CHEG 3143	**Free Convection Heat Transfer from an Upward Facing**	**CHEG 3232**
Heat Transport	**Vertical Plate- Comparison of Experimental**	**Chem. Eng. Lab II**
Fall 2004	**By Crystal Hall and Noor El-Qatto**	**Fall 2004**
Professor Penny	**December 1st, 2004**	**Professor Clausen**

INTRODUCTION AND OBJECTIVE:

The objectives of these experiments were;

1. Determination of experimental heat transfer coefficient for cooling vertical plates.

2. Comparison of the experimental coefficients with coefficients predicted from literature correlations.

The experimental coefficients will be determined by heating a plate, orienting it vertically and allowing it to cool in room air.

EQUIPMENT LIST:

1. Aluminum plate.
Dimensions are 18 inches height, 12 inches width and 1.5 inches thickness. The plate surfaces are highly oxidized hence, the outside surface will be considered Al_2O_3 for calculation purposes.

2. Plate Stand:
Composed of 2 two-by-fours that are two feet in height. There are bolts extending through the two-by-fours that can be screwed in or out to support the plate.

3. Hairdryer:
Has 2 temperature settings (Hartman Pro-Tech model 1600, 1600 W)

4. Stopwatch:
Digital hand held stopwatch calibrated in 0.01 s.

5. Thermocouple:
1/8 in OD X 12 in Long type K thermocouple.

6. Styrofoam insulation:
½ in thick X 1 ½ in wide Styrofoam strips used to insulate the top and sides of the plate.

7. Heating box:
Dimensions are 25.25x22x16 inches (outside lengths)
22.5x20x12.625 inches (inside lengths)

EXPERIMENT SCHEMATIC & EXPERIMENT PHOTOGRAPH:

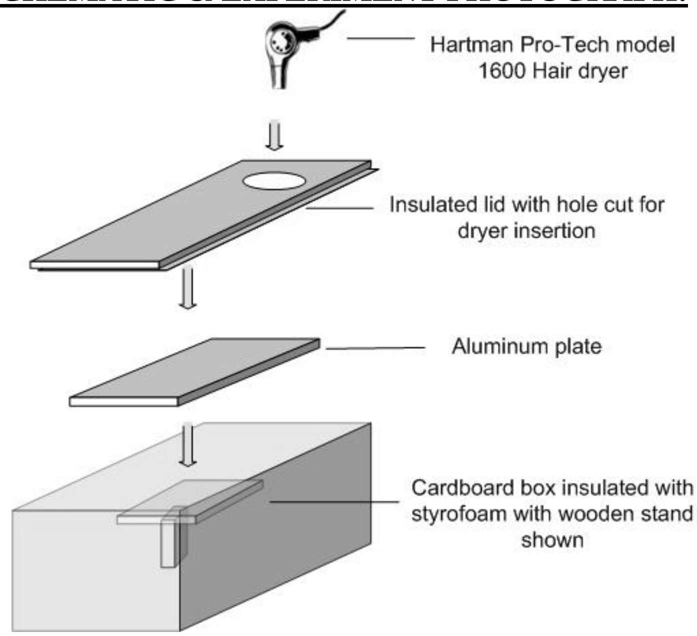

FIGURE 1.1. Schematic of Heating Box

.Figure 2. Photo of the heating box along with the hair dryer.

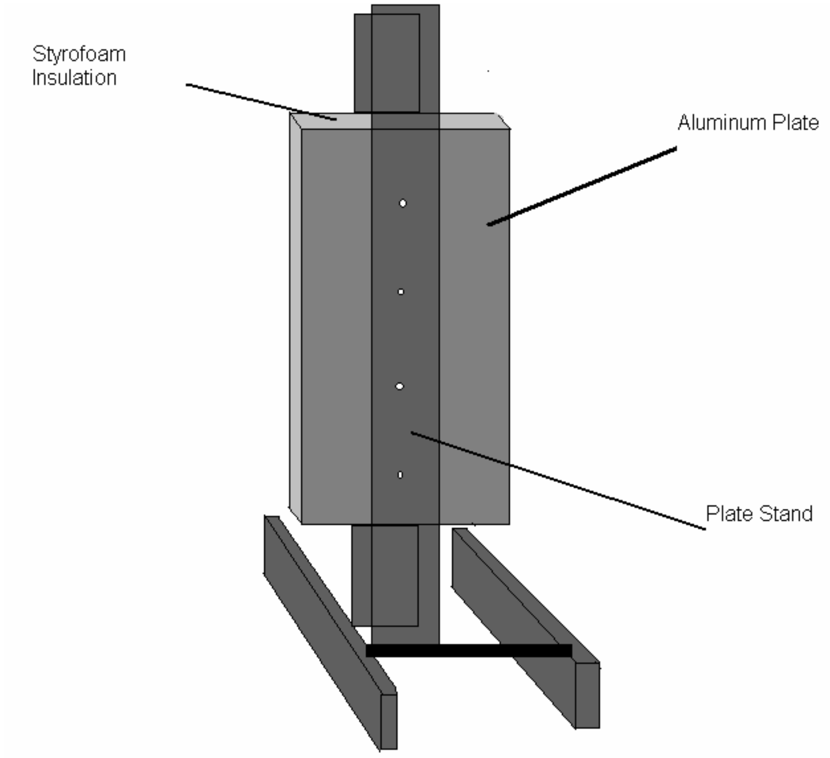

Figure 3.. Schematic of the Experimental Apparatus

Figure 4. Photo of Experimental Apparatus, Top View

Figure 5. Photo of Experimental Apparatus, Side View

DESCRIPTION OF EQUIPMENT

1. **Hartman Pro-Tech Model 1600 hair dryer**
   The aluminum plate was heated by inserting the nozzle of the dryer into the circular opening of the top of the heating box lid.
2. **Styrofoam insulation**
   The inside of the heated box was insulated with 1 3/16" thick Styrofoam insulation; the purpose of this insulation was reduce the amount of heat loss to the surroundings so that the plate would heat quickly.
3. **Insulated Heating Box (Figure 3)**
   The heating box, composed of an insulated cardboard box with an insulated wooden top, was used as an enclosure for heating the aluminum plate by means of the hairdryer. A wooden stand was located inside the heating apparatus and was used to hold the plate above the insulated bottom of the box to obtain maximum and thorough heating.

4. **Aluminum plate (Figure 4)**
   This 18” x 12” x 1.5” aluminum plate weighed approximately 14.35 kg. It has a heavily oxidized mill finish. A 5/32” diameter by 4” deep hole is drilled into the 1.5”x12” face of the plate for insertion of a 1/8” diameter sheathed thermocouple.
5. **Omega HH12 thermocouple reader**
   This digital device reads temperatures indicated by the thermocouple.
6. **Sheathed thermocouples**
   The type K thermocouple is 1/8” in diameter and 12” long.
7. **Stopwatch**
   A standard stopwatch was used to record the time for every temperature change in increments of 1 degree Fahrenheit.
8. **Plate Stand**
   A wooden apparatus was used to maintain the plate’s vertical position. This plate stand was comprised of two yellow pine 2x4’s and bolts that were adjusted to hold the plate in position.

EXPERIMENTAL PROCEDURES

1. Measure the mass of the plate.
2. Obtain the necessary dimensions of the plate so that the total vertical surface area can later be calculated.
3. Record the room temperature.
4. Obtain the emissivity of the aluminum plate either from literature values. There literature value was 0.25.
5. Heat the plate using the heating box.
   a. Place the aluminum plate inside the heating box, atop of the wooden stand.
   b. Place a thermocouple inside the heating box to monitor the temperature.
   c. Seal the heating box by putting on the insulated top.
   d. Insert the nozzle of the hair dryer in the hole in the insulated top and start to heat the aluminum plate to the desired temperature.
   e. Heat the aluminum plate to a temperature of approximately 125 F.
   f. Once the desired temperature is obtained, turn off the dryer, and remove the insulated lid.
6. Using insulated gloves, remove the aluminum plate from the heating box and place it vertically in the plate stand.
7. Secure the plate in place by tightening the bolts on either side of the plate stand.
8. Insert the thermocouple into the plate to monitor the plate’s temperature.
9. Shut the door to the room to minimize air circulation in the room as much as possible to decrease the effects of forced convection on the cooling of the plate.

10. Using a stopwatch, record the time increment for each degree (Fahrenheit) drop in plate temperature. Begin timing once the initial heated temperature drops one degree Fahrenheit as the plate begins to cool by convection and radiation.

SAFETY CONCERNS:

1. Wear safety glasses at all times
2. Wear gloves when handling equipment
3. Watch hairdryer to make sure insulation does not char or burn
4. Handle the heavy plate with caution to avoid injury.
5. Make sure plates are securely fastened with bolts

DATA REDUCTION PROCEDURES:

1. Do a heat balance on the plate:

$$-q_{out} = q_{accum}$$

2. Define each term in the overall heat balance equation:

$$-q_{out}= q_{conv} + q_{rad}$$

$$-q_{out}= [(h_{exp}*A_s*(T_s - T_{sur})) + (\varepsilon*\sigma*A_s(T_s^4 - T_{sur}^4))]$$

$$q_{accum}= m*Cp* dT/dt$$

3. Calculate the surface area of the aluminum plate:

$$A_s= L*W$$

4. Calculate the volume of the aluminum plate:

$$V= L*W*T$$

5. Calculate the mass of the aluminum plate:

$$m= V*\rho$$

6. Construct a plot of temperature versus time for the experimental data.

7. Determine dT/dt, which is the slope of the plot.

$$dT/dT = (T_2-T_1)/(temp_2-temp_1)$$

8. Calculate the film temperature:

T_{film}= (T_s-T_{sur})/2

9. Calculate the experimental heat transfer coefficient at the specified time:

$$m*Cp*dT/dt = [(h_{exp}*A_s*(T_s - T_{sur})) + (\varepsilon*\sigma*A_s(T_s^4 - T_{sur}^4))]$$

$$(m*Cp*dT/dt)- (\varepsilon*\sigma*A_s(T_s^4 - T_{sur}^4))= h_{exp}*A_s*(T_s - T_{sur})$$

$$h_{exp}= [(m*Cp*dT/dt)- (\varepsilon*\sigma*A_s(T_s^4 - T_{sur}^4))] / (A_s*(T_s - T_{sur}))$$

10. Calculate the volume expansion coefficient:

$$B= 1/T_s$$

11. Calculate the Rayleigh number:

$$Ra= [g*B (T_s - T_{sur}) L^3/v^2] Pr$$

12. Calculate the correlational Nusselt number for a vertical plate: Eqn. 9-21 by Churchill and Chu p. 468, Cengel, 2nd edition.

$$Nu= [0.825 + (0.387*Ra^{1/6})/(1+(.0492/Pr)^{9/16})^{8/27}]^{2}$$

13. Calculate the correlational heat transfer coefficient:

$$Nu= (h_{calc}*L)/ k$$

$$h_{calc}= (Nu*k)/L$$

14. Calculate the percent difference between h_{calc} and h_{exp}:

$$\% Diff = (h_{exp} - h_{calc})/ h_{exp} * 100$$

<u>NOMENCLATURE:</u>

A_s	heat transfer surface area	m^2
B	volume expansion coefficient	1/K
Cp	specific heat capacity of aluminum	J/kg*K
dT	incremental change in temperature	K
dt	incremental change in time	s
ε	emissivity of aluminum plate	dimensionless
g	gravitational constant	m/s^2
h_{calc}	calculated heat transfer coefficient (correlations)	W/m^2*K
h_{exp}	experimental heat transfer coefficient	W/m^2*K
k	thermal conductivity constant (aluminum)	W/m*K

L	length of aluminum plate	m
m	mass of aluminum plate	kg
Nu	Nusselt number for a vertical plate	dimensionless
Pr	Prandtl number	dimensionless
q_{accum}	heat accumulated by the system	W
q_{conv}	convection heat transfer rate	W
q_{out}	heat transfer rate out of the system	W
q_{rad}	radiation heat transfer rate	W
Ra	Rayleigh number	dimensionless
σ	Stefan-Boltzmann constant	W/m^2K^4
ρ	density of aluminum	kg/m^3
T	plate thickness	m
T_{film}	film temperature	K
T_s	surface temperature of aluminum plate	K
T_{sur}	ambient air temperature	K
V	volume of plate	m^3
ν	kinematic viscosity of aluminum	m^2/s
W	width of plate	m

COMPARISON OF EXPERIMENTAL RESULTS WITH CORRELATIONAL CALCULATIONS:

The experimental data of plate temperature versus time are tabulated below.

Time, s	Temperature, K
0	324.3
159	323.7
305	323.2
486	322.6
687	322.04
904	321.5
1108	320.9
1334	320.4
1573	319.8
1815	319.3

These experimental data are plotted and curve fitted on the plot from Excel below.

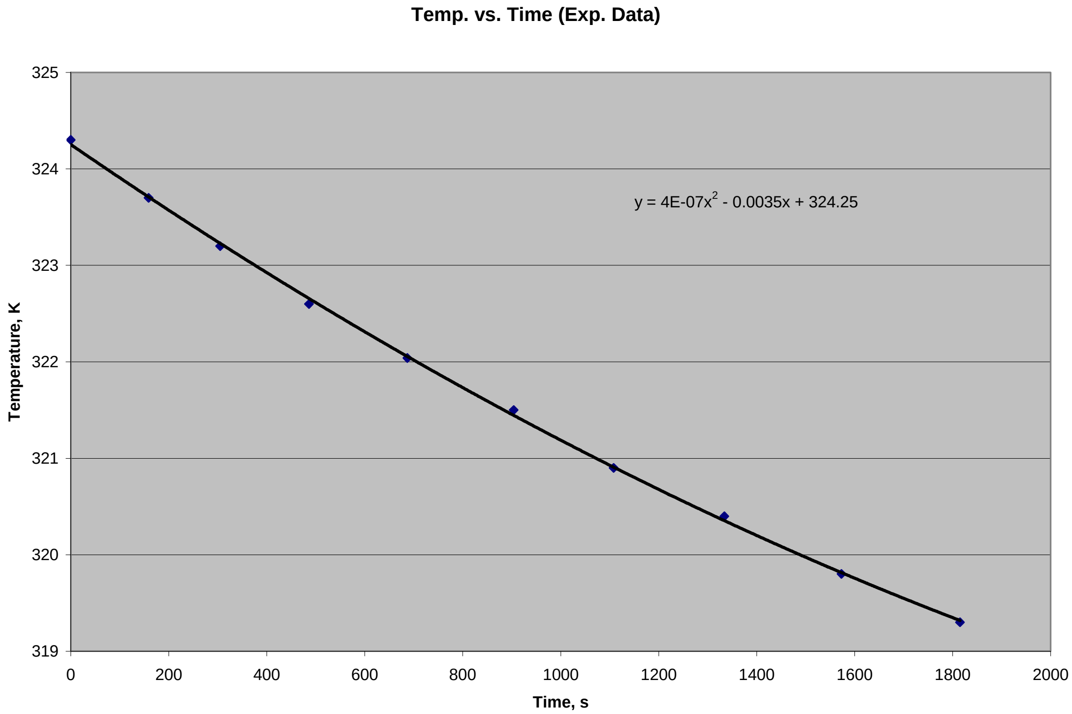

Figure 6. Experimental plot of Temperature vs. time

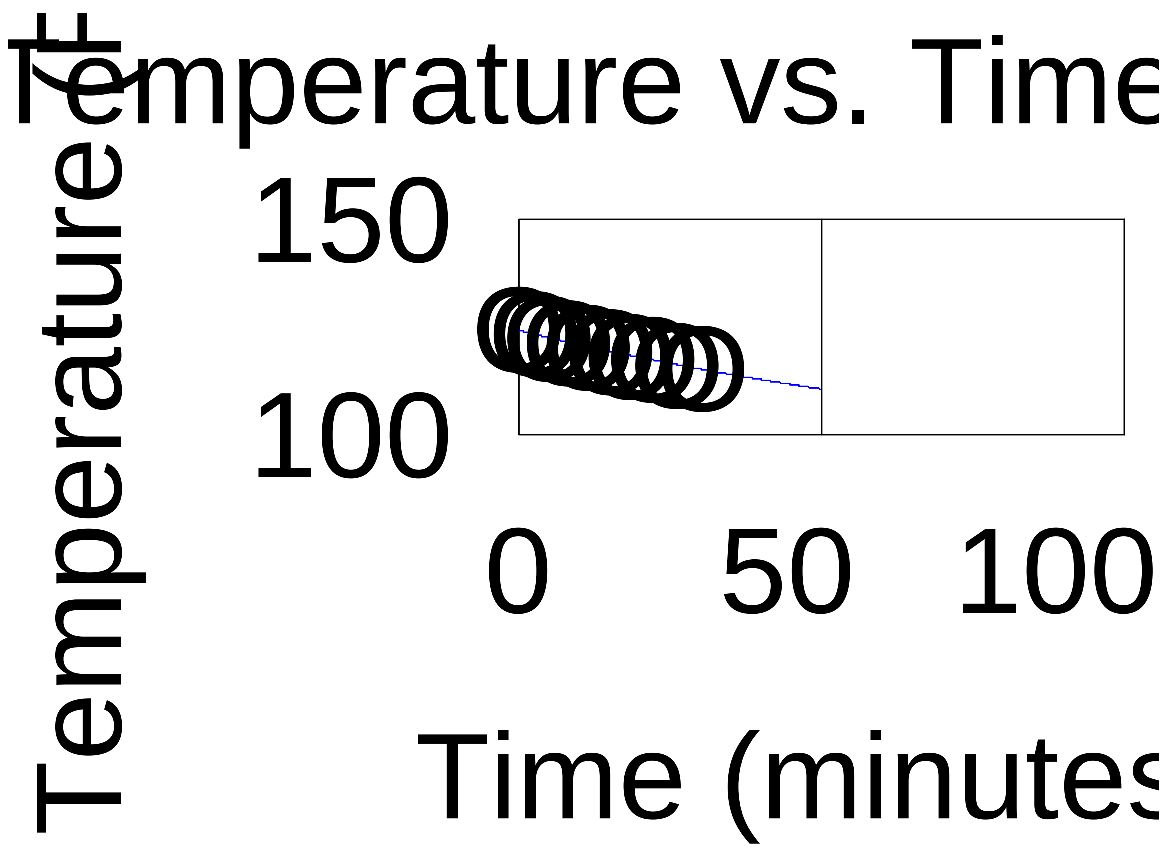

Figure 7. Temperature vs. time predicted (by an euler integration TK Program, solid line) and experimental (O).

The transient simulation from the TK program presented in Figure 7 uses a heat transfer coefficient which is 1.7 times the value calculated from the Churchill/Chu correlation. Thus the forced convection in the room increases the free convection coefficient.

CONCLUSIONS:

1. The effect of forced convection increases the free convection coefficient by a factor of 1.7 relative to the calculated free convection coefficient.
2. With this correction the transient temperature distribution of the plate is predicted very well by the Euler integration.

RECOMMENDATIONS:

1. Conduct experiment in a room without any forced convection
2. Use a better fitting thermocouple
3. Run the experiment for a longer duration of time.
4. Try to reach steady state temperature as close as possible.
5. Repeat the experiment to reduce the experimental error.

EXPERIMENTAL DATA:

Table 1. Table of experimental data

Time, s	Time, minutes	Temperature, K	Temperature, F
0	0	324.3	124.34
159	2.65	323.7	123.26
305	5.083333	323.2	122.36
486	8.1	322.6	121.28
687	11.45	322.04	120.272
904	15.06667	321.5	119.3
1108	18.46667	320.9	118.22
1334	22.23333	320.4	117.32
1573	26.21667	319.8	116.24
1815	30.25	319.3	115.34

TK SOLVER PROGRAMS:

Rule Sheet

Status	Rule
Comment	; Free Convection & Radiation for a Vertical Plate
* Unsatisfied	CALL EulerIntegration(;A,V)

Variable Sheet

Sta	Input	Name	Output	Unit	Comment
	.139385	A			Surface Area of one side of Plate, m^2
	.0053	V			Volume of Plate, m^3

Function Sheet

St	Statement
	;THIS PROGRAM CALCULATES THE TEMPERAURES WHEN SOLVING
	;VERTICAL NATURAL CONVECTION OF A PLATE USING A NUMERICAL ANALYSIS.
	Pr:=0.726 ;Pradtl number
	ó:=5.67e-8;Stefan-Boltzmann constant (W/m^2.K^4)
	L:=0.457;(m)
	A:=0.457*0.305 ;(area of the plate on one side, m^2)
	Ta:=302.59 ;Ambient Temperature (Kelvin)
	ñ:=2702 ;density of oxidized Aluminum (Kg/m^3)
	Cp:=875 ;specific heat capacity of oxidized Aluminum (J/kg.K)
	å:=0.5 ;emmissivity
	dt:=10 ;time increment (seconds)
	kAir:=0.0263;thermal conductivity of air (W/m.K)
	g:=9.81 ; m/s^2(acceleration due to gravity)
	v:=1.61E-5 ;Kinematic viscosity (m^2/s)
	V:=0.0053 ;volume of the plate (m^3)
	'Ts[1]=324.555
	'h[1]=4.08
	For i=1 to 300
	;Coding for the plates surface
	'Time[1]:=0 ;initial time (s)
	'Tfilm[i]:=('Ts[i] +Ta)/2 ;Temperature of the Film on the plates surface (K)
	'â[i]:=1/'Tfilm[i] ;Volume expansion coefficient at any film Temperature (K^-1)
	'Ra[i]:=g*'â[i]*('Ts[i] -Ta)*(L^3)*Pr/(v^2) ;Rayleigh number at any film temperature (Dimensionless)
	'Nu[i]:=1.7*(0.825 + (0.387*'Ra[i]^(1/6))/((1+((0.498/Pr)^(9/16))^(9/27))))^2 ;Nusselt number for a vertical plate;
	'h[i+1]:='Nu[i]*kAir/L ;heat transfer Coefficient at each nusselt number (W/m^2.K)
	'qconv[i]:='h[i]*2*A*('Ts[i] -Ta) ;heat due to convection (W)
	'qrad[i]:=2*A*å*ó*('Ts[i]^4 -Ta^4) ;Heat transfer due to radiation (W)
	'qout[i] :='qconv[i] + 'qrad[i] ;total heat out (w)
	'dTdt[i] :=- 'qout[i]/(ñ*Cp*V) ;Temperature increment with respect to time (K/s)
	'TsF[i]:=('Ts[i]*1.8-460) ;Conversion of Temperature from C to F (F);
	'Ts[i+1]:='Ts[i]+'dTdt[i]*dt ;Temperature at the next time interval(K)
	'time_minutes[i]:='Time[i]/60
	'Time[i+1] := 'Time[i] +dt ; Next Element of time has a dt time increment (s)
	NEXT i

St	Statement
	;THIS PROGRAM CALCULATES THE TEMPERAURES WHEN SOLVING
	;VERTICAL NATURAL CONVECTION OF A PLATE USING A NUMERICAL ANALYSIS.
	Pr:=0.726 ;Pradtl number
	ó:=5.67e-8;Stefan-Boltzmann constant (W/m^2.K^4)
	L:=0.457;(m)
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	'dTdt[i] :=- 'qout[i]/(ñ*Cp*V) ;Temperature increment with respect to time (K/s)
	'TsF[i]:=('Ts[i]*1.8-460) ;Conversion of Temperature from C to F (F);
	'Ts[i+1]:='Ts[i]+'dTdt[i]*dt ;Temperature at the next time interval(K)
	'time_minutes[i]:='Time[i]/60
	'Time[i+1] := 'Time[i] +dt ; Next Element of time has a dt time increment (s)
	NEXT i

Table 7. TK Solver Variable Sheet for Numerical analysis

REFERENCES:

1. Cengel, Yunus A. “Heat Transfer: A Practical Approach”, McGraw-Hill, New York, 2003