COMPARISON OF HEAT EXCHANGERS NA-CO_2 FOR NUCLEAR POWER PLANT WITH SODIUM COOLED FAST REACTOR

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Abstract: The study deals with alternative heat exchanger for NPP with sodium cooled fast reactor. At first there was performed a selection of possible conceptions of heat exchangers for given parameters of heat transfer media in secondary (terciary) cycle of NPP with sodium cooled fast reactor. From this comparison, the shell and tube heat exchanger with internally finned tubes was selected as the basic conception. Design and operational parameters of heat exchanger were optimized according to chosen criterions. In the summary of the study, there is a comparison of heat exchanger with internally finned tubes with heat exchanger with smooth tubes and the influence of internal fins on design and operational parameters is discussed.

Keywords: Heat exchanger, carbon dioxide, sodium

1. INTRODUCTION

Given the trend to increase in electric energy consumption and fuel cycle closing it is necessary to continuously develop new types of power plants, which would meet this demand and would be economical and ecologically acceptable at the same time. Nuclear power plants represent a stable power source of high performance and among other things the new power plants of generation IV are characterized by high level of passive safety.

The sodium cooled fast reactor (SCFR) seems as one of the most promising option of the generation IV reactors. For higher operational safety there can be carbon dioxide in the secondary (terciary) cycle working in the Brayton cycle instead of water (steam) working in the RC cycle. Due to the fact that carbon dioxide has worse thermo-physical properties in compare with water, reasoning is in place to improve the heat transfer on the side of carbon dioxide in the heat exchanger, e.g. with finned tubes.

At this point, it is desirable to consider the influence of using finned tubes on design and operational characteristics of heat exchangers. On one hand improved heat transfer can be expected, on the other hand this application will certainly lead to increased pressure loss, regardless of the negative influence of internally finned tubes during reactor shutdown. Author of this article find as contributing to perform calculations of heat exchanger with smooth tubes and heat exchanger with internally finned tubes and compare the results consequently.

2. INPUT PARAMETERS OF HEAT TRANSFER MEDIA FOR HEAT EXCHANGER CALCULATIONS

By the heat exchanger calculation, there is author’s effort to approximate the real situation as much as possible. From this reason, the used data will be taken from current projects and consequently the results can be used by solution of actual problems. So the input data are taken from the results of the 7th Frame Program of European Union, namely from the project European Sodium Cooled Fast Reactor (ESCFR).

Reference [1] gives following possible coolant parameters of ESCFR:

heat performance of one loop	600	[MW]
sodium temperature in the 2nd cycle at the output from heat exchanger	340	[°C]
sodium temperature in the 2nd cycle at the input to heat exchanger	525	[°C]

Tab. 1: Coolant parameters and heat performance of one loop of ESCFR [1]

For temperatures given in the Table 1, appropriate parameters of carbon dioxide were found in [2]. The study [2] deals with optimization of Brayton cycle with CO2 in application by sodium cooled fast reactor. Following parameters were found:

temperature of CO2 at the outlet from heat exchanger	520	[°C]
temperature of CO2 at the inlet to heat exchanger	323,8	[°C]
intermediate pressure of CO2	8,89	[MPa]

Tab. 2: Parameters of carbon dioxide proposed for thermal calculation of heat exchanger

3. POSSIBLE OPTIONS OF HEAT EXCHANGER

Two basic conceptions were selected which can be used in the application by NPP with sodium cooled fast reactor.

The first possible option is shell and tube heat exchanger in modular conception. Modular conception is characterized by high operational reliability, ease of fabrication, transportability on the site and repairability in the case of leakage increase. Shell and tube exchangers have also some disadvantages: high demand on material amount for fabrication and high amount of welds, which increase the material inhomogeneity.

The second possible option is plate heat exchanger, specifically PCHE type (Printed Circuit Heat Exchanger). The big advantage of this heat exchanger type is the homogeneity of corpus – the probability of leakage increase is strongly reduced. On the other hand, this type of heat exchanger is still under development and has never been used in application with sodium cooled fast reactor. In addition, it is a bit difficult to find information for calculation of this heat exchanger type.

From the comparison the shell and tube heat exchanger in modular conception was selected as the basic conception for further consideration. The selection was made due to the fact, that this type of heat exchanger acquitted oneself well in praxis and there is enough information for calculation.

The study [4] deals with calculation of Brayton cycle with carbon dioxide in the use by NPP with sodium cooled fast reactor. This study proposes to transfer the performance of one loop with six heat exchangers. So the heat exchanger will be calculated for the performance of 100 MW and it is assumed that six of these units will work in parallel lay-out to transfer the performance of one loop. It is assumed that sodium will be in inter tube space and carbon dioxide will be tubes. In order to enhance the heat transfer on the side of carbon dioxide, internally finned tubes will be used. Results of calculations of heat exchangers with internally finned tubes will be compared with results of calculations of heat exchangers with smooth tubes.

4. GEOMETRICAL CHARACTERISTICS OF HEAT EXCHANGER

By the calculation of heat exchanger more geometrical options were considered which differed in the outer diameter of heat transfer tubes, in number of heat transfer tubes and in adequate inner diameter of heat exchanger shell. From the different options the most fitting one was selected.

4.1. CONSIDERED OUTER DIAMETER OF HEAT TRANSFER TUBES

There was an effort to approximate the real conditions for heat exchanger calculation and so industrially produced seamless tubes were considered. The seamless tubes were chosen from catalogue [3].

Data given in the Tab. 3 are shown for internally finned tubes. Further, three types of smooth tubes are considered which have the same outer diameter and wall thickness as internally finned tubes. Mutual comparison of results for smooth and internally finned tubes will lead to determination of influence of internal fins on the heat exchanger parameters.

		Tube nb.1	Tube nb.2	Tube nb.3
outer diameter	D [mm]	24	28	30
wall thickness	T [mm]	2,5	3	3
number of fins	n [-]	8	8	8
height of fins	h [mm]	0,7	0,7	0,7
width of fins	s [mm]	3	3	3
helix angle of fins	α [°]	35	35	35

Tab. 3: Considered types of internally finned tubes for heat exchanger calculations.

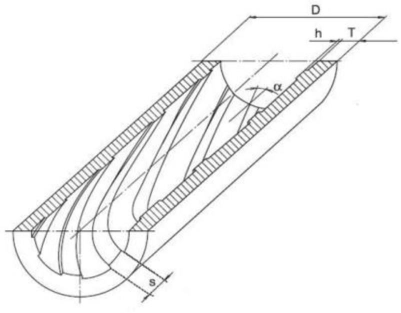

Fig. 1: Schematic cross section of internally finned tube [3]

4.2. NUMBER OF HEAT TRANSFER TUBES AND INNER DIAMETER OF HEAT EXCHANGER

There was a requirement during heat exchanger calculations – the heat exchanger should contain maximal number of heat transfer tubes to efficiently use the cross section of the heat exchanger. Tab. 4 shows the number of heat transfer tubes (in triangle lay-out) which fills completely the inner cross section of heat exchanger shell for given diameter (according to regulation ČSN 69 0010).

	Tubes in tube bundle	Inner shell diameter [mm]		
	[-]	(heat exchanger with the tube ø24)	(heat exchanger with the tube ø 28)	(heat exchanger with the tube ø 30)
1	241	597,6	665,6	699,6
2	301	666,8	742,8	780,8
…	…..			
9	1045	1220,4	1360,4	1430,4
10	1165	1289,6	1437,6	1511,6
11	1303	1358,8	1514,8	1592,8

Tab. 4: Internal diameters of heat exchanger and number of heat transfer tubes in tube bundle

5. ASSESSMENT CRITERIONS FOR SELECTION OF THE MOST SUITABLE VARIANT OF HEAT EXCHANGER

Conceptions of heat exchanger variants shown in the Tab. 4 led to many results. It was necessary to select criterions according which the most suitable option of heat exchanger. Following assessment criterions were proposed:

- **modified specific weight** – this criterion expresses the sum of weight of heat transfer tubes and weight of tube wall. The sum is divided by heat performance of heat exchanger; this criterion is also a parameter expressing economical costs for building of one heat exchanger module
- **allowable length of the heat exchanger module** – this criterion expresses the length of module, which is limited by the maximal producible length of seamless tubes. In the case that the calculated length of tube bundle is longer than maximal length of seamless tubes, it is necessary to divide the heat exchanger into more modules
- **average specific heat flux through heat transfer area** – this parameter expresses the specific heat flux which has an influence on the lifetime of heat exchanger
- **inner diameter of shell -** this parameter expresses that the number of heat transfer tubes, which can be placed into heat exchanger cross section, is limited
- **total pressure loss on the side of sodium -** this parameter describes the pressure losses of sodium which can be considered as one of the operational costs of heat exchanger

6. ASSESSMENT OF CALCULATION RESULTS AND CONCLUSION

In the following Tab. 5 there are shown the basic calculation results of heat exchanger with internally finned tubes and smooth tubes. Whereas the fact that the calculated total length of tubes in the tube bundle overcame the maximal producible length of seamless tubes (according to the producer data [3]), it would be necessary to divide the heat exchanger into more identical modules which would be arranged serially.

		heat exchanger with smooth tubes	heat exchanger with internally finned tubes
shell internal diameter	[mm]	1220,4	1220,4
tube number	[-]	1045	1045
needed total length of tube bundle	[m]	74,5	50,8
number of modules	[-]	5	3
length of the tube in the module	[m]	14,9	16,9
average specific heat flux	[kW/m^2]	24,1	35,1
total pressure loss of Na	[kPa]	101,7	64,1
total pressure loss of CO2	[kPa]	1172,8	1124,2
estimation of modified specific weight	[kg/MW]	1288,4	951,7

Tab. 5: Comparison of calculated parameters of heat exchanger with smooth tubes and with internally finned tubes for the temperatures and pressures of heat transfer media in Tab. 1 and Tab. 2

Both units of heat exchangers are identical in the number of heat transfer tubes and in internal diameter of heat exchanger shell. It is apparent that heat exchanger with internally finned tubes has much shorter tube bundle and so it can be divided into less number of heat exchanger modules. This fact indirectly expressed in the estimation of modified specific weight which is also lower by the heat exchanger with internally finned tubes. This parameter is one of the indicators indicating the investment costs. The length and number of modules have a substantial influence on pressure losses of heat transfer media, which are one of the indicators indicating the operational costs of heat exchanger. It is apparent from the comparison that pressure losses on the side of carbon dioxide are almost the same for both cases. The pressure loses on the side of sodium are lower by the heat exchanger with internally finned tubes than by the heat exchanger with smooth tubes.

Average specific heat flux is higher by the heat exchanger with internally finned tubes as consequence of the lower heat transfer area. It can be mentioned that both values are very small.

On the other the inspection feasibility of heat transfer tubes should be considered. In the case of smooth tube it is possible to inspect the tubes by conventional methods, e.g. eddy current. Due to the fact that internally finned tubes have complex shape, their inspection can be performed just by visual method.

ACKNOWLEDGEMENT

Author of the study thanks the Ministry of Industry and Trade of the Czech Republic for financial support by solution of the project 2A-1TP1/067. Based on this support this study could increase.

The principal author, the holder of Brno PhD Talent Financial Aid sponsored by Brno City Municipality, also gratefully acknowledges for that financial support.

REFERENCES

[1] *FISA 2009 : Seventh European Commission conference on Euratom research and training in reactor systems*. Španělsko: Neuvedeno, 2010c. 718 s. ISBN 13-978-92-79-13302-2.

[2] [2] FIEDLER, J.; ŠEN, H. Výzkum parametrů a vlastností Braytonova cyklu pro pokročilý rychlý reaktor. Energetický ústav, Odbor enegetického inženýrství, FSI, VUT v Brně: FSI, VUT v Brně, 2008. s. 1-48.

[3] *Katalóg výrobkov : spoločnosti na rok 2009* [online]. 6. vydanie. Podbrezová : Železiarně Podbrezová, a.s., 2008 [cit. 2010-02-28]. Dostupné z WWW: <http://www.zelpo.sk/>.

[e-kniha]

[4] NETOPILOVÁ, P. *Systémy přeměn energie pro jaderné elektrárny se sodíkem chlazeným reaktorem (SFR)*. Brno: Vysoké učení technické v Brně, Fakulta strojního inženýrství, 2011. 110s. Vedoucí diplomové práce prof. Ing. Oldřich Matal, CSc.

[5] FORAL, Š. *Výměníky tepla sodík-oxid uhličitý pro JE se sodíkem chlazeným rychlým reaktorem (SFR).* Brno: Vysoké učení technické v Brně, Fakulta strojního inženýrství, 2011, 69 s. Vedoucí diplomové práce: prof. Ing. Oldřich Matal CSc.