Natural Convection Heat Transfer
ME 4313

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ABSTRACT

Free (or natural) convection fluid motion is a mechanism, or type of heat transform in which the fluid motion is not generated by an external source (such as forced convection) but rather by the forces of buoyancy due to density differences caused by a temperature gradient. A lower surface cold plate will be examined and evaluated inside a hot quiescent tub, the experiment will reveal the fluid motion of a food colored ice cube placed inside of it.

NOMENCLATURE

We know hot particles are less dense than a colder particle, thus colder particles will sink to the bottom of the environment. Due to the fluid motion, a boundary layer is formed and may contain a zone in which turbulent flow exists. It is important to investigate this phenomenon with the right tools. Similar to other forms of convection, a Prandtl number, and a new term similar to the Reynolds number is introduced, the Grashof number. The combination of these two formulas yields the Rayleigh number, which is simply the product of the Grashof and Prandtl numbers. This special number will define if there exists turbulence in our velocity profile. Finally able to obtain the heat transfer coefficient via the Nusselt number; the ratio of convective to conductive heat transfer across (normal to) the boundary layer. The Nusselt number applied is of special correlation for a lower surface cold plate.

$$q'' = h(T_{hot} - T_{cold}) \quad (9.3)$$

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p \quad (9.4)$$

$$Gr_L \equiv \frac{g\beta(T_s - T_\infty)L^3}{\nu^2} \quad (9.12)$$

$$Ra_{x,c} = Gr_{x,c}Pr = \frac{g\beta(T_s - T_\infty)x^3}{\nu\alpha} \approx 10^9 \quad (9.23)$$

$$\overline{Nu}_L = 0.54\,Ra_L^{1/4} \quad (10^4 \lesssim Ra_L \lesssim 10^7, Pr \gtrsim 0.7) \quad (9.30)$$

$$\overline{Nu}_L = 0.15\,Ra_L^{1/3} \quad (10^7 \lesssim Ra_L \lesssim 10^{11}, \text{all } Pr) \quad (9.31)$$

$$\overline{Nu}_L = \frac{\bar{h}L}{k} = C\,Ra_L^n \quad (9.24)$$

β	-	Thermal Expansion Coeff.
Gr	-	Grashof Number
Ra	-	Rayleigh Number
Nul .30	-	Nusselt Number (Laminar)
Nul .31	-	Nusselt Number (Turbulent)
h	-	Heat Transfer Coefficient

INTRODUCTION

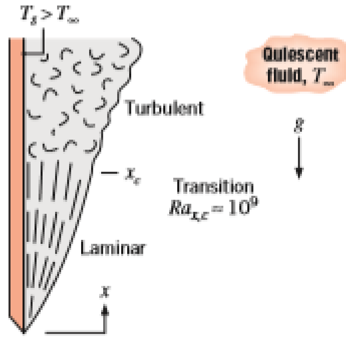
Natural (free) convection can be seen almost anywhere. This natural convection behavior is similar to external flow over a flat plate, meaning a boundary layer develops due to the fluid motion. However, in natural convection the forces partaking in

the motion are due to gravity and buoyant forces. The temperature gradient in the fluids sink or floats depending on the density it carries.
Acquiring a small cold object and placing it a warm or hot medium. Once mixed, the observer should be able to notice a convective reaction take place

The principle in this experiment is to observe this phenomenon take place. First, by determining the overall heat transfer coefficient (“h”) at the surface. From there the Nusselt number is determined. Finally by determining the heat flux by natural convection.

THEORY

Heat transfer theory seeks to predict the energy transfer that takes place between material bodies as a result of temperature differences. The three modes are through conduction, convection and radiation. Natural convection is a branch of convection with its own properties and behavioral characteristics. Convection involves the transfer of heat by motion and mixing of a fluid. Convection is called free or natural convection when the motion and mixing of fluids is done by density variation depending on buoyancy forces, resulting from temperature differences within the fluid. The density of a fluid near a cold surface is more than that of the hotter fluid away from the cooled surface and gravity creates a buoyant force, which drops the cooler surface to the bottom.



(Figure 1: Vertical Plate Natural Convection)

INSTRUMENTATION

The components utilized in the experiment are minimal. All that is required to run the experiment is a large plastic (clear) container, ice cube tray and food-coloring dye.

The instrument used to measure temperature is a thermometer.

(Figure 2: Thermometer)

PROCEDURE

The procedure of this experiment is as follows:

First, fill up the ice cube tray with water and mix in the food-coloring dye; let it sit until frozen solid (approx. 4 hours).

(Figure 3: Ice Cube Tray)

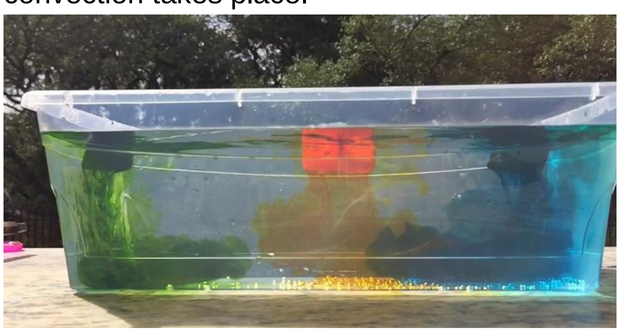
Once the mixture is frozen fill up the large clear plastic container with hot sink water.

(Figure 4: Plastic Container)

Once full, take out the ice cube tray. Take temperature reading of the tub (approx. 38°C or 311K) and the ice (approx. -8°C or 265K) using the thermometer.

We will consider the ice cubes as the lower surface cold plate with constant surface temperature Ts where, Ts < T∞ (quiescent water in tub).

Once all this is in order, gently start accommodating the colored ice cubes inside the hot tub. Observe as natural convection takes place.



(Figure 5: Natural Convection)

RESULTS

By first finding a film temperature ((Ts + T∞)/2 + 273 K) We can obtain the right properties between our surface and quiescent fluid. Since Tf = 288K we must interpolate table A.6 to get corrected property values.

(Table A.6 – Sat. Water properties)

TABLE A.6 Thermophysical Properties of Saturated Water[a]

Temperature, T (K)	Pressure, p (bars)[b]	Specific Volume (m³/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m²) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K⁻¹)	Temperature, T (K)
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05	273.15
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74	275
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04	280
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1	285
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0	290

Once finding these properties, we find our Rayleigh number.

(Table 1 – Properties)

Ts	T∞				
. - 8 C	38 C				
Tf	B	mu	v	L	g
288K	1.50E-04	1.14E-03	1.14E-06	0.05m	9.81E+00

(Table 2 – Rayleigh Number)

Gr	6498.25	< Cr - E9

The critical Rayleigh number is 1X10^9. The value we get is 6498.25 far less than the critical, thus we only have laminar flow.

With the Laminar flow correlation (equation 9.30) we may find a Nusselt number to fit our data, thus finding the heat transfer coefficient ("h").

(Table 3 – Nu & h)

Nu	4.84	
h	57.67	W/m2K

Finally, giving us a heat flux of:

(Table 4 – Heat Flux)

q"	2653.08	W/m2

DISCUSSION

Based on the results, we know that the natural convection at the given temperature gradients results in laminar flow. Thus, resulting in a low Rayleigh number, Nusselt number and heat transfer coefficient.

Once we gathered the heat flux from the information we can obtain other results such as the heat transfer per unit length or the convective heat flow.

Knowing this information, we may also manipulate the temperatures around to gain different results.

Other changes to experiment could've been done such as changing the fluid type, switching the cold surface to a hot surface and seen how the fluid reacts etc.

CONCLUSIONS

In conclusion, Natural convection is a type of heat transfer, which pertains to fluid motion due to density differences caused by temperature gradients.

The Grashof number and Prandtl number yields the Rayleigh number, which dictates if turbulent flow exists within the fluid medium.

The Nusselt number is found through empirical data using a special correlation thus resulting in finding the heat transfer coefficient, which from there heat flux or flow can be found.

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