MECH 489/582 EXPERIMENTAL THERMOFLUIDS – Lab #2

An Experimental Study of Heat Transfer from a Flat Heated Plate to a Circular Impinging Jet

Introduction

Jet impingement heating/cooling is used in many engineering and industrial applications such as metal processing, drying, cooling of computer electronics, tempering of glass plate, and cooling of gas turbine components. An experiment is setup here for studying the forced convection heat transfer above a heated flat plate where a single turbulent air jet impinging on the surface.

Objectives

The main objectives of this experiment are

- Familiarize students with some of the basic equipments used in fluid flow and heat transfer experiments;
- Practice data analysis and processing techniques;
- Discuss different fluid flow and heat transfer phenomena observed;
- Communicate your experimental results to others;
- Compare results with available correlations in the literature;
- Practice the uncertainty analysis;
- Develop skills in data reduction and technical report writing

Experimental Setup

Schematic illustration of the experimental setup is presented in Figure 1.

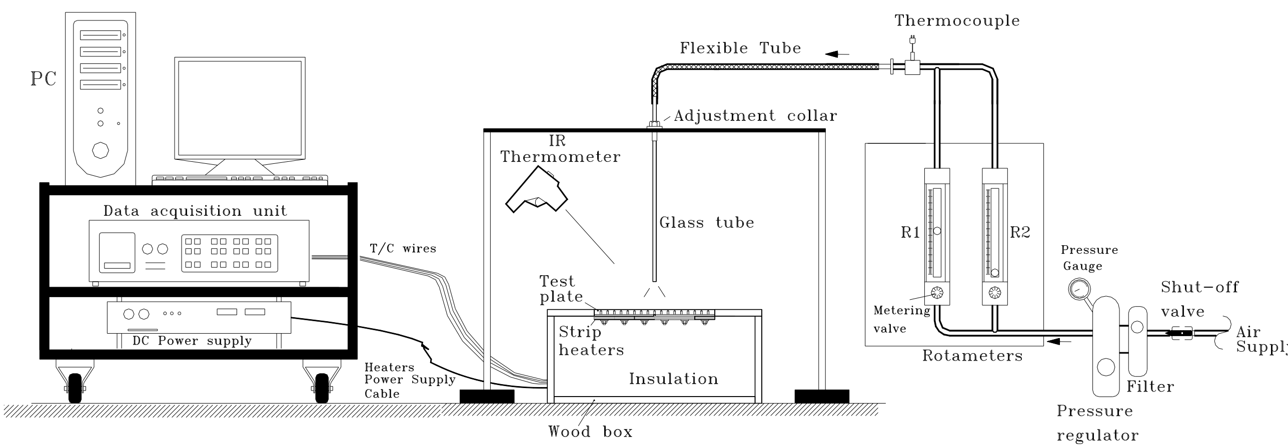

Fig. 1. Schematic of the experimental setup

The experimental setup consists of a compressed air system, a long pipe, and a heated impinging surface (test plate).

The test plate (stainless steel 303: 8.8×8.5×0.25 in) is designed to provide a known heat flux and allow measurement of the temperature at various locations. Thirty-one thermocouples are embedded in the test plate. Thermocouples are connected to a data acquisition and control system (Agilent 34970A) hooked to a PC. Six strip heaters are bounded to the back side of the test plate. The ensemble of the plate and heaters is installed in a box (made of wood) filled with thermal insulation for minimizing heat losses (see Figure 1). A DC power supply is used ensuring continuously adjustable and stable power inputs to these heaters. At steady-state condition, the local heat transfer coefficient is obtained knowing the local heat flux and the local temperature at the plate surface. The local surface heat flux is obtained knowing the total power supply to the heaters and accounting for radiation heat losses from the plate surface and heat losses through the insulation system. An infrared thermometer is used to estimate the surface emissivity. A heat flux meter installed within the plate insulation system is used for estimating the rate of heat losses from the strip heaters.

Compressed air essentially at room temperature is used as the working fluid, and its flow rate is measured using Rotameters. The air temperature is measured using an inline thermocouple. In this setup, air flows through a long (12 in) and straight glass tube (0.156 in, ID) to obtain a fully-developed turbulent circular jet.

Test plate

The thermocouple locations on the surface of the test plate are presented in Figure 2 (dimensions are in inches). The impingement jet is aligned to hit the center of the plate, where thermocouple #1 is installed.

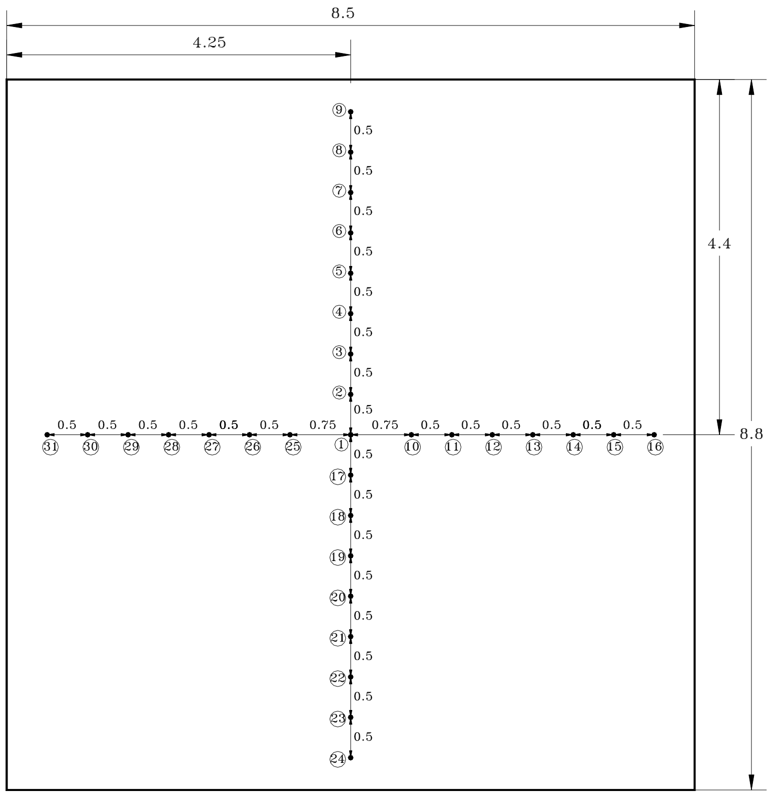

Fig.2. Thermocouple map

Expected Results

The local Nusselt numbers will be obtained for various (jet) Reynolds numbers ranging from 12,000 to about 20,000. For a given Reynolds number, the effects of the jet-exit to impingement-plate separations will be studied. The obtained results will be compared with the experimental correlations available in the literature.

Test Procedure

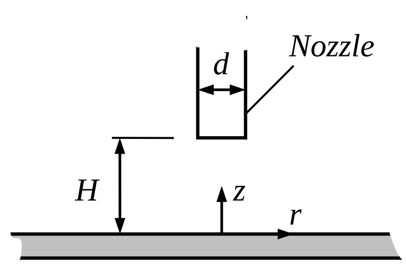

Fig.3. Circular jet

1. Become familiar with all of the equipments involved in this experiment
2. Turn on the PC, DAS, and the power supply (no power output) for warm-up of all electronics at least 15 min before doing any experiments

3. With the help of the TA start the data acquisition software (LabView program) for reading and collecting data
4. Set the plate-nozzle distance to obtain H/d = 2.5 (see Figure 3 above). Please be very careful to not break the glass tube
5. Set the power input to the plate to about 100W by adjusting the DC power supply voltage and current
6. Observe the plate temperature variation with respect to the ambient air temperature on the screen of the PC
7. Make sure the Rotameters metering valves are closed, and then open the main air flow valve. Set the pressure to 20 Psig.
8. Very gently open the metering valve of the appropriate Rotameter and set the flow to have a Reynolds number (based on the nozzle ID) of $\mathrm{Re}_d = 12,000$
9. Let the system reach the steady state conditions and record all the temperature data, the heat-flux meter data, the total power input, the airflow rate and temperature and the ambient temperature.
10. Use the IR Thermometer to estimate the plate surface emissivity
11. Repeat the measurements for $\mathrm{Re}_d = 20,000$
12. Set the plate-nozzle distance to obtain H/d = 10, and repeat the experiment for $\mathrm{Re}_d = 12,000$ and $20,000$.
13. Once all the measurements are collected, zero the power input to the plate; turn off the air flow and all other equipment before leaving the lab.

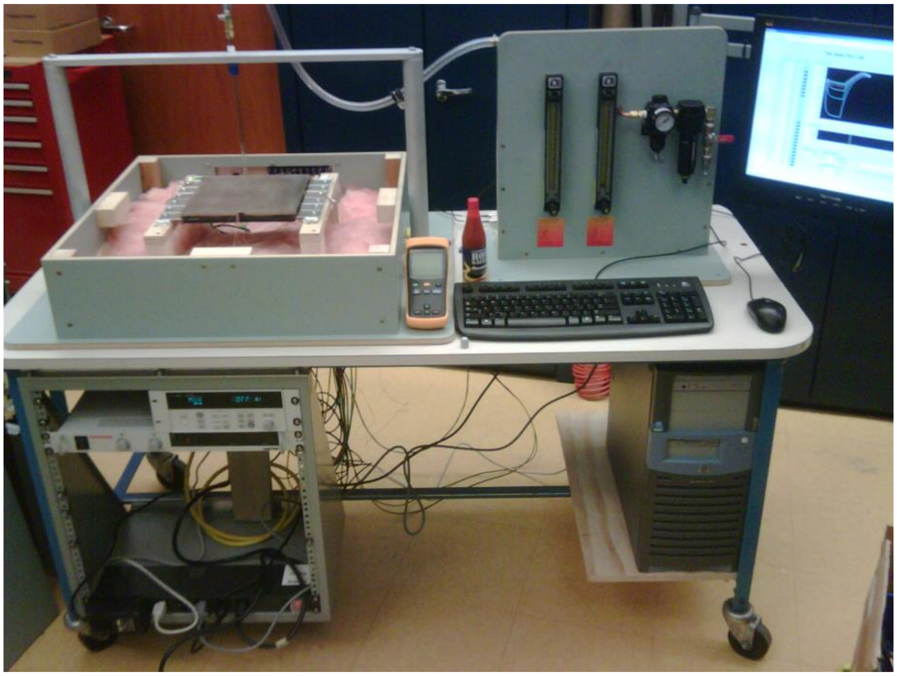

Fig.4. Photograph of the setup

Report

a. For each value of H/d and different values of Reynolds number, calculate and plot the local Nusselt number versus the r/d, wher r is the distance from the stagnation point.
b. Normalize the local Nusselt number by the stagnation Nusselt number and plot your data again
c. Discuss the effect of the variation of the Re, and H/d on the local Nusselt numbers.

d. Calculate and report the average Nusselt numbers

e. Identify the sources of errors in your experiments; estimate the uncertainties and report them as error bars in your plots

f. Compare your results for the average Nusselt number with the correlation provided by Martin (1977) that is cited in Incropera et al. (2007):

$$\left.\begin{aligned} &\frac{\overline{Nu}}{\mathrm{Pr}^{0.42}} = G\left[2\,\mathrm{Re}^{1/2}\left(1+0.005\,\mathrm{Re}^{0.55}\right)^{1/2}\right] \\ &G = 2A_r^{1/2}\frac{1-2.2A_r^{1/2}}{1+0.2\left(H/d-6\right)A_r^{1/2}}; \quad A_r = \frac{d^2}{4r^2} \end{aligned}\right\} \qquad \begin{gathered} 2{,}000 \le \mathrm{Re} \le 400{,}000 \\ 2 \le H/d \le 12 \end{gathered}$$

References

1- Incropera F.P., Dewitt D.P, Bergman T.L, Lavine A.S. (2007), Fundamentals of Heat and Mass Transfer, 6th Edition, Wiley.

2- Lee D, Greif R., Lee S.J., Lee J.H., Heat transfer from a plate to a fully developed axisymmetric impinging jet, *ASME Journal of Heat Transfer*, (117) 772-776, 1995.

3- Stevens J., Webb, B.W., Local heat transfer coefficients under an axisymmetric single-phase liquid jet, *ASME Journal of Heat Transfer*, (113) 71-78, 1991.

4- Goldstein R.J., Sobolik, K.A., Seol W.S., Effect of entrainment on the heat transfer to a heated circular air jet impinging on a flat surface, *ASME Journal of Heat Transfer*, (112) 608-611, 1990.