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The Effect of Mass Flow Rate on the Effectiveness of Plate Heat Exchanger

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Abstract-This paper is an extension to modeling and simulation of Plate Heat Exchanger where a mathematical model of plate heat exchanger had been developed by considering simplified assumptions. It had been described by a set of continuity, momentum and energy balance equations. The effect of mass flow rate of hot and cold fluid on the effectiveness of plate heat exchanger has been further studied by solving the model equations using finite difference method.

Keywords: Heat transfer, corrugated plate type heat exchanger, mass flow rate.

1. INTRODUCTION.

The plate heat exchanger is widely recognized as the most economical and efficient type of heat exchanger. With its low cast, flexibility, easy maintenance and high thermal efficiency, it is unmatched by any type of heat exchanger. The key to the plate heat exchanger's efficiency lies in its plates. With corrugation patterns that induce turbulent flows, it not only achieves unmatched efficiency, it also creates a self cleaning effect, thereby reducing fouling.

Here a plate heat exchanger with n number of channels is considered. Odd channels (1,3,5….n-1) have cold fluid whereas even channels (2,4,6….n) have hot fluid. Shell balance approach has been used to develop the model.

2. MATHEMATICAL MODEL (see [1], [2], [3], [6], [7], [9]).

In the development of present model, the following assumptions have been considered.

(i) The fluids are Newtonian.
(ii) There is no flow in the lateral direction.
(iii) There is no change of phase in any channel.
(iv) All the physical properties of fluids remain constant.
(v) Overall heat transfer coefficient is same for all the flow channels in the plate heat exchanger.
(vi) Turbulent flow condition exists in the heat exchanger.
(vii) Resistance offered by metal for heat transfer is negligible.
(viii) Mass transfer does not occur in any flow channel.
(ix) Chemical reaction does not occur in any flow channel.
(x) The plates in the plate heat exchanger are clean and there is no fouling/scaling.
(xi) Convection heat transfer dominates in the flow direction.
(xii) No heat losses occur from the plate heat exchanger to the surrounding.

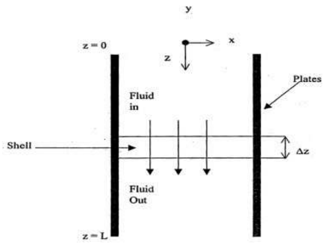

Fig. 1.1: Sketch of a flow channel in a plate heat exchanger

NOMENCLATURE

A	Cross sectional area of channel, m^2
C	Specific heat capacity of fluid, J/kg °C
D	Equivalent diameter of channel, m
F	Friction factor
h	Film heat transfer coefficient of fluid, W/m^2 °C
K	Thermal conductivity of fluid W/m °C
L	Length of plate, m
m	Mass flow rate of fluid, kg /s
NTU	Number of transfer unit of fluid
T	Temperature of fluid °C
T^{j}_{ik}	Temperature of fluid at node (j,k) in channel i, °C
U	Overall heat transfer coefficient in channel, w/m^2°C
ν_z	Velocity of fluid, m/s
W	Plate width, m

Subscripts

c	Cold fluid
h	Hot fluid
i	Channel number
p	Plate
c_i	Inlet of cold fluid
h_i	Inlet of hot fluid
c_o	Outlet of cold fluid
h_o	Outlet of hot fluid

Greek Characters

α	Film heat transfer coefficient of fluid, W/m^2 °C
ΔP	Pressure drop in channel, pa
Δt_m	Mean temperature difference, °C
δt	Temperature change in fluid, °C
ε	Effectiveness of plat heat exchanger
θ	Number of transfer unit
μ	Fluid viscosity, Ns/m^2
ρ	Fluid density, kg/m^3
ρ_c	Density of cold fluid, kg/m^3
ρ_h	Density of hot fluid, kg $/m^3$
τ_i	Residence time in channel i, s

Continuity equation is mass balance equation. Mass balance has been made only in the z direction, which is the flow direction and as fluid enters or leaves the channel, either from top or from the bottom. Continuity equations are presented below (see [7], [9]).

Momentum balance (see [5], [7]) equations have been made only in flow direction as there is no fluid entry or exit into the channel from the sides.

Channel i: $$\rho \frac{\partial v_{zi}}{\partial z} = \mu \frac{\partial^2 v_{zi}}{\partial x^2} - \frac{\partial P}{\partial z} + \rho g = 0$$ for i = 1 to n

Channel i: $$\frac{\partial v_{zi}}{\partial z} = 0$$ for i = 1 to n (1)

In energy balance (see [1], [7],[8]), heat enters the shell not only in the flow direction, but also from the side metal walls.

Channel 1: $$\frac{\partial T_1}{\partial t} = \pm v_{zi} \frac{\partial T_1}{\partial z} + \alpha_1 (T_2 - T_1)$$

Channel i: $$\frac{\partial T_1}{\partial t} = \pm v_{zi} \frac{\partial T_1}{\partial z} + \alpha_1 (T_{i+1} - T_{i-1} - 2T_i)$$

Channel n: $\frac{\partial T_n}{\partial t} = \pm\, v_{zn}\frac{\partial T_n}{\partial z} + \alpha_n(T_{n-1} - T_n)$

Where $\alpha_i = \frac{U v_{zi} w}{m_i C_i}$

The model equations are solved by specifying initial and boundary conditions which depend upon the flow pattern in the heat exchanger. Finite difference method is used to solve the above set of equations.

3. MODEL RESULT

Performance of a plate heat exchanger is given in terms of its effectiveness ε, which is defined as

$$\varepsilon = \frac{\text{Actual heat transfer}}{\text{maximum possible heat transfer}}$$

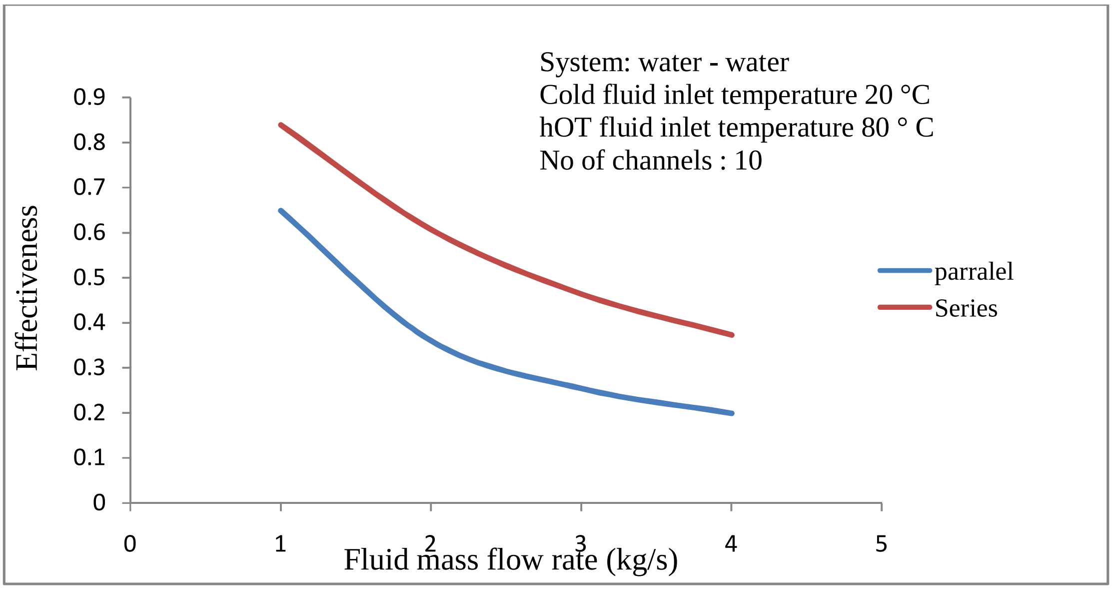

Fig 1.2 Effect of cold fluid mass flow rate on the effectiveness of plate heat exchanger

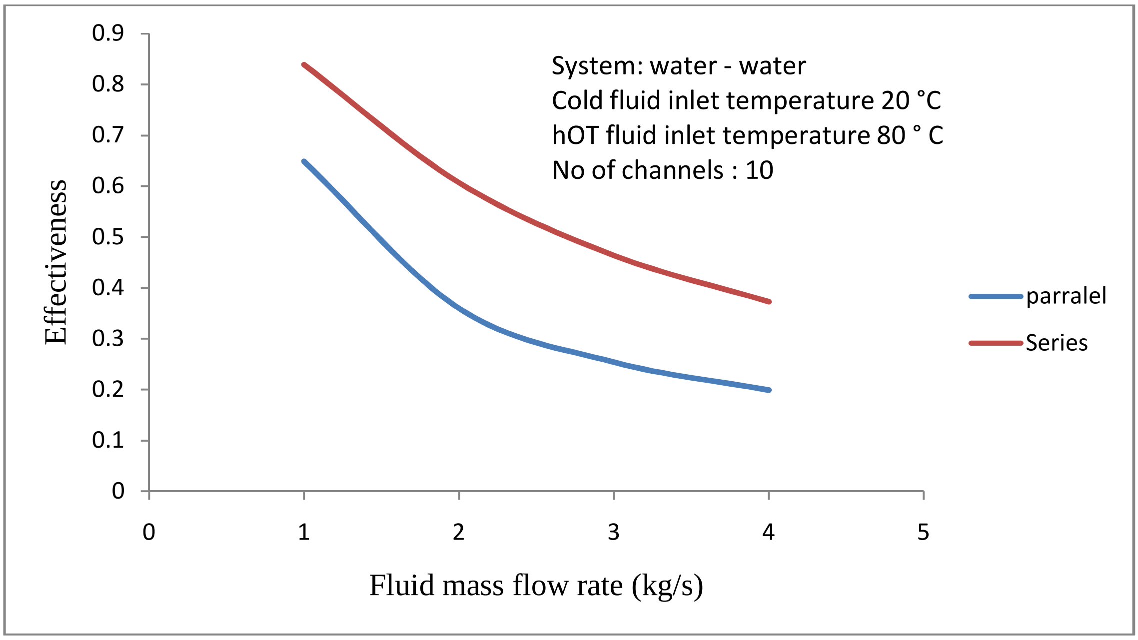

Fig 1.3 Effect of hot fluid mass flow rate on the effectiveness of plate heat exchanger

Figures 1.2 and 1.3 show the effect of mass flow rate of fluids on the effectiveness of plate heat exchanger. The fluid flow rate has been varied from 1 kg/s to 4 kg/s. When the flow rate flow rate of one fluid is varied, the mass flow rate of the other fluid is kept constant at 4kg/s. In all the flow patterns, number of flow channels considered is 10. From these figures it is noted that, in all flow patterns effectiveness decreases; with increase in mass flow rate of cold fluid. This is because, as heat capacity of fluid increases temperature change in fluid decreases. And For all the flow patterns, the effectiveness decreases with increase in hot fluid mass flow rate, due to similar reasons.

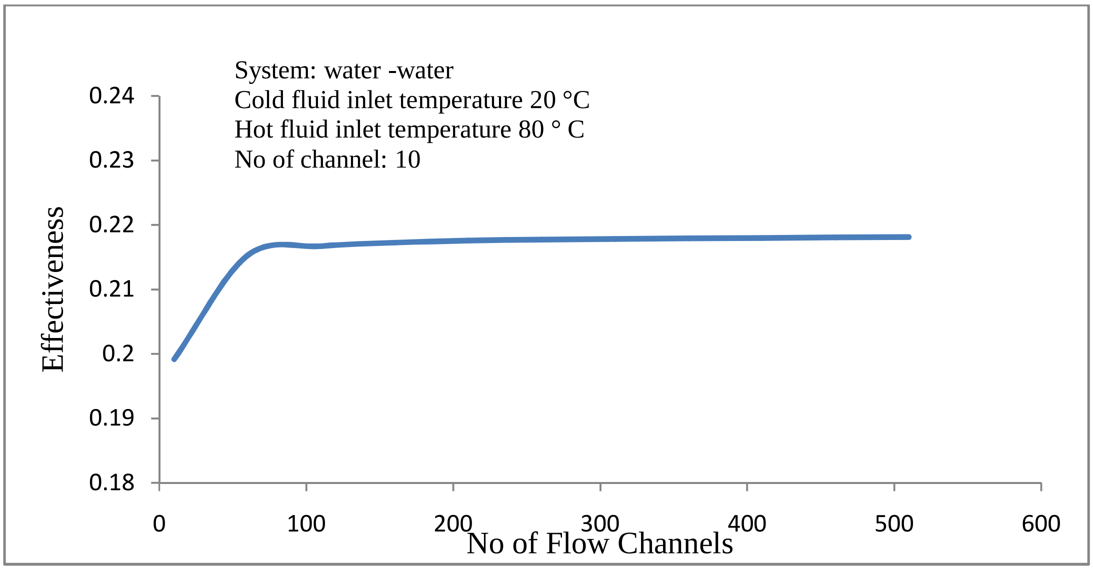

Fig 1.4: Effect of no. of channels on the effectiveness of plate heat Exchanger for parallel flow.

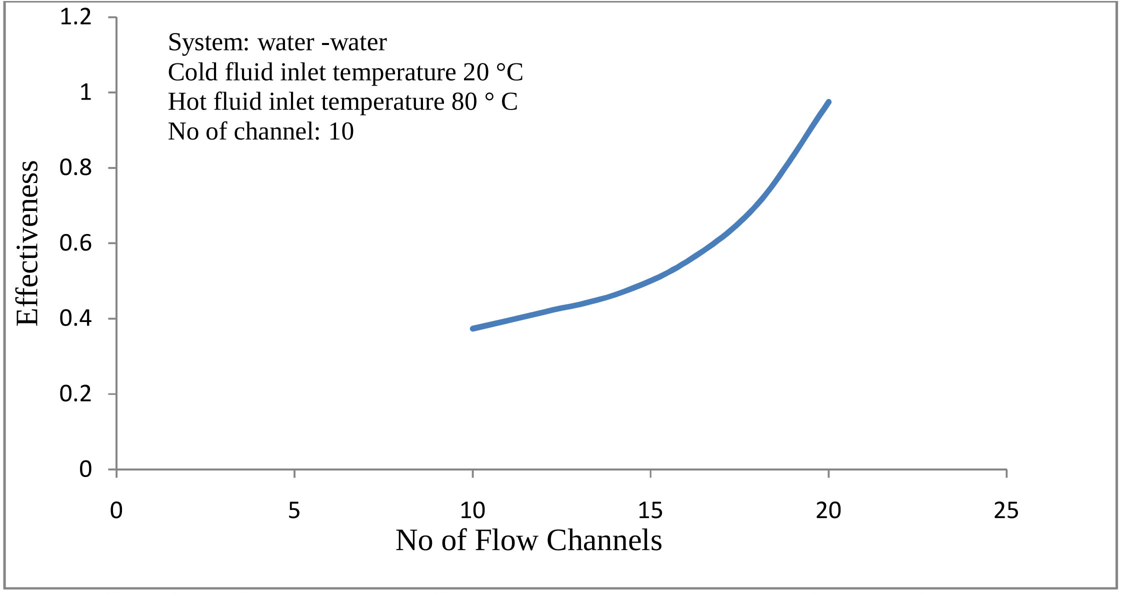

Fig 1.5: Effect of no. of channels on the effectiveness of plate heat exchanger for Series flow pattern

Figures 1.4 and 1.5 show the effect of number of flow channels on the effectiveness of plate heat exchanger. It is also dependent on the flow pattern existing in the heat exchanger. For all flow patterns, effectiveness increases with number of flow channels. This is because, as the number of channels is increased, heat transfer area increases causing greater temperature change to occur in fluids. In series flow patterns the effectiveness increases and approaches unity. In parallel flow, effectiveness does not increase much and approach a very modest value of 0.218. This is due to the fact that, in parallel flow, addition of flow channels not only increases heat transfer area, but also increases heat capacity of both the fluids.

4. CONCLUSION

Effectiveness decreases with increasing mass flow rate of cold fluid in parallel flow pattern and series flow pattern. And also effectiveness decreases in mass flow rate of hot fluid in parallel flow pattern and series flow pattern. Effectiveness has been found to increase with the increase in number of flow channels in parallel flow pattern and series flow pattern.

REFERENCES

[1] A. Cooper, “Recover more heat with plate heat exchanger”, The Chemical Engineer, May 1974, pp. 280-284.
[2] S. K. Das and W. Roetzel, “Dynamic analysis of plate heat exchanger with dispersion in both fluids”, Int. J Heat Mass Transfer, 1995, Vol. 38, No. 6, pp. 1127-1140.
[3] S. K. Das, B. Spang and W. Roetzel, “Dynamic behavior of plate heat exchanger-Experiment and Modeling”, ASME Journal of Heat Transfer, August 1995, pp. 859-864.
[4] W. W. Focke, “Selecting optimum plate heat exchanger surface pattern”, ASME Journal of Heat Transfer, February 1986, Vol. 108, pp. 153-160.
[5] S. G. Kandilkar and R. K. Shah, “Multipass plate heat exchanger effectiveness-NTU results and guidelines for selecting pass arrangement”, ASME Journal of Heat Transfer, may 1989, Vol. 111 pp. 300-313.
[6] A.R Khan, N.S Baker and A.P Wardle “the dynamic characteristic of a counter current plate heat exchanger”, Int. J Heat Mass Transfer, 1988, Vol. 31, No. 6, pp. 1269-1278.
[7] Khan Naseem Ahmad and Rahman Wasi, “Modelling and Simulation of Plate Heat Exchanger”, International Journal of Mechanical Engineering, 2012 Volume 2 Issue 1,pp.22-30.
[8] J. R. Lines, “Asymmetric plate heat exchanger”, Chemical Engineering Progress, July1987, pp. 27-30.
[9] C.C .Lakshmanan and O.E Potter, “dynamic simulation of plate heat exchanger ”, Int. J Heat Mass Transfer, 1990, Vol. 33, No. 5, pp.995-1002.