International Journal of Electronics, Communication & Soft Computing Science and Engineering
ISSN: 2277-9477, Volume 2, Issue 8

Modelling of Heat Transfer Augmentation using Hexagonal Finned Surfaces by Artificial Neural Network

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***Abstract*: - An attempt has been made for the experimental evaluation to study the effect of the hexagonal finned surface on the local heat transfer coefficients between the impinging circular air jet and flat plate. Reynolds number is varied between 7000 and 30000 based on the nozzle exit condition and jet to plate spacing between 0.5 to 6 times of the nozzle diameter. The fins used are in the form of hexagonal prism of side 2.04 mm and height of 2 mm spaced at a pitch of 7.5 mm on the target plate. It is observed that there is increase in the heat transfer coefficient up to 39.11 % depending on the nozzle plate spacing and the Reynolds number. Experimental results are validated using Artificial Neural Network (ANN) in the present study. The perfect validation of experimental results has been observed.**

***Keywords:* - Impinging air jet, Heat transfer augmentation, Finned surface, Nusselt number**

Nomenclature

D	Diameter of the nozzle exit (m)
h	Heat transfer coefficient (W/m^2.K)
Nu	Nusselt number (Dimensionless)
r	Radial distance from the stagnation point (m)
Re	Reynolds number based on nozzle exit condition (Dimensionless)

I. INTRODUCTION

Impinging jets have received considerable attention due to their inherent characteristics of high rates of heat transfer besides having simple geometry. Various industrial processes involving high heat transfer rates apply impinging jets. Heat transfer rates in case of impinging jets are affected by various parameters like Reynolds number, nozzle plate spacing, radial distance from stagnation point, Prandtl number, target plate inclination, confinement of the jet, nozzle geometry, curvature of target plate, roughness of the target plate, low scale turbulence intensity i.e., turbulence intensity at the nozzle exit. Gardon and Cobonpue [1] have reported the heat transfer distribution between circular jet and flat plate for the nozzle plate spacings greater than 2 times the diameter of jet, both for single jet and array of jets. They have used specially designed heat flux gauge for the measurement of local heat transfer rates from a constant wall temperature plate. Gardon and Akfirat [2] studied the effect of turbulence on the heat transfer between two dimensional jet and flat plate. They also studied effect of multiple two-dimensional jets on the heat transfer distribution [3]. Baughn and Shimizu [4] and Hrycak [5] have conducted experiments of heat transfer between round jet and flat plate employing different methods of surface temperature measurement. Review of the experimental work on impinging jets is done by Martine [7], Jambunathan *et. al.* [8] and Viskanta [9] . Hansen and Webb [10] have studied the effect of the modified surface on the heat transfer between impinging circular nozzle and the flat plate. However their data reflects the average Nusselt number variation rather than local data because of the large thickness of the target plate used.

Literature review suggests that there is lack of information on local heat transfer data in case of the finned surfaces. Therefore, the aim of the present work is to study the effect of the hexagonal finned surface on the local heat transfer coefficients between the impinging circular jet and flat plate. The experimental parameters are the Reynolds number varied between 7000 and 30000 based on the nozzle exit condition and jet to plate spacing of 0.5, 1, 2, 4, 6 times the nozzle diameter. Similarly ,experimental results are validated using Artificial Neural Network in the present study.

II. ARTIFICIAL NEURAL NETWORK

Artificial neural network is a data processing system consisting of a number of simple, highly interconnected processing elements in an input/output architecture [11-12]. ANNs have found varied applications in the field of heat and mass transfer. ANNs are massively parallel, distributed and adaptive system, modeled on the general features of biological networks with the potential for ever improving performance through a dynamical learning process. Neural networks are made up of great number of individual processing elements, the neurons, which perform simple tasks. A neuron is the basic building block of neural network technology, which performs a nonlinear transformation of the weighted sum of the incoming inputs to produce the output of the neurons .

Neural networks are comprised of a great number of interconnected neurons. There exists a wide range of network architectures. The choice of the architecture depends upon the task to be performed. For modelling of a physical system, a feedforward layered is usually used. A feedforward neural network, which is the most common neural network type, consists of layer of input neurons, and one or more hidden layers. The connections are typically formed by connecting each of the nodes in a given layer to all the neurons in the next layer. In this way every node in a given layer is connected to every another node in the next layer. The input layer does no processing, it is simply where the data vector is fed into the network. The input layer then feeds into the hidden layer. The hidden layer in turn, feeds into the output layer. The actual processing in the network occurs in the nodes of the hidden layer and the output layer.

III. EXPERIMENTATIONS

Air jet is supplied by a three-cylinder two-stage air compressor through a calibrated orifice flow meter. Air filter and pressure regulator are installed upstream of the orifice flow meter to filter the air and to maintain the downstream pressure at a value of 4 ± 0.05 bar. The flow rate is controlled by two needle valves, one on each side of the orifice flow meter. The nozzle, which directs the air until it impinges upon a heated target plate, is constructed with a 7.3 mm inner diameter aluminum pipe of length to diameter ratio of 83. The impinging plate is constructed using $1mm$ thick stainless steel plate of size $120mm \times 120mm$. Nichrome heater of size $100mm \times 100mm$ is packed between impinging plate and a bakelite support plate with mica sheets to isolate the impinging plate from the heater electrically.Electric power is supplied to the heater through variac. The voltage and the current are measured by digital panel meters. Thermocouples are attached on finned surface along the flow direction to measure the wall temperature distribution.

IV. RESULTS AND DISCUSSION

1. Comparison of The Nusselt Number for Smooth and Hexagonal Finned Surfaces at Reynolds Number of 23000 for Different Z/D's:

Figure 1 (a) to figure 1 (e) reveals the comparison of the Nusselt number for smooth and hexagonal finned surfaces at different Z/D and Reynolds number of 23000. The heat transfer results for hexagonal finned surface show an enhancement in Nusselt number as compared to smooth plate results for all the values of Z/D's. The increase in heat transfer is highest for Z/D of 1 as compared to all other nozzle plate spacings. At Z/D of 1, the maximum Nusselt number is found to occur with a value equal to 185.78 for hexagonal finned surface whereas it is 133.55 for smooth surface at the stagnation point. This high rate of heat transfer at Z/D of 1 is due to the acceleration effect which causes the local thinning of the boundary layer. Similarly, roughness increases the swirl i.e. superposition of the tangential velocity component onto axial flow, which can markedly affect the flow and turbulence characteristics of the flow. As the degree of swirl increases, the jet spread, the rate of entrainment of the surrounding fluid, and the rate of the jet velocity decay are all increased, resulting in higher heat transfer.

2. Comparison of the Nusselt Number for Smooth and Hexagonal Finned Surfaces at Z/D of 6 and for Different Reynolds Number:

Figure 2 (a) to figure 2 (f) shows the comparison of the Nusselt number for the smooth and the hexagonal finned surfaces at a Z/D of 6 for different Reynolds number of 7000,12500,16000,21500,25000 and 30000.It is observed that the increase in the heat transfer for hexagonal finned surface as compared to the smooth surface is higher in the stagnation region as compared to wall jet region for the entire range of Reynolds number. At Reynolds number of 30000, as seen from figure 2 (f), the maximum Nusselt number is found to occur with a value equal to 196.01 for hexagonal finned surface whereas it is 181.29 for the smooth surface at the stagnation point. The lowest Nusselt number has been observed at Reynolds number of 7000, which is 50.23 for the hexagonal finned surface and 44.34 for the smooth surface at the stagnation point. Comparing the entire range of Reynolds number for hexagonal finned surface, it is observed that the percentage increase in Nusselt number increases from the Reynolds number of 7000 to 16000 and thereafter percentage increase in Nusselt number is lower for further increase in Reynolds number. For low Reynolds number, roughness shows the small effect on heat transfer. The flow over the plate for a low Reynolds number can be considered as aerodynamically smooth where the roughness effect is so small that the flow behaves as if the wall was smooth. But, at higher Reynolds numbers, the flow changes from hydraulically smooth to the fully rough where the roughness so dominates the momentum transport to the wall that the viscous effects are negligible. Roughness increases the swirl i.e. superposition of the tangential velocity component onto axial flow, which can markedly affect the flow and turbulence characteristics of the flow. As the degree of swirl increases, the jet spread, the rate of entrainment of the surrounding fluid, and the rate of the jet velocity decay are all increased, resulting in higher heat transfer.

3. Validation of Experimental Results using Artificial Neural Network:

The experimental results are validated using Artificial Neural Network (ANN) in the present study. The observed values are compared with predicted values obtained by Artificial Neural Network for hexagonal finned surface at various parameters. Details of the validation is as follows.

(i) Figure 3 (a) depicts the RMSE values for hexagonal finned surface at Re = 23000 and Z/D = 6. It is observed from the validation using ANN that the correlation coefficient (R^2) is 0.998.

(ii) Figure 3 (b) shows the RMSE values for hexagonal finned surface at Z/D = 6 and Re

= 16000.It is observed from the validation using ANN that the correlation coefficient (R^2) is 0.999.

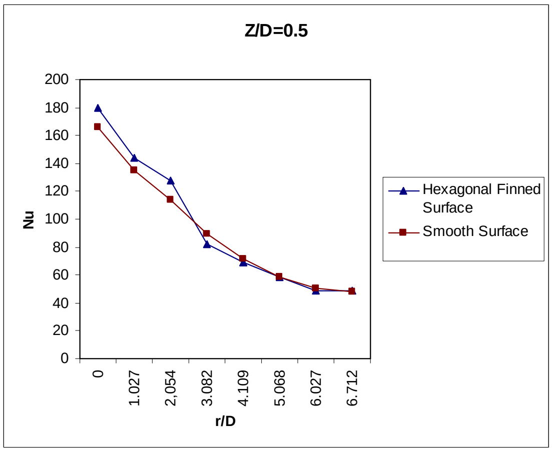


Figure 1 (a)

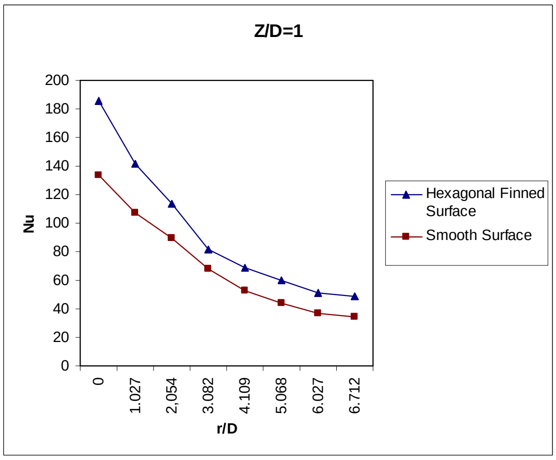


Figure 1 (b)

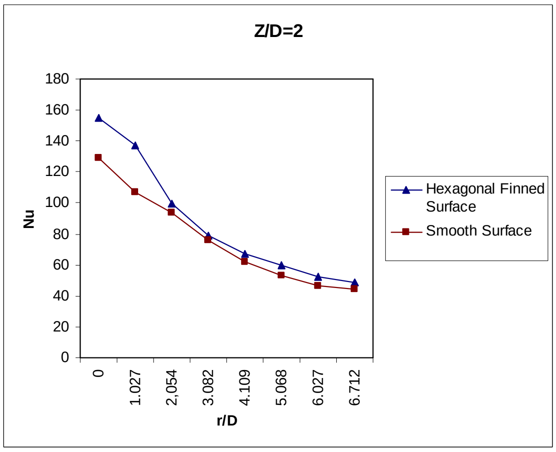


Figure 1 (c)

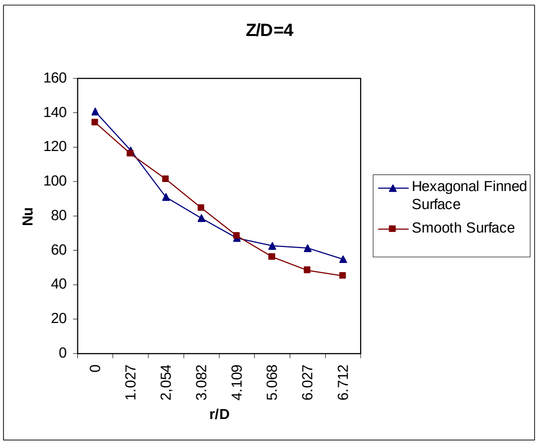


Figure 1 (d)

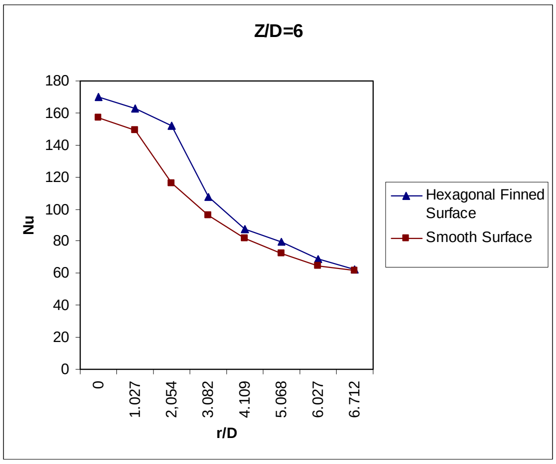


Figure 1 (e)

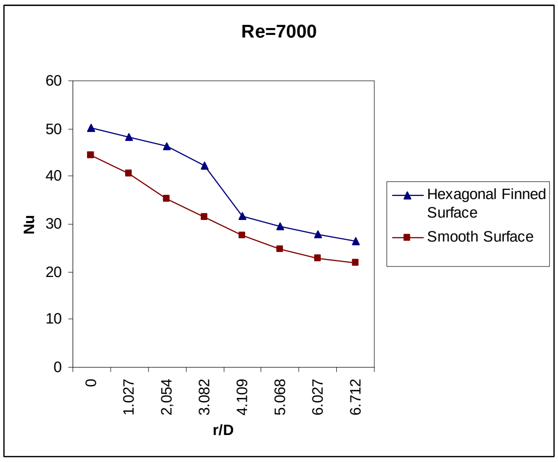


Figure 2 (a)

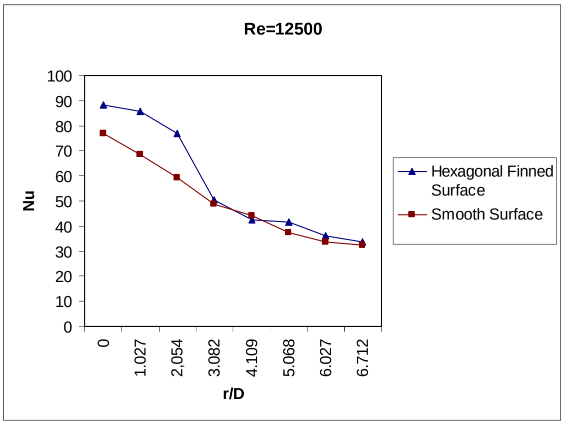


Figure 2 (b)

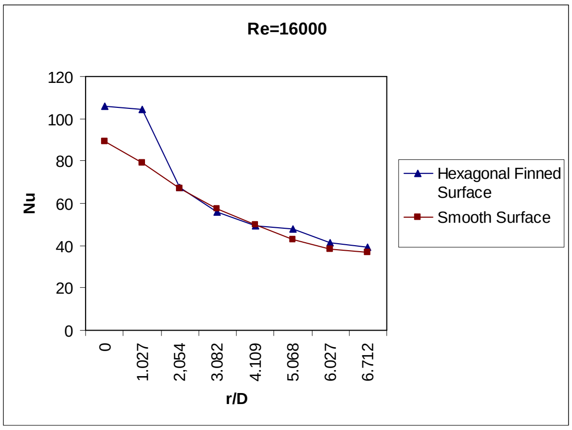


Figure 2 (c)

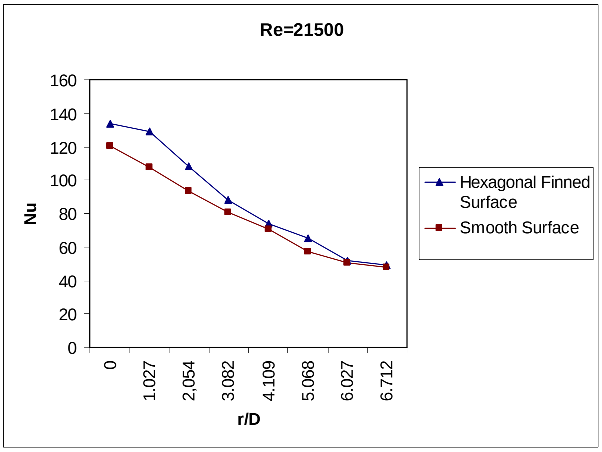
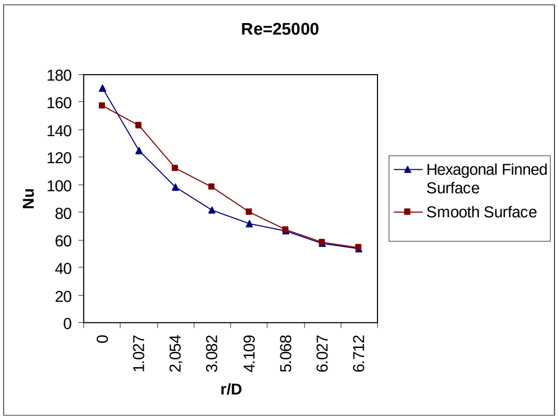


Figure 2 (d)



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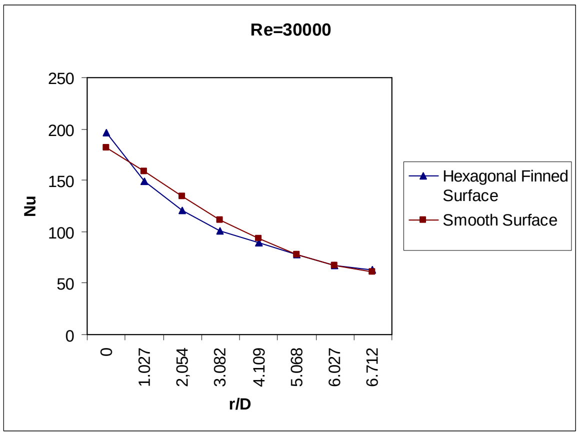

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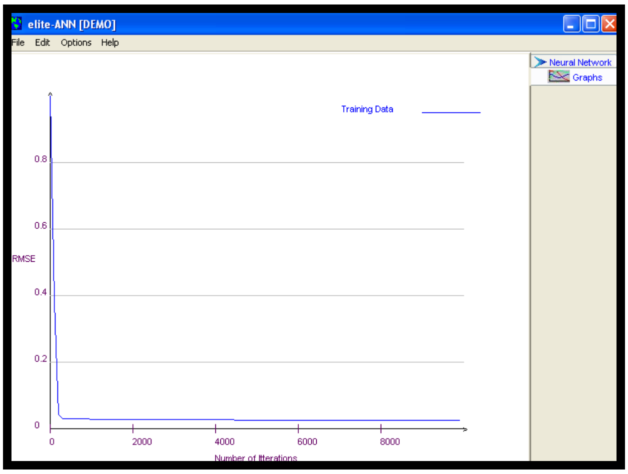

Figure 3(a): RMSE value for Hexagonal Finned Surface at Re = 23000, Variable Z/D

1st Input r/D	2nd Input Temp.	1st Actual output (Nu)	1st Predicted output (Nu)
0.01	32.4	170	168.256
1.027	33.2	163.08	163.817
2.054	33.7	151.91	151.231
3.082	36.7	107.66	109.074
4.109	39.1	87.32	84.969
5.068	40.3	79.78	77.718
6.027	42.5	68.88	73.898
Correlation Coefficient =			0.998
Root mean square Error =			2.420
Average Percentage Error =			2.257

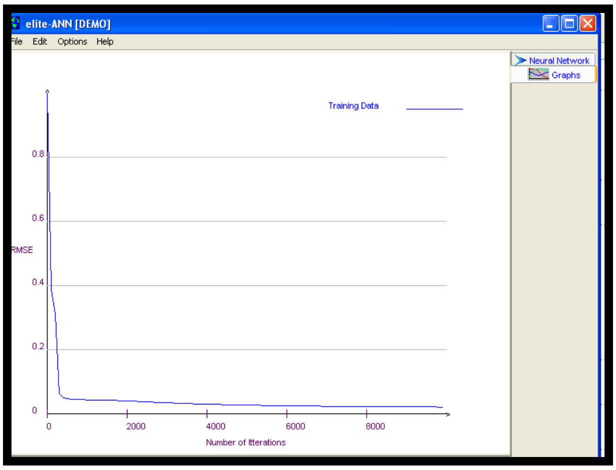

Figure 3(b): RMSE value for Hexagonal Finned Surface at Z/D =6, Variable Re (Optimum 16000)

1st Input r/D	2nd Input Temp	1st Actual output (Nu)	1st Predicted output (Nu)
0.01	32.2	105.91	105.518
1.027	32.3	104.47	104.158
2.054	36.3	67.58	67.937
3.082	38.6	56.17	55.868
4.109	40.4	49.62	49.734
5.068	41.8	48.04	46.314
6.027	43.6	41.1	43.950
Correlation Coefficient =			0.999
Root mean square Error =			1.287
Average Percentage Error =			1.785

CONCLUSIONS

1. From the comparison of the Nusselt number for smooth and hexagonal finned surface at different Z/D's and Reynolds number of 23000**,** the increase in heat transfer is favourable for Z/D of 1 as compared to all other nozzle plate spacings. For Z/D of 1, the maximum Nusselt number is found to occur at stagnation point with a value equal to 185.78 for hexagonal finned surface whereas it is 133.55 for the smooth surface. Thus, the percentage increase in Nusselt number for hexagonal finned surface is 39.11 % for Z/D of 1. This percentage increase in Nusselt number at Z/D of 1 is due to the acceleration effect which causes the local thinning of the boundary layer.

2. Similarly, from the experimentation at Z/D of 6 and different Reynolds number, it is observed that the increase in the heat transfer on hexagonal finned surface as compared to that of smooth surface is higher in the stagnation region as compared to the wall jet region. At Reynolds number of 30000, the maximum Nusselt number is found to occur at stagnation point with a value equal to 196.01 for hexagonal finned surface whereas it is 181.29 for the smooth surface . The minimum Nusselt number has been observed at Reynolds number of 7000 which is 50.23 for the hexagonal finned surface and 44.34 for the smooth surface at stagnation point. The percentage increase in Nusselt number for hexagonal finned surface compared to the smooth surface is 8.11 % to 18.74 % at the stagnation point for the entire range of Reynolds number.

3. After training the Artificial Neural Network, it is found that every case of experimental results is in good agreement with the predicted values obtained by ANN. The coefficient of correlation (R^2) for every case tested is found to be in the range of 0.998 to 0.999 which suggest the validation of experimentation carried out in the present work.

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