NATURAL AND FORCED CONVECTION EXPERIMENT

1. OBJECTIVE

The objective of this experiment is to compare the heat transfer characteristics of free and forced convection.

2. THEORY

Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion. Convection is classified as natural (or free) and forced convection depending on how the fluid motion is initiated. In natural convection, any fluid motion is caused by natural means such as the buoyancy effect, i.e. the rise of warmer fluid and fall the cooler fluid. Whereas in forced convection, the fluid is forced to flow over a surface or in a tube by external means such as a pump or fan.

By applying simple overall energy balance, the heat transfer rate from a heated surface can be calculated as,

$$q = \dot{m} c_p (T_{m,e} - T_{m,i})_c$$

where C_p is the specific heat of the fluid [J / kgK], T_m is the mean temperature, subscript e and i stands for exit and inlet, and m& is the mass flow rate [kg/s] which can be written as,

$$\dot{m} = \rho u_m A_c ,$$

where ρ is the density of the fluid [kg/m^3], um is the mean velocity of the fluid [m/s], and Ac is the cross-sectional area of the flow [m^2]. The average heat transfer coefficient of the system, $\bar{h}$ [W /m^2 K], can be calculated as,

$$\bar{h} = \frac{q}{A \Delta T_{lm}},$$

where q is the heat transfer rate, A is the area of the heated surface, and ΔT_{lm} is the log-mean temperature difference defined as,

$$\Delta T_{lm} = \frac{T_{m,o} - T_{m,i}}{\ln\left(\frac{T_s - T_{m,i}}{T_s - T_{m,o}}\right)},$$

where Ts is the surface temperature. The heat transfer characteristics of a system strongly depends on whether the flow is laminar or turbulent. The dimensionless quantities are Rayleigh number (Ra) (for free convection) and Reynolds number (Re) (for forced convection) that are used to determine the flow characteristics of the system. If they are smaller than a critical value, the flow is assumed to be laminar, otherwise the flow is assumed to be turbulent. The definitions of Ra and Re together with the critical values are given as follows,

$$Ra_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha}, \quad Ra_{L,cr} \approx 10^9$$

$$Re = \frac{u_m L}{\nu}, \qquad Re_{L,cr} \approx 5 \times 10^5$$

where g is the gravitational acceleration [m^2 /s], β is the volumetric thermal expansion coefficient (for an ideal gas, β =1/T), T_∞ is the ambient temperature, ν is the kinematic viscosity of the fluid [m^2 /s], α is the thermal diffusivity of the fluid [m^2 /s], and L is the characteristic length of the flow. The average heat transfer coefficient h can be calculated for a given geometry by using the correlations given in the literature. In the case of free convection from a heated vertical surface, the average value of the Nusselt number ($\overline{Nu}$), which is a dimensionless number and provides a measure of the convective heat transfer, can be determined by using the following correlation,

$$\overline{Nu}_L \equiv \frac{\bar{h}L}{k} = CRa_L^n,$$

where k is the thermal conductivity of the fluid. C and n are the correlation coefficients given as C = 0.59, n=1/4 for laminar flow and C = 0.10, n = 1/3 for turbulent flow case. 3 In the case of a forced convection from a heated surface, the average Nusselt number can be calculated as,

$$\overline{Nu}_L \equiv \frac{\bar{h}L}{k} = 0.664\, Re_L^{1/2}\, Pr^{1/3} \text{ (laminar)},$$

$$\overline{Nu}_L \equiv \frac{\bar{h}L}{k} = 0.037\, Re_L^{4/5}\, Pr^{1/3} \text{ (turbulent)},$$

where Pr is the Prandtl number (Pr = ν /α).

3. EXPERIMENTS TO BE PERFORMED

During the experiments, the power input value, the flow speed of the air inside the duct, the inlet and exit temperatures of air and the temperature of the heater surface are recorded.

Procedure

1. Turn on the power and adjust a power input value.

2. Wait until the system reaches the steady-state.

3. Record inlet and exit temperatures of the air.

4. Record the surface temperature of the heater.

5. Turn on the fan.

6. Record the speed of the air, inlet and exit temperatures of the air.

7. Record the surface temperature of the heater.

For natural convection,

	Inlet Temperature (K)	Exit Temperature (K)	Surface Temperature (K)
Plate			
Cylindrical Fins			

For forced convection,

Plate /Speed of Air (m/s)	Inlet Temperature (K)	Exit Temperature (K)	Surface Temperature (K)
5 m/s			
10 m/s			
15 m/s			
20 m/S			

Cylindrical Fins /Speed of Air (m/s)	Inlet Temperature (K)	Exit Temperature (K)	Surface Temperature (K)
5 m/s			
10 m/s			
15 m/s			
20 m/S			

Analysis For free convection:

1. Calculate the mass flow rate of the air and the heat transfer rate.

2. Calculate the efficiency (η) of the heat transfer, which is the measure of what fraction of energy input is transferred to the fluid ($\eta = q/P_{el}$).

3. Calculate the log-mean temperature difference and the average heat transfer coefficient.

4. Calculate Ra and the corresponding Nu and the average heat transfer coefficient.

5. Compare the measured heat transfer coefficient with the theoretical value.

For forced convection:

1. Calculate the mass flow rate of the air and the heat transfer rate.

2. Calculate the efficiency ($\eta = q/P_{el}$).

3. Calculate the log-mean temperature difference and the average heat transfer coefficient

4. Calculate Re and the corresponding Nu and the average heat transfer coefficient.

5. Compare the measured heat transfer coefficient with the theoretical value.

Report Questions

• Compare the heat transfer coefficients for free and forced convection. Comment on the results.

• Compare the efficiency values for free and forced convection. Are they different? Is it expected?

• Are the flows for free and forced convection laminar or turbulent? What would be the case if otherwise?

• Compare your results with the theoretical results available in the literature. Comment on the discrepancy between the results if any.

REPORT

In your laboratory reports must have the followings;

a) Cover

b) A short introduction

c) All the necessary calculations and answers of the questions which is mentioned above

d) Discussion of your results and a conclusion.