CHAPTER - 5

CONCLUSIONS

5.0 Introduction

In the previous chapter all the results of the current work are presented and discussed. Agreement or disagreements with the published scientific literature are discussed. Possible reasons for deviations are presented. Important conclusions are drawn case wise. This chapter summarizes the conclusions of the present investigation and proposes the scope for further research in this area.

5.1 Conclusions

1. An experimental test facility has been successfully designed developed, tested and commissioned, which is capable of reproducing the results of standard reference or bench mark experiments.

2. Experiments are performed to evaluate the heat transfer coefficients by impinging air jet emanating from circular, square and rectangular nozzles. The numerical results of the present study agree satisfactorily with the experimental data available in literature.

3. The experimental results of the present investigation provide a good understanding of the fluid flow and heat transfer characteristics of air impinging jets.
4. The salient parameters controlling the process are found to be H/d nozzle-to-resistor spacing to nozzle diameter, H/d, jet Reynolds number Re and, surface temperature T_s. The effect of these parameters on local heat transfer coefficients and heat fluxes are obtained from the experimental results.

5. Numerical results are obtained for different values of system parameters controlling the process, such as the velocity of air V, the surface temperature, T_s, the normalized velocity u*, and pressure distribution, C_p*.

6. From the numerical results the local and stagnation Nusselt number, heat flux (q), heat transfer coefficient (h), and jet Reynolds number (Re_d) are estimated.

7. Experimental results for jet arrays in different orientations are in good agreement with the numerical results computed by the theoretical analyses presented in this report.

8. Experimental data are obtained for forced convection heat transfer from the jet arrays coming out of nozzles of three different geometries, viz. (a) circular nozzle with different Reynolds number and nozzle-to-target heater spacing, (b) rectangular nozzle with different Reynolds number and nozzle-to-target heater spacing and (c) square nozzle with different Reynolds number and nozzle-to-target heater spacing. Data are obtained at different radial locations with circular, rectangular and square nozzles.
9. The numerical results for the stagnation Nusselt number and heat flux and heat transfer coefficient from literature are subjected to regression analysis. The correlations are

For 5mm diameter of the nozzle:

$$Nu_o = 0.193(Re_d)^{0.16}(Pr)^{0.33} = \frac{hd}{k_{air}}$$

For 8mm diameter of the nozzle:

$$Nu_o = 0.683(Re_d)^{0.5}(Pr)^{0.33} = \frac{hd}{k_{air}}$$

For 10mm diameter of the nozzle:

$$Nu_o = 0.86(Re_d)^{0.5}(Pr)^{0.33} = \frac{hd}{k_{air}}$$

For square nozzle:

$$Nu_o = 0.175(Re_d)^{0.675}(Pr)^{0.33} = \frac{hd}{k_{air}}$$

For rectangular nozzle:

$$Nu_o = 0.55(Re_d)^{0.62}(Pr)^{0.31} = \frac{hd}{k_{air}}$$

10. Regression equations are developed from the present experimental results to predict the stagnation Nusselt number of jet arrays in all orientations. The present correlations are

For 5mm diameter of the nozzle:

$$Nu_{Reg} = 0.2(Re_d)^{0.5}(Pr)^{0.33}\left(\frac{H}{d}\right)^{-0.06} = \frac{hd}{k_{air}}$$
For 8mm diameter of the nozzle:

\[
\text{Nu}_{\text{Re}} = 1.296 (Re_d)^{0.4} (Pr)^{0.4} \left( \frac{H}{d} \right)^{-0.012} = \frac{hd}{k_{\text{air}}}
\]

For 10mm diameter of the nozzle:

\[
\text{Nu}_{\text{Re}} = 1.38 (Re_d)^{0.46} (Pr)^{0.35} \left( \frac{H}{d} \right)^{-0.0147} = \frac{hd}{k_{\text{air}}}
\]

For square nozzle:

\[
\text{Nu}_{\text{Re}} = 0.61 (Re_d)^{0.62} (Pr)^{0.33} \left( \frac{H}{d} \right)^{-0.016} = \frac{hd}{k_{\text{air}}}
\]

For rectangular nozzle:

\[
\text{Nu}_{\text{Re}} = 1.61x(Re_d)^{0.5} x(Pr)^{0.33} x \left( \frac{H}{d} \right)^{-0.011} = \frac{hd}{k_{\text{air}}}
\]

The above correlations are valid in range \(2 < H/d < 10\), and \(6500 < Re_d < 23000\) with average deviation \(\pm 10\%\) and standard deviation \(\pm 12\%\). A comparison with the experimental data existing in literature indicates satisfactory agreement. A similar characteristic is found for the square and circular jets on heat transfer rate.

11. The heat transfer rate increases from 0.73W to 0.97W as the jet spacing decreases from 6 to 2 not withstanding the reduction of the surface area of the impingement region.
12. A detailed systematic uncertainty analysis is made to estimate the errors associated with experimentation. The maximum error in the present investigation is not more than ±5.92%.

13. The jet Reynolds numbers and local heat transfer coefficients are calculated from the experimental results and compared with the theoretical results for different H/d ratios.

14. The jet Reynolds number, distance between nozzle tip-to-surface of the electronic component, normalized velocity and pressure distribution have an strong influence on the heat transfer coefficient of impinging rectangular jets.

15. Effect of nozzle aspect ratio on heat transfer rates decrease as the nozzle to electronic component spacing increases. The effect of nozzle aspect ratio on heat transfer is practically independent of the jet Re.

16. The experimental results indicate that the jet Reynolds number, the nozzle-to-electronic component spacing and surface heat flux have an important influence on the heat transfer of impinging rectangular jets, mainly in the impingement region.

17. The surface heat flux from the electronic components obtained from the experiments for the case of circular nozzle for different jet Reynolds numbers and H/d ratios are presented.

18. The present experimental analysis may also be used for the case of jet Reynolds numbers up to 65000 and H/d ratio of 12.
5.2 Scope for future work

The following are some areas for future research work in the field of impingement cooling.

1. The investigations may be extended for the case of multiple jets to investigate the effect of the parameters Re, H/d and r* on stagnation Nusselt number.

2. In the present study, the effect of temperature of the electronic component is evaluated at H/d ratio up to 10. This may be extended to about 15. H/d ratio beyond 15, the effect of temperature is not expected to be significant, but has to be verified experimentally.

3. The investigation may be extended to the nozzle diameter of 2mm, 4mm, and 15mm also. The nozzles of these dimensions are also likely to be important in the future.

4. The variations of the turbulence intensity profiles with respect to the nozzle tip-to-electronic component spacing can be extended to the combination of H/d ratio of 15 and jet Reynolds number of 30000. This study may be useful in understanding the phenomenon better.

5. Typical flow visualization structures of impinging air jet for system parameters with various mesh solidities at Re= 23000 and H/d ratio of 6 may be attempted. This may be helpful in explaining the heat transfer phenomena in the system.
6. The experimental investigation may be extended to measure flow profile with hot-wire anemometry to establish the relation between turbulence intensity and mesh solidity.