	500	5.99	102883	290	5.99	483
82.88	501	5.99	108601	280	5.99	474
83.00	501	5.99	109961	280	5.99	477

Table 4 Auxiliary steam mass flow rates to each auxiliary device

Propulsion propeller speed (rpm)	Steam temperature (°C)	Steam pressure (MPa)	Splash steam mass flow rate (kg/h)	Dump steam mass flow rate (kg/h)	Deaerator steam mass flow rate (kg/h)	Desuperheater steam mass flow rate (kg/h)	Air heaters steam mass flow rate (kg/h)
25.00	313	6.01	428	15764	5881	3022	4781
34.33	309	6.08	441	13178	6467	2797	4827
41.78	304	6.11	416	3696	6049	2687	4860
53.50	297	6.07	442	0	3639	2792	5297
56.65	297	5.94	475	0	8392	2796	5375
61.45	297	5.94	472	0	5367	2685	5962
62.52	299	5.95	470	0	5282	2903	5873
63.55	298	5.95	478	0	5657	2677	6103
65.10	299	6.10	470	0	6318	2587	6258
66.08	300	6.04	489	0	6541	2690	6413
67.68	301	6.04	494	0	6983	2797	6482
68.66	302	6.05	488	0	3840	2685	6605
69.49	302	6.05	483	0	4077	2792	6687
70.37	302	6.05	472	0	4078	2688	6912
71.03	302	6.06	464	0	3994	2687	6809
73.09	301	6.07	494	0	4484	2584	7128
74.59	299	6.04	491	0	0	2688	7462
76.56	299	6.04	468	0	0	2793	7587
78.41	299	6.06	472	0	0	2687	7585
79.46	298	5.92	479	0	0	2794	0
80.44	297	5.94	478	0	0	2906	0
81.49	290	5.99	483	0	0	0	0
82.88	280	5.99	474	0	0	0	0
83.00	280	5.99	477	0	0	0	0

Cumulative auxiliary steam flow stream is divided on flow streams to each auxiliary device. Losses of steam pressure and temperature in auxiliary steam pipeline are neglected (pressure and temperature of auxiliary steam are the same as at the steam generator's outlet), so for energy power calculation to each auxiliary device is needed only steam mass flow rates. Those steam mass flow rates are measured with the same control and regulation measuring equipment as before and presented in Table 4.

5 Results of Main and Auxiliary Steam Flow Streams Energy Analysis with Discussion

As declared before, the auxiliary steam flow stream is produced from the main flow stream. One part of produced main steam stream, which was not led to steam turbines, was sent back to steam generators where passing through steam drums and transferred a part of its heat content to feed water. In such way, the auxiliary steam temperature significantly decreases.

The temperature difference change between main and auxiliary steam flow streams during the increase in steam system load can be seen in Fig. 2. That temperature difference continuously increases during the increase in steam system load from 188 °C at propulsion propeller speed of 25.00 rpm up to 221 °C at propulsion propeller speed of 83.00 rpm. In the whole range of observed steam system loads auxiliary steam flow stream, when compared to main steam flow stream, has lower temperature for 208.4 °C on average.

Auxiliary steam flow stream pressure also decreases when compared to main steam flow stream, but that decrease is not as significant as decrease in temperature, Fig. 3. The highest pressure differences between main and auxiliary steam flow streams can be seen at the lowest steam system loads (between 25.00 rpm and 41.78 rpm). When compared to main steam flow stream, the auxiliary flow stream has lower pressure for 0.0425 MPa on average throughout the whole range of observed steam system loads.

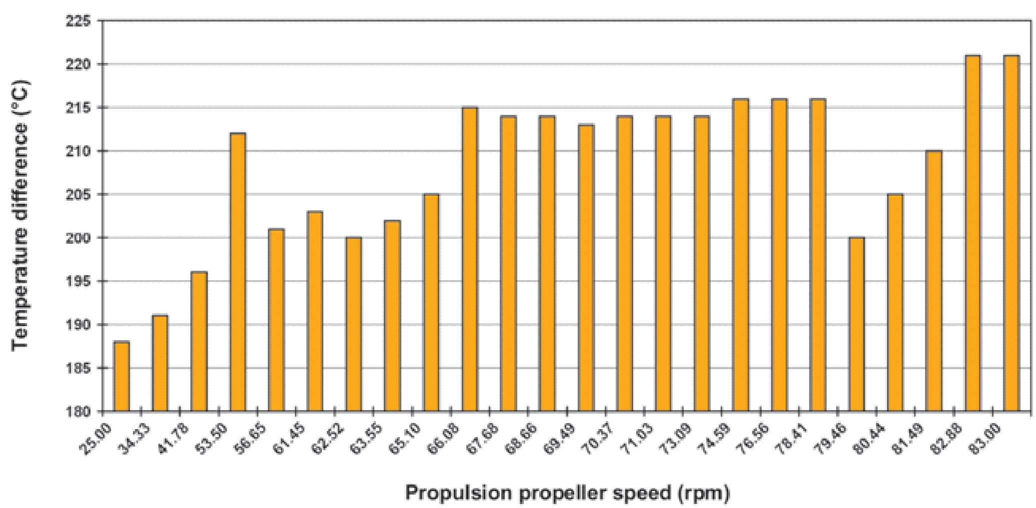

Figure 2 Temperature difference change between main and auxiliary steam flow streams

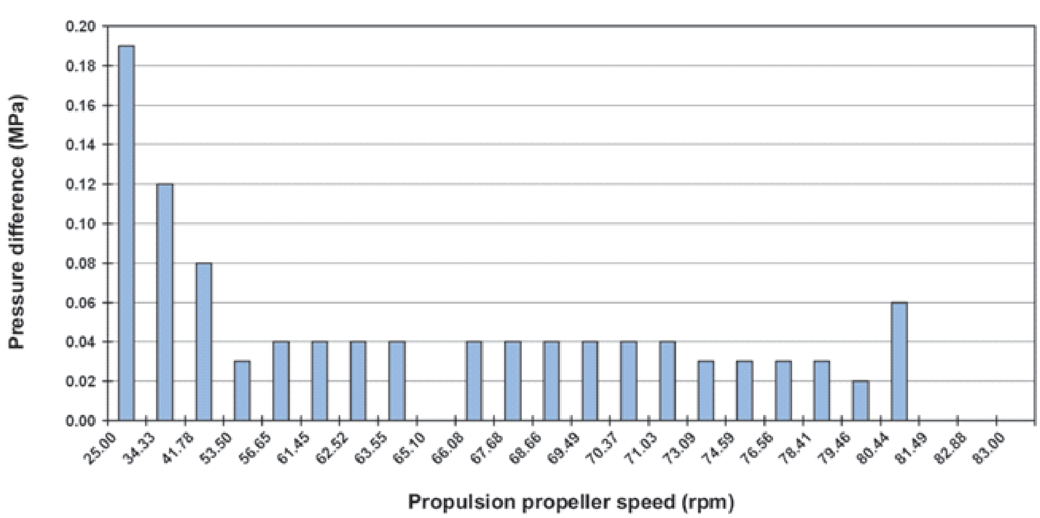

Figure 3 Pressure difference change between main and auxiliary steam flow streams

At the highest steam system loads (between propulsion propeller speeds of 81.49 rpm and 83.00 rpm) main and auxiliary steam flow streams has the same pressure, Fig. 3. From this observation can be concluded that the main reason of producing an auxiliary steam flow stream is to reduce its temperature and to properly use it in auxiliary system devices. The main steam flow stream cannot be used for any auxiliary device operation because such high temperatures can cause serious damage of auxiliary devices.

Auxiliary steam flow stream production transferred a certain amount of heat to feed water in steam drums. From that feed water will be produced main steam flow stream. In such way, production of auxiliary steam flow stream also reduces steam generators fuel consumption.

Change in energy power of main and auxiliary steam flow streams is presented in Fig. 4. Energy power of the auxiliary flow stream is higher than energy power of the main flow stream at the lowest two steam system loads. Increase in steam system load (increase in propulsion propeller speed) resulted with continuous increase in energy power of the main steam flow stream, while at the same time energy power of the auxiliary steam flow stream continuously decreases. At the highest observed steam system load (83.00 rpm) energy power of the main steam flow stream amounts 104634 kW, while at the same load energy power of the auxiliary steam flow stream amounts only 371.7 kW.

Continuous decrease in energy power of the auxiliary steam flow stream during increase in steam system load does not mean that auxiliary devices use less and less steam as the system load increases. Deaerator, desuperheater and air heaters take auxiliary steam from steam generators until certain system loads after which they are supplied with steam from main steam turbine subtractions. Only the splash steam system is constantly supplied with an auxiliary steam flow stream from steam generators.

Increase in steam system load resulted with an increase in steam consumption of auxiliary devices. Steam

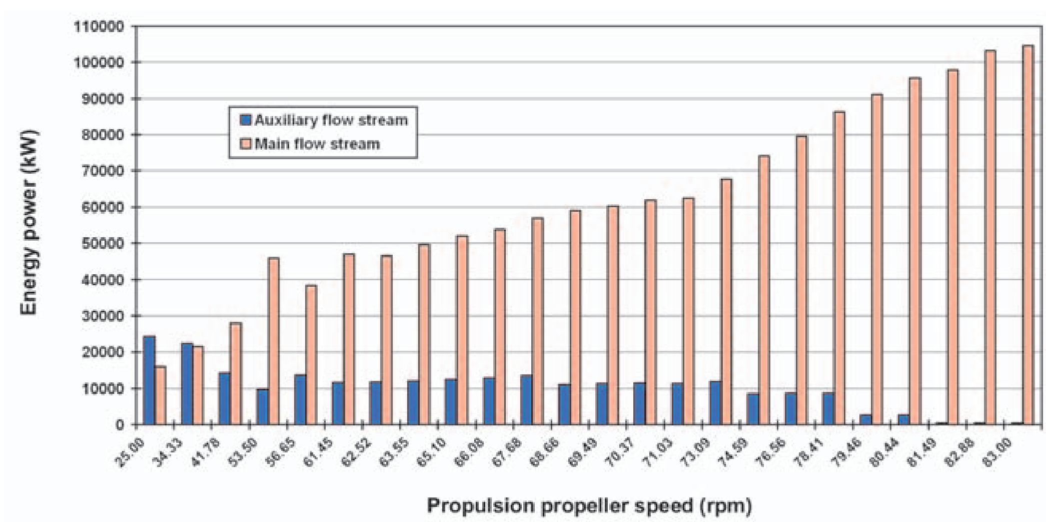

Figure 4 Change in energy power of main and auxiliary steam flow streams

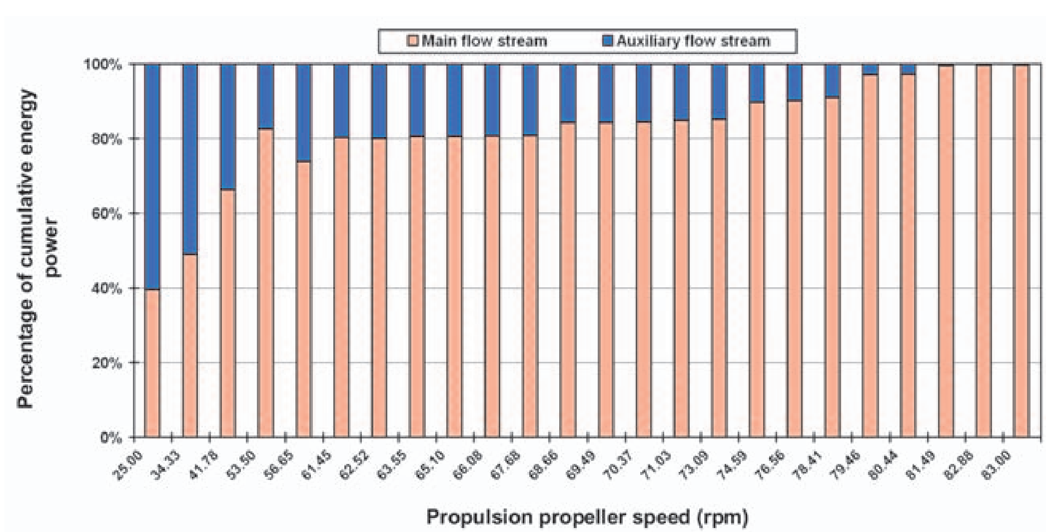

Figure 5 Energy power of main and auxiliary steam flow streams share in cumulative energy power

for auxiliary devices operation is obtained from steam generators (auxiliary steam flow stream) at low and middle system loads, while the majority of auxiliary devices gets steam from main steam turbine subtractions at high system loads.

Energy power of main and auxiliary steam flow streams, equation (5), represents cumulative energy power. As can be seen from Fig. 5, auxiliary flow stream energy power has a higher share in cumulative energy power only at 25.00 rpm (60.43 %) and at 34.33 rpm (50.98 %). Increase in steam system load reduces a share of auxiliary flow stream energy power in cumulative energy power. At middle steam system loads (between 53.50 rpm and 67.68 rpm) energy power of the auxiliary flow stream takes share around 20 % in cumulative energy power. At the highest observed steam system loads (from 81.49 rpm to 83.00 rpm) energy power of the main steam flow stream takes a share in cumulative energy power of 99.60 %.

Energy power of the auxiliary steam flow stream produced in steam generators was led to each auxiliary device. Due to different scales, energy power to each auxiliary device must be divided according to steam system loads on low loads, Fig. 6 and middle/high loads, Fig. 7.

At low steam system loads, between 25.00 rpm and 41.78 rpm, Fig. 6, the highest amount of auxiliary steam flow stream energy power was irretrievably lost because it is not needed in the steam system – so it passes through the dump line. As system load increases, energy power sent to the dump line decreases, and after 41.78 rpm dump line is closed. Deaerator is the second consumer of auxiliary steam energy power at low system loads (deaerator uses energy power of 4963 kW on average at low loads), after which follows air heaters and desuperheater. A splash steam system at low system loads takes the lowest amount of auxiliary steam flow stream energy power, much lower than the other auxiliary devices, Fig. 6.

The largest consumers of auxiliary steam flow stream energy power at the middle and high steam system loads are deaerator and air heaters, Fig. 7. Air heaters at middle and high system loads uses auxiliary flow stream energy

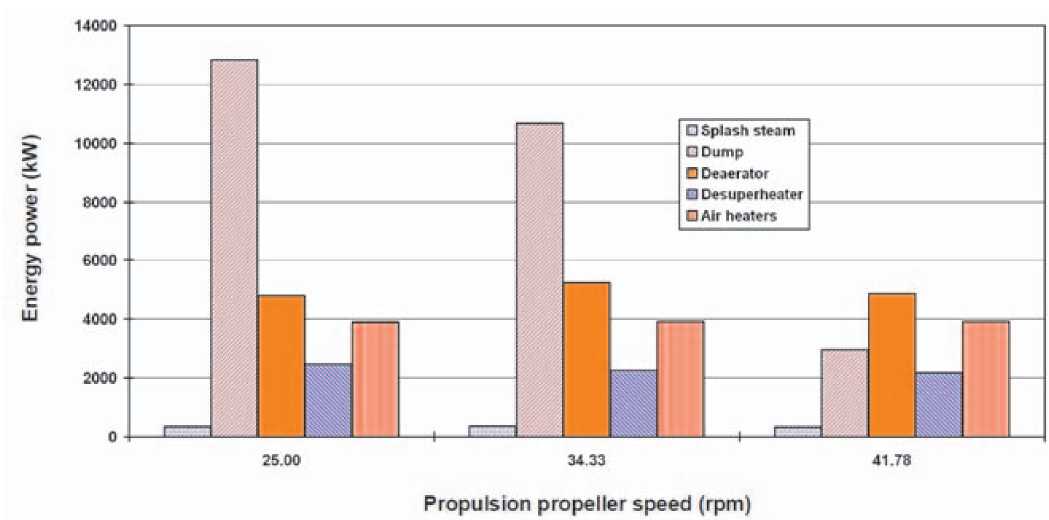

Figure 6 Steam energy power to each auxiliary device – low propulsion propeller speeds

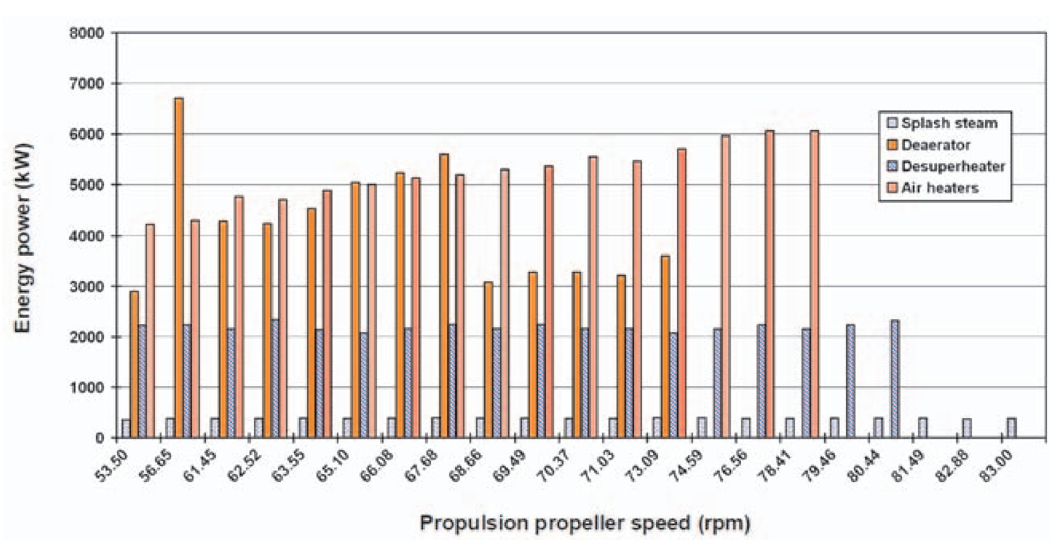

Figure 7 Steam energy power to each auxiliary device – middle and high propulsion propeller speeds

power of 5240 kW on average. At 79.46 rpm, air heaters steam supply was not anymore from steam generators but from the main turbine subtraction.

The deaerator uses energy power of 4900 kW on average from 53.50 rpm to 67.68 rpm. At 68.66 rpm, the auxiliary steam flow stream which was led to deaerator significantly decreases because from that moment on steam was led to deaerator simultaneously from steam generators (auxiliary stream flow) and from the main turbine subtraction. At propulsion propeller speed of 74.59 rpm, deaerator gets steam for its operation only from the main turbine subtraction.

Throughout the entire time of its operation while using an auxiliary steam flow stream, desuperheater uses approximately 2200 kW of auxiliary steam energy power. At three highest observed system loads (81.49 rpm, 82.88 rpm and 83.00 rpm), desuperheater gets a steam from the main turbine subtraction, as deaerator and air heaters.

The splash steam system is the only auxiliary device which operates with auxiliary steam flow stream produced in the steam generators during entire period of steam system operation, at any loads, Fig. 6 and Fig 7. Splash steam system uses a small amount of auxiliary flow stream energy power which amounts 377 kW on average for the entire range of observed propulsion propeller speeds (from 25.00 rpm to 83.00 rpm).

In Fig. 8 and Fig. 9 is presented share of each auxiliary device in cumulative auxiliary energy power produced in steam generators. As before, it was necessary to present share of each auxiliary device in cumulative auxiliary energy power at low system loads, Fig. 8 and at middle/high system loads, Fig. 9 due to different scales.

At low propulsion propeller speeds (at low steam system loads) share of dump line in cumulative auxiliary energy power decreases during the load increase from 52.76 % at 25.00 rpm to 47.56 % at 34.33 rpm and finally to 20.87 % at 41.78 rpm, Fig. 8. Between the same

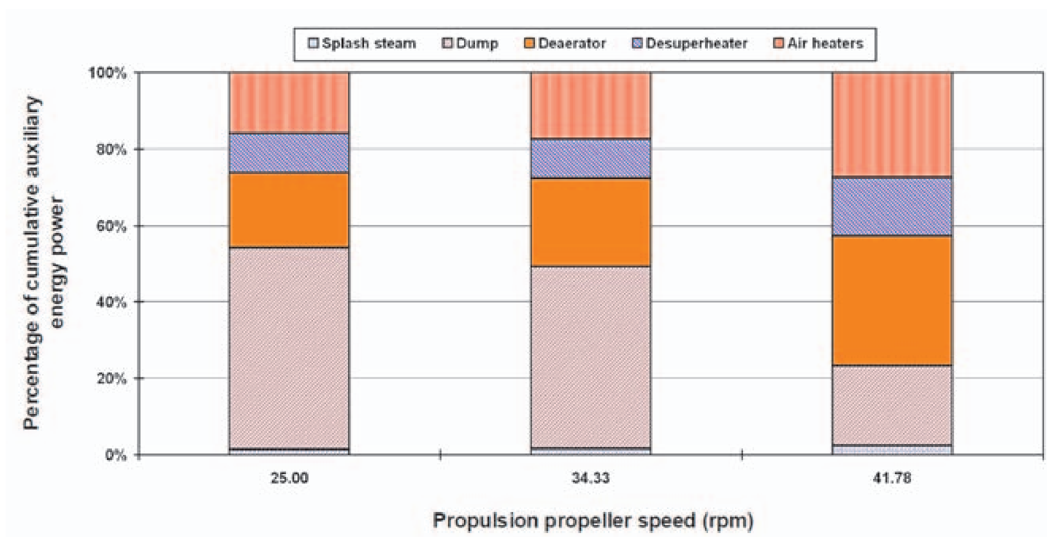

Figure 8 Share in the cumulative auxiliary energy power of each auxiliary device – low propulsion propeller speeds

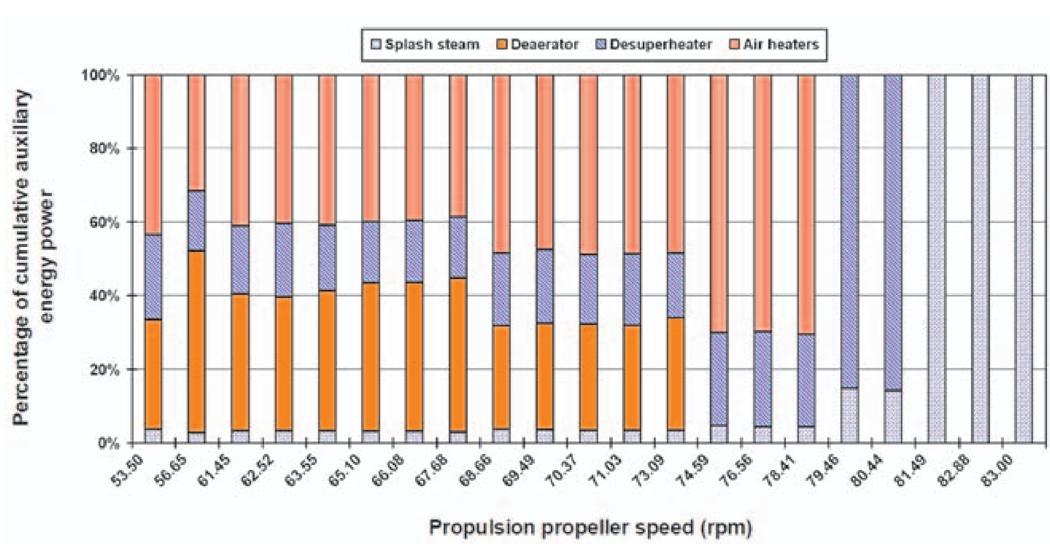

Figure 9 Share in the cumulative auxiliary energy power of each auxiliary device – middle and high propulsion propeller speeds

propulsion propeller speeds share of deaerator and air heaters in cumulative auxiliary energy power increases (from 19.68 % – 25.00 rpm to 34.16 % – 41.78 rpm for deaerator and from 16.00 % – 25.00 rpm to 27.45 % – 41.78 rpm for air heaters). Increase in system load resulted also with the increase of the desuperheater share in cumulative auxiliary energy power from 10.10 % at 34.33 rpm to 15.17 % at 41.78 rpm. Splash steam system share in cumulative auxiliary energy power also increases during the increase in steam system load, but that increase is lower than 1 % at observed low propulsion propeller speeds.

At middle and high propulsion propeller speeds dump line is closed, so share in cumulative auxiliary energy power produced in steam generators takes another four auxiliary devices, Fig. 9.

Until 68.66 rpm, deaerator uses the share of approximately 37 % in cumulative auxiliary energy power, while the average shares of other auxiliary devices are: air heaters – 41 %, desuperheater – 18 % and splash steam system – 3 %.

Between 68.66 rpm and 73.09 rpm, deaerator uses a steam flow simultaneously from steam generators (auxiliary steam) and from main steam turbine subtraction, so its share in cumulative auxiliary energy power decreases on approximately 29 %. At the same time, share of air heaters increase to 49 % on average and share of desuperheater increases to 19 % on average. Splash steam system share in cumulative auxiliary energy power also increases between 68.66 rpm and 73.09 rpm, but the increase is almost negligible.

From 74.59 rpm on, deaerator uses a steam flow only from main steam turbine subtraction, so between 74.59 rpm and 78.41 rpm air heaters takes the highest share in cumulative auxiliary energy power which amounts around 70 %, desuperheater takes a share of 25 % and splash steam system share is around 5 %.

From 79.46 rpm on, air heaters takes a steam flow only from main steam turbine subtraction. At 79.46 rpm and 80.44 rpm only two auxiliary steam flow consumers are desuperheater and splash steam system, which takes a share in cumulative auxiliary energy power of 85 % – desuperheater and 15 % – splash steam system.

At three highest steam system loads only auxiliary device which operates with auxiliary steam produced in steam generators is a splash steam system, Fig. 9.

6 Conclusion

This paper analyzes changes in main and auxiliary energy steam flow streams from steam generators during the increase in steam system load at conventional LNG carrier. Differences in steam pressure and temperature between main and auxiliary steam energy flow streams were compared and analyzed during the all specter of system loads. Energy power of main and auxiliary steam flow streams was compared and its share in cumulative energy power produced in steam generators was presented. Energy flow stream consumption of each auxiliary device was also investigated and it is presented share of each auxiliary device in cumulative auxiliary energy power at all observed steam system loads. The main conclusions obtained from the analysis are:

- Marine steam generators simultaneously produced main and auxiliary steam flow streams, regardless of steam system load,
- Main steam flow stream has significantly higher temperature and just little higher pressure when compared to auxiliary steam flow stream,
- Auxiliary flow stream is used for the operation of auxiliary devices in steam system,
- Energy power of the auxiliary steam flow stream is higher than energy power of the main steam flow stream only at the lowest steam system loads,
- Energy power of cumulative auxiliary flow stream decreases during the increase in steam system load,
- Auxiliary devices use an auxiliary steam flow stream from steam generators until the opening of steam subtractions from the main turbine (with an exception of deaerator),
- Dump line is the highest consumer of the auxiliary steam flow stream at the lowest system loads. A steam flow stream which passes through the dump line represent a direct heat loss of the system,
- The splash steam system is the only auxiliary device which continuously uses auxiliary steam flow stream produced in the steam generators throughout the entire steam system operation period.

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