ENVIRONMENTAL AND MECHANICAL ENGINEERING LABORATORY
Heat Transfer –Week 2.
DETERMINATION OF HEAT TRANSFER COEFFICIENTS

General description

This experiment consists of heated plate in an air flow. Heat is supplied to the plate to maintain it at a given temperature. By measuring the power required to maintain the plate temperature the heat flux is determined. The goal is to measure the heat transfer coefficient for a range of temperatures and air flow rates, covering free convection, laminar and turbulent forced convection regimes. The Labview VI automatically controls the heater so that the temperature rapidly reaches the set point. Once the set point is reached the system is set to manual operation and the heater is maintained at a fixed power. The heat transfer coefficient and the Nusselt number are determined from the measurements of the power output and the temperature of the air and the plate.

Objectives

1. Measure the heat flux in free convection, laminar and turbulent forced convection
2. Determine the heat transfer coefficients
3. Plot Nusselt numbers (*Nu*) against Rayleigh (*Ra*) or Reynolds (*Re*) numbers

Procedures

1. Measure the heat flux in free convection, laminar and turbulent forced convection

- Set the channel flow velocity to the desired speed
- Set the Labview VI to Automatic and choose the desired set point temperature
- When the temperature is within 1-2℃ of the set point temperature switch the VI to Manual
- Using the heater power knob set the heat flux to hold the temperature steady (it does not have to be exactly the original desired temperature)
- Record the plate, air temperatures and the power to the heater
- Using the power calibration (voltage and current rms) determine the actual heat flux to the plate

*****Note: It is best to set the plate temperature beginning with the lowest temperature setting and increasing the temperature sequentially through all temperatures listed in Table 1. At each temperature setting perform measurements for all flow speeds before increasing the plate temperature to the next setting.**

Table 1: Trial temperatures and flow speeds for plate.

Exp #	1	2	3	4	5	6	7	8	9	10	11
Plate Temp (ºC)	40	50	60	70	80	60	60	60	60	80	80
Flow speed (m s^{-1})	0	0	0	0	0	0.5	1.0	1.5	2.0	1.0	2.0

2. Determine the heat transfer coefficients

Using the definitions below calculate the heat transfer coefficient h_c, the Nusselt number *Nu* and the Reynolds number *Re* of the flow.

Calculate the range of Reynolds numbers (*Re*) that can be achieved in the duct. The transition from laminar to turbulent flow takes place around $Re \approx 10^6$. Determine which flow speeds are laminar and which are turbulent.

3. Plot Nusselt numbers against Reynolds numbers and Rayleigh numbers

Plot the results both in a linear and a log-log plot for free convection, laminar and turbulent. Then compare the results with expected theory (log Nusselt/theoretical log Nusselt vs. Reynolds numbers and Rayleigh number)

Error analysis

1. Calculate any systematic errors in the measurements you take.
2. Determine random errors from repeated samples.
3. Plot all data with appropriate error bars.

Definitions

The power *P* to the heater is given by

$$P = IV, \tag{1}$$

where *P* is in watts, *V* is the voltage and *I* is the current (amps).

The Reynolds number (*Re*) is

$$\mathrm{Re} = \frac{UD}{v}, \tag{2}$$

where *U* is the flow speed, *D* is the hydraulic radius and *v* is the kinematic viscosity (momentum diffusivity) of air. Take the kinematic viscosity of air as $v \approx 19.4 \times 10^{-6}$ m^2 s^{-1}. The hydraulic radius *D* is defined as

$$D \equiv \frac{4A}{p}, \tag{3}$$

where A is the cross-sectional area of the duct and P is the length of its perimeter.

The Rayleigh number (Ra) is an important non-dimensional parameter in free convection flows given by the product of the Grashof number (Gr) and the Prandtl number (Pr).

$$Ra = GrPr = \frac{g\beta(\Delta T)L^3}{\upsilon\alpha}, \tag{4}$$

where g is the gravitational acceleration, $\beta \approx 1/T_{air} \approx 0.003\ K^{-1}$ is the coefficient of volume expansion for air, ΔT is the temperature difference between the plate and the air, L is the length of the plate and $\alpha \approx 27.6\ x10^{-6}\ m^2\ s^{-1}$ is the thermal diffusivity of air.

The heat transfer coefficient h_c is defined as

$$h_c = \frac{H}{(A_p)(\Delta T)}, \tag{5}$$

where H is the heat flux and A_p is the surface area of the plate. The units of h_c are W m^{-2} $^oC^{-1}$. The Nusselt number Nu is defined as

$$Nu = \left(\frac{h_c L}{\lambda}\right), \tag{6}$$

where $\lambda \approx 0.0279$ W m^{-1} $^oC^{-1}$ is the thermal conductivity of air and L is the length of the plate in the flow direction.