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To Study Heat Transfer Characteristics of Plate Finned Tube Heat Exchanger

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ABSTRACT

The paper present analysis of calculation of heat transfer coefficient, fin efficiency on the fin inside one-tube plate finned-tube heat exchangers for various air inlet speeds and temperature difference between the ambient temperature and tube surface temperature, for different materials like steel and Al. Based on the mathematical model, a computer simulation program in the MATLAB for plate finned-tube heat exchanger is developed. The temperature data is proposed to predict the average heat transfer coefficient and fin efficiency on the fin inside one tube plate finned tube heat exchangers. The validation is done using the available data from the research papers. The prediction agrees with the data very well.
Keywords : Heat Exchanger, Fin Tube, MATLAB

I. INTRODUCTION

The heat exchange at different temperature between two fluids that are separated by a solid wall covers the wide area of engineering applications. The device simply used to exchange the heat is known a heat exchanger, and the major area of heat exchanger comprise space heating, and air-conditioning, power production, waste heat recovery, and chemical processing.

From the last two and half decades, heat exchanger playing a crucial role in energy conversion and recovery and leading the way to search new energy resources. The introduction of heat exchanger in environmental engineering create unbeaten opportunities to deal with different types of pollution such as thermal pollution, air pollution, water pollution, and waste disposal.

In the indirect contact heat exchanger, one fluid is a gas (more commonly, air) and the other secondary fluid is a liquid (more commonly, water) and are readily separable after the energy exchange. A water cooling tower with forced- or natural-draft airflow is the most common application. Other applications are the air-conditioning spray chamber, spray drier, spray tower, and spray pond. The heat transfer coefficient h for gases is generally one or two orders of magnitude lower than that for water, oil, and other liquids.

To increase the heat transfer area, appendages may be intimately connected to the primary surface to provide an extended surface. These extended surface elements are referred to as fins. Thus, heat is conducted through the fin and convected from the fin to the surrounding fluid.

Now a days, fin–tube heat exchangers have very important application in power stations, chemical plants, refrigerating industries, aircrafts, automobiles, etc. So far, many researchers have studied to enhance the efficiency of the fin–tube heat exchanger.

In the present work, an attempt is made analysis the heat transfer rate and heat transfer co-efficient, fin efficiency, fin effectiveness for different material of fin, using mat lab programming for one plate finned tube heat exchanger.

Aganda et al.1999 has studied ‘A comparison of the predicted and experimental heat transfer performance of a finned tube evaporator’. **Jorge** et al.2003 has studied on ‘Modelling of plate heat exchangers with generalized configurations’. **Pinto et al.** 2002 studied the optimization method for ‘Optimal selection of plate heat exchanger configuration’. **Lee** et al. 2013 studied ‘An efficient method to predict the heat transfer performance of a louver fin radiator in an automotive power system'. **Herchang et al. 2002** has studied the 'Local heat transfer measurements of plate finned-tube heat exchangers by infrared thermography' using the infrared thermovision. **Jiong et al. 2005**studied 'A study on the thermal contact conductance in fin–tube heat exchangers with 7 mm tube', have been investigated through the experimental–numerical method.

II. METHODS AND MATERIAL

NOMENCLATURE

A	area of the whole plate fin,	m^2
Aj	area of the *j*th sub-fin region,	m^2
[*A*]	global conduction matrix	
do	outer diameter of the a tube,	m
h	local heat transfer coefficient,	W/m^2K
$\bar{h}$	average heat transfer coefficient on the whole plate fin	W/m^2K
$\bar{h}j$	average heat transfer coefficient on the *j*th sub-fin region	W/m^2K
k	thermal conductivity of the fin,	W/mK
L	length of plate fin,	m
l	distance between two neighboring nodes in the x and y directions.	
m	dimensionless parameter	
$\bar{m}j$	dimensionless parameter on the jth sub-fin region.	
Nx	number of nodes in x-direction	
Ny	number of nodes in y-direction	
Q	total heat flux dissipated from the whole plate fin	W
qj	heat flux dissipated from the jth sub-fin region.	W
Red	Reynolds number	
ro	outer diameter of the circular tube	m
T	temperature	
Tj	temperature measurements on the jth sub-fin region	
To	outer surface temperature of the circular tube	
Tamb	ambient temperature	
ΔT	temperature difference,	To-Tamb
Vair	velocity of air,	m/sec
X,Y	spatial coordinates,	m
x,y	dimensionless spatial coordinates	

Greek Symbols

δ	fin thickness m
ηf	fin efficiency
υ	kinematic viscosity of the air, m^2/sec

DESIGN SPECIFICATIONS

Type of heat exchanger	One plate fin tube heat exchanger
Tube diameter	40 mm
Tube thickness	2mm
Plate fin thickness	2mm
Fin length	100mm
Fin width	100mm
Fin materials	stainless Steel, aluminium
Fin thermal conductivity	14.9, 200, W/mK

ASSUMPTION

The basic assumptions are as follow-

- The heat flow in the fin and its temperatures remain constant with time.
- The fin material is homogeneous, its thermal conductivity is the same in all directions and it remains constant.
- Negligible tube thermal resistance.
- The temperature of the medium surrounding the fin is uniform.
- The temperature at the base of the fin is uniform.
- There are no heat sources within the fin itself.
- The heat transferred through the tip of the fin is negligible compared with the heat leaving its lateral surface.
- Radiation heat transfer from and to the fin is neglected.
- Fin is considered to be insulated at the tip.

ANALYSIS

The analysis of work indicates that most of the researchers has studied plate finned tube heat exchanger, and the effect of tube arrangement. The present work mostly focuses on the study of heat transfer coefficient, fin efficiency and fin effectiveness using matlab for the one plate finned tube heat exchanger, for the different material of the fin.

- To develop a programs in mat lab.
- Validation.

- To analyse heat transfer coefficient, heat transfer rate, fin efficiency for steel and aluminium.
- Comparative study

MATHEMATICAL FORMULATION

The schematic diagram of the one-tube plate fin heat exchanger is shown in Fig1 and Fig2 which shows the physical model of the two-dimensional thin plate fin inside a one-tube plate fin heat exchanger, where ro, L and d denote the outer radius of the circular tube, the side length of the square plane fin and the fin thickness, respectively.

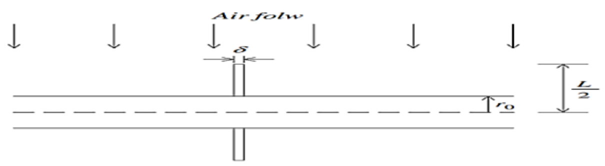

Figure1. schematic diagram of one-tube plate fin heat exchanger [chen 2006]

The circular tube is located at (L/2,L/2). To and T∞ respectively denote the surface temperature of the circular tube and the ambient temperature.

Fin heat transfer area is divided into six regions. The region 2 and 5 are the wake fin area and upstream fin area respectively. The region 4 and 6 are leading edge area of the fin. The Reynolds number is defined as Re=Vd0/υ, where V is frontal air speed, do is the outside diameter of the circular tube and υ is the kinematic viscosity of the air. The Re number values ranges from 2500 to 13000. It is clear that in the present work, if the airflow is greater than 5m/sec, it become turbulent.

The "insulated tip" assumption can be an adequate approximation provided that the actual heat flux dissipated through the tip is much smaller than the total heat flux drawn from the base wall. The heat transfer coefficient on the fin inside a plate finned-tube heat exchanger can be estimated provided that the fin temperatures at various locations can be taken.

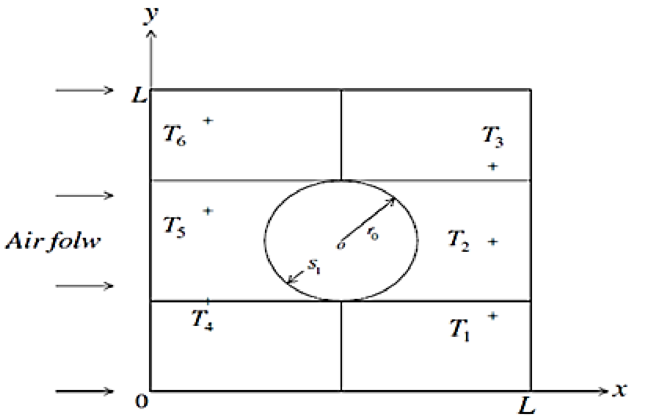

Figure 2. physical geometry of two-dimensional plate fin with a circular tube

The circular tube is located at (L/2,L/2). To and T∞ respectively denote the surface temperature of the circular tube and the ambient temperature.

Fin heat transfer area is divided into six regions. The region 2 and 5 are the wake fin area and upstream fin area respectively. The region 4 and 6 are leading edge area of the fin. The Reynolds number is defined as Re=Vd0/υ, where V is frontal air speed, do is the outside diameter of the circular tube and υ is the kinematic viscosity of the air. The Re number values ranges from 2500 to 13000. It is clear that in the present work, if the airflow is greater than 5m/sec, it become turbulent.

Under the assumptions of the steady state and the constant thermal properties, the two-dimensional heat conduction equation for the continuous thin fin inside a plate finned-tube heat exchanger can be expressed as-

$$\partial^2T/\delta X^2 \quad + \quad \partial^2T/\delta Y^2 \quad = 2h(X, Y)(T-T\infty)/k\delta \qquad (1)$$

Its corresponding boundary conditions are-

$$\partial T/\partial X=0, \text{ at } X=0 \text{ and } X=L \qquad (2)$$

$$\partial T/\partial Y=0, \text{ at } Y=0 \text{ and } Y=L \qquad (3)$$

$$T=T0 \quad (X, Y) \text{ on } S1 \qquad (4)$$

Where T is the fin temperature. X and Y are Cartesian coordinates.

DESIGN METHODOLOGY

S1 denotes the boundary of the circular tube with radius ro. k is the thermal conductivity of the fin.
For convenience of the inverse analysis, the following dimensionless parameters are introduced as-

$$x=X/L,\ y=Y/L, \text{ and } m(x, y)=2L^2h(x, y)/k\ \delta \qquad (5)$$

Substitution of Eq. (5) into Eqn (1)–(4) gives the following equations

$$\partial^2\theta/\partial x^2 + \partial^2\theta/\partial y^2 = m(x, y)\theta \qquad (6)$$

$$\partial\theta/\partial x=0, \text{ at } x=0 \text{ and } x=1 \qquad (7)$$

$$\partial\theta/\partial y=0, \text{ at } y=0 \text{ and } y=1 \qquad (8)$$

And

$$\theta=0 \quad (x, y) \text{ on } S1 \qquad (9)$$

Where $\theta = T-T\infty$

Rearrangement of eqn in conduction with difference equations in the neighbouring of the circular tube can yield the following matrix equation.

$$[A][\theta] = [F] \qquad (10)$$

Where [A] is global conduction matrix. [θ] is a matrix representing the nodal temperature. [F] is a force matrix. With this a set of N algebraic equations are obtained, and by solving equations, heat transfer coefficient, and heat transfer are obtained for sub-fin region.

The step wise design methodology are used in this dissertation are presented below-1-The average heat transfer coefficient on the whole plate fin $\overline{h}$ can be written as-

$$\overline{h}=\Sigma\, \overline{h}jAj/Af$$

Where *N* is the total number of sub-fin regions. *Af* is the area of whole plate fin.

2-Heat flux dissipated from the sub-fin region *qj* are given by-

$$qj = \overline{h}j \int(T-T\infty)dA \quad for\ j=1,2,..............................,N$$

3- The efficiency of the continuous plate fin Ƞf is defined as the ratio of the actual heat transfer from the continuous plate fin to the dissipated heat from the fin, maintained at the tube temperature To. Thus the fin efficiency Ƞf can be expressed as-

$$\eta f = \Sigma qj/Af(To-T\infty)\overline{h}$$

4-The total heat flux dissipated from the whole plate fin to the ambient *Q* can be expressed as-

$$Q = \Sigma qj = \eta fAf$$

$$Q= \sqrt{(hPkA)}\ \theta \tanh mL$$

In order to estimate the unknown heat transfer coefficient on the *jth* sub-fin region *hj*, and heat transfer rate the additional information of the steady-state temperature measurements is required at N interior measurement locations. The more a number of the sub-fin regions are, the more accurate the estimation of the unknown average heat transfer coefficient on the whole plate fin is. Relatively, a more computational time can be required. The temperature measurement taken from the jth thermocouple at the measurement location *xj* is denoted by Tj(j=1........,N), as shown below in Tables 1 and table 2.

Table 1 shows the list of various temperatures on sub-fin region at frontal air velocity 1-5 m/sec at the tube surface temperature 59.6^0C and 25.6^0C ambient temperature.

Table 2 shows the list of various temperatures on sub-fin region at frontal air velocity 1-5 m/sec at the tube surface temperature 69.6^0C and 26.5^0C ambient temperature.

	V1	V2	V3	V4	V5
T1	42.3	39.8	38.00	36.8	35.8
T2	46.00	41.40	39.80	39.50	37.80
T3	41.70	38.80	36.00	35.20	34.20
T4	38.5	36.10	34.60	33.20	32.70
T5	36.10	35.40	32.30	31.30	30.80
T6	35.60	34.90	30.30	30.10	30.00

Table 1. Temperature value under various air velocity condition and T0=59.6^0C and T∞=25.6^0C

	V1	V2	V3	V4	V5
T1	45.00	42.10	39.80	38.80	37.60
T2	49.20	46.20	43.40	42.40	40.10
T3	44.50	41.80	38.80	37.30	35.40
T4	41.20	36.80	36.30	35.00	33.00
T5	38.00	33.70	33.00	31.80	31.10
T6	37.10	33.50	32.50	31.10	30.30

Table 2. Temperature value under various air velocity condition and T0=69.5^0C and T∞=26.5^0C

III. RESULTS AND DISCUSSION

In the present work, attempt has been made to study the heat transfer characteristics; heat transfer coefficient, heat transfer rate, fin efficiency of plate finned tube heat exchanger.

Materials for the manufacture of fins are limited by the operating temperature of certain applications. For low to moderate temperature application, fins can be made from aluminium, copper and thus maintain high fin efficiency. For the high temperature application stainless steel and heat resistance alloys may be used with the possibly a reduction in fin efficiency.

Here we are calculating average heat transfer coefficient, fin efficiency on the entire fin surface. For this we consider three fin materials-

1- stainless steel
2- aluminium

1-when steel is used as fin material at ΔT=33°C

	V1	V2	V3	V4	V5
h1	5.5875	5.5869	7.5878	9.6146	10.4938
h2	5.7941	15.5606	18.9656	18.4412	25.9454
h3	5.3104	6.6349	8.6208	11.0224	12.8045
h4	5.1242	9.211	9.2462	12.1108	12.9194
h5	43.8683	47.5002	96.4123	131.7694	157.7106
h6	11.3691	12.3908	41.2363	39.8819	38.4363
q 1	0.2799	0.2380	0.2823	0.3231	0.3211
q2	0.3243	0.6745	0.7388	0.7032	0.8684
q3	0.2565	0.2627	0.2690	0.3174	0.3304
q4	0.1983	0.2901	0.2496	0.2761	0.2752
q5	1-2636	1.2771	1.7721	2.0608	2.2508
q6	0.3411	0.3457	0.5814	0.5384	0.5074
havg	12.4904	15.6959	29.5422	36.0257	41.6200
Q	2.6637	3.0881	3.8933	4.2191	4.5533
η(%)	61	58	33	31	31

Table 3. When the temperature is T0=59.6^{0}C and T∞=25.6^{0}C

2- when steel is used as fin material at ΔT=43°C

	V1	V2	V3	V4	V5
h1	6.9433	8.4702	11.313	12.57	12.207
h2	9.4814	14.421	20.421	23.025	33.807
h3	6.0935	6.9912	10.621	12.718	16.338
h4	5.7628	10.053	9.6079	11.666	21.374
h5	57.583	138.04	166.07	236.21	292.37
h6	15.148	27.018	33.134	50.361	67.786
q 1	0.38536	0.39641	0.45138	0.46383	0.40651
q2	0.59045	0.77939	0.94677	1.0043	0.43622
q3	0.32905	0.3209	0.3919	0.41206	0.43622
q4	0.25416	0.31067	0.28252	0.29749	0.41681
q5	1.8169	2.7271	2.9629	3.4344	3.6898
q6	0.48172	0.5674	0.59649	0.69498	0.77277
havg	16.345	32.932	40.353	55.648	71.365
Q	3.8576	5.1019	5.632	6.3071	6.9834
η(%)	62	42	33	29	27

Table 4. When the temperature is T0=69.5^{0}C and T∞=26.5^{0}C

3-When aluminium used as fin material at ΔT=33°C

	V1	V2	V3	V4	V5
q1	0.46656	0.39667	0.47044	0.53842	0.53518
q2	0.54044	1.1241	1.2314	1.172	1.4473
q3	0.42749	0.43789	0.4483	0.52908	0.5506
q4	0.33052	0.48365	0.4161	0.46022	0.45863
q5	2.1058	2.1276	2.9532	3.4352	3.753
q6	0.56845	0.57627	0.96887	0.89734	0.84557
Q	4.4393	5.1463	6.4883	7.0323	7.5903
η(%)	71	66	44	39	36

Table 5. When the temperature is T0=59.6^{0}C and T∞=25.6^{0}C

4-When aluminium used as fin material at ΔT=43°C

	V1	V2	V3	V4	V5
q1	0.64225	0.66069	0.75229	0.77306	0.67752
q2	0.98408	1.299	1.5779	1.6739	2.1022
q3	0.54841	0.53481	0.65317	0.68677	0.72705
q4	0.42359	0.51796	.47077	0.49582	0.69476
q5	3.0285	4.542	4.9406	5.7237	6.1481
q6	0.80282	0.94593	0.99395	1.1583	1.2879
Q	6.4297	8.5004	9.3887	10.512	11.638
η(%)	62	41	37	30	26

Table 6. When the temperature is T0=69.5^{0}C and T∞=26.5^{0}C

IMPROVED EFFICIENCY

Thus, from the above result we can see, the fin efficiency is reduced from 0.71 to 0.61, about 14% reduction, by changing material from aluminium to steel. This in turn will reduce fin heat transfer by about 14%.

LOW WEIGHT

The mass of the fin is proportional to ρ/K. It may be seen that by using aluminium, instead of steel, a weight saving can be achieved. Steel have weight 40 times of aluminium, as shown below in table-

Material	Thermal conductivity	Density(kg /m³)	ρ/K	ρ/K / (ρ/K)al
Aluminium	200	2723	13	1
Steel	15	7850	525	40

Table 7. Comparison of different fin material

It is seen that aluminium is preferred for fin material of a heat exchanger, because it has low cost, low weight, and ability to resistance corrosion.

The various graph plotted for η with velocity for various conditions of temperature for steel and aluminium. This shows the effect of frontal air speed on the heat transfer coefficient, heat transfer rate, fin efficiency. It is clear that wavy flow behind the tube has become turbulent and random in motion. Due to the blockage of tube, the heat transfer coefficient and heat transfer is maximum at upstream fin region. This implies that region 2 is contributing most of heat transfer. Heat transfer coefficient is low at the back surface(downstream region of fin) and contribute little heat transfer. It is also clear from the tables' result that, at the same speed the average heat transfer coefficient increases with the ΔT value and fin efficiency decreases with increasing ΔT value. The value of average heat transfer coefficient is also increasing with the increase in air velocity. The fin efficiency in the range of 1-5 m/sec decreases with increasing air velocity.

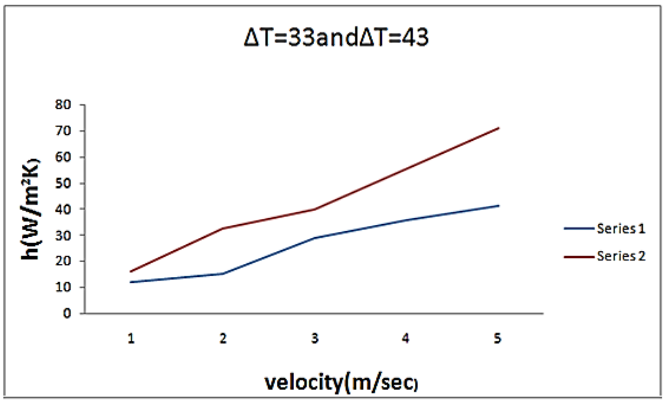

Figure 1. Variation of h under various ΔT conditions for steel

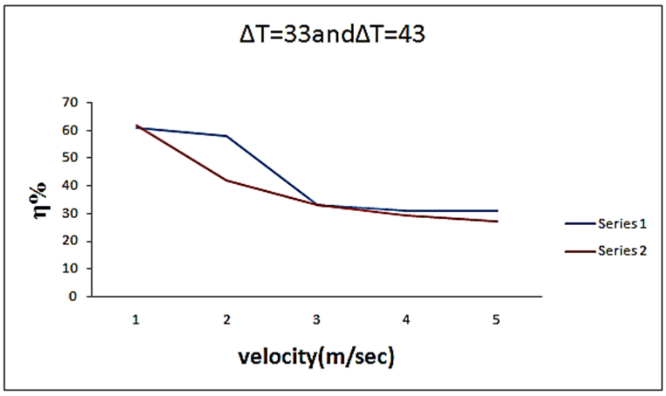

Figure 2. Variation of η under various ΔT conditions for steel

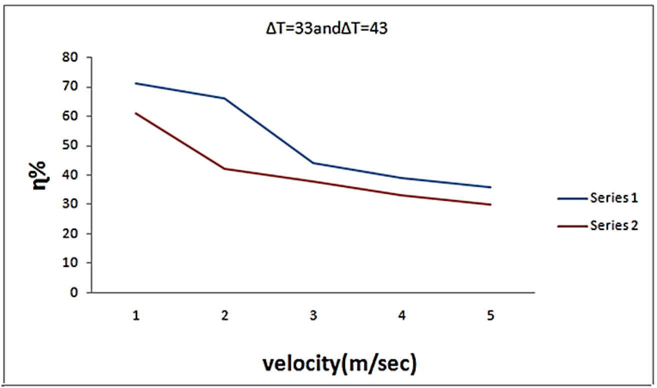

Figure 3. Variation of η under various ΔT conditions for aluminium

FIN TEMPERATURE DISTRIBUTION

The fin temperature distribution is shown in figure below-

The fin temperature decreases more rapidly away from the circular centre when the frontal air speed increases, which is different from the ideal isothermal temperature distribution. Within a plate finned tube heat exchanger, there exists a complex flow pattern due to flow separation. The flow accelerates around the tube and forms a low-velocity wake region behind the tube. The fin temperatures on the downstream fin region are markedly higher than those on the upstream regions for various air speed. It can be observed from the figure shown below, that there is a temperature drop between the tube wall and edge of the plate fin.

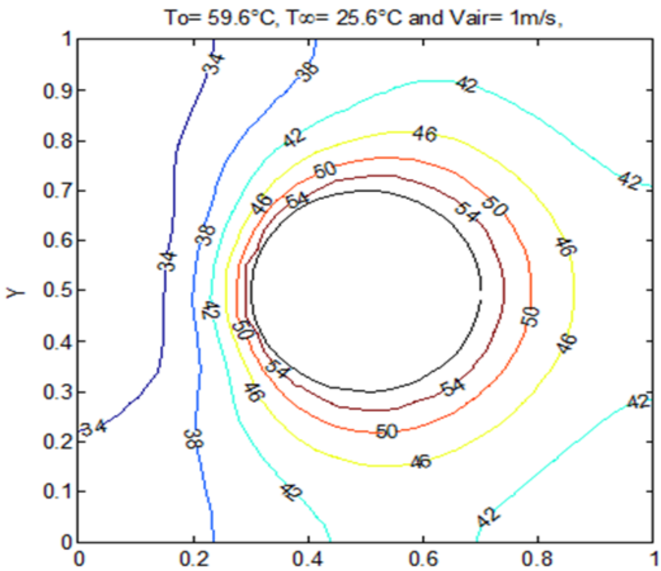

Figure 4. Variation of fin temperature over fin surface for 1m/sec velocity for ΔT=33°C

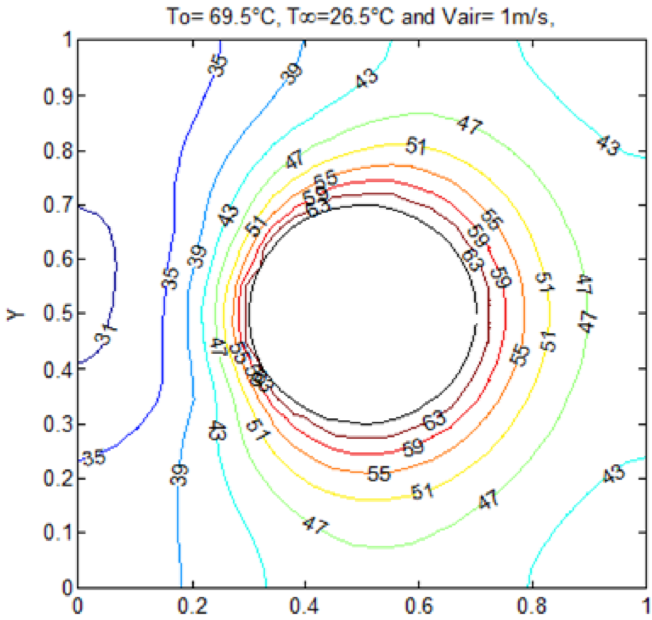

Figure 5. Variation of fin temperature over fin surface for 1m/sec velocity for ΔT=43°C

IV. CONCLUSION

A study of correlation to predict heat transfer characteristics of plate finned tube heat exchanger with the matlab program is carried out at the six sub-fin region. The heat transfer coefficient, fin efficiency and fin effectiveness has been estimated, and it has found-

1. Fin efficiency increases from 61 to 71% by changing material steel to aluminium; it means there is 14% increment in heat transfer.

2-Fin efficiency decreases from 61 to 31% for steel at $\Delta T=33$ with the increase in air velocity from 1m/sec to 5m/sec for the same fin material.

4-Heat transfer coefficient increases from 12 to 41W/m²K with air velocity from 1m/sec to 5m/sec.

V. REFERENCES

[1] A Aganda, coney, farrant, shepperd, ‘A comparison of the predicted and experimental heat transfer performance of a finned tube evaporator’, Applied Thermal Engineering 20 (2000) 499-513

[2] Ala Hasan, kai siren, "Performance investigation of plain and finned tube evaporatively cooled heat exchangers", Applied Thermal Engineering 23 (2003) 325–340

[3] Ameel, joris, christophe,"Effect of heat exchanger length in performance of compact fin and tube heat exchanger", Applied Thermal Engineering 65 (2014) 544-553

[4] C. Bougriou, bessaih, "Determination of apparent heat transfer coefficient by condensation in an industrial finned-tube heat exchanger", Applied Thermal Engineering 25 (2005) 1863–1870

[5] Chen, join rong, "Study of heat transfer characteristics of two row plate finned tube heat exchanger," International journal of heat and mass transfer vol.55, (2012), 4088-4095

[6] Chen, zhen li, yuon guo, "Experimental investigation of plastic finned-tube heat exchangers, with emphasis on material thermal conductivity" ,International journal of thermal and fluid science. Vol. 922, (2009)

[7] Cheng-Hung Huang, yao-long Tsai,"A transient 3-D inverse problem in imaging the time-dependent local heat transfer coefficients for plate fin",Applied Thermal Engineering 25 (2005) 2478–2495

[8] Comini, savino,"Accuracy of one-dimensional design procedures for finned-tube heat exchangers", Applied Thermal Engineering 29 (2009) 2863–2869

[9] Frank and David P. Dewitt, "Heat and mass transfer published" by John wiley & sons, Inc., (2005) Printed in the United States of America

[10] Getu, bansal, "New frost property correlations for a flat-finned-tube heat exchanger",International journal of thermal sciences vol 50, (2011),544-557

[11] Han-Taw Chen, chou, "Investigation of natural-convection heat transfer coefficient on a vertical square fin of finned-tube heat exchangers",International Journal of Heat and Mass Transfer 49 (2006) 3034–3044

[12] Han-Taw Chen, wei-lun Hsu, "Estimation of heat transfer coefficient on the fin of annular-finned tube heat exchangers in natural convection for various fin spacings" International Journal of Heat and Mass Transfer 50 (2007) 1750–1761

[13] Han-Taw Chen, wei-lun Hsu, "Estimation of heat-transfer characteristics on a vertical annular circular fin of finned-tube heat exchangers in forced convection", International Journal of Heat and Mass Transfer 51 (2008) 1920–1932

[14] Herchang, yuh jang, nan yeh, "Local heat transfer measurements of plate finned-tube heat exchangers by infrared thermography", International Journal of Heat and Mass Transfer 45 (2002) 4069–4078

[15] Huang, "A three-dimensional inverse problem in imaging the local heat transfer coefficients for plate finned-tube heat exchangers", International Journal of Heat and Mass Transfer 46 (2003) 3629–3638

[16] Huang, yuon, "An experimental study in determining the local heat transfer coefficients for the plate finned-tube heat exchangers", International Journal of Heat and Mass Transfer (2009) 52 vol.4883–4893

[17] Jang, J.T. lai, "Numerical and experimental analysis of heat transfer in finned tube heat exchanger", International conference on CFD and mineral processing CSIRO (1997)

[18] Jiong, kim, yuon, "A study on the correlation between the thermal contact conductance and effective factors in fin–tube heat exchangers with 9.52 mm tube", International Journal of Heat and Fluid Flow 25 (2004) 1006–1014

[19] Jiong, kim, yuon, "A study on the thermal contact conductance in fin–tube heat exchangers with 7 mm tube", International Journal of Heat and Mass Transfer 49 (2006) 1547–1555

[20] Jung, yang, "3D numerical and experimental analysis for thermal–hydraulic characteristics of air flow inside a circular tube with different tube inserts, "Applied Thermal Engineering 29 (2008) 250–258

[21] Lee and kim, "Air-side heat transfer characteristics of spiral-type circular fin-tube heat exchanger", international joural o f refrieration vol.33, (2010), 313-320

[22] P.K. nag, "Heat and mass transfer", published by Mc Graw hill education india private limited(2003).

[23] Pongson, wongwises,"Heat transfer characteristics of spiral fin and tube heat exchanger" International journal of heat and mass transfer 79(2014), 417-421

[24] Qijun yu, Straatman, "Carbon-foam finned tubes in air–water heat exchangers", Applied Thermal Engineering 26 (2006) 131–143

[25] Ramesh k. Shah and Dusan P.Sekulic, "Design of heat exchanger" Published by John Wiley & Sons, Inc., Hoboken, New Jersey(2003)

[26] Saboya, Fransisco, "Experiment on elliptical sections in one and two row arrangement of plate fin and tube heat exchanger", Thermal and fluid science 24(2001), 67-75

[27] Tao, Y.l. he, W.Q.tao, "Design of efficient wavy fin surface based on heat transfer study", Journal of Enhanced Heat Transfer, vol. 14(4), (2007), page1–18

[28] Y.B. tao, Y.l.he, Huang, "Numerical study of local heat transfer coefficient and fin efficiency of wavy fin-and-tube heat exchangers", International Journal of Thermal Sciences 46 (2007) 768–778

[29] Yin, chen, zeming he, "Effect of change of tube location on heat transfer characteristics on plate fin tube heat exchanger", International journal of thermal science by ASME,vol. 6, (2013)

[30] Yonghan Kim, yongchan kim "Heat transfer characteristics of flat plate finned-tube heat exchangers with large fin pitch", International Journal of Refrigeration 28(2005) 851–858