IJST, Transactions of Mechanical Engineering, Vol. 37, No. M2, pp 233-239
Printed in The Islamic Republic of Iran, 2013

"Research Note"

EXPERIMENTAL, NUMERICAL ANALYSIS AND OPTIMIZATION OF ELLIPTICAL ANNULAR FINS UNDER FREE CONVECTION*

N. NAGARANI[1],** K. MAYILSAMY[2], AND A. MURUGESAN[3]
[1, 3]Dept. of Mechanical Eng., K. S. Rangasamy College of Technology, Tiruchengode-637215, Tamil Nadu, India
Email: jothirani2004@yahoo.com
[2] Dept. of Mechanical Eng., Institute of Road and Transport Technology, Erode- 638316, Tamil Nadu, India
[3] Dept. of Mechatronics Eng., K. S. Rangasamy College of Technology, Tiruchengode-637215, Tamil Nadu, India

Abstract– This paper presents the total heat transfer rate by Elliptical Annular Fin (EAF) and Circular Annular Fin (CAF) by experimental set-up, validated CFD analysis and optimization of EAF using Genetic Algorithm (GA). The experimental result of EAF shows that, the surface temperature of EAF goes on decreasing gradually along with the projected surface area in the direction of the major axis. The STE decreases with the Biot number (Bi) and Shape factor (SF). The rate of reduction of STE with increasing Bi is higher for Bi < 0.013. The experimental results are validated with CFD result. The deviation is within acceptable range for surface temperature, STE and fin effectiveness are 5-8%. The GA developed is validated with the experimental result. It is observed that, the fin effectiveness is higher when the minor axis touches the circumference of the CT, and for smaller values of SF and smaller values of the radius of the CT. This optimization method is universal and may be used for optimization of EAF under specified volume.

Keywords– Axis ratio, biot number, elliptical annular fin, fin effectiveness, heat transfer coefficient

1. INTRODUCTION

The heat exchangers with the finned system used in automobiles and electronic kits are designed according to the availability of space in the device containing them, with progressively less weight, compact size and cost. Hence, the problem of identifying configuration that provides maximum heat transfer for a given space is described in [1-3]. When the space is restricted in one direction and there is enough space in perpendicular direction the elliptical fin with circular tube heat exchanger which is visualized in [4-5] is a suitable choice. The heat exchanger with elliptical fins was studied numerically in refs. [6-9]. The application of GAs in thermal engineering is discussed in [10-12]. The aforementioned research works show that no effort has been made so far with the performance of EAF by experimental method and optimization by GA under free convection. The prime objective of this paper is an experimental heat transfer analysis of EAF and CAF, and the EAF results are validated by CFD analysis. The second objective is to develop a novel technique using the GA optimization process to gain maximum fin effectiveness for EAF.

2. EXPERIMENTAL SET -UP DESCRIPTION, PROCEDURE AND NUMERICAL ANALYSIS

Figure 1 shows the schematic diagram of the experimental set-up. The set-up has a circular-tube heat exchanger with circular and elliptical fins. The K-type thermocouples are fitted at eight locations to measure the temperatures of eight different spots of the fin. The control unit consists of a voltmeter, an

*Received by the editors August 20, 2012; Accepted July 2, 2013.
**Corresponding author

ammeter and a regulator and Proportional Integral Derivative (PID) controller. The measuring unit consists of a Data Acquisition System (DAS) and it acquires the measured temperatures from the fins. By switching on the power supply to the heater, the electrical heating rod is heated to a particular temperature to bring about the steady-state condition. The readings are taken up by varying input current and voltage. All the data signals are collected and stored in the DAS. Fig.2 represents the temperature distribution of EAF by CFD analysis. Likewise, for all the experimental values, surface temperature is evaluated.

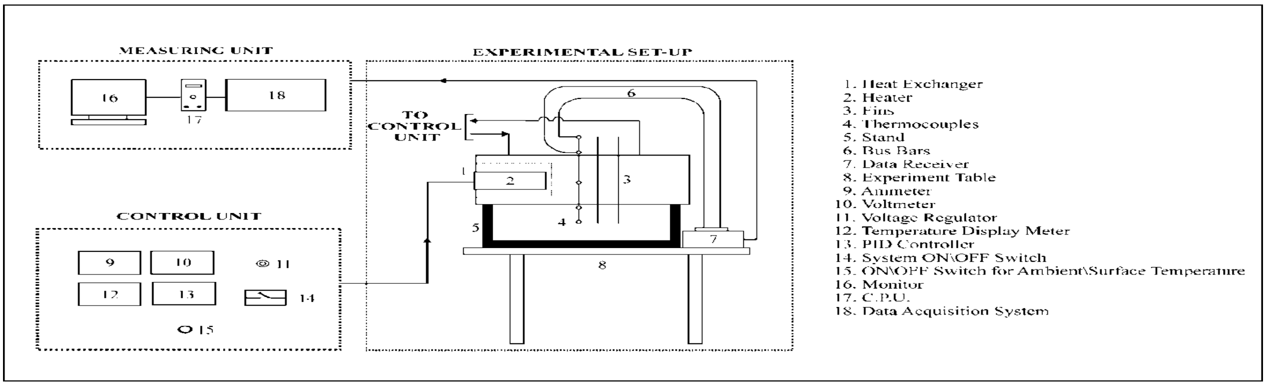

Fig. 1. Schematic diagram of the experimental set-up

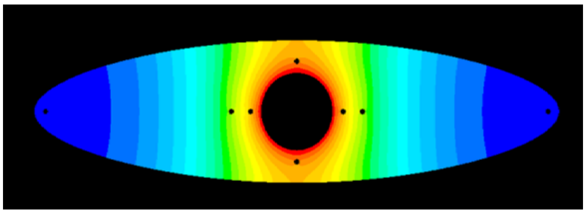

Fig. 2. Temperature distribution of elliptical fin by CFD analysis

3. OPTIMIZATION BY GENETIC ALGORITHM

The problem has been analyzed with the following prior assumptions to complete the development of the GA model. The fin materials are homogenous and thermal conductivity is constant in all directions. The surrounding temperature and base temperature of the fin are uniform. There is no heat transfer in axial direction. The thickness of the fin is small and may be neglected. In this work, the single objective optimization process is used and real coding is written in C sharp dot net language. In the GA optimization process, an area of the fin and radius of the CT are considered as variables and unit thickness and constant volume are considered as constraints. The GA procedure is given as the population is created with the given individuals for every one millimeter increment till the length of semi major axis becomes equal to the length of semi minor axis. The individuals are represented by a set of codified chromosomes. In this population, the individuals are chosen to mate by roulette; the best fitted mate is chosen more often. To calculate the population fitness values, a numerical simulation must be performed until convergence occurs, with the corresponding set of fin effectiveness for each individual. The convergence value will give the maximum fin effectiveness and the values of semi minor and semi major axes lengths.

4. RESULT AND DISCUSSION

Results and discussion are given in two parts. In the first part, the performance of EAF has been estimated and compared to that of CAF obtained by experimental results and in the second part, optimization by newly developed GA is validated with results.

a) Experimental Method- temperature distribution

A comparison of surface temperature(T_s) near the tip of the fin with respect to the base temperature (T_b) has been presented in Fig. 3. The surface temperature increases linearly with increase in base temperature. The surface temperature of EAF is lower than that of CAF for the same heat input along with the same kind of metal and equal surface area. It is observed from the experimental results that the percentage of decrease in surface temperature for EAF is from 2.5 to 3.6% compared to CAF. It is noted that there is a more significant temperature distribution along the major axis due to its projected surface area with its convection and conduction effects on the surface area**.** Many researchers such as Kundu [4], Prasanta [8] and Chien-Nan Lin [9] have reported only numerical results for the performance of the elliptical fin.

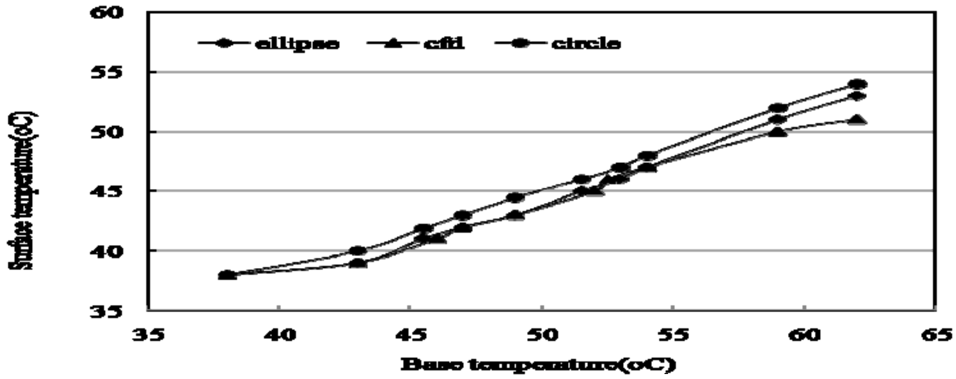

Fig. 3. Surface temperature with respect to base temperature

b) Shaped tube efficiency

Figure 4 represents the shaped tube efficiency for EAF and CAF plotted against Biot number (Bi). All the results are presented for Bi<0.019. From Fig. 4, the STE decreases with Bi and SF. The rate of decrease of the STE with Bi is higher for Bi < 0.013. So Biot number smaller than 0.13 implies that the heat conduction inside the body is much faster than the heat convection away from its surface, and temperature gradients are negligible inside of it. The Biot number for AISI steel is 0.013 and conduction rate is higher than the convection rate. From [6], most of the metal is in the range of Bi <0.3. Li *et al.* [7] numerically calculated the STE for EAF when SF varied from 1 to 0.08. The STE curve of the present experimental results with shape factor 0.25 is lower than that of results with SF 0.3 obtained from [6]. The experimental result deviates 5% from CFD result and is within acceptable range.

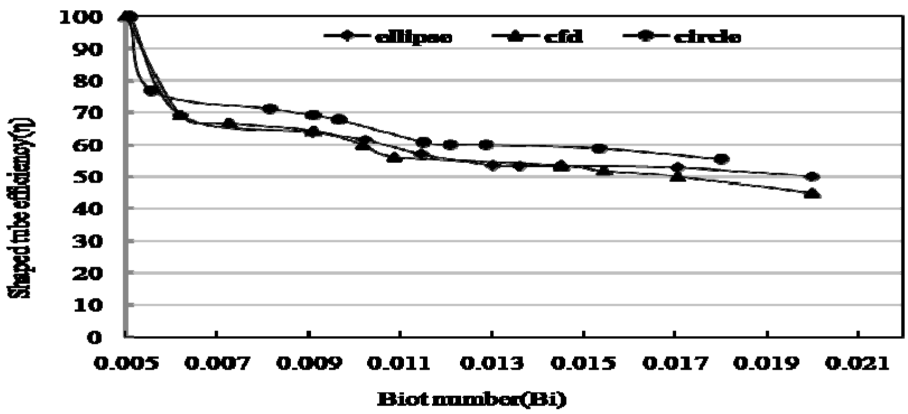

Fig. 4. Shaped tube efficiency with respect to Biot number

c) Fin effectiveness

From the experimental results, the behavior of fin effectiveness as a function of Bi and SF is displayed in Fig. 5. Bi ranges from 0.004 to 0.019. The fin effectiveness decreases with Bi up to 0.013. For Bi < 0.013, the EAF produces the most heat transfer. The experimental results prove that the heat transfer rate of the fin gets increased as the EAF is projected along the major axis and fin effectiveness is higher. The longer fin is better because conductive resistance is lower than the convective resistance in heat transfer and the trends of the plot are similar to Li *et al*. [7]. The experimental result has a 5% deviation from CFD result and it is within acceptable range.

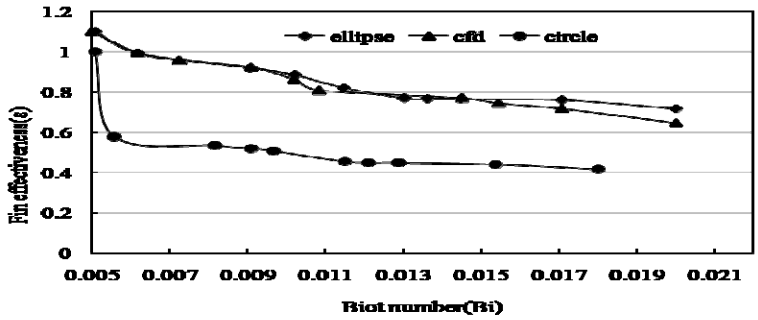

Fig. 5. Variation of fin effectiveness with respect to Biot number

d) GA Optimized result- fin effectiveness with shape factor

Figure 6 represents the fin effectiveness with respect to SF for EAF and CAF. Each curve represents the fin effectiveness with SF for the fin efficiency value varying from 60% to 90%. From Fig. 6 it is clear that when SF values are smaller, the fin effectiveness is higher for all curves. The GA has been validated with the experimental results for EAF with SF 0.25. The experimental results for EAF are 9% less than the optimal result in the efficiency range from 60 to 70%. For circular fin the experimental results are 13% less than the optimal result in the 60 to 70% efficiency range. When the SF value is 0.0858 the minor axis touches the circumference of the circular tube and when SF is equal to 1 it becomes circular.
circular fin

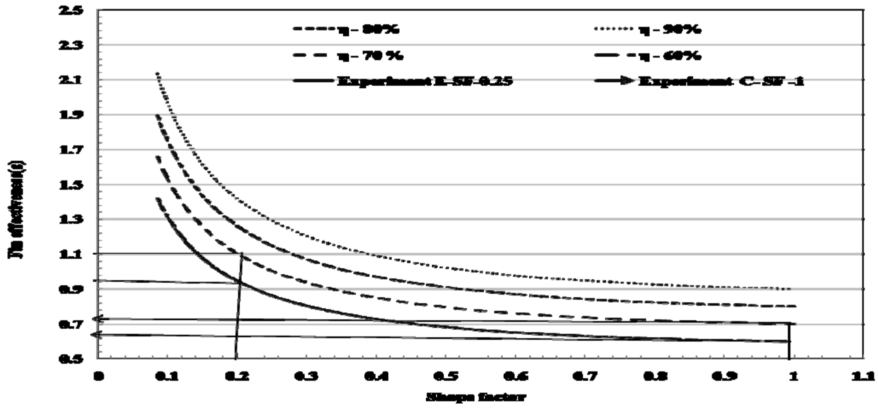

Fig. 6. Evolution of fin effectiveness and shape factor with efficiencies

e) Fin effectiveness with radius of the circular tube

Figure 7 illustrates the fin effectiveness of the EAF for different efficiency values; efficiency as the semi major axis length is increased. The arrow head indicates the validation of GA with experimental results. For the semi major axis length 99mm, the effectivenesses are 0.75 and 1.0 for efficiency 60% and 70%.

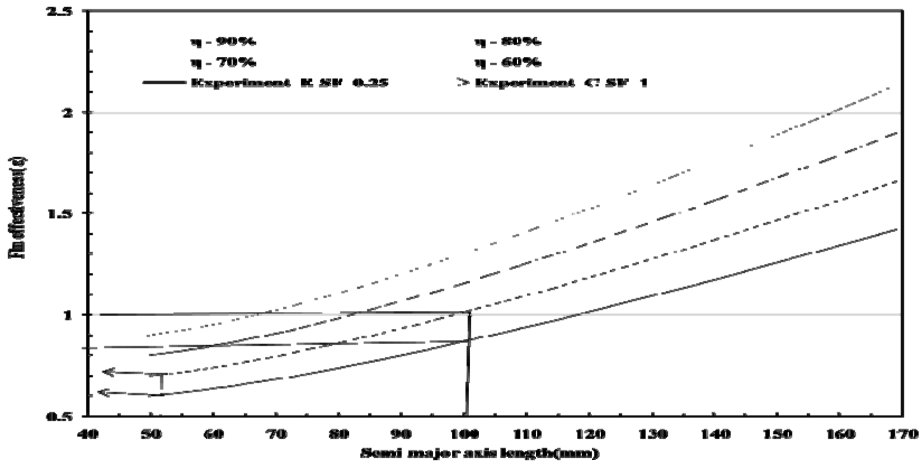

Fig. 7. Evolution of fin effectiveness with respect to semi major axis length

f) Fin effectiveness with STE

The fin effectiveness with respect to fin efficiency is represented in Fig. 8. Curves are drawn for SF 0.0858, 0.2449 and 0.92. Curves denote fin effectiveness is higher for smaller SF. The increase in efficiency increases the fin effectiveness and authenticates that fin with lower SF has better conduction and convection.

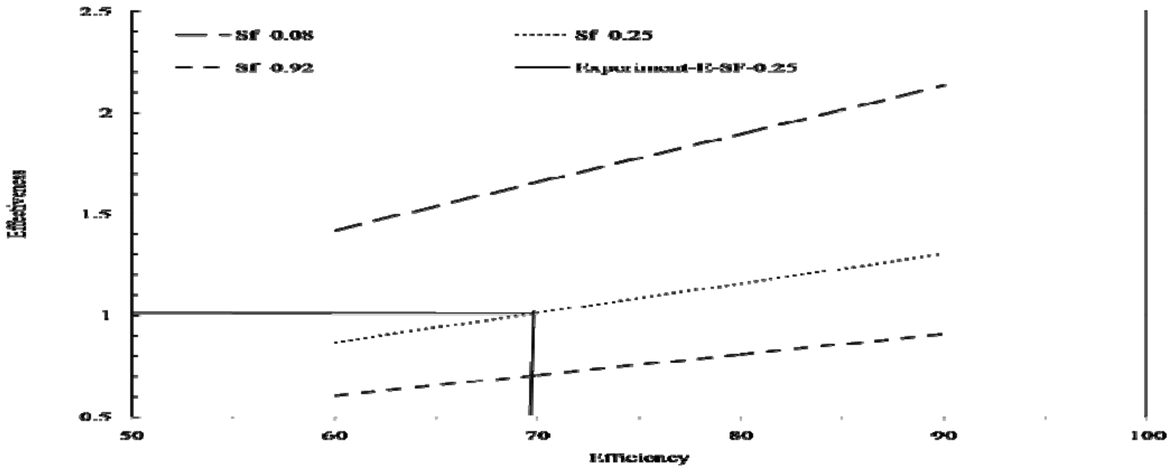

Fig. 8. Evolution of fin effectiveness as a function of efficiency for different shape factor

g) Fin effectiveness with radius of the circular tube

Figure 9 represents fin effectiveness with respect to the radius of the circular tube varying from 14mm to 30mm. 9. Curves are drawn for efficiency of 60%, 70%, 80% and 90%. The surface area of EAF is kept constant. As the area of the circular tube goes on increasing, the fin effectiveness is decreased. For efficiency curves shown in Fig. 10, when the tube radius is increased twice that of the initial condition, the fin effectiveness is decreased by 38%. The fin effectiveness is reduced for every incremental step of increase in area of the tube. This reveals that smaller area of the cross section of the circular tube is advantageous.

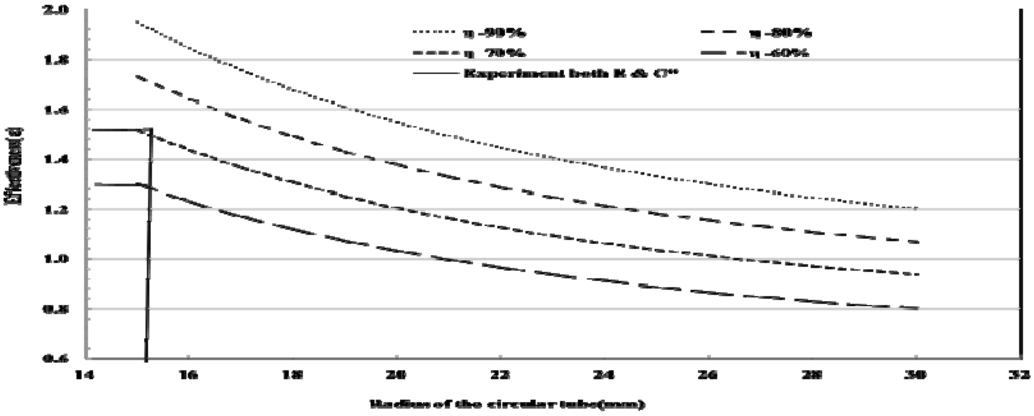

Fig. 9. Fin effectiveness with respect to the radius of the circular tube for different efficiencies

5. CONCLUSION

From the above results and discussion the following conclusions are drawn, the experimental result of EAF shows that the surface temperature of EAF goes on decreasing gradually along with the projected surface area in the direction of the major axis. The GA result has proved that EAF is more effective than circular fin for the same area of cross section when SF value is less than 0.5, irrespective of efficiency. The fin effectiveness is maximum when the minor axis touches the circumference of the CT, the SF value is very low and smaller than the radius of the CT. The experimental result which is applied on the GA also gives only 9%deviation and it is in an acceptable range. This optimization method is universal and may be used for optimization of EAF under specified volume.

ABBREVIATIONS

CAF	circular annular fin
CT	circular tube
EAF	elliptical annular fin
FE	fin effectiveness
GA	genetic algorithm
SF	shape factor
STE	shaped tube efficiency
Experiment–E–SF-.025	experiment value of shape factor for elliptical fin
Experiment –C-SF-1	experiment value of shape factor for circular fin

REFERENCES

1. Kern, Q. D. & Kraus, D. A. (1988). *Extended surface heat transfer*. McGraw-Hill, New York.
2. Allan, D. Kraus, (2009). Sixty -five years of extended surface technology (1922–1987). *Applied Mechanics Reviews*, Vol. 41, pp. 321-364.
3. Mirzaei, M. & Sohankar, A. (2013). Heat transfer augmentation in plate finned tube heat exchangers with vortex generators: a comparison of round and flat tubes. *Iranian Journal of Science and Technology, Transactions of Mechanical Engineering*,Vol. 37, No. M1, pp. 39-51.
4. Kundu, B. & Das, P.K.B. (2007). Performance analysis and optimization of elliptical fins circumscribing a circular tube. *International Journal of Heat and Mass Transfer*, Vol. 50, pp.173 -180.
5. Brauer, H. (1964). Compact heat exchangers. *Chemical Process Engineering*, Vol. 45, pp. 451- 460.

6. Jang, J. Y. & Yang, J. Y. (1998). Experimental and numerical analysis of the thermal-hydraulic characteristics of elliptic finned tube heat exchangers. *Heat Transfer Engg*, Vol. 19, pp. 55-67.
7. Li, Z., Davidson Susan, H. & Mantell, C. (2004). Heat transfer enhancement using shaped polymer tubes fin analysis. *Journal of Heat Transfe*r, Vol. 126, pp. 211-218.
8. Prasanta, Ku. Das, (2008). Heat conduction through heat exchanger tubes of the non circular cross section. *ASME Journal of heat transfer*, Vol. 130, pp. 011301-308.
9. Chien-Nan, L. & Jiin-Yuh J. (2002). A two-dimensional fin efficiency analysis of combined heat and mass transfer in elliptic fins. *International Journal of Heat and Mass Transfer*, Vol. 45, pp. 3839–3847.
10. Kalyanmoy, deb (1995). Optimization for engineering design process*. Prentice Hall of India,* 1995 Edition.
11. Gosselin, L., Maxime, T. G. & François, M. P. (2009). Review of utilization of genetic algorithms in heat transfer problems. *International Journal of Heat and Mass Transfer*, Vol. 52, pp. 2169– 2188.
12. Jafarsalehi, A., Mohammad Zadeh, P. & Mirshams, M. (2012). Collaborative optimization of remote sensing small satellite mission using genetic algorithms*. Iranian Journal of Science and Technology, Transactions of Mechanical Engineering*, Vol. 36, pp 117-128.