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CFD Modelling of Hydrodynamic Phenomena and Heat Transfer in Channels of Plate Heat Exchangers

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Abstract **-** The subject of this paper is modeling of fluid flow and heat transfer in channels of plate heat exchangers for heating domestic hot water heating substation in Belgrade. Of particular importance is that in this paper modeling hydraulic parameters of fluid flow and heat transfer parameters made in the collective and individual channels plate heat exchangers. Geometric model of collective channel plate for the passage of fluid is obtained by connecting all geometrical model of individual channels on one plate exchanger. On both geometric models are separately generated numerical network, and the boundary conditions of fluid flow parameters of the budget adopted different mass flow rates of fluids through them. The uneven distribution of shear stresses on the walls of plate exchanger is determined at various speeds of fluid in the collective and individual channels for the fluids flow. At the same time the rate of flow in the channels had cumulative value of 0.1m / sec, and in individual channels amounted to 0.01m / sec. Intensities specified shear stresses obtained CFD modeling are compared with experimental results of these stress obtained from the measurement of process parameters of fluid flow, and at approximately the same velocity (0.1m / sec). Because of the significant impact the distribution and intensity of tangential stress on the plate fouling heat exchanger, results can serve as a basis for determining the new project of procedures plate heat exchangers in district heating systems.

Keywords**:** Plate heat exchangers, fluid flow, chanells

1. Introduction

Domestic hot water (DHW) system is a part of district heating system in Belgrade (Serbia). JKP Beogradske elektrane (municipal company for district heating in Belgrade) continuously improves the system by incorporating prefabricated compact substations which serve two purposes: heating of water for radiator heating system and heating of DHW.

This paper will describe the influence of water velocity on fouling factor in plate heat exchangers, based on measurements on 4 district heating substations (DHS) in the Sector of the Heat Plant Zemun.

In this paper, CFD modeling is applied to the plate inseparable heat exchanger for heating domestic hot water in a heat-transmitting substation for district heating, whose scheme is given in the following figure:

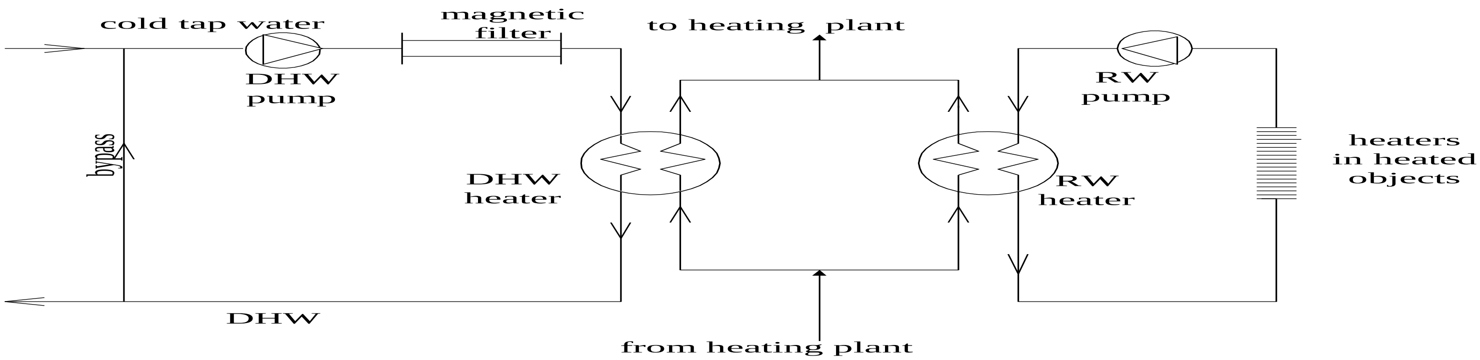

Fig. 1: Technological scheme of heat-transfer stations for district heating with the preparation of consumable sanitary hot water.

1.1. CFD modelling

General conservation (transport) equations for mass, momentum, energy, species, etc. are solved on this set of control volumes [13]:

$$\frac{\delta}{\delta t}\int_V \boldsymbol{\rho\phi} d\boldsymbol{V} + \oint_A \boldsymbol{\rho\phi V}\cdot d\boldsymbol{A} = \oint_A \Gamma_{\boldsymbol{\phi}}\nabla\boldsymbol{\phi}\cdot d\boldsymbol{A} + \int_V \boldsymbol{S_{\phi}}\cdot d\boldsymbol{V}, \quad (1)$$

where:

$$-\int_V \boldsymbol{\rho\phi} d\boldsymbol{V} - \text{unsteady}; \quad (1.1)$$

$$-\oint_A \boldsymbol{\rho\phi V}\cdot d\boldsymbol{A} - \text{convection}; \quad (1.2)$$

$$-\oint_A \Gamma_{\boldsymbol{\phi}}\nabla\boldsymbol{\phi}\cdot d\boldsymbol{A} - \text{diffusion:} \quad (1.3)$$

$$-\int_V \boldsymbol{S_{\phi}}\cdot d\boldsymbol{V} - \text{generation.} \quad (1.4)$$

- Partial differential equations are discretized into a system of algebraic equations;
- All algebraic equations are then solved numerically to render the solution field.

1.2. Shear Stress

In past few decades, wall shear stress became a significant parameter in fouling factor analysis, since it is a measure of the fluid stress along the face of the corrugated plate.

Wall shear stress is defined as follows [11]

$$\tau = \Delta p\frac{b}{2L} \quad (2)$$

where
-p, Pa, is the pressure drop due to friction;
-b, m, is the distance between plates;
-L, m, is the effective plate length.

1.2.1. Shear Strain Rate

The strain rate tensor is defined by [13]:

$$S_{ij} = [\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}] \quad (3)$$

The tensor has three scalar invariants, one or which is often simply called the shear strain rate:

$$sstrnr = [2\frac{\partial U_i}{\partial x_j} S_{ij}]^{\frac{1}{2}} \quad (4)$$

With velocity components Ux,Uy ,Uz , this expands to:

$$sstrnr = \left[2\left\{\left(\frac{\partial U_x}{\partial x}\right)^2 + \left(\frac{\partial U_y}{\partial y}\right)^2 + \left(\frac{\partial U_z}{\partial z}\right)^2\right\} + \left(\frac{\partial U_x}{\partial y} + \frac{\partial U_y}{\partial x}\right)^2 + \left(\frac{\partial U_x}{\partial z} + \frac{\partial U_z}{\partial x}\right)^2 + \left(\frac{\partial U_y}{\partial z} + \frac{\partial U_z}{\partial y}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

The viscosity of non-Newtonian fluids is often expresed as a function of this scalar shear rate.

2. CFD Modeling of Fluid Flow in the Plate Heat Exchanger

2.1. Geometric Display Model

CFD modeling was done for flat -consolidated channels between developed flat-panel and for individual channels between the profiled plate,so the heat transfer and fluid flow modeled for flat plate heat exchanger which has a total active surface area for the passage of thermal power generation is identical as with ruffle plate, from which the flat plate obtained by the development.

Collective channels to "fluid 1" and "fluid 2", among which is developed flat plate heat exchanger, and individual channels of plate are drawn in three-dimensional software ANSYS Design Modeler, Figure No. 2. and Figure No. 3.

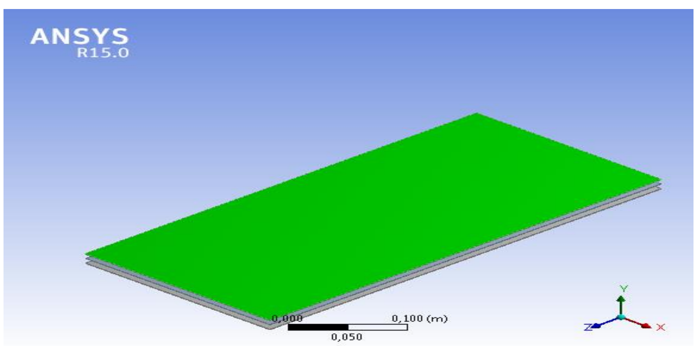

Fig. 2: Flat panels plate heat exchanger.

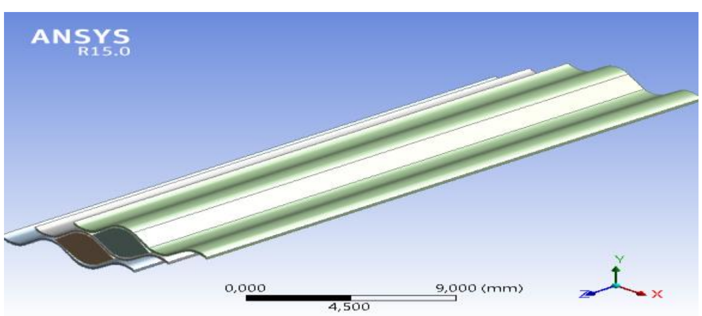

Fig. 3: Individual channels of plate.

Consequently, all of the fluid flows through the individual channels are taken as a sum ("Fluid 1" and "Fluid 2"), and the inlet and outlet cross-sections of collective channels (for the total fluid flow) are the same length (length 119mm- flat plate exchanger) and a width of 0.96 mm, which actually represents the equivalent diameter or width of the individual channel plates for the flow of liquid.

It also adopts the same flow rate for both fluid as in single-channel plate- 0.1 m / sec [1], and this gives the collective channels for the flow of fluid passed the same flow boundary conditions to be set for each channel individually.

In these individual channels of plate, velocity Fluid 1 and Fluid 2 are identical and amounted to 0.01 m / sec.

2.2. CFD Numerical Network

Within the numerical modeling of networks, made previously to mark all the surfaces that are used for heat exchange and fluid movement.

After such labeling surface was performed numerical generation networks on them, Figure No.4.

In the same way are numbered surface of individual channel plate whose numerical network Figure No.5.

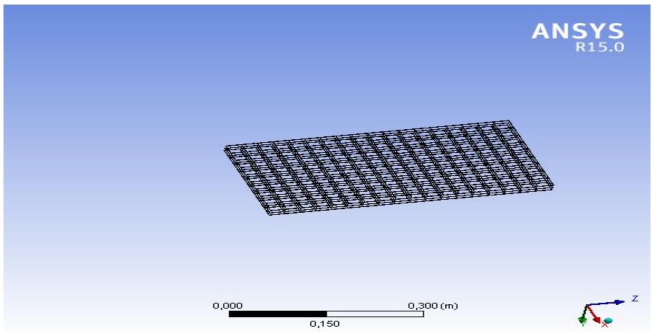

Fig. 4: Generated numerical meshed flat plate heat exchangers.

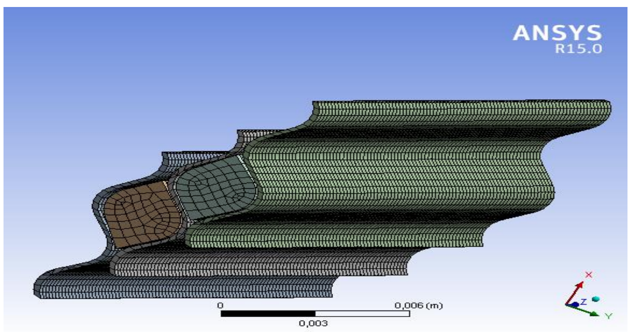

Fig. 5: Generated numerical meshed individual channel plate exchanger.

2.3. ANSIS-FLUENT Modeling - Determination of Boundary Conditions on Numerical Networked Designated Areas and Budget Parameters

The consolidated boundary conditions for the exchange of heat and fluid flow rates are as follows:

1. FLUID 1- input, FLUID 2- input:

- Mass of fluid flow or fluid flow between the plates exchangers during the heat exchange.

2. FLUID 1- input, FLUID 2- input:

- Medium value of static pressure.

3. The initial temperature of the fluid during periods of heat exchange at any designated numerical networked surface.

For the solution of problems used CFX module that has the capability of numerical networked surfaces that are multi-touch so you can simulate their interactions and also has a large number of options for setting the limit conditions for them. In this modeling defines the plate materials, types of fluids, streamline (or turbulence) fluid flow and determine the boundary conditions on the surfaces of a networked indicated above initialization is done by determining the interval of the budget increase rate calculation parameters in the direction of all three axes and the number of iterations of the proposed budget.

The value sof absolute pressure fluid "1" are not treated as boundary conditions due to its volatility and conditionality with the state of hydraulic parameters in other parts of the hydraulic system (hot water system).

This does not apply to the distribution of shear stresses, for which the esteemed absolute pressure fluid "2", the boundary conditions, and due consideration of the actual value of these stresses, the real working conditions.

For all designated board surface through which the heat exchange, it is possible to simulate the value of fluid flow, projections velocity of fluid flow in the direction of all three axes and the total energy exchanged, and that for a number of iteration- until these parameters are not closer to their asymptotic values as shown in the following Figure No.6.

The same value (excluding energy exchanged) for individual channels of ruffle plate heat exchangers are given in the following Figure No.7.

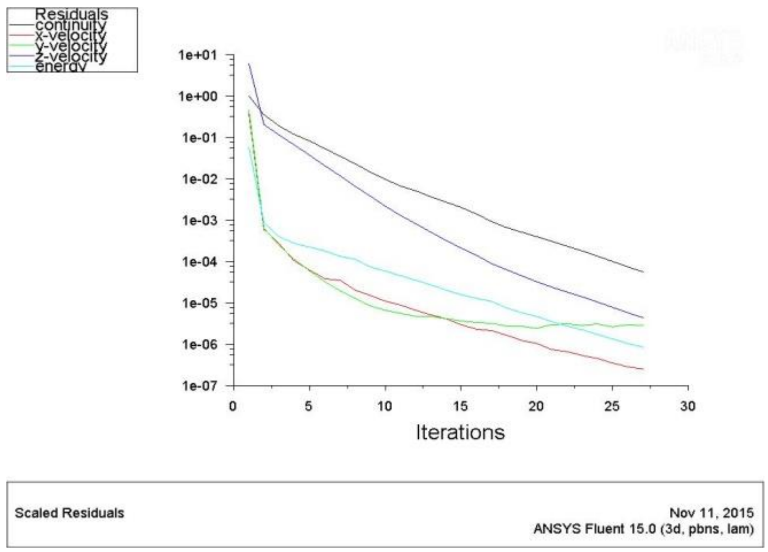

Fig. 6: Asymptotic values of parameters of heat exchange and fluid flow between the flat plates of the heat exchanger.

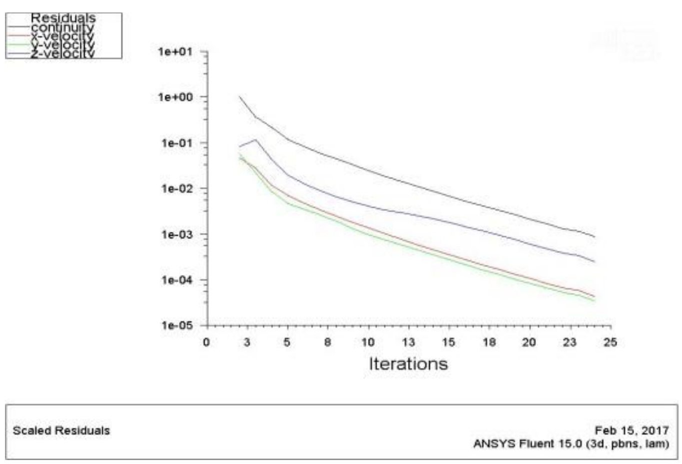

Fig. 7: Asymptotic values of parameters of fluid flow (in individual channels) between the ruffle plates of the heat exchanger.

The following figures shows the intensity of the input and output of the vector velocity of the fluid in the collective channels of plate heat exchangers and vector velocity Fluid 1 and Fluid 2 along the individual channel of ruffle plate heat exchanger:

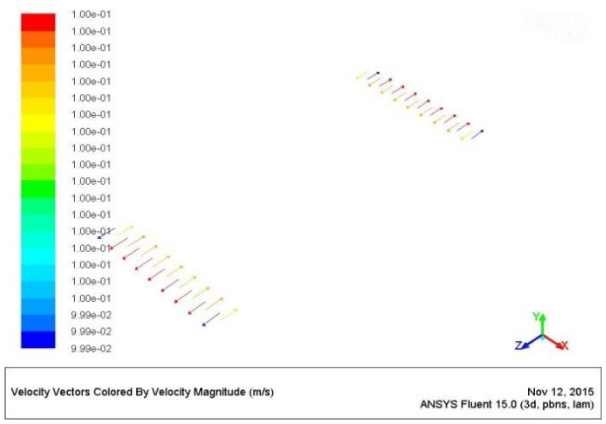

Fig. 8: Flow velocity vectors "1" and "2" in input and output channel plate heat exchanger.

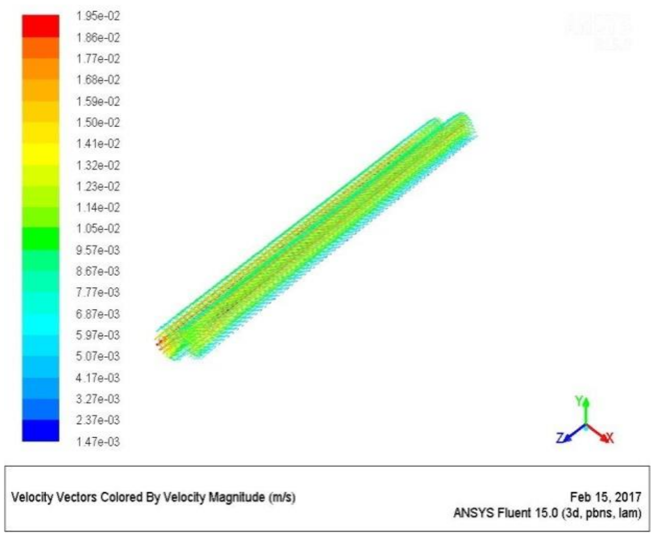

Fig. 9: Velocities Fluid 1 and Fluid 2 along the individual channel of ruffle plate heat exchanger.

The diagram may be seen that the fluid velocity vectors of highest intensity in the center profile parts of their input-output areas and to reduce by end points of these sections. The distribution of the static pressure of the fluid to "1" and "2" in the course of the flow between the flat plates of the heat exchanger and along the individual channel of ruffle plate heat exchanger, given in the following figures:

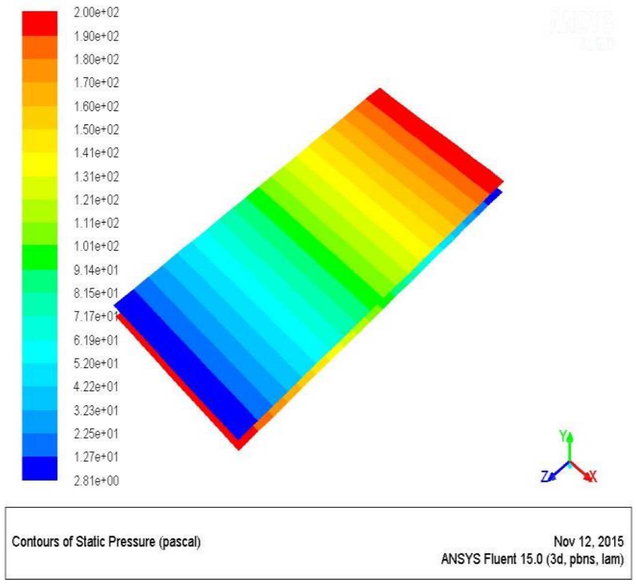

Fig. 10: Change static-pressure fluid "1" and "2" in the course of the flow between the flat plates exchanger heat.

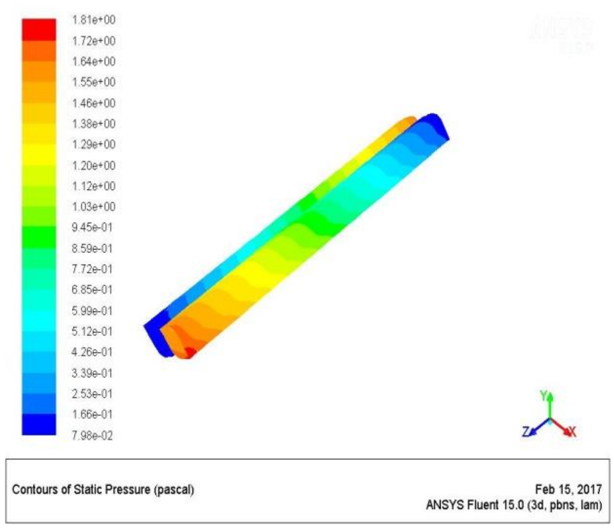

Fig. 11: Change static-pressure fluid "1" and "2" in the course of the flow along the individual channel of ruffle plate heat exchanger.

2.4. CFD Modeling Postprocesual

Within postprocesual modeling it is possible to change the relevant parameters such as flow rate, temperature, dynamic pressure and speed, display an arbitrary number of intervals to complete the indicated numerical networked areas. It is significant that in the context of postprocesual research can examine the value of tangential stress on the surface plate exchangers that have a direct impact on their dirt.

In this paper postprocesual modeling parameters relating to the exchange of heat and tangential stresses on the common surface between the plate heat exchangers and fluid.

2.4.1. Shear Stresses between the Surface of Flat Plate of Heat Exchangers and the Fluid in Collective Channels

Within postprocessing research, shear stresses on the surfaces of plate heat exchangers, which have a direct impact on their contamination were discussed at an absolute pressure fluid "2" from 520000Pa (at the exit from the plate exchanger) and at an absolute pressure fluid "2" from 550000Pa (at the entrance from the plate exchanger). Listed pressure is a pressure level of cold tap water that is added to the systemic circulation at the entrance to a heat exchanger to compensation water losses in the system due to sanitary needs in housing.

Its should be noted that the absolute value of the water pressure entrance to the heat exchanger changes in the interval from 550000Pa to 520000Pa, as a result of loss of water in the system that is consumed for sanitary purposes.

When the value of this pressure falls below 520000Pa (due to loss of water) once again conducted its addition to the level of absolute pressure 550000Pa.

Changes in levels these pressures are the current (from a few seconds to a few bits per second) and are directly proportional to the length of the interval of water consumption in homes.

2.4.2. Shear Stresses between the Surface of Ruffle Plate of Heat Exchangers and Fluid in Individual Channels

From the images we can see that the values of shear stresses in the individual channels of plate exchangers range from 0.0283 Pa to 0.0646 Pa.The boundary conditions for the calculation of these stresses were related to the speed of flow in the channels of plate, and she Fluid 1 and Fluid 2 has a estimated value of 0.01m / sec.It may be noted that the value of the stresses in the individual channels about 100 times smaller than the collective channels of plate heat exchangers.These results have been achieved in the 10-fold speed of fluid flow in the individual channels (0.01m / sec) in relation to the speed of fluid flow channels in the collective flat plate (0.1m / sec.).The following figure shows a change in the character of these stresses:

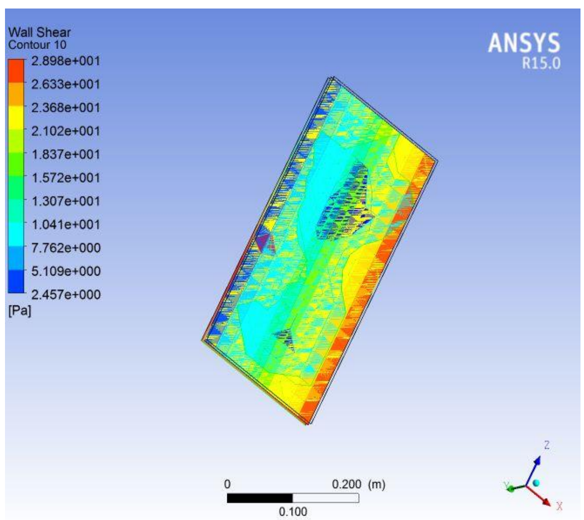

Fig. 12: Change shear stresses in the fluid flow stream "2" at a joint surface between the plate heat exchangers and fluid.

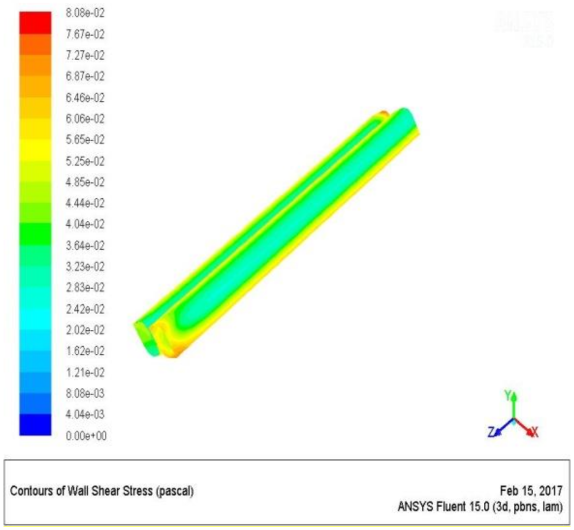

Fig. 13: Shear stresses between the surface plate exchangers and fluid channels in individual plates.

The following table shows the value of tangential stress on the plates exchangers, which are calculated on the basis of the measured values of the parameters of fluid flow and to compare the values of the stress obtained by CFD modeling:

Table 1: Experimental data and comparisons with CFD simulations-without inlet and outlet zones effect.

Experiment number	1	2	3	4
Velocity, m/sec (measured value)	0,109	0,107	0,105	0,108
Wall shear stress correlation,Pa [1](S.Genic,D.Mandic et.al.2012)	9,72	9,39	9,07	9,56
Wall shear stress-in the collective flat plate (CFD),Pa	2,457-28,98			
Velocity(CFD), m/sec	0,1			

From Table No.1 shows that the experimental values of tangential stress on the plates exchanger (fluid flow at speeds of 0.105m / sec to 0,109m / sec) differ substantially from the calculated values of the stress in the CFD module (at a constant velocity of 0.1m / sec).

Also on the surface plate modulated in CFD in large disparities can be observed distribution of the intensity of the stress that is not consistent with the character level change other parameters of heat exchanger.

The uneven distribution of shear stresses are caused by great changes of the absolute level of water pressure at the entrance to the heat exchanger are occur in seconds are the initial boundary conditions for the calculation of the parameters of heat exchange in CFD. Therefore appear enormous value of the difference of intensity of the stress relative to the value obtained by the experimental method.

3. Conclusion

Based on the foregoing, it can be said that the CFD simulations fully applicable to practical research and analytical parameters of fluid flow and heat delivery in plate heat exchangers.

The benefit of this model is that in a very wide range of perceived variability of these parameters in different technological processes that are difficult to predict in the project and budgetary procedures.

Optimization of these procedures is possible by using this module because it allows for varying operating parameters to predict lowering maintenance costs of technological processes.

In this case it refers to the contamination plate heat exchangers, which requires cleaning high costs and downtime.

Although the results of the CFD modeling of shear stresses in the plate heat exchanger differ greatly from the experimental values of the stress (at almost the same speed fluid flow), CFD simulations pointed to a large uneven distribution of these stresses on the plates of the heat exchanger on the basis of which they can predict segments of the surface of the board with the possibility of intense contamination (compared to other segments of the surface of the plate) to the extent that endangers the process of exchanging heat.

Nomenclature

Pa, N/m^2, Pascal;
B, m,width;
b. m, the distance between the plates;
L, m,lenght;
β,°,Corner of the globe;
δ, m,thickness;
p, Pa, is the pressure drop due to friction;
b, m, is the distance between plates;
L, m, is the effective plate length;
τ, shear stress or sub-grid scale,molecular stress tensor;
ρ ,kg/m^3 , density;
ϕ, kg/m· sec, Additional Variable (non-reacting scalar) ;
V, m^3,volume;
Γ_ϕ,kg/m· sec, dynamic diffusivity of an Additional Variable;
A, m^2,area;
S_ϕ, kg/m^3·sec, mass source;
S_{ij} ,- ,strain rate tensor;
U, m/sec, vector of velocity $U_{x,y,z}$.

Subscrits

ef, effective
pl, plate

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