ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 1, July 2018

# Performance Studies on Plate Fin Heat Exchanger with CFD Simulation

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***Abstract*— In the cryogenics field, maximum effectiveness heat exchangers of the order of 0.96 or higher are used for preserving the low temperature effect produced. The Compact Heat Exchanger (CHE) is modifies by a cross flow passages between small volume and a high rate of energy exchanges of two fluids. Thermo-hydraulic performances of Compact Heat Exchangers (CHE) is strongly depends upon Colburn 'j' and Fanning friction 'f' factors of effectiveness of performance of various types of heat transfer surfaces such as Offset Strip fins, Wavy fins, Rectangular fins, Triangular fins, Triangular and Rectangular perforated fins. This thesis on the offset strip plate fin heat exchanger compares the effectiveness, overall thermal coefficient & the pressure loss obtained from the experimental data with some correlations on offset strip plate fin heat exchanger i.e., Manglik-Bergles correlation , Joshi-Webb correlation, Maiti-Sarangi correlation and also with the numerically achieved data obtained by using CFD.***

***Index Terms*— Compact heat exchanger, colburn, fanning friction, offset strip plate fin and computational fluid dynamics.**

## I. INTRODUCTION

ADevice by which thermal energy or enthalpy is transferred between two or more fluids having different temperatures and which are also in thermal contact with each other that is called as heat exchanger. The thermal contact with each other between two or more fluids, fluid and solid particulates and fluid and a solid surface in which enthalpy can transfer easily. Usually no work interaction in heat exchangers. The heat exchangers no heat transfer takes place due to adiabatically insulated. The main applications of the heat exchanger is cooling and heating of a fluid, condensation of a single or multi- compound fluid, evaporation of a single or multi-compound fluid. Generally, cryogenic applications used in high effectiveness heat exchangers. The effectiveness of heat exchangers used in liquefiers is of the order of .96 and above. The heat exchangers falls below the design value of effectiveness due to no liquid yield. The aim is to keep the weight and volume of the heat exchanger minimum in case of the use of heat exchangers in aircrafts, high effectiveness and performance is required higher. The generation of compact heat exchangers are considering by low volume and weight. In general Compact heat exchangers have large surface area density i.e. large surface area to volume ratio which is of the order 700 $m^2/m^3$ or greater than this value for gas and it should be 300 $m^2/m^3$ for two-phase streams and liquids

Heat exchangers are used to transfer thermal energy between two or more medium. There are wide range of heat exchangers which used in different industrial application, one of the important among them are Compact Heat Exchangers, which include plate-fin types and tube-fin type heat exchangers. Cross flow plate-fin heat exchangers are widely used in gas-gas applications such as cryogenics and micro turbine; in addition it is also used in automobile, chemical process plants, naval and aeronautical applications. Plate-fin heat exchangers has high thermal effectiveness. The fins are employed on both sides to interrupt boundary layer growth, has high thermal conductivity due to thin thickness of plate and large heat transfer surface area per unit volume. This leads to reduce space, weight, energy requirement and cost. However the expense of higher frictional losses for superior thermal performance of the compact heat exchanger (i.e. pressure drop). Therefore, the optimum design of compact heat exchanger required the maximum trade-off between the heat transfer rate and the power consumption due to higher pressure drop within the given set of constrain. The second law of thermodynamics is one of the effective way to evaluate the heat transfer enhancement methods by consideration of both trade-off factors.

The various types of compact plate fin heat exchangers depending on their fin structures. Some fin types are:

1. Triangular cross-section plate fins
2. Wavy fins.
3. Offset strip fin, perforated fin, louver and pin fin are interrupted fins. The strip fins are known as serrated or segmented fin lance offset fin and offset fin.

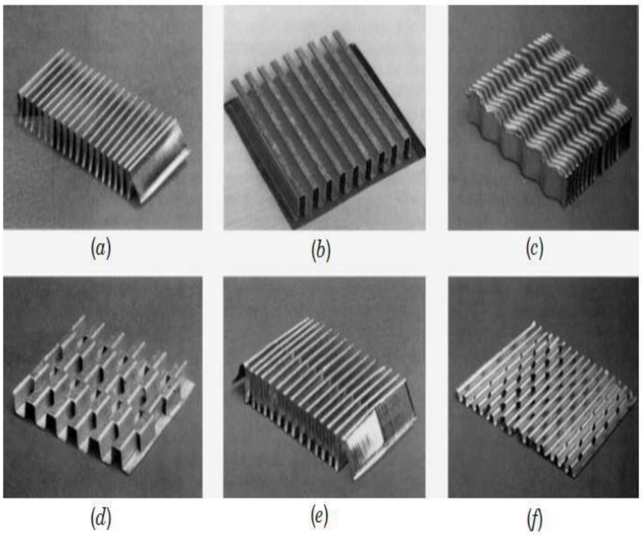


**Fig 1. Plate fin heat exchangers having corrugated fin geometries (a) Triangular plain fin (b) Rectangular plain fin (c) Wavy fin (d) Serrated or offset strip fin (e) Multi-louver fin (f) Perforated fin (Shah and Sekulic [2])**

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## II. MEASUREMENT PRINCIPALES

The heat transfer characteristics of the Plate fin heat exchanger experimented by Kays and London on along with the pressure drop characteristics, in a most effective and reliable manner [1]. A cross-flow type heat exchanger experimental set-up dealted. But we did our set-up for offset strip fin type surface as counter flow type plate fin heat exchanger [3]. Here the cool ambient air is drawn by the compressor through a channel and is being heated by using heat exchanger and a heater where air is heated & these heated air transfers heat to the cold air through the exchanger. The pressure gauges are used for measuring the pressure at the inlets of the both the fluids. Similarly Resistance Temperature Detectors (RTDs) are used for measuring the temperature at the inlet and outlet of both the fluids. By measuring the temperature and mass flow rate, effectiveness can be calculated. Overall thermal conductance and Number of Transfer units (NTU) can be determined from the measurement of effectiveness.

## III. OBJECTIVE OF THE STUDY

The offset strip plate fin heat exchanger rating and sizing, we have reviewed many correlations between the heat transfer factor in the literature coefficient and friction. The main objective is the evaluation of the performance parameters of a counter flow heat exchanger. This is done by following steps:

i. Based on the chosen correlation, an offset strip plate fin heat exchanger have been designed.
ii. For a given design data, industrial fabrication of the plate fin heat exchanger is done.
iii. Test fabrication for testing.
iv. The effectiveness, heat transfer coefficient, pressure drop etc. are obtained for the experiment and these obtained values will be compared with the rating values of the plate fin heat exchanger based on various correlations and by CFD analysis.

The correlations used for Plate Fin Heat Exchanger design are:

a. Correlation by Maiti-Sarangi [15].

b. Correlation by Manglik-Bergles [14].

c. Correlation by Joshi-Webb [13].

## IV. DESIGN OF THE PLATE FIN HEAT EXCHANGER

The basic design considerations of a plate fin heat exchanger include:

I. Process & design specifications
II. Hydraulic & thermal design
III. Mechanical design
IV. Manufacturing considerations

## V. TRADE-OFF FACTORS AND SYSTEM BASED OPTIMIZATION

In heat exchanger design, the process & problem specification is one of the most important steps. Any specification for process and design procedure counts all the required information for designing and optimizing the exchanger for a particular application. It includes:

- Specification of the problem for operating conditions
- Type of heat exchanger
- Type of flow arrangement
- Materials
- Considerations for design/manufacturing/operation
- Information on the minimum input specifications

The selection of design conditions is the first and important consideration. Then, the next is the off-design and design point condition. The specification for operating conditions and the operating environment should be mentioned which includes:

- Mass flow rates
- Fluid types and their thermos-physical properties
- Inlet temperature & pressure of both fluid streams
- Maximum allowable pressure drop on both fluid sides
- Inlet temperature & pressure fluctuation due to variation in the process or environmental parameters
- Corrosiveness
- Fouling characteristic of fluids and
- Operating environment

The heat exchanger specification includes heat exchanger includes exchanger construction type, flow arrangement, core geometry, & fin type. For compact plate fin heat exchangers, one can choose offset strip fin, louver fin or other fin geometry.

## VI. NUMERICAL ANALYSIS BY CFD

The computational fluid dynamics is used for the prediction of fluid flows & heat transfer using the computation method.

***1. Description to the problem & geometry:***

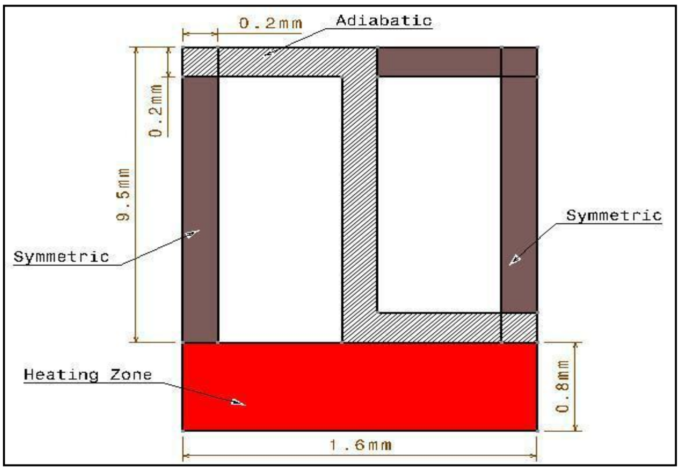


**Fig 2. The geometry of the offset fin with the dimensions**

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 8, Issue 1, July 2018

In the present paper, obtained result numerically for offset strip fin plate heat exchanger & is compared with the experimentally.

## 2. *Materials properties*

The fin material is made of aluminum or aluminum based alloys. Offset strip fin heat exchangers made up of Aluminum because of its good thermos-physical characteristics, small density & relatively low price. Aluminum are used for the numerical calculations for constant thermos-physical properties:

Density of aluminum= $\rho_{Al}$ =2719 Kg/m$^3$

Specific heat of aluminum= $C_{p\ ,\ Al}$ =871 J/Kg K

Thermal conductivity of aluminum=202.4 W/m K

The offset strip fin heat exchanger flows air through fluid. CFD calculations are:

Density of air = $\rho_{air}$ =1.225 Kg/m$^3$

Specific heat of air= $C$ =1006.43 J/Kg K

Thermal conductivity of air= 0.0242 W/m K

Coefficient of viscosity= $\mu$ = 1.7894 x10$^{-5}$ Kg/m s

## 3. *Boundary conditions*

Boundary conditions are given to the physical models in order to solve the numerical problem.

- Inlet boundary condition: velocity is defined as the inlet boundary condition. The uniform velocity value is obtained from constant temperature of 333 K, the Reynolds number based on the hydraulic diameter of the offset strip fin and viscosity.
- Outlet boundary condition: The static pressure is defined as the outlet boundary condition.
- Symmetric boundary condition: The symmetric conditions means there is zero flux across the boundary. The symmetric boundary conditions are given to the side walls of the heat exchanger.
- Thermal boundary wall: At the bottom surface a constant heat flux of 20000 w/m^2is applied.
- The top surface of the offset- strip fin adiabatically insulated from the heat flow for PFHX.

The experimentally obtained results are compared with the theoretical correlations e.g., Joshi-Webb correlation, Maiti-Sarangi correlation, Manglik-Bergles correlation & also compared with the plots obtained by the CFD analysis. The plots are shown below:

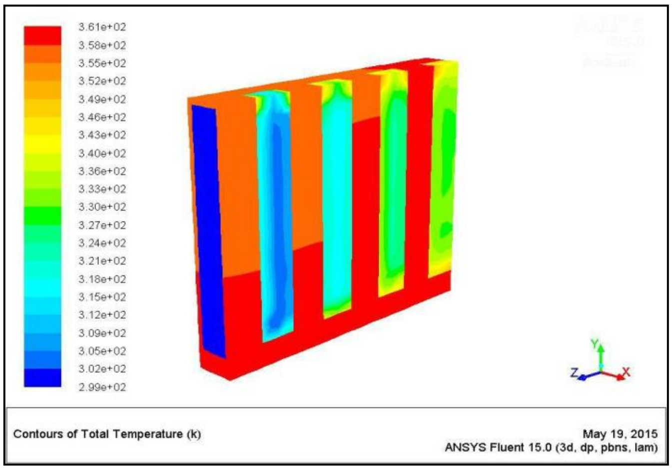


**Fig 3. Temperature Contour of a offset strip fin**

### 1. Variation of effectiveness with the mass flow rate

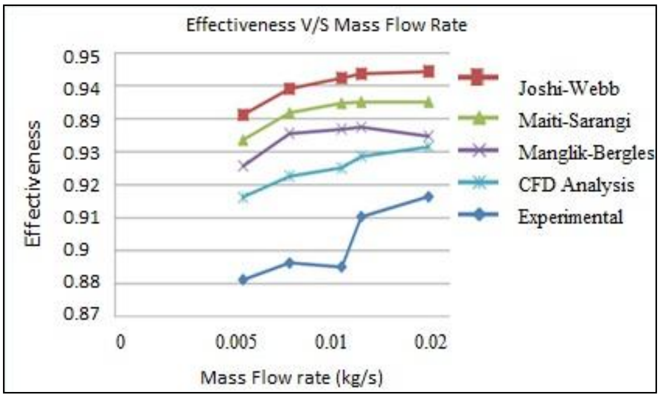


**Fig 4. Effectiveness variation with the mass flow rate (at hot inlet temperature of 66 ℃ or 339 K)**

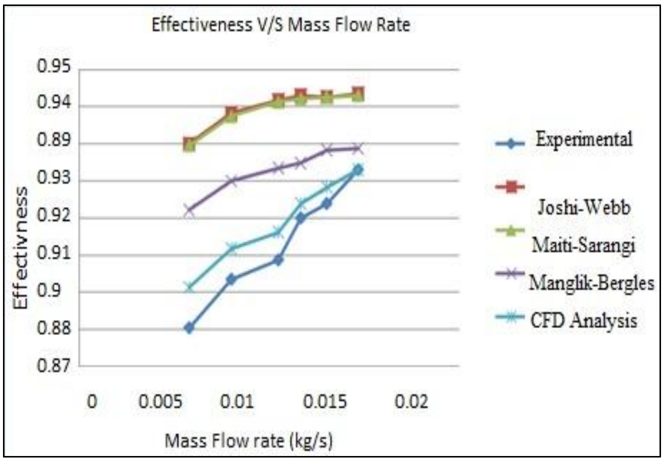


**Fig 5. Effectiveness variation with the mass flow rate (at hot inlet temperature of 86 ℃ or 359 K)**

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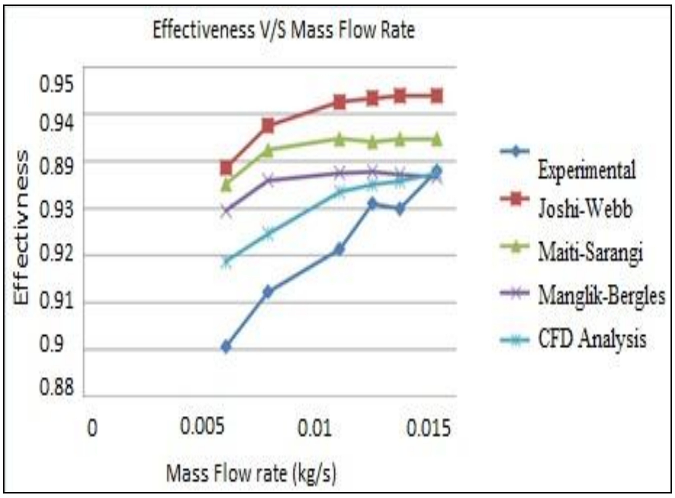


**Fig 6. Effectiveness variation with the mass flow rate (at hot inlet temperature of 96 ℃ or 369 K)**

From the graphs, it can be observed that with the mass flow rate, the effectiveness increases. It can be also observed that the effectiveness value is more at the hot inlet temperature of 369 K in comparison to the effectiveness value at the hot inlet temperature is 339 K. The effectiveness of the heat exchanger at hot inlet temperature of 359 K lies within 339 K and 369 K.

### *2. Variation Of Overall Thermal Conductance With The Mass Flow Rate*

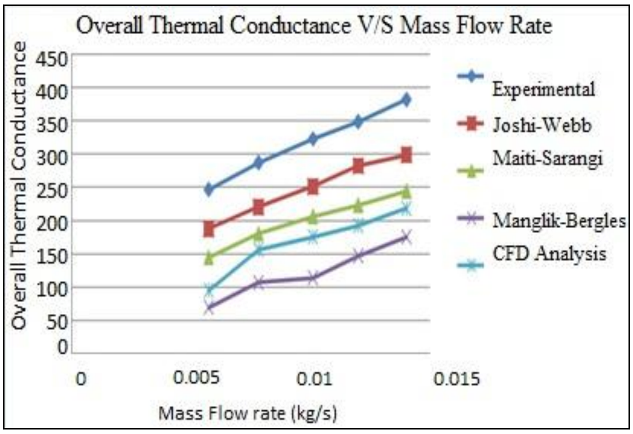


**Fig 7. Variation of Overall thermal conductance with the mass flow rate (at hot inlet temperature of 66 ℃ or 339 K)**

The overall thermal conductance variation with the mass flow rate for hot inlet temperature of 339 K & 369 K are shown in the figures 7 & 8. It can be observed that the theoretical as well as the experimental overall heat transfer coefficient increases with increase in the mass flow rate. It is because of the fact that the Reynolds number increases with the increase in the mass flow rate. As a result the Colburn factor (*j*) also increases. Since, the Colburn factor is proportional to the heat transfer coefficient, the overall thermal conductance increases

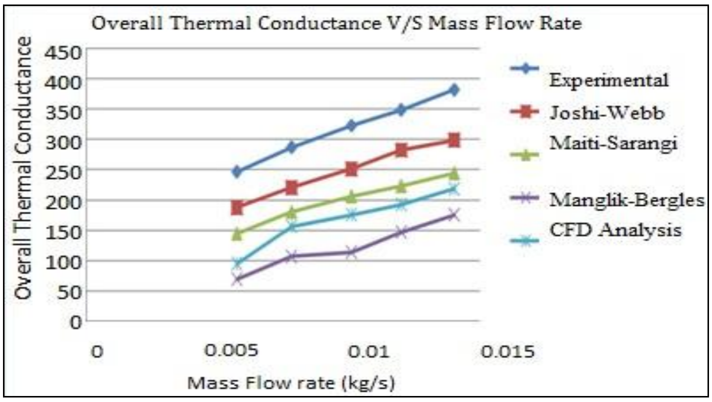


**Fig 8.Variation of overall thermal conductance with the mass flow rate (at hot inlet temperature of 96 ℃ or 369 K).**

### *3. Variation Of Pressure Drop With The Mass Flow Rate*

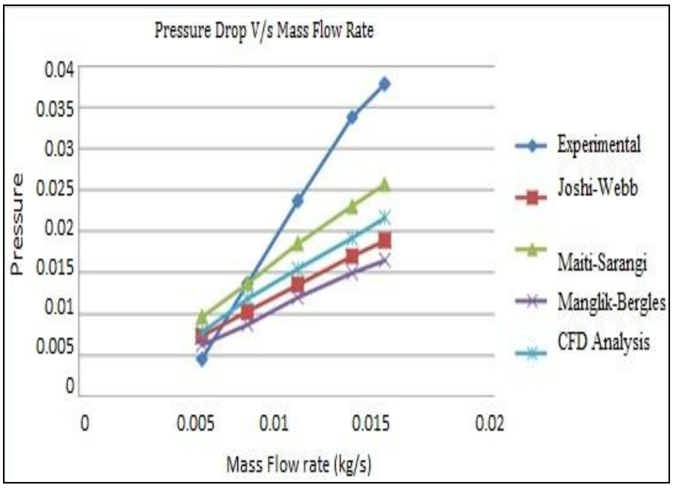


**Fig 9. Variation of pressure with the mass flow rate (at hot inlet temperature of 66 ℃ or 339 K)**

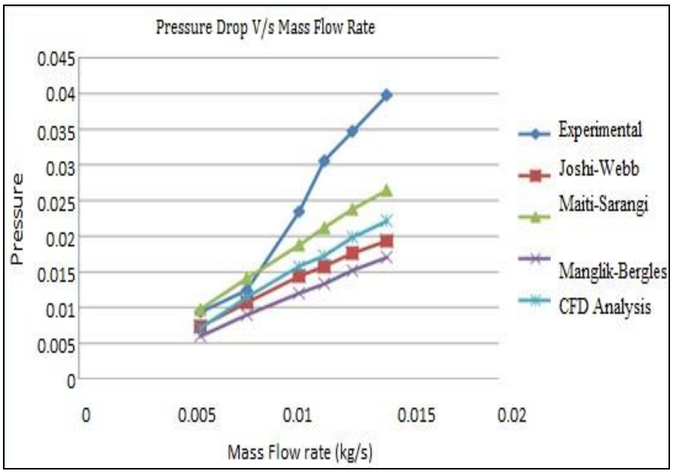


**Fig 10. Variation of pressure with the mass flow rate (at hot inlet temperature of 86 ℃ or 359 K)**

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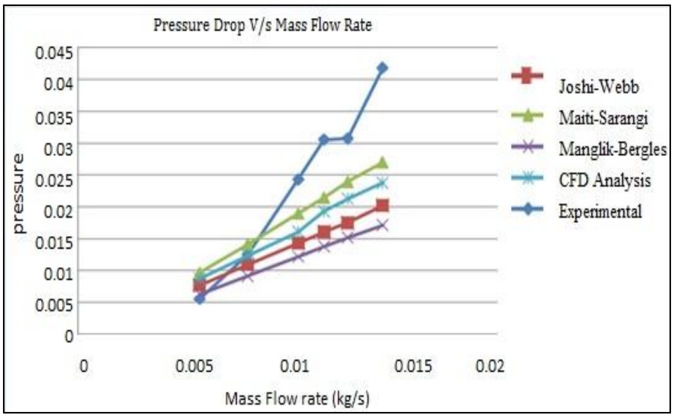


**Fig 11. Variation of pressure with the mass flow rate (at hot inlet temperature of 96 ℃ or 369 K)**

It can be observed from the plot that the pressure drop in the heat exchanger varies with the varying mass flow rate. The pressure drop obtained by the theoretical is much less compared to the experimentally because in the theoretical pressure drop calculation the header loss, the manufacturing irregularities, pressure drop in the piping etc. are ignored.

## V. CONCLUSION

The experimentally obtained results are compared with the simulation software of the CFD-fluent and also with the results obtained from various correlation results. The effectiveness v/s mass flow rate, overall thermal conductance v/s mass flow rate & pressure drop v/s mass flow rate for different hot inlet temperature are evaluated by using the correlations and by using CFD, fluent simulation software. The correlations used for the comparison of the performance parameters with the experimental results are Joshi-Webb correlation, Maiti- Sarangi correlation and Manglik-Bergles correlation. The comparison of the experimental results with the results obtained from the correlations & from the simulation software of Ansys fluent gives the following points:

I. The simulation software Ansys fluent shows a percentage deviation of the effectiveness of experimentally obtained results.

II. There are also deviations between the experimental value & the predicted values of effectiveness calculated by using Maiti-Sarangi, Joshi-Webb and Manglik-Bergles.

III. It is observed that the experimental results compared to the other correlations and the correlation developed by Maiti-Sarangi is better suited.

IV. Up to the Reynolds number 500 the pressure drop of the fluids is below the allowable pressure drop of 0.05 bar. Thereafter, the pressure drop increases rapidly. There is a large amount of deviation.

## REFERENCES

[1] Kays, W.M. and London, A.L. “Compact Heat exchangers”, (1984) McGraw-Hill, New York.

[2] Shah R. K and Sekulic D. P. “Fundamentals of heat exchanger design” (2003), John Wiley & Sons, Inc., Hoboken, New Jersey.

[3] Rao, R. V., and V. K. Patel. "Thermodynamic optimization of cross flow plate-fin heat exchanger using a particle swarm optimization algorithm." International Journal of Thermal Sciences 49.9 (2010): 1712-1721.

[4] Ranganayakulu, Ch, and K. N. Seetharamu. "The combined effects of longitudinal heat conduction, flow nonuniformity and temperature nonuniformity in cross flow plate-fin heat exchangers." International communications in heat and mass transfer 26.5 (1999): 669-678.

[5] Ranganayakulu, Ch, K. N. Seetharamu, and K. V. Sreevatsan. "The effects of longitudinal heat conduction in compact plate-fin and tube-fin heat exchangers using a finite element method." International journal of heat and mass transfer40.6 (1997): 1261-1277.

[6] Rao, R. V., and V. K. Patel. "Thermodynamic optimization of cross flow plate-fin heat exchanger using a particle swarm optimization algorithm." International Journal of Thermal Sciences 49.9 (2010): 1712-1721.

[7] Hajabdollahi, Hassan, Mojtaba Tahani, and MH Shojaee Fard. "CFD modeling and multi-objective optimization of compact heat exchanger using CAN method." Applied Thermal Engineering 31.14 (2011): 2597-2604.

[8] Zhang, Feini, Jessica Bock, Anthony M. Jacobi, and Hailing Wu. "Simultaneous heat and mass transfer to air from a compact heat exchanger with water spray precooking and surface deluge cooling." Applied Thermal Engineering 63, no. 2 (2014): 528-540.

[9] Müller-Menzel, T., and T. Hecht. "Plate-fin heat exchanger performance reduction in special two-phase flow conditions." Cryogenics 35.5 (1995): 297-301.

[10] Dubrovsky, E. V. "Experimental investigation of highly effective plate-fin heat exchanger surfaces." Experimental thermal and fluid science 10.2 (1995): 200-220.

[11] Peng, Hao, and Xiang Ling. "Optimal design approach for the plate-fin heat exchangers using neural networks cooperated with genetic algorithms." Applied Thermal Engineering 28.5 (2008): 642-650.

[12] Kundu, B., and P. K. Das. "Optimum dimensions of plate fins for fin-tube heat exchangers." International journal of heat and fluid flow 18.5 (1997): 530-537.

[13] Wang, Simin, Yanzhong Li, Jian Wen, and Yansong Ma. "Experimental investigation of header configuration on two-phase flow distribution in plate-fin heat exchanger." International Communications in Heat and Mass Transfer 37, no. 2 (2010): 116-120.

[14] Joshi, H.M. and Webb, R.L. Heat Transfer and Friction in the Offset Strip-fin Heat Exchanger, International Journal of Heat and Mass Transfer, (1987) 30 (1) 69-84.

[15] Manglik, R. M., & Bergles, A. E. (1995). Heat transfer and pressure drop correlations for the rectangular offset strip fin compact heat exchanger. Experimental Thermal and Fluid Science, 10(2), 171-180.

[16] Maiti, D.K.,and Sarangi.S.K. Heat Transfer and Flow Friction Characteristics of Plate Fin Heat Exchanger Surfaces- A Numerical Study PhD Dissertation, Indian Institute of Technology, Kharagpur (2002).

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