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CONTRIBUTIONS REGARDING NUMERICAL SIMULATION OF FLUID FLOW IN A PLATE HEAT EXCHANGER

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Abstract: *Plate heat exchanger is one of the most common equipment in industrial application. It is a very compact heat exchanger and it has a good heat transfer performance. This paper presents an analysis of the plate heat exchanger performance according to its number of plates and directions of fluids flows. 3D models are realized and numerical simulations are performed using the finite element method.*
Key words: *plate heat exchanger, number of plates, counter-flow, parallel-flow, heat exchanger effectiveness, log mean temperature difference*

1. INTRODUCTION

A heat exchanger is equipment for transferring heat from one fluid to another. This equipment is used in almost all industries, from food to energy. Plate heat exchanger is very advantageous because it has a high heat exchange area per unit volume and a good heat transfer performance (Badea et al., 2003).

Internationally there is a constant concern for studying heat transfer and finding an optimal configuration of plate heat exchangers, being conducted numerous works and studies in the field: (Kandlikar & Shah, 1987), (Pinto &Gut, 2002) (Kanaris et al., 2008), (Dardour et al, 2009). In the same time, the paper represents a continuation of work presented in (Grigore&Popa, 2009), (Grigore et al., 2010), from a new perspective.

3D models are drawn with Solid Works program and using the Cosmos/Flow program, are made numerical simulations of fluids flows inside the plate heat exchanger.

2. TYPES OF CONSIDERED HEAT EXCHANGERS

The studied heat exchangers are a pack of few thin plates of stainless steel with gaskets. The thermal agents are directed into their proper chambers either by a suitable gasket made from rubber EPDM. The width of channel is 0,004 m, the diameter of inlet tube is 0,002 m, the thickness of plate is 0,002m. The number of passes is one. The geometric dimensions of the thermal plate are: effective length is 0,43 m and effective width is 0,13 m.

The presented heat exchangers are used to heat cold water, considered as secondary thermal agent, with hot water, considered as primary thermal agent. The influence of the number of plates on heat transfer and on the heat exchanger effectiveness is investigated considering a variable number of plates: 3,4,5,6. The effectiveness of heat exchangers and the mode of operation are determined by the direction of the fluid flow inside the equipments, too. In this paper are considered the most common arrangements for flow path inside the heat exchanger: counter flow and parallel flow, like in figure 1.

It is observed that for a plate heat exchanger with an odd number of plates, the number of flow channels is identical for hot and cold water. For a heat exchanger with an even number of plates, in the studied cases, the number of flow channels for hot water is one greater than cold water- this means a better heat transfer.

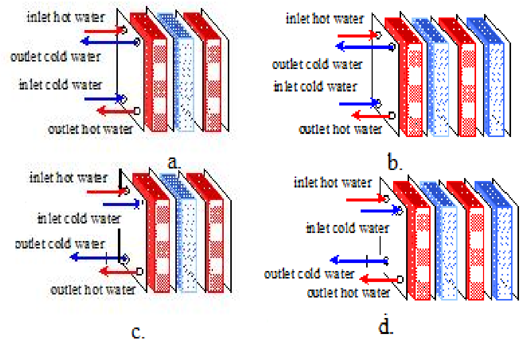

Fig.1. Functional schemes of plate heat exchangers: a. 4 plates counter-flow; b. 5 plates counter-flow; c. 4 plates parallel-flow; d. 5 plates parallel-flow

3. MATHEMATICAL MODELING AND NUMERICAL SIMULATION

Once 3D models were made, it is used the COSMOS/Flow program to realize numerical simulation. Mathematical modeling includes assignation of governing equations. The partial differential equations (pdes) governing fluid flow and heat transfer include the continuity equation, the Navier-Stokes equations and the energy equation (Grigore &Popa, 2009). The finite element method is used to discretize the flow domain, thereby transforming the governing partial differential equations into a set of algebraic equations.

A set of simplified hypothesis are introduced for modeling (Grigore et al., 2010):

- Hot water and cold water are Newtonian fluids;
- No phase change occurs, the fluids are unmixed;
- Turbulent flow is fully developed;
- Working fluids are incompressible;
- Steady state conditions;
- Coefficient of heat retention = 1.

There are not modeled the two end plates and it is not considered the influence of end plate under thermal performance of plate heat exchangers. The study was defined in COSMOS/Flow as fluid flow type, and analyze is declared thermal analyze. It is created mesh, the disparagement mode, which is very important for the final results. Mesh type is solid mesh and the quality of mesh is high (10-node tetrahedral).

The next boundary conditions are proposed for all cases:

No.	Fluid	Description	Unit	Value
1	Hot Water inlet	Temperature $T_{1,in}$	°C	53
2		Velocity, v_1	m/s	0,303
4	Cold Water	Temperature $T_{2,in}$	°C	8

5	inlet	Velocity, v_2	m/s	0,26
6	Hot water outlet	Static pressure	N/m^2	0
7	Cold water outlet	Static pressure	N/m^2	0
8	Air	Convection on exterior plate,α	W/m^2K	5
9	Air	Convection on exterior plate,α	W/m^2K	5

Tab. 1. Inlet data for analysis

Analysis runs for 100 iterations, for turbulence conditions, for each case. The mesh is finer, the COSMOS/Flow program takes longer to run. The results can be visualized under graphical form or numerical values. In figure 2 is presented the distribution of the nodal temperature, after 100 iterations, for counter-flow heat exchanger with 5 plates.The numerical values are presented in table 2.

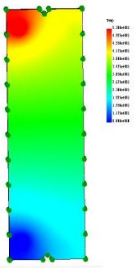

Fig.2. Distribution of the temperature on heat exchanger surface

Fluid	INLET Temperature [ºC]	PHE with 3 plates	PHE with 4 plates	PHE with 5 plates	PHE with 6 plates
		counter flow - OUTLET temperatures [ºC]			
Hot water	53	31,3	25,2	27,8	22,7
Cold water	8	32,6	40,2	37,4	22,7
		parallel flow - OUTLET temperatures [ºC]			
Hot water	53	34,7	32,6	33,3	32,3
Cold water	8	29,2	31,6	30,8	32,1

Tab. 2. Averages outlet temperatures

Based on these values obtained, it can compute log mean temperature difference - *LMTD*, a very important parameter for the study of heat transfer in a heat exchanger. *LMTD* is computed with relation (1) and ΔT_{max}, ΔT_{min} are shown in figure 3.

$$LMTD = \frac{\Delta T_{max} - \Delta T_{min}}{\ln\left(\frac{\Delta T_{max}}{\Delta T_{min}}\right)}, (1)$$

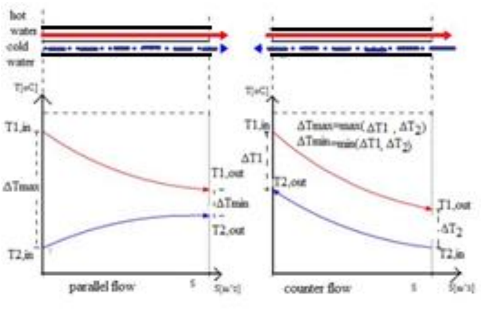

Fig.3. The temperatures distributions in heat exchanger

In the table 3 are presented calculated values for *LMTD:*

Value	3 plates cf	4plates cf	5 plates cf	6 plates cf
LMTD[ºC]	22,056	14,892	17,616	12,085
	3 plates pf	4plates pf	5 plates pf	6 plates pf
LMTD[ºC]	18,792	11,559	14,704	8,272

Tab. 3 Values determinate for *LMTD*, cf-counter flow, pf - parallel flow

4. CONCLUSIONS

Results from numerical simulation are consistent with those obtained in the technical literature. As it was expected, better performances in terms of heat transfer and greater *LMTD*, are obtained for the counter flow plate heat exchangers. Temperature of secondary thermal agent at the outlet increases with increasing number of plates. Parallel flow heat exchangers are recommended when it is necessary to obtain at the outlet, thermal agents with close temperatures. The used models are perfectible and represent important tools for study the fluid flow distribution and heat transfer in a plate heat exchanger.

As future work will be accomplished the study of heat exchangers with a larger number of plates, for both cases: counter-flow and parallel – flow, in order to find an optimal configuration of plate heat exchanger.

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