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CAPABILITY OF IDENTIFYING AND PREDICTING THE TECHNICAL CONDITION OF PLATE HEAT EXCHANGERS IN OPERATION

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Abstract

The paper presents a test stand for plate heat exchangers, allowing to identify the technical condition and to predict durability of the heat exchangers used aboard the sea-going ships: "Oceanograf", "Władysław Orkan"and a passenger-car ferry, under the condition that they are of the same type and manufactured by the same company.

In the first part three different installations with plate heat exchangers in the engine rooms of sea-going ships were chosen. Then for those ship installations heat exchangers were selected similar to the plate heat exchangers installed on the laboratory test stand. Next a diagnostic model was developed based on the heat similarity. At the end the measurement results were analysed and it was concluded that durability of plate heat exchangers operated aboard sea-going ships could be predicted.

Key words: kinetic diagnostic model, thermal flux

1. Introduction

Capacity of plate heat exchangers in the ship power plant installations has a direct impact on the engine work efficiency and on the achieved economic effects. Fouled flow channels in the exchanger, boiler scale on the plates or the leakage causing cracks are only some of the causes of engine decreased efficiency or even its defect or breakdown. Unplanned stoppages due to necessary servicing those sometimes extensive defects are connected with increased costs and reduced profits. Therefore, thinking about actions ensuring effectiveness of a plate heat exchanger and elimination of the risk of its unserviceability or defect is always worthwhile.

The paper describes a simple research stand for heat exchangers, for which a diagnostic model has been developed allowing to predict technical condition of plate heat exchangers operating aboard the sea-going ships, under the condition that they are of the same type and manufactured by the same company. Development of the model and carrying out the research process required at the beginning that proper plate heat exchangers be selected, such as are used aboard similar ships, which the model is capable of simulating.

2. Selection of plate heat exchangers

Selection of the plate heat exchangers was carried out with relation to the coolers for:

A. Heat recuperation from the generating set cooling water aboard the "Oceanograf" ship now under construction in the S.R. NAUTA shipyard. The requirements of the heat exchanger have been determined by the installation designer in accordance with the type of generating set, type of installation and parameters of the central heating system. The cooling medium in that heat exchanger is the forty-percent ethylene glycol $C_2H_6O_2$, which is the installation working medium. Glycol input temperature is 92°C and output temperature 77°C. The cooling medium is the technical fresh water from the central heating system, whose input temperature is 70°C and output temperature 85°C [6].

B. Cooling the technical fresh water in the installation aboard the "Władysław Orkan" ship built in 2003 in China and classified by the Polish Register of Shipping. The cooling medium in the heat exchanger is the technical fresh water and the cooling medium is the sea (overboard) water. The input temperature of the cooled medium is 53°C and the output temperature 36°C. The cooling medium input temperature is 32°C and the output temperature 43.8°C [5].

C. Cooling the DMA diesel oil aboard the passenger-car ferry. The fuel input temperature is 54°C and the output temperature 44°C. Temperature of the technical water as a cooling medium increases from 38°C by nearly 3°C [7].

As the APV-manufactured bolted plate heat exchangers were tested on the test stand, selection of the new plate heat exchangers was done with the APV SPX company by means of the WinQuat 6.0 program and is presented in Table 1.

Table 1. Abbreviated heat exchanger selection cards

	A	B	C
	40% ethylene glycol	Seawater	Diesel oil
$\dot{G}$	8596kg/h	447850kg/h	2428kg/h
ρ	1,014kg/dm^3	1,019 kg/dm^3	0,871 kg/dm^3
c_w	3,769kJ/kgK	3,999kJ/kgK	1,99kJ/kgK
λ	0,45W/mK	0,625W/mK	0,628W/mK
η_{wej}	0,61cP	0,82cP	9,31cP
η_{wyj}	0,76 cP	0,66 cP	13 cP
$\dot{Q}$	135 kJ/s	5870 kJ/s	13 kJ/s
k	4485W/m^{2}K	5479,9W/m^{2}K	994,1W/m^{2}K
Type	SR2MG-16E/1	J107MGS-06C/3	TR1M-26/1

where: $\dot{G}$ – mass rate of flow, ρ – density, c_w – specific heat, λ – thermal conductivity, η_{wej} – inlet viscosity, η_{wyj} – outlet viscosity, $\dot{Q}$ – thermal flux, k – heat transfer coefficient

A diagnostic model was developed for the so selected coolers, allowing to predict changes of technical condition of the tested plate heat exchanger.

3. Diagnostic model of plate heat exchangers

Four types of similarity between physical systems of different size: geometrical, mechanical, thermal and chemical similarity, may be applied in order to reduce or to increase the scale of processes [1,4]. In the analysed plate heat exchangers the most important is similarity of the type of cooled medium (glycol, diesel oil) and the cooling medium (seawater) and also of the temperature range and the connected thermal similarity. Therefore, a diagnostic model was developed taking into account that type of similarity (Fig.1).

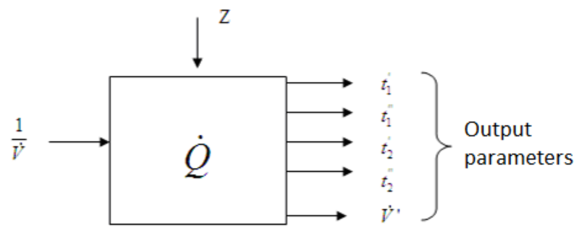

Fig.1. Schematic diagram of the diagnostic model of plate heat exchanger operation: $1/\dot{V}$ - inverse of the tested medium flow rate; $\dot{Q}$ -thermal flux as a diagnostic parameter (state parameter), $\dot{V}'$ - technical water flow rate, t'_1 ,t''_1 – cooled medium input and output temperatures, t'_2, t''_2 – cooling medium input and output temperatures, Z – disturbances (e.g. thermal losses to the environment, losses in the conduits)

The input or output thermal flux value (disturbances not taken into accout) was adopted as the technical condition identifying parameter. The measured values were inlet and outlet temperatures and also the technical (distilled) water volumetric flow rate $\dot{V}'$. Those values varied, as with a given flow rate of the tested media (ethylene glycol, seawater and diesel oil) it was necessary to obtain the same values of the mentioned temperatures as those occurring during operation of the heat exchangers aboard the ships. Change of the tested medium flow rate is caused, among others, by deposits or boiler scale on the heat exchanger plates, so it was concluded that decrease in the flow rate indicated reduced heat exchanger durability. Therefore, the inverse of tested medium flow rate ($1/\dot{V}$) was adopted as a diagnostic parameter and a measure of functionality correctness of that heat exchanger in the operation phase τ.

4. Testing on the laboratory stand

Schematic diagram of the heat exchanger and the testing apparatus is presented in Fig.2. The essential element of the stand is the heat exchanger (1) made from the AISI 316 (λ= 15 W/mK) stainless steel. This is a single-section exchanger where media flow in 10 channels. The heat exchange surface of 0.25 m2 consists of 21 plates, each 0.3 mm thick. Distance between the adjacent plates is 1.2 mm, length of the inter-plate channel is 220 mm and its width 80 mm.

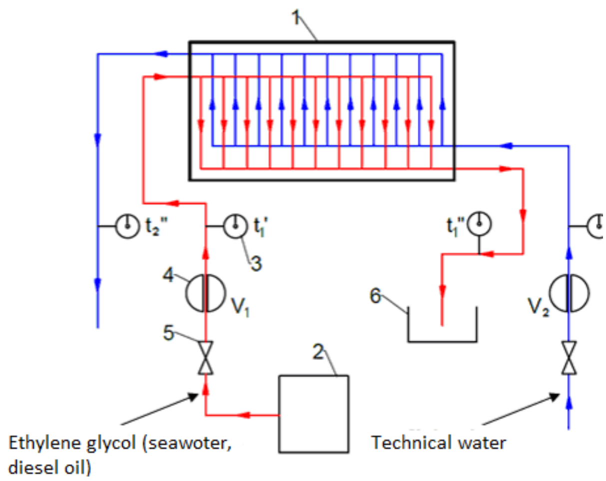

Fig. 2. Schematic diagram of the measurement stand : 1 – Plate heat exchanger, APV type U 121R, 2 – Small-capacity ultrathermostat, type UTM ZN-69 / CZSP - D3- 275, operates in the medium temperature range from -60 °C to 200°C, heater measurement uncertainty is ± 0.03 °C, 3 – UT50 digital temperature meter, measurable temperature range from -40°C to 1000°C , measurement accuracy ± (1 ÷ 3)%, 4 - JS 16 Smart+ water meter, admissible measurement error within the (1 ÷ 3)% range for the medium flow rates occurring during the tests, 5 – flow rate adjustment valve, 6 – overflow vessel

The objective of all the tests was the following:

A. Heating the ethylene glycol in ultrathermostat up to the required 92ºC temperature and passing it through the plate cooler to receive the outlet temperature of 77ºC. The cooling medium was technical (distilled) water. Tests were carried out with three different ethylene glycol flow rates. Temperature measurements at points marked in the diagram were performed four times for each flow rate [6].

B. Heating the seawater in ultrathermostat up to the required 32ºC temperature and passing it through the plate cooler to receive the outlet temperature of 43.8ºC. The cooling medium was technical water. Tests were carried out with three different seawater flow rates. Temperature measurements at points marked in the diagram were performed four times for each flow rate [5].

C. Heating the diesel oil in ultrathermostat up to the required 54ºC temperature and passing it through the plate cooler to receive the outlet temperature of 44ºC. The cooling medium was technical water. Tests were carried out with three different diesel oil flow rates. Temperature measurements at points marked in the diagram were performed four times for each flow rate [7].

The tests were carried out on a fully operational cooler (Test 1) and on a partially operational cooler (Test 2). All the measurements were repeated four times. Fig.3 presents plate photographs of the two coolers. Mean values of the measurement results and the calculated values of thermal flux (complete calculation results are given in the [2,3,6,7,8] references) are presented in Tables 2, 3 and 4.

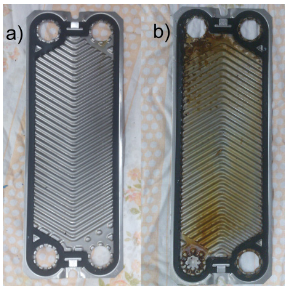

Fig. 3. Heat exchanger plates [5,6,7]:
a) in fully operational condition, b) in partially operational condition

Table 2. Laboratory test results of glycol ethylene coolers

	Test 1			Test 2		
$\frac{1}{\dot{V}}\cdot 10^{-4}\left[\frac{m^3}{s}\right]$	1,47	1,5	1,54	1,64	1,76	2,05
$t_1^{'}$ [ºC]	92			92		
$t_1^{''}$ [ºC]	77			77		
$\dot{Q}_A\left[\frac{J}{s}\right]$	3848	3771	3449	3673	3222	2758

Table 3. Laboratory test results of technical water coolers

	Test 1			Test 2		
$\frac{1}{\dot{\mathrm{V}}}\cdot 10^{-4}\left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$	0,16	0,19	0,23	0,29	0,33	0,45
$\mathrm{t}_2^{'}$ [ºC]	32			32		
$\mathrm{t}_2^{''}$ [ºC]	43,8			43,8		
$\dot{Q}_B\left[\frac{J}{s}\right]$	2374	1909	1766	1699	1361	1259

Table 4. Laboratory test results of diesel oil coolers

	Test 1			Test 2		
$\frac{1}{\dot{V}}\cdot 10^{-4}\left[\frac{m^3}{s}\right]$	0,15	0,16	0,2	0,27	0,3	0,4
$t_2^{'}$ [°C]	54			54		
$t_2^{''}$ [°C]	44			44		
$\dot{Q}_C\left[\frac{J}{s}\right]$	838	786	729	669	624	581

The limiting values determining the exchanger thermal flux are necessary for predicting the technical condition. In this work, the assumed upper limiting value was the maximum value of thermal flux obtained with the maximum cooled medium flow rate in a fully operational heat exchanger, because coolers manufactured by the APV company were designed for such parameters. As an admissible lower limiting value, the maximum value of thermal flux obtained with the maximum cooled medium flow rate in a partially operational heat exchanger. Fig. 4, 5 and 6 present diagrams of thermal flux in the plate heat exchangers used in the laboratory tests, as functions of the inverse of medium flow rate, i.e. the operation measure.

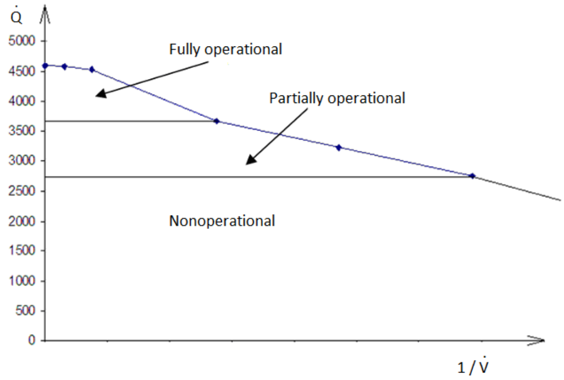

Fig.4. Three-level evaluation of the ethylene glycol cooler technical condition

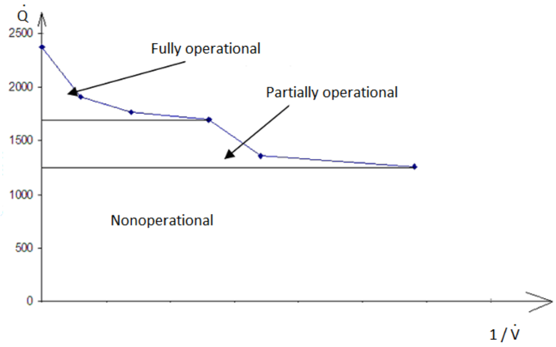

Fig.5. Three-level evaluation of the technical water cooler technical condition

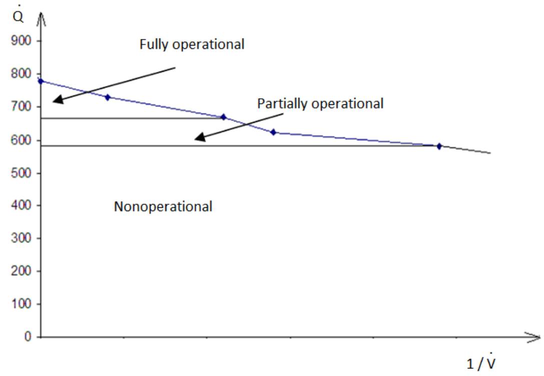

Fig.6. Three-level evaluation of the diesel oil cooler technical condition

From the course of thermal flux curves, the trend exponential functions were determined allowing to predict the operational condition of plate heat exchangers. The functions are described by the following equations:

$$\dot{Q}_A = 8498,7 \cdot e^{-0,5463 \cdot \tau}$$
$$\dot{Q}_B = 985,61 \cdot e^{-2,0367 \cdot \tau}$$
$$\dot{Q}_C = 985,61 \cdot e^{-1,4001 \cdot \tau} \quad (1)$$

By changing the operation measure τ, one can monitor the plate heat exchanger technical condition and predict the necessary operations, e.g. plate chemical cleaning when the partially operational state is found (Fig. 4, 5, 6).

5. Final conclusions

The APV-manufactured heat exchangers were selected, similar to those used in or designed for the fresh water and seawater cooling installations aboard the ships: ”Oceanograf”, ”Władysław Orkan” and on a passenger-car ferry. Besides, a diagnostic model was developed of the APV company plate heat exchangers. As main connecting elements between the designed and the tested heat exchangers the same working media and temperature distributions were assumed. Data generated by the model allowed to identify the technical condition of the selected plate heat exchangers and to predict their durability.

The tests and their results [5,6,7] were repeated four times and although they did not take disturbances into account, they appeared reliable, because they were compatible with the tests carried out in real conditions. Therefore, they may be used by manufacturers of the plate heat exchangers to predict, by means of a simple and cheap laboratory test stand, durability of a plate heat exchanger operated in real conditions.

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