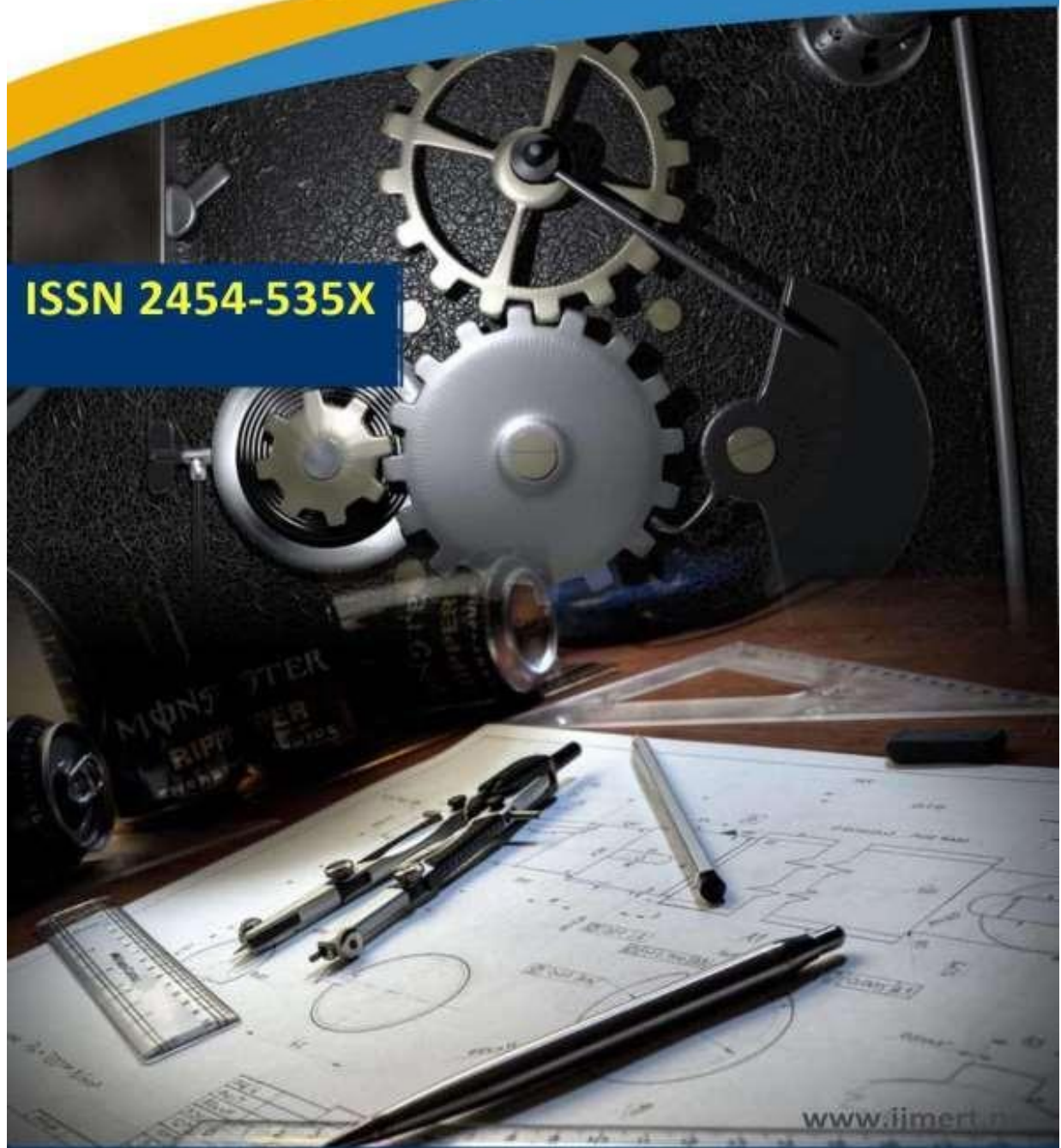




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Using CFD and genetic algorithms, baffle design in a parallel heat exchanger header is numerically optimized.

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ABSTRACT: One of the primary causes of the decrease in thermal performance in a parallel heat exchanger is the maldistribution of refrigerant flow. This work presents a numerical technique to automatically calculate the height of the baffles to maximize the two-phase flow refrigerant's distribution inside the heat exchanger header. Using a genetic algorithm and a computational fluid dynamics (CFD) model, this technique simultaneously generates the ideal dimensions of several baffles. According to the numerical results, compared to the original design, the maldistribution of flow might be reduced by up to nine times. Additionally, this framework has the potential to increase the design space, making it a valuable tool for improving header designs that employ in parallel heat exchangers.

KEYWORDS: refrigerant; computational fluid dynamics (CFD); parallel heat exchanger

INTRODUCTION

When building an air-cooled heat exchanger, one of the most crucial considerations is the flow maldistribution inside the input header. The maldistribution of flow could drastically impair the heat exchanger's performance [1-2]. To increase the efficiency of the parallel flow heat exchanger, it is therefore necessary to examine and adjust the flow behavior inside the inflow header. Geometry and

operational conditions may both contribute to flow maldistribution in parallel inlet headers in practical design [3]. According to Jiao et al. [4], an ideal header configuration design might greatly enhance the flow distribution. The experimental findings in this study also indicated that certain geometry parameters, such as the inlet pipe, had an impact on the flow distribution in plate fin heat exchangers.

NUMERICAL MODEL

Mathematical model

In present study, two-phase flow of refrigerant is simulated using the OpenFOAM software. The working fluid is R-134a. Since the experimental test was taken under the adiabatic condition, the simulation will only solve the continuity and momentum equations. VOF method, therefore, has been implemented. In this work, VOF solver

in OpenFOAM calculates one momentum and one continuity equation for both liquid and gas phases of R134a. The physical properties of one phase are determined based on the volume fraction, α , of two phases in a cell. The continuity equation is defined as follow

(1)

The momentum equation is determined as

$$\frac{\partial \rho U}{\partial t} + \nabla \cdot (\rho U U) - \nabla \cdot (\mu \nabla U) - \rho g = -\nabla p - F_s$$

(2)

t^s

where F_s is the surface tension force at free surfaces and is defined as:

$$F_s = \sigma \kappa(x) n \quad (3)$$

where κ is the curvature of the interface and n is a unit vector normal to the interface. κ and n are calculated as follow:

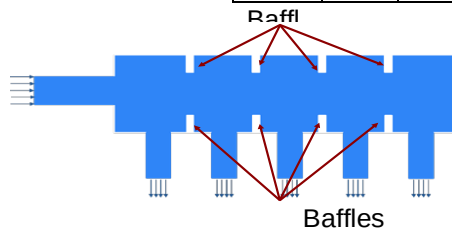


$$\kappa(x) = \nabla \cdot n4)$$

and

Table 1. Properties of R134a

Sat. Tem p. (°C)	P (kPa)	Density of liquid (kg/m ³)	Density of vapor (kg/m ³)	Liquid Vis. (Pa.s)	Vapor Vis. (Pa.s)
24.47	665	1208.7	31.841	1.96E-04	1.17E-05



$$n =$$

$$(5)$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha U) = 0$$

$$(6)$$

Volume fraction, α , in a cell is 0 if it is completely filled by vapor phase and, on the contrary, volume fraction equals 1 if cell is completely filled by fluid phase. Volume fraction is calculated by a transport equation as following: The compression of the surface in OpenFOAM is defined as follow:

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha U) + \nabla \cdot (\alpha (1-\alpha) \nabla \alpha) = 0 \quad (7)$$

where U_r is a suitable velocity field to compress the interface.

Geometry and grid generation

In this study, the original dimensions of the header is obtained from a report of Fei and Hrnjak [11].

In the first step, we set up a CFD model to validate the experimental data. A three-dimensional geometry was then created. The grid was generated with fully hexahedral elements to reduce the computational cost as well as to enhance the accuracy and stability of simulation. In addition, to validate the independence of grid, three types of

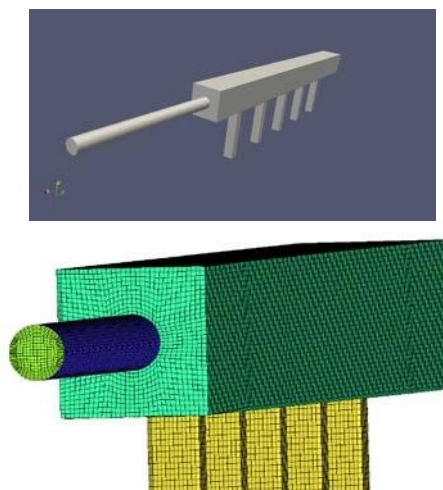


Figure 1. Geometry and grid

**Table 2.** Dimension of header

Inlet length (mm)	Inlet diameter (mm)	Body Length (mm)	Body Height (mm)	Outlet hydraulic diameter
120	9.5	305	25.4	8.8

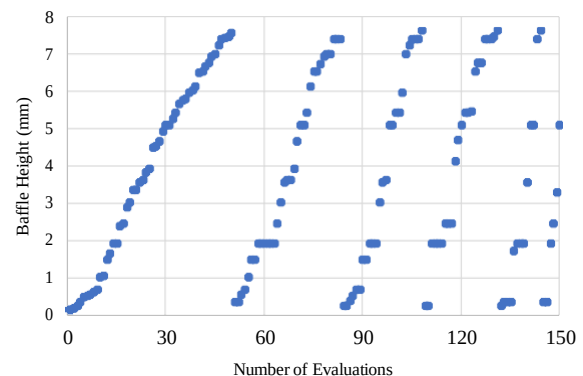
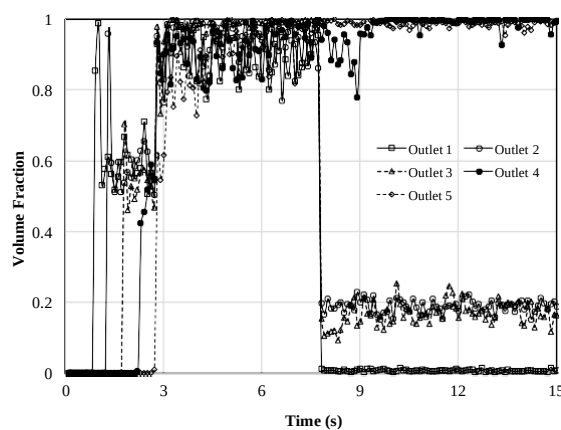
mesh were also made. The detail dimension of manifold is illustrated in Table. 1. The geometry and sample of a grid are shown in Fig. 1. And the properties of two-phase flow of R134a obtained in REFPROP 8 [12] are listed in Table 2.

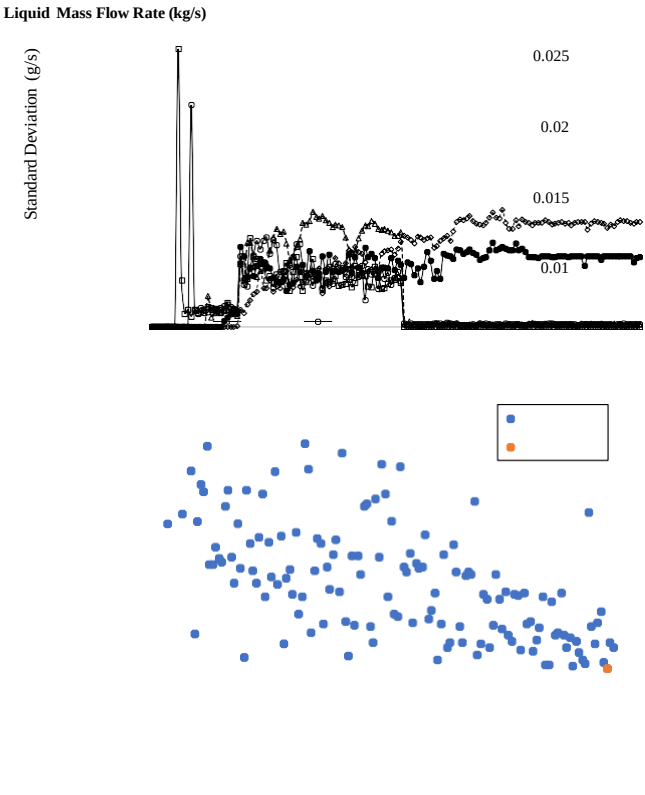
In the second step, we applied the validated numerical model to the same dimension geometry but inserting the inside baffles between each outlet channel. Since the baffles divide the header to separated subsections, the geometry now can be expressed in 2D model. The geometry and grid are then generated using script. The structure of proposed header design is shown in Figure 2.

Optimization procedure

In present work, a surrogate-based optimization model and single objective genetic algorithm (SOGA) were implemented as the optimizers. The purpose of algorithm is to minimize the standard deviation of the flow rate at the outlets. The optimization block automatically generates baffle dimensions and other continues design space. CFD code, driven by a script, then runs and exports the results to sample-dataset. Total 120 samples were generated. The optimizer then runs evaluation processes bases on the data set and proposed the best results. In SOGA block, the fitness type was set as domination count. The cross over is 80%, the mutation scale is 10%, and the number of evaluations in this study was set as 150 [13-16].

RESULTS AND DISCUSSIONS







Number of Evaluations

	Outlet 1 Outlet 4	Outlet 2 Outlet 5	Outlet 3 -----	

(b) Standard deviation
 Figure 3. History of mass fraction and liquid massflow rate
 Figure 4. History of evaluation

Fig. 3 shows the history of volume fraction liquid phase and the mass flow rate of five outlet channels. In this case, the total mass flow rate at the inlet of header is 25g/s and the vapor quality is 0. As seen in the figure, after few first seconds, the liquid flow rate is stable and most of liquid is concentrated at fourth and fifth outlets are

stable and mostly equal. The interference of the forward flow from inlet of header and the backward flow bouncing from the last wall is believed to be the reason for this phenomenon. This case also addresses both the non-uniformity and fluctuation of flow could occur inside a generic header. Thus, optimizing of structure of inlet is needed.

The height of baffle and standard deviation of mass flow rate during the evaluation were illustrated in Fig. 4. In this work, total 120 samples were generated from CFD solver. The baffle height is ranged from 0.1 to 7.9 mm and 150 evaluations were created. The optimal point is successfully found at evaluation 148th with the baffle height of 2.44 mm. The optimal results show the optimal design could reduce the maldistribution up to 9 times.

CONCLUSIONS

In current work, the CFD simulation and a novel optimization approach of two-phase flow distribution of R134a in an inlet header of heat exchanger have been investigated. The simulations were established using VOF model. An optimization procedure which used SBO-GA coupled with CFD simulation has been developed. The results from this study show that the optimal design could reduce the maldistribution of flow up to 9 times compared to the original one. In addition, this procedure

could be expanded its application to other design parameters that help designers to saving time in deploying new structure of inlet header used in heat exchanger.

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