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EXPERIMENTAL STUDY ON THERMAL AND FLOW PROCESSES IN SHELL AND TUBE HEAT EXCHANGERS
- influence of baffle cut on heat exchange efficiency -

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Abstract. *Experimental investigations were done to identify influence of thermal and flow quantities and shell side geometry on STHE's heat exchange intensity. In this paper special attention was paid to segmental baffle cut influence on apparatus efficiency.*

Key words: *Shell and Tube Heat Exchanger, Experimental Research, Baffle Cut*

1. INTRODUCTION

Shell and tube heat exchangers (STHE's) are apparatuses in which the heat exchange between hoter and colder fluid is done. Fluid flowing through tubes is called – tube fluid, and fluid flowing around tube bundle is called – shell side fluid. Baffles, placed in shell side space, are providing the cross flow direction of shell side fluid and so the more intensive heat exchange between fluids could be realized. Besides, baffles are carriers of tube bundle, which helps them to decrease the deflection in horizontal and vibrations in horizontal and vertical units. STHE's usually have combined fluid flow, which means that there is parallel in one, and counterflow in other part of the exchanger. These apparatuses are usually denoted as m-n STHE's, where *m* is the number of fluid passes through the shell, and *n* is the number of fluid passes through the tube bundle [9, 14]. If the STHE is with so called "full tube bundle", the shell side fluid flows through baffle cuts along the tubes. On the shellside, there is not just one stream, beside a main cross-flow stream the four leakage or bypass streams exist as a result of design type: baffle to tubes, baffle to shell and tube bundle to shell gaps (tube – to – baffle hole leakage stream, bundle bypass stream, pass – partition bypass stream and baffle – to – shell leakage stream).

One of STHE manufacturer's main goals is to improve their exploitation reliability and efficiency. Two approaches in STHE design improving are possible: experimental inves-

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tigation and numerical investigations. Experimental investigations are very expensive and long lasting, because of shell side complex geometry. Numerical simulations can be used to check the old design and to develop a new more efficient STHE design. Shellside flow is almost always turbulent since tube bundle and baffles are very nice turbulent promoters [5, 7, 13, 15]. Character of flow around some tube rows in tube bundle is strongly influenced by tube layout (square, rotated square, triangular, rotated triangular, circular). Character of flow around the tubes has a direct influence on heat exchange between fluids. Problem is more complex if heat transfer is simultaneous with phase change. Since the detailed measurements of turbulent characteristics of shellside fluid flow are almost impossible, the calculated fields of pressure, velocity, temperature as well as turbulent characteristics are of great significance in explaining very complex thermal and flow processes in STHE's.

Basically, one can conclude that heat transfer between fluids in STHE's is highly influenced not only by thermal and flow quantities, such as inlet temperatures and velocities, but also with baffle cut size, baffle spacing, size of inlet and outlet zones and number of baffles [1, 2, 3].

To investigate influence of mentioned parameters, thermal, flow and geometric, or by other words, to find the "apparatus response" to thermal and fluid quantities and shell side geometry, in steady regime, by experimental and numerical methods, it was necessary to conceive of one compact experimental STHE.

In this paper special attention was paid to segmental baffle cut influence on apparatus efficiency.

2. EXPERIMENTAL INVESTIGATION

2.1. Experimental installation and principle of operation

Experimental STHE, type 1-2U, was projected and manufactured in cooperation with firm "MIN Inzinjering" from Niš. A measuring place was formed in the boiler house of the Mechanical Engineering Faculty in Niš. Experimental installation is shown in Photograph 1, and schematic in Figure 1.

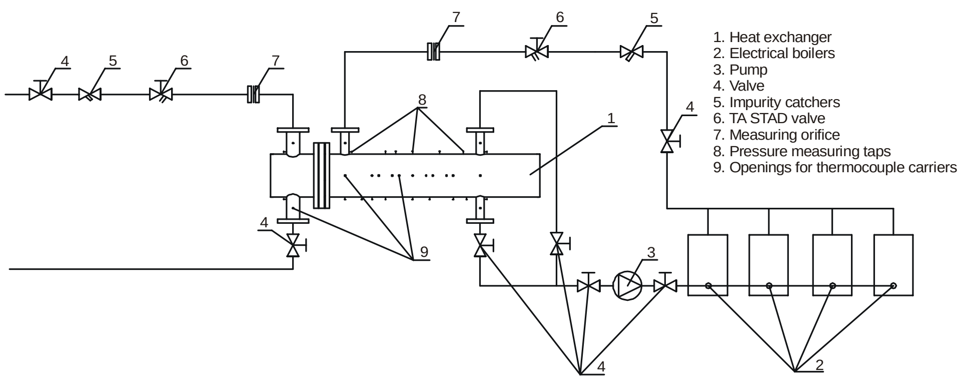
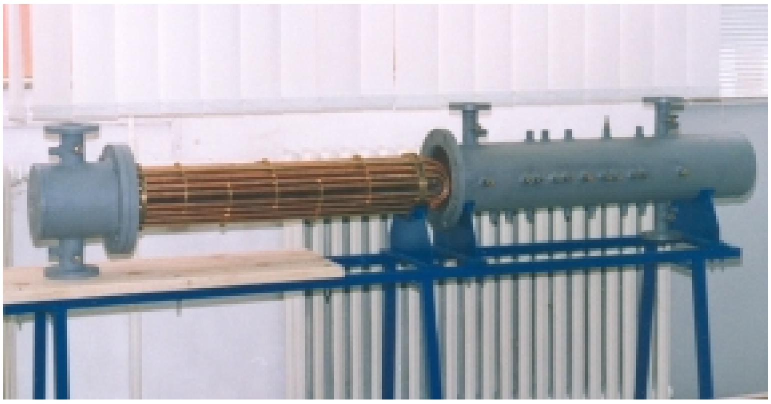


Fig. 1. Experimental installation (schematic)

Photograph 1. Experimental installation

The main parts of the installation are denoted with numbers from 1 to 9. Basic part of the installation is STHE (1), type 1-2U, which is shown in Photograph 2. Tube bundle is made of copper U-pipes, Φ15/13 mm, with rotated triangular tube layout and tube pitch of 21mm. There are 48 tubes in the tube bundle. STHE's active area for heat exchange is $1.9m^2$. Shell is made of carbon steel, Φ193.7/182.9mm. STHE's full length is 1217mm.



Photograph 2. Experimental shell and tube heat exchanger

Taps (8) for pressure drop measurements are set up on the shell, along with openings for thermocouple carriers (9). Positions where the temperature is measured are shown in Figure 2. Three packages of segmental baffles with baffle cuts of 22%, 27% and 32% are located in the shell. There are 5 segmental baffles in every package. Segmental baffles and horizontal baffle are made of copper. Two measuring test sections with impurity catchers (5), measuring orifice (7) and TA-STAD valves (6) are made. There are long enough straight pipe sections before and after the orifice in order to stabilize the water flow. Water flow regulation is done with valves (4). Heating of water up to certain temperature is done with four electrical boilers (2), with 30KW of power. Water temperature adjustment is provided with a variable transformer connected to one of the boiler heaters.

The heating fluid is warm water, and the cold water from the local water supply was heated. Flowing of the heating fluid through the shell is done by circulation pump (3).

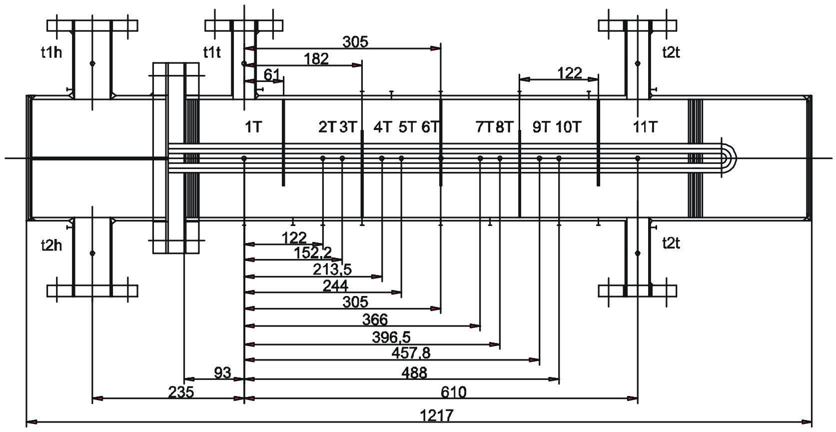


Fig. 2. Position for temperature measurements

2.2. Operation parameters and their range of changing

Experimental investigation is done under summer ambient conditions in the period May-September 2003. In all experiments constant volume flow rate ($9m^3/h$), as well as inlet temperature (15^0C) of cold fluid were maintained. Volume flow rate of heated fluid ($3m^3/h$, $4m^3/h$, $5m^3/h$) and temperature (50^0C, 60^0C) were varied at the inlet. At the beginning the series of experiments without baffles in the shell were done. After that, baffles (with baffle cut of 22% and 26% and 32%) were set into the shell (one, two, three, four and five baffles). Six experiments were done for every geometric configuration. Finally a series of experiments was done with one segmental baffle (baffle cut 22%), in which the baffle to shell leakage flow was eliminated, by using rubber sealing placed between baffle and shell.

3. EXPERIMENTAL RESULTS

Heating and heated fluid volume flow rate measurements were done with standard measuring orifices, as well as on the basis of pressure drop measurements on TA-STAD valves with CBI acquisition system (Computerized Balancing Instrument).

Pressure in the closed circulation heating fluid circle was measured with laboratory mechanical manometer. In all experiments manometer indicators were in the range of 3÷3.5bar.

Pressure drops in the STHE's tube bundle and on orifices were measured by the hydrostatic manometer (U-pipe with mercury). In the performed measurements the average tube bundle pressure drop was 3710Pa.

STHE's shell side pressure drops were measured by specially made system consisting of taps set up on the shell, transparent plastic hoses, collector with 16 connections, valves, shanks, millimeter partitioned scale and hand pump (see Photograph 2.1).

During each experiment, after accomplishing steady state heat exchange regime (which was accomplished after 25-30 min. in experiments done), fluid temperatures are measured with 16 previously calibrated chromel-allumel thermocouples of 0.2mm diameter, using the Hewlett-Packard acquisition system. Cold sides of all thermocouples were sunk into insulated tank filled with 1:2 water and ice mixture. All thermocouples were set into so called thermocouple "movable supports". Apparatus inlet and outlet, heating and heated fluid temperatures (five thermocouples), as the heating fluid temperatures in the central shell's plane and 5mm from the shell wall (Figure 3), on eleven formerly defined locations along the STHE, were measured. Heated fluid inlet temperatures in the beginning, and outlet temperatures in the end of the experiment were controlled with a mercury thermometer. This thermometer was also used for ambient temperature measurements.

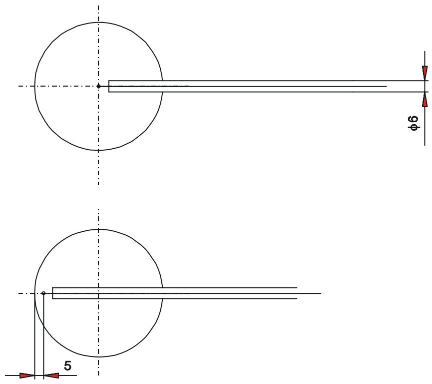


Fig. 3. Position of thermocouple joint

Measuring results are showed in the form of diagrams. On the x-axis the measuring position is shown, and temperature value on the y-axis.

In this paper the experimental results for the case without baffles in shell and for the case with one baffle (baffle cut 22%, 26%, 32%) placed at middle position, are shown.

Figures 4 - 7 show the heating fluid temperature change along the STHE's axis and on 5mm from the shell wall.

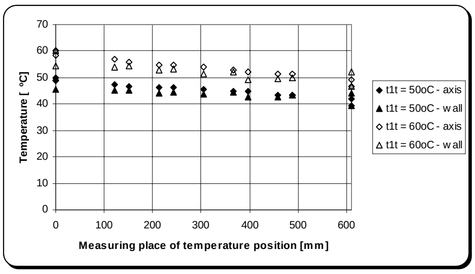


Fig. 4. Heating fluid temperature change along the STHE's axis and on 5mm from the shell wall for $V_t = 5 m^3/h$ (no baffle)

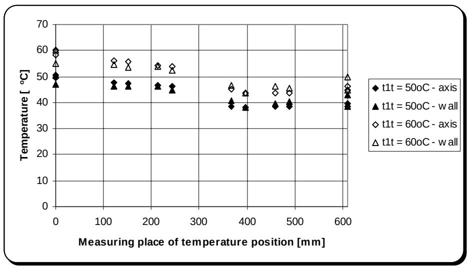


Fig. 5. Heating fluid temperature change along the STHE's axis and on 5mm from the shell wall for $V_t = 5 m^3/h$ and baffle cut 22%

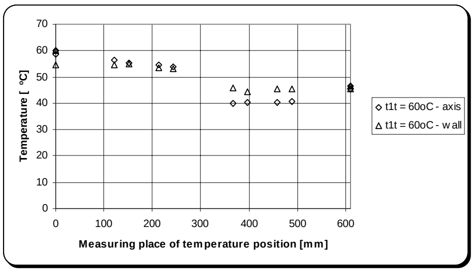


Fig. 6. Heating fluid temperature change along the STHE's axis and on 5mm from the shell wall for $V_t = 5 m^3/h$ and baffle cut 26%

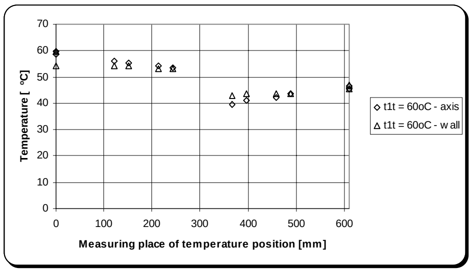


Fig. 7. Heating fluid temperature change along the STHE's axis and on 5mm from the shell wall for $V_t = 5 m^3/h$ and baffle cut 32%

Figure 8 show the heating fluid temperature change in the STHE's axis depending on the baffle cut.

Figure 9 shows the apparatus heat efficiency for three different baffle cuts and for the case with no baffle.

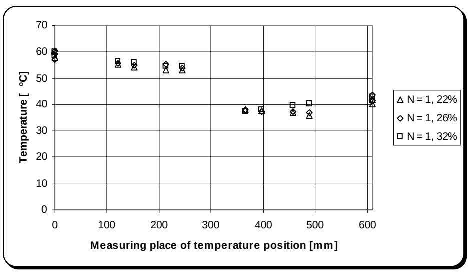


Fig. 8. Heating fluid temperature change along the STHE's axis for $V_t = 3 m^3/h$ and $t_{1t} = 60^oC$

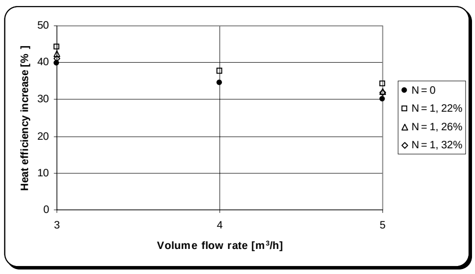


Fig. 9. Apparatus heat efficiency for three different baffle cuts and for the case with no baffle, for $t_{1t} = 60^oC$

4. DISCUSSION OF THE RESULTS

Results of the experiments done show that STHE's heat exchange strongly depends on the shell side geometry (number of segmental baffles, baffle cut size, baffle distance, the first and the last baffle position to inlet and outlet nozzle, respectively, size of the constructive clearances).

With the experimental results analysis the following can be concluded:

- Shell side baffle strongly influences the fluid flow characteristics and cause vortex appearance (downstream from the baffle);
- Downstream fluid temperatures are significantly lower (up to 10^0C downstream from the baffle) which is caused by intensive heat exchange in the cross flow ahead and before the baffle, and by axial flow in the baffle cut. Certainly, this is also caused by baffle to shell leaking, and by cooling of the fluid through the shell wall;
- Increasing of heating fluid volume flow rate decreases temperature drops downstream from the baffle;
- Increasing of the heating fluid inlet temperature, and/or flow rate maintains temperature change character in the axis and near the shell wall;
- The most intensive heat exchange is in the STHE's inlet zone (up to the first baffle)
- Heating fluid temperature near the shell wall is lower, compared to the heating fluid temperature in the STHE's axis, up to the first baffle, and after the first baffle situation is reversed, which is consequence of the baffle to shell leaking, because it doesn't take place in the heat exchange;
- When segmental baffles are present in HE shell, values of heat characteristics are increasing. For example, for case of one segmental baffle with baffle cut of 22%, at $t_{1t} = 60^oC$ and $V_t = 5m^3/h$, HE heat eficiency [5, 10, 11] is increasing for 13.6% comparing to the case without baffles in a shell.
- HE heat efficiency is decreasing with increasing of baffle cut from 22% to 32%. For the above case, apparatus heat efficiency increase with one baffle with cut of 26% was 6.9% and for baffle cut of 32% was 5.6%, comparing with case without baffles in a shell.

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EKSPERIMENTALNO ISTRAŽIVANJE TERMO-STRUJNIH PROCESA U DOBOŠASTIM IZMENJIVAČIMA TOPLOTE
- uticaj veličine okna pregrade na efikasnost razmene toplote -

Nenad Radojković, Gradimir Ilić, Žarko Stevanović, Mića Vukić, Dejan Mitrović, Goran Vučković

Eksperimentalno istraživanje izvršeno je u cilju ispitivanja uticaja termo-strujnih veličina i geometrije međucevnog prostora na intenzitet razmene toplote kod dobošastih izmenjivača toplote. U ovom radu posebna pažnja posvećena je ispitivanju uticaja veličine okna pregrade na toplotnu efikasnost aparata.

Ključne reči: *Dobošasti izmenjivač toplote, eksperimentalno istraživanje, veličina okna pregrade*