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Manual :

مختبر حراريات
Thermal Lab

اللجنة الأكاديمية لقسم الهندسة الصناعية

2023

Exp. # 1

Two stage piston type air compressor

Objective:

1. To determine the polytropic index (n), for the compressor.
2. To calculate the isothermal and polytropic work.
3. To calculate the isothermal efficiency.

Apparatus:

Two stage piston type air compressor, operated by an electrical motor coupled by means of pulleys and V-belt.

The compressed air outgoing from the first stage of the compressor passes through a water/air heat exchanger (intercooler), then it is sucked by the second stage. The outlet air from the second stage passes through a second exchanger (after cooler) and it is sent to the storage tank. (See fig. 1).

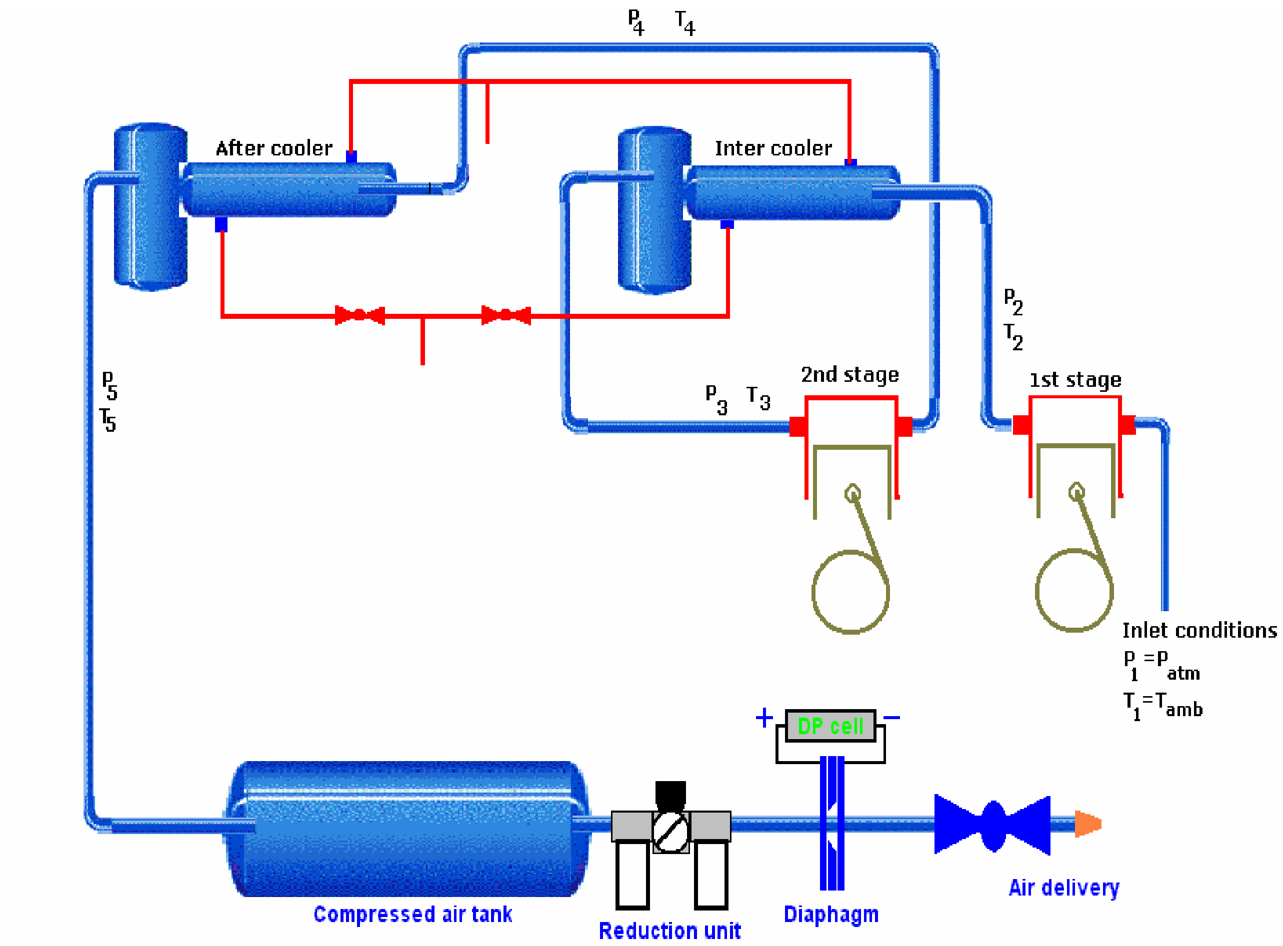


Fig. 1 Two stage piston type air compressor

- ***State 1 : inlet conditions to first stage.***

P_1: Atmospheric pressure.
T_1: Ambient temperature.

- ***State 2 : outlet from first stage, inlet to intercooler.***

P_2: Pressure of air outlet from first stage.
T_2: Temperature of air outlet from first stage.

- ***State 3 : outlet from intercooler, inlet to second stage.***

P_3: Pressure of air outlet from intercooler. ($P_3 = P_2$)
T_3: Temperature of air outlet from intercooler.

- ***State 4 : outlet from second stage, inlet to after cooler.***

P_4: Pressure of air outlet from second stage.
T_4: Temperature of air outlet from second stage.

- ***State 5 : outlet from after cooler, inlet to storage tank.***

P_5: Pressure of air outlet from after cooler. ($P_5 = P_4$)
T_5: Temperature of air outlet from after cooler.

Theory:

3.1 P-V Diagram for an ideal compressor (fig. 2).

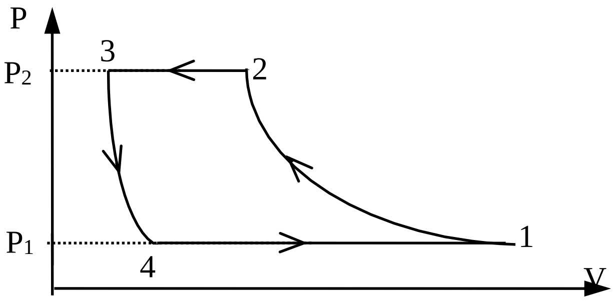


Fig. 2

1-2: Compression process: both valves are closed; air is compressed from P_1 to P_2.
2-3: discharge process: Exit valve is open, air is supplied to the tank at P_2.
3-4: Expansion process: both valves are closed; air in clearance volume expands to original state P_1.
4-1: intake process: inlet valve is open; air enters the cylinder at state 1, and mixed with air already present in the clearance volume.

3.2 Compression of gases (process 1-2).

1. Isothermal compression:

The compression of gases occurs at constant temperature (fig.3) from state 1 to state 2.
The equation of path for this process is given by :

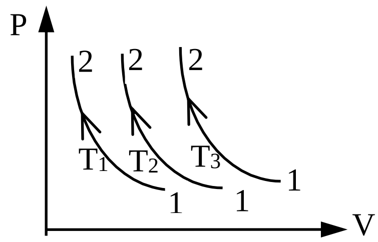


Fig. 3

PV = constant....................... (1)

The isothermal work is given by:

$$W_{iso} = PVLn\frac{V_2}{V_1} = PVLn\frac{P_1}{P_2} = mRT_1Ln\frac{P_1}{P_2} \quad .... (2)$$

Where P: Absolute pressure (bar).
V: Specific volume (m^3/kg).
m: Intake mass flow rate of air (kg/s).
T_a: Temperature of inlet air (ambient temperature).
R: Gas constant (For air = 287.14 j/kg K).
The subscripts 1,2 denotes for initial and final states.

2. Adiabatic compression (isentropic):

The compression is of adiabatic type if it is performed with out thermic exchange with the outside. Of course, in this case the temperature cannot remain constant during the transformation.
On P-V field, the equation of path is given by:

$$PV^{\gamma} = \text{constant}$$

Where the exponent γ is the specific heat ratio, and it is a function molecular structure of the gas (for air γ = 1.4)

3. Polytropic compression:

Actually, the compression of gases takes place with some kind of thermic exchange with the out side. The transformation is called polytropic, which is intermediate between the isothermal and adiabatic ones.
The equation of the polytropic bath and polytropic work is given by:

$$PV^{n} = \text{constant} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$W_P = \frac{n}{n-1} m R T_1 \left(\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right) \quad \ldots\ldots\ldots\ldots (4)$$

Where n is the polytropic index.

The polytropic index is a general process, and all other processes is a special case of the polytropic one, so when: (see fig. 4)

n = 0 P = constant (isobaric process) $W = P(V_2 - V_1) = mR(T_2 - T_1)$.

n = ∞ V = constant (isochoric process) W = 0.

n = 1 T = constant (isothermal process) $W = mRT_1 \, \text{Ln} \frac{P_1}{P_2}$.

n = γ S = constant (isentropic process) $W = \left(mRT_1 \left(\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} \right) - 1 \right)$.

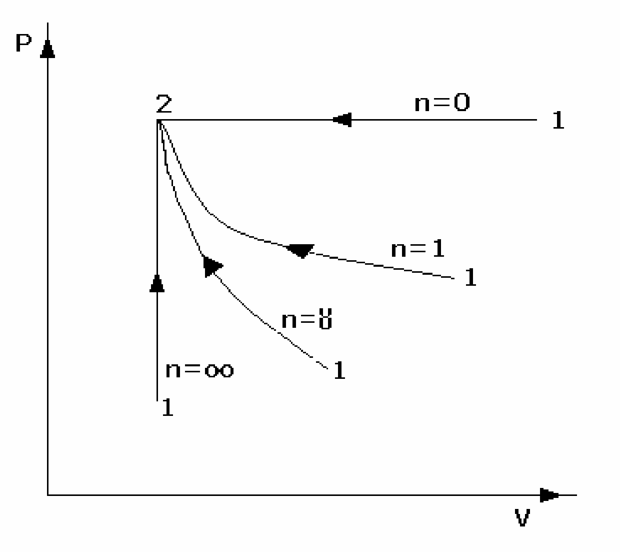


Fig. 4

The compression produced by a very fast reciprocating compressor is very close to the adiabatic type, since the short period of time in which transformation take place don't allow an effective thermal exchange with the out side. But for intermediate speed compressors (500-1000 rpm) the compression occurs according to the polytropic process. The work done on air through compression decreases as n decreases, for this reason the compressor cylinder should be cooled. The compression work is minimum when n=1 (i.e.) for isothermal process. The isothermal efficiency is defined as:

$$\eta_{iso} = \frac{\text{Isothermal Work}}{\text{Actual indicated Work}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The P-V diagram for a reversible two stage compressor is shown in fig. 5 , air is compressed from P_a to intermediate pressure P_1 , in the low pressure cylinder and then Transferred to the high pressure cylinder for final compression to P_2 .
Equation 4 indicates that the work required decreases as the inlet temperature decreases, so an inter cooler is fitted between the stages. Cooling the air leaving the first stage to T_1 before it enters the second stage, the work required to drive the second is reduced, fig. 5 illustrate this, shaded area represents the saving in work.

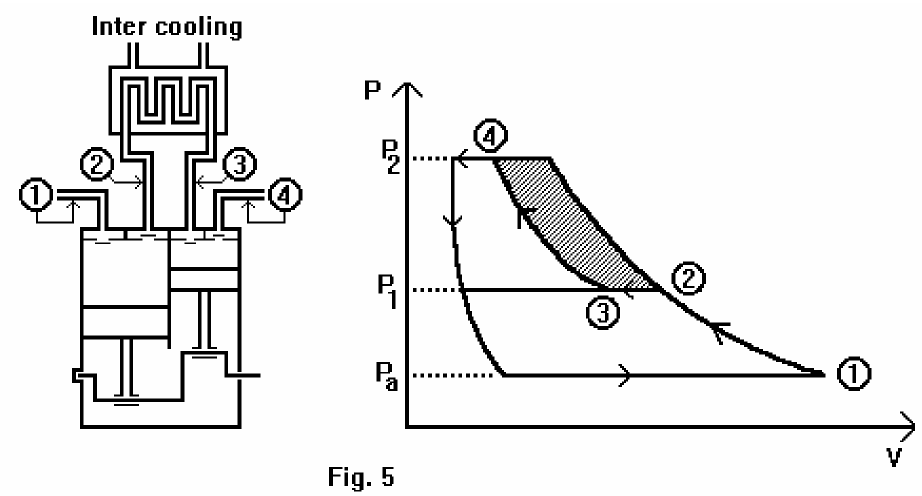


Fig. 5

4. PROCEDURE:

1. Turn on the power supply to start the compressor.
2. Turn on the cooling water and adjust flow rates to a suitable value.
3. Adjust the compressor speed to 1200 rpm using the potentiometer.
4. Open the exit valve, so that the second stage pressure P_2 is 2 bars.
5. Record all temperatures, pressures, voltmeter, ammeter and the manometer readings.
6. Readjust the exit valve, so that P_2= 3 bar, and record all values as step 4.
7. Repeat steps 3, 4 and 5 for different values of P_2.
8. Fill the results at table 1.
9. Turn off the compressor, turn off the cooling water and allow air to release, and drain water from cylinder and coolers.

5. RESULTS:

Ambient temperature $T_a = T_1$= °C Atmospheric pressure $P_a = P_1$= bar

Test	Speed	Electrical Power		After stage 1		After intercooler	After stage 2		After Second cooler	Air flow rate
No.	rpm	V volts	I amp	P_2	T_2	T_3	P_4	T_4	T_5	
1										
2										
3										
4										
5										

Table: 1

6. CALCULATIONS:

1. Polytropic index (n)

PV^n = constant

$P_1V_1^n = P_2V_2^n$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \quad \text{...} \quad (10)$$

From gas law $P_1V_1 = mRT_1$

$P_2V_2 = mRT_2$

$$\text{So} \quad \frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2} \quad \text{...} \quad (11)$$

From equations 10 & 11

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

$$\mathrm{Ln}\frac{P_2}{P_1} = \frac{n}{n-1}\mathrm{Ln}\frac{T_2}{T_1}$$

The last equation is a line of form Y = S X where S is the slop.
So for the first stage calculate

$Ln\frac{P_2}{P_1}, Ln\frac{T_2}{T_1}$ Then Plot $Ln\frac{P_2}{P_1} Against Ln\frac{T_2}{T_1}$ and find the slop S_1 , and from the slop find the polytropic index n_1 .

Similar plot $Ln\frac{P_4}{P_3} Against\ Ln\frac{T_4}{T_3}$ and find n_2 .

2. Work

<u>a. Isothermal specific work:</u>

For first stage $(W_{iso})_1 = R\,T_1\,\mathrm{Ln}\frac{P_1}{P_2}$.

For second stage $(W_{iso})_2 = R\,T_3\,\mathrm{Ln}\frac{P_3}{P_4}$

<u>b. Polytropic specific work:</u>

For first stage $(W_p)_1 = \frac{n_1}{n_1-1}\left(mRT_1\left(\left(\frac{P_2}{P_1}\right)^{\frac{n_1-1}{n_1}}-1\right)\right)$

For second stage $(W_p)_2 = \frac{n_2}{n_2-1}\left(mRT_3\left(\left(\frac{P_4}{P_3}\right)^{\frac{n_2-1}{n_2}}-1\right)\right)$

3. Indicated isothermal efficiency:

$$(\eta_{iso})_1 = \frac{(W_{iso})_1}{(W_p)_1} \quad \text{for the first stage.}$$

$$(\eta_{iso})_2 = \frac{(W_{iso})_2}{(W_p)_2} \quad \text{for the second stage.}$$

$$\eta_{iso} = \frac{(W_{iso})_1 + (W_{iso})_2}{(W_p)_1 + (W_p)_2} \quad \text{for the compressor.}$$

Exp. # 1

GAS CALORIFIC VALUE

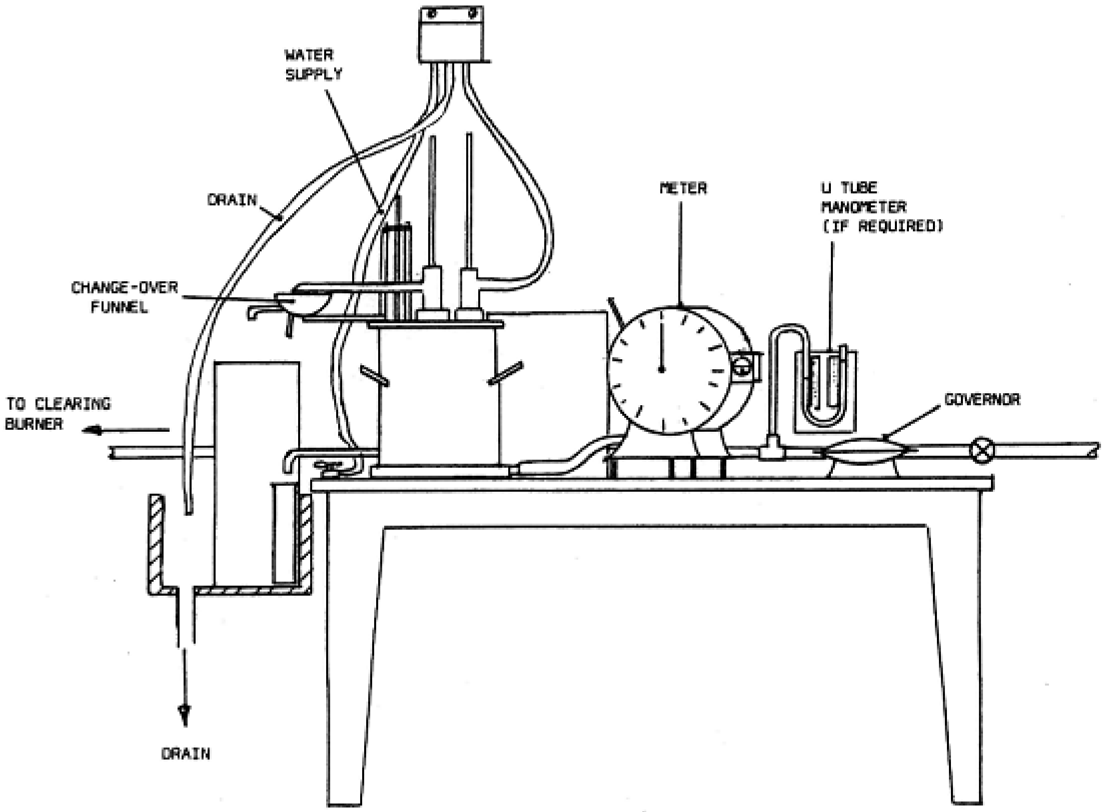
Objective:

To determine the calorific value of a gaseous fuel.

Apparatus:

Boys gas calorimeter, with the following parts and instruments:

- Gaseous fuel source.
- Water source and sink.
- Gas control valve.
- Pressure reducing valve.
- “Hyde meter” (Gas meter): To measure the flow rate of the gas, where 2 liter of gas flows per one revolution.
- The calorimeter with burner.
- Alkaline bath.
- Thermometers.
- Stopwatch.
- Graduated glass vessel.



Theory:

The calorific value of any fuel is defined as the amount of heat generated by completely burning (1m3 or 1kg) of that fuel.

In this experiment a given amount of gaseous fuel is burned, and then the generated heat is used to heat a measured amount of water, so:

$$\text{Calorific value} = \frac{M_w \times C_{p(water)} \times \Delta T_{avg} \times (G.V)}{V_f} \qquad \text{.................................} \ (1)$$

Where:

M_w : The amount of water collected (L).

$C_{p\ (water)}$: Specific heat of water (4.18 kj/kgK).

ΔT_{avg}. : Average difference of water temperature between inlet and outlet.

G.V : Gas volume factor which can be found from table (3) at atmospheric pressure and average gas temperature.

V_f : Volume of burned fuel = No. of revolutions $\times$ 2 (L).

= No. of revolutions $\times$ 2 $\times$ 10^{-3} (m^3).

Procedure:

1. Turn the gas supply on, light the burner, and adjust gas flow rate using gas control valve to give one revolution per minute at the Hyde meter.
2. Turn on water to over head funnel, with small over flow to the sink.
3. Lift the coils from the alkali bath (allow to drain for few minutes) and lower into the calorimeter casing.
4. Allow gas to burn and water run about 45 min. to reach the steady state.
5. Read and record the temperature of the inlet gas by the thermometer on Hyde meter.
6. When the pointer of Hyde meter at (100), turns change over funnel at 300ml beaker to measure the amount of water.
7. Through a number of a revolutions, record inlet and outlet water temperature (T_{wi}, T_{wo}) at each half revolution.
8. At the completion of the last revolution. Turn change over funnel to sink, then record the values of the water temperatures, the inlet gas temperature and amount of water collected.
9. Record the atmospheric pressure.
10. Fill the results at tables 1 & 2.

Analysis:

1. Find the average difference of water temperature.
2. At atmospheric pressure and average inlet gas temperature, find the gas volume factor (G.V) from table 3.1 & 3.2.
3. Calculate the calorific value using equation 1.

Results:

Temperature (^oC)	Number of Revolutions					
	0.5	1.0	1.5	2.0	2.5	3.0
T_{wi}						
T_{wo}						

Table: 1

$(T_g)_{initial}$	$(T_g)_{final}$	Volume of water (L)	Patm. (mbar)	G.V

Table: 2

P_{atm}								Temperature(°C)								$P_{atm.}$
mm Hg	*10*	11	*12*	13	*14*	15	*16*	17	*18*	19	*20*	21	*22*	23	*24*	mm Hg
730	*1.095*	1.098	*1.101*	1.105	*1.108*	1.111	*1.116*	1.121	*1.126*	1.132	*1.137*	1.142	1.148	1.154	*1.160*	**730**
732	*1.092*	1.095	*1.098*	1.101	*1.105*	1.108	*1.113*	1.118	*1.123*	1.128	*1.134*	1.139	*1.145*	1.151	*1.157*	**732**
734	*1.089*	1.092	*1.095*	1.098	*1.102*	1.105	*1.110*	1.115	*1.120*	1.125	*1.131*	1.136	*1.142*	1.148	*1.154*	**734**
736	*1.085*	1.088	*1.092*	1.095	*1.099*	1.102	*1.107*	1.112	*1.117*	1.122	*1.128*	1.133	*1.139*	1.145	*1.151*	**736**
738	*1.081*	1.085	*1.088*	1.092	*1.095*	1.099	*1.104*	1.109	*1.114*	1.119	*1.125*	1.130	*1.136*	1.142	*1.148*	**738**
740	*1.077*	1.081	*1.085*	1.088	*1.092*	1.096	*1.101*	1.106	*1.111*	1.116	*1.122*	1.127	*1.133*	1.139	*1.145*	**740**
742	*1.074*	1.078	*1.082*	1.085	*1.089*	1.093	*1.098*	1.103	*1.108*	1.113	*1.119*	1.124	*1.130*	1.136	*1.142*	**742**
744	*1.071*	1.075	*1.079*	1.082	*1.086*	1.090	*1.095*	1.100	*1.105*	1.110	*1.116*	1.121	*1.127*	1.133	*1.139*	**744**
746	*1.068*	1.072	*1.076*	1.079	*1.083*	1.087	*1.092*	1.097	*1.102*	1.107	*1.113*	1.118	*1.124*	1.130	*1.136*	**746**
748	*1.065*	1.069	*1.073*	1.076	*1.080*	1.084	*1.089*	1.094	*1.099*	1.104	*1.110*	1.115	*1.121*	1.126	*1.132*	**748**
750	*1.062*	1.066	*1.070*	1.073	*1.077*	1.081	*1.086*	1.091	*1.096*	1.101	*1.107*	1.112	*1.118*	1.123	*1.129*	**750**
752	*1.059*	1.063	*1.067*	1.070	*1.074*	1.078	*1.083*	1.088	*1.093*	1.098	*1.104*	1.109	*1.115*	1.120	*1.126*	**752**
754	*1.056*	1.060	*1.064*	1.067	*1.071*	1.075	*1.080*	1.085	*1.090*	1.095	*1.101*	1.106	*1.112*	1.117	*1.123*	**754**
756	*1.053*	1.057	*1.061*	1.064	*1.068*	1.072	*1.077*	1.082	*1.087*	1.092	*1.098*	1.103	*1.109*	1.114	*1.120*	**756**
758	*1.050*	1.054	*1.058*	1.061	*1.065*	1.069	*1.074*	1.079	*1.084*	1.089	*1.095*	1.100	*1.106*	1.111	*1.117*	**758**
760	*1.047*	1.051	*1.055*	1.058	*1.062*	1.066	*1.071*	1.076	*1.081*	1.086	*1.092*	1.097	*1.103*	1.108	*1.114*	**760**
762	*1.044*	1.048	*1.052*	1.055	*1.059*	1.063	*1.068*	1.073	*1.078*	1.083	*1.089*	1.094	*1.100*	1.105	*1.111*	**762**
764	*1.042*	1.046	*1.049*	1.053	*1.056*	1.060	*1.065*	1.070	*1.075*	1.080	*1.086*	1.091	*1.097*	1.102	*1.108*	**764**
766	*1.039*	1.043	*1.046*	1.050	*1.053*	1.057	*1.062*	1.067	*1.072*	1.077	*1.083*	1.088	*1.094*	1.099	*1.105*	**766**
768	*1.037*	1.041	*1.044*	1.047	*1.050*	1.054	*1.059*	1.064	*1.069*	1.074	*1.080*	1.085	*1.091*	1.096	*1.102*	**768**
770	*1.034*	1.038	*1.042*	1.045	*1.048*	1.052	*1.057*	1.062	*1.067*	1.072	*1.078*	1.083	*1.089*	1.094	*1.100*	**770**
772	*1.031*	1.035	*1.039*	1.042	*1.045*	1.049	*1.054*	1.059	*1.064*	1.069	*1.075*	1.080	*1.086*	1.091	*1.096*	**772**
774	*1.029*	1.031	*1.035*	1.038	*1.041*	1.046	*1.051*	1.056	*1.061*	1.066	*1.072*	1.077	*1.083*	1.088	*1.094*	**774**
776	*1.026*	1.029	*1.032*	1.036	*1.039*	1.043	*1.048*	1.053	*1.058*	1.063	*1.069*	1.074	*1.080*	1.085	*1.091*	**776**
778	*1.024*	1.027	*1.030*	1.033	*1.037*	1.040	*1.045*	1.050	*1.055*	1.060	*1.066*	1.071	*1.077*	1.082	*1.088*	**778**
780	*1.021*	1.025	*1.028*	1.031	*1.033*	1.038	*1.043*	1.048	*1.053*	1.058	*1.063*	1.068	*1.074*	1.079	*1.085*	**780**

$P_{amt.}$	Temperature(°C)															$P_{atm.}$
Mm Hg	***25***	**26**	***27***	**28**	***29***	**30**	***31***	**32**	***33***	**34**	***35***	**36**	***37***	**38**	***39***	**mm Hg**
730	*1.166*	1.173	*1.180*	1.187	*1.194*	1.201	*1.208*	1.216	*1.223*	1.231	*1.236*	1.247	*1.256*	1.266	*1.275*	**730**
732	*1.163*	1.169	*1.176*	1.183	*1.190*	1.197	*1.205*	1.212	*1.220*	1.227	*1.235*	1.244	*1.253*	1.263	*1.272*	**732**
734	*1.160*	1.166	*1.173*	1.180	*1.187*	1.194	*1.201*	1.209	*1.216*	1.224	*1.231*	1.240	*1.249*	1.259	*1.268*	**734**
736	*1.157*	1.164	*1.171*	1.178	*1.185*	1.191	*1.198*	1.205	*1.212*	1.220	*1.228*	1.237	*1.246*	1.255	*1.264*	**736**
738	*1.154*	1.161	*1.168*	1.174	*1.180*	1.187	*1.194*	1.202	*1.209*	1.217	*1.224*	1.233	*1.242*	1.251	*1.260*	**738**
740	*1.151*	1.158	*1.164*	1.171	*1.178*	1.184	*1.191*	1.199	*1.206*	1.214	*1.221*	1.230	*1.239*	1.247	*1.256*	**740**
742	*1.148*	1.155	*1.161*	1.168	*1.175*	1.181	*1.188*	1.196	*1.203*	1.210	*1.218*	1.227	*1.235*	1.244	*1.252*	**742**
744	*1.145*	1.152	*1.158*	1.165	*1.172*	1.178	*1.185*	1.193	*1.200*	1.208	*1.215*	1.223	*1.232*	1.240	*1.249*	**744**
746	*1.142*	1.148	*1.155*	1.161	*1.168*	1.174	*1.181*	1.189	*1.196*	1.204	*1.211*	1.220	*1.228*	1.237	*1.245*	**746**
748	*1.138*	1.145	*1.151*	1.158	*1.165*	1.171	*1.178*	1.186	*1.193*	1.201	*1.208*	1.216	*1.225*	1.233	*1.242*	**748**
750	*1.135*	1.142	*1.148*	1.155	*1.161*	1.167	*1.174*	1.182	*1.169*	1.197	*1.204*	1.212	*1.221*	1.229	*1.238*	**750**
752	*1.132*	1.139	*1.145*	1.152	*1.158*	1.164	*1.171*	1.179	*1.186*	1.194	*1.204*	1.209	*1.218*	1.226	*1.235*	**752**
754	*1.129*	1.136	*1.142*	1.149	*1.155*	1.161	*1.168*	1.175	*1.183*	1.190	*1.197*	1.205	*1.214*	1.222	*1.231*	**754**
756	*1.126*	1.133	*1.139*	1.146	*1.153*	1.158	*1.165*	1.172	*1.180*	1.187	*1.194*	1.202	*1.211*	1.219	*1.228*	**756**
758	*1.123*	1.130	*1.136*	1.143	*1.149*	1.155	*1.162*	1.169	*1.176*	1.183	*1.190*	1.198	*1.207*	1.215	*1.224*	**758**
760	*1.120*	1.127	*1.133*	1.140	*1.146*	1.152	*1.159*	1.166	*1.173*	1.180	*1.137*	1.195	*1.204*	1.212	*1.221*	**760**
762	*1.117*	1.124	*1.130*	1.137	*1.143*	1.149	*1.156*	1.163	*1.170*	1.177	*1.134*	1.191	*1.200*	1.208	*1.217*	**762**
764	*1.114*	1.120	*1.126*	1.133	*1.139*	1.145	*1.152*	1.159	*1.167*	1.174	*1.131*	1.189	*1.197*	1.206	*1.214*	**764**
766	*1.111*	1.117	*1.123*	1.129	*1.136*	1.142	*1.149*	1.156	*1.163*	1.170	*1.177*	1.185	*1.194*	1.202	*1.210*	**766**
768	*1.108*	1.114	*1.120*	1.126	*1.132*	1.139	*1.146*	1.153	*1.160*	1.167	*1.174*	1.182	*1.190*	1.199	*1.207*	**768**
770	*1.105*	1.111	*1.117*	1.123	*1.130*	1.136	*1.143*	1.150	*1.157*	1.164	*1.171*	1.179	*1.187*	1.196	*1.204*	**770**
772	*1.102*	1.108	*1.114*	1.120	*1.126*	1.133	*1.140*	1.147	*1.154*	1.161	*1.168*	1.176	*1.184*	1.193	*1.201*	**772**
774	*1.099*	1.105	*1.111*	1.117	*1.123*	1.130	*1.137*	1.144	*1.151*	1.158	*1.165*	1.173	*1.131*	1.189	*1.197*	**774**
776	*1.096*	1.102	*1.108*	1.114	*1.120*	1.127	*1.134*	1.141	*1.147*	1.154	*1.161*	1.169	*1.177*	1.186	*1.194*	**776**
778	*1.093*	1.099	*1.105*	1.111	*1.117*	1.124	*1.131*	1.138	*1.144*	1.151	*1.158*	1.165	*1.173*	1.181	*1.189*	**778**
780	*1.090*	1.096	*1.102*	1.108	*1.114*	1.121	*1.128*	1.155	*1.141*	1.148	*1.155*	1.162	*1.169*	1.176	*1.183*	**780**

Table 3.1: Gas Volume Factor.

Exp. # 1

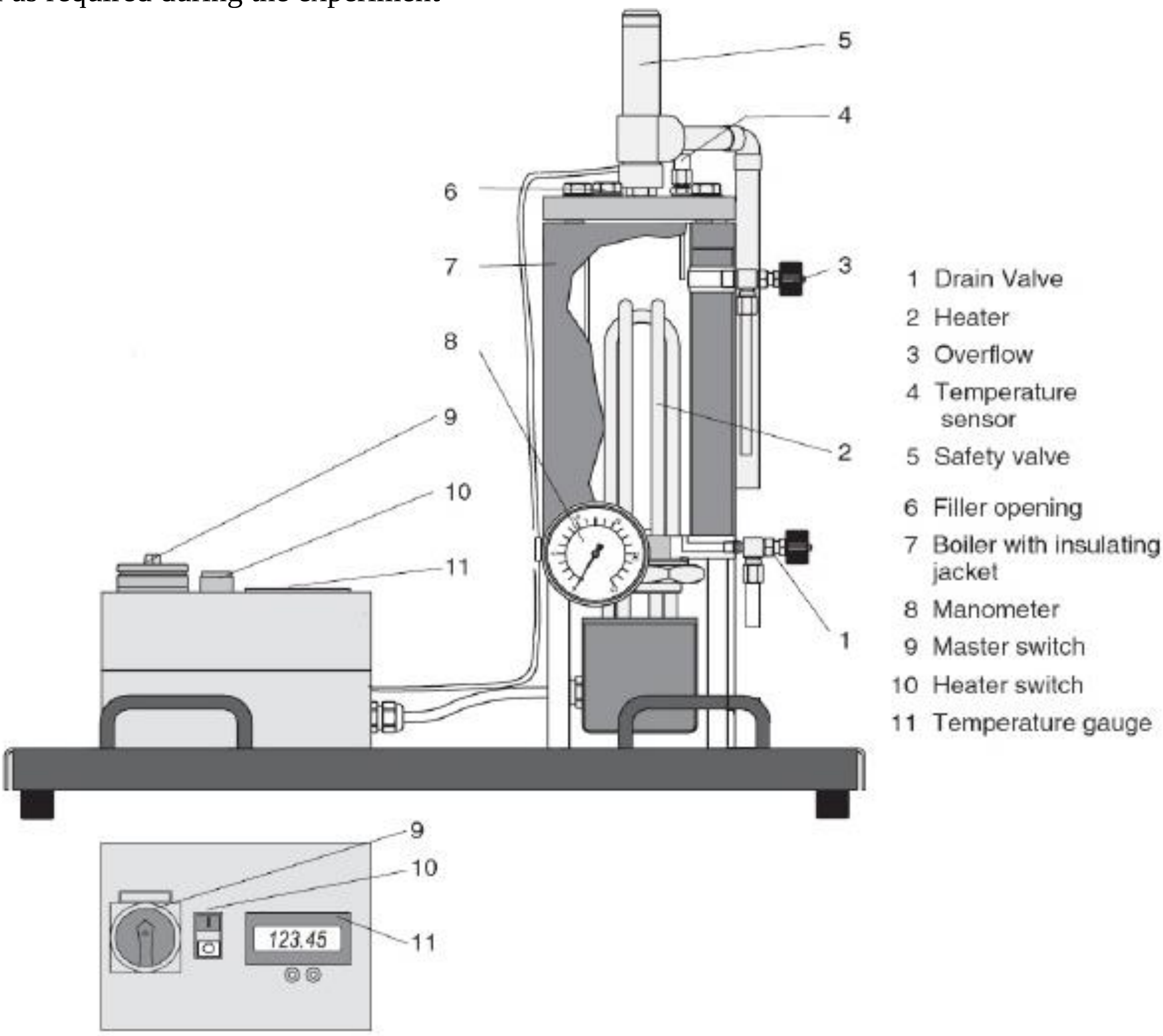
Marcet boiler

Objective:

To investigate the relationship between (pressure) and (temperature) of a saturated steam, in equilibrium with (water).

Apparatus:

The main element of the WL 204 unit is the stainless steel steam boiler (7). It has a mineral wool insulating jacket. The filler opening (6) is used to pour water into the boiler. The overflow valve (3) closed off by means of a hand wheel, is used to ensure the vessel is filled to the correct level. The drain valve (1) can be used to drain the vessel. An electrical heater (2) is bolted to the floor of the boiler in such a way that the heating filament protrudes from below into the boiler. A manometer (8) is fitted in the lid of the boiler to provide a direct indication of the boiler pressure. There is also a temperature sensor (4) to measure the boiler temperature, and a safety valve (5) to prevent excess pressure build-up in the boiler. The boiler temperature can be read from the digital display (11) fitted into the switch cupboard. The unit is switched on at the master switch (9). The additional heater switch (10) can be used to switch the heater on and off as required during the experiment



Theory:

At a given pressure, the temperature at which a pure substance changes phase is called the saturation temperature Tsat. Similarly, at a given temperature, the pressure at which a pure substance changes phase is called the saturation pressure Psat.

This experiment explores the relationship between the saturation temperature and the corresponding pressure for water.

The water inside the boiler is heated up by the electrical resistance and starts to evaporate. As more water changes phase from liquid to vapor, more vapor accumulates inside the boiler vessel and increases the pressure imposed on the water surface. This pressure buildup tends to increase the resistance faced by liquid molecules as they change into vapor, consequently increasing the saturation pressure of the remaining liquid.

For a pure substance existing as a mixture of two phases, the Clapeyron relationship relates the pressure, heat and expansion during a change of phase provided that the two phases are in equilibrium. The Clapeyron relationship is:

$$\frac{dT}{dP} = \frac{T\left(v_g - v_f\right)}{h_{fg}} = \frac{Tv_g}{h_{fg}}$$

where:

v_f	specific volume of water.
v_g	specific volume of steam.
h_f	enthalpy of water.
h_g	enthalpy of steam.
h_{fg}	latent heat of vaporization = h_g - h_f.
T	absolute temperature.
P	absolute pressure.

Procedure:

The boiler need only be filled once before the unit is run for the first time. The level should subsequently be routinely checked at regular intervals after a certain number of experiments have been performed.-

- Place the bench top unit on a flat surface.-
- Fit the enclosed section of tubing to the overflow and open the valve (3).
- Fill the enclosed section of tubing to the drain (1) and close the valve.
- Remove the plug from the filler opening (6) and pour water into the boiler until it emerges at the overflow.
- Close the off the filler opening again with the plug.
- Connect the unit to the main electricity supply.

- Switch on the unit at the master switch (9).
- Press the heater switch (10) to start the experiment.
- Heat up the boiler to 100 ºC. let the water cook approx. 1 min, so the steam can pass through the open valve (3)
- Close off the valve (3) again
- Log the boiler pressure and temperature values in the table below
- After the experiment switch off the unit at the master switch and leave the boiler to cool down.

Analysis:

1. Plot the graph of temperature against pressure experimentally and theoretically
2. Find the slop value experimentally and theoretically, (to measure the slop $\left(\frac{dT}{dP}\right)_{\text{expermental}}$ take previous & next values of pressure and temperature for each record.)

Conclusion:

Point out any possible of error

Working Sheet:

Test No.	Gauge pressure (bar)	Absolute pressure	Steam temperature (°C)	Experimental slope	Theoretical slope	Error percentage%
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Atmospheric pressure:						

Pressure (P) bar	Temperature (T) °C	Specific volume (v_g) m^3/kg	Latent heat of vaporization (h_{fg})
1.0	99.6	1.694	2258
2.0	120.0	0.8856	2202
3.0	133.5	0.6057	2164
4.0	143.6	0.4623	2134
5.0	151.8	0.3748	2109
6.0	158.8	0.3156	2087
7.0	165.0	0.2728	2067
8.0	170.4	0.2403	2048
9.0	175.4	0.2149	2031
10.0	179.9	0.1944	2015
11.0	184.1	0.1774	2000
12.0	188.0	0.1632	1986
13.0	191.6	0.1512	1972
14.0	195.0	0.1408	1960
15.0	198.3	0.1317	1947
16.0	201.4	0.1237	1935
17.0	204.3	0.1167	1923
18.0	207.1	0.1104	1912
19.0	209.8	0.1047	1901
20.0	212.4	0.09957	1890

Table 1: Saturated Water and Steam Tables

Exp. # 7

Refrigeration Cycle

Objective:

To demonstrate the refrigeration cycle as a part of the air conditioning system, and to find the coefficient of performance of both refrigerator and heat pump.

Theory:

A refrigerator is a machine whose function is to remove heat from a low temperature region, and dissipated it to a high temperature region (surroundings). According to the Clausius statement of second law of thermodynamics, which states that heat will not transfer from a cold body to a hotter one unless work is added to the system. So the refrigerator will require an external work, which is the compressor work as shown in figure (1).

If the function of the system is to use the dissipated heat at high temperature e.g. for space heating, then the machine is called a heat pump.

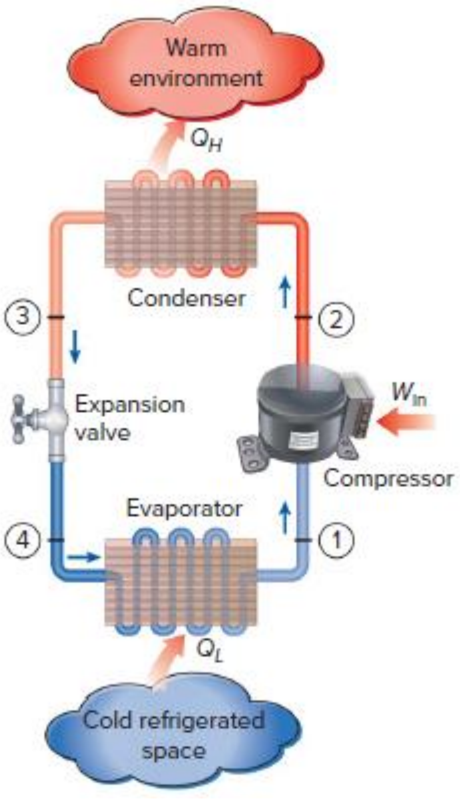


Figure (1): Refrigeration cycle

The ideal vapor compression refrigeration cycle (reversible Carnot cycle) has four thermodynamic processes which can be drawn on P-h diagram (Fig 2) where:

Process (1-2) : Compression

Isentropic process in compressor, the compressor increases the pressure and temperature (i.e. enthalpy) of the refrigerant.

Process (2-3) : Condensation

Condensation through the condenser at a constant pressure and temperature, so at point (3) refrigerant is saturated liquid.

Process (3-4) : Expansion

Refrigerant expands from high pressure P3 to low pressure P4 at constant enthalpy.

Process (4-1) : Evaporation

Refrigerant boils and evaporate in the evaporator at a constant pressure and temperature.

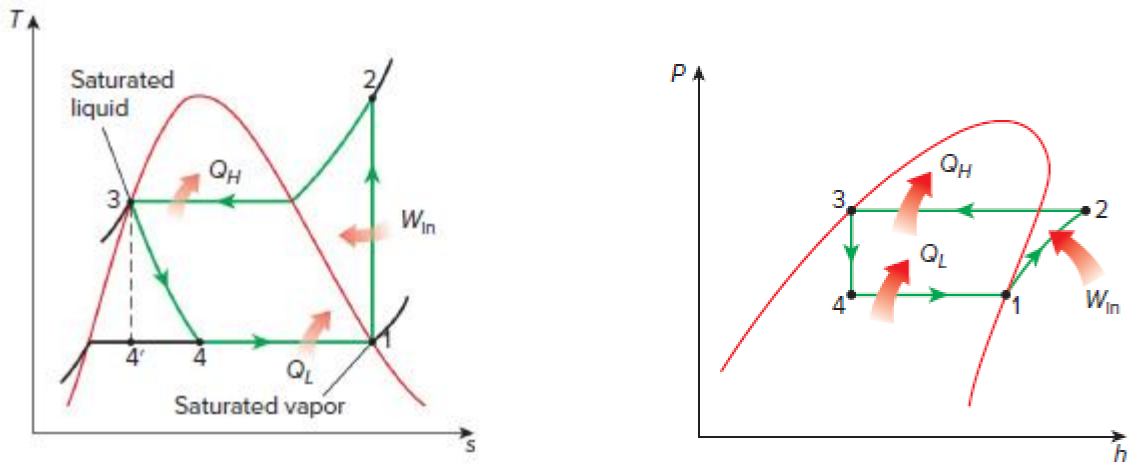


Figure (2): The T-S and P-h diagrams of an ideal vapor compression refrigeration cycle.

Coefficient of performance of a refrigeration cycle is defined as: the amount of heat removed from the cooling space to the work done by the compressor:

$$COP_R = \frac{Q_L}{W}$$

Where:

Q_L : Heat absorbed at evaporator (kW). $Q_L = m_{ref}\,(h_1 - h_4)$

Q_H : Heat rejected from condenser (kW). $Q_H = m_{ref}\,(h_2 - h_3)$

W : Compressor work (kW). $Q_H = Q_L + W$

h_1, h_2, h_3, and h_4 are enthalpies at the given temperature and pressure (experimentally) in (kJ/kg).

m_{ref} is the refrigerant flow rate (kg/s).

The actual cycle is different from the ideal one because the pressure losses both in the evaporate and in the condenser, which clarify the bending of the straight lines (3-4) and (7-8). The section 1-2' represents the actual behavior of the compression and entropy increases due to the irreversible processes, therefore the compression line 1-2' comes out to be a polytrophic curve with variable component.

Moreover the compressor does not take any liquid, so it is necessary to have a sight superheating of the intake vapor

The actual cycle is shown in figure (3)

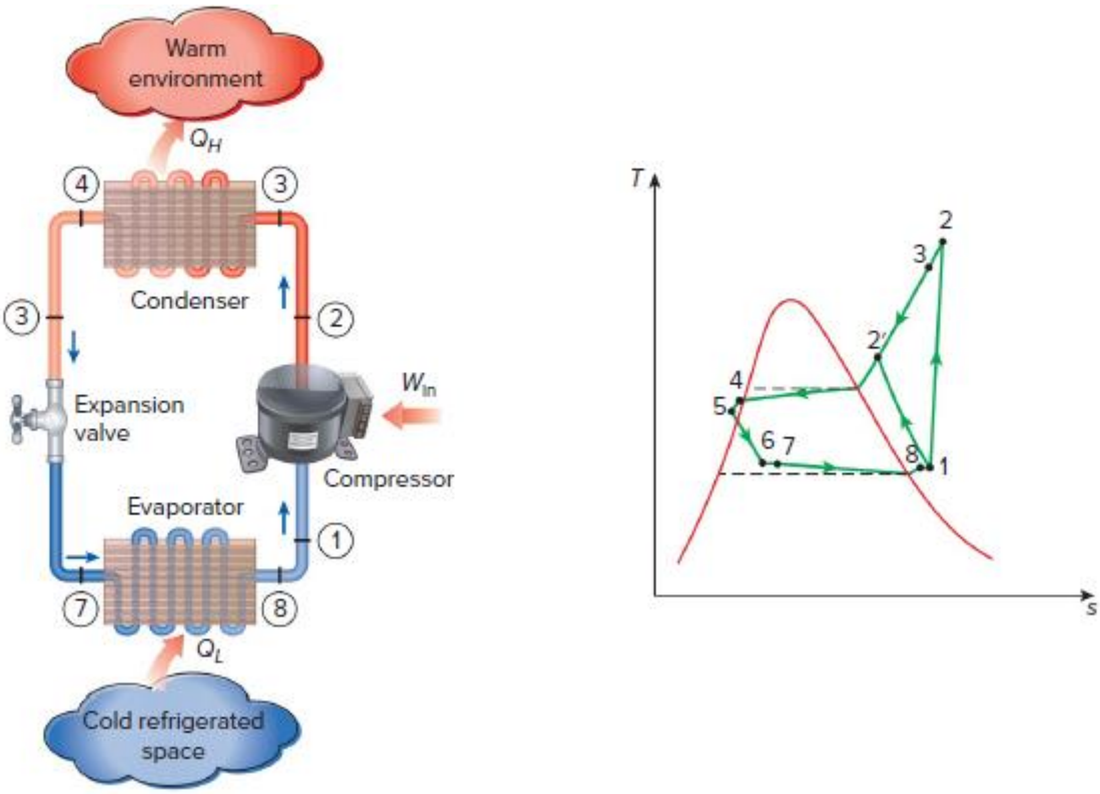


Figure (3): Schematic and T-s diagram for the actual vapor-compression refrigeration cycle.

Apparatus:

Experiment's rig consists of refrigeration circuit assembled on a metal board. All instruments for reading pressure, temperature, and flow rates are included and installed in place.

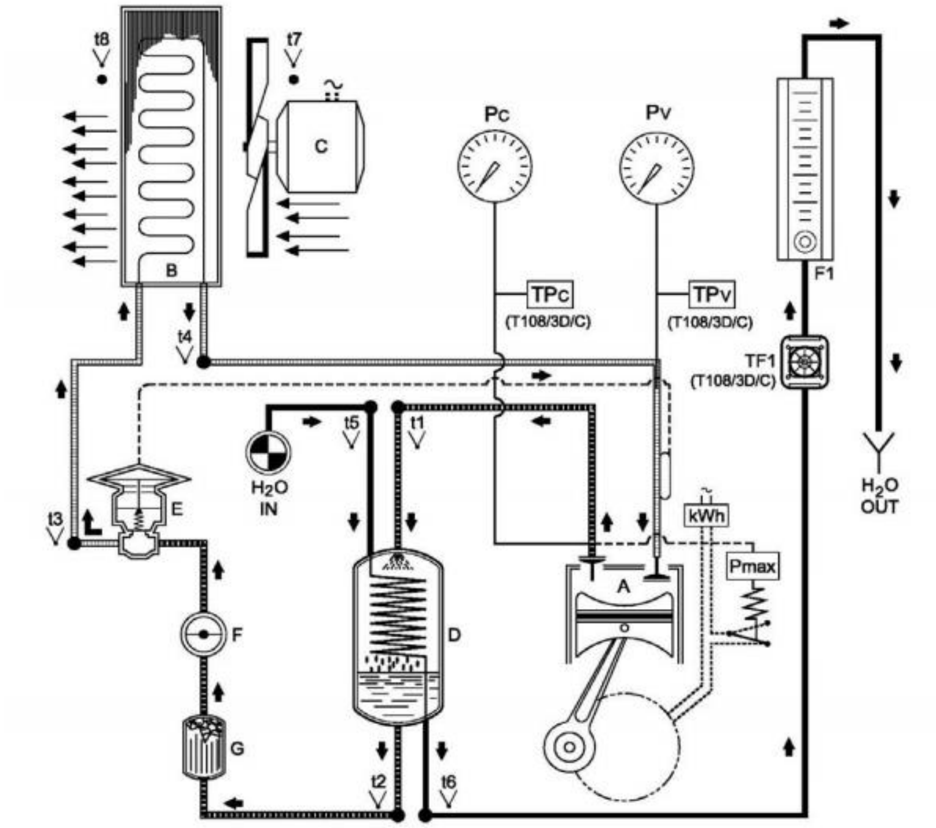


Figure (4): The refrigeration system rig

Keys:

A. hermetic compressor
B. air/R134a evaporator
C. motor fan
D. water/R134 condenser
E. thermostatic isenthalpic valve
F. cooling fluid sight glass
G. dehydrator filter
t1. temperature sensor: condenser coolant inlet
t2. temperature sensor: condenser coolant outlet
t3. temperature sensor: evaporator coolant inlet
t4. temperature sensor: evaporator coolant outlet
t5. temperature sensor: condenser water inlet
t6. temperature sensor: condenser water outlet
t7. temperature sensor: evaporator air inlet
t8. temperature sensor: evaporator air outlet
F1. flowmeter with control valve of the condenser H_2O flow rate
TF1. flow transducer for the condenser H_2O flow rate (on T108/3D/C only)
Pc. pressure gauge for condensation pressure
TPc. pressure transducer for condensation pressure (on T108/3D/C only)
Pv. pressure gauge for condensation pressure
TPv. pressure transducer for evaporation pressure (on T108/3D/C only)
Pmax. maximum pressure switch
KWh. electric energy counter

Procedure:

1. Connect the apparatus with the water source, and to the drain.
2. Switch on the main power supply, and adjust the water flow rate to a low value
3. Wait until steady state conditions. Then take readings of the temperatures from (T_1 to T_8), P_c, P_v, m_w.

4. Increase the flow rate of the water, and wait for steady state, and then take the same readings.
5. Fill the results in table 1

Results and analysis:

Temperatures (^{0}C)								P_v	P_c	m_w
T1	T2	T3	T4	T5	T6	T7	T8	MPa	MPa	L/hr

1. Draw the cycle on the P-h diagram and find the enthalpies.
2. Calculate the COP_R and $COP_{H.P}$ for Carnot cycles
3. State the differences between actual and Carnot cycle , support your answer with T-s and P-h drawings for both cycles.
4. Plot COP_R against the condensation temperature, in accordance with your graph state when do we have better COP_R, in summer or in winter?

Exp. # (7)

Thermal Resistance of Multilayer Insulation Materials

Objective:-

The purpose of this experiment is to determine thermal resistance of multilayer insulation materials.

Theory:-

Several standards have been drawn up to define an acceptable method of thermal conductivity measurements, which are as follows: -

1. ***steady state method: -***

The thermal conductivity is determined from measurements of temperature gradient in the material and the heat input.

2. ***Transient method: -***

The hot wire method is based on transient conditions. The linear heat source is a wire to which is welded a thermocouple. The thermal conductivity is determined from the rate of the thermocouple reading.

3. ***Heat Flow meter method: -***

The specimen under test is placed between a hot plate and the heat flow meter, which is attached to a cold plate. The apparatus is surrounded by insulation. The hot and cold plates are maintained at suitable constant temperatures measured by surface thermocouples. A calibration constant for the individual apparatus is derived from testing a sample of known constant thermal conductivity.
By measuring the heat flow meter output and he mean temperature of the test sample, the thermal conductivity is calculated using this calibration constant.
The thermal conductivity is a material property defined by the following equation:-

$$q_x = -kA\frac{(T_c - T_h)}{\Delta x}$$

The minus sign is a consequence of the second law of thermodynamics, which requires that heat must flow in the direction of lower temperature. If more than one material is present, as in the multilayer wall shown in the figure 1, the analysis would proceed as follows:

$$q_{1-2} = q_{2-3} = q_{3-4}$$

Or

$$q_x = k_a.A.\frac{(T_1 - T_2)}{\Delta x_a} = k_b.A.\frac{(T_2 - T_3)}{\Delta x_b} = k_c.A.\frac{(T_3 - T_4)}{\Delta x_c}$$

Solving these equations gives:

$$q = \frac{T_1 - T_4}{\frac{\Delta x_a}{k_a.A} + \frac{\Delta x_b}{k_b.A} + \frac{\Delta x_c}{k_c.A}} = \frac{T_1 - T_4}{R_a + R_b + R_c} = \frac{(T_1 - T_4)}{R}$$

Where:

R_a, R_b, R_c : thermal resistances of each material in ^{o}C/W.
R : thermal resistance of the multilayer material in ^{o}C/W.

Equation (1) can be introduced by:

$$\text{Heat Flow} = \frac{\text{Thermal potential difference}}{\text{Thermal Resistance}}$$

Which is quite like Ohm's law in electric circuit theory, therefore we can represent these layers of materials in figure as three electric resistances in series:-

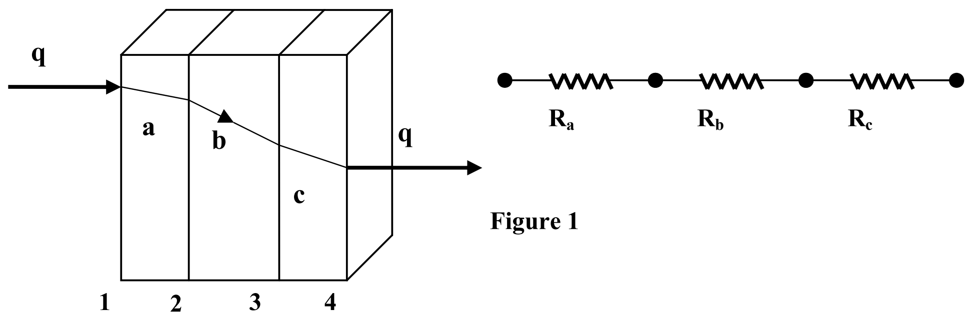


Figure 1

In this experiment the thermal conductivity can be calculated as follows:-

$$k = \frac{l_s * [(C_1 + (C_2 * \bar{T})) + ((C_3 + (C_4 * \bar{T})) * HFM) + ((C_5 + (C_6 * \bar{T})) * HFM^2)]}{dT}$$

Where:-

HFM : Heat flow in mille volts (mV).
l_s : Specimen thickness (m).
$C_1, C_2, C_3, C_4, C_5, C_6$: Calibration constants for the apparatus and have the following values.

$C_1 = -5.4636$ $\quad C_4 = 0.0499$

$C_2 = 0.0983$ $\quad C_5 = 0.0644$

$C_3 = 2.6335$ $\quad C_6 = -0.0002$

$$\mathbf{dT = (T_1 - T_2)}$$

$$\bar{\mathbf{T}} = \frac{\mathbf{(T_1 + T_2)}}{\mathbf{2}}$$

Then;

$$\mathbf{R = \frac{\Delta x}{kA}}$$

Apparatus:-

The thermal conductivity of building and insulating materials unit is shown in figure 1.

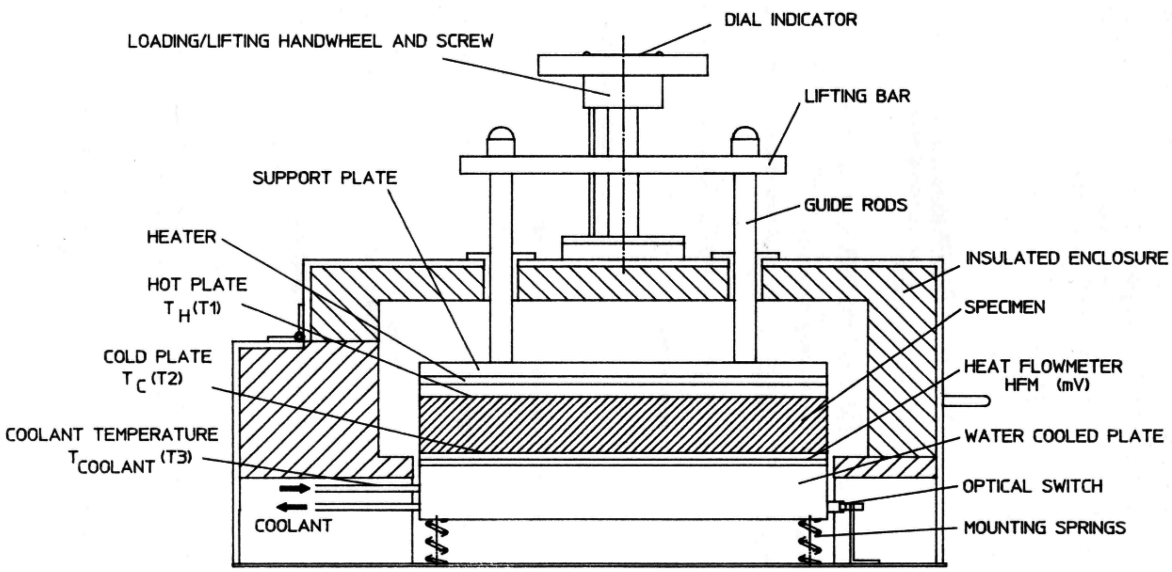


Figure (1): Thermal conductivity of building and insulating materials unit.

Procedure:-

1. Switch on the unit at the main switch.
2. Place the specimen then close the lid.
3. Rotate the screw hand wheel anti-clockwise to lower the hot plate assembly down onto the heat flow meter plate.
4. At the point when the green “Test Position” lamp illuminates stop the turning and note the dial reading.
5. Multiply this value by 0.25 to give the thickness of the specimen under test in (mm).

Analysis:-

- Fill the table(1) below. **Table(1)**

Readings

Time (s)	T_1 (^oC)	T_2 (^oC)	HMF (mV)

- Draw T_1, T_2 versus time and show the steady state region.
- Calculate the equivalent thermal resistance **R** of the multilayer insulation materials.
- Compare the experimental value of **R** with the theoretical one, given the table of material properties below.

	K (w/m.K)	Thickness (mm)	ρ (kg/m^3)
Cork board	0.043	3	160
Plaster Board	0.182	10	720
Plaster Gypsum	0.170	11	800

- Mention other different ways of measuring the thermal conductivity k

Exp. # 1

Calibration of Bourdon Gauge

Objective:
The main objective of this experiment is to establish a calibration curve for a Bourdon Gauge.
Apparatus:
Bourdon Gauge is one of the common devices for measuring the static pressure in a fluid system. Bourdon Gauge consists of a tube with an elliptical cross sectional area takes a curved shape (or circular shape) as shown in the figure below.

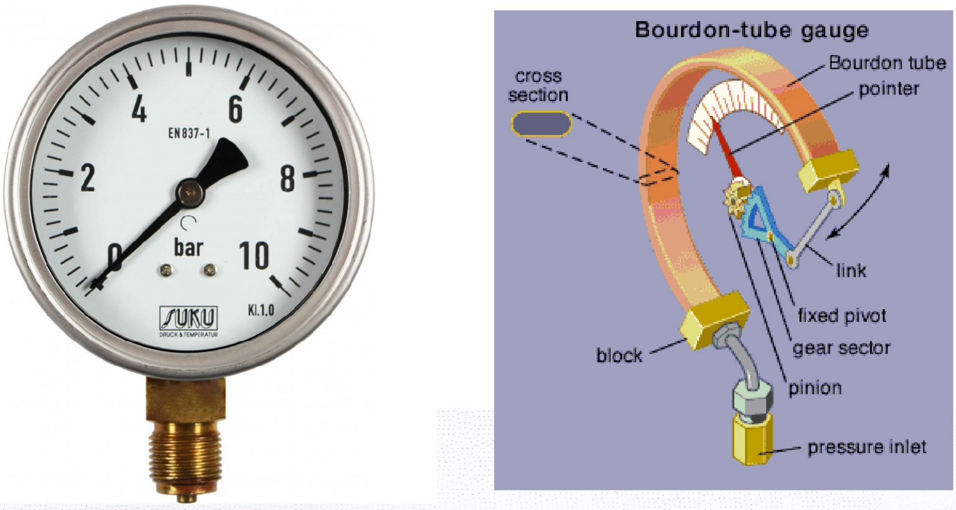


Figure 1 : Bourdon Gauge:

Figure (2): Dead Weight Calibrator

Theory:
When atmospheric pressure (zero gage pressure) is applied the gauge reading is calibrated to point to zero. When pressure applied to the gauge (positive gauge pressure) the curved tube tends to straighten then it will actuate a small gear mechanism, which holds the pointer to read a higher pressure.

Procedure:

The gauge pressure is calculated as

$$P = W/A$$

Where:

W: is the weigh added + the weight of the Piston

A: Cross section Area of the Piston = $244.8 \times 10^{-6}\ m^2$

Weight of the piston is 340 gr

Weight of the platform is 173 gr

The absolute pressure error is $= |P_{reading} - P_{calculated}|$

The relative pressure error is $= \dfrac{|P_{reading} - P_{calculated}|}{P_{calculated}}$

- Remove the air bubbles from the instrument tube by using the bleeding screw (Cock)
- To take reading while minimum friction between the piston and the cylinder, rotate the piston slightly and while the piston is turning take the reading.
- Change the applied weight and record the Bourdon Gauge reading

Results:

Test No.	Mass Kg	Weight W (N)	Calculated Pressure (Pa)	Gauge reading (Loading), Pa	Gauge reading (Unloading), Pa	Average Gauge Reading Pa	Absolute Error Pa	Relative error %
1								
2								
3								

Table: 1

Analysis:

1. Plot the calibration curve of the Bourdon Gauge (Calculated pressure Vs the Bourdon Gauge reading, loading and unloading on the same graph).
2. Discuss the source of errors in your experiments

Exp. # 5

Bernoulli's Theorem application- flow through Venturi tube

Objective:

Demonstrate the relation of pressure head, velocity head and static head and compare it with Bernoulli's Theorem. Study the flow through the Venturi meter as a device of measuring the flow rate. Find the Venturi discharge coefficient.

Apparatus:

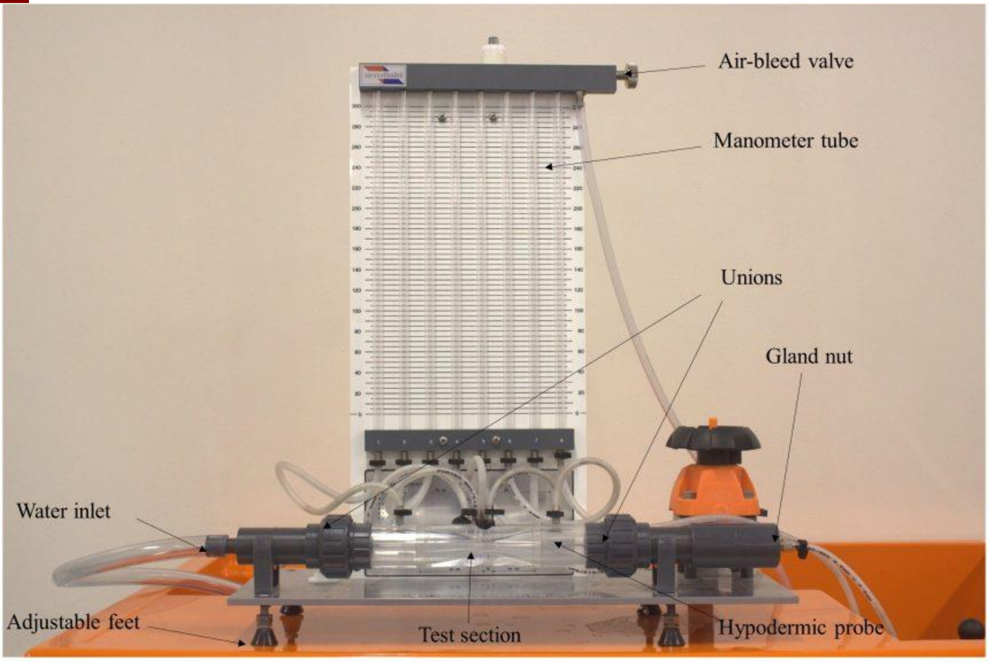
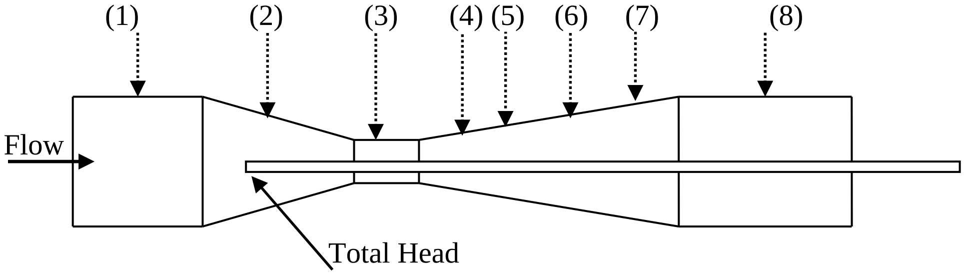


Figure 1 : Experimental setup

The equipment consists of Venturi tube with 28 mm and 14 mm inside diameters. Eight pressure tapping points along the wall of the tube for connection with manometer. The total head probe of stainless steel tube (1.9 mm inside diameter) which can be moved axially along the Venturi tube. The total head tube is connected by a hose to manometer tube No. 7. A control valve at the outlet of the Venturi tube is used to control the flow rate.



D_1=28mm, D_2=21mm, D_3=14mm, D_4=16.8mm, D_5=19.6mm, D_6=22.4mm
D_7=25.2mm, D_8=28mm

Figure 2: Venturi setup

Theory:

- Bernoulli's Equation Demonstration

Bernoulli's Theorem states that: "The total head of flowing liquid between two points remains constant assuming there is no loss due to friction and no gain due to application of external work between the two points".

The total head (H_t) of a flowing liquid is made up of Elevation head (H_z), Pressure head (H_s) and Velocity head (H_v) and according to Bernoulli's theorem the total head is constant between any two points along the streamline of a flowing fluid.

$$H_t = \frac{P}{\rho g} + \frac{V^2}{2g} + Z$$

Where: Ht is the total head (m), V is the average velocity (m/s), P is the pressure (Pa), Z is the elevation (m), ρ is the density (Kg/m^3) and g is the gravitational acceleration (m/s^2). Thus between point 1 and 2 for example

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + h_L\,(Head\ loss)$$

If the Bernoulli's tube is horizontal then $Z_1 = Z_2$ and if loss between point 1 and 2 is negligible then the equation becomes

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

Or
$$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = \frac{V_2^2}{2g} - \frac{V_1^2}{2g}$$

If point 1 and point 2 are of different diameters, then V_1 and V_2 are different. It is demonstrated by the difference in manometer water level reading between point 1 and 2.

Also at the same time we can compare total head at any point along the Venturi tube using total head probe whose total head can be read from tube number 7

$$H_t = \frac{P_{tip}}{\rho g} + \frac{V_{tip}^2}{2g} + Z_{tip} = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1$$

At the tip of the total head probe $Z_{tip} = Z_1$ and hence $V_{tip} = 0$ (stagnation point)

$$H_t = \frac{P_{tip}}{\rho g_t} = \frac{P_1}{\rho g} + \frac{V_1^2}{2g}$$

Or
$$\frac{P_{tip}}{\rho g} - \frac{P_1}{\rho g} = \frac{V_1^2}{2g} \quad = Velocity\ head$$

Thus velocity head can be demonstrated by the difference between total head ($\frac{P_{tip}}{\rho g}$) and the static pressure head ($\frac{P_1}{\rho g}$)

- Venturi meter

By applying Bernoulli's equation from 1 to 3 and the mass balance one can get:

$$Q_{th} = A_3 \sqrt{\frac{2g(hs_1 - hs_3)}{1-(A_3/A_1)^2}}$$

Where: Q_{th} is the theoretical flow rate calculated from Bernoulli's and the continuity equations. A_1 and A_3 are the cross sectional area at point 1 (inlet) and 3 (throat) as shown in the figure 2 and hs_1 and hs_3 are the pressure head difference, $\frac{P_1}{\rho g}$ and $\frac{P_3}{\rho g}$ respectively. But the actual flow rate is different from the one calculated by the above equation (why?). The discharge coefficient of the Venturi, C_d, will be introduced as:

$$C_d = \frac{Q_{act.}}{Q_{th.}}$$

Where $Q_{act.}$ Is the actual flow rate measured experimentally then the Venturi meter equation in its final form will be:

$$Q_{act.} = C_d A_3 \sqrt{\frac{2g(hs_1 - hs_3)}{1-(A_3/A_1)^2}}$$

Procedure:

- Connect the Hydraulic bench outlet valve to obtain small flow such as 5 lpm. Adjust the set outlet valve and/or top air chamber (by hand air pump) such that the water levels in all tubes of the manometer can be observed.
- Move the total head probe along the tube, the total head at any point is indicated on tube No. 7.
- Record flow rate, manometer readings and the total head at all points at different flow rate (5, 10, 15, 20, 25, 30 lpm). First take the manometer readings without the probe being inserted then repeat the experiment with the probe being inserted at different points. Thus the effect of the probe diameter on the manometer readings can be eliminated.

Results:

Flow rate (m^3/s)	Vol. L	Time sec	Manometer readings						
			H_s#1	H_s #2	H_s #3	H_s#4	H_s #5	H_s #6	H_s #8

Table: 1

Flow rate (m^3/s)	Manometer readings at tube No. 7 at varies points						
	H_t #1	H_t #2	H_t #3	H_t #4	H_t.#5	H_t #6	H_t #8

Table: 2

No.	Time (sec)	V (m^3)	$Q_{act.}$ (m^3/s)	h1-h3 (m)	ΔP (P_1 - P_3) Pa	Q_{th} (m^3/s)	C_d	Re

Table: 3

Analysis:

1. Plot a graph of $\sqrt{h_1 - h_3}$ against Q_{act} . The points should lay on a straight line through the origin. Use the slop of your plot to calculate the discharge coefficient C_d
2. Calculate values of C_d for each flow rate and plot a graph of C_d vs. Re. Comment on this graph.
3. Plot the total head H_t, Pressure head H_p and the velocity head H_v versus point numbers.

Conclusions:

The following comments should be discussed on your conclusion:

1. Does the discharge coefficient show a significant variation with the flow rate
2. Why is there a difference between the actual and theoretical value?
3. Comment on all figures.

Exp. # (6)

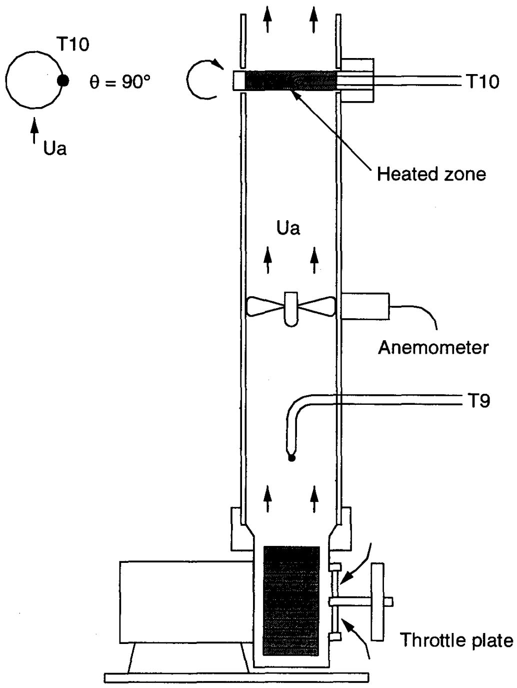
Combined forced convection & radiation

Objective:-

1. To determine the effect of force convection on heat transfer from the surface of a cylinder at varying air velocities and surface temperatures.

2. To demonstrate the relationship between air velocity and surface temperature for a cylinder subject to forced convection.

Apparatus:-



Figure(1): Combined convection and radiation apparatus

Theory:-

In free (natural) convection the heat transfer rate from a surface is limited by the movement of air which are generated by change in the density of the air as the air is heated by the surface. In force convection the air movement can be greatly increased resulting in improved heat transfer rate from a surface. Therefore a surface subjected to force convection will have a lower surface temperature than the same surface subjected to free convection, for the same power input . If a surface, at a temperature above that of its surroundings, is located in moving air at the same temperature as the surroundings then heat will be transferred from the surface to the air and surroundings. This transfer of heat will be a combination of force convection to the air (heat is transferred to the air passing the surface) and radiation to the surroundings. A horizontal cylinder is used in this experiment to provide a simple shape from which the heat transfer can be calculated.

The heat transfer coefficient Hf_m due to force convection and Hr_m due to radiation can be calculated using the following relationships:

- *Calculation of heat transfer coefficient for radiation*

$$Hr_m = \sigma \xi F \frac{(Ts^4 - Ta^4)}{Ts - Ta}$$

Where:-

σ is Stefan Boltzman constant = 5.67 x 10^{-8} (W/m^2K^4).

ξ is the emissivity of surface = 0.95.

F is the view factor = 1.

Ts is surface temperature of the cylinder (K).

Ta is the ambient temperature.

Then the heat loss due to radiation (Qr) can be calculated using the following relationship.

$$Qr = Hr_m As(Ts - Ta) \qquad (W)$$

Where A_S is the heat transfer area (surface area).

- *Calculation of heat transfer coefficient for force convection*

$$Hf_m = \frac{k}{D} Nu_m$$

Where:

k is the thermal conductivity of the air (W/m^2K).

D is the diameter of the cylinder. (m).

Nu_m is the average Nusselt number.

An empirical formula can be used to calculate the value for Nu_m as follows:

$$Num = 0.3 + \frac{\left(0.62\,Re^{0.5}\,Pr^{0.33}\right)}{\left[1+\left(\frac{0.4}{Pr}\right)^{0.66}\right]^{0.25}}\left[1+\left(\frac{Re}{282000}\right)^{0.5}\right]$$

Where;

Re is the Reynolds number = U_cD/υ

Pr is the Prandtl number for air.

U_c is the corrected air velocity (m/s).

Corrected air velocity = $1.22U_a$(m/s)

Note The physical properties of air K, υ,and Pr are take at film temperature (T_f).

Then the heat loss due to force convection (Qf) can be calculated using the following relation.

$$Qf = Hf_m As(Ts - Ta) \qquad \text{(W)}$$

Where A_S is the heat transfer area (surface area).

The total heat loss from the cylinder (Q_{tot}) = Qf + Qr

Procedure:-

1. Start the centrifugal fan by pressing the switch on the connection box.
2. Open the throttle plate on the front of the fan by rotating the knob at the center to give a reading of 0.5m/s on the upper panel meter.
3. Set the heater voltage to 20 Volt (adjust the voltage control potentiometer to give reading of 20 Volt on the top panel meter with the selector switch set to position V).
4. Allow the surface temperature of the cylinder Ts to stabilize using the lower selector switch/meter
5. When the temperatures are stable record Ua, Ta, Ts, V, and I in the table below.
6. Adjust the throttle plate to give a velocity of 1.0 m/s (stop selector switch set to position Ua).
7. Allow the temperature stabilize then repeat the above reading.
8. Repeat the above procedure changing the air velocity in steps of 1.0 m/s until the air velocity is 7.0 m/s.

Diameter of cylinder (D) = 10mm.

Heated length of cylinder (L) = 70mm.

Teat No	Velocity of air Ua (m/s)	Voltage V (V)	Current I (A)	Air temperature T9(°C)	Surface temperature T10 (°C)

Analysis & Results:-

Test No	Power Q_{in}(W)	Corrected Air velocity Uc (m/s)	Hf_m (W/m^2K)	Hr_m (W/m^2K)	Qc(W)	Qr(W)	Q_{tot}(W)

- Compare the theoretical values for Qtot with the measured values for Qin and explain any difference in the two value values.
- Compare the calculated heat transferred due to force Convection Qf and radiation Qr.
- Plot a graph of surface temperature Ts against corrected air velocity.

Exp. # (5)

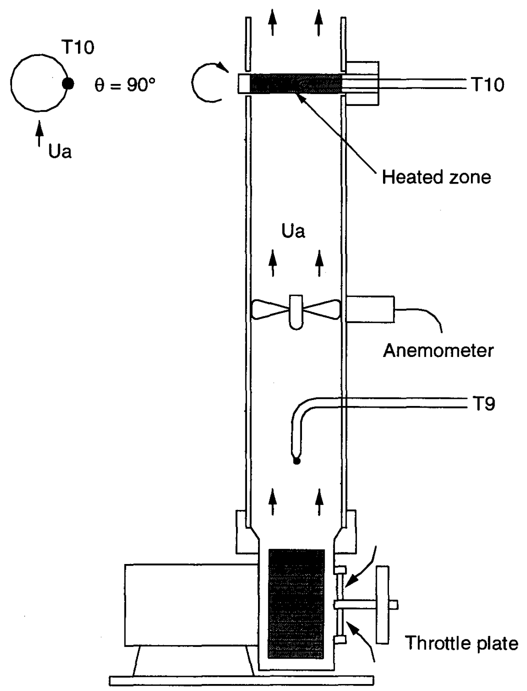
Combined free convection &radiation

Objective

1. To determine the combined heat transfer (radiation convection) from a horizontal cylinder in natural convection over a wide range of power inputs and corresponding surface temperatures.

2. To demonstrate the relationship between power input and surface temperature in Free convection.

Apparatus



Figure(1): Combined convection and radiation apparatus

Theory

If a surface, at a temperature above that of its surroundings, is located in stationary air at the same temperature as the surroundings then heat will be transferred from the surface to the air and surroundings. This transfer of heat will be a combination of natural convection to the air (air heated by contact with the surface) and radiation to the surroundings. A horizontal cylinder is used in this experiment to provide a simple shape from which the heat transfer can be calculated. In the case of natural (free) convection the mean heat transfer coefficient (Hc_m) can be calculated using the following steps.

1. Grashof number calculation

$$Gr_D = \frac{g\beta(Ts - Ta)D^3}{\upsilon^2}$$

Where:-

g = Acceleration due to gravity = 9.81 (m/s^2)

β = Volume expansion coefficient (K^{-1})

ν = Dynamic viscosity of air (m^2/s)

The volumetric expansion coefficient (β) = 1/ T_f

Where T_f is the film temperature which equal $(T_s+T_a)/2$

2.Raleigh number Ra

$$Ra_D = Gr_D \Pr = \frac{g\beta(Ts - Ta)D^3}{\upsilon^2}\Pr$$

Where Pr is the prandtl number

3. Nusselt number

$$Nu_m = c(Ra_D)^n$$

Where c and n are obtained from the table below

Ra_D	C	n
10^{-9}to10^{-2}	0.675	0.058
10^{-2}to10^{2}	1.02	0.148
10^{2}to10^{4}	0.850	0.188
10^{4}to10^{7}	0.480	0.250
10^{7}to10^{12}	0.125	0.333

Table (1): listing constant c and exponent n for natural convection on a horizontal cylinder

4. Mean heat transfer coefficient (Hc_m)

$$Hc_m = \frac{(KNu_m)}{D}$$

Where:-

Hc_m is the mean heat transfer coefficient for natural convection (W/m^2K).

K is thermal conductivity of air (W/Mk).

Note The physical properties of air K, υ,and Pr are take at film temperature (T_f).

Also the heat transfer coefficient for free convection may be calculated using the following simplified equation.

$$Hcm = 1.32\left[\frac{(Ts - Ta)}{D}\right]^{0.25}$$

Then the heat loss due to natural convection (Qc) can be calculated using the following relation.

$$Qc = Hc_m As(Ts - Ta) \qquad (W)$$

Where A_S is the heat transfer area (surface area).

In the case of radiation the mean heat transfer coefficient (Hr_m) can be calculated using the following relationship.

$$Hr_m = \sigma\xi F\frac{(Ts^4 - Ta^4)}{Ts - Ta}$$

Where:-

σ is Stefan Boltzman constant = 5.67×10^{-8} (W/m^2K^4).

ξ is the emissivity of surface = 0.95.

F is the view factor = 1.

Then the heat loss due to radiation (Qr) can be calculated using the following relationship.

$$Qr = Hr_m As(Ts - Ta) \qquad (W)$$

The total heat loss from the cylinder (Q_{tot}) = Qc + Qr

Procedure

1. Set the heater voltage to 5 Volt (adjust the voltage control potentiometer to give reading of 5 Volt on the top panel meter with the selector switch set to position V).
2. Allow the surface temperature of the cylinder to stabilize using the lower selector switch/meter
3. When the temperatures are stable record Ts, Ta, V, and I in the table below.
4. Repeat steps 2&3 for 8, 12, and 15 Voltage.

Diameter of cylinder (D) = 10mm.

Heated length of cylinder (L) = 70mm.

Test No	Voltage (V)	Current(I)	Air temperature Ta(°C)	Surface temperature Ts (°C)
1	5			
2	8			
3	12			
4	15			

Analysis & Results:-

No	Power Q_{in}(W)	Hc_m(W/m^{2}K)	Hr_m(W/m^{2}K)	Qc(W)	Qr(W)	Q_{tot}(W)
1						
2						
3						
4						

- Compare the theoretical values for Qtot with the measured values for Qin and explain any differences in values.
- Compare the calculated heat transferred due to Convection Qc and radiation Qr.
- Compare the value for Hc_m obtained using the simplified and full empirical equations and comment on any difference.
- Plot a graph of surface temperature Ts against power input Qin and observe the relationship.

Exp. #5

Fluid Friction in Pipes and Losses from Fittings

Objectives

To demonstrate the friction loss in pipes, valves and other fittings. To determine experimentally the relationship between friction factor and Reynolds number for flow of water in a pipe.

Experimental Setup:

The main components for this test are pump and water storage tank, differential manometer for measuring the head at different point along the pipe and across the fittings, and volume flow meter for measuring the flow rate. The friction loss will be measured across the fittings and along the pipe of the following:

- Horizontal pipes, PVC (3/4 inch and ½ inch) and BP (3/4 inch)
- Regular elbow
- Tee section and sudden expansion and contraction.
- Gate valve, Globe valve, Ball valve and check valve.

The components are joined together with pressure taps across each loss components.

Theory:

When a liquid flows from one point to another, part of the total energy is lost due to friction between the liquid and the wall and the interaction of the liquid molecules. The resulting head loss is called friction head (h_L). The friction head between two points can be expressed by

$$h_L = \left(\frac{P_1}{\gamma} - \frac{P_2}{\gamma}\right) + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) + \left(Z_1 - Z_2\right) \text{ -- (1)}$$

and the total energy of water at any point may be expressed as the total head at that point h_t *where*

Total head (h_t) = Pressure head +velocity head + static head (elevation)

$$= h_p + h_v + h_s = \frac{P}{\gamma} + \frac{V^2}{2g} + Z \text{ ------------------------------------- (2)}$$

Pipe Friction

Fluid flow in a direction of decreasing pressure and the decrease in the pressure is caused by the frictional loss in a pipe. The friction loss in a pipe depends on the type of the flow (Laminar or turbulent) and the surface roughness of the pipe.
Friction loss for laminar flow in a pipe is given as

$$h_f = \frac{32\mu LV}{\gamma D^2} \qquad \text{or } f = 64/Re \qquad \frac{h_f}{L} \propto V \text{ ---------------------------------- (3)}$$

where V is the average velocity and D is the pipe diameter and L is the pipe length = 1.25 m, γ is the specific weight and μ is the dynamic viscosity. But for the friction factor for turbulent flow f is a function of Reynolds number ,*Re* ,and pipe roughness, $\frac{k_s}{D}$, the following equation could be used

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \qquad \frac{h_f}{L} \propto V^2 \text{ -- (4)}$$

Consider a flow in a pipe and apply Bernoulli's equation between any two points then

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + h_L \text{ -------------------------(5)}$$

For horizontal pipe with constant diameter, $Z_1 = Z_2$ and $V_1 = V_2$ then Bernoulli's equation becomes

$$\frac{P_1}{\gamma} - \frac{P_2}{\gamma} = h_L$$

Where: $\frac{P_1}{\gamma}$ is the pressure head at point 1

$\frac{P_2}{\gamma}$ is the pressure head at point 2

h_L is the head loss between 1 and 2 due to friction $\equiv h_f$

γ is the specific weight of the fluid = ρg

Friction Loss for Valves and Pipe Fittings

There is no established formula for friction of Valves and pipe fittings. However from experimental results

$h_L = K\dfrac{V^2}{2g}$ where K is a constant called fittings loss coefficient

Procedure:

- This experiment is used for measurement of friction or pressure loss when fluid flow through various pipes, fittings or valves. Differential pressure is measured by manometer. For low pressure use water manometer and for high pressure use Mercury.
- Flow rate can be measured by measuring volume of liquid passed in certain period of time using volume flow meter and stop watch. There are three volume flow meters: X 0.0001 m^3 = 0.1 Liter
  X 0.001 m^3 = 1 Liter
  X 0.01 m^3 = 10 Liter
- Open the flow control valve for high flow rate to purge air bubbles then reduce the flow rate to about 10 lt/min.
- Time and record the volume flow rate using volume flow meter and stop watch.
- Take the measurements for 5,10,20,30,40, and 50 lt/min

Results:

The following data should be taken

Type of Pipe/ fittings	Pipe Diameter (m)	Volume (m^3)	Time (sec)	Flow rate (m^3/s)	Head loss- Δh (m)

1. Plot a graph of the head loss versus the average velocity for all pipes and identify the laminar and turbulent zones on the graph.
2. Plot *f* versus *Re.*
3. Find K for all fittings and compare with literature.
4. Discuss any source of error in this experiment.