ISSN 2321-807X
Volume 12 Number14
Journal of Advances in chemistry

INFLUENCE OF TWISTED TAPE INSERT ON OVERALL HEAT TRANSFER COEFFICIENT AND EFFECTIVENESS CHARACTERISTIC OF AUTOMOBILE RADIATOR

Christaraj FRANCIS VIMAL RAJ[1], Chockalingam SUNDARRAJ[2], Muthukrishnan VARATHARAJULU[3] , Arumugam THIAGARAJAN[4]
[1,2,3,4]A. V. C. College of Engineering, Mannampandal 609 305, Tamilnadu, India

[1]francis.avcce@gmail.com
[2]csundarraj@yahoo.com
[3]rajulu_production@yahoo.co.in
[4]thiagu.avcce@gmail.com

ABSTRACT

In this work, the overall heat transfer coefficient and the effectiveness of a circular tube automobile radiator with aluminium twisted tape insert having three different twist ratio (y = 8, 12, and 16) is investigated experimentally by varying the fluid flow rate and temperature. The results show that the presence of twisted tape inserts increases the overall heat transfer coefficient and the effectiveness compared with the plain tube radiator. The empirical correlations of these parameters were statistically analyzed and optimized using ANNOVA table by implementing Design expert Software.

Indexing terms/Keywords

Automobile radiator, Overall heat transfer coefficient, Effectiveness, Twisted tape, Empirical correlation.

Academic Discipline And Sub-Disciplines

Mechanical Engineering and Chemical Engineering

SUBJECT CLASSIFICATION

Heat Transfer

TYPE (METHOD/APPROACH)

Experimental Investigation

INTRODUCTION

Industries like chemical, refrigeration and air conditioning, power plant and automotives are in need of heat transfer methods in order to increase the efficiency of the system and to reduce the size and cost of the equipment through the improvement of the heat exchangers. Consecutively to increase the efficiency of heat exchanger, lots of techniques were used by many researchers.

Bhuiya *et al* [1, 2] analyzed the thermodynamic properties of a heat exchanger using air as working fluid with four different twisted tape insert having twist ratios ranging from 1.95 to 7.75. The tests were conducted in a circular tube turbulent flow dominion varying by Reynolds number. The same experimental test were taken by inserting triple twist as a replacement for of double counter twisted tape and the results were studied. It is found to be that the Nusselt number, friction factor and thermal enhancement efficiency were increased with decreasing twist ratio. Further the heat transfer rate in the tube fitted with both double counter twisted tape and triple was considerably increased with relatively increases pressure drop. An experimental analysis conducted by Suriya Chokphoemphun *et al* [3], in a round tube containing a uniform heat-fluxed wall for enhanced heat transfer and pressure loss quality by using single twist tape with two different twist ratios (y/w = 4 and 5) and the rest double, triple, and quadruple twisted-tape inserts are at y/w = 4. The study has been made in the heat exchanger tube inserted with the mentioned various twisted-tape by co-twist and counter-twist arrangements for the turbulent air flow, in the range of Reynolds number (R_e) from 5300 to 24000. The result shows a better Nusselt number *(Nu)* for the inserted tube 1.15 to 2.12 times than that of the plain tube while friction factor (*f)* 1.9 to 4.1 times. The quadruple counter-twisted tape insert provides the maximum thermal performance.

The heat transfer rate, friction factor and thermal performance were higher in the combined circular-ring turbulators (CRT) and TT on round tube over those with the CRT alone was investigated by Smith Eiamsa-ard *et al* [4]. Bodius Salam *et al* [5] studied the heat transfer rate, friction factor and heat transfer enhancement efficiency in a circular tube fitted with rectangular cut twisted tape insert. The results shows that the tube which is having rectangular cut twisted tape insert enhanced Nusselt number, friction factor and heat transfer enhancement efficiency by 2.3 to 2.9 times,1.4 to 1.8 times and 1.9 to 2.3 times compared with plain tube respectively. Murugesan *et al* [6] conducted the thermal performance test in a circular tube using V-cut twisted tape with three different twist ratios and with three different width and depth ratios. The result revealed that the Nusselt number and friction factor with V-cut twisted tape increase with decreasing twist ratios, width ratios and increasing depth ratios. In addition an empirical correlation also developed for the Nusselt number and friction factor. And also the above author [7, 8] compared heat transfer and friction factor in a double pipe heat exchanger furnished with Twisted Tape Consisting Wire nails (WN-TT) and Plain Twisted Tapes (P-TT) with three different twist ratios of *y* = 2.0, 4.4 and 6.0. Researcher concluded that wire nails twisted tape provides higher thermal performance while compared to the plain one. These occurred because of the combined effect of WN-TT. P-TT generates swirl flow in additional turbulence effect offered by wire nails. The same could be attained by implementing square cut twisted tape instead of wire nail twisted tape. The thermal performance characteristics in the heat exchanger tubes fitted with regularly-spaced twisted tapes showed heat transfer rate and friction increased with decreasing twist ratio and space ratio was concluded by Eiamsa-ard *et al* [9].

Bhuiya *et al* [10] investigated with the perforated twisted tape insert with four different porosities in a circular tube having uniform heat flux using air as a fluid. The investigational results exposed that both heat transfer rate and friction factor of the tube equipped with perforate twisted tapes were considerably superior to those of the plain tube. Eiamsa-ard *et al* [11] examined the heat transfer, friction factor and thermal performance behaviours in a tube with a loose – fit twisted tape insert at different clearance ratios (CR = 0.0 (tight-fit), 0.1, 0.2 and 0.3). The experimental results revealed that thermal performance factor tended to increase with decreasing clearance ratio. Among the examined tapes, the tight-fit tape (CR=0.0) gave the highest thermal performance factor. Pongjet Promvonge [12] analyzed the thermal performance in a circular tube having uniform heat flux with both circular coiled wire and square coiled wire by varying pitch length. Author concluded that tubes with coiled wire which are lesser pitch length produces more thermal performance while compared with the plain tube. In the coiled wire insert square wire provides greater heat transfer than the circular wire due to maximum turbulence of lateral edge.

Heydar Maddah *et al* [13] studied Al_2O_3 with water nanofluid in the horizontal double pipes fitted with different geometrical progression ratio (GPR). Pitch length of the twisted tapes twist ratios changed along the twists with respect to the GPR by reducer (RGPR < 1) and increaser (IGPR > 1). Concerning the experimental data, RGPR twists jointly with nanofluids tends to augment heat transfer and friction factor by 12% to 52% and 5% to 28% respectively compared with the tube with typical twisted tapes (GPR = 1) and nanofluid. The heat transfer and friction factor in a circular tube with twisted tape by varying thickness and Al_2O_3/water nanofluid was analysed by Esmaeilzadeh *et al* [14]. Result shows that larger thickness will enhance the heat transfer rate as well as friction factor. At the mean time nanofluids also enhance the same effectively. Finally two new correlations created for the Nusselt number and thermal performance. Azmi *et al* [15] created a numerical model to estimate the nanofluid friction factor and Nusselt number by conducting the experimental test in the tube having five different twisted tape insert with SiO_2 nanofluid as a coolant. The same equation is validated with other nanofluids like Al_2O_3 and Fe_3O_4 with twisted tape. Naik *et al* [16] compared the thermal performance of twisted tape and wire coil using CuO/water nanofluid. The result designated that wire coil provides better thermal performance while compared to the twisted tape. Friction factor also reduced in the wire coil instead of twisted tape. Smith Eiamsa-ard and Kunlanan Kiatkittipong [17] investigated the thermal performance characteristics in a heat exchanger tube by adopting multiple twisted tapes in different arrangements and TiO_2 nano particles with different concentrations as the working fluid. Better fluid mixing attained by introducing number of twisted tape replicates in enhancing swirl flow. Distinct arrangement of twisted tapes in counter current provides higher energy saving. Especially quadruple counter tapes in the cross directions enlarged heat transfer with relatively low friction loss penalty. In addition with swirl flow devices nanofluids plays a major role for the thermal performance factor.

Shabanian *et al* [18] studied the experimental and Computational Fluid Dynamics (CFD) modelling on an air cooled heat exchanger equipped with butterfly, classic and jagged twisted tape insert. The results revealed that the heat transfer, friction factor and heat transfer enhancement efficiency was obtained by the butterfly insert with an inclined angle of 90° compare with other two inserts. Erika Y. Rios-Iribe *et al* [19] conducted a CFD analysis on non-Newtoniam fluid flowing through a circular tube with twisted tape inserts. Researcher found that twist tape create a swirl flow and it disturbs the boundary layer by that heat transfer rate will also increase. Thermo-hydraulic performance is improved while twist ratio is decreased. Finally CFD data and the dimensionless numbers were correlated. Among those techniques swirl flow devices plays a major role in the passive cooling techniques. Hirkude *et al* [20] studied the effect of compression ratio on performance of CI engine fuelled with biodiesel from waste fried oil, used Response Surface Methodology (RSM) to predict the optimal input parameters. Experimental investigation compared with the hypothesis and optimum parameters attained through RSM. Vijayaraj and Varatharajulu [21] optimised the process parameters of wet scrubbing of biogas from night soil and vegetable waste using historical and Taguchi design. Empirical relation was build by historical design and influence of the parameters identified by Taguchi method. RSM used as effective tool by Varatharajulu *et al* [22] in order to optimize the process input parameter of machining operation.

Literature shows that most of the researchers investigated in the circular tube and shell and tube heat exchangers with various twisted tape insert, further a huge gap identified in the study of bank of tubes. Therefore, this work deals with bank of tubes, automobile radiator used as heat exchanger equipped with three different twist ratios twisted tape to find out the thermal performance. In additional an empirical correlation was carried out by Box-Behnken method.

EXPERIMENTAL SETUP

In order to measure the hot fluid side heat transfer coefficients in the car radiator having circular cross section bank of 36 vertical tube of length 410 mm arranged in line position and 235 aluminium sheets fixed in a horizontal position 360 × 32.5 × 200 mm as fins, a flow loop shown in Fig. 1 has been used. This investigational rig includes a storage tank, heater, pump, flow meter, forced draft fan, cross flow finned tube heat exchanger (car radiator), and flow lines. The hot fluid flows through the Chlorinated polyvinyl chloride (CPVC) pipe (0.75 inch diameter) from the feed tank to the radiator by a centrifugal pump with varying flow rate ranging from 100 lph to 500 lph. A bye pass line with a ball valve was used to attain the predestined flow rate. A storage tank of 30 litres capacity (height of 35 cm and diameter of 30 cm) could be filled by

25% of working liquid has been used to keep the volume of circulating liquid constant at all working conditions. The flow rate of the working fluid has been controlled by a flow meter of 0 to 1000 lph range with the precision of 0.1 litre per minute. The temperature of the working fluid is maintained between 60°C and 80°C using an immersion electrical heater and a controller.

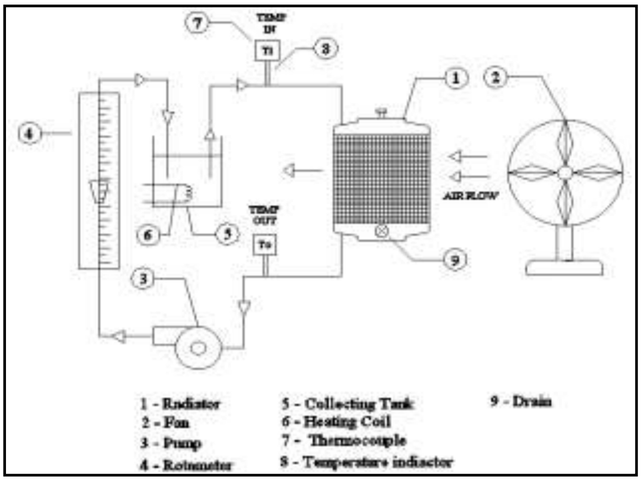


Fig. 1 Schematic diagram of experimental setup

Four numbers of Pt-100 Ω resistance temperature detectors (RTD) were implemented on the flow line to trace both hot fluid and cold fluid inlet and outlet temperatures. Two other RTDs were also used to record the radiator wall temperature measurement. These RTDs were installed at the centre of the radiator surfaces (both sides). Due to very small thickness and very high thermal conductivity of the round tubes, it is reasonable to equate the inside temperature of the tube with the outside one. The measured temperatures from these RTDs have been shown on two digital monitors with the accuracy of 0.1 °C. All used RTDs were thoroughly calibrated by using a constant temperature water bath, and their accuracy was noted to be ±0.2 °C.

DATA REDUCTION

The overall heat transfer coefficient and effectiveness of the heat exchanger has been calculated using the following routes with Newton's cooling law.

$$Q = mC_p\Delta T = mC_p(T_{in} - T_{out}) \quad (1)$$

For hot fluid
$$Q_h = m_h c_{ph}(T_{hi} - T_{ho}) \quad (2)$$

For cold fluid
$$Q_c = m_c c_{ph}(T_{ci} - T_{co}) \quad (3)$$

$$Q_{ave} = \frac{Q_h + Q_c}{2} \quad (4)$$

To attain the overall heat transfer coefficient by using logarithmic mean temperature difference (LMTD).

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \quad (5)$$

where,
$$\Delta T_1 = T_{hi} - T_{co}$$
$$\Delta T_2 = T_{ho} - T_{ci}$$

From the equation ΔT_{lm} was carried out. After that the overall heat transfer coefficient can be calculated by

$$U = \frac{Q_{ave}}{A \times \Delta T_{lm}} \quad (6)$$

The values from the eq.(1) and eq.(4) will be adopted in the above eq.(5) to attain the overall heat transfer coefficient. The effectiveness of the entire system is analysed by the conventional LMTD technique and the effectiveness is characterized by

$$\varepsilon = \frac{Q_{ave}}{Q_{max}} \quad (7)$$

$$\varepsilon = \frac{Q_{ave}}{(mc_p)_{min}(T_{hi} - T_{ci})} \quad (8)$$

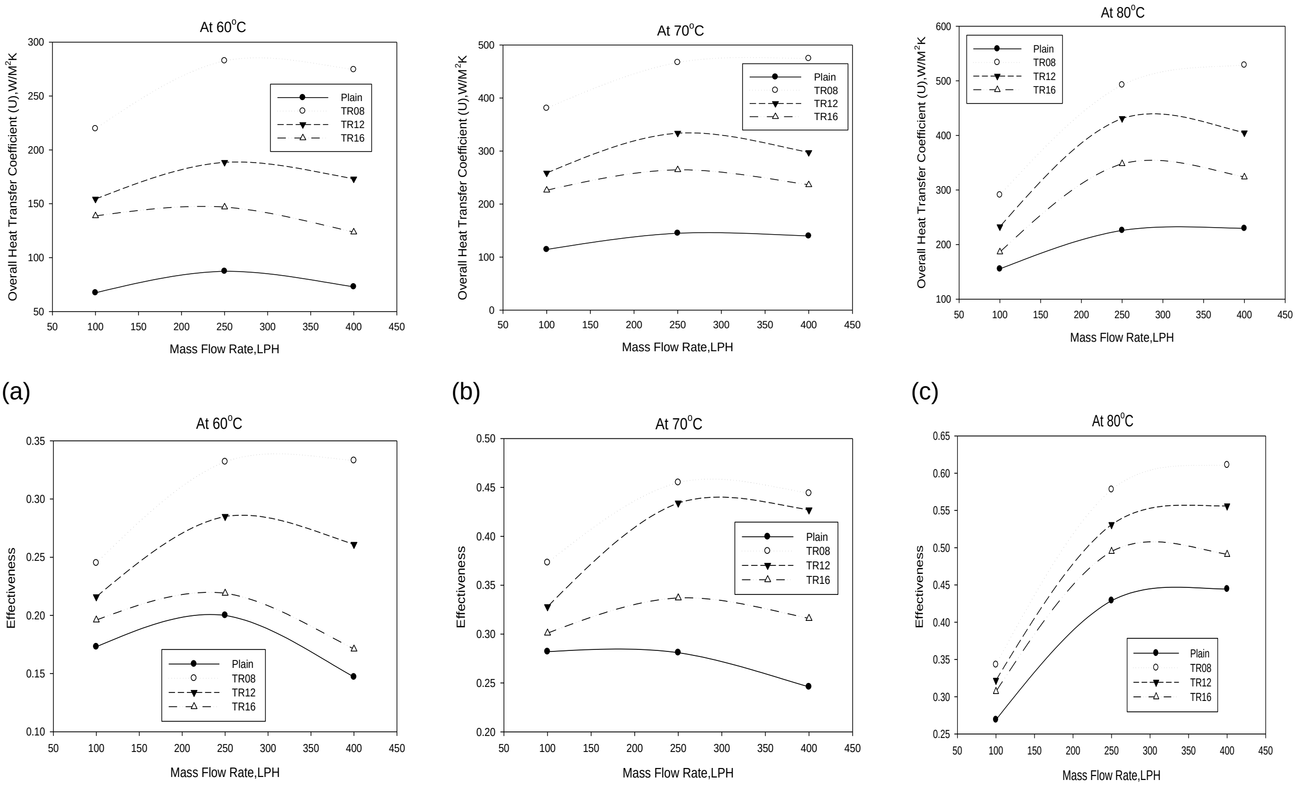
RESULT AND DISCUSSION

In this work, the experimental results of the round tube radiator with and without twisted tape insert on the overall heat transfer coefficient and effectiveness were studied. The evaluation was made by varying working temperature and fluid flow by inserting three different aluminium twist ratio of (y = 8, 12, 16) called as TR08, TR12 and TR16 and it is compared with the plain tube.

Effect of twisted tape insert on the overall heat transfer Coefficient and effectiveness

Effects of twisted tape on overall heat transfer coefficient of an automobile radiator are demonstrated in Fig. 2 (a, b, c). It was observed that the tube fitted with the twisted tape insert offered higher values of heat transfer augmentation i.e., 1.19 to 2.94 times higher than those of plain tube radiator due to swirl flow or secondary flow generated by twisted tape inserts. Also the full length twisted tape made continuous swirling flow over the entire length of tubes in the radiator to increase the residence time of the flow, destruction of the thermal boundary layer and the mixing between the core and the tube wall flow as demonstrated by Eiamsa-ard. S et al [23]. The increase in mass flow rate of the coolant makes the average heat transfer of the fluid to increase and hence the overall heat transfer coefficient to be increased. However, the decrease in temperature difference at high mass flow rate due to the reduced residence time makes the average heat transfer to decrease and that makes the overall heat transfer coefficient to decrease for very high mass flow rate[3].

The effectiveness of the radiator fitted with the twisted tape inserts having different twist ratios compared with the plain radiator at different working temperature and fluid flow is presented in the Fig. 2 (d, e, f). About 12 to 38 % increase in effectiveness is observed for the radiator with twisted tape insert at different working conditions than the plain tube due to higher residence time. Insert of twist ratio TR08 records a maximum effectiveness of 0.60 at 80^{0}C against 0.44 for plain tube as the heat transfer enhancement increases with decreased twist ratio due to the fact that at lower twist ratio, stronger swirl intensity will be generated, which led to more efficient interruption of boundary layer [4, 9].



(d) (e) (f)

Fig. 2 (a, b, c): Mass flow rate Vs Overall heat transfer co-efficient for various temperature
Fig. 2 (d, e, f): Mass flow rate Vs Effectiveness for various temperature

ANOVA and response plots

The analysis of variance (ANOVA) was applied to study the effect of the input parameters on the output parameters. Reduced quadratic modes are the best model, because it has the improved statistical values than linear, two factor interactions and cubic model. Table 1 shows the sample ANOVA result of the reduced quadratic model. ANOVA is commonly used to summarize the test for significance on individual model coefficient.

Table 1. ANOVA for Plain U

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	46821.69	7	6688.81	3350.1	< 0.0001
A-Flow rate	140.4	1	140.4	70.32	< 0.0001
B-Temperature	7548.91	1	7548.91	3780.88	< 0.0001
AB	3232.57	1	3232.57	1619.04	< 0.0001
A^2	1521.05	1	1521.05	761.82	< 0.0001
B^2	30430.76	1	30430.76	15241.29	< 0.0001
A^2B	445.71	1	445.71	223.23	< 0.0001
AB^2	1183.98	1	1183.98	593	< 0.0001
Residual	17.97	9	2		
Lack of Fit	17.97	1	17.97		
Pure Error	0	8	0		
Cor Total	46839.66	16			

The Model F-value of 3350.10 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, AB, A^2, B^2, A^2B, AB^2 are significant model terms. A & B are the coded factors of hot fluid flow rate and its temperature respectively. Values greater than 0.1000 indicate the model terms are not significant. The "Pred R-Squared" of 0.9759 is in reasonable agreement with the "Adj R-Squared" of 0.9993. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. For this analysis ratio of 171.428 indicates an adequate signal. This model can be used to navigate the design space.

Mathematical model

The regression models for the responses are detailed in equation (9) to (16) respectively. Statistical values of those equations are charted in table 2. The coefficient of determination R^2 is a measure of reliability of the model, if it match's with 1 the model well predicted, here all the responses very closer to unity. Adjusted R^2 is used for comparing the residual per unit degree of freedom. Adequate precision is a measure of signal to noise ratio, which revealing the effect of uncontrollable factors influence over the responses. The ratio more than 4 is adequate for model discrimination. Considering all these aspect the model can be used to navigate the response space in a reliable manner.

$$PlainU = 2528.97796 + 4.68155\times A - 66.62252\times B - 0.17496\times A\times B + 3.80080\times 10^{-3}\times A^2 + 0.44344\times B^2 - 6.63480\times 10^{-5}\times A^2\times B + 1.62206\times 10^{-3}\times A\times B^2 \quad (9)$$

$$Plain\,E = 7.63913 - 1.74237\times 10^{-3}\times A - 0.21207\times B + 2.56790\times 10^{-5}\times A\times B + 8.55101\times 10^{-7}\times A^2 + 1.50033\times 10^{-3}\times B^2 - 9.87654\times 10^{-9}\times A^2\times B \quad (10)$$

$$TR8U = 8243.27304 + 3.86895\times A - 219.76878\times B - 0.21323\times A\times B + 0.012419\times A^2 + 1.47476\times B^2 - 2.02802\times 10^{-4}\times A^2\times B + 2.46824\times 10^{-3}\times A\times B^2 \quad (11)$$

$$TR8\,E = 10.44582 - 3.99096\times 10^{-3}\times A - 0.28776\times B + 8.41906\times 10^{-5}\times A\times B + 3.16106\times 10^{-7}\times A^2 + 2.03614\times 10^{-3}\times B^2 - 4.75653\times 10^{-7}\times A\times B^2 \quad (12)$$

$$TR12U = 7922.83458 + 2.19117\times A - 219.45837\times B - 0.12060\times A\times B + 5.68181\times 10^{-3}\times A^2 + 1.52750\times B^2 - 1.02504\times 10^{-4}\times A^2\times B + 1.43522\times 10^{-3}\times A\times B^2 \quad (13)$$

$$TR12\,E = 7.71409 - 5.30890\times 10^{-3}\times A - 0.21141\times B + 1.06173\times 10^{-4}\times A\times B + 1.95749\times 10^{-6}\times A^2 + 1.49546\times 10^{-3}\times B^2 - 1.97531\times 10^{-8}\times A^2\times B - 5.50265\times 10^{-7}\times A\times B^2 \quad (14)$$

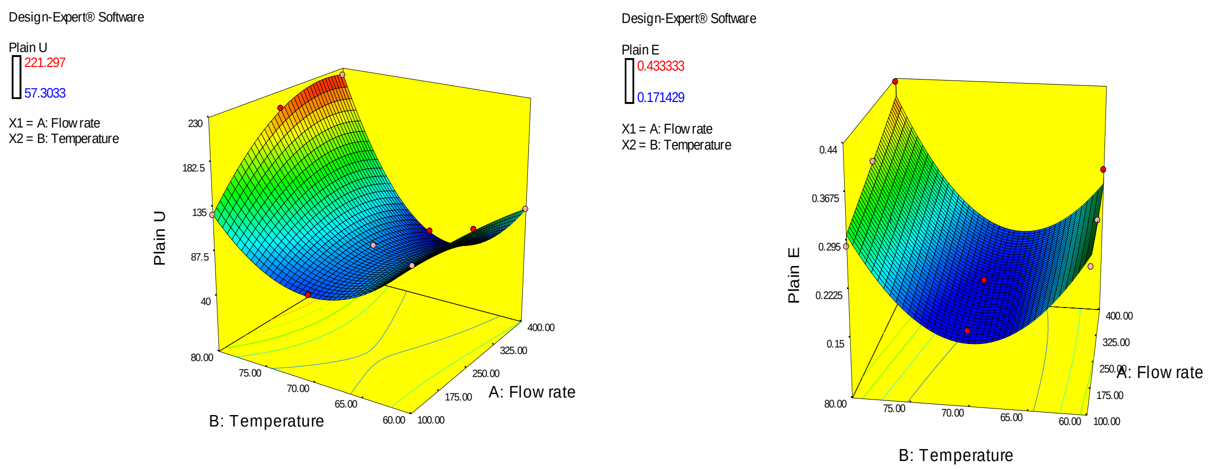
$$TR16U = 2720.70434 + 17.84727\times A - 81.58817\times B - 0.42545\times A\times B - 0.015787\times A^2 + 0.64283\times B^2 + 2.33733\times 10^{-4}\times A^2\times B + 2.36244\times 10^{-3}\times A\times B^2 \quad (15)$$

$$TR16\,E = 6.79403 + 1.75379\times 10^{-3}\times A - 0.18673\times B - 1.05898\times 10^{-4}\times A\times B + 4.42256\times 10^{-6}\times A^2 + 1.33020\times 10^{-3}\times B^2 - 5.99116\times 10^{-8}\times A^2\times B + 1.05599\times 10^{-6}\times A\times B^2 \quad (16)$$

Table 2. Regression Statistics

Statistical values	Plain U	Plain E	TR8 U	TR8 E	TR12 U	TR12 E	TR16 U	TR16 E
R-Squared	0.999	0.970	0.997	0.998	0.977	0.989	0.956	0.988
Adj R-Squared	0.999	0.953	0.995	0.998	0.959	0.982	0.922	0.980
Pred R-Squared	0.975	0.568	0.844	0.990	-0.421	0.365	-0.636	0.983
Adeq Precision	171.42	21.64	65.501	102.863	20.546	30.523	17.173	30.067

Statistical tool Design Expert 7.0.0 was used to find the effect of input over the responses and to optimize the parameters. The optimized parameters are detailed in table 3. The 3D response surface plots for responses are illustrated in figure 3.



(a) (b)

Fig. 3: Influence of input parameters over the responses

The interaction between the inputs (hot fluid flow rate and its temperature) and output is shown in figure 3. For plain radiator, TR 8 TR 12 and TR 16 interaction of individual input shows, increase in flow rate increases heat transfer coefficient. Considering temperature increase for all the radiators, heat transfer coefficient and effectiveness increases till 67.5 °C later slightly decreases, a parabolic relation observed. In the case of radiator with and without twisted tape insert having higher flow rate produced higher effectiveness, linear relation observed. For TR 8 decreased twist ratio produced enhanced effectiveness, linear relation noticed.

Performance evaluation

Every new model has to be evaluated in order to ensure the consistency. Here validation made on the quadratic model and the results confirming that the study of automobile radiator of Design Expert could yield the same hear transfer rate and effectiveness for a plain radiator and TT radiator. The fig. 4 & 5 shows the comparison between actual versus predicted responses and percentage of deviation between actual versus predicted illustrated in fig. 6. The figures illustrating that the actual and predicted values are very closer, considering the percentage of deviation except middle run all other values are well within the limit.

The percentage of deviation at the middle portion is high due to the uncontrollable factor. The average percentage of deviation for plain U, plain E, TR8 U, TR8 E, TR21 U, TR12 E, TR16 U and TR16 E was calculated as 1.0799, 0.8682, 2.0911, 1.3102, 9.0223, 4.5502, 10.5145 and 3.0968 percentage respectively, which also well within the range. The average deviations between actual and predicted values are very smaller so this work extended for optimization.

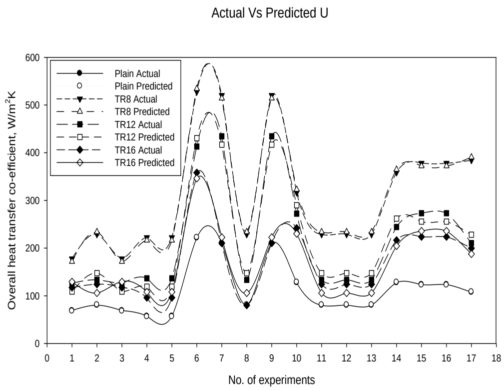


Fig. 4: Actual Vs Predicted heat transfer coefficient

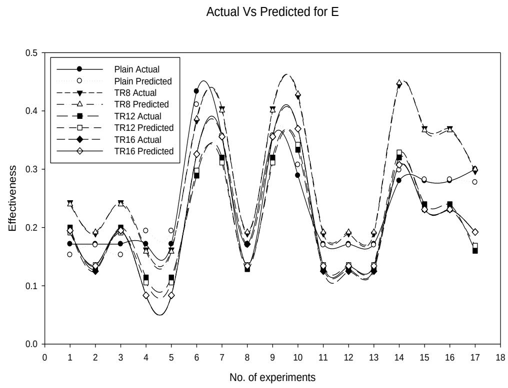


Fig. 5: Actual Vs Predicted Effectiveness

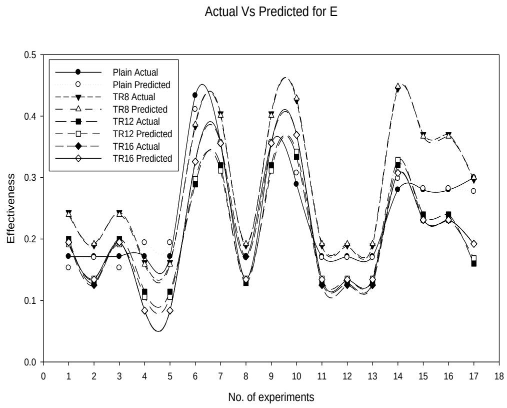


Fig. 6: Percentage of the predicted model

Optimization of parameters

The RSM is further extended to obtain the optimum input parameters in order to get the required feedback. Optimum search carried out based on the developed model according to the input parameters over the responses. Here the objective of the optimization is to maximize the overall heat transfer rate and effectiveness irrespective of plain and TT. The local confines considered for the optimization. Previously single objectives are attained to achieve maximized response later multi objective were considered. Optimum parameters are detailed in table 3, desirability for all the process attained greater than 0.9, which detailing the well working range of those input parameters.

Table 3. Optimum Parameters

Objective	Single objective								Multi objective
Type	Max.	Max.	Max.	Max.	Max.	Max.	Max.	Max.	Max.
Flow rate	356.36	400	312.99	101.31	309.91	100.67	400	100	400
Temp	79.86	80	79.71	60.06	79.99	79.97	80	80	80
Plain U	222.07								222.385
Plain E		0.411							0.411
TR8 U			528.17						534.162
TR8 E				0.445					0.387
TR12 U					435.205				430.532
TR12 E						0.341			0.298
TR16 U							346.163		346.161
TR16 E								0.369	0.326
Desirabiliy	1.000	0.914	1.000	1.000	1.000	1.000	0.957	0.999	0.914

CONCLUSIONS

Experimental investigations of overall heat transfer coefficient and effectiveness have been carried out in an automobile radiator. The tube with and without twisted tape insert were studied for the three different twist ratios 8, 12 and 16. Box-

Behnken design used in the present investigation has confirmed its competence to be an effective tool for analyzing the effect of process parameters of automobile radiator. Mathematical model for correlating responses with the predominant parameters has been obtained. Response plots are obtained to exhibit the influence of the selected parameters on the response. The conclusion can be drawn as follows

I. The twisted tape inserts offered a significant enhancement of overall heat transfer coefficient and effectiveness compared with the plain tube values.
II. The tube fitted with the twisted tape insert has been offered higher values of heat transfer augmentation i.e., 1.19 to 2.94 times higher than those found in the tube without twist tape.
III. The overall heat transfer rate increases with a decrease of twist ratio. Insert of twist ratio TR08 records a maximum effectiveness of 0.60 at 80^0C against 0.44 for plain tube.
IV. Mathematical model for the responses were proposed (Eqs. (9) to (16)) to correlate in input and responses. Average percentage of deviation was observed low for the responses respectively shows a reliable impact on the model.
V. From the experimental design and RSM, the optimal values of working fluid temperature and mass flow rate for maximum overall heat transfer coefficient and effectiveness was obtained as 400 lph and 80°C respectively, with a desirability index of 0.914.

NOMENCLATURE

A	Area of tube [m^2]
C_{ph}	Hot fluid specific heat at constant pressure [J/(kgK)]
k	thermal conductivity [W/(mK)]
Q_{ave}	average heat transfer rate [W]
Q_c	Cold fluid side Heat transfer rate [W]
T_{ho}	Hot fluid outlet temperature [K]
T_{co}	Cold fluid outlet temperature [K]
y	Twist ratio, dimensionless
ε	Effectiveness of the heat exchanger.
C_p	Specific heat at constant pressure [J/(kgK)]
C_{pc}	Cold fluid specific heat at constant pressure [J/(kgK)]
m	mass flow rate [kg/s]
Q_h	Hot fluid side Heat transfer rate [W]
T_{hi}	Hot fluid inlet temperature [K]
T_{ci}	Cold fluid inlet temperature [K]
U	Overall heat transfer coefficient [W/(m^2K)]
ΔT_{lm}	Logarithmic Mean Temperature difference.

REFERENCES

1. Bhuiya, M. M. K., Sayem, A.S.M., Islam, M., and Chowdhury, M.S.U. 2014. Performance assessment in a heat exchanger tube fitted with double counter twisted tape inserts. *International Communications in Heat and Mass Transfer,* 50, 25-33.
2. Bhuiya, M. M. K., Chowdhury, M.S.U., Shahabuddin, M., and Saha, M. 2013. Thermal characteristics in a heat exchanger tube fitted with triple twisted tape inserts. *International Communications in Heat and Mass Transfer,* 48, 124-132.
3. Suriya Chokphoemphun., Monsak Pimsarn., Chinaruk Thianpong., and Pongjet Promvonge. 2015. Thermal performance of tubular heat exchanger with multiple twisted-tape inserts. *Chinese Journal of Chemical Engineering,* 23, 5, 755–762.
4. Smith Eiamsa-ard., Vichan Kongkaitpaiboon and Kwanchai Nanan. 2013. Thermohydraulics of turbulent flow through heat exchanger tubes fitted with circular-rings and twisted tapes. *Chinese Journal of Chemical Engineering,* 21 6), 585-593.
5. Bodius Salam., Sumana Biswas., Shuvra Saha., and Muhammad Mostafa K. Bhuiya. 2013. Heat transfer enhancement in a tube using rectangular-cut twisted tape insert. *Procedia Engineering,* 56, 96-103.
6. Murugesan, P., Mayilsamy ., Suresh, S., and Srinivasan, P.S.S. 2011. Heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert. *International Communications in Heat and Mass Transfer,* 38(3), 329-334.
7. Murugesan, P., Mayilsamy, K., and Suresh, S. 2010. Heat transfer and friction factor studies in a circular tube fitted with twisted tape consisting of wire-nails. *Chinese Journal of Chemical Engineering,* 18(6), 1038-1042.
8. Murugesan, P., Mayilsamy, K., and Suresh, S. 2010). Turbulent heat transfer and pressure drop in tube fitted with square-cut twisted tape. *Chinese Journal of Chemical Engineering,* 18(4), 609-617.

9. Smith Eiamsa-ard., Chinaruk Thianpong., and Pongjet Promvonge. 2006. Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements. *International Communications in Heat and Mass Transfer,* 33(10), 1225-1233.
10. Bhuiya, M.M.K., Chowdhury, M.S.U., Saha, M., and Islam, M.T. 2013. Heat transfer and friction factor characteristics in turbulent flow through a tube fitted with perforated twisted tape inserts. *International Communications in Heat and Mass Transfer,* 46, 49-57.
11. Eiamsa-Ard, S., Wongcharee, K., and Sripattanapipat, S. 2009. 3-D Numerical simulation of swirling flow and convective heat transfer in a circular tube induced by means of loose-fit twisted tapes. *International Communications in Heat and Mass Transfer,* 36(9), 947-955.
12. Promvonge Pongjet. 2008. Thermal performance in circular tube fitted with coiled square wires. *Energy Conversion and Management*, 49(5), 980-987.
13. Maddah Heydar., Mostafa Alizadeh., and Nahid Ghasemi. 2014. Experimental study of Al_2 O_3/water nanofluid turbulent heat transfer enhancement in the horizontal double pipes fitted with modified twisted tapes. *International Journal of Heat and Mass Transfer,* 78, 1042-1054.
14. Esmaeilzadeh, E., Almohammadi, H., Nokhosteen, A., and Motezaker, A. 2014. Study on heat transfer and friction factor characteristics of γ-Al_2O_3/water through circular tube with twisted tape inserts with different thicknesses. *International Journal of Thermal Sciences,* 82, 72-83.
15. Azmi, W.H., Sharma, K.V., and Sarma, P.K. 2014. Numerical validation of experimental heat transfer coefficient with SiO 2 nanofluid flowing in a tube with twisted tape inserts. *Applied Thermal Engineering,* 73(1) 296-306.
16. Naik, M.T., Syed Sha Fahad., and Syam Sundar, L. 2014. Comparative study on thermal performance of twisted tape and wire coil inserts in turbulent flow using CuO/water nanofluid. *Experimental Thermal and Fluid Science,* 57, 65-76.
17. Smith Eiamsa-ard., and Kunlanan Kiatkittipong. 2014. Heat transfer enhancement by multiple twisted tape inserts and TiO_2/water nanofluid. *Applied Thermal Engineering,* 70(1) 896-924.
18. Shabanian, S.R., Rahimi, M., Shahhosseini, M., and Alsairafi, A.A. 2011. CFD and experimental studies on heat transfer enhancement in an air cooler equipped with different tube inserts. *International Communications in Heat and Mass Transfer,* 38(3) 383-390.
19. Erika Y Rios-Iribe., Maritza, E., Cervantes-Gaxiola., Eusiel Rubio-Castro., and José, M. 2015. Ponce-Ortega. Heat transfer analysis of a non-Newtonian fluid flowing through a circular tube with twisted tape inserts. *Applied Thermal Engineering,* 84, 225-236.
20. Jagannath Hirkude., Atul Padalka.r, Shafee Shaikh., and Avil Veigas**.** 2013. Effect of Compression Ratio on Performance of CI Engine Fuelled with Biodiesel from Waste Fried Oil Using Response Surface Methodology. *International Journal of Energy Engineering,* 3(5) 227-233.
21. Vijayaraj, S., and Varatharajulu, M. 2015. Optimisation of process parameters of wet scrubbing of biogas from night soil and vegetable waste using historical and Taguchi design. *Progress in Industrial Ecology – An International Journal,* 9(2), 168-181.
22. Varatharajulu, M., Loganathan, C., and Baskar, N. 2015. Influence of cutting parameters on burr height and burr thickness in drilling of Duplex 2205 using Solid Carbide. *International Journal of ChemTech Research,* 8(2), 768 – 777.
23. Smith Eiamsa-ard., Chinaruk Thianpong., Petpices Eiamsa-ard., and Pongjet Promvonge. 2009. Convective heat transfer in a circular tube with short-length twisted tape insert. *International Communications in Heat and Mass Transfer,* 36(4), 365–371.