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MODELLING FLUID FLOW & HEAT TRANSFER IN THE ORC POWER PLANT CO-FUELLED BY HEAT SOURCES OF DIFFERENT TEMPERATURE

A concept and arguments to fuel the ORC power plant by four heat sources with different temperatures are presented. The scheme and effectiveness of the ORC power plant being fuelled by four heat sources is analyzed on example of four volume flows of hot water from the local district heating system, whereby the hot water temperatures are assumed at the values of 105°C, 110°C, 115°C and 120°C respectively. The results of the analysis account also for different temperatures of water being returned from the evaporators for the latter being provided with internal hot water circulation systems. The results of the analysis are given in Tables and respective diagrams, and serve to form the concluding remarks on usefulness of the discussed concept.

INTRODUCTION

Recently, the ORC power plants have attracted a growing interest. They work according to the thermodynamic cycle that is analogous to that of traditional steam power plants, but organic fluids are used instead of water in the cycle.

The ORC systems enable generation of electricity from low temperature heat sources due to the properties of the organic fluids. That characteristic allows utilizing some waste heat streams with the temperature of even below 110°C .

The ORC systems usually work with a single heat source that has a constant output temperature. In case when several heat sources (waste heat or alike) should be utilized then, usually, there is no justification to apply for them all just one ORC system, and several ORC systems should be designed, respectively.

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In the present paper, the Authors will present the way in which the four heat sources of different temperature can be applied for one single ORC system.

The idea outlined for the ORC system in Fig. 2 resolves itself into application of the appropriate heat exchangers in form of the evaporators incorporating the internal hot water circulation system (Fig. 1.).

The organic fluid (vapour) supplied by all evaporators in that ORC system is delivered to a single turbine.

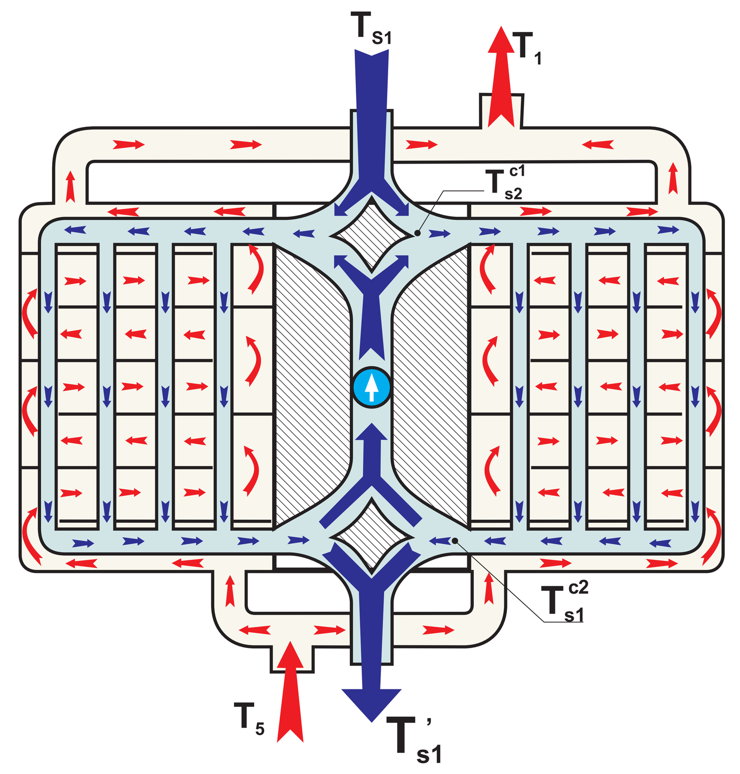

Fig.1. Evaporator with the internal hot water circulation system

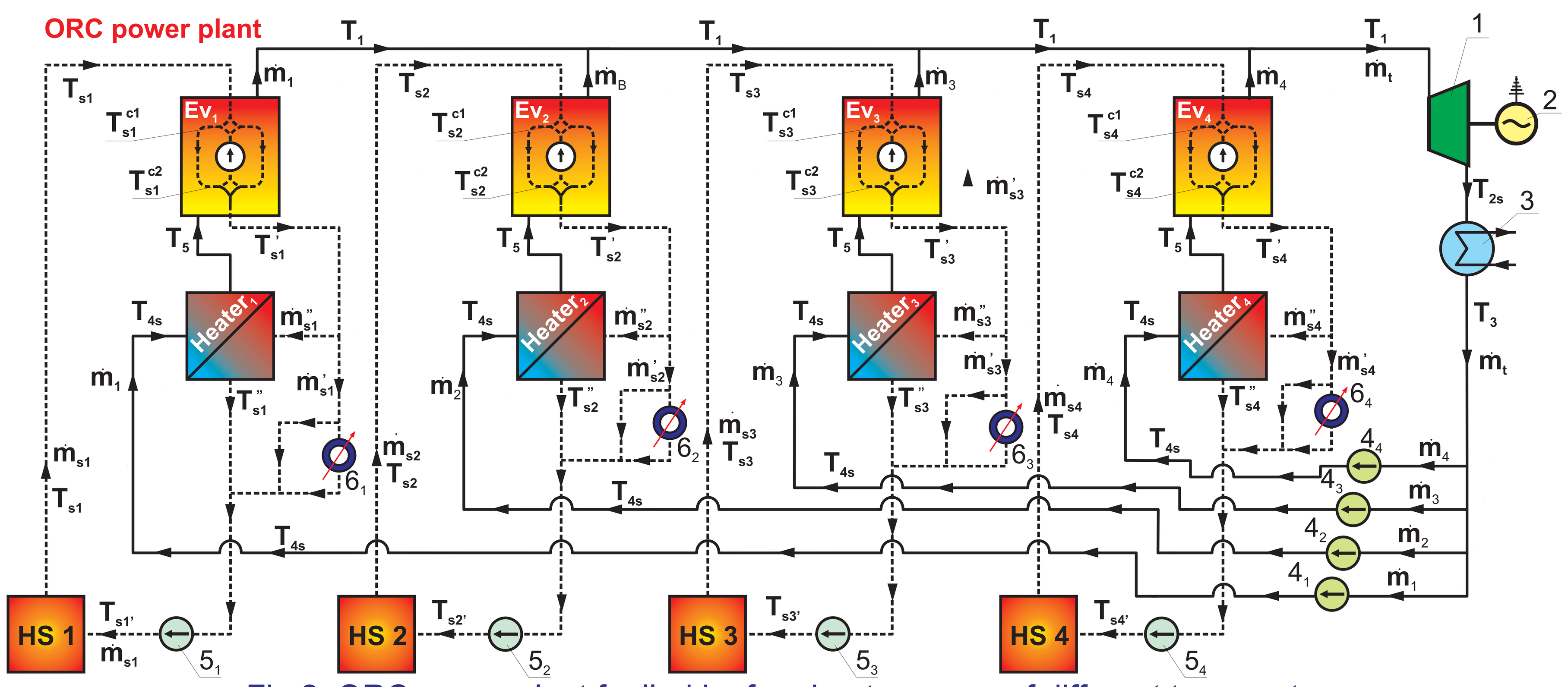

Fig.2. ORC power plant fuelled by four heat sources of different temperatures

The heat from the individual heat sources is carried by the four streams of hot water supplied from the local district heating system. The power plant incorporates an organic fluid vapour turbine that drives an electric generator. The turbine is supplied with the dry saturated vapour produced in the evaporators that are provided with the internal hot water circulation systems. The application of this type of evaporators enables, at proper adjustments of the internal circulation coefficients, that the dry saturated vapour delivered by each evaporator has equal temperature and pressure, independently from the temperature of the heat source being associated with the evaporator.

The dry saturated vapour generated in all evaporators is jointly directed to the turbine. After expansion in the turbine, the organic fluid vapour is directed to a condenser and, after condensation, by using the cycle pump it is directed to the pre-heaters. The organic liquid is then heated from the condensation temperature up to the evaporation temperature and is directed back to the respective evaporators.

The individual hot water streams are supplied to the appropriate evaporators and next to the pre-heaters, and leave the system at the prescribed temperature to secure the constant heat source temperature of the respective heat sources. Such temperature balancing system is achievable through application of the proper characteristics of the internal hot water circulation provided in the evaporators.

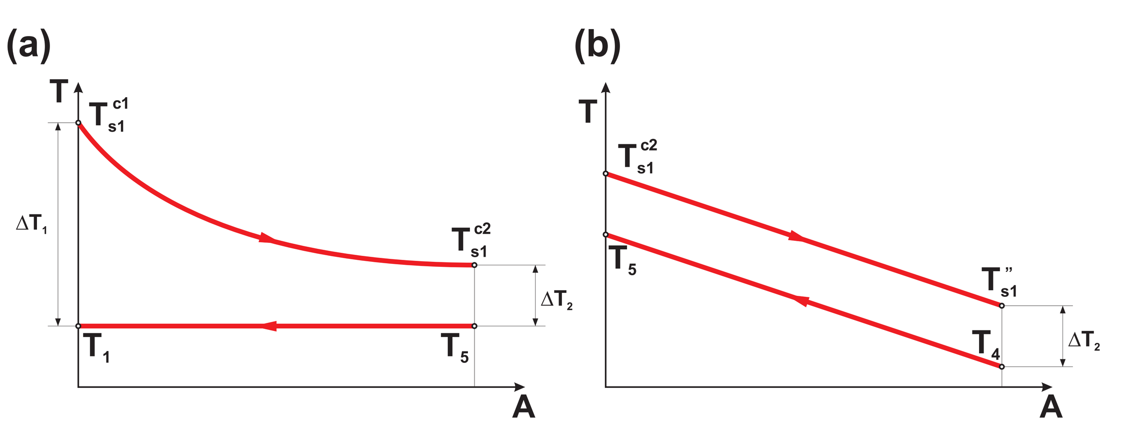

Fig.3. Temperature distribution in the evaporator (a) and pre-heater (b)

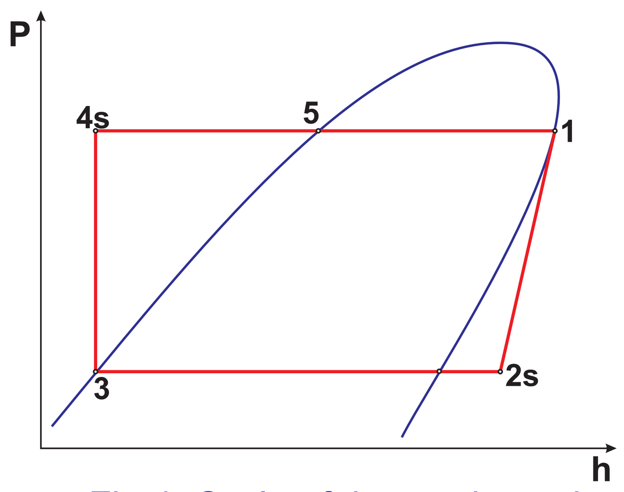

Fig.4. Cycle of thermodynamic changes of the C-R cycle for group I low-boiling fluids.

CALCULATION ALGORITHM

The internal circulation is characterized by circulation ratio of φ, which is defined as the relation of the return flow in the evaporator to the initial value of the heat carrier flow :

$$\varphi = \frac{\Delta \dot{m}_s}{\dot{m}_s}$$

The inlet and outlet district heating water temperature values for the evaporator with the internal circulation system have been calculated from the relations, respectively:

$$T^{c1}_{s1} = T_{s1} - \Delta T^{c}_{s1} \qquad T^{c2}_{s1} = T_{s1} - (1+\varphi)\Delta T^{c}_{s1}$$

On the basis of the converted equation of the energy balance for the evaporator the organic fluid mass flow in the Clausius-Rankine cycle was calculated from the following relation (for the heat source 1):

$$\dot{m}_1 = \dot{m}_{s1}\frac{c_s(1+\varphi)\Delta T^{c}_{s1}}{h_1 - h_5}$$

On the basis of the converted equation of the energy balance for the pre-heater the value of the hot water mass flow directed to the pre-heater was calculated from the following relation (for the heat source1):

$$\dot{m}''_{s1} = \frac{\dot{m}_1(h_1 - h_5)}{c_s(T'_{s1} - T''_{s1})}$$

RESULTS OF CALCULATIONS

The calculation results are given for the case when all four hot water streams delivered from the heat sources are equal to 1 kg/s.

Table 1. Performance parameters of the single cycle ORC power plant, with R227ea

	Evaporator characteristics				Parameters of the cycle						
	T_{s1} / T^{c}_{s2}	$\Delta T_1 / \Delta T_2$	j	T_{Ev}	$\dot{m}_n$	N_{C-R}	η_{C-R}	$\dot{Q}_{do}$	$\dot{m}_{s1}$	$\dot{m}_{s2}$	T_{s4}
	°C	K	-	°C	kg/s	kW	%	kW	kg/s	kg/s	°C
Ev 1	105 / 83	13 / 3	1,2	80	1,36	20,23	11,18	180,9	0,43	0,57	61,8
Ev 2	110 / 87	17 / 7	1,3	80	1,42	21,15	11,18	189,1	0,42	0,58	64,8
Ev 3	115 / 90	20 / 10	1,5	80	1,54	22,98	11,18	205,6	0,43	0,57	65,9
Ev 4	120 / 93	23 / 13	1,7	80	1,66	24,82	11,18	222,0	0,44	0,56	66,9
		ORC power plant			**4,31**	**64,26**	**11,18**	**574,77**			

Table 2. Performance parameters of the single cycle ORC power plant, with RC318

	Evaporator characteristics				Parameters of the cycle						
	T_{s1} / T^{c}_{s2}	$\Delta T_1 / \Delta T_2$	j	T_{par}	$\dot{m}_n$	N_{C-R}	η_{C-R}	$\dot{Q}_{do}$	$\dot{m}_{s1}$	$\dot{m}_{s2}$	T_{s4}
	°C	K	-	°C	kg/s	kW	%	kW	kg/s	kg/s	°C
Ev 1	105 / 83	13 / 3	1,2	80	1,28	18,78	11,07	169,7	0,38	0,62	64,5
Ev 2	110 / 87	17 / 7	1,3	80	1,34	19,63	11,07	177,4	0,37	0,63	67,6
Ev 3	115 / 90	20 / 10	1,5	80	1,45	21,34	11,07	192,8	0,38	0,62	68,9
Ev 4	120 / 93	23 / 13	1,7	80	1,57	23,05	11,07	208,2	0,39	0,61	70,2
		Siłownia ORC 3			**5,64**	**82,79**	**11,07**	**748,1**			

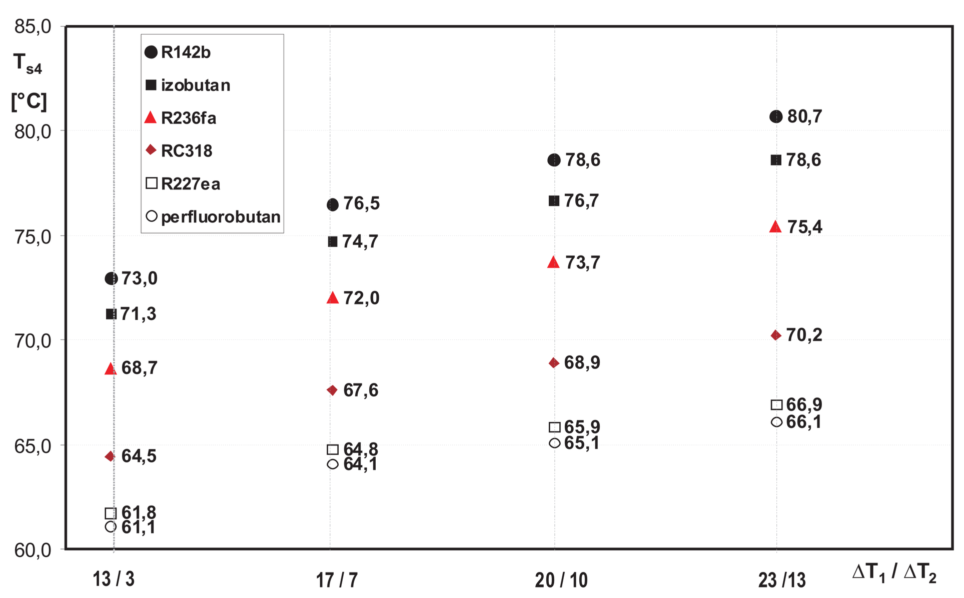

Fig.5. Influence of the organic fluid type and of the evaporator characteristics on the return water temperature of the individual heat sources (1, 2, 3, 4)

Analysis of various characteristics of the evaporators yielded the conclusion that the proper characteristic of the evaporator can result in the adjustment of the heat source return water temperature to the value that secures a constant heat flow delivered by that heat source. The diagram presented in Fig. 5 gives the return water temperature values for the individual heat sources. These values depend on the organic fluid selected and on the evaporator characteristics $\Delta T_1 / \Delta T_2$

The diagram presented in Fig. 6 gives the values of the analysed ORC power plant output N_{C-R} for the 6 organic fluids under consideration and at hot water supply from four different heat sources.for the individual heat sources. These values depend on the organic fluid selected and on the evaporator characteristics $\Delta T_1 / \Delta T_2$

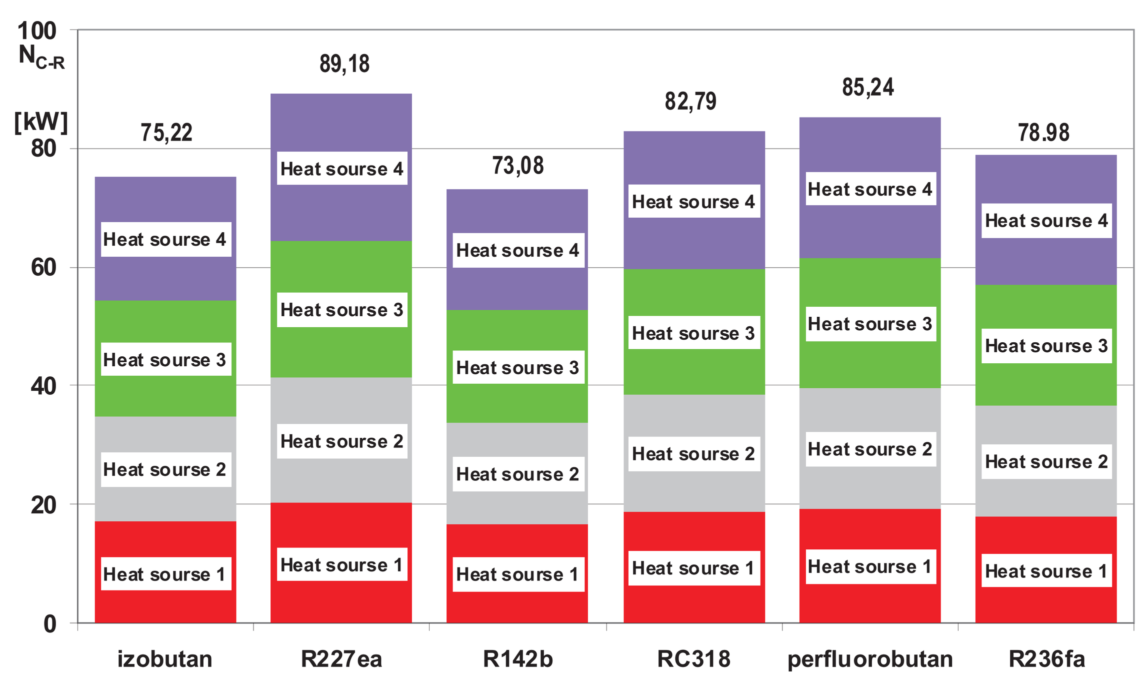

Fig. 6. Influence of the organic fluid selection on the ORC power plant output for the power plant fuelled by four different heat sources

COMMENTS AND FINAL CONCLUSIONS

The presentation of the new concept of the single cycle ORC power plant that is fuelled by several heat sources with different temperatures was the principal goal of the present work. This concept was explained on example of the power plant being fuelled by four district heating water streams of different temperatures and with a possibility to adjust the return water temperature to the value that is required to secure a constant heat stream to be supplied by the heat sources. The return water temperature depends on the type of the organic fluid applied in the power plant cycle and on characteristics of the evaporators that are equipped with the internal hot water circulation systems. This dependency, for each individual heat source, is presented in Fig. 6.