College of Engineering - Muzahimiyah Branch

AME 2710 - ENGINEERING THERMODYNAMICS

STUDENTS' LABORATORY EXPERIMENTAL MANUAL

Sept 2016

Measurement of Thermal Conductivity Experiment

Measurement of Thermal Conductivity

a. Objective

The objectives of this experiment are:
1. To evaluate the thermal conductivity of copper experimentally.
2. To use the conductivity value to determine the conduction through constant and variable area copper bars.

b. Introduction

When a temperature gradient exists in a stationary medium, which may be a solid or a fluid, we use the term conduction to refer to the heat transfer that will occur across the medium. The physical mechanism of conduction involves concepts of atomic and molecular activity, which sustains the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles. Consider a gas occupying the space between two surfaces maintained at different temperatures and assume that there is no bulk motion. We associate the temperature at any point with the energy of the gas molecule. This energy is related to the random translational motion, as well as to the internal rotational and vibration motions of the molecules.
Higher temperatures are associated with higher molecular energies, and when neighboring molecules collide, as they are constantly doing, a transfer of energy from the more energetic to the less energetic molecules must occur. In the presence of a temperature gradient, energy transfer by conduction must then occur in the direction of decreasing temperature. We may speak of the net transfer of energy by this molecular motion as a diffusion of energy. The situation is much the same in liquids, although the molecules are more closely spaced and the molecular interactions are stronger and more frequent. In a solid, conduction is attributed to atomic activity in the form of lattice vibrations and electron migration. We treat the conduction phenomena by Fourier's law, which is defined in terms of an important material property, defined as thermal conductivity.
It is important to emphasize that he origin of Fourier's law is phenomenological. That is, it is developed from observed phenomena - the generalization of extensive experimental evidence rather than being derived from first principles. Mathematically, it is defined as

$$q = kA\,(\Delta T / \Delta x)$$

The objectives of this experiment are achieved through the use of Thermal Conduction System. The system consists of two hot plate type heat sources copper bars and 10 thermocouple junctions on each bar. Unit 3 has a tapered bar and Unit 4 has a cylindrical bar as indicated in the figure.
It should be noted that these units provide vertical heat flux paths. Referring to figure, the one at the left is a cylindrical bar while the one at the right is a tapered bar. Each bar is in contact at its lower end with its own hot plate. Contact for the tapered bar is at the smaller end. The maximum electrical input through the plate is 750 Watts. The surface temperature can be modulated between 5 oF above the room temperature to 400 oF. A metal plate attached to the actual heater plate functions as a heat source, concentrating the heat flux concentrically into the test bar. Both bars are of the same diameter at the upper end and in contact with a non-immersion type fluid-cooled heat sink. Instrumentation and control of coolant flow through these heat sinks is provided to monitor and control the heat flow rates through the bars.

c. Equipment

d.Pre-Lab

List some metals in the order of their thermal conductivity

What are the methods available for temperature measurement?

What is Fourier's Law of heat conduction?

e. Operating Instructions and Procedure

It is important to recognize that in the tapered bar, the heat flux is not constant along it. In fact, it is the heat transfer rate that remains constant, while the flux increases with the decrease of cross-sectional area. The temperature distribution through the bar can be

calculated 6by using Equation 8.1 in the limiting condition; i.e.,
when $\Delta x \rightarrow 0$.

The following experimental procedure should be followed while conducting this experiment:
• Establish constant and steady cooling water flow of about 400 mL/min
• Turn on heaters to Units 3 and 4 - set each one to 500 W. Allow the system to reach steady-state conditions.
• Start recording temperatures using the chrome alumel thermocouple and the milli-voltmetre. The milli-voltmeter reading is converted to temperature units using the table supplied to you.
• Measure cooling water flow rates using the flow rate-measuring device provided by your instructor.
• Record data under steady conditions. You may have to wait for about an hour after setting up the apparatus to allow the unit to reach the desired state conditions.

Data Analysis

Notice that ten thermocouples, located at the centre of each bar and positioned along it, enable the student to measure temperature under both dynamic and stable conditions.
The electrical input is determined by measuring (with laboratory meters) voltage and current.
The heat flux through the bar as well as the heat loss through the insulation should be calculated.

In your report, you are required to present the following:
(1) On a single graph plot the temperature versus position along the bar length for both the bards.
(2) Using data for constant cross-sectional area bar, calculate the thermal conductivity for the copper bar and compare with the value given in your heat transfer text.
(3) For the tapered bar, derive an equation that can be used to predict temperature distribution as a function of x.
(4) Plot the temperature distribution from your equation and the one obtained from your experiment for the tapered bar.
(5) Carry out sensitivity analysis of k in terms of input (measured) variables.

f. Working sheet

Sl.No.	Distance of the thermpcouple from the hot end (m)	Milli-voltmeter Reading (mV)	Temperature from the conversion chart (degree Centrigrade)
1 to 10 reading			

g. Calculations

Under steady-state condition, heat flux (in W/m2) through the constant cross-section cylindrical bar is constant over the entire length. As a result, the heat transfer rate along the cylindrical bar, since it is insulated on its sides, is given by the above, while the heat flux by

$$q''_x = q/A = -k\ (\Delta T/\Delta x)$$

The quantity of heat, which is conducted through the rod, is transferred to the cooling water. Therefore, the heat transferred to the cooling water can be expressed as

$$q_x = -\ kA\ (\Delta T\ /\Delta x) = mC_p\ \Delta T$$

$$\Delta T = T\ w\ out\ -\ T\ w\ in$$

h. Nomenclature

q is defined as the heat transfer rate, in Watts;
A, is the heat transfer area normal to the direction of heat flow, in m^2;
k, is the material property defined as thermal conductivity, in W/m.K;
ΔT is the temperature difference, in K; and
Δx is the rod length, in m.
m is defined as the mass flow rate of water, in kg/s;
Cp, is the specific heat of water, in J/kg.K;
T w out , , is the outlet temperature of water, in oC;
T w in , , is the inlet temperature of water, in oC;

i. Reference

Fundamentals of Heat and Mass Transfer, Fifth Edition by Frank P. Incropera and David P. Dewitt.

Natural (Free) Convection

Natural (Free) Convection
Newton's Cooling Law

Importance of Natural Convection to the Mechanical Engineer:

a. Natural convection is the main cooling/heating mechanism in most heat transfer conditions.

b. Analyses of a simple physical problem whose results (solution) can be a bit complicated.

c. Physical similarity to emptying of an electrical charge by a capacitor.

1. Objectives:

1. To determine the natural convective heat transfer coefficient for a brass cylinder.
2. To find the Biot Number.
3. To calculate the instantaneous and total heat transferred.

2. Theoretical Background:

Background: A heated surface dissipates heat primarily through a process called convection. Heat can also be dissipated by conduction and radiation, however, these effects are not considered in this experiment. Air in contact with the hot surface is heated by the surface and rises due to a reduction in density. The heated air is replaced by cooler air which is in turn heated by the surface and rises. This process is called natural convection.

Natural, or free, convection occurs due to temperature differences which affect the density, and thus relative buoyancy, of the fluid. Heavier (more dense) components will fall while lighter (less dense) components rise, leading to bulk fluid movement. Natural convection can only occur, therefore, in a gravitational field. Natural convection will be more likely and/or more rapid with a greater variation in density between the two fluids, a larger acceleration due to gravity that drives the convection, and/or a larger distance through the convecting medium. Convection will be less likely and/or less rapid with more rapid diffusion (thereby diffusing away the gradient that is causing the convection) and/or a more viscous (sticky) fluid.

For natural convection problems, the onset of natural convection can be determined by the Rayleigh number (Ra). The Biot number (Bi) is another dimensionless number used in non-steady-state (transient) heat transfer calculations and gives a simple index of the ratio of the heat transfer resistances inside of and at the surface of a body. This ratio determines whether or not the temperatures inside a body will vary significantly in space, while the body heats or cools over time, from a thermal gradient applied to its surface.

$Ra = \frac{g\beta}{\upsilon\alpha}(T_s - T_\infty)x^3 = Gr.\Pr$	Rayleigh number for buoyancy driven problems. Very high numbers. Critical values dictates whether heat transfer is mainly by conduction or convection.
$Bi = \frac{hD}{k_S}$	Biot number. Ratio of heat transfer resistances inside and at the surface of a body.
$Gr = \frac{g\beta}{\upsilon^2}(T_s - T_\infty)D^3$	Grashoff number for bluff bodies. Ratio of buoyancy to viscous forces.
$\Pr = \frac{\mu.C_P}{k}$	Prandtl number. Ratio of viscous to thermal diffusion
$\beta = 1/T$	Volumetric thermal expansion coeff. (ideal gases)
$\alpha = \frac{k.\rho}{C_P}$	Thermal diffusivity.
$\upsilon = \mu/\rho$	Kinematic viscosity
T_S, T_B	Temperatures: Surface, Bulk

Introduction: With natural convection acting slowly to change a body's temperatures (due to the absence of a fan or a pump like in forced convection), the process tends to take a long time to occur and is usually therefore a case of un-steady heat transfer. In such scenarios, time will play an important role in dictating the levels of temperature and heat transfer. With the gradual reduction in temperature differences between the hot and cold sources, the amount of heat transferred will continue to decrease with time until it stops completely when $T_{HOT} = T_{COLD}$. If a hot body with little differences in internal temperature (possibly due to high internal conduction) was immersed in a cold fluid, the rates of natural convection at fluid-solid interface will equal the resulting change in internal energy, figure 1.

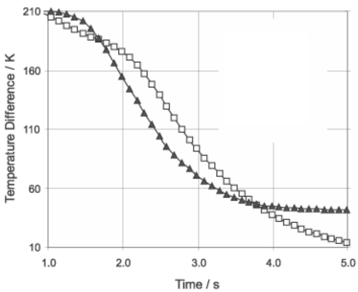


Figure 1: Examples of Temperature Drop Profiles of Cooling Bodies

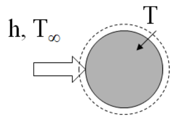


Figure 2: Round Body in Transient Natural Convection Conditions

For a highly conductive circular object, figure 2, with a body of mass (m), density (ρ), thermal capacity (C_P), temperature (T), surface area (A_S) and surface heat transfer coefficient (h), and where T_i and T_∞ are the initial and final temperatures. **If the Biot number (Bi) is lower than 0.1, then it is possible to assume that the whole cylinder is at the same temperature and the body will behave in a similar manner to an electrical capacitor**. Therefore;

$$\frac{dE}{dt} = hA_S(T_\infty - T) = \frac{d(m.C_P T)}{dt}$$

$$hA_S(T_\infty - T) = \rho.C_P.V\frac{dT}{dt}$$ or $$\rho.C_P.V\frac{d\theta}{dt} = -h.A_S\theta$$ where $\theta = T - T_\infty$

$$\frac{d\theta}{d\theta} = \frac{-h.A_S}{\rho V C_P}dt$$ Integrating leads to...

$$\ln\theta = \frac{-hA_S}{\rho V C_P}t + C_1$$ where; $$\theta(t) = C_2.\exp\left[\frac{-hA_S}{\rho V C_P}t\right]$$ and; $\theta(0)=C_i=C_2$

Hence, the general solution for the lumped parameter model is:

$$\frac{\theta(t)}{\theta_i} = \frac{T(t)-T_\infty}{T_i - T_\infty} = \exp\left[\frac{-hA_S}{\rho V C_P}t\right]$$

$$\tau = \frac{t}{\ln\frac{\theta_o}{\theta}}$$

τ= Time Constant= $\left[\frac{\rho V C_P}{hA_S}\right] = \rho V C_P.\frac{1}{hA_S}$ = Thermal Capacitance * Convective Thermal Resistance

Larger and heavier bodies will therefore have a larger time constant (suffering smaller changes in temperature with time) while objects with a larger surface area or surface heat transfer coefficients will have a smaller time constant (and suffering higher temperature changes).

Therefore; $$T(t) = T_\infty + (T_i - T_\infty)e^{\frac{-hA_S}{\rho V C_P}t} = T_\infty + (T_i - T_\infty)e^{-t/\tau} = T_\infty + (T_i - T_\infty)e^{-Bi.Fo}$$

$$F_O = \frac{\alpha t}{L_c^2}$$ Fourier number. Measure of thermal waves speeds!

These equations above give the following graphical behaviors:

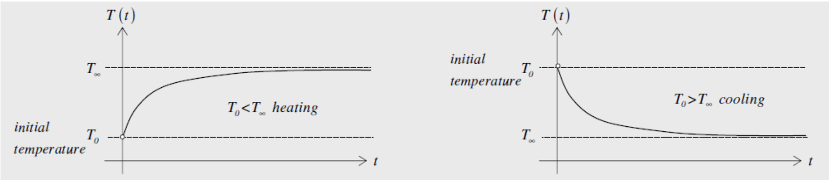


Figure 3: Lumped Capacitance Method Performance Curves in Heating and Cooling

Using the equation: If T(t) was the un-known, it is possible to find it out by knowing T_i and T_θ and the value of the time constant, it is also possible to estimate the time needed to achieve a certain temperature change using this formula. Figure 4 shows an analogy to this discharging effect of an electrical capacitor over time leading to a similar charge reduction profile similar to the temperature one shown in figure 1 earlier. This analogy is the reason for the lumped capacitance model name!

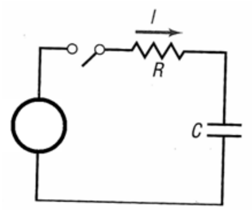


Figure 4: Possible Electrical Discharging from a Capacitor (when switch is connected!)

5. <u>Planning:</u>

Read the experimental material before coming to the lab.

Understand the theory, its significance and implications.

Bring along your laptop and try to immediately input your measurements into an Excel spreadsheet.

Use the formulae given to obtain your results immediately.

Prepare a report template.

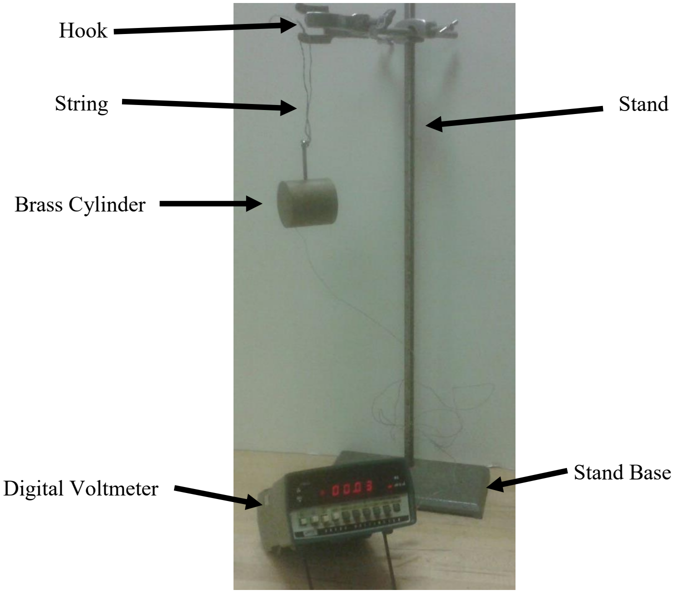


Figure 5: Experimental Apparatus

6. Experimental Setup:

4.1 Apparatus: A heated brass cylinder is heated and suspended by a string and has a Copper-Constantan thermocouple fixed in it. The cylinder is let to cool while suspended motionless in air, figures 5 and 6.

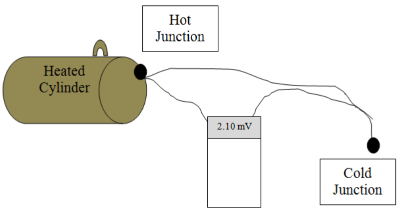


Figure 6: Experimental Setup

4.2 Procedure:

Pre- Lab

- Read all experimental material. Understand the theory and experimental procedures.
- The lab engineer will have the unit setup and the brass cylinder heating prepared before your arrival at the laboratory.

In the Laboratory:

- Measure accurately the length and diameter of the cylinder. Also, record the weight of the cylinder and hook.
- Heat the cylinder over a flame or in hot water in a beaker, to produce about 95°C output on the recorder.
- Remove the flame, or take the cylinder out of the hot water and dry. Then suspend the cylinder motionless in air and let it cool, recording its temperature with time, at every one minute interval.
- Stop recording when the cylinder temperature is slightly above the ambient temperature.
- Measure the ambient temperature at the beginning and at the end of the experiment.

At Home:

Following the instruction and the relevant analysis given to you in the lecture course, perform the following calculations.

• Take the initial body temperature Ti to be the first temperature below 80oC in the cooling process. The corresponding new initial would then be t=0.

• From the temperature time relation, determine the "thermal time constant" for cooling, τ.

• From the thermal time constant and cylinder characteristics, determine the value for the heat transfer coefficient, hc, and compare with the range expected for free convection.

• Calculate the value of Biot number and comment on the accuracy to be expected in the analysis, since we assumed the system to be of negligible internal resistance.

• Calculate the instantaneous heat transfer rate at a few instants in time; say at 0, 10, 20, 30 and 40minutes in the cooling process. Discuss the outcome of your results.

• Calculate the total amount of heat transferred from the solid for different periods in time [Q(t)]. Take the different periods in the cooling process to be the first 10, 20, 30 and 40minutes in the cooling process. Also, calculate the heat transferred from the solid for equal periods of time, say every successive 10minutes.

• Perform any other calculations of relevance.

5. Measurements:

Given Data:

$m_{Cylinder}= \rho V=$	0.753kg	$m_{Screw}=$	0.005kg
$L=$	4.94cm	$d= 2r=$	4.82cm
$C_P=$	385J/kg.K	$k=$	111W/m.K

$T_\infty=$ ^oC

#	Time (min)	Voltmeter Reading (mV)	Temperature from the Conversion Chart (^oC)	Thermal Time Constant (s)
1				
2				
3				
4				
5				
6				
7				
8				
8				
10				

6. Calculations:

$A_S= 2\pi rL+2\pi r^2$

$V= \pi r^2 L$

$L_C= V/A_S$

$$\tau = \frac{t}{\ln\frac{\theta_o}{\theta}}$$

$h_C= mC/\tau.A_S$

$Bi= h_C.L_C/k$

Table (1): Thermocouples Conversion Table

Temperature in Degrees Celsius (IPTS 1968)

EMF in Absolute Millivolts

Reference Junctions at 0 C

THERMOELECTRIC VOLTAGE IN ABSOLUTE MILLIVOLTS

DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C
-270	-6.458											-270
-260	-6.441	-6.444	-6.446	-6.448	-6.450	-6.452	-6.453	-6.455	-6.456	-6.457	-6.458	-260
-250	-6.404	-6.408	-6.413	-6.417	-6.421	-6.425	-6.429	-6.432	-6.435	-6.438	-6.441	-250
-240	-6.344	-6.351	-6.358	-6.364	-6.371	-6.377	-6.382	-6.388	-6.394	-6.399	-6.404	-240
-230	-6.262	-6.271	-6.280	-6.289	-6.297	-6.306	-6.314	-6.322	-6.329	-6.337	-6.344	-230
-220	-6.158	-6.170	-6.181	-6.192	-6.202	-6.213	-6.223	-6.233	-6.243	-6.253	-6.262	-220
-210	-6.035	-6.048	-6.061	-6.074	-6.087	-6.099	-6.111	-6.123	-6.135	-6.147	-6.158	-210
-200	-5.891	-5.907	-5.922	-5.936	-5.951	-5.965	-5.980	-5.994	-6.007	-6.021	-6.035	-200
-190	-5.730	-5.747	-5.763	-5.780	-5.796	-5.813	-5.829	-5.845	-5.860	-5.876	-5.891	-190
-180	-5.550	-5.569	-5.587	-5.606	-5.624	-5.642	-5.660	-5.678	-5.695	-5.712	-5.730	-180
-170	-5.354	-5.374	-5.394	-5.414	-5.434	-5.454	-5.474	-5.493	-5.512	-5.531	-5.550	-170
-160	-5.141	-5.163	-5.185	-5.207	-5.228	-5.249	-5.271	-5.292	-5.313	-5.333	-5.354	-160
-150	-4.912	-4.936	-4.959	-4.983	-5.006	-5.029	-5.051	-5.074	-5.097	-5.119	-5.141	-150
-140	-4.669	-4.694	-4.719	-4.743	-4.768	-4.792	-4.817	-4.841	-4.865	-4.889	-4.912	-140
-130	-4.410	-4.437	-4.463	-4.489	-4.515	-4.541	-4.567	-4.593	-4.618	-4.644	-4.669	-130
-120	-4.138	-4.166	-4.193	-4.221	-4.248	-4.276	-4.303	-4.330	-4.357	-4.384	-4.410	-120
-110	-3.852	-3.881	-3.910	-3.939	-3.968	-3.997	-4.025	-4.053	-4.082	-4.110	-4.138	-110
-100	-3.553	-3.584	-3.614	-3.644	-3.674	-3.704	-3.734	-3.764	-3.793	-3.823	-3.852	-100
-90	-3.242	-3.274	-3.305	-3.337	-3.368	-3.399	-3.430	-3.461	-3.492	-3.523	-3.553	-90
-80	-2.920	-2.953	-2.985	-3.018	-3.050	-3.082	-3.115	-3.147	-3.179	-3.211	-3.242	-80
-70	-2.586	-2.620	-2.654	-2.687	-2.721	-2.754	-2.788	-2.821	-2.854	-2.887	-2.920	-70
-60	-2.243	-2.277	-2.312	-2.347	-2.381	-2.416	-2.450	-2.484	-2.518	-2.552	-2.586	-60
-50	-1.889	-1.925	-1.961	-1.996	-2.032	-2.067	-2.102	-2.137	-2.173	-2.208	-2.243	-50
-40	-1.527	-1.563	-1.600	-1.636	-1.673	-1.709	-1.745	-1.781	-1.817	-1.853	-1.889	-40
-30	-1.156	-1.193	-1.231	-1.268	-1.305	-1.342	-1.379	-1.416	-1.453	-1.490	-1.527	-30
-20	-0.777	-0.816	-0.854	-0.892	-0.930	-0.968	-1.005	-1.043	-1.081	-1.118	-1.156	-20
-10	-0.392	-0.431	-0.469	-0.508	-0.547	-0.585	-0.624	-0.662	-0.701	-0.739	-0.777	-10
- 0	0.000	-0.039	-0.079	-0.118	-0.157	-0.197	-0.236	-0.275	-0.314	-0.353	-0.392	- 0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.162	1.203	20
30	1.203	1.244	1.285	1.325	1.366	1.407	1.448	1.489	1.529	1.570	1.611	30
40	1.611	1.652	1.693	1.734	1.776	1.817	1.858	1.899	1.940	1.981	2.022	40
50	2.022	2.064	2.105	2.146	2.188	2.229	2.270	2.312	2.353	2.394	2.436	50
60	2.436	2.477	2.519	2.560	2.601	2.643	2.684	2.726	2.767	2.809	2.850	60
70	2.850	2.892	2.933	2.975	3.016	3.058	3.100	3.141	3.183	3.224	3.266	70
80	3.266	3.307	3.349	3.390	3.432	3.473	3.515	3.556	3.598	3.639	3.681	80
90	3.681	3.722	3.764	3.805	3.847	3.888	3.930	3.971	4.012	4.054	4.095	90
100	4.095	4.137	4.178	4.219	4.261	4.302	4.343	4.384	4.426	4.467	4.508	100
110	4.508	4.549	4.590	4.632	4.673	4.714	4.755	4.796	4.837	4.878	4.919	110
120	4.919	4.960	5.001	5.042	5.083	5.124	5.164	5.205	5.246	5.287	5.327	120
130	5.327	5.368	5.409	5.450	5.490	5.531	5.571	5.612	5.652	5.693	5.733	130
140	5.733	5.774	5.814	5.855	5.895	5.936	5.976	6.016	6.057	6.097	6.137	140
150	6.137	6.177	6.218	6.258	6.298	6.338	6.378	6.419	6.459	6.499	6.539	150
160	6.539	6.579	6.619	6.659	6.699	6.739	6.779	6.819	6.859	6.899	6.939	160
170	6.939	6.979	7.019	7.059	7.099	7.139	7.179	7.219	7.259	7.299	7.338	170
180	7.338	7.378	7.418	7.458	7.498	7.538	7.578	7.618	7.658	7.697	7.737	180
190	7.737	7.777	7.817	7.857	7.897	7.937	7.977	8.017	8.057	8.097	8.137	190
200	8.137	8.177	8.216	8.256	8.296	8.336	8.376	8.416	8.456	8.497	8.537	200
210	8.537	8.577	8.617	8.657	8.697	8.737	8.777	8.817	8.857	8.898	8.938	210
220	8.938	8.978	9.018	9.058	9.099	9.139	9.179	9.220	9.260	9.300	9.341	220
230	9.341	9.381	9.421	9.462	9.502	9.543	9.583	9.624	9.664	9.705	9.745	230
240	9.745	9.786	9.826	9.867	9.907	9.948	9.989	10.029	10.070	10.111	10.151	240
250	10.151	10.192	10.233	10.274	10.315	10.355	10.396	10.437	10.478	10.519	10.560	250
260	10.560	10.600	10.641	10.682	10.723	10.764	10.805	10.846	10.887	10.928	10.969	260
270	10.969	11.010	11.051	11.093	11.134	11.175	11.216	11.257	11.298	11.339	11.381	270
280	11.381	11.422	11.463	11.504	11.546	11.587	11.628	11.669	11.711	11.752	11.793	280
290	11.793	11.835	11.876	11.918	11.959	12.000	12.042	12.083	12.125	12.166	12.207	290
300	12.207	12.249	12.290	12.332	12.373	12.415	12.456	12.498	12.539	12.581	12.623	300
310	12.623	12.664	12.706	12.747	12.789	12.831	12.872	12.914	12.955	12.997	13.039	310
320	13.039	13.080	13.122	13.164	13.205	13.247	13.289	13.331	13.372	13.414	13.456	320
330	13.456	13.497	13.539	13.581	13.623	13.665	13.706	13.748	13.790	13.832	13.874	330
340	13.874	13.915	13.957	13.999	14.041	14.083	14.125	14.167	14.208	14.250	14.292	340
DEG C	0	1	2	3	4	5	6	7	8	9	10	DEG C

7. <u>Results and Discussion:</u>

- Draw the cooling process in terms of T versus t.
- Is the time constant changing at various intervals? Why?
- Comment on the outcome of your results.
- What is the difference between the Bi and Nu numbers.

8. <u>Conclusions:</u>

Provide a brief summary here of your most important findings.

References:

1. “Heat Transfer”, Holman, J. P., 7th Edition, McGraw-Hill Publishing.

2. "Fundamentals of Heat and Mass Transfer", Frank P. Incropera and David P. Dewitt, 5th Edition.

Bernoulli Theorem Verification and Flow Measurement

Bernoulli Theorem Verification and Flow Measurement

Importance of the Bernoulli Theorem and Flow Measurement: The Bernoulli equation provides the only link between the static, dynamics and elevation pressures. It therefore provides an easy coupling between the velocity and pressure fields within a flow. Further applications use flowrate measurement devices that depend entirely on the Bernoulli equation in their calculations. Remember that the next time you fill up your car with gasoline or think about the accurate invoicing for the Kingdom's exports of crude oil. Understanding the equation allows for the proper understanding of the relationship between changes in the static and their relationship to the dynamic pressure.

There are a number of flow measurement techniques that are available to researchers and engineers. Four such techniques are utilized in this experiment, hence, allowing for comparisons between the various methods.

Besides using the flow bench to collect water while measuring the time used, three other flowrate measurement devices are also available: [1] A Venturi Meter, [2] An Orifice Meter and [3] Rotameter.

1. Objectives:

1. Verification of Bernoulli theorem.
2. Comparison between theory and testing for various measurement devices.
3. Comparison between various flow measurement techniques.
4. Understanding of total, static and dynamic pressure (or head) relationships.
5. Measure the density of the working fluid (water).

2. Theoretical Background:

The Bernoulli Theorem:

Born in the 17th century, Bernoulli went to affirm the presence of an energy like equation for fluid flow where the sum of all pressures (static, dynamic and datum) remains constant, in the absence of losses.

$$\frac{P}{\rho.g} + \frac{V^2}{2g} + Z = const. \qquad \text{Eqn. 1}$$

This allows to stipulate that:

$$\frac{P_1}{\rho.g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho.g} + \frac{V_2^2}{2g} + Z_2 \qquad \text{Eqn. 2}$$

And if the datum (Z) may be ignored (when $Z_1=Z_2$) then;

$$\frac{P_1}{\rho.g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho.g} + \frac{V_2^2}{2g}$$ Eqn. 3

The Bernoulli theorem itself allows for the coupling of the static and dynamic pressures (or heads) to one another and forms a good basis for many incompressible flow calculations. It is a special solution of the more complete Navier-Stokes equation. The theory stipulates that a flow whose velocity is increased must forego a static pressure reduction and vice versa (ignoring the datum effect).

4. <u>Experimental Setup:</u>

4.1 Apparatus:

Venturi / Orifice Meters:

Both the Venturi and orifice meters base their theory on the Bernoulli theorem to calculate the flow rate. By measuring the static pressure change across the flow obstruction placed inside the flow measurement device (by reducing the cross-sectional area), it is possible to measure the flowrate using a modified Bernoulli equation expression. A coefficient of discharge (Cd) is added into the equation to correct for any discrepancies. Hence, if;

$$Q = \frac{\pi}{4} D^2 V_1 = \frac{\pi}{4} D_2^2 V_2$$ Eqn. 4

Coupling equations 3 and 4 gives:

$$V_2 = \left[\frac{2(P_1 - P_2)}{\rho(1 - D_2^4 / D^4)} \right]^{\frac{1}{2}}$$ Eqn. 5

If β=d/D and Q is constant:

$$Q = C_d * A_T \left[\frac{2(P_1 - P_2)/\rho}{1 - \beta^4} \right]^{\frac{1}{2}}$$ Eqn. 6

Where P_1 and P_2 are the static pressures before and after the obstruction and at the throat of the obstruction (minimal area), A_T is the area at the obstruction and β= d/D.

Cd values for Venturi meters are around 0.92-0.985 and for the orifice meters is usually around 0.6. International Standards, such as BS1042 provide formulae for finding Cd values for such devices as a function of Reynolds number. **In this case, the venture meter has a Cd of 0.98 and the orifice of 0.63.**

Manometer head readings (for static and elevation pressures) can be changed to pressure using the following formula:

$$P = \rho.g.h$$ Eqn. 7

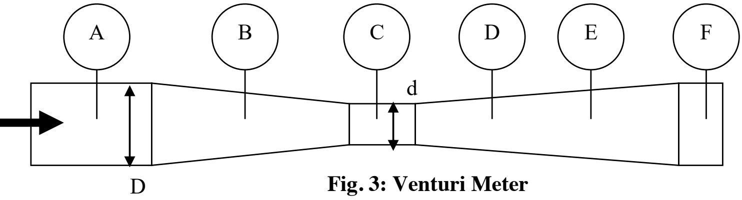


Fig. 3: Venturi Meter

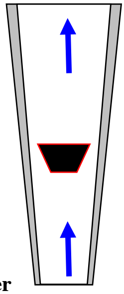


Fig 4: Rotameter

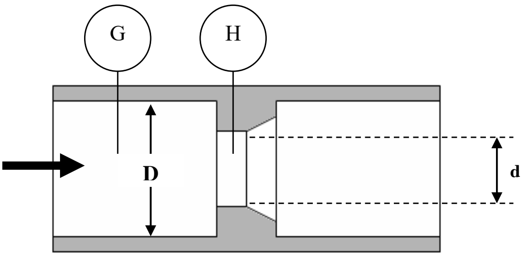


Fig. 5: Orifice Meter

The higher Cd value for the venture meter indicates that most of the pressure will be recovered after the device (only 2% losses) as opposed to the lower CD for the orifice meter where higher levels of pressure losses can be incurred. Error calculations can be based on the tank flowrates collected where;

$$Error(\%) = \frac{(Q_{Device} - Q_{Tank})}{Q_{Tank}} * 100 \qquad \text{Eqn. 8}$$

Pressure Types: According to Bernoulli eqn., there are three types of pressure, static, dynamic and elevation. The sum of the static and elevation (level) pressures is sometimes used and is called the piezometric pressure (both can use Eqn. 7 in their measurement).

The dynamic pressure on the other hand is a function of the local speed. It is usually calculated using:

$$P_D = \frac{1}{2}\rho V^2 \qquad \text{Eqn. 9}$$

The sum of the static, elevation and dynamic pressures is called the total pressure. This term is the real term of total flow energy. Hence, pressure losses are subtracted from this term and not from the other pressures (static, elevation and dynamic). However, while there are methods for

estimating and measuring pressure losses, it is the dynamic pressure with its velocity that dictates the remaining available pressure for the static pressure since:

$$P_T = P_{Static} + P_{Elevation} + P_{Dynamic} \qquad \text{Eqn. 10}$$

And when we include pressure losses (and since the total pressure is constant):

$$P_T = (P_{Static} + P_{Elevation} + P_{Dynamic})_1 = (P_{Static} + P_{Elevation} + P_{Dynamic} + \Delta P_L)_2 \qquad \text{Eqn. 11}$$

The term ΔP_L stands for the pressure losses incurred in the system. Note how this term was added to the right hand side (RHS) of the equation to balance it.

There are two main types of pressure losses for the ΔP_L term;

$$\boxed{\Delta P_L = (\Delta P_L)_{MAJOR} + (\Delta P_L)_{MINOR}} \qquad \text{Eqn.12}$$

Major losses: This is the pressure loss caused by straight pipes. It is called major losses since pipes are usually long (such as in petrol lines) and, hence, cause higher pressure losses.

$$\boxed{(\Delta P_L)_{MAJOR} = \rho.g.\Delta h_L = \rho.g.\left[\frac{fLV^2}{2gD_H}\right]} \qquad \text{Eqn. 13}$$

where f is the friction factor obtained from a "Moody diagram" and is a function of the Reynolds number and pipe condition, L is the pipe length and D_H is the hydraulic diameter of the pipe section. This formula is used this way in the USA. A slightly different formula is used in the UK.

Minor Losses: This is the pressure loss caused by various fittings that include valves, bends, nozzles, etc…
It is calculated as a function of the dynamic pressure multiplied by a factor (K) which is obtained by experiment per fitting type, size and other characteristics.

$$\boxed{(\Delta P_L)_{MINOR} = K(\frac{1}{2}\rho V^2)} \qquad \text{Eqn. 14}$$

PROCEDURE:

IN THE LAB:

Before taking any reading, the unit should be primed with water by starting the pump first –probably at maximum flowrate- until conditions are steady with least air-bubbles. Once this is achieved, the air bleed valve pin is pressed and air is allowed to flow into the manometers to bring their levels down to a level where manometer readings can be taken.

Once this point is achieved, further control of flow rate can be achieved using the discharge valve alone.

1. **A minimal of 5-7 readings are required in this experiment**.
2. For accuracy purposes while the flow bench timed fluid collection, **avoid using the first 10 litres of water collected** in your calculations.

3. It is advisable to measure the density of the water used in this experiment.
4. Fill in table 1.

AFTERWARDS:

1. Finish filling tables 1 and 2.
2. On one sheet: Sketch the various flowrates against the tank collected flowrate.
3. Sketch the total, static and dynamic pressures versus location.
4. ***Discuss your results. Answer the questions. You have 1 week to hand-in your report!***

QUESTIONS:

1. Which measurement device is the most accurate in your opinion? Why??
2. What are the main sources of error in each approach?
3. What does the plotting of the static and dynamic pressures across the pipe length give us? Where would you use such a plot extensively for design purposes??
4. Carry out a comparison between the venturi, orifice and rotameter devices from an operational point of view?
5. What are limitations of use of the orifice and rotameters?
6. What are the design requirements of venturi meters and orifice plates?
7. What are the effects of the boundary layer and turbulence inside the venturi meters and orifice plates?

Pressure Losses in Pipes

Pressure Losses in Pipes

Importance of Pressure Losses to the Mechanical Engineer:

a. Sizing the pipes and pumps needed to meet the design requirements of flow systems.

b. Establish the pressure losses and energy consumption levels.

1. Objectives:

6. Calculation of fittings minor loss coefficients (K).
7. Finding pressure losses' friction factor for straight pipe.
8. Comparison between measured and calculated K and f factors.

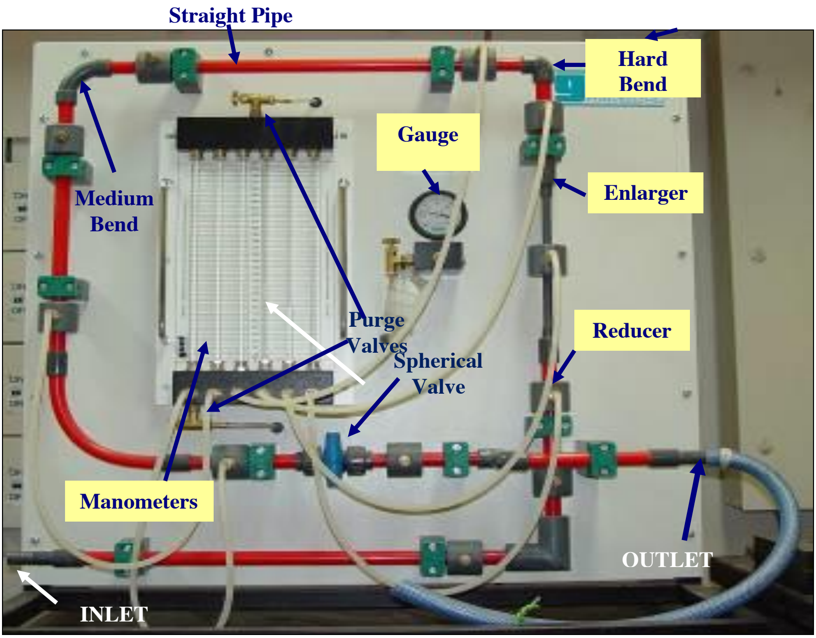


Figure 1: Experimental Apparatus

2. Theoretical Background:

The Bernoulli Theorem:

Born in the 18th century, Bernoulli went to affirm the presence of an energy like equation for fluid flow where the sum of all pressures (static, dynamic and datum) remains constant, in the absence of losses.

$$\frac{P}{\rho.g}+\frac{V^2}{2g}+Z=const.$$ Eqn. 1

This allows to stipulate that:

$$\frac{P_1}{\rho.g}+\frac{V_1^{\,2}}{2g}+Z_1=\frac{P_2}{\rho.g}+\frac{V_2^2}{2g}+Z_2$$ Eqn. 2

This is the Bernoulli equation in pressure head form since each of its term has units of (m).

$$\frac{P_1}{\rho.g}+\frac{V_1^{\,2}}{2g}+Z_1=\frac{P_2}{\rho.g}+\frac{V_2^2}{2g}+Z_2+\Delta h_L$$ Eqn. 3

When head losses (Δh_L) are involved.
Bernoulli equation can also be expressed in pressure terms

$$P_1+\frac{\rho V_1^{\,2}}{2}+\rho g Z_1=P_2+\frac{\rho V_2^2}{2}+\rho g Z_2+\rho g\Delta h_L$$ Eqn. 4

Elevation Pressure **Pressure Losses**

Dynamic Pressure

Static Pressure

PRESSURE LOSSES: Pressure losses and the knowledge of any coefficients involved in their prediction are very important in fluid mechanics. Such information is critical at the design and development level of new flow systems and in their control. It is also common practice for flow fittings' suppliers to provide the K factors of their fittings among other geometrical data. ***All pressure losses in flow systems are related to the dynamic pressure within them***.

There are two main types of pressure losses for the ΔP_L term;

$$(\Delta P_L)_{TOTAL}=(\Delta P_L)_{MAJOR}+(\Delta P_L)_{MINOR}$$ Eqn.5

Major Losses: This is the pressure loss caused by straight pipes. It is called major losses since pipes are usually long (such as in petrol lines) and, hence, cause higher pressure losses.

$$(\Delta P_L)_{MAJOR}=\rho.g.\Delta h_{L\,MAJOR}=\rho.g.\left[\frac{fLV^2}{2gD_H}\right]=\left[\frac{fL}{D_H}\right]\left[\frac{\rho V^2}{2}\right]$$ Eqn. 6

where f is the friction factor obtained from a "Moody diagram" and is a function of the Reynolds number and pipe condition, L is the pipe length and D_H is the hydraulic diameter of the pipe section. This formula is used this way in the USA. A slightly different formula is used in the UK.

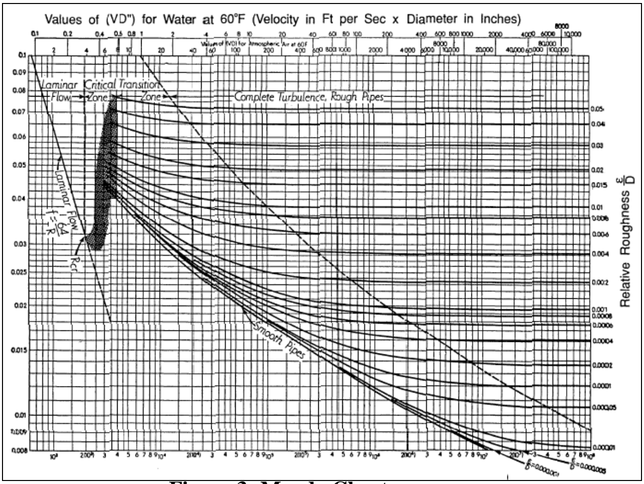


Figure 3: Moody Chart

Where f is found from the Moody chart (a function of relative roughness $\frac{\varepsilon}{D}$).

Minor Losses: This type of losses occurs mainly due to changes in velocity, direction or flow area. It is relevant to various fittings that include valves, bends, nozzles, etc… It is calculated as a function of the dynamic pressure multiplied by a factor (K) which is obtained by experiment per fitting type, size and other characteristics.

$$(\Delta P_L)_{MINOR} = K(\frac{\rho V^2}{2}) \qquad \text{Eqn. 7}$$

or

$$h_L = K\left(\frac{V^2}{2g}\right) \qquad \text{Eqn. 8}$$

V is calculated at the smaller cross-section (where a change in cross-section occurs) and the Δh direction (or sign) is reversed for the enlarger type of fittings.

Manometer Head Readings: can be changed to pressure using the following formula:

$$P = \rho.g.h \qquad \text{Eqn. 9}$$

$$h_{lm} = \frac{fL_eV^2}{2gD}$$

3. Planning:

1. Find the average velocity per flowrate in the network's large and small diameter pipes using the water collected in water basin, a stop-watch (for collection time measurement) and the knowledge of the pipes diameters (given).
2. Measure the head, and therefore the head loss between the two pressure tapping before and after each measurement section.
3. Calculate the measured pressure losses and substitute in the formulae given to find K pre fitting and f for the straight pipe per flow rate (*maybe use Excel!*).
4. Compare the measured K and f factors to their theoretical values found in your Fluid Mechanics book. You might need to measure the water's density and the radii of curvature for the network's fittings. Explain your results in detail.

4. <u>Experimental Setup</u>:

4.1 Apparatus:

The experimental unit is a comprised from a pipe system with a valve and a number of fittings. The unit also allows for two methods of pressure measurements using 6 manometers and a pressure gauge. The fittings include a number of bends, a reducer, an enlarger, spherical valve and a straight pipe portion. Pressure readings from before and after any section of the system, shown in figure 1, can be measured using the manometers to find the corresponding pressure loss.

Figure 2: Flow Bench and Submersible Pump

4.2 Procedure:

In the Lab:

1) **De-Airing the Manometers**: This is achieved by the opening of both purge valves (upper for air and lower for water) while the flow in the unit is at a maximum, i.e. pump and spherical valves both wide open. This will allow any air bubbles in the system and the manometers' flexible connectors (should be shaken by hand) to be purged out of the system.

2) **Manometers Level Setting:** While the pump is on, the spherical valve then the pump valves should be both closed. Then, and in a controlled manner, both purge valves should be opened in a way that will bring the level of water in the manometers to the least level possible. This is where water is allowed to flow down out of the manometers through the lower purge and air is allowed to flow up the manometers to the upper purge valve. This should be done without allowing any air to get into the flexible connectors to avoid repeating step 1 above.
3) **Obtaining 5 or 6 Readings:** The water level inside manometer with the highest pressure (h1) at the inlet of the reducer (in this case) can easily go out of the range of manometers lengths (despite leveling to the minimum in step 2 above!). Hence, there is only so many different flow rates (or spherical valve openings that can be achieved) here. Therefore, it is necessary to find the maximum flow rate and divide it by the number of steps required. This will help in producing the number of readings required. Here, a 25mm change in h1 manometer level from lowest level is found to give about 5-6 readings.
4) **Measure Flow Rates and Manometer Heads**: Please fill-in table 1, attached at the end of this sheet.

At Home:

1. Complete filling of table 1 (attached).
2. Find ΔP for all fittings/sections including the straight pipe section.
3. Calculate the K factors for all fittings per reading.
4. **Draw ΔP versus dynamic head curves per fitting. From this, obtain the average K per fitting.**
5. **Find the theoretical ΔP for the straight pipe section using the Moody chart.**
6. **Calculate pipe friction factor and compare to that for a smooth pipe from Moody chart.**
7. Discuss your results and the reasons behind their behavior.
8. Compare Moody based f factor with that obtain by experiment. Provide reasoning for any differences.

5. Measurements:

Density= ????? kg/m³ **$L_{STRAIGHT\_PIPE}$= 415 mm**

D_{SMALL}= 9.6 mm **D_{LARGE}= 17 mm**

Table of Measurements:

	Flow Collection		**Manometer Head Readings**					
	Volume	**Time**	**h_1**	**h_2**	**h_3**	**h_4**	**h_5**	**h_6**
#	**mL**	**Sec**	**mm H_2O**	**mm H_2O**	**mm H_2O**	**mm H_2O**	**mm H_2O**	**mm H_2O**
1								
2								
3								
4								
5								

Table of Results:

		Velocity		ΔP				
	Q	**V_{SMALL}**	**V_{LARGE}**	**Reducer**	**Enlarger**	**Hard Bend**	**Straight Pipe**	**Medium Bend**
#	**L/s**	**m/s**	**m/s**	**Pa**	**Pa**	**Pa**	**Pa**	**Pa**
1								
2								
3								
4								
5								

	K				f Pipe	
	Reducer	**Enlarger**	**Hard Bend**	**Medium Bend**	**Measured**	**Moody Chart**
#						
1						
2						
3						
4						
5						

6. <u>Calculations</u>:

Finding a Pipe's Flow Average Velocity:

Vavg = Q/A = (WaterVolumeCollectedInTank/CollectionTime)/PipeDiameter
= $(V/t)/((22/7)*(Dpipe^2)/4)$

Note: There are two different pipe sizes in the network.

Finding K per Fitting:

$dP_{Fitting} = \rho.g.(\Delta h_{Fitting}) = K_{Fitting} * (½ .\rho.(Vavg)^2)$

$K_{Fitting} = \rho.g.(\Delta h_{Fitting}) / (½ .\rho.(Vavg)^2)$

Finding f for the Straight Pipe:

$$h_{lm} = \frac{fL_eV^2}{2gD}$$

Pumping Power:

Power = Q. ΔP

7. **Results and Discussion:**

1. Discuss the reasons and difference between f values obtained experimentally and analytically using the Moody chart.
2. Compare the results and comment on the reasons for the variation of loss coefficients among fittings.
3. Compare K per fitting to that published in the literature.
4. Find $L_{Equivalent}$ for each fitting using small pipe diameter.
5. What would affect the accuracy of your K and f factors obtained?
6. Why was one of your ΔL (enlarger) negative?!
7. Quantify the pumping power conumed within your network at all flow rates

8. **Conclusions**:

1. Were your experimental results comparable to your Fluid Mechanics book results. Why?
2. How can your results be used to choose a suitable pump for your network?

Air-Conditioning and Refrigeration Experiment

Heating, Humidification, Cooling and De-Humidification of Air

Objectives

The main objective of this experiment is to apply the air conditioning and refrigeration theories to the air flow going through an air conditioning unit coupled with an understanding of the processes occurring on the refrigerant side (R134a) of the unit. The experiment will concentrate on the use of the psychrometric and P-h charts in conjunction with measured air' humidity and refrigerant properties to verity the steady mass flow and energy balance equations. It is also hoped that the student gets familiar, through this experiment, with some air conditioning and refrigeration processes and with thermodynamic equipment as a whole.

In the present experiment, we will carry out three main sub-experiments
1) Humidification (try to create a cloud!);
2) Humidification and Sensible Heating (effect of heating and increased temperature on humidity);
3) Heating, Humidification, Cooling and De-Humidification (main experiment) all in one.

The latter sub-experiment tries to closely mimic industrial Air Handling Unit processes attempting to achieve certain moisture content and dry bulb temperatures. **Finally, the C.O.P. for the refrigeration cycle will be calculated.**

Apparatus

This experiment will be conducted on the computerized Hilton Air Conditioning Unit (A660). This test rig facilitates the study of different air-conditioning processes either separately or in some combinations. Data can be acquired either manually through an analog read-out or by the computer through an analog to digital converter. Data can be stored on disk for later processing. A boiler, whose source of heat is an electric heating coil, generates steam.

Experimental Procedure

1- Start up the test rig as recommended.
   Make sure no thermocouples reach a temperature of 48°C throughout these experiments.

Run the rig at medium speed in order to achieve suitable airflow rate. This will help in obtaining clear effect for humidification.

2- Select a humidification boiler setting. You have a number of boiler settings: **2 kW, 2 kW, 1 kW** and a combination thereof.

3- Wait until steady conditions are obtained after starting the humidification process.

4- Take readings for the first experiment.

5- Turn on the pre-heater coils to 2kW. Wait for **20 minutes**.

6- Take your readings for the second experiment.

7- Turn on the vapor-compression system (the cooling equipment) for cooling/dehumidification.

8- Wait until steady conditions are obtained as observed by the steadiness of various temperature readings. This usually takes about **25 minutes**.

9- Follow the on-screen menus and store the readings of all temperature and pressure differential sensors on hard disk and get a printout. At the same time, write down some analog readings for verification purposes.

Measurements

Note that the unit needs about **20 minutes** to reach steady state. However, this is reduced if the experiment is carried out in the order given above in the objectives. Nevertheless, it is therefore important to carry out the experiments in quickly for the laboratory time to be sufficient.

Record the following:

1- the Lab barometric pressure,

2- the humidification boiler setting used,

3- the dry- bulb and wet-bulb temperatures at all stations along the air-path. Of particular interest are the values at sections **B** and **C,**

4- the pressure differential across the orifice plate at Station **E**, and

5- mass of condensate and time for condensation.

Calculations

1- Calculate the air-mass flow rate from the pressure drop across the orifice plate according the formula provided in the manual.

$$\dot{m}_a = 0.0517 \sqrt{\frac{z}{v_E}} \qquad \textit{Kg/Sec}$$

where, z = Orifice differential head (mm H_2O)

v_E = Specific volume of air obtained from the psychrometric chart at $\mathbf{t_{db} = t_9}$ and $\mathbf{t_{wb} = t_{10}}$.

2- Locate points **A, B** and **C** on the psychrometric chart and determine ω_A, ω_B, ω_C, ω_D, h_A, h_B, h_C and h_D.
3- Apply the mass balance of the moisture content of air between sections **B** and **C** to obtain the rate of condensation.

$$\dot{m}_{Condensate} = \dot{m}_a\,(\omega_B - \omega_C) \qquad \text{Kg/Sec}$$

4- Find h_w and h_{fg} for the water at the condensation and evaporation conditions.
5- Apply the 1st Law of thermodynamics between sections **B** and **C** and estimate the rate of cooling.

$$\dot{Q}_{cooling} = \dot{m}_a(h_B - h_C) - \dot{m}_w\, h_w$$

6- Estimate the mass rate of condensation, $\dot{m}_{condensate}$, from the mass of condensate divided by time of condensation; compare with value obtained previously.

7- Calculate the rate of cooling provided by the coil.

$$\dot{Q}_{cooling} = \dot{m}_{ref.}(h_1 - h_4)$$

where : $\dot{m}_{ref.}$ is the refrigerant mass flow rate ,
h_1 , h_4 are the refrigerant enthalpies after and before the evaporator coil.

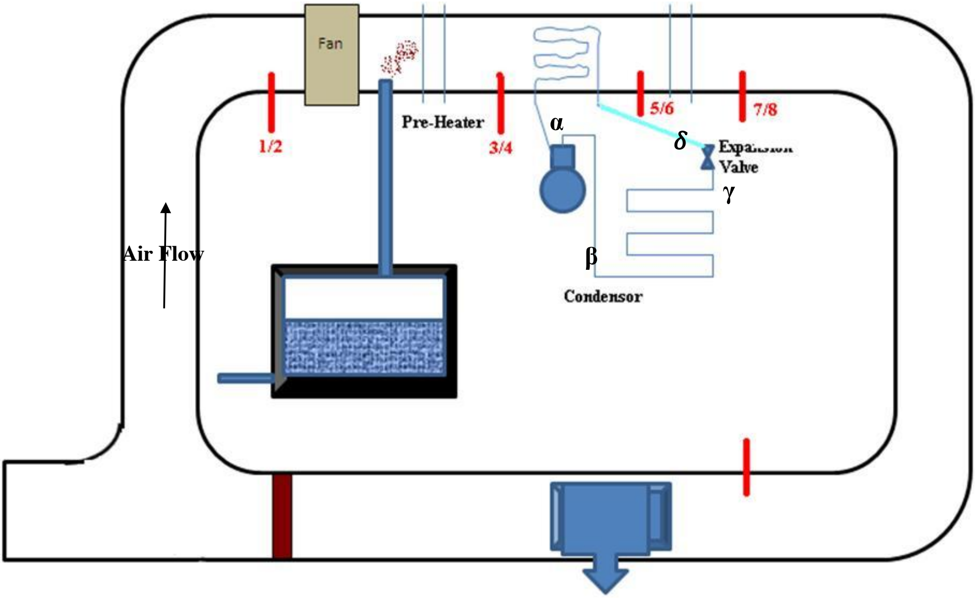
Compare with the $\dot{Q}_{Cooling}$ determined in (4) previously.

Observations

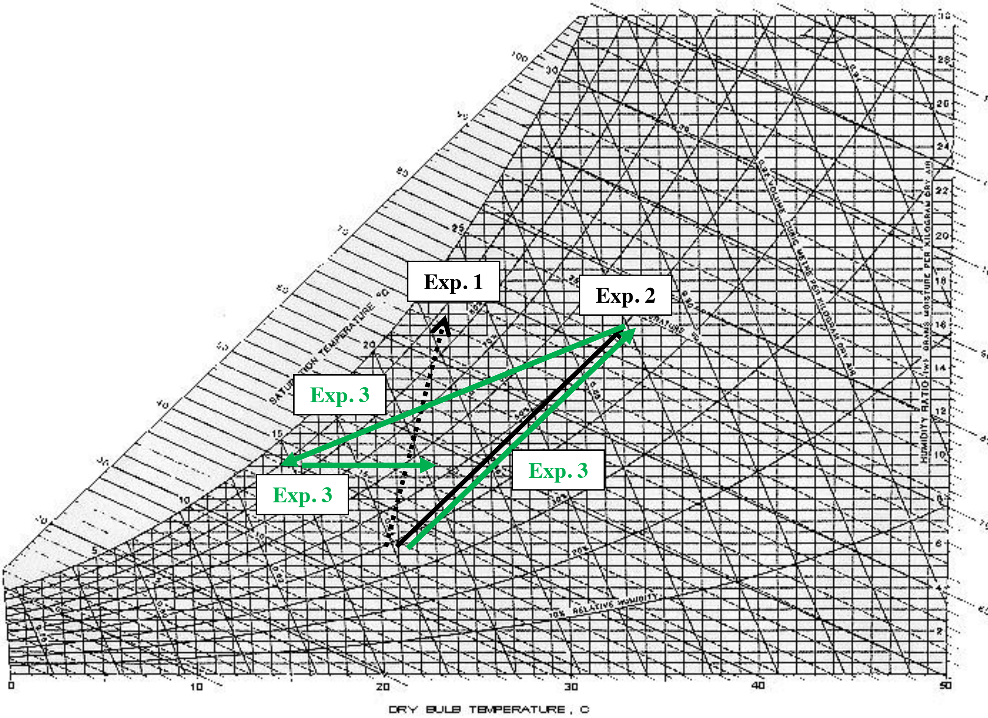
Measurement	Description	Units	Experiment 1	Experiment 2	Experiment 3
*** SETUP ***					
$Q'_{Pre\text{-}Heater}$	Pre-Heater Power	kW			
Q'_{Boiler}	Boiler Power	kW			
Compressor	Compressor On/Off	0 or 1			
$Q'_{Re\text{-}Heater}$	Re-Heater Power	kW			
*** GLOBAL READINGS ***					
z	Orifice Differential Head	mm H_2O			
$\dot{m}_a$	Air-Mass Flow Rate	kg/s			
m'_r	Refrigerant-Mass Flow Rate	kg/s			

m'_w	Condensate Water Collected	mL			
$T_{condensate}$	Time to collect condensate	s			
$\mathbf{m'_{condensate}}$		kg/s			
$\mathbf{P_{Lab}}$	Lab Air Pressure	Pa			
v_E	Specific volume of air at $\mathbf{t_{db} = t_9}$ and $\mathbf{t_{wb} = t_{10}}$	m^3/kg			
*** AIR SIDE ***					
Section A					
$\mathbf{T_1}$	Section A Dry Bulb Temperature	ºC			
$\mathbf{T_2}$	Section A Wet Bulb Temperature	ºC			
Properties	Moisture Content ω	kgH2O/ kg Dry Air			
	Enthalpy h	kJ/kg			
Section B					
$\mathbf{T_3}$	Section B Dry Bulb Temperature	ºC			
$\mathbf{T_4}$	Section B Wet Bulb Temperature	ºC			
Properties	Moisture Content ω	kgH2O/kg Dry Air			
	Enthalpy h	kJ/kg			
Section C					
$\mathbf{T_5}$	Section C Dry Bulb Temperature	ºC			
$\mathbf{T_6}$	Section C Wet Bulb Temperature	ºC			
Properties	Moisture Content ω	kgH2O/ kg Dry Air			
	Enthalpy h	kJ/kg			

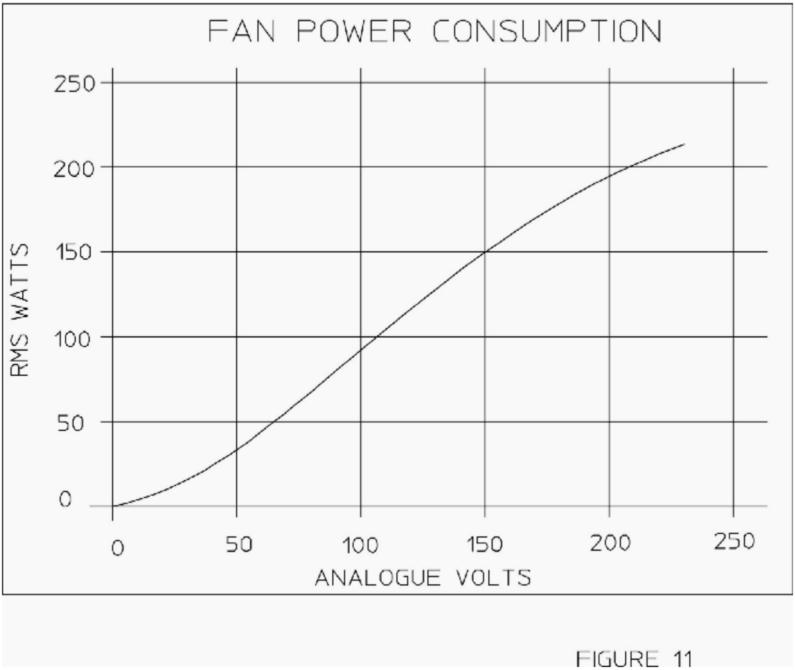
Section D					
T_7	Section D Dry Bulb Temperature	ºC			
T_8	Section D Wet Bulb Temperature	ºC			
Properties	Moisture Content ω	kgH2O/ kg Dry Air			
	Enthalpy h	kJ/kg			
*** REFRIGERANT SIDE ***					
P_{High}	Gauge Condenser Pressure	Bar			
P_{Low}	Gauge Evaporator Pressure	bar			
Evaporator Outlet					
T	Temperature	ºC			
	Enthalpy	kJ/kg			
Compressor Outlet					
T	Temperature	ºC			
	Enthalpy	kJ/kg			
Condenser Outlet					
T	Temperature	ºC			
	Enthalpy	kJ/kg			
Evaporator Inlet					
T	Temperature	ºC			
	Enthalpy	kJ/kg			
Performance					
$Q'_{Condensor}$		kW			
$Q'_{Compressor}$		kW			
$Q'_{Evaporator}$		kW			
C.O.P.	Coefficient of Performance	-			



Schematic of the Experimental Apparatus



The three experimental processes paths if started from the same point (See Objectives for Descriptions)



Fan Power Curve

Data Processing

Section	Processes	Energy Transfer [W]			Moisture Content Change [kg]		
-	-	Measured	Air Side Calculated	Refrigerant Side Calculated	Evaporated (Calculated)	Air Side (Calculated)	Condensate Collected (Measured)
A - B	**Moisture Addition and Pre-Heating**	Register Input Power from Pre-Heater and Boiler Switches $E_{pre\text{-}heater}$= E_{Boiler}= E_{TOTAL}= $E_{pre\text{-}heater}$ + E_{Boiler}	**E = m'a*(h_B - h_A)**	No refrigeration here N/A	**m'v= E_{Bolier} / h_{fg}** **Result=**	$\Delta m'_v$= m'a*(($)_B$- $)_A$)	No Condensation Here! N/A

		Result=	**Result=**			**Result=**		
B - C	**Cooling and Condensation**	None Measurable Here N/A	**E = m'a*(h_C - h_B)** **Result=**	**E = m'r*(h_β - h_α)** **Result=**	No evaporation here N/A	Δm'$_v$= m'a*(( )$_C$-)$_B$) **Result=**	m'$_c$= **Result=**	
C - D	**Re-Heating**	Register Input Power from Re-Heater $E_{re\text{-}heater}$= **Result=**	**E = m'a*(h_D - h_C)** **Result=**	No refrigeration effects here N/A	No evaporation here N/A	Δm'$_v$= m'a*(( )$_D$-)$_C$) **Result=**	No Condensation Here! N/A	

Calculations

(1) Calculate:

(a) Mass flow rate of dry air.

(b) Condensate mass flow rate (where appropriate).

(c) The enthalpy at all sections.

(d) The moisture content at all air sections.

(e) Thermal loads per component and experiment along with C.O.P.

(2) A plot of the various processes on the psychrometric chart. List the following properties: $\mathbf{t_{db}}$, $\mathbf{t_{wb}}$, ϕ, ω, **h** and $\boldsymbol{v}$ tabulated at all the stations along the unit at which measurements are taken.

(3) Present the calculations discussed previously and comment on any discrepancies you observe.

Sheet Questions

(4) What is the importance and level of usage of R134a in industrial applications and why?

(5) What are the sources of discrepancy between the theoretical processes taught and the real processes that you observed in this experiment.

(6) Do you have any suggestions to improve the experimental unit design.

(7) How can you improve this unit's C.O.P.?

Final Requirements

A report covering the sheet questions and the following items should be submitted after **ONE** week from the date of the experiment.

(8) The data sheet for the readings including the averaged final data values of various measured quantities in S.I. units.

(9) Presentations of the processes on the psychrometric and P-h charts provided to you. Make sure that the Lab barometric pressure is very close to the mixture pressure of the chart $\mathbf{P_t}$.

(10) Comment on any discrepancies you observe in heat and moisture transfer processes at all sections.

APPENDICES

A. WRITE UP AND SUBMISSION OF YOUR LAB REPORTS

In general, your lab reports are due one weeks after the experiment, i.e. at the beginning of your next lab session. Your report will be judged on the technical content, but the readers should be able to understand it. Therefore, report should be written in proper English prose with complete sentences. The following sections will help you to understand what is expected from your lab reports i.e. structure of your reports. The formal report should consist of:

Cover Page (use standard KSU cover page)…

Table of Contents (guess what it is?)

Abstract or summary

Introduction

Theoretical Background

Experimental or Numerical method

Results and Discussion

Conclusions

Acknowledgement (if applicable

References

Nomenclature

Appendix (if applicable)

1. Abstract (or Summary)

This section should be about 200 words and present the content of your report and its brief results.

2. Introduction

This section should highlight the importance of the experiment, present some background about the equipment (and system), and state your objectives. Some key questions: What is the aim? What is the motivation for it? That means finding out, where the results from the experiment are used, and why you as an engineer should know about the experiment and its results. For example, can the finding be used to monitor or control flow rates? If so, where and how? Or is the knowledge gained important for the design of machines? Is there any historical background which might be interesting to mention?

3. Theory or Theoretical Background

This section should be present the theory behind the experiment. The governing equations relevant the experiment and for the data analysis should be derived, or at least presented. You may use well known equations without reference, e.g., Newton law or first law of thermodynamics, but all other equations need to be either derived from these, or you need to give a reference to where you found the equation, e.g., text book or lecture notes.

4. Experimental Apparatus and Procedure

This section should describe the experimental apparatus and procedure, with a flow diagram or a schematic diagram of the apparatus used. This diagram, like all other figures, diagrams and graphs needs to be numbered and described in a short caption (e.g., Figure 1. Schematic diagram or layout of the apparatus). The diagram, however, should be supplemented by a textual description of the apparatus. If there are any dimensions or fluid properties which affect the data, results, and conclusions, they should be listed here, possibly in form of a table (Tables also need to be numbered and described in a caption). It might help you to write this section a bit better if you imagine how much you would be able to do the experiment (or even build a new piece of equipment testing the same thing) if the only material given to you is this report. This recommendation applies to all sections of the report.

Please note that this section is not a recipe of how to do the experiment. It is a record of what you did in the experimental session, especially any difficulties you observed, and steps you undertook to remedy them. As in all other sections, the text must not be a list of bullet points. Do not copy exactly from the lab or instruction manual.

5. Results and Discussion

This section should present your results in graphs and tables and their discussion in detail. You should interpret the results and compare them with the predictions from theory. Also, you should try to explain the reasons for discrepancies between your theory and experimental results. To quantify systematic errors (i.e. real differences between theory and results) you need to have done the error estimates of your measurements. If the differences between theory and results are less than your measurement reliability, you cannot even say that there is a difference. On the other hand, if the discrepancies are larger than the reading errors, you must try to find reasons for those differences. These might either lie in the experiment, that it actually doesn't do what the theory predicts, or they might be in the derivation of the equations. (For instance, certain physical phenomena, e.g., viscous friction or eddies/turbulence have been ignored in the derivation but are actually noticeable and give you a persistently different reading from the expected value.

Discharge coefficients are usually found by measuring the systematic difference between the measured and predicted flow rates while random error gives an estimate of the accuracy of the calculated discharge coefficient.)

When you use Excel or Sigma Plot, it is important that you think beforehand about what information the graphs have to convey and how it should look like. Then you have to edit it to show the information as best as possible. For example, sometimes it is useful to have the axes cross at the origin, but sometimes the measurements would all be bunched up in a small corner of the graph sheet. In those cases, it is best to adjust the limits of the axes so that the measurements fill the graph sheet. Since all your measurements are subjected to fluctuations and reading errors, a line going through each individual point is meaningless. Plot only the points and do not join them with a line unless a line is necessary to keep points from different measurement series separate. If several graphs are plotted on the same sheet, use different symbols (crosses, stars, circles etc.). To join the points, use the 'Add Trendline' option in Excel to draw a best-fit curve. This option also returns you the parameters of the best fit, e.g. the gradient of a straight line (to see this you need to select this in the options menu of the trendline menu). Before you add the trendline, think about what type of curve you expect, linear which goes through the origin, quadratic. You should be able to give a theoretical justification for the type of curve you choose.

You should note a typical error margin for each measured quantity, and how you would expect this error margin to affect the reliability of the calculated results. This can be done either by proper error analysis, or by some well-argued estimates. You will have to deal with two kinds of errors; a) random errors, and b) systematic errors. The random errors are due to measurement errors and fluctuations in the desired quantities (e.g. fluid flow, principle stress, thermodynamics variables etc.). These errors will result in an uncertainty of each individual measurement without affecting the overall results. Those kinds of errors need to be estimated in this section, because they help you to state the reliability of your results. Frequently it is enough to identify the largest uncertainty in the measurements, and estimate from this the uncertainty in the results. It is impossible to calculate the systematic errors from your data alone. They need to be guessed by interpretation of your results and therefore need to go into the discussion section.

6. Conclusions

This section should summarize the experiment and its brief concluding remarks. The statement that 'the experiment was a success and objective was met' is not good enough. You need to specify what the success was. For example, you need to specify that you found a reliable estimate of the heat transfer coefficient or thermal efficiency for some specific piece of equipment? If so, what is its value and what is the accuracy of this value? If not, why not? What were the main obstacles? This section often does not state anything new but just draws together the most noteworthy elements of the report and its findings.

7. Acknowledgement

You may use this section to acknowledge the support and help given to you to carry out your experimental work and analysis.

8. Nomenclature

This is a list of symbols used in your report, with the appropriate units.

9. References

In this section, you are required to make a list of the references used in your report. Make sure references are properly cited and are in order. References should be cited consecutively in the text using numbers to refer to the list (e.g. [3], [5-9]). You should list all authors and the titles of the papers with first and last page numbers, volume number and year of publication. For conference reports, sufficient information should be given to enable the readers to identify the reference easily. Material not freely available (e.g., private group communications) should not be included in the references. You should follow the following guidelines to list the references:

- For a text book reference:

1. Siegel, R., and J.R. Howell. *Thermal Radiation Heat Transfer*. McGraw-Hill, New York, 1972.

- For a refereed journal paper:

2. I. Dincer and M.A. Rosen, Exergy as a Driver for Achieving Sustainability. Int. J. Green Energy 1(1), 1-19, 2004.

- For a conference paper:

3. A. Grami, K. Gordon, and A. Shoamanesh "An Advanced Satellite Providing Local and National DBS and Interactive Multimedia Services," in Proceedings of IEEE Wireless Communications and Networking Conference (WCNC'99), New Orleans, September 1999.

- For an article from a book:

4. M.A. Rosen and D.A. Horazak, Energy and Exergy Analyses of PFBC Power Plants. Chapter 11 of Pressurized Fluidized Bed Combustion, ed. M. Alvarez Cuenca and E.J. Anthony, Chapman and Hall, London, England, pp. 419-448, 1995.

- For a web material:

DOE. Fuel Cells, US-Department of Energy, www.doe.org, Accessed on 20 December 2010.

10. Appendix

In this section, you should include your calculations, raw data and anything that you think is relevant to your experiment but is not critical to have in the main body of your report. This section may also contain essential extended explanation of statements in the text.

Final Reminders:

- Report should be written in the third person, in simple and concise terms.
- All figures, illustrations and tables should have captions.
- All equations should be numbered consecutively.
- Sufficient introduction to the subject should be given so that it can be understood readily without undue reference to other publications (especially to your lab manual).

- Reports should be typed (because hand written reports will not be accepted).
- For the record, you should keep a copy of your report.
- You should use A4 sized paper with at least 1” margin on top, bottom and both sides.
- All pages should be numbered.
- On each page your name should appear in the header or footer.
- Use Times New Roman, minimum size 11.
- Normally be a maximum of 3000 words (including the abstract ~200 words).