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Numerical Analysis of Header Configuration of the Plate-Fin Heat Exchanger

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Abstract: *Numerical analysis of a plate fin heat exchanger accounting for the effect of fluid flow maldistribution onthe inlet header configuration of the heat exchanger is investigated. In this analysis , it was found that flow maldistribution has effect on the flow perpendicular to its velocity direction. The peak velocity occurs in the central zone of the header while the velocityalong the perpendicular direction of the inlet flow diminishes more and more. By this investigation,the results of the flow maldistribution are presented for a plate fin heat exchangerwhich is reduced as compare to theexisting configuration of the plate fin heat exchanger.*

Keywords:*Plate fin heat exchanger, Flow maldistribution,Header configuration,ComputationalFluid Dynamices(CFD).*

I. Introduction

Plate fin heat exchanger is specially designed for transferring the heat between medium and low pressure fluids. It is small in size but having high efficiency heat exchanger. It uses the metal plates to transfer heat between two fluids. A major advantage of the plate fin heat exchanger over a conventional heat exchanger is that the fluids are exposed to a much larger surface area because the fluids spread out over the plates. This facilitates the transfer of heat and greatly increases the speed of the temperaturechange. With the characteristics of compact structure, light weight and high heat transfer efficiency. The aluminum plate fin heat exchanger is widely used in various industries such as industrial gas separation plant, LNG plant, petrochemical, transportation and refrigeration plant, aerospace, chemical engineering, artificial organs. In the design of the plate fin heat exchanger, it is generally assumed that the fluid flow distribution is uniformly distributed among all the parallel fin passages through the heat exchanger core. But in actual practices, it is impossible to distribute the fluid flow uniformly because of flow maldistribution. Flow maldistribution is a non-uniform distribution of mass flow rate in a heat exchanger core. Flow maldistribution depends on several factors such as heat exchanger's geometrical configuration (i.e. mechanical design, channel and header geometry and dimensions, manufacturing tolerances or imperfections), operating conditions (flow velocity changes along the headers, fluid viscosity, and multiphase flow). Flow maldistribution is a very important factor that affects the performance of heat exchanger to a great extent [1].

A number of researchers have studied the maldistribution problem analytically and experimentally.Ch. Ranganayakulu et al [2] studied a cross flow plate-fin compact heat exchanger, accounting for the combined effects of two-dimensional longitudinal heat conduction through the exchanger wall and non-uniform inlet fluid flow and temperature distribution is being carried out by using a finite element method.KoenGrijspeerdt et al [3] analyzed the flow pattern of milk between two corrugated plates that was carried out using 2D and 3D computational fluid dynamics (CFD). The results obtained can be helped identifying those regions where turbulent backflows and thus higher temperature regions near the wall can occur.L. J. Shah et al.[4] developed a three block model for the analysis purposes through which revealed that fluid distribution along the mantle is being affected by recirculation produced due to buoyancy force in the mantle in case of high and low temperature inputs, respectively.Jian Wen and Yan Zhong Li [5] analyzed the fluid flow maldistribution for the conventional header used in industry. According to him, a baffle with small holes of three different kinds of diameters is recommended to be installed in the header to control the flow maldistribution in the heat exchanger. The numerical result obtained effectively improved the performance of the heat exchanger.Zhe Zhang and Yan Zhong Li [6] found that the flow maldistribution is very serious in the perpendicular to the flow of header for the conventional header used in industry. By the investigation, two modified headers with a two-stage-distributing structure are proposed and simulated. It is verified that the fluid flow distribution in plate-fin heat exchangers is more uniform if the ratios of the outlet and inlet equivalent diameters for both headers are equal.Li-Zhi Zhang [7] analyzed that the inlet and outlet duct geometry in an air to air compact heat exchanger is always irregular. The results indicated that flow distribution depends upon the channel pitch size.V. V. Dharaiya et al [8] studied the flow distribution through a plate-fin heat exchanger (straight Z-type flow) with parallel micro-channels and mini-channels by using a CFDcode FLUENT. They suggested that the flow maldistribution was quite severe with constant cross-sectional area headers. Myoung II Kim et al. [9] estimated the flow pattern characteristics of the shell-and-tube type heat exchanger. Different header types were considered and results indicated that the smallest header length and minimum flow rate (655 mm and 0.54 m^3s^1) is not sufficient in distributing the flow uniformly along the length whereas the larger length header (1092.5 mm and 1.62 m^3s^1) yields the best results.

The main objective behind this present work is to investigate the previously developed header configuration systematically and to optimize the design for the plate fin heat exchangers regarding flow distribution i.e. to reduce the effect of flow maldistribution for the Reynolds number from Re=4000-6000.

Nomeclature
k- turbulant kinetic energy(m^2s^{-2})
n – channel number
S – flow nonuniformity
s_Φ-source term for generalized transport variableΦ
SIMPLEC – Simple Implicit Method for the Pressure Linked Equation Consistent

Greek Symbol
ε-turbulant energy dissipation rate(m^2s^{-3})
Γ - effective diffusivity(m^2s^{-1})
ρ-density of the fluid(kgm^{-3})
Φ -a generalized transport variable.

II. Analysis of the Flow Maldistributionin Plate-Fin Heat Exchanger

2.1 CFD Model

Fig 1 shows a parametric view of the plate fin heat exchanger with its geometrical dimensions.The section of the plate fin heat exchanger has the dimension of 200 x 250 x 178 mm. The inlet tube of header is of 40 mm in diameter and thelength of the header is 250 mm.The header consist of a hemicylindrical tube of 60 mm diameter and 250 mm in length.It has T-shaped connection with the inlet tube.

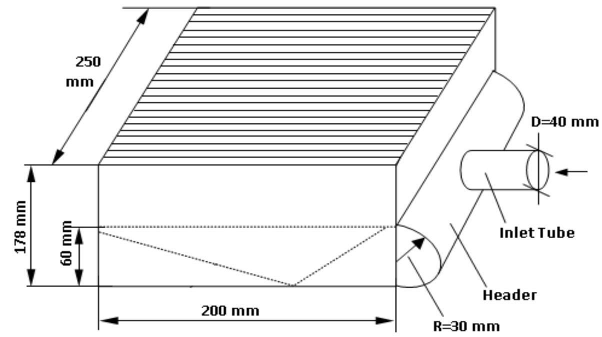


Plate -fin heat exchanger
Fig. 1

2.2 Mathematical Model Equation:

In this design process, to determine the flow motion a nonlinear Partial differential equation i.e. Reynolds transport equation is used.

$$\frac{\partial y(\rho u\Phi)}{\partial x} + \frac{\partial(r\rho v\Phi)}{r\partial r} + \frac{\partial(\rho w\theta)}{r\partial\theta} = \frac{\partial\left(\Gamma\frac{\partial\Phi}{\partial x}\right)}{\partial x} + \frac{\partial\left(\frac{\Gamma r\partial\Phi}{\partial r}\right)}{r\partial r} + \frac{\partial\left(\frac{\Gamma r\partial\Phi}{\partial\theta}\right)}{r\partial\theta} + S_\Phi$$

Where, Φ stands for a generalized transport variable,which is used for all conserved variables in a fluid flow problem, including mass, momentum, and the turbulence variables k and ε. Γ represents the effective diffusivity (sum of the eddy diffusivity and the molecular diffusivity).s_{Φ} is the source term for the respective dependent variable. The initial step for solving a partial differential equation is to discretized the equation.Here, Gauss Seidal method .The accuracy of the solution depends upon the mesh size.The solution of above equation develop the velocity and turbulance levels in the header.

2.3 Boundary Conditions

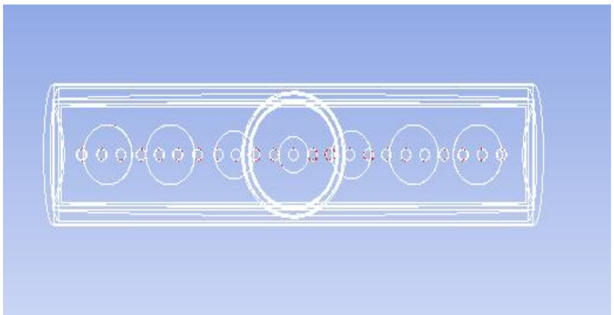
Intial conditions are given as follows:

At inlet the axial velocity is specified i.e. no radial or swirl components,outlet is considered as pressure outlet and for walls adiabatic and non slip boundary condition are applied.Convergent condition is specified to scaled residuals$\leq 10^{-6}$. The solution being converges when the change in the solution variable in consecutive iterations are negligible.

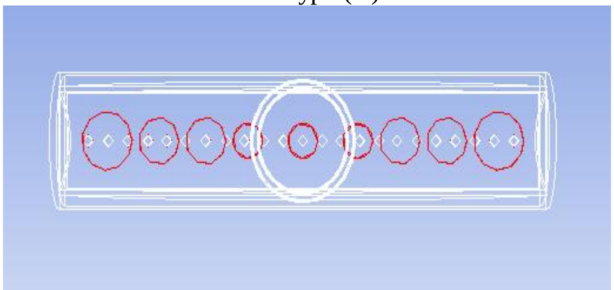
2.4 Analysis of Flow maldistribution

2.4.1 Numerical Solution Procedure

The whole analysis is performed on ANSYS-FLUENT version 14.0 developed by ANSYS inc. In today's industry sector, ANSYS is one of the widely used software for the analysis purposes.The turbulance flow problem is solved through pressure-based segregated algorithm i.e. SIMPLEC scheme(Simple Implicit Method for the Pressure Linked Equation Consistent). For spatial discretization Least Square Cell Based scheme is used.The geometry is created in Solid Edge developed by UGS Corps as shown in Fig.2.



Type (A)



Type(B)

Fig.2 Schematic model of modified header configurations with type(A) and type(B)

Here, two types of header has been designed which are named astype(A) and type(B). Both header are different in their structural design.Type A represents the header configuration with 7 outlets at the first header and 23 channels at the main outlet while Type B represents the header configuration having 9 outlets at the first header and 23 channels at the main outlet.

2.4.2 Grids

In the present model triangular surface mesh is implemented.The number of nodes created is 20134 while the elements are 81432 in number.For the modest geometries quad/hex meshes provide a good solution as compared to the tri/tet mesh while for the complexgeometriestri/tetshows the goodresult.

2.4.3 Solver

In this analysis we uses segregated algorithm under the pressure-based solver. In the segregated algorithm the governing equations are solved sequentially, segregated from one another.

2.4.4 Evaluation of flow maldistribution

To evaluate the flow maldistribution in 23 passages , the flow non uniformity for the individual section and the whole section is given as follows:

$$Si = \frac{Vi - Va}{Va}$$

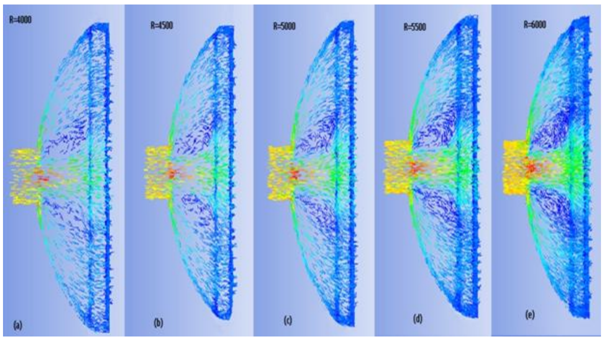
$$S = \sum_{i=1}^{n} |(Vi - Va)/Va|$$

Where Si and S is the individual flow non uniformity and the total nonuniformity of the crossection .Vi and Va is the flow velocity at the individual section and the average velocity for the whole crossection.

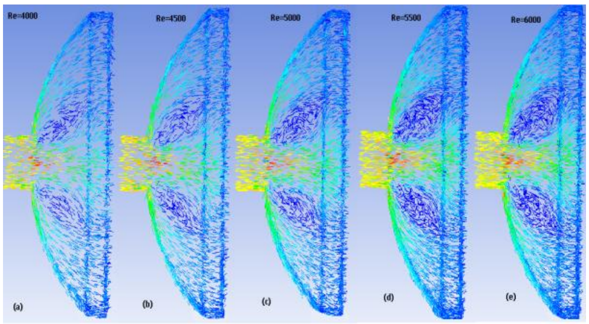
III. Results And Discussion

Flow distribution in the Plate fin heat exchanger with modified header:

In this analysis, we investigate the flow distribution in modified header within the turbulance range i.e.Reynolds number from Re=4000-6000.Figures 3 shows the flow distribution at different Reynolds Number for the modified header configuration.



Type (A)



Type (B)

Fig. 3Velocity vector distribution for the Type (A)and Type (B) configurationsat (a)Re=4000 (b)Re=4500 (c)Re=5000 (d)Re=5500 (e)Re=6000

As shown in the fig. 3 , the yellow coloured portion shows the maximum velocity while the light blue colour shows the minimum velocity. Flow maldistribution increases as the value of Reynolds number increases but it is less as compared with the conventional header configuration.We can also see the uniform distribution of flow along its length.Also,the eddy loses developed due to the reverse flow in the conventional header is being reduced in the above shown header configuration.The efficiency of the heat exchanger and the flow distribution depends upon the geometrical configuration of the header.

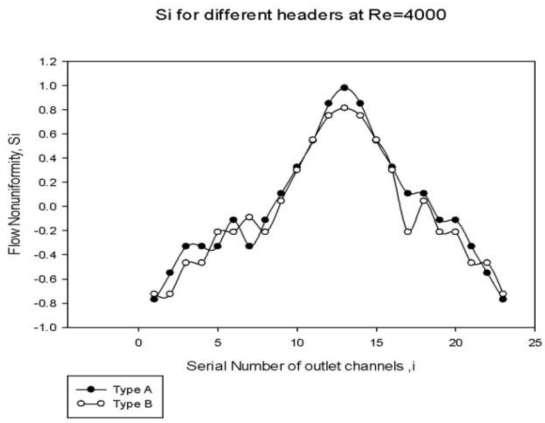


Fig. 4 Flow nonuniformity for the different headers at Re=4000

Comparison of the flow nonuniformity between the both Type A and Type B header configuration has been illustrated in Fig. 4. The flow distribution of Type B is much better than as compared to that of Type A.Also the flow maldistribution reduces from the 0.98 to 0.81 at Reynolds number i.e. at Re=4000.The optimization of the geometrical configuration improves the flow distribution in the heat exchanger.Also,with the increased smooth spread of flow along the length oulet increases the performance of the heat exchanger.

IV. Conclusion

In the present paper , a modified header configuration with two-stage distributing structure is developed and flow distribution in the range of Reynolds Number,Re= 4000-6000 is simulated by CFD.The proposed modified header configuration plays a remarkable role in the flow distribution. The flow nonunformity has been reduced from 0.98 to 0.81 at Reynolds number , Re=4000.This simulation shows that CFD is a suitable tool for predicting the flow distribution and to optimizing the design of header configuration of the plate fin heat exchanger.

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