OVERALL ENERGY BALANCE AND HEAT TRANSFER IN A SHELL AND TUBE HEAT EXCHANGER

[1]QAZIZADA MOHAMMAD EMAL [2]PIVARCIOVA ELENA

[1,2]Technical University in Zvolen, Faculty of Environmental and Manufacturing Technology, Department of Manufacturing and Automation Technology Masarykova 24, 960 53 Zvolen, Slovakia
E-mail: [1]qazizada198@gmail.com [2]pivarciova@tuzvo.sk,

Abstract - The shell and tube heat exchanger is one of the most common exchangers which is wieldy used in many engineering processes. This concentric shell and tube heat exchanger allows the study of heat transfer between hot water flowing through an internal tube and cold water flowing in the ring area lying between the internal and external tubes, and this shell and tube heat exchanger allows measuring hot and cold water temperatures in different points of the exchanger. The objectives of this paper determine to formulate a global energy balance in a shell and tube heat exchanger and to study the heat losses, firstly focuses to study the heat transfer in countercurrent and parallel flow and to measure the temperature profile in a shell and tube heat exchanger. An addition to calculate the overall heat transfer coefficient using criteria equations, also focused to draw the temperature profile of the heat exchanger for both configurations countercurrent and parallel flow with temperature on the axial axis and thermocouple position on the horizontal axis. Furthermore discussed the behavior of temperature across the heat exchanger and compare the countercurrent and parallel flow arrangements.

Keywords - Energy balance, heat transfer, overall heat transfer coefficient

I. INTRODUCTION

A heat exchanger is a device originally developed for heat transfer between two fluids at different temperatures separated by a solid wall. They have many applications in engineering such as food industry, oil and petrochemical industries, electric power generation, and, as a consequence, there are many models adapted to each application. The simplest exchanger consists of two concentric tubes, where fluids can move in the same or opposite directions. The other common configuration is the shell and tube exchanger constituted by a group of tubes inside an external tube (shell). Among the various types of heat exchangers, the shell and tube heat exchangers find a wide range of applications, while around 35–40 % of all the heat exchangers, used in all kinds of industrial applications, are shell and tube heat exchangers (STHE) [1] [3]. The behavior of the fluid inside the internal circulation system of a shell and tube heat exchanger is complex due to the influence of many factors. The flow distribution has a significant influence on the performance of fluidic apparatus such as shell and tube heat exchangers. Several types of heat exchangers exist and choosing the appropriate type for a given process is not a trivial procedure [4]. The one of frequently used type is the tubular heat exchanger, which has the advantage of offering a large heat transfer surface and a compact design. The key design aspect of this type of exchangers is to make the distribution of the flow as uniform as possible [5][6] [14]. A lot of experimental and numerical studies on structure parameters of the shell and tube heat exchanger have been conducted in recent years. In another recent study of the optimization of the shell and tube heat exchanger, [2] proposed a method, motivated by constructed theory. In this method, a global heat exchanger is divided into several sub heat exchangers in series-and-parallel arrangement [14]. Li-Zhi Zhang investigated the flow unfavorable and thermal performance deterioration in cross-flow air to air heat exchangers [7] and in a parallel plate's membrane core case [8]. The flux in the dividing collectors was formulated by a standard equation by the works of Wang [9] [10] [11]. Diverse baffles shapes are exploited to enhance the shell side thermal performance of the shell and tube heat exchangers, [15] by their experimental investigations of fluid flow and heat transfer in a shell-and-tube heat exchanger with one pass of warm water on the shell side and two passes of cold water in tube bundle, proved that the STHE's heat exchange performance is strongly depending on the shell side geometry parameters [16]. Zhen-Xing Li and Li-Zhi Zhang investigated the flow unfavorable distribution and the consequent performance deteriorations in a cross flow and in a counter flow hollow fiber membrane module, they found that the packing fraction affects the flow unfavorable distribution substantially [12]. Mohammadi and Malayeri proved that the unfavorable distribution in the turbulent regime is not a function of Reynolds number, but it depends considerably on the geometrical characteristics of the heat exchanger regardless of the exchanger type. They reported that the geometrical parameters affect the flow distribution in the shell and tube heat exchangers [13]. The novelty of this work is to formulate a global energy balance in a shell and tube heat exchanger and to study the heat losses [14]. Sanaye et al, optimized the shell and tube heat exchangers to obtain the maximum effectiveness (heat recovery) and the minimum total cost [17] [18]. Hajabdollahi et al, perform economic optimization of STHE with nine decision variables and genetic algorithm as an optimization tool. The authors also present the sensitivity of design variable on optimum value of objective function [19]. Khosravi et al, investigates the performance of three different evolutionary algorithms for economic optimization of STHE [20] [21].

II. EQUIPMENT DESCRIPTION AND ITS PERFORMANCE

The heat exchanger consists of a group of tubes inside a shell. The hot water flows through the internal tubes and cooling water circulates in the space between the internal and the external tubes. There are traverse baffles placed in the external tube to guide the cold water and maximize the heat transfer. The shell and tube heat exchanger has 8 thermocouples placed strategically: 5 for measuring cold water temperature (ST-3, ST-4, ST-5, ST-6 y ST-7), 2 for measuring hot water temperature (ST-1 and ST-2), and 1 for measuring the temperature inside the heating tank (ST-16). The hot flow streams of water are C-1, C-4 and the cold flow streams are C-2, C-3. These exchangers usually feature baffles to increase the heat transfer as shown in Figure 1.

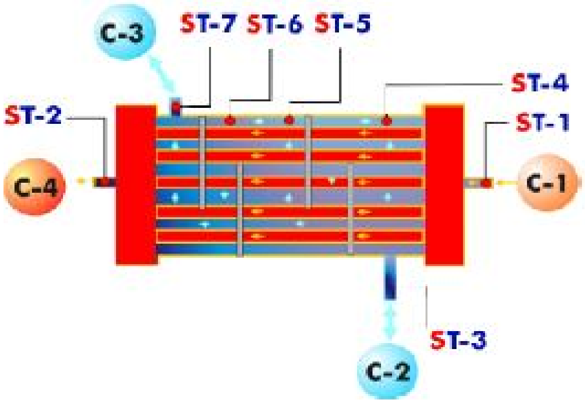

Figure 1 Shell and Tube Heat Exchanger [24]

The flow arrangement in a shell and tube heat exchanger can also be parallel or countercurrent. For detail dimensions of the shell and tube exchanger form Edibon Company, see Figure 2, which we have done experimented work.

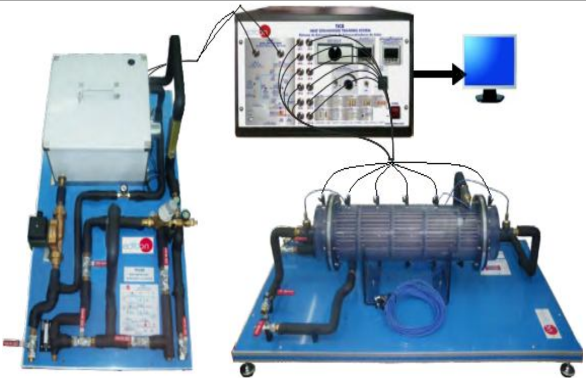

Figure 2 The Experimental Unit of Shell and Tube Heat Exchanger [23]

The scheme of experimental apparatus for experiment work and the sensors which are set in equipment are shown in Figure 3, determined as follows:

- ST-16 Water tank temperature sensor
- ST-1 Hot water temperature sensor at the inlet of the exchanger
- ST-2 Hot water temperature sensor at the outlet of the exchanger
- ST-3 Cold water temperature sensor at the inlet/outlet of the exchanger
- ST-4 Cold water temperature sensor in the first section of the exchanger
- ST-5Cold water temperature sensor in the second section of the exchanger
- ST-6 Cold water temperature sensor in the third section of the exchanger
- ST-7 Cold water temperature sensor at the inlet/outlet of the exchanger
- SC-1 Hot water flow sensor
- SC-2 Cold water flow sensor
- AVR-1 Hot water flow regulation valve
- AVR-2 Cold water flow regulation valve
- AN-1 Water tank level switch
- AR-1 Electric resistance
- AB-1 Hot water flow centrifugal pump
- AV-2,AV-3, AV-4, AV-5 Cold water circuit ball valves to set parallel / countercurrent flow
- AV-1, AV-6 Ball valves for pipe draining

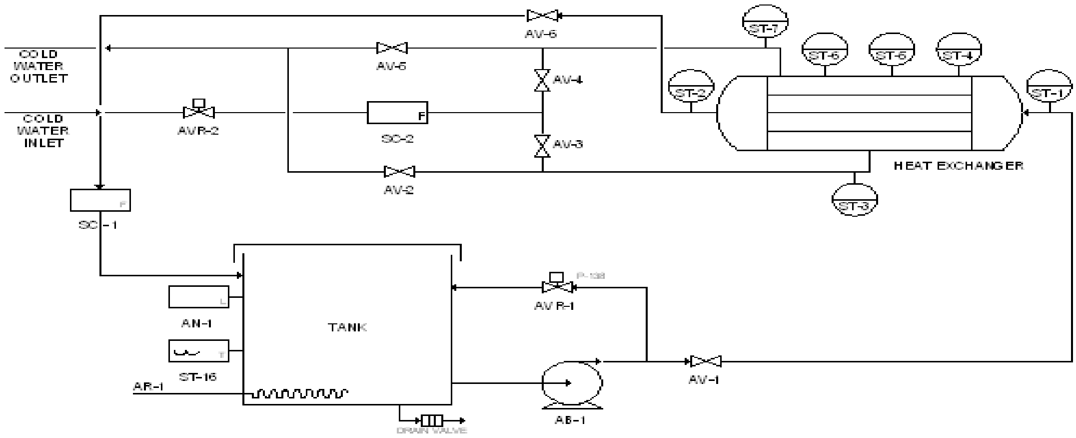

Figure 3 Schematic of the Experimental Unit [25]

The performance of the fluid inside the internal circulation system of a shell and tube heat exchanger in parallel and counter current arrangement described as follows:

2.1 Hot water circuit

Hot water flows through a closed circuit. An electrical resistance (AR1) immersed in the tank heats the water to a certain temperature (ST-16). Water leaves the tank and is driven by a pump (AB-1) into the exchanger. Some amount of water enters the exchanger and some returns to the tank via a bypass. To facilitate this, a bypass valve (AVR-1) is included. Water is cooled along the exchanger then it flows through a flow sensor (SC-1) as it exits and later flows back into the heating tank and the cycle is repeated. For drainage and control of hot water, the circuit is equipped with 4 ball valves: 2 at the base unit (AV-1 and AV-6) and 2 at the inlet and outlet of the exchanger.

2.2 Cold water circuit

Cooling water enters from the main net, goes through a flow control valve (AVR-2) then through a pressure regulator programmed at 0.5 Bar to avoid any excess pressure on the equipment. Before entering the exchanger, it goes through a flow sensor (SC-2) and then into the exchanger where it is heated. Water exits the exchanger and flows to the drainage system. Cold water can enter the exchanger at either end. Depending on the configuration of the valves (AV-2, AV-3, AV-4 and AV-5), parallel or countercurrent flow can be obtained.

III. ENERGY BALANCE OF A HEAT EXCHANGER

If there are no changes of phases in the heat exchanger, the heat flow from the hot fluid can be calculated by the equation:

$$q_h = m_h c_{ph}\ (t_{h,in} - h_{h,out})$$

The heat flow to the cold fluid is:

$$q_c = m_c c_{pc}\ (t_{c,out} - h_{c,in})$$

Where m_h and m_c are the mass flows (kg s^{-1}), and c_{ph} and c_{pc} ($Jkg^{-1}K^{-1}$)are the specific heat capacities of the hot and cold fluids.

Theoretically, q_h should equal q_c, but due to environmental energy losses and also due to instrumental and observational measurement errors, they are not always equal.

IV. OVERALL HEAT TRANSFER COEFFICIENT IN A SHELL AND TUBE HEAT EXCHANGER

Transfer of heat from the hot fluid with temperature t_{f1} to the solid wall or from the wall to the cold fluid with temperature t_{f2} occurs by the mechanism of conduction. It can be expressed in terms of the Newton equation:

$$q = \alpha_1 A_1\ (t_{f1} - h_{w,in})$$
$$q = \alpha_2 A_2\ (t_{w,ex} - h_{f2})$$

where q (J s^{-1}) represents the heat transferred per unit of time, A (m^2) is the heat transfer surface area, α_1 (J m^{-2} K^{-1}) and α_2 are the heat transfer coefficients in hot and cold fluid, respectively, ($t_{f1} - t_{w,in}$) denotes the local driving force from the hot fluid to the solid wall and ($t_{w,ex} - t_{f2}$) the local driving force from the solid wall to the cold fluid. The heat transfer in homogeneous solid materials is known as heat conduction and it follows the Fourier's law:

$$q = \alpha_1 A_1\ (t_{f1} - h_{w,in})$$
$$q = \alpha_2 A_2\ (t_{w,ex} - h_{f2})$$

where q (J s^{-1}) represents the heat transferred per unit of time, A (m^2) is the heat transfer surface area, α_1 (J m^{-2} K^{-1}) and α_2 are theheat transfer coefficients in hot and cold fluid, respectively, ($t_{f1} - t_{w,in}$) denotes the local driving force from the hot fluid to the solid wall and ($t_{w,ex} - t_{f2}$) the local driving force from the solid wall to the cold fluid. The heat transfer in homogeneous solid materials is known as heat conduction and it follows the Fourier's law:

$$q = -\ kA\ \nabla t$$

Where k (J m^{-1} K^{-1}) is the thermal conductivity of the material and $\nabla t$is the temperature gradient. When the transfer of heat from the hot fluid to the cold fluid through a separation wall is studied, we talk about overall heat transfer.

In the differential form, the transferred heat, dq, is proportional to the isothermal surface area perpendicular to the heat transfer direction, dA, the temperature difference in the heat transfer direction, (1) ($t_h - t_c$), and a proportionality factor, U, called the overall local heat transfer coefficient.

$$dq = U\ (t_h - t_c) dA \qquad (2)$$

Equation (6) is solved by integration taking into account the variation of the heat transfer driving force and the overall heat transfer coefficient with the position in the heat exchanger. When constant values of the overall heat transfer coefficient and of the heat capacities of liquids in the equipment are assumed, integral form of the heat transfer rate equation is:

$$q = UA\Delta t_{lm} \qquad (7)$$

Where Δt_{lm} is the logarithm mean of the driving force considering its value at the beginning of the heat exchanger, Δt_1 and at the end of heat exchanger, Δt_2.

$$(\Delta t)_{lm} = \frac{\Delta t_1 - \Delta t_2}{ln\frac{\Delta t_1}{\Delta t_2}}$$

While $\Delta t_1 = t_{h,in} - t_{c,in}$ and $\Delta t_2 = t_{h,out} - t_{c,out}$ for parallel flow and $\Delta t_1 = t_{h,in} - t_{c,out}$ and $\Delta t_2 = t_{h,out} - t_{c,in}$ for countercurrent flow. Heat flow, on its way from hot to cold fluid, has to overcome the resistances of the hot fluid limit layer, the resistance of the separation wall and the resistance of the cold fluid limit layer. For a shell and tube exchanger of the total length of tubes, L, in which hot fluid flows through the internal tube and cold fluid flows in the space between the tubes and the shell, the exchange surfaces is:$A_1 = \pi d_{int} L$ and $A_2 = \pi d_{ex} L$ with d_{int} and d_{ex} being the internal and external diameters of the tubes.

$$UA = \frac{1}{R_t} = \frac{1}{\frac{1}{\alpha_1 \pi\, d_{int} L} + \frac{\ln\left(\frac{d_{ex}}{d_{int}}\right)}{2\,\pi\, L\, k} + \frac{1}{\alpha_2 \pi\, d_{ex}\, L}}$$

4.1 Heat transfer coefficients calculation

The heat exchanger operates with two fluids moving at known velocities. Therefore, convection is forced. Values of the convection heat transfer coefficients $\alpha_1$and α_2 depend on the hydrodynamic conditions, geometry of the heat exchanger, and properties of the respective liquids. These dependencies are usually expressed in form of criteria equations in which the following dimensionless criteria are employed:

$$N_u = \frac{\alpha\, l}{k}$$
$$R_e = \frac{l\, w\, \rho}{\mu}$$
$$P_r = \frac{c_p\, \mu}{k}$$

where N_u, R_e, and P_r stand for the Nusselt, Reynolds, and Prandtl numbers, respectively, l represents the characteristic dimension of the heat exchanger domain (in case of a tube, it is the tube diameter), ρ (kg m^{-3}) is the fluid density, μ(Pa s) the dynamic viscosity, c_p (J kg^{-1}K^{-1}) the specific heat capacity and k is the thermal conductivity (Wm^{-1}K^{-1}). On both sides of the heat exchanger using the relation between velocity and volume flow.

$$w = \frac{4\, Q}{\pi d^2}$$

Different empirical correlations depending on the flow character and heat exchanger geometry can be used for obtaining the Nusselt number. However, before selecting the corresponding experimental correlation for the calculation of the Nusselt number, the flow should be thermally and hydrodynamic ally defined.

Seider and Tate recommend the following equation for the Nusselt number for laminar (R_e< 2300) forced flow in a tube [29]:

$$N_u = 1{,}86\, (R_e P_r \frac{d}{L})^{1/3} (\frac{\mu}{\mu_w})^{0{,}14} \qquad (8)$$

Where μ_w is the liquid viscosity at the wall temperature.

For intermediate flow regime 2300 <R_e< 10000 in a tube, the Hausen relation can be employed:

$$N_u = 1{,}66\, \left(R_e{}^{2/3} - 125\right) P_r{}^{1/3} [1 + (\frac{d}{L})^{2/3}]\ (\frac{\mu}{\mu_w})^{0{,}14}$$

For a hydrodynamic and thermally fully developed turbulent flow with 0.6 ≤ P_r ≤160, R_e ≥ 10000 and (L/d) ≥ 10:

$$N_u = 0{,}023\, R_e{}^{0{,}8} P_r{}^{n}$$

Where $n = 0.4$ when the fluid is warming up and $n = 0.3$ when it is cooling down. (9)

Kern provided us with the following correlation for the calculation of the Nusselt number for flow in the area between tubes and shell of a heat exchanger [28]:

$$N_u = 0{,}36\, R_e{}^{0{,}55} P_r{}^{1/3} (\frac{\mu}{\mu_w})^{0{,}14}$$
$$R_e = \frac{d_e m_s}{\mu\, S_s}$$

Where d_e is the equivalent diameter. For a square configuration of the tubes,

$$de = 4\frac{A}{P} = \frac{4(P^2{}_T - \frac{\pi\, d^2{}_{ex}}{4})}{\pi\, d_{ex}} \qquad (10)$$

(11)

(12)

Where P_T is the distance between the tube's centers and m_s is the mass flow of the fluid flowing in the shell. The parameter S_s is the cross flow area in the shell and can be calculated as:

$$S_s = \frac{D_s\, C\, L_B}{P_T}$$

Where D_s is the shell inner diameter, d_{ex} is the external diameter of tubs, C is the distance between the tubes (Clearance) and L_B is the distance between the baffles [25]. The equivalent diameter characteristics illustrated in Figure 4.

(13)

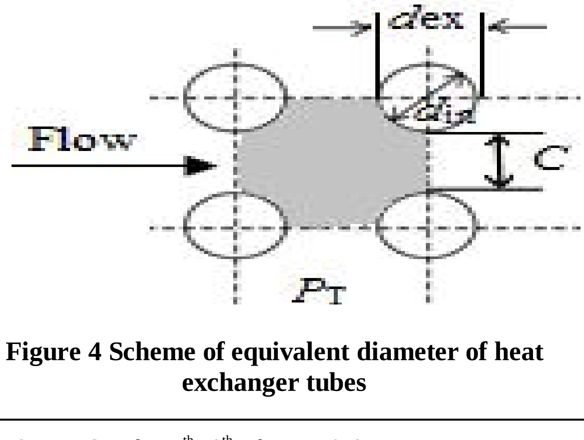

Figure 4 Scheme of equivalent diameter of heat exchanger tubes

V. OPERATING AND GENERAL PROCEDURE OF EXPERIMENT

To evaluate the energy balance, heat losses study and overall heat transfer coefficient the following procedures completed: using the software, the tank temperature is sited to a value between 40–50 °C, the resistor and the hot water circuit pump are turn on. The hot water flow fixed at about 3 [l min^{-1}]. Via the valves of AV-2, AV-3, AV-4 and AV-5, and choosing of the counter current flow, the cold water flow set 1.5 [l min^{-1}]. The air should be removed from the shell side of the heat exchanger using. Whenever the system reaching to stationary operating conditions we write down the temperature indicated by all sensors and the flow of hot and cold water, the procedure will repeat until five measurements as shown in Table 1.

Parameters	**Countercurrent flow**				
Q_h[l min^{-1}]	3.2	2.8	2.4	2	1.5
Q_c[l min^{-1}]	1.5	1.5	1.5	1.5	1.5
ST16 [°C]	44.8	44.7	44.5	44.3	44
ST1 [°C]	44.6	43	42	41	40
ST2 [°C]	35.7	34	33.1	32.5	30.6
ST3 [°C]	34.9	33	32	31.5	30
ST4 [°C]	32.7	29.6	29.3	29.1	28.3
ST5 [°C]	30.9	29	28	27.5	26
ST6 [°C]	28.2	26.1	25.7	25	24
ST7 [°C]	19.7	19.5	19.4	19.3	19.2
Parameters	**Parallel flow**				
Q_h[l min^{-1}]	3.1	2.8	2.4	2	1.5
Q_c[l min^{-1}]	1.5	1.5	1.5	1.5	1.5
ST16 [°C]	44.4	44.7	44.8	44.9	45.5
ST1 [°C]	42.1	41.6	41.2	41	40.6
ST2 [°C]	35.8	34.8	34	33.3	31.7
ST3 [°C]	21.4	21.1	20.4	20.2	20
ST4 [°C]	28.1	27.4	27.1	26.6	25.9
ST5 [°C]	29.3	28.8	28.4	28	27
ST6 [°C]	31.1	30.3	29.8	29.3	28.3
ST7 [°C]	31.3	30.6	30	29.4	28.3

Table 1 Recording of measured data during experiment

VI. MEASURED DATA PROCESSING

For the computation processing experiment data, first we calculate the average temperature of hot and cold water in the system then we find the density, dynamic viscosity, specific heat capacity and thermal conductivity of water in properties table of water. For countercurrent flow the measured data processing according to measured data during experiment in Table 2 the calculation processing experiment data are shown in Table 2.

$t_{av,h}$ =41.15 [°C] $t_{av,c}$ = 23.95 [°C] S_s = 0.00074 [m^2] d_e= 0.008 [m]					
$C_{p,h}$ = 4179 [Jkg^{-1}K^{-1}] $C_{p,c}$ = 4180 [Jkg^{-1}K^{-1}] ρ_h = 992 [kg.m^{-3} ρ_c = 997.2 [kg.m^{-3}]					
μ_h = 0.652 10^{-3} [Pa.s] μ_c = 0.932 10^{-3} [Pa.s] k_h = 0.631 [Wm^{-1}K^{-1}] k_c = 0.616 [Wm^{-1}K^{-1}]					
Number	1	2	3	4	5
Q_h [m^3 s^{-1}]	5.3E-05	4.6E-05	4.0E-05	3.3E-05	2.5E-05
Q_c [m^3 s^{-1}]	2.5E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05
m_h [kg s^{-1}]	0.053	0.046	0.04	0.033	0.025
m_c [kg s^{-1}]	0.025	0.025	0.025	0.025	0.025
q_h [W]	2429.39	2125.71	1822.04	1518.37	1138.77
q_c[W]	888.25	888.25	888.25	888.25	888.25
q_h- q_c [W]	1541.14	1237.46	933.79	630.12	250.52

Δt_{lm} [°C]	15.18	15.18	15.18	15.18	15.18
U_h[W m^{-2} K^{-1}]	31.84	27.86	23.88	19.90	14.92
U_c[W m^{-2} K^{-1}]	9.27	9.27	9.27	9.27	9.27
w_h[m s^{-1}]	1.06	0.92	0.79	0.66	0.49
W_c[m s^{-1}]	0.49	0.49	0.49	0.49	0.49
$R_{e,h}$	804.83	704.22	603.62	503.02	377.26
$R_{e,c}$	309.08	309.08	309.08	309.08	309.08
$P_{r,h}$	4.34	4.34	4.34	4.34	4.34
$P_{r,c}$	5.43	5.43	5.43	5.43	5.43
$Nu_{,h}$	8.73	7.85	6.94	6.00	4.76
$Nu_{,c}$	3.75	3.75	3.75	3.75	3.75
α_h[W m^{-2} K^{-1}]	689.30	619.46	547.59	473.27	375.97
α_c[W m^{-2} K^{-1}]	25.40	25.40	25.40	25.40	25.40
UA[W m^{-2} K^{-1}]	0.07	0.08	0.089	0.099	0.11

Table 2 Measured data processing for countercurrent connection configuration

The scope of temperature is defined as a distribution of temperatures in individual points of the heat exchanger in a certain time [26]. By plotting the graphs of temperature according to the length or flow in/of devices with different flows configuration (countercurrent or parallel), it is possible to give a basic idea of heat transfer between hot and cool streams. The Figure 5 represents the temperature change in cross length of shell and tube heat exchanger.

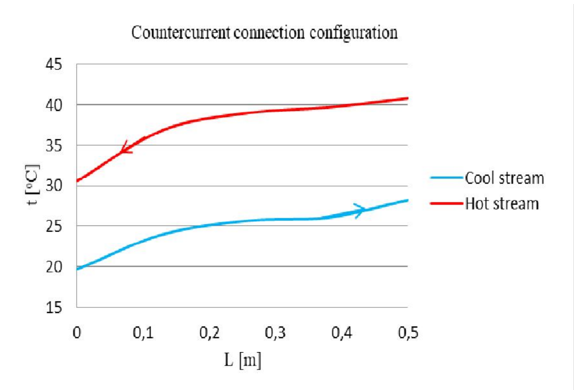

Figure 5 Countercurrent flow connection in a shell and tube heat exchanger

To demonstrate the temperature change as function of flow a shell and tube heat exchanger, which have done during experimental research in the laboratory of Kabul polytechnic University, the Figure 6, shows the countercurrent flow connection in STHE that the heat transfer processing is sufficient if there are a huge different between hot and cold flow of water in a shell and tube heat exchanger.

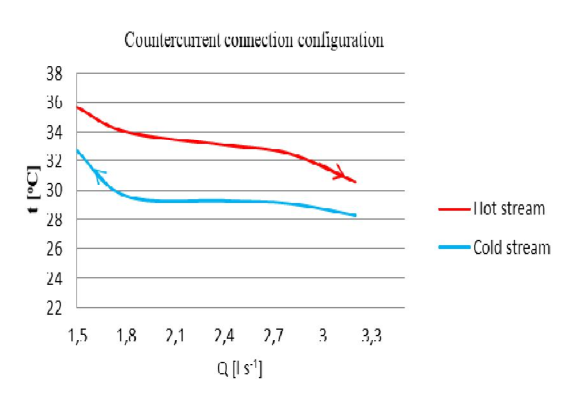

Figure 6 Changing of Temperature in a Countercurrent Flow of Hot and Cold Streams

By calculation of the average temperature of hot and cold water in the system we find the density, dynamic viscosity, specific heat capacity and thermal conductivity of water in properties table of water. For parallel flow the measured data processing according to measured data during experiment in Table 1, the calculation result are shown in Table 3.

tav, $_h$ = 41.15 [°C] Ss = 0.00074 [m^2]	tav, $_c$ = 23.95 [°C] de = 0.008 [m]
Cp,$_h$ = 4179 [Jkg^{-1}K^{-1}] ρ_h = 992 [kg.m^{-3}]	Cp,$_c$ = 4180 [Jkg^{-1}K^{-1}] ρ_c = 997.2 [kg.m^{-3}]
μ_h = 0.652 10^{-3} [Pa.s] k$_h$ = 0.631 [Wm^{-1}K^{-1}]	μ_c = 0.932 10^{-3} [Pa.s] k$_c$ = 0.616 [Wm^{-1}K^{-1}]

No.	1	2	3	4	5
Q_h [$m^3 s^{-1}$]	5.16E-05	4.6E-05	4.0E-05	3.3E-05	2.5E-05
Qc [$m^3 s^{-1}$]	2.5E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05
mh [$kg\ s^{-1}$]	0.051	0.046	0.04	0.033	0.025
mc [$kg\ s^{-1}$]	0.025	0.025	0.025	0.025	0.025
qh [W]	1360.26	1228.62	1053.10	877.59	658.19
qc [W]	564.16	564.16	564.16	564.16	564.16
qh - qc [W]	796.09	664.46	488.94	313.42	94.02
Δtlm [^{o}C]	9.13	9.13	9.13	9.13	9.13
Uh [$W\ m^{-2}\ K^{-1}$]	18.21	16.44	14.09	11.74	8.81
Uc [$W\ m^{-2}\ K^{-1}$]	6.03	6.03	6.03	6.03	6.03
wh [$m\ s^{-1}$]	1.02	0.92	0.79	0.66	0.49
Wc [$m\ s^{-1}$]	0.49	0.49	0.49	0.49	0.49
Re,h	777.17	701.96	601.68	501.4	376.0
Re,c	309.70	309.70	309.70	309.70	309.70
Pr,h	4.34	4.34	4.34	4.34	4.34
Pr,c	5.43	5.43	5.43	5.43	5.4
Nu,h	8.49	7.83	6.92	5.98	4.75
Nu,c	3.75	3.75	3.75	3.75	3.75
αh [$W\ m^{-2}\ K^{-1}$]	670.28	617.87	546.18	472.05	375.01
αc [$W\ m^{-2}\ K^{-1}$]	25.44	25.44	25.44	25.44	25.44
UA [$W\ m^{-2}\ K^{-1}$]	2.70	2.71	2.73	2.74	2.78

Table 3 Measured data processing for parallel connection configuration

According to the separation process, the flow rate should be variable in one side and fixed in the other side (to keep constant thermal resistance) in a single test [22]. The Figure 7, represents the temperature change for parallel flows connection system in a shell and tube heat exchanger, which shows a huge difference between the cold and hot flow streams.

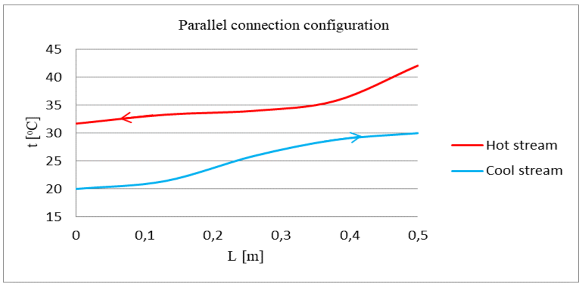

Figure 7 Temperature changing in a parallel flow connection in

The temperature profiles were determined from the experimentally calculated data of temperature scopes, and local parameters of heat transfer were calculated [27]. Anyway, the difference between the amount of hot and cold flow streams in a parallel flow connection system in a shell and tube heat exchanger as well shows the change of temperature in various amount of hot and cold flow which is indicated in Figure 8.

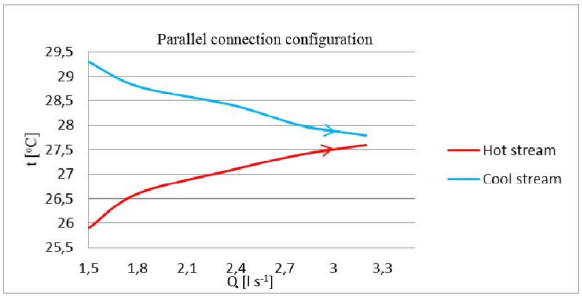

Figure 8 Temperature change of hot and cold streams in a parallel flow connection

VII. RESULT

In a countercurrent flow the outlet temperature of the cold fluid can exceed then the outlet temperature of the hot fluid but this cannot happen in a parallel flow system as shown Figure 6 and Figure 8. In fact, the hot and cold water temperatures change continuously along the length of the heat exchanger too, as shown Figure 5 and Figure 7. Measuring hot and cold water temperatures in countercurrent and parallel flow at different points in five step along the length of heat exchanger are shown in Table 1. The calculated results for a total energy balance, the overall heat transfer coefficient using criteria equations, the effective of average temperature difference between the two heat transfer fluids over the length of the heat exchanger and though derived for countercurrent and parallel flow, are presented in Table 2 and Table 3. The calculation of mentioned parameters is as follows: from the work documentation, we write all necessary information on the dimensions of the heat exchanger and calculated equivalent diameter d_e = 0.091 [m], and the cross flow area in the shell S_s = 0.00074 [m^2] using Equations (19) and (20). For each column of countercurrent flow from Table 1, calculated the heat flow from the hot fluid q_h = 2429.39 [W], from the cold fluid q_c = 888.25 [W]and for parallel connection configuration the heat flow from the hot and cold fluid q_h = 1360.26 [W], q_c = 564.16 [W] using Equation (1) and Equation (2), individually.The estimation of the heat losses for both countercurrent and parallel connection streams are calculated in Table 2 and Table 3 individually. As well for countercurrent and parallel connection streams calculated the logarithmic mean of the driving force Δt_{lm} = 15.18 [^{o}C], Δt_{lm} = 9.13 [^{o}C] using Equation (8) one-by-one. The value of the heat transfer surface aria, A = 0.0126 [m^2], is available in the laboratory work documentation. In countercurrent configuration calculated the theoretical values of the overall heat transfer coefficient UA = 0.07 [W m^{-2} K^{-1}], using criteria equations (equation (9)) which consist of the following the steps: calculated the velocity of hot and cold water streams, w_h = 1.06 [m s^{-1}] and w_c = 0.49 [m s^{-1}]. on both sides of the heat exchanger using the relation between velocity and volume flow rate Equation (13), calculated the Reynolds number, $R_{e,h}$ = 804.83 and the Prandl number, $P_{r,h}$, = 4.34 using Equations (11) and (12), and based on the values of R_e and P_r, select the right equation for the calculation of the Nuselt number. Instead of the wall temperature, considered the temperature of water at the other side of shell and tube heat exchanger. Furthermore calculated the heat transfer coefficients of countercurrent flow α_h = 689.30 [W m^{-2} K^{-1}]and α_c = 25.40 [W m^{-2} K^{-1}] for both sides of the heat exchanger. Recorded the calculated data according to mentioned equations for both countercurrent and parallel configuration in tables such Table 2 and Table 3.The results obtained from the figures and calculated data in tables indicate that this heat exchanger is effective in the process of the operation.

CONCLUSION

The shell and tube heat exchanger let us the heat transfer study between hot water that circulates through an internal tube and cold water that flows through the annular zone between the internal and the external tubes. This exchanger permit to measure cold water and hot water temperatures in different points of the exchanger [TIBC, 2014]. As well the shell and tube heat exchanger allow to study global energy balance, the study of losses, the flow influence in the heat transfer. Study of the heat transfer in crosscurrent and parallel flow conditions and determination of the shell and tube heat exchanger effectiveness. The examined shell and tube heat exchanger type is designed supervisory control and data acquisition software. Thevalidate and correct results of different researches, andthe performance of shell and tube heat exchangers in industrial processes has always a major goal for engineers and designers. The aim of the present study is to investigate application of heat transfer between hot and cold water to evaluate the influence of the flow in the heat transfer. This research has compared against experimental data in terms of accuracy and simulation time. The mentioned graphs and tables which are summarized above indicated the main conclusions from this study. Current work includes inspecting the real system in order to the effects of countercurrent and parallel flow on the heat exchanger tubes for a better thermo-hydraulic performance.

ACKNOWLEDGMENT

This paper was prepared within the work on a research project KEGA MŠ SR 003TU Z-4/2016: Research and education laboratory for robotics.
As well this work was done as a result of the project SAMRS/2013/ of the Slovak official development assistance supporting the cooperation between the Slovak University of Technology in Bratislava (STU) and the Kabul Polytechnic University (KPU) in Afghanistan.

UNDING

KEGA MŠ SR 003TU Z-4/2016: Research and education laboratory for robotics

REFERENCES

[1] Master, B.I. Chunangad, K.S. Pushpanathan, V., 2003,"Fouling mitigation using helix changer heat exchangers," in: Proceedings of the ECI Conference on Heat Exchanger Fouling and Cleaning: Fundamentals and Applications, Santa Fe, USA, pp. 317–322. (Cited in Mohsen Mirzaei, Hassan Hajabdollahi, Hadi Fadakar, 2017)
[2] Yang, J. Sun-Ryung, Oh. Liu, W., 2014,"Optimization of shell-and-tube heat exchangers using a general design approach motivated by constructed theory," Int. J. Heat Mass Transf. 77 (2014) 1144–1154. (Cited in Mohsen Mirzaei, Hassan Hajabdollahi, Hadi Fadakar, 2017)
[3] Mirzaei, M., Hajabdollahi, H., Fadakar, H., 2017,"Multi-objective optimization of shell-and-tube heat exchanger by constructed theory," Applied Thermal Engineering 125, 9–19
[4] Mueller, A., 1987,"Effects of some types of maldistribution on the performance of heat exchangers," Heat Transf. Eng. 8 (1987) 75–86. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)
[5] Thome, J.R. Eng.,2004, "Data book III,"(Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)
[6] Wang, Q. Chen, Q. Chen, G. Zeng, M., 2009,"Numerical investigation on combined multiple shell-pass shell-and-tube heat exchanger with continuous helical baffles," Internat. J. Heat Mass Transf. 52 (2009) 1214–1222. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)
[7] Zhang, L.-Z., 2009, "Flow maldistribution and thermal performance deterioration in a cross-flow air to air heat exchanger with plate-fin cores," Internat. J. Heat Mass

Transf. 52 (2009) 4500–4509. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[8] Zhang, L.-Z., 2009,"Performance deteriorations from flow maldistribution in air-to-air heat exchangers," a parallel-plates membrane core case, Numeric. Heat Transfer, Part A: Appl. 56 (2009) 746–763. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[9] Wang, J., 2010,"Pressure drop and flow distribution in parallel-channel configurations of fuel cells," Z-type arrangement, Internat. J. Hydrogen Energy 35 (2010) 5498–5509. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[10] Wang, J., 2011,"Theory of flow distribution in manifolds," Chem. Eng. J. 168 (2011) 1331–1345. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[11] Rebrov, E.V. Schouten, J.C. De Croon, M.H., 2011,"Single-phase fluid flow distribution and heat transfer in microstructured reactors," Chem. Eng. Sci. 66 (2011) 1374–1393. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[12] Li, Z.-X. Zhang, L.-Z., 2014,"Flow maldistribution and performance deteriorations in a counter flow hollow fiber membrane module for air humidification/ dehumidification," Internat. J. Heat Mass Transf. 74 (2014) 421–430. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[13] Mohammadi, K. Malayeri, M., 2013,"Parametric study of gross flow maldistribution in a single-pass shell and tube heat exchanger in turbulent regime," Internat. J. Heat Fluid Flow 44 (2013) 14–27. (Cited in O. Labbadlia, B. Laribi, B. Chetti, P. Hendrick, 2017)

[14] Labbadlia, O. Laribi, B. Chetti, B. Hendrick, P., 2017,"Numerical study of the influence of tube arrangement on the flow distribution in the header of shell and tube heat exchangers," Applied Thermal Engineering 126 (2017) 315–321

[15] Vuki_c MV, Tomi_c MA, Z_ivkovi_c PM, Gradimir S., 2014,"Effect of segmental baffles on the shell-and-tube heat exchanger effectiveness," Hem Ind 2014; 68(2):171e7. (Cited in Mustapha Mellal, Redouane Benzeguir, Djamel Sahel, Houari Ameur, 2017)

[16] Mellal, M. Benzeguir, R. Sahel, D. Ameur, H., 2017,"Hydro-thermal shell-side performance evaluation of a shell and tube heat exchanger under different baffle arrangement and orientation," International Journal of Thermal Sciences 121 (2017) 138e149

[17] Sanaye, S. Hajabdollahi, H., 2010,"Multi-objective optimization of shell and tube heat exchangers," Applied Thermal Engineering 30 (2010) 1937-1945. (Cited in Jian wen, Xin Gu, Mengmeng Wang, Yuce Liu, Simin Wang, 2017)

[18] wen, J. Gu, X. Wang, M. Liu, Y. Wang, S., 2017,"Multi-parameter Optimization of Shell-andTube Heat Exchanger with Helical Baffles Based on Entransy Theory," Applied Thermal Engineering 130 (2017) 804–813

[19] Hajabdollahi, H. Naderi, M. Adimi, S., 2016,"A comparative study on the shell and tube and gasket-plate heat exchangers," the economic viewpoint, Appl. Therm. Eng. 92 (2016) 271–282. (Cited in Bansi D. Raja, R.L. Jhala, Vivek Patel, 2017)

[20] Khosravi, R. Khosravi, A. Nahavandi, S. Hajabdollahi, H., 2015,"Effectiveness of evolutionary algorithms for optimization of heat exchangers," Energy Convers Manage. 89 (2015) 281–288. (Cited in Bansi D. Raja, R.L. Jhala, Vivek Patel, 2017)

[21] Bansi, D. Raja, R.L. Jhala, V. P., 2017,"Many-objective optimization of shell and tube heat exchanger," Thermal Science and Engineering Progress 2 (2017) 87–101

[22] Qian, J. Ling Kong, Q. Wu Zhang, H. Hong Zhu, Z. Huang, W.G Hui Li, W., 2017,"Experimental study for shell-and-tube molten salt heat exchangers," Applied Thermal Engineering 124 (2017) 616–623

[23] TICC , 2014, "Practical exercises manual," Edibon Spain

[24] TICB , 2014, "Practical exercises manual," Edibon Spain

[25] Haydary, J.,2013, "Chemical Engineering l", Laboratory manual, Ministry of higher education of Afghanistan, Kabul

[26] Pivarciova, E. Cernecky, J.,2011, "Wood texture influence on temperature fields," In: Annals of DAAAM for 2011& Proceedings of the 22th International DAAAM symposium „Intelligent manufacturing & automation: Power of knowledge and creativity". Vienna (Austria). ISBN 978–3–901509–83–4. ISSN 1726–9679. p. 1069–1070

[27] Černecký, J. Brodnianská, Z. Blasiak, P. Koniar, J., 2017"In Journal of heat transfer: transactions of the ASME," č. no. 8, s. ISSN 0022-1481

[28] Kern, D.Q.,1950, "Process Heat Transfer," New York. ISSN 0-07-085353-3

[29] Welty, J.R. Rorrer, G.L. and Foster, D.G., 2014,"Fundamentals of Momentum, Heat, and Mass Transfer," Sixth Edition, Wiley, New Jerse

★★★