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Parametric Optimization of Fin-Tube Type Evaporator Using FEA-DOE Hybrid Modeling

KEYWORDS Fin-tube Evaporator, Experimental Data, Solid-Works, ANSYS-CFX, FEA, DOE

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ABSTRACT *An Evaporator is the Main component of Air-conditioning system. An evaporator is mainly used in different refrigeration and air-conditioning applications in food and beverage industry, in the pharmaceutical industry etc. An evaporator in air conditioning system is used to evaporate liquid and convert in to vapour while absorbing heat in the processes, this paper presents the study of the fin tube type Evaporator; an Experimental data were collected from the IC ICE MAKE Company. After collecting data of fin tube evaporator model is prepared using solid works. At the end, FEA analysis is carried out on it using ANSYS CFX. At the end, by using DOE Method get optimum Model of Evaporator.*

INTRODUCTION

An evaporator is used in an air-conditioning system or refrigeration system to allow a compressed cooling chemical, such as Freon or R-22, to evaporate from liquid to gas while absorbing heat in the process. It can also be used to remove water or other liquids from mixtures. The process of evaporation is widely used to concentrate foods and chemicals as well as salvage solvents. In the concentration process, the goal of evaporation is to vaporize most of the water from a solution which contains the desired product.

In the evaporator, the refrigerant is evaporated by the heat transferred from the heat source. The heat source may be a gas or a liquid or, e.g. in food freezers, a solid. During evaporation, the temperature of a pure refrigerant is constant, as long as the pressure does not change. The basic temperature profile through an evaporator with liquid or gas phase heat source is therefore as shown in Figure .As shown; the temperature of the refrigerant must be below that of the heat source. This low refrigerant temperature is attained as a result of the reduction in pressure caused by the compressor: When the compressor is started and the pressure reduced, the equilibrium between liquid and vapour in the evaporator is disturbed. To re-establish equilibrium, more vapour is formed through evaporation of liquid.

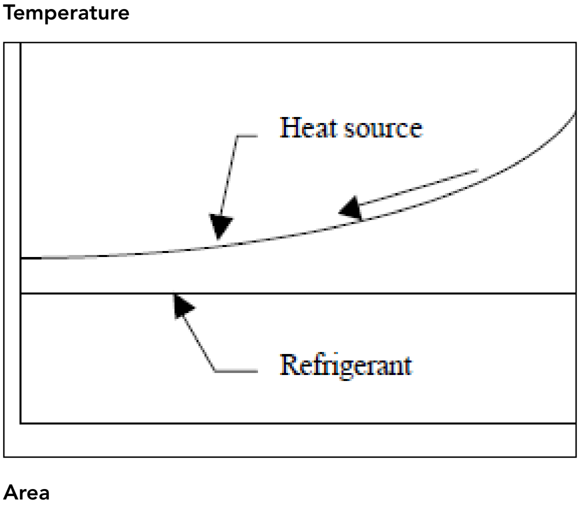

Figure 1 temperature versus area graph

The heat of vaporization necessary for this is taken from the liquid itself, and therefore the liquid temperature drops. As heat starts to flow from the heat source, a new equilibrium temperature is established. In the evaporator there is thus a balance between the heat transferred to it due to the temperature difference between the evaporator and the surroundings, and the heat transferred from it in the form of heat of vaporization of the vapour drawn into the compressor.

The evaporator is one of the four basic and necessary hardware components of the refrigeration system. Pressure drop, heat transfer rate, evaporation rate and most important thing is efficiency of evaporator, all four things are increase and improve by getting optimum parameter of evaporator, this optimum parameter of evaporator are generated with the help of experimental data and CFD analysis.

The equations of fluid mechanics which have been known for over a century are solvable only for a limited no. of flows. The known solutions are extremely useful in understanding fluid flow but rarely used directly in engineering analysis of design. CFD makes it possible to evaluate velocity, pressure, temperature, and species concentration of fluid flow throughout a solution domain, allowing the design to be optimized prior to the prototype phase.

DOE is a technique of defining and investing all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels, each with the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. In a designed experiment, the engineer often makes deliberate changes in the input variables (or factors) and then determines how the output functional performance varies accordingly. It is important note that not all variables affect the performance in the same manner. Some may have strong influences on the output performance; some may have medium influence sand some have no influence at all. Therefore, the objective of a carefully planned designed experiment is to understand which set of variables in a process affects the performance most and then determine the best levels for these variables to obtain satisfactory output functional performance in products.

EXPERIMENTAL DATA OF FIN TUBE EVAPORATOR

The experimental investigation has been carried out at IC ICE MAKE REFRIGERATION to improve the performance characteristics of evaporator. The following data are collected during experiment.

Figure 2 Actual model of evaporator

Parameter of Evaporator:

1) Tube Outer Diameter:9.53 mm
2) Tube Inner Diameter:8.53 mm
3) Tube thickness: 0.5mm
4) Tube Pitch(Longitudinal and Transverse both): longitudinal pitch=25mm,transverse pitch=30m
5) Tube Material: Copper
6) No. of Turns:9
7) Fin Pitch and thickness: pitch=4.33mm,fins thickness=0.25mm
8) Position of inlet and Outlet
9) Overall Size of Evaporator:1448*406.4mm
10) Material of Fin: aluminium
11) Tube bending Radius:30mm
12) Inlet Temperature and Pressure(Experimental):259k
13) Outlet Temperature(Experimental):269k
14) Mass flow rate:1.5 kg/sec
15) Tube Fluid:R-22
16) Refrigerant : R-22
17) Mass of refrigerant: 1.5kg
18) Capillary length: 11’ + 6_ coil
19) Capillary diameter: 0.036 mm

An evaporator is the main component of heat exchange between the working fluid (The refrigerant) and the environment of freezer.

REVIEW

T. Sriveerakul et al [1] investigated the use of CFD in predicting performance of a steam ejector used in refrigeration applications. This study is reported in a series of two papers. In this part, the CFD results were validated with the experimental values. The effects of operating conditions and geometries on its performance were investigated. The CFD’s results were found to agree well with actual values obtained from the experimental steam jet refrigerator. David Yashar at al [2] presented a comparable evaluation of R600a (isobutene), R290 (propane), R134a, R22, R410A, and R32 in an optimized finned-tube evaporator, and Analyzes the impact of evaporator effects on the System coefficient of performance (COP), The study relied on a detailed evaporator model derived from NIST’s EVAP-COND simulation package and used the ISHED1 scheme employing a non-Darwinian learnable evolution model for circuitry optimization. Devendra A. Patel et al [3] observed that 1. Case-I shows calculation for actual readings and case-II shows calculation for simulation when inlet temperature of oil & cooling water are kept unchanged. 2. As the outlet temperature of oil is 1 degree less in case-II, the values of heat transfer rate, overall heat transfer co-efficient & effectiveness are higher for case-II compared to the case-I. 3. Case-II, III & IV shows the calculation and results for simulation readings. The cooling water inlet temperature is gradually decreased by 2 degree in each case. 4. As the temperature difference between oil inlet temperature and water inlet temperature, becomes larger, the values of qmax increases. This is why, the heat transfer rate, overall heat transfer co-efficient and effectiveness is higher in case-III and case-VI compared to case-II. The CFD analysis enables us to find out, on an average base, the performance of an actually operating heat exchanger. We can also come to know the temperatures at any points in heat exchanger. However, the results available through CFD analysis are for the ideal condition, i.e. for no-loss operating condition. Qi Fan et al [4] said that the numerical simulations of dimple jacket constructions were performed by a computational fluid dynamics (CFD) program FLUENT in this work. The effects of geometrical parameters such as cone angle, arrangement, interval and height of dimple on heat transfer and pressure drop of dimple jackets in thin-film evaporator were investigated numerically. The results of numerical simulations were provided for comparison in order to get advisable configuration. The distance between dimples was found to have a considerable effect On heat transfer and in-line configuration was recommended because the pressure drop in it was smaller under the same heat transfer rate. Taijong Sung et al [5] presented an optimal design of a micro evaporator, to maximize the heat transfer coefficient (HTC) and it forms the starting point in developing miniaturized vapour compression refrigeration system. The experimental design is adopted to determine the optimal parameters of the evaporator for realizing the inlet–outlet conditions of the refrigerating cycle, and for increasing the HTC. The number of lateral gaps, channel width, and lateral gap size were optimized to maximize HTCs of 2062, 2029, and 1895 W/m2K for heating powers of 40, 60, and 80 W, respectively. The refrigerant and the mass flow rate were fixed as R-123 and 0.72 g/s, respectively. Among the three design parameters, the channel width is the most sensitive parameter influencing the HTC. The optimal parameters have been designed to maximize the heat transfer coefficient. it was found that the periodic change of flow pattern occurs at the evaporator with a high heat transfer coefficient, while the dry out occurs at the evaporator with a low heat transfer coefficient. Sangrok Jin et al [6] presented an optimal design for an orifice in a small cooler. The objective of the optimal design is to maintain constant superheat at the outlet of an evaporator while the flow rate and cooling load are changed. Four parameters are chosen for the optimal design the diameter of the orifice, the aspect ratio between length and diameter, the entrance angle to the orifice, and the surface roughness. R-123 is used as the refrigerant. We perform a simulation to check the sensitivities of each parameter, and we determine the orifice diameter as the most sensitive design parameter among the four parameters to maintain the constant superheat. To find the optimal orifice diameter, experiments are performed on orifices of various diameters. To simulate the vapour-refrigeration cycle, the inlet condition of the orifice upstream flow is fixed at 3 bars and 60 C. The superheat is measured at the outlet of the orifice while the cooling loads vary by 60, 80, and 100Wand the flow rate varies by 20e70 mL/min. An orifice diameter of 350 μm selected as the optimal value to keep constant superheat at the evaporator outlet for various flow rates and cooling loads. The resulting optimal orifice design will be used in a small cooler.

MODELLING OF FIN TUBE EVAPORATOR

After Getting Experimental data, the modeling has been performed on the Solid works 2009 version and then after the analysis work has been performed on the ANSYS 12.0 version.

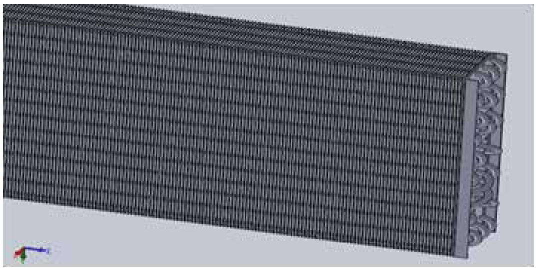

Figure 3 modeling of fin tube evaporator

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CFD ANALYSIS OF EVAPORATOR

The equations of fluid mechanics which have been known for over a century are solvable only for a limited no. of flows. The known solutions are extremely useful in understanding fluid flow but rarely used directly in engineering analysis or design. CFD makes it possible to evaluate velocity, pressure, temperature, and species concentration of fluid flow throughout a solution domain, allowing the design to be optimized prior to the prototype phase.

Availability of fast and digital computer makes techniques popular among engineering community. Solutions of the equations of fluid mechanics on computer has become so important that it now occupies the attention of a perhaps a third of all researchers in fluid mechanics and the proportion is still is increasing. This field is known as computational fluid dynamics. At the core of the CFD modeling is a three-dimensional flow solver that is powerful, efficient, and easily extended to custom engineering applications. In designing a new mixing device, injection grid or just a simple gas diverter or a distribution device, design engineers need to ensure adequate geometry, pressure loss, and residence time would be available. More importantly, to run the plant efficiently and economically, operators and plant engineers need to know and be able to set the optimum parameters.

Results of Analysis
Outlet Temperature of Refrigerant

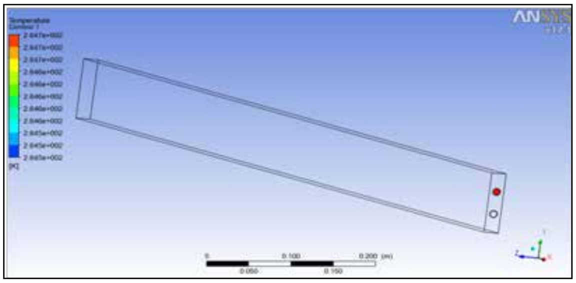

Figure 4 Outlet Temperature of Refrigerant

TABLE 1
COMPARISON OF EXPERIMENTAL RESULTS AND CFD ANALYSIS RESULTS

Description	Experimental	CFD Analysis	% Deviation
Temperature	269	268.9	3.7

. The deviation in results is due to perfectness of CFD analysis and uncertainty of experiments.

DOE OF EVAPORATOR

After performing experiment of design with various parameters of Fin tube Evaporator such as Tube Diameter, Tube Pitch and Mass flow Rate, the Outlet Temperature, Heat transfer rate, Efficiency and Effectiveness are measured by ANSYS software as described in earlier chapter. This chapter describes results obtained by TAGUCHI METHOD and analysis of results.

Taguchi Model with Minitab16

Minitab offers four types of designed experiments: factorial, response surface, mixture, and Taguchi (robust). The step you follow in Minitab to create, analyze, and graph an experimental design are similar for all design types. After you conduct the experiment and enter the results, Minitab provides several analytical and graphing tools to help you understand the results.

Taguchi designs experiments using especially constructed tables known as "orthogonal arrays" (OA). The use of these tables makes the design of experiments very easy and consistent.

From the Table 8.1 it was identified that minimum Outlet Temperature value 264.15 K was obtained at the value of 9.525 mm, 27 mm, 1,2 kg/sec for Tube diameter, Tube Pitch, Mass Flow rate respectively. The maximum Outlet Temperature value 272.14 K was obtained at the value of 10.525 mm, 25 mm, 1,2 kg/sec for Tube diameter, Tube Pitch, Mass Flow rate respectively.

TABLE 2
EXPERIMENTAL RESULTS TABLE

Sr. No.	Tube Diameter (mm)	Tube Pitch (mm)	Mass flow rate (kg/sec)	Outlet Temp (K)
1	8.525	23	1.2	266.50
2	8.525	25	1.5	267.90
3	8.525	27	1.8	265.41
4	9.525	23	1.5	268.90
5	9.525	25	1.8	269.80
6	9.525	27	1.2	264.15
7	10.525	23	1.8	271.50
8	10.525	25	1.2	272.14
9	10.525	27	1.5	270.45

Experimental Result Analysis for Outlet Temp

First Minitab version 16 was used for the analysis of result obtained by experimental work. The S/N ratio for minimum surface roughness coming under smaller-is-better characteristic, which can be calculated as logarithmic transformation of the loss function as shown below.

Larger is the better characteristic:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i}\frac{1}{Y_i^2}\right)$$

The optimal setting is the parameter combination, which has the highest positive S/N ratio.

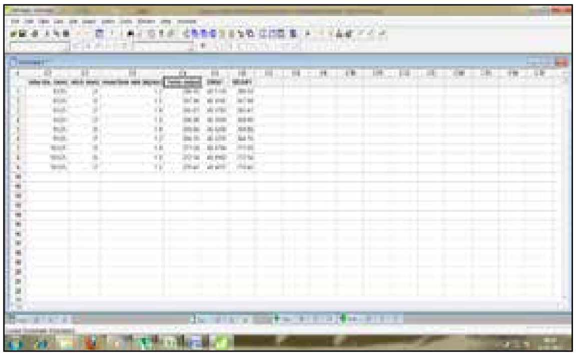

Figure 5: Experiment result in Minitab

Fig 5 shows the Minitab window which shows the creation of design and Mean and S/N ratio data for Outlet Temp.

Analysis of Main Effects Plot for Outlet Temp

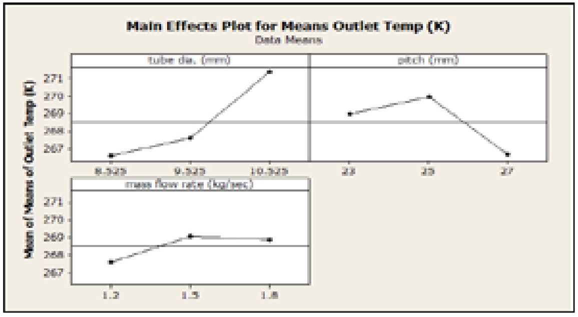

Figure 6 Main Effects plot for Mean data

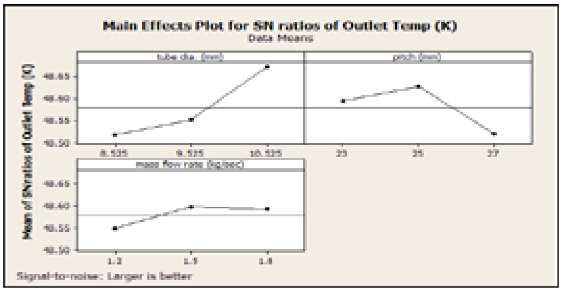

Figure 7 Main Effects plot for S/N ratio data

Main Effects Plot for Mean data and S/N ratio are shown in Figure 6 and 7 displays effect of Tube Diameter, Tube Pitch, and Mass Flow rate on Outlet Temperature on same scale base of Outlet Temp.

Effect of Tube Diameter on Outlet Temperature
The effect of Tube Diameter of fin tube Evaporator on Outlet Temperature show in figure 6 and 7, from graph we can seen easily when tube diameter value increases from 8.525 to 9.525 and 9.525 to 10.525 proportionally outlet temp graph also increases from 265 to 268 and 268 to 272.

Effect of Tube Pitch on Outlet Temperature
Fig. 6 and 7 shows that the Outlet Temperature increase with the increase in Tube Pitch up to 25 mm, and then starts to decrease under given working conditions. Starting decreases from 25 mm to 27 mm so we can occlude from graph the optimum value for pitch is 25 mm.

Effect of Mass flow rate on Outlet Temperature
It can be observed from Fig.5 and Fig. 6 that the Outlet Temp increases at a value of 1.2 kg/sec to 1.5 kg/sec of mass flow rate then starts to Decreases with increase of mass flow rate.

Taguchi Analysis: Outlet Temp versus tube dia. (mm), pitch (mm), mass flow rate (kg/sec)

TABLE 3
RESPONSE TABLE FOR MEANS

LEVEL	TUBE DIAMETER (mm)	TUBE PITCH (mm)	MASSFLOW RATE (kg/sec)
1	266.6	269.0	267.6
2	267.6	269.9	269.1
3	271.4	266.7	268.9
DELTA	4.8	3.3	1.5
RANK	1	2	3

TABLE 4
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO

LEVEL	TUBE DIAMETER (mm)	TUBE PITCH (mm)	MASSFLOW RATE (kg/sec)
1	48.52	48.59	48.55
2	48.55	48.63	48.60
3	48.67	48.52	48.59
DELTA	0.15	0.11	0.05
RANK	1	2	3

CONCLUSION

From level of prediction S/N ratio and Mean value are 48.7353, 273.338

Factor levels for predictions

Sr.no	Tube Diameter (mm)	Tube Pitch (mm)	Mass Flow Rate (kg/sec)
1	10.525	25	1.5

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