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ESE – 40... ENERGY SYSTEMS LABORATORY -...
Natural and Forced Heat Convection Experiment
Experiment Report

Student No :
Name-Surname :
Experiment Date : 01.06.2023
Grade :

2.3 Natural and Forced Heat Convection Experiment

2.3.1 Objective

The objective of this experiment is to compare the heat transfer characteristics of free and forced convection so can the students who participate in the experiment can experience the convection from the first hand.

2.3.2 Introduction

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.

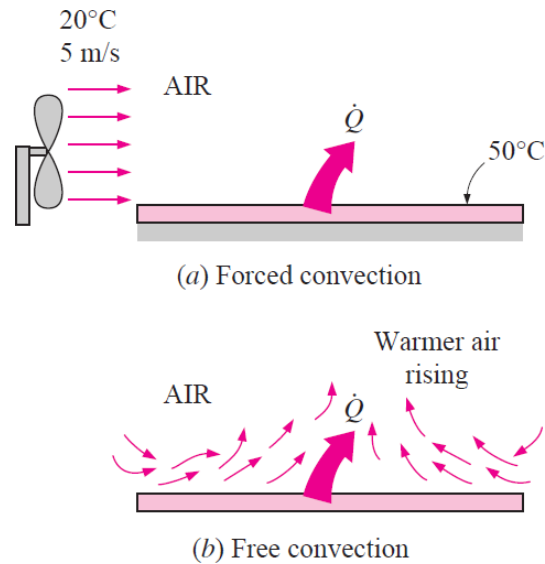


Figure 2.8.1. Heat transfer from a hot surface to the surrounding fluid by convection.

2.3.3 Theory

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

$$q = \dot{m} c_p (T_{m,e} - T_{m,i}) \quad (2.8.1)$$

where c_p is the specific heat of the fluid [J/kg·K], T_m is the mean temperature, subscript e and i stands for exit and inlet, and $\dot{m}$ is the mass flow rate [kg/s] which can be written as,

$$\dot{m} = \rho u_m A_c \quad (2.8.2)$$

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

$$\bar{h} = \frac{q}{A \Delta T_{lm}} \quad (2.8.3)$$

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,

$$\Delta T_{lm} = \frac{\Delta T_{m,i} - \Delta T_{m,e}}{\ln(\Delta T_{m,i}/\Delta T_{m,e})} = \frac{T_{m,o} - T_{m,i}}{\ln\left(\frac{T_s - T_{m,i}}{T_s - T_{m,o}}\right)} \quad (2.8.4)$$

where T_s 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;

$$Ra_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha} \quad \begin{array}{ll} Ra_L < 10^9 & \text{laminar} \\ Ra_L > 10^9 & \text{turbulent} \end{array} \quad (2.8.5)$$

$$Re = \frac{u_m L}{\nu} \quad \begin{array}{ll} Re_L < 5 \times 10^5 & \text{laminar} \\ Re_L > 5 \times 10^5 & \text{turbulent} \end{array} \quad (2.8.6)$$

where g is the gravitational acceleration [m^2/s], β is the volumetric thermal expansion coefficient (for an ideal gas, $\beta = 1/T$), 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 $\bar{h}$ 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,

$$\overline{Nu}_L = \frac{\bar{h}L}{k} = C Ra_L^n \quad (2.8.7)$$

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.

In the case of a forced convection from a heated surface, the average Nusselt number can be calculated as,

$$\overline{Nu}_L = \frac{\bar{h}L}{k} = 0.664 Re_L^{0.5} Pr^{1/3} \quad (\text{laminar}) \quad (2.8.8)$$

$$\overline{Nu}_L = \frac{\bar{h}L}{k} = 0.037 Re_L^{0.8} Pr^{1/3} \quad (\text{turbulent}) \quad (2.8.9)$$

where Pr is the Prandtl number ($Pr = \nu/\alpha$)

2.3.4 Experiments

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.



Figure 2.8.2. Convection experiment unit

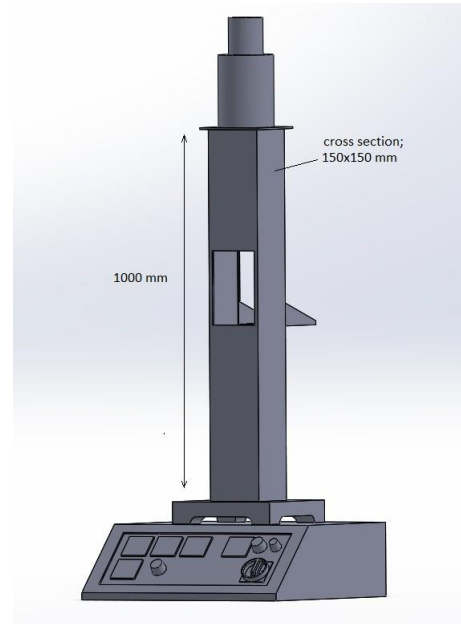


Figure 2.8.3. Schematics of the experimental unit

Table 2.8.1. Natural convection data

	Inlet temperature (°C)	Exit temperature (°C)	Surface temperature (°C)
Flat plate	22,8	23,1	79,7
Cylindrical fins	23	26,1	52,5

2.3.5. Report

The following should be in your laboratory report;

- Cover,
- All the necessary calculations and answers to the questions which is mentioned above.