

Department of Mechanical Engineering

Lab Manual

Thermodynamics and Fluid Mechanics (MEC 205)

Laboratory Location: Ground Floor, Room No-001 & 004



Indian Institute of Technology (Indian School of
Mines) Dhanbad-826004

INDEX

Sl .No.	Particulars	Page
1	Safety in the lab	3
2	Lab report format	4
3	List of Experiments of Thermodynamics and Fluid Mechanics	5
4	Instruction Manual of Thermodynamics and Fluid Mechanics	6 - 75

Safety in the Lab

- You are only allowed in the laboratory when there is a 'responsible person' present such as a demonstrator or the laboratory staff.
- Do not touch any equipment or machines kept in the lab unless you are asked to do so.
- A tidy laboratory is generally safer than an untidy one, so make sure that you do not have a confused tangle of electrical cables. Electrical equipment is legally required to be regularly checked, which means it should be safe and reasonably reliable: do not tamper or attempt to repair any electrical equipment (in particular, do not rewire a mains plug or change a fuse - ask one of the laboratory staff to do it). Never switch off the mains using the master switches mounted on the walls. Please make yourself aware of the fire exits when you first come into the lab. When the alarm sounds please leave whatever you are doing and make your way quickly, calmly and quietly out of the lab. You must always follow instructions from your demonstrators and the laboratory staff.
- You must keep walkways clear at all times and in particular coats and bags must be stowed away safely and must not pose a trip hazard.
- It is important that you make a point of reading the "Risk Assessment" sheet included in the manuscript of each experiment before you start work on the experiment.
- Please take notice of any safety information given in your scripts. If an experiment or project requires you to wear PPE (personal protective equipment) such as gloves and safety glasses, then wear them.
- Always enter the lab wearing your shoes. It is strictly prohibited to enter the lab without shoes.
- There must be NO smoking, eating, drinking, use of mobile phones or using personal headphones in the laboratory. This last point is not because we dislike your choice of music but because you must remain aware of all activity around you and be able to hear people trying to warn you of problems.
- Keep the lab neat and clean.

Lab Report Format

Title:

- Provide a title that is a description of your lab followed by a lab number.
- The title should clearly identify the experiment's variables (independent & dependent)

Objective/Purpose/Problem:

- This is the place to explain what you are trying to find out or what you are going to do in the lab.
- Include information about the variables involved.

Hypothesis: "If.....then.....because....."

- This is a cause/effect statement.
- This is a prediction of what the expected outcome of the lab will be.
- Relate the hypothesis to the purpose/problem of the lab.
- Try to focus your hypothesis on the information/research you collected.

Materials:

- List all items in a column.
- Make sure to record the exact size and amount of each item required.

Procedures:

- List and number each step.
- Use complete sentences (begin with a capital letter and use end punctuation).
- Should be clear enough for someone else to use as instructions for repeating your experiment.

Observations/Data:

- Be sure to accurately record your observations/data in a chart or table.
- Create a graph to provide a visual of your data.
- Provide a verbal description of your data.
- List all quantitative (numbers) and qualitative (words) data.
- List all variables and explain what your control was.

Conclusion: "When.....then....."

- Match your conclusion to the purpose or the problem.
- Base your conclusion on your analysis of your observations and any data that has been collected.
- **Explain:** (The following are just suggestions and DO require elaboration.)
 - What you did in the experiment
 - What you observed (trends/patterns in your data that supported or did not support your hypothesis)
 - What you learned from the lab
 - If you think it was a fair test (i.e. – was there anything that may have impacted the accuracy of your results)
 - Questions for further research and investigation
- **Application:** Can you think of an analogous situation that applies to real life?

List of Experiments

Sl. No.	Name of the Experiment	Page
1	Determination of Calorific value of solid/liquid fuel.	6 - 11
2	Performance study of single cylinder 4-s Petrol Engine.	12 - 19
3	Performance study of single cylinder 4-s Diesel Engine.	20 -37
4	Determination of Mechanical equivalence of Heat.	38 -42
5	Determination of Dryness fraction of Steam	43 – 50
6	Determination of Darcy's friction coefficient	51 - 57
7	Verification of Bernoulli's Theorem	58 - 62
8	Determination of discharge coefficient (C_d) of a Venturimeter	63 - 68
9	Determination of Hydraulic coefficient C_d , C_v & C_c of an orifice	69 - 75

Experiment no. 1

Title: Determination of Calorific value of solid/liquid fuel using bomb calorimeter apparatus

Objective: To determine Calorific value of solid/liquid fuel using bomb calorimeter

Theory:

A Bomb Calorimeter will measure the amount of heat generated when solid/liquid fuel is burnt in a sealed chamber (Bomb) in an atmosphere of pure oxygen gas.

A known amount of the sample is burnt in a sealed chamber. The air is replaced by pure oxygen. The sample is ignited electrically. As the sample burns, heat is produced. The rise in temperature is determined since barring heat loss is equal to the heat absorbed by calorimeter assembly. The rise in temperature enables to calculate the heat of combustion of the sample.



Fig. 1: Cut section of Bomb calorimeter (source: ministry of steel)

W: Water equivalent of the calorimeter assembly in calories per degree centigrade (2330 cal /⁰C)

ΔT: Rise in temperature (registered by a sensitive thermometer) in degree centigrade

H: Heat of combustion of material in calories per gram

M: Mass of sample burnt in grams

Then $W \Delta T = HM$

“H” is calculated easily since W, ΔT and M are known.

$$\therefore H = \frac{W\Delta T}{M}$$

Experiment setup (Bomb calorimeter)

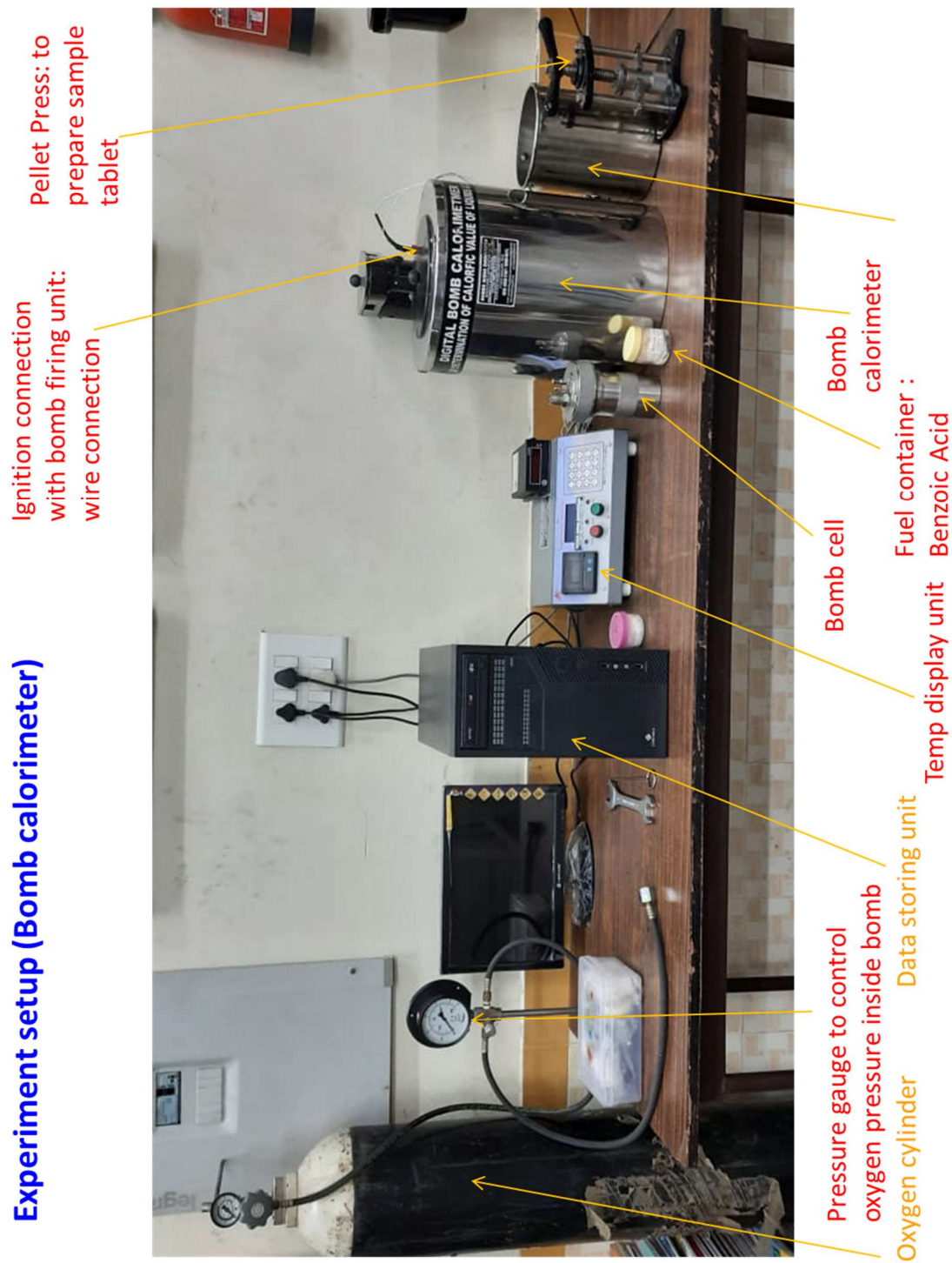


Fig. 2: Experiment setup

Calculations:

GIVEN DATA- Calorific value of Standard Benzoic Acid (H) = 6319 Cal /gm

Water equivalent of Calorimeter (W) 2330 Cal/ °C

Heat liberated by Nichrome wire (E_1) = 0.335 Cal/mg

Heat liberated by cotton thread (E_2) = 4.180 Cal/mg

$$W\Delta T = HM$$

$$H = \frac{W \times \Delta T - (E_1 * MN + E_2 * MC)}{M}$$

Where:

W= Water equivalent of Calorimeter Cal/°C

H= Calorific Value of solid fuel sample in Cal/gm to be determined

ΔT = Rise in temperature due to combustion of solid fuel inside the Bomb °C.

M=Mass of solid fuel sample Burnt inside the Bomb gms

M_N =Mass of Nichrome wire, gm

M_C =Mass of Cotton thread, gm

Experimental Procedure:

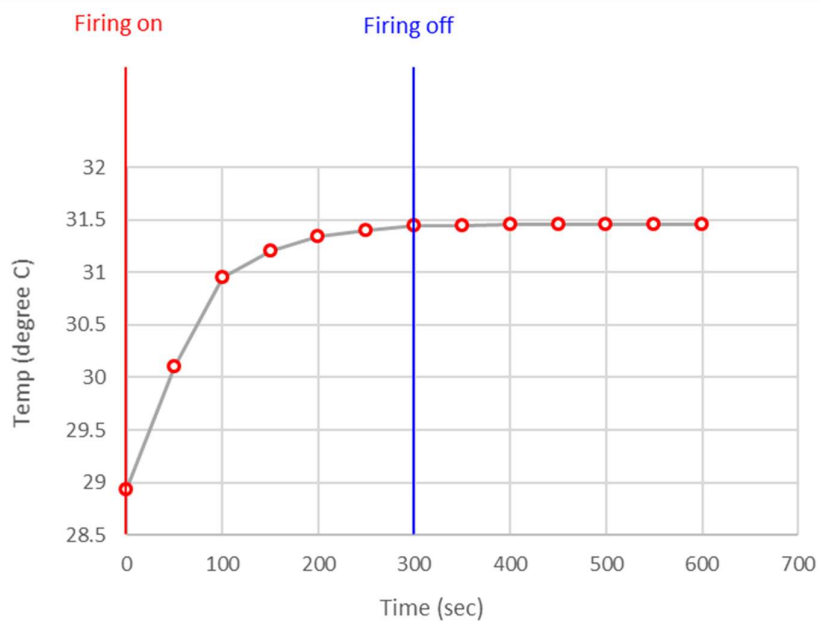
1. Install the equipment on a plain flat table near a 230V, 50Hz, 5amps electrical power source and 15mm tap size water source.
2. Weigh the empty S.S. crucible and record.
3. Weigh exactly 1 gm of powdered dry fuel sample, pour it into the pellet press and press it to form a briquette (tablet / pellet), put it into the crucible and weigh it again to get the exact weight of the solid fuel sample. i.e. weight of (crucible + sample) – (empty crucible)
4. Open the bomb lid, keep it on the stand; insert the S.S. crucible into the metallic ring provided on one of the electrode stud.
5. Take a piece of ignition wire of about 100 mm length, weigh it and tie it on the electrode studs, in such a way that the wire touches the fuel pellet, but not the sides of the S.S. crucible.
6. Insert a piece of cotton thread of known weight on to the ignition wire without disturbing it.
7. Lift the Bomb lid assembly from the stand, insert it into the S.S. Bomb body and secure it with the cap.
8. Fill water into the outer shell to its full capacity, insert a glass thermometer with rubber cork. Keep the insulating base in position inside the shell.
9. Fill oxygen gas to about 20 atmospheres into the Bomb with the help of copper tubes with end connectors through pressure gauge from an oxygen cylinder.

10. Fill water into the calorimeter vessel up to half its capacity and place the assembled Bomb unit, charged with oxygen into it in position. Top up with more water to bring the water level in the calorimeter vessel up to the Bomb lid level. For this setup it is 2 lit.
11. Keep the entire vessel assembly on the insulated base already placed in the outer shell. This should be carried out without disturbing the vessel assembly.
12. Connect the bomb unit to the Bomb firing unit with the electrical leads (connecting wires) and close the shell lid.
13. Insert the stirrer unit into the calorimeter vessel in proper position through the shell lid and secure it; connect the stirrer unit with the firing unit, also insert the thermocouple sensor into the calorimeter vessel through the shell lid and connect it to the firing unit.
14. Connect the Bomb firing unit to an electrical source of 230v, 50Hz, 5 amps keeping all the switches on the firing unit in “OFF” position.
15. Switch “ON” the main switch of the firing unit. Now the temperature indicator indicates the temperature sensed by the thermocouple.
16. Switch “ON” the stirrer unit.
17. Press the “green” button on the firing unit to check the continuity in the Bomb unit, observe the indicator glow.
18. Wait till the temperature in the calorimeter vessel, stabilize and record it as initial temperature. Press the “red” button on the firing unit to fire the sample inside the Bomb.
19. Now the temperature of the water in the calorimeter vessel starts rising, note and record the rise in temperature at every one-min. interval until the rise in temperature stabilizes or starts dropping.
20. Tabulate all the readings and calculate the calorific value of the solid fuel under test.
21. To close the experiment switch “OFF” the stirrer and main switch, open the shell lid and take out the Bomb assembly from the calorimeter vessel. Release all the flue gases from the Bomb with the help of release valve, unscrew the cap open the lid and observe all the fuel sample is burnt completely.
22. Clean the Bomb and crucible with clean fresh water and keep it dry.

Observation table with sample data

		Time (Sec)	Temp (degree C)
Firing on	600	0	28.91
	550	50	30.1
	500	100	30.95
	450	150	31.2
	400	200	31.34
	350	250	31.4
Firing off	300	300	31.44

	250	350	31.45
	200	400	31.46
	150	450	31.46
	100	500	31.46
	50	550	31.46
	0	600	31.46



Sl No.	Sample type	Sample Name	Mass of fuel burnt inside the bomb (M) (gm)	Water Equivalent of calorimeter (W) Cal/°C	Rise in Temperature (°C)	Heat Liberated by Nichrome wire (E ₁) Cal/mg	Heat Liberated by Cotton thread (E ₂) Cal/mg	Calorific Value of solid fuel sample in Cal/gm
1	Solid	Benzoic acid	1.0	2330	2.55	0.335	4.180	5825.0

Result:

Conclusion:

EXPERIMENT NO. 2

Title: Performance study of a single-cylinder 4-stroke petrol engine

Objectives:

1. To perform load tests at the given speed in a single-cylinder 4-stroke petrol engine,
2. To determine different performance parameters, like, (i) Brake power, (ii) Total fuel consumption, (iii) Brake specific fuel consumption, (iv) Brake thermal efficiency, and (v) Brake Mean Effective Pressure.
3. To draw performance characteristics curves.

Apparatus: Single cylinder 4-stroke petrol engine experimental setup coupled with electric transmission DC dynamometer (Generator), air-flow measuring device and a fuel flow rate measuring device. The engine is loaded using electrical heater banks, each of which is 500 W. There are a total of 6 no. of heaters of 3 kW total load. A digital voltmeter and an ammeter are used to measure output DC voltage and DC current from the generator.



Fig. 1: Photograph of the experimental setup

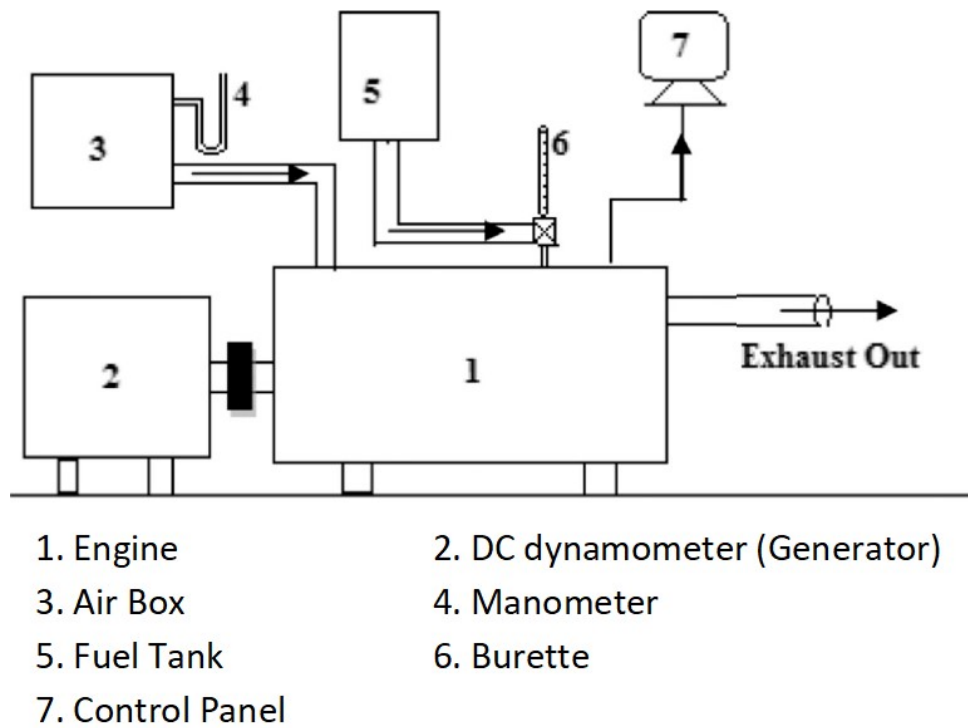


Fig. 2: Schematic of the single-cylinder 4-Stroke Petrol Engine Setup

Fuel Measuring Unit: It measures volumetric fuel flow to the engine. The unit consists of a glass burette which has markings showing the volume of fuel consumed. When the valve is open, fuel from the tank goes to the engine directly. During measurement, the valve is closed, and the fuel required for running the engine is consumed from the burette. The time needed for the fall of fuel level in the burette by the desired amount (say 10 ml) is measured with the help of a stopwatch, and the volume flow rate is calculated by dividing the fuel volume by time. The fuel consumption rate can then be determined by multiplying the volume flow rate by the fuel density.

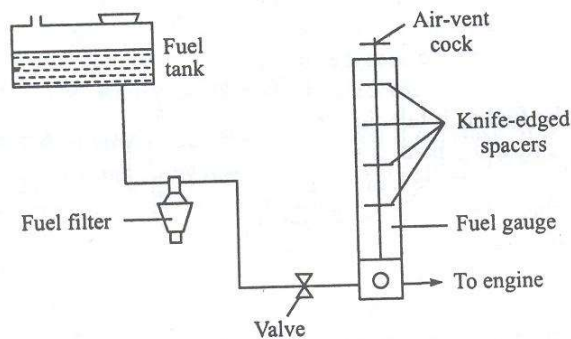


Fig. 3: Fuel measuring unit

Specifications of the engine:

No. of cylinders	1
No. of strokes	4
Fuel	Petrol
Rated power	5.2 kW
Rated speed	3600 RPM
Cylinder diameter (D)	76 mm
Stroke Length (L)	60 mm
Orifice diameter (d)	16 mm
Orifice discharge coefficient (C_d)	0.63

Experimental Procedure:

1. Ensure that sufficient fuel is available in the fuel tank.
2. Give water supply (approx. 500 – 700 LPH) to calorimeter from water connection available in the lab.
3. Start the engine by hand starting.
4. Switch on the mains button.
5. Take all the readings as per the observation table with NO LOAD condition.
6. Load the engine gradually. Repeat the above procedure and note down the readings.
7. To stop the engine, first, unload the engine. After completely unloading the engine, press the stop lever towards the pump.

Observation Table with sample data:

No.	Load (kg)	Engine Speed (RPM)	Time for fuel consumption of 10 ml (sec)	Voltage (V) (Volts)	Current (I) (amp)
1		35	.8	0	
2	00	47	.6	0	3
3	00	58	.3	0	9
4	00	54	.9	0	
5	00	55	.6	0	
6	00	59	.9	0	.2

Calculations: Calculations for engine performance parameters are as follows:

1. Brake Power (BP): The useful power developed by an engine is called brake power. This power is available at the end of the output shaft for driving a vehicle. The brake power can be measured easily by a dynamometer.

$$\text{Generator Power} = \text{Voltage (V)} \times \text{Current (I)}$$

$$\text{Generator Efficiency} = 90\% = 0.9$$

$$\text{Engine Brake Power (BP)} = \text{Generator Power} / \text{Generator Efficiency}$$

$$= \text{Voltage (V)} \times \text{Current (I)} / (1000 \times 0.9) \text{ kW}$$

2. Total Fuel Consumption (TFC, $\dot{m}_f$): It is the mass of fuel consumed by the engine per unit time.

$$TFC(\dot{m}_f) = \frac{10 \times \rho_{oil} \times 3600}{t \times 10^6} = \frac{0.036 \times \rho_{oil}}{t} \text{ kg/hr}$$

where, t : time for consumption of 10 cc of fuel,

ρ_{oil} : density of fuel = 760 kg/m³ for gasoline/petrol

3. Brake Specific Fuel Consumption (BSFC): It is the mass of fuel consumed by the engine per unit time per unit brake power developed.

$$BSFC = \frac{\text{Total Fuel Consumption}}{\text{Brake Power}} = \frac{0.036 \times \rho_{oil}}{t \times BP} \frac{\text{kg}}{\text{kW} \cdot \text{hr}}$$

4. Brake Thermal Efficiency (η_{bth}): It is defined as the ratio of BP to the rate of heat energy input by means of fuel supply.

$$\eta_{bth}(\%) = \frac{\text{Brake Power in kW}}{\text{Rate of heat input}} = \frac{\text{Brake Power}}{\text{Fuel consumption in kg/s} \times HV}$$

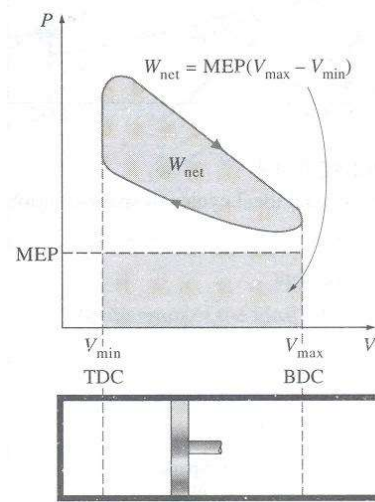
$$\eta_{bth}(\%) = \frac{\text{Brake Power} \times 3600}{\dot{m}_f \times HV} \times 100$$

where, $\dot{m}_f$: Total fuel consumption in kg/hr

HV: Heating value of fuel in kJ/kg = 45,500 kJ/kg for petrol

5. Brake Mean Effective Pressure (BMEP): It is the hypothetical constant pressure acting on the piston during the working stroke to do the same amount of work as

done by the actual varying pressure produced during one cycle.



Brake work done per cycle = BMEP $\times$ Swept Volume

Brake Power = Brake work done per cycle $\times$ No. of cycles per sec.

Brake Power = BMEP $\times$ Swept Volume $\times$ No. of cycles per sec.

$$BP \text{ (in kW)} = BMEP \text{ (in bar)} \times 100 \times V_s \times \frac{N}{2 \times 60}$$

$$BMEP = \frac{BP \text{ (in kW)} \times 2 \times 60 \times 4}{\pi \times D^2 \times L \times N \times 100} \text{ bar}$$

$$V_s = \text{Swept volume of the engine} = n \times \frac{\pi}{4} \times D^2 \times L, m^3$$

n: No. of cylinders = 1

D: Diameter of the engine cylinder = 0.076 m

L: Stroke length = 0.060 m

N: Engine speed in RPM

Result Table:

No.	Brake Power (W)	Fuel Consumption C (kg/hr)	Specific Fuel Consumption SFC (g/kW-hr)	Brake Mean Effective Pressure MEP (bar)	Brake thermal efficiency (η_{BT})

Precautions:

1. It is to be ensured that a sufficient quantity of petrol is available in the fuel tank.
2. It is to be ensured that a sufficient quantity of lubricating oil is available in the oil sump.
3. The water supply to the calorimeter is to be checked.
4. After starting the engine, the engine should be run at NO LOAD condition for at least 5 minutes.
5. The engine should be loaded/unloaded gradually by switching ON/OFF the load switches.
6. The engine should be brought to NO LOAD condition after the experiment is over and should be run in this condition for 2 – 3 minutes before stopping the engine.
7. The fuel tank and the fuel pipes should be drained when the engine is not working for a long duration.

Preparation of Lab Report: Your report should have the following contents:

1. Name of the Experiment.
2. Objectives of the experiment.
3. Description of the apparatus with the Schematic diagram of the experimental setup and the specifications of the engine.
4. Describe the experimental procedure.
5. Define the following parameters and relevant formulae for calculating them: (i) Brake power, (ii) Total fuel consumption, (iii) Brake specific fuel consumption (BSFC), (iv) Brake thermal efficiency, and (v) Brake Mean Effective Pressure.
6. Prepare the Observation Table.
7. Show sample calculation for estimating all performance parameters (**for one set of readings only; calculations for other sets of readings are not to be shown in the Lab report**):
8. Complete the Result Table for all sets of readings.
9. Draw the following graphs:
 - a. Brake thermal efficiency vs brake power
 - b. Total fuel consumption (TFC in kg/hr.) vs brake power

- c. Brake specific fuel consumption (BSFC in kg/kW-hr.) vs brake power
- d. Brake Mean Effective Pressure (BMEP in bar) vs brake power

10. Conclusions

Review Questions:

1. Define the following parameters and formulae for calculating them: Brake power, Total fuel consumption, Brake specific fuel consumption, Brake thermal efficiency, Mean effective pressure.
2. What is the heating value of fuel?
3. How BSFC and brake thermal efficiency are related?
4. What are the precautions to be taken before starting the engine and after finishing the experiment?

EXPERIMENT NO. 3

Title: To Study the Construction and Operation of 4-Stroke Diesel Engines

Objectives:

1. To study the basic terminology related to a reciprocating engine,
2. To study various component of an internal combustion engine,
3. To study the working of a 4-stroke petrol engine,
4. To study the working of a 4-stroke diesel engine,
5. To study the theoretical valve-timing diagram of a 4-stroke engine,
6. To study the actual valve-timing diagram of a 4-stroke petrol engine,
7. To study the actual valve-timing diagram of a 4-stroke diesel engine, and
8. To compare a petrol engine to a diesel engine.

1. Introduction:

An engine is simply defined as a machine that converts heat energy to mechanical energy. The engine does this through either internal or external combustion.

Combustion is the act of burning. Internal means inside or enclosed. Thus, in internal combustion engines, the burning of fuel takes place inside the engine; that is, burning takes place within the same cylinder and is directly responsible for forcing the piston to move downward to produce mechanical energy by turning the crankshaft. In external combustion engines, such as steam engines, the burning of fuel takes place outside the engine. Figure 1 shows, in the simplified form, an external and an internal combustion engine.

The external combustion engine contains a boiler that holds water. Heat applied to the boiler causes the water to boil, which, in turn, produces steam. The steam passes into the engine cylinder or steam turbine to produce mechanical energy.

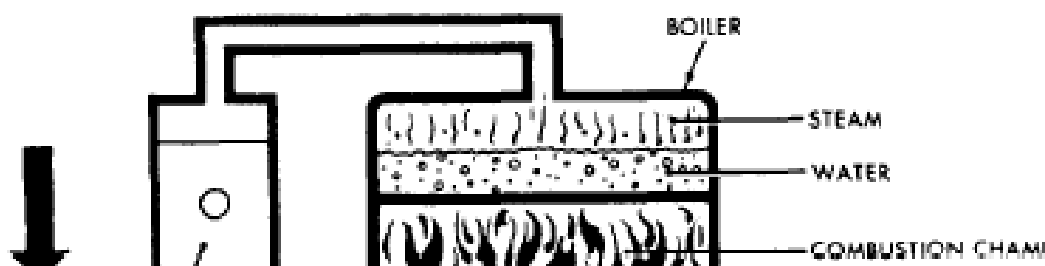


Fig. 1: Simple external and internal combustion engine.

When a gas is compressed, its pressure and temperature increase. If this compressed gas is confined with no outlet for escape and heat is added to it, its temperature and pressure will be further increased. In an internal combustion engine, air or air/fuel mixture (known as charge) is taken in a cylinder. The charge is compressed and then heat is added by combustion of fuel resulting in gases at high temperature and pressure. This high pressure acts against the

head of a piston, causing it to move downward and thereby turning the crankshaft of the engine and producing mechanical energy.

The piston of the engine moves up and down in the cylinder. The up-and-down motion is known as reciprocating motion. This reciprocating motion (straight line motion) must change to rotary motion (turning motion) to turn the wheels of a vehicle. A crank and a connecting rod change this reciprocating motion to rotary motion.

All internal combustion engines, whether petrol or diesel, rely on three essential elements: air, fuel, and ignition. Fuel contains potential energy for operating the engine; air contains the oxygen necessary for combustion; and ignition starts combustion. Various components and mechanisms of an engine are involved in delivering them to the combustion chamber at the proper time.

2. Basic Terminology

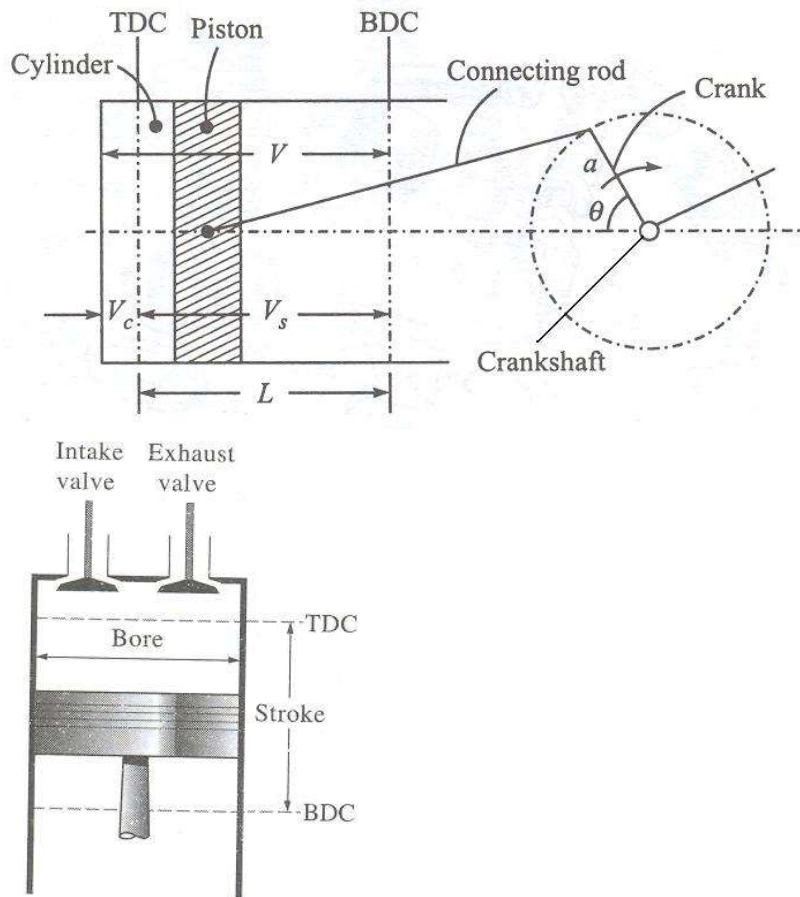


Fig. 2: Definition of basic terminology

Bore (D): It is the inside diameter of the engine cylinder. It is called the bore as it is made through a boring process.

Stroke (L): During the travel of the piston, there is an upper as well as a lower limiting position at which the direction of motion of the piston is reversed. The linear distance through which the piston travels between the extreme upper and lower positions of the piston is called the stroke. It is equal to two times the crank radius, $L = 2a$, where a is the crank radius.

Top Dead Centre (TDC): When the piston is at the topmost position of the cylinder during its travel, that position is called the Top Dead Centre. At this position the piston velocity is zero and the piston reverses its direction of motion to travel downwards. It is the dead centre when the piston is farthest from the crankshaft.

Bottom Dead Centre (BDC): When the piston is at the bottom-most position of the cylinder during its travel, that position is called the Bottom Dead Centre. At this position the piston velocity is zero and the piston reverses its direction of motion to travel upwards. It is the dead centre when the piston is nearest to the crankshaft.

Clearance volume (V_c): When the piston is at the TDC position, the volume contained in the cylinder above the top of the piston is called the clearance volume. The piston cannot occupy any part of this volume and always keeps this volume clear. Clearance volume provides the space for combustion of air-fuel mixture to take place and the space for movement of the valves inside the cylinder during opening.

Piston displacement or swept volume (V_s): It is the volume swept through by the piston in moving between the IDC and the BDC, i.e. $V_s = \pi D^2 L / 4$.

Cylinder volume (V): The cylinder volume includes both the clearance volume and the swept volume, i.e. $V = V_c + V_s$.

Compression ratio (r): It is the ratio of the volume when the piston is at BDC to the volume when the piston is at TDC. Hence, it is the ratio of total cylinder volume (V) to clearance volume (V_c).

Mean piston speed: As the piston moves inside the engine cylinder its speed changes continuously. It is zero at TDC and BDC and maximum at the mid-position of TDC and BDC. The crank angle (θ) is zero at TDC, it is 90° when the piston speed is maximum and 180° at BDC. Thus in a half rotation of the crank, the piston moves a distance equal to the length of the stroke, L . In full rotation, the distance travelled by piston will be $2L$. If N is the engine speed in revolutions per minute (rpm) and L is in meter, the mean piston speed will be $2NL/60$ m/s.

3. Main Components of an Engine

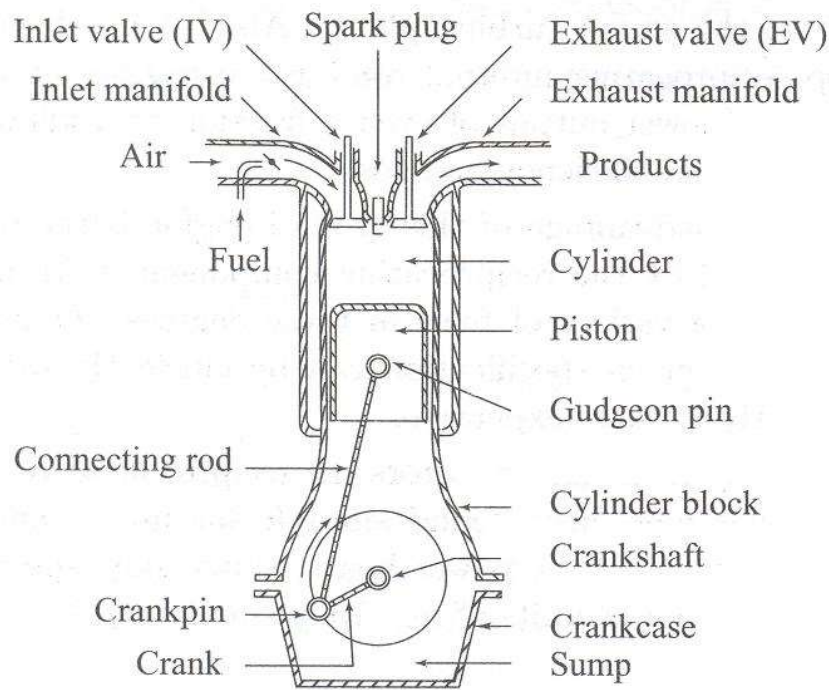


Fig. 3: Cross-sectional view of a 4-stroke petrol engine

Cylinder: It provides the space for combustion and compression. Inside the cylinder the piston reciprocates. The cylinder head holds valves, spark plugs or injectors. The cylinder head is bolted to the top of the cylinder block to close the upper end of the cylinders.

Crankcase: It is that part of the engine block below the cylinders. It supports and encloses the crankshaft and provides a reservoir for the lubricating oil. The lower part of the crankcase is the oil pan or sump, which is bolted at the bottom of the cylinder block

Exhaust Manifold: It carries waste exhaust gases (Products of combustion) from the cylinders. They have a smooth interior surface with no abrupt change in size.

Intake Manifold: In a gasoline engine, it carries the fuel-air mixture from the carburetor and distributes it as evenly as possible to the cylinders. In a diesel engine, the manifold carries only air to the cylinders.

Piston: It is a cylindrical piece of metal that moves up and down inside the cylinder. It transmits the force from expanding gas in the cylinder to the crankshaft through a piston rod or connecting rod.

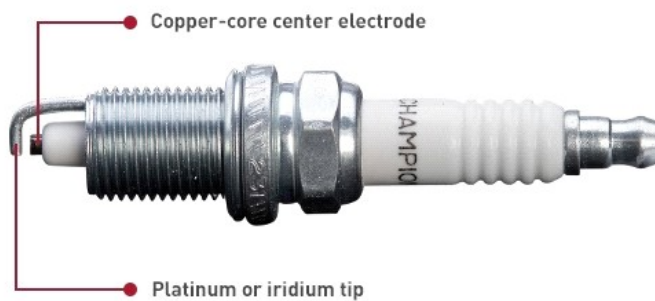
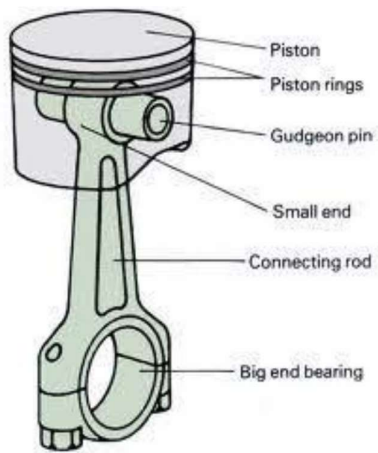


Fig. 4: Piston, Piston pin, Piston rings, Connecting rod

Fig. 5: Spark plug

Piston Pin: The piston is attached to the connecting rod by the piston pin (wrist pin). It is commonly known as gudgeon pin.

Piston Rings: Piston rings are used on pistons to maintain gastight seals between the pistons and cylinders, to aid in cooling the piston, and to control cylinder-wall lubrication. The rings serve two purposes:

- ⇒ They prevent the fuel/air mixture and exhaust in the combustion chamber from leaking into the sump during compression and combustion.
- ⇒ They keep oil in the sump from leaking into the combustion area, where it would be burned and lost.

Connecting Rod: It connects the piston to the crankshaft. It can rotate at both ends so that its angle can change as the piston moves and the crankshaft rotates. Connecting rods must be light and yet strong enough to transmit the thrust of the pistons to the crankshaft.

Spark plug (Only in Petrol engines): It is a device for delivering electric current from an ignition system to the combustion chamber of a spark-ignition engine to ignite the compressed fuel/air mixture by an electric spark. Electrical energy is transmitted through the spark plug,

jumping the gap in firing end of the plugs if the voltage supplied to the plug is high enough. This electrical spark ignites the gasoline/air mixture in the combustion chamber.

Ignition system (Only in Petrol engines): Combustion process in a petrol engine is initiated by a spark, which is caused by applying a sufficiently high voltage across two electrodes separated by fuel charge. Breakdown voltage is the critical voltage below which no sparking occurs. Its value is of the order of 20000 – 50000 volts.

The primary function of an ignition system is to create an electric spark in the engine combustion chamber at the proper time so that the petrol and air mixture can ignite. It produces high spark voltage spark is supplied to each spark plug in the correct sequence.

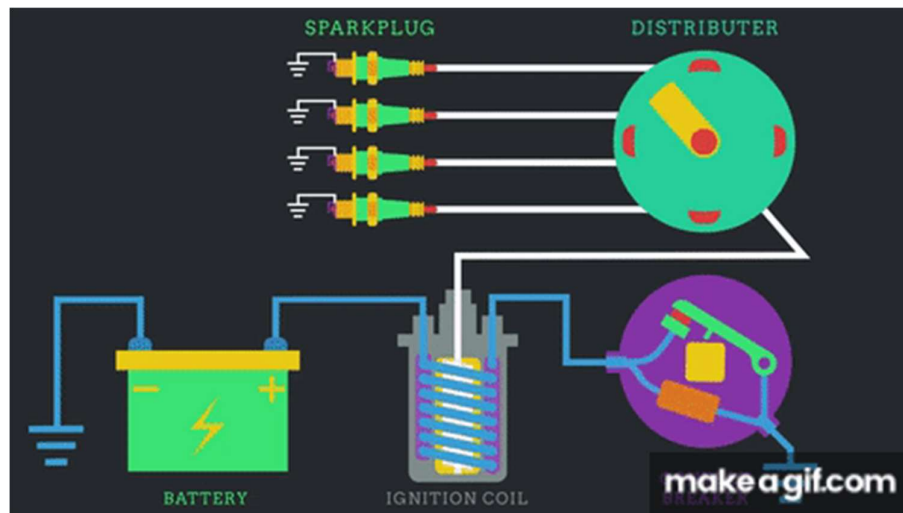


Fig. 6: Schematic diagram of Battery ignition System

Crankshaft: If the piston is heart of the engine, then the crankshaft is the backbone. It ties together the reactions of the pistons and the connecting rods, transforming their reciprocating motion into rotary motion. It transmits engine power through the flywheel, clutch, transmission, and differential to drive a vehicle.

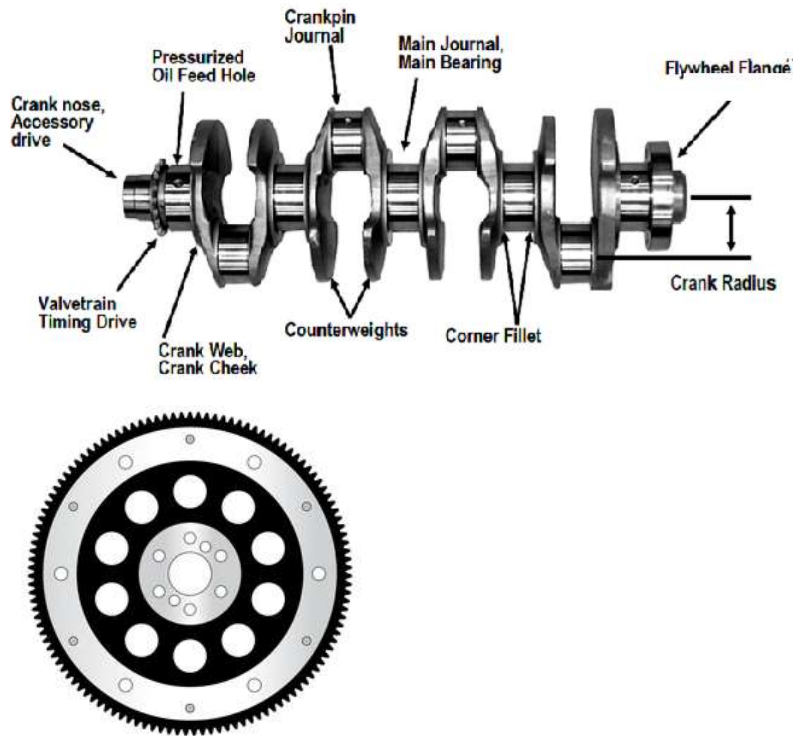


Fig. 7: Connecting rod and Flywheel

Flywheel: The flywheel is mounted at the rear of the crankshaft. It stores up kinetic energy during the power impulses of the engine. It releases this energy between power impulses, thus assuring less fluctuation in engine speed and smoother engine operation.

Valves: At least two valves for each cylinder – one intake and one exhaust. They open at the proper time to let in air and fuel and to let out exhaust. Both valves are closed during compression and combustion so that the combustion chamber is sealed.

Valve Mechanisms: Separate operating mechanisms are provided for operating each valve. Valves are normally held closed by heavy springs and by compression in the combustion chamber. The purpose of the valve mechanism is to overcome the spring pressure and open the valves at the proper time. This valve mechanism includes the engine camshaft, camshaft followers (tappets), pushrods, and rocker arms.

Camshaft: The valves are opened and closed by means of a camshaft. A camshaft is a rotating shaft that has individual lobes for each valve. The lobe pushes against a valve lifter moving it up and down. When the lobe pushes against the lifter, the lifter in turn pushes the valve open. When the lobe rotates away from the lifter, the valve is closed by a spring that is attached to the valve.

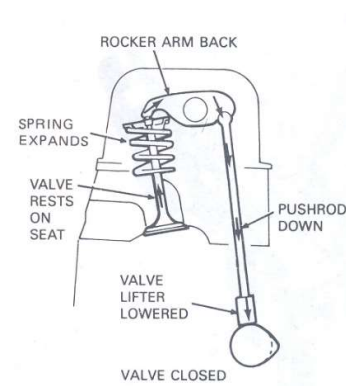
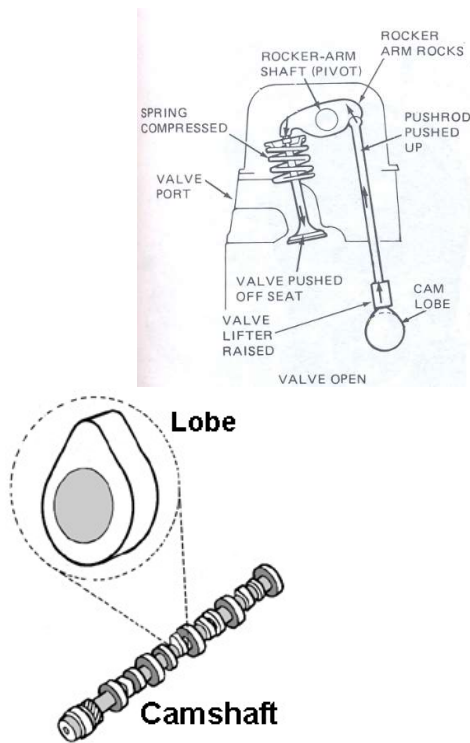


Fig. 8: Valve mechanism, (a) valve open and (b) valve closed and cam

Fig. 9: Camshaft

Carburettor (Only in Petrol engines): A petrol engine sucks the mixture of fuel and air into the cylinder of the engine. The amount of air and fuel required at any time depends on the operating conditions, like speed, load, acceleration, time of operation, etc. A carburetor is a device which mixes the fuel and air in correct proportions as per the demand of the engine. It allows air and fuel to pass into the engine through valves, mixes them together in different quantities to meet the engine requirements in varied driving conditions.

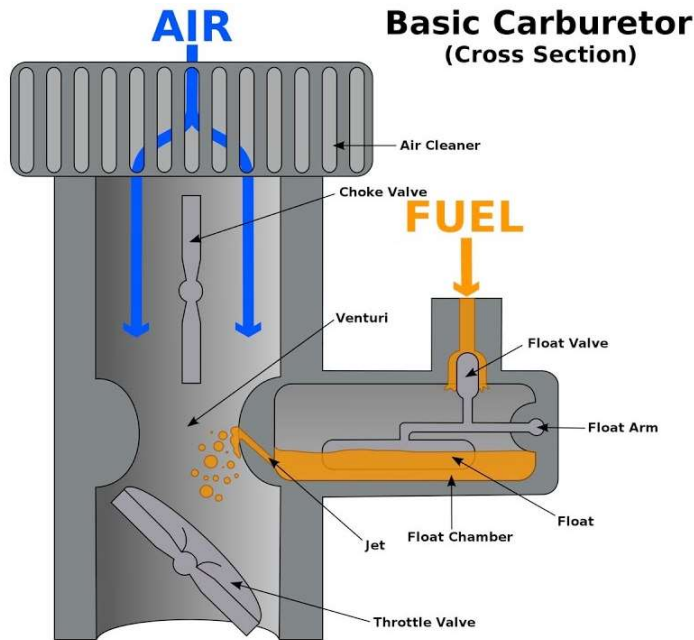


Fig. 10: Cross-section of a simple Carburettor

Petrol injection system (Only in Petrol engines): There are number of drawbacks and limitations of a carburetor in petrol engine. Therefore, in all modern petrol engine carburetors have been replaced by petrol injection system.

In petrol injection system, a special pump sends the fuel under pressure from the fuel tank to the engine bay where the fuel is distributed individually to each cylinder.

Depending on the particular system, the fuel is injected into either the inlet manifold or the inlet port via an injector. This works much like the spray nozzle of a hose, ensuring that the fuel comes out as a fine mist. The fuel mixes with the air passing through the inlet manifold or port and the fuel/air mixture enters the cylinder. Some cars have multi-point fuel injection where each cylinder is fed by its own injector.

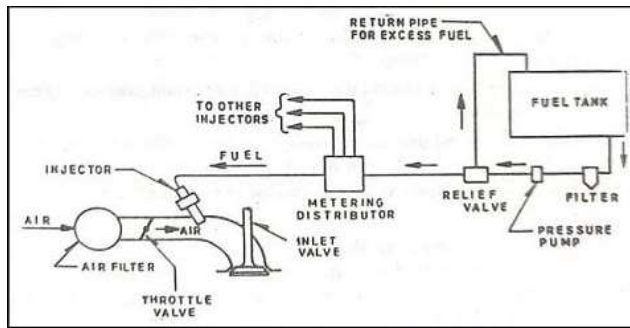


Fig. 11: Petrol injection system

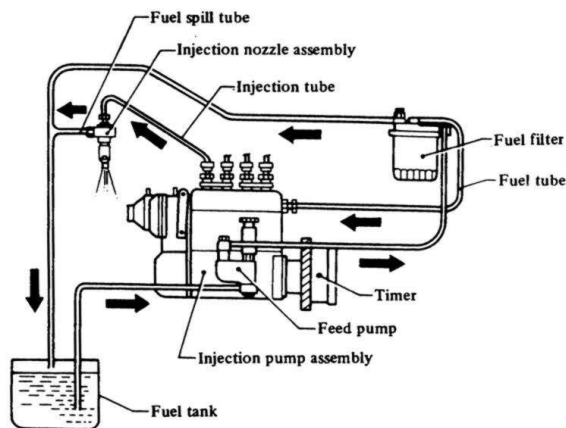


Fig. 12: Diesel injection system

Diesel fuel injection (Only in Petrol engines): The function of the diesel fuel system is to inject a precise amount of atomized and pressurized fuel into each engine cylinder at the proper time. Combustion in a diesel engine occurs when this rush of fuel is mixed with hot compressed air. Unlike petrol engines, no *electrical spark* is required in a diesel engine. Hence, *ignition system and spark plug* are absent in a diesel engine.

4. Working of 4-stroke Petrol Engine

- The intake valve opens at a precise time to allow the air/fuel mixture to enter the cylinder.
- The exhaust valve opens at a precise time to allow the burned gases to leave the cylinder.
- The spark plug ignites the air/fuel mixture in the cylinder, which creates an explosion.
- The force of the explosion is transferred to the piston. The force from the piston is then transferred to the crankshaft through the connecting rod.
- Each movement of the piston from top to bottom or from bottom to top is called a stroke.
- The piston takes two strokes (an upstroke and a down stroke) as the crankshaft makes one complete revolution.
- The cycle is completed in four strokes, which are Intake, Compression, Expansion or Power, and Exhaust.

- Hence, number of cycles completed by an engine per unit time is half of RPM (revolutions per minute) of the crankshaft.

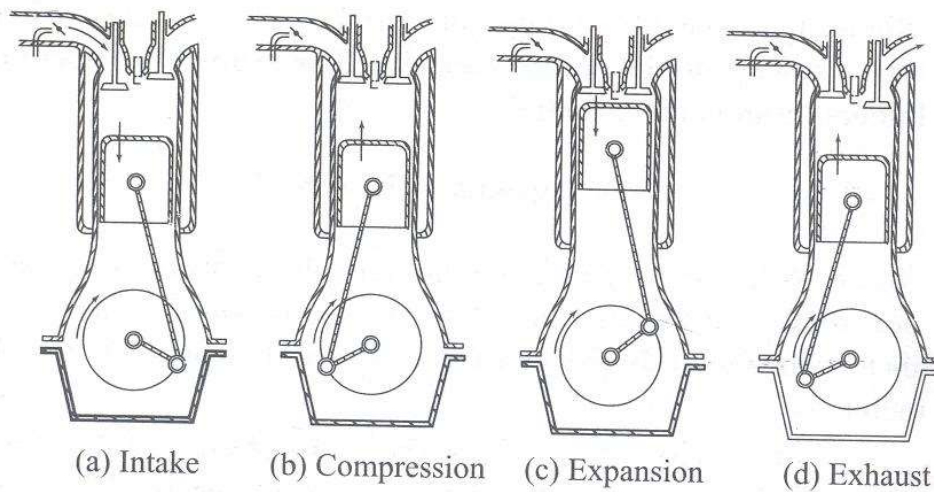


Fig. 13: Working of 4-stroke petrol engine cycle

Intake Stroke

- The first stroke in the sequence is the intake stroke.
- During this stroke, the piston is moving downward and the intake valve is open.
- This downward movement of the piston produces a partial vacuum in the cylinder, and air and fuel rush into the cylinder past the open intake valve.

Compression stroke

- When the piston reaches BDC at the end of the intake stroke, the intake valve closes and seals the upper end of the cylinder.
- The piston then moves upward and compresses the combustible mixture in the cylinder. This action is known as the compression stroke.
- In gasoline engines, the compression ratio is 6 – 10 while that for diesel engine is 16 – 22.
- This compression of the air-fuel mixture increases the pressure and temperature of the mixture within the cylinder.

Expansion or power stroke

- As the piston reaches TDC at the end of the compression stroke, the ignition system produces an electric spark.
- The spark sets fire to the fuel-air mixture.
- In burning, the mixture gets very hot and its pressure rises to about 40 – 50 bar and the force produced by the expanding gases forces the piston down.
- This force is carried through the connecting rod to the crankshaft.
- This turning effort rapidly repeated in the engine and carried through gears and shafts will turn the wheels of a vehicle and cause it to move along the highway.

Exhaust stroke

- As the piston reaches the BDC, the exhaust valve opens.
- Then the piston moves up on the exhaust stroke, it forces the burned gases out of the cylinder through the exhaust port.
- When the piston reaches the TDC, the exhaust valve closes, and the intake valve opens.
- The cycle repeats again with the intake stroke. The four strokes are continuously repeated during the operation of the engine.

5. Diesel Engine Operation vs. Petrol Engine Operation

- In Diesel engines, the fuel is not mixed with the air entering the cylinder during the intake stroke. Air alone is sucked during inlet stroke and compressed during the compression stroke. The Diesel fuel oil is injected or sprayed into the cylinder at the end of the compression stroke.
- In Diesel engines, compression ratios are high (16:1 to 22:1) and hence, pressures and temperatures have high values at the end of the compression stroke.
- This temperature is high enough to spontaneously ignite the fuel as it is injected into the cylinder.
- The high pressure of the explosion forces the piston down as in the petrol engine.

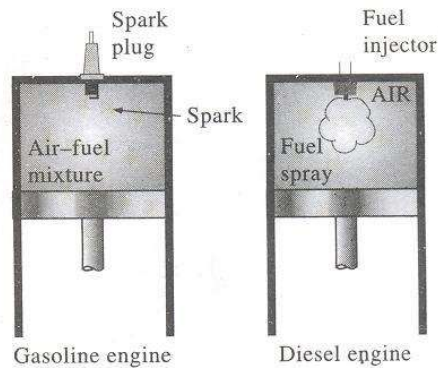


Fig. 14: Main difference between petrol/gasoline and diesel engines

6. Working of 4-stroke Diesel Engine

- The intake valve opens at a precise time to allow the air to enter the cylinder.
- The exhaust valve opens at a precise time to allow the burned gases to leave the cylinder.
- The injector injects fuel near the end of compression in a stream of compressed air which is already at high pressure and temperature. Combustion is started immediately after injection of fuel.
- Heat liberated because of combustion, increases the temperature and pressure of the gas inside the cylinder.
- The force of the gases is transferred to the piston. The force from the piston is then transferred to the crankshaft through the connecting rod.
- Each movement of the piston from top to bottom or from bottom to top is called a stroke.

- The piston takes two strokes (an upstroke and a down stroke) as the crankshaft makes one complete revolution.
- The cycle is completed in four strokes, which are Intake, Compression, Power, and Exhaust.
- Hence, number of cycles completed by an engine per unit time is half of RPM (revolutions per minute) of the crankshaft.

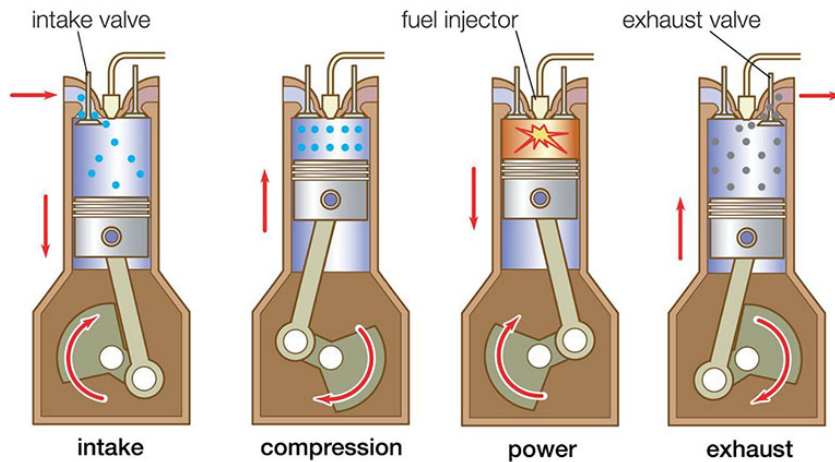


Fig. 15: Working of 4-stroke diesel engine cycle

Intake Stroke

- The first stroke in the sequence is the intake stroke.
- During this stroke, the piston is moving downward and the intake valve is open.
- This downward movement of the piston produces a partial vacuum in the cylinder, and air from the atmosphere rushes into the cylinder past the open intake valve.

Compression Stroke

- When the piston reaches BDC at the end of the intake stroke, the intake valve closes and seals the upper end of the cylinder.
- The piston then moves upward and compresses air in the cylinder. This action is known as the compression stroke.
- In diesel engines, the compression ratio is 16 – 22 while that for gasoline engines is 6 – 10.
- This compression of air increases the pressure and temperature of air within the cylinder to a sufficiently high value for autoignition of the fuel.

Expansion or Power Stroke

- As the piston reaches TDC at the end of the compression stroke, the injector starts injecting fuel in atomised condition.
- Fuel is autoignited because of high temperature of air.
- In burning, the mixture gets very hot and its pressure rises to about 60 – 70 bar and the force produced by the expanding gases forces the piston to move towards BDC.
- This force is carried through the connecting rod to the crankshaft.

- This turning effort rapidly repeated in the engine and turns the wheels of a vehicle and cause it to move along the highway.

Exhaust Stroke

- As the piston reaches the BDC, the exhaust valve opens.
- Then the piston moves up on the exhaust stroke, it forces the burned gases out of the cylinder through the exhaust valve.
- When the piston reaches the TDC, the exhaust valve closes, and the intake valve opens.
- The cycle repeats again with the intake stroke. The four strokes are continuously repeated during the operation of the engine.

7. Valve-timing Diagram

A valve timing diagram is a graphical representation of the opening and closing of the intake and exhaust valve of the engine. The opening and closing of the valves of the engine depend upon the movement of piston from TDC to BDC. The valve timing diagram comprises of a 720° degree rotation of the crank, which represents the movement of the piston 4 times between TDC and BDC to complete four strokes or one cycle of the engine.

It may be noted that one cycle is completed by 4 strokes of the piston, i.e., by 2 revolutions of the crankshaft, i.e., by 720° rotation of the crank.

For the theoretical cycle:

- During the suction stroke, the inlet valve opens as the piston which is at TDC starts moving towards BDC and the air-fuel mixture in case of petrol engine and fresh air in case of diesel engine starts entering the cylinder, till the piston reaches BDC and this point the inlet valve closes. The exhaust valve remains closed during this stroke. At the end of suction stroke, the inlet valve closes.
- During the compression stroke, the piston moves from BDC to TDC. In order to compress the air-fuel (petrol engine) and fresh air (diesel engine), both inlet and exhaust valves remain closed during this operation.
- After compression, combustion of air-fuel mixture takes place by the ignition of spark plug in case of petrol engine and by injection of fuel in case of a diesel engine.
- During the expansion stroke, the piston moves from TDC towards BDC in order to release the pressure developed by the combustion and output is obtained. Both inlet and exhaust valves remain closed during this stroke.
- During the exhaust stroke, the piston moves from BDC towards TDC. The exhaust valve opens when the piston is at BDC to remove of the exhaust gases and remains open till the piston reaches TDC. The inlet valve remains closed during this stroke.
- At the end of the exhaust stroke, the exhaust valve closes and the inlet valve opens to start a new cycle.

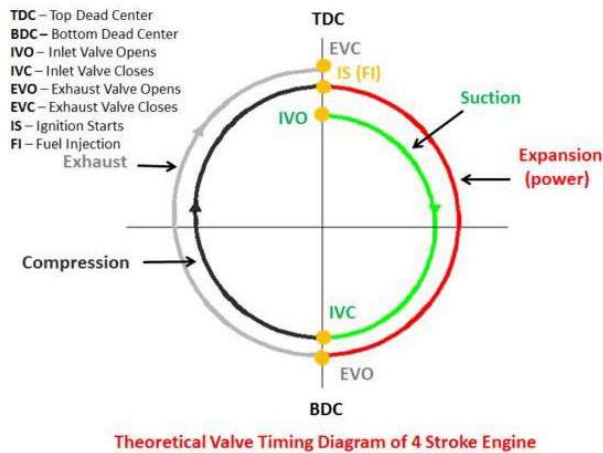


Fig. 16: Theoretical valve-timing diagram of a 4-stroke engine

For the Actual engine cycle:

- The valve timing diagrams of an actual engine cycle differ from the theoretical cycle due to the followings:
 - The theoretical cycle assumes that opening and closing of the valves are instantaneous. But in actual engines, since the mechanisms responsible for opening and closing of the valves are mechanical components, it requires some time to make the valves fully open from closed position or to close the valves completely from open position.
 - The theoretical cycle assumes that injection fuel (in case of diesel engine) and combustion of air-fuel mixture and associated heat release are instantaneous. But, in actual petrol engines, it requires certain amount of time for the combustion to take place. While for actual diesel engines, it requires certain amount of time for the injection of fuel and for the combustion to take place.
- To compensate for the time required for opening of the valves, the intake valve opens (IVO) 10-20 degree advance to the TDC (I.e., during the exhaust stroke) for the proper intake of air-fuel(petrol) or air (diesel), which also provides cleaning of remaining combustion residuals in the combustion chamber.
- The exhaust valve opens 30-50 degree before BDC (i.e., during the expansion stroke) which in turn starts the exhaust of the combustion residual.
- To compensate for the time required for closing of the valves, the intake valve closes (IVC) 25-30 degree past the BDC (I.e., during the compression stroke) which provide complete seizure of the combustion chamber for the compression of air-fuel(petrol engine)and air(diesel engine).
- The exhaust valve closes (EVC) 10-20 degree after the piston reaches TDC (i.e., during the suction stroke stroke).
- It can be seen, for certain amount of crank rotation, starting from few degrees before the end of exhaust stroke of the previous cycle up to few degrees after the beginning of suction stroke of the next cycle, both exhaust and inlet valve remain open. This amount of crank rotation is called ‘valve overlap’.

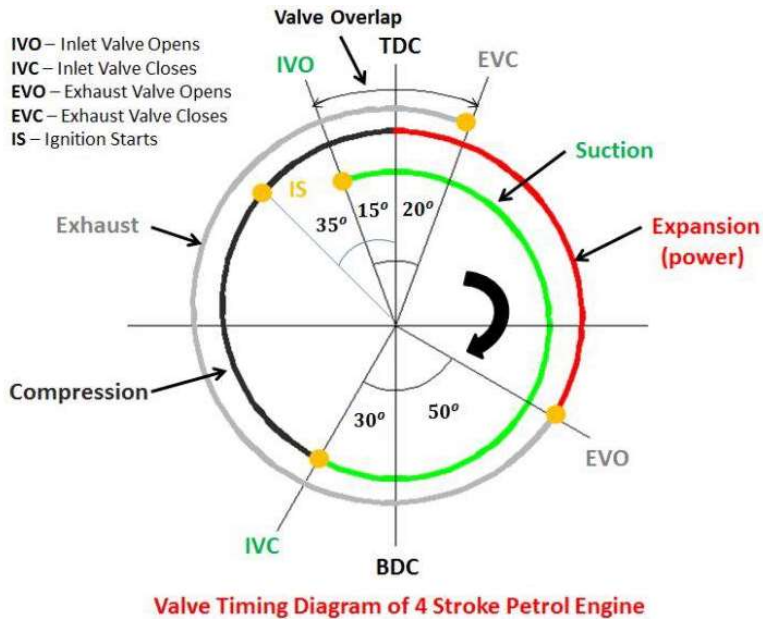


Fig. 17: Actual valve-timing diagram of a 4-stroke petrol engine

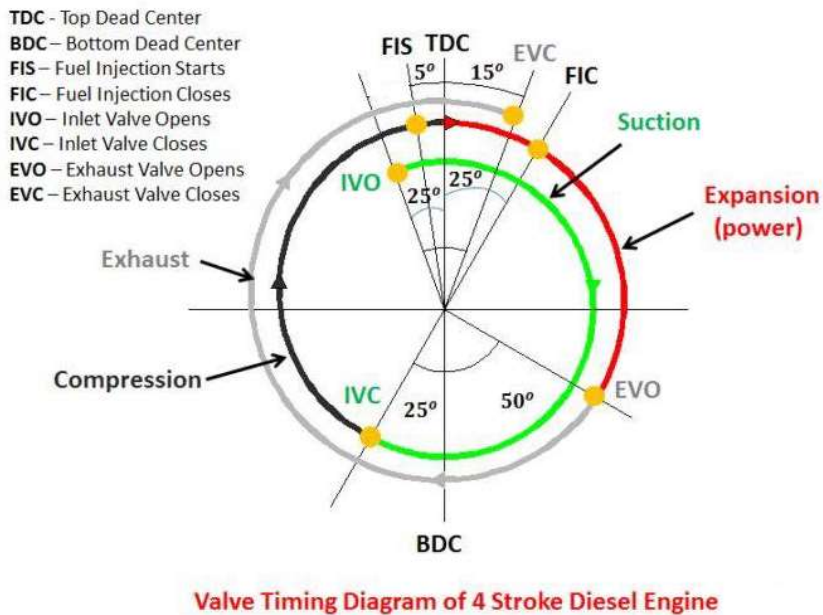


Fig. 18: Actual valve-timing diagram of a 4-stroke diesel engine

- In petrol engine, to provide the time required for combustion, the spark is given and ignition starts (IS) 10 – 20 degrees before the piston reaches the TDC (i.e., during the compression stroke). The crank angle between the ignition start (IS) point and the TDC is called the 'spark advance', which provides the proper combustion of fuel and proper propagation of flame.

- In diesel engines, to compensate for the time required for injection of fuel, injection starts (FIS) 20 – 35 degrees before the piston reaches the TDC (i.e., during the compression stroke) and injection continues for certain during and fuel injection closes (FIC) after the TDC (i.e., during the expansion stroke).
- The crank angle between the fuel injection start (FIS) point and the TDC is called the ‘injection advance’ and the crank angle duration between the fuel injection start (FIS) point and the fuel injection close (FIC) point is called ‘injection duration’

8. Comparison of Petrol and Diesel engines:

Petrol engine	Diesel engine
The ideal air-standard cycle is Otto cycle.	The ideal air-standard cycle is diesel cycle.
Petrol or gasoline or high octane fuel is used.	Diesel or high cetane fuel is used.
Fuels having high self-ignition temperature are better	Fuels with low self-ignition temperature are better.
Fuel and air introduced as a gaseous mixture in the suction stroke and is compressed together in the compression stroke.	Only air is sucked during the suction stroke and is compressed in the compression stroke. Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor / petrol injection system is used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure injection pump are used to supply of fuel. Quantity of fuel regulated in the injection pump.
Compression ratio is 6 to 10.5	Compression ratio is 14 to 22
Ignition system and spark plug are used for ignition of air-fuel mixture.	Compression of air increases the temperature, required for self-ignition of air-fuel mixture.
Battery is essential for generating the spark.	Battery is not essential but is required for starting and lighting purposes.
For the same size and speed of the engine, petrol engine produces higher maximum power due to higher heating value of fuel.	For the same size and speed of the engine, diesel engine produces lower maximum power due to lower heating value of fuel.
Flywheel is lighter	Flywheel is heavier
For the same output power, engine is lighter	Heavier due to higher pressures
Maximum RPM is higher due to lower weight	Lower maximum RPM

Maximum efficiency is lower due to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Fuel consumption is relatively higher.	Relatively lower fuel consumption
While working this engine makes less vibrations and noise.	While working this engine makes more vibrations and noise.
Generally, used in light vehicles such as motorcycles and cars.	Generally used in heavy vehicles such as trucks and buses
Comparatively low initial cost and maintenance cost	High initial and maintenance costs
Main advantages: Lighter in weight, more compact, less initial and maintenance cost	Main advantages: Higher efficiency, better fuel economy, robust construction, longer life.

Review Questions:

1. Describe working of a 4-stroke petrol engine.
2. Describe working of a 4-stroke diesel engine.
3. Describe various components of a petrol engine.
4. Define the followings: (i) Swept volume, (ii) Clearance volume, (iii) compression ratio, and (iv) Mean speed of piston.
5. Describe the purpose of the followings: (i) Carburetor, (ii) Spark plug, (iii) Ignition system, (iv) Petrol injection system, and (v) Diesel injection system.
6. What is a valve timing diagram? Why the valve-timing diagram of an actual engine cycle is different from the valve-timing diagram of an ideal cycle.
7. Define the followings: (i) Valve overlap, (ii) Spark Advance, (iii) Injection advance, and (iv) Injection duration.
8. Compare a petrol engine to a diesel engine.

Experiment no. 4

Title: Determine mechanical equivalent of heat

Objective: To determine (i) mechanical equivalent of heat (ii) comparing the experimental results to those predicted by the model of the experiment, and (iii) identifying and quantifying any possible energy losses in the experiment.

Theory:

Mechanical energy can be converted into heat, and heat can be converted into some mechanical energy. This important physical observation is known as the mechanical equivalent of heat. This means one can change the internal energy of a system by either doing work to the system, or adding heat to the system.

In 1850, James Prescott Joule reported to the Royal Society of London the results of a series of experiments in which he determined “the mechanical equivalent of heat with exactness”. His experiments truly accomplished the objective. His results established that “the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended”. Joule conducted series of experiments using water, mercury, and cast iron. His experiments using water involved over one thousand trials, with each trial lasting almost an hour. Joule's use of the term *exactness* was not an exaggeration. Joule carefully designed his experiment to minimize any energy losses, such as friction and heat transfer to the environment.

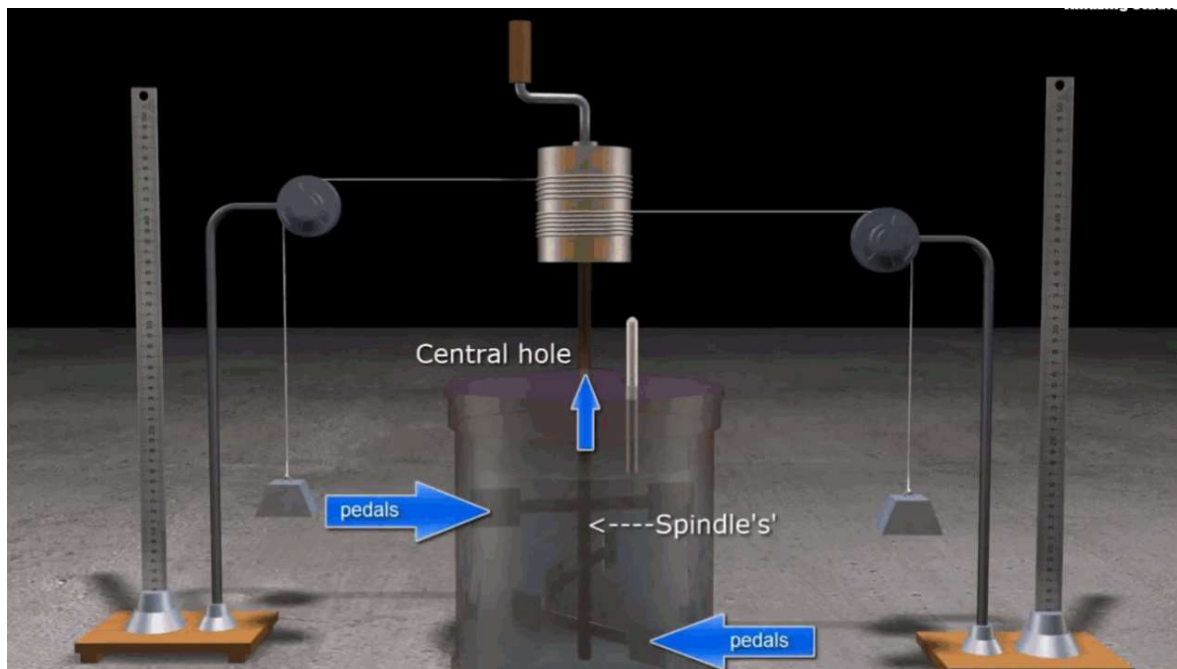


Fig. 1: Schematic of experiment setup (source: www.machinedesignonline.com)

In Joule's apparatus, the gain in the paddle wheel's energy from the energy gained in dropping the weight becomes the gain in the heat energy of the liquid.

The **potential energy loss** (or “force expended” in Joule's words) per weight drop equals $w\Delta h$, where w is the weight and Δh is the height over which the weight is dropped.

This loss becomes the gain in the **paddle's mechanical energy**, ΔE_m .

This mechanical energy is delivered to the liquid by the fins of the turning paddle wheel's fins, causing an increase in the **liquid's thermal energy**, ΔE_t (the “quantity of heat produced” in Joule’s words).

This **thermal energy gain** is expressed as $m_L C_p \Delta T$, where m_L is the mass of the liquid, C_p its specific heat at constant pressure of the liquid, and ΔT the increase in temperature of the liquid. The mass of the water can be determined from its density, ρ , and its known volume, V_L , using the expression $m = \rho V_L$.

Experiment setup (Joules experiment)

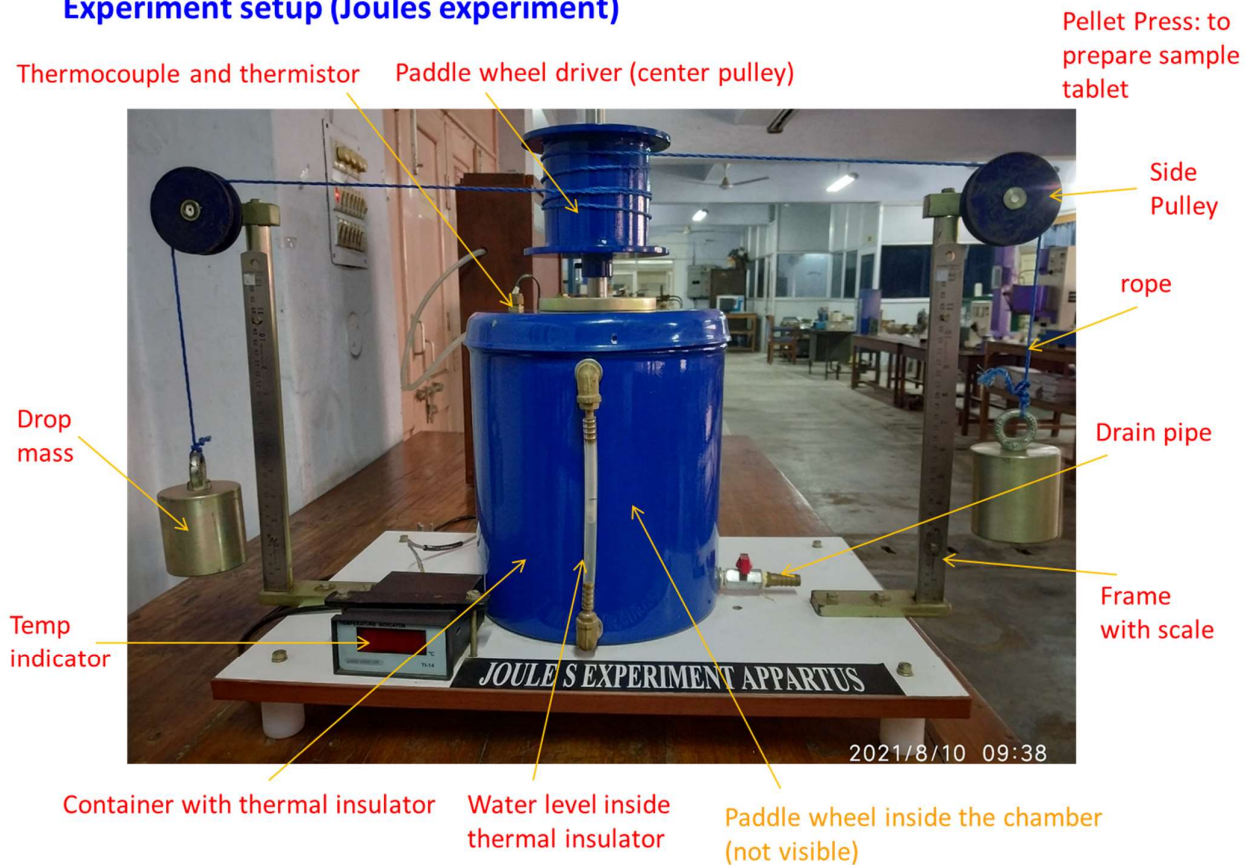


Fig 2 Experiment setup

Apparatus components

1. Liquid Container:

Material: Brass Mass: 1.378 kg

Volume of distilled water in container: 5830 mL

2. Paddle Assembly:

Rotating Paddle and Stationary Frame Material: Brass Rotating Paddle Mass: 1.200 kg

Stationary Frame Mass: 2.037 kg Rotating Paddle Radius: 6 in. Shaft Radius: 0.5 in.

3. Center Pulley:

Material: Phenolic

Center Pulley Radius: 2 in.

Center Pulley Length: 8 in.

4. Side Pulley:

Pulley Material: Pine Wood

Pulley Radius: 6 in.

Wood Pulley Thickness: 2.25 in.

Al Pulley Radius: 1 in.

Al Pulley Thickness: 4.5 in.

Experimental Procedure:

Before beginning, assign tasks among your group. Have one person be responsible for recording the temperature, time, and data. Have each of the other two responsible for dropping a weight on a side of the apparatus.

1. Measure the distance that a weight drops. Record the distance.
2. Record the ambient temperature, the thermistor resistance, and the time at which you begin the experiment.
3. Secure one of the weights to the wire on one side of the apparatus. Let the weight drop and record the amount of time it takes to drop using the stopwatch. The amount is approximately 25 seconds. Record the time.
4. Remove the weight from the wire.
5. Secure the other weight to the wire on the other side of the experiment. Let the weight drop.
6. Remove the weight from the wire.
7. Repeat steps 3 through 6 four more times, but do *not* measure the time for the weight to drop anymore. This will amount to a total of 10 weight drops, 5 for each side.
8. Record the time, thermistor resistance, and temperature of the liquid using the digital thermometer. The temperature change for this number of weight drops will be small, possibly only 0.1 °F to 0.2. °F.
9. Repeat steps 3 through 8 nine more times, for a total of 100 weight drops. Be sure to record the final temperature, thermistor resistance, and time. If you have more time,

continue repeating the weight drops to achieve a greater temperature rise. Finally, be sure record any other information that you think you may need to analyze the results.

Notes:

- One hundred weight drops should take approximately 45 minutes.
- A temperature increase of greater than approximately 1 °F should occur for water.

Observation table:

Distance for first weight drop Δh (m)	
Time for first weight to drop (s)	

Potential energy loss = $w\Delta h$ in Nm or J or $kg \times 9.81(m/s^2) \times m$

Thermal energy gain = $m_L C_p \Delta T$ in J

where

m_L = mass of the liquid, in kg,

C_p = specific heat at constant pressure of the liquid, 4182 J/kg°C

ΔT = increase in temperature of the liquid, in °C.

The mass of the water can be determined from its density, ρ , and its known volume, V_l , using the expression $m = \rho V_l$.

Weight drop distance and time.

Number of Drops	Time (s)	Temperature (°F)	Resistance (kΩ)
0			
10			
20			
30			
40			
50			

60			
70			
80			
90			
100			

Result:

Calculate:

- (i) Work performed on cylinder
- (ii) Heat absorbed by Cylinder
- (iii) Percent Difference between Heat Absorbed and Work Performed
- (iv) Mechanical Equivalent of Heat
- (v) Draw the Time vs Temp graph

Conclusion:

EXPERIMENT NO.: 5

Title of the Experiment: Determination of dryness fraction of steam

Objective: *To determine the dryness fraction of wet steam*

Apparatus: Steam boiler plant, combined separating and throttling calorimeter, measuring beaker, manometer, thermometer.

Theory: The dryness fraction/ quality of any two-phase liquid and vapour mixture is defined as the mass fraction of dry saturated vapour present in it. If the mixture is a saturated vapour, then the quality is 1, and if the mixture contains only saturated liquid, the dryness fraction is zero. Hence the dryness fraction of any two-phase mixture varies as:

$$0 \leq x \leq 1$$

Unlike the superheated and sub-cooled regions, the pressure and temperature are dependent properties for the two-phase zone. In a two-phase liquid vapour mixture, the liquid must be at saturated liquid and vapour at the saturated vapour state. So for a two-phase mixture, if the pressure or the temperature is known, all other specific properties of the saturated liquid and saturated vapour can be obtained from the property table. However, to know the specific properties of the mixture, the mass fraction of vapour needs to be known.

There are different techniques to determine the dryness fraction of steam. A simple throttling calorimeter can be used for the same. The basic principle of the throttling calorimeter is to bring the two-phase mixture to a single-phase (i.e., either dry saturated or superheated) by expanding the steam through a throttle valve. Once the steam is in the superheated state, the exit enthalpy can be obtained by measuring two independent intensive properties such as pressure and temperature. The dryness fraction of the incoming steam can be calculated by comparing the enthalpy of the steam before and after throttling

$$h_o = h_{in} = h_{f, p_{in}} + x_{in} h_{fg}$$

$$x = \frac{(h_2 - h_{f, p_{in}})}{h_{fg}}$$

The main disadvantage of the throttling calorimeter is that at the exit of the throttle valve, the steam may not be in the superheated zone, depending on the inlet dryness fraction. Hence the combination of a separator and throttling calorimeter is used.

The separator is a vessel used to initially separate some moisture mechanically from the incoming steam to ensure superheated condition after throttling. The dryness fraction measured with the help of separating calorimeter is always higher than the actual because of incomplete separation of moisture by mechanical means. The dryness fraction of highly wet steam (0.6 to 0.9) cannot be measured; therefore, the dryness fraction of highly wet steam is measured accurately by combining in series separating and throttling calorimeter. The arrangement of a separating and throttling calorimeter is shown in the figure, where these calorimeters are placed in series.

The separating calorimeter consists of two concentric chambers, inner and outer, with baffles. In this calorimeter, the steam is made to change the direction suddenly. The water droplets are heavier than the vapour, drop out by colliding with the baffles and are collected at the vessel's bottom. The remaining steam with a slightly higher dryness fraction is passed to the throttling calorimeter through an orifice.

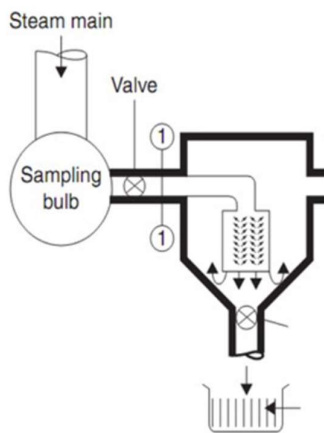


Fig. Separating unit

When the comparatively dry steam passes through the orifice/partially opened valve, its pressure drops due to friction; as a result, the liquid flash into vapour, the velocity of the steam increases resulting in a further decrease in pressure (i.e., the momentum pressure drop). Due to significant pressure drop at the exit, all the liquid flashes into vapour and vapour goes to a

superheated state (i.e., the exit pressure and temperatures are such that the temperature is higher than the saturation temperature corresponding to the exit pressure)

Dryness fraction is defined as the ratio of the mass of the saturated vapour present to the total mass of the steam that contains it.

$$\text{Dryness fraction, } x = \frac{m_s}{m_s + m_w}$$

Where m_s = mass of saturated water vapour

m_w = mass of saturated liquid water

From figure 1, it can be seen that process 1-2 represents the moisture separation from the wet sample of steam at constant pressure $p_1 = p_2$, and process 2-3 represents throttling to pressure p_3 . With p_3 and t_3 being measured, h_3 can be found from the superheated steam table.

Now,

$$h_3 = h_2 = h_{f @ p_2} + x_2 h_{fg @ p_2}$$

h_3 can also be obtained by using saturation data and the specific heat of the vapour as given below

$$h_3 = h_{g, p_3} + c_{p, v} (T_3 - T_{sat @ p_3})$$

Therefore: x_2 the quality of steam after partial moisture separation can be evaluated. If m kg of steam is taken through the sampling tube in, t secs, m_1 kg of water is separated mechanically, not by condensation, and m_2 kg is throttled and then condensed to water and collected, then

$$m = m_1 + m_2,$$

At state 2, the mass of dry vapour will be $x_2 \times m_2$. Therefore, the quality of the sample of steam at state 1, x_1 is given by

$$x_1 = \frac{\text{mass of dry vapour at state 2} = \text{mass of dry vapour at state 1}}{\text{mass of liquid separated} + \text{liquid and vapour mixture at state 2}} = \frac{x_2 \times m_2}{m_1 + m_2}$$

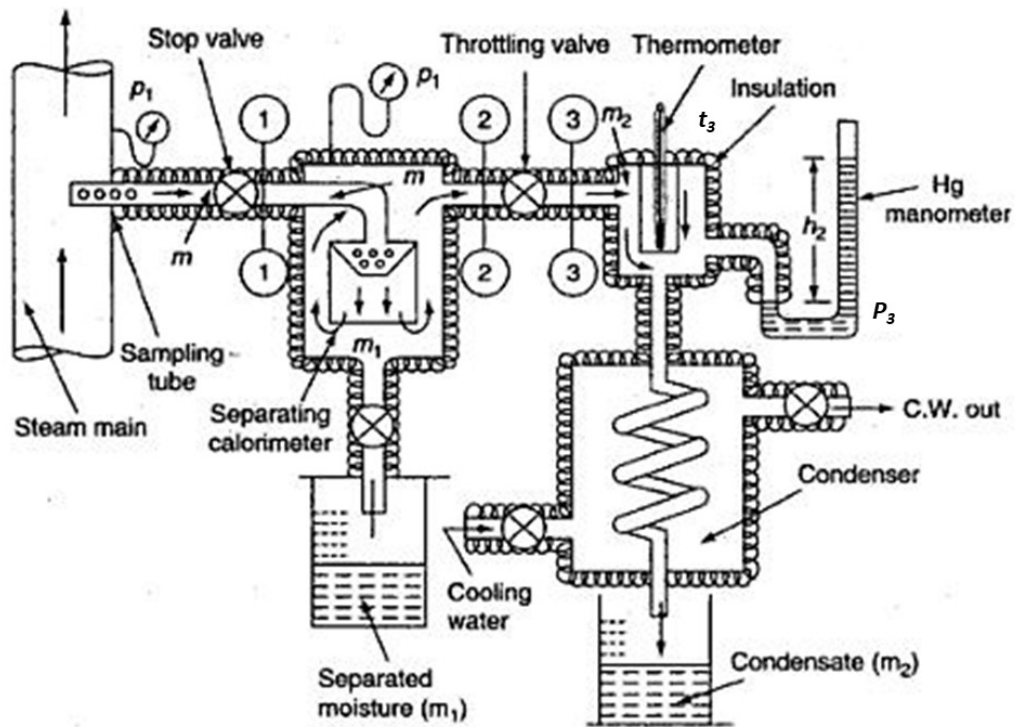


Figure 1: Schematic of a separating and throttling calorimeter



Fig. 2 Photograph of separating and throttling calorimeter

Experimental procedure:

- Run the steam boiler unit for sufficient amount of time such that adequate amount of steam will be produced.
- Part of the steam before entering into the turbine is bypassed through the separating and throttling calorimeter by opening the bypass valve.
- Keep the water drain valve in open condition both for the separating unit and throttling calorimeter.
- Open the cooling water inlet and exit valves.
- Partially open the throttle valve present between separating unit and the throttling calorimeter.
- In this condition run the unit for sufficient amount of time such that steady state is reached.
- The steady state can be ensured by looking at inlet and exit temperatures.

- Once steady state is reached the volume of the water separated in the separating unit within a given interval of time is obtained by collecting the water from the drain pipe in a measuring flask and noting the time.
- Similarly, the condensate coming from the throttling calorimeter is collected in the measuring flask and corresponding time interval is noted down.
- Under steady state and steady flow operation the steam pressure in the main i.e., p_1 , the pressure and temperature after throttling i.e., p_3 and T_3 and noted

Observation table:

Readings	First Observation	Second Observation	Average
Steam pressure in the main P_1 (bars)			
Steam pressure after throttling P_3 (bars)			
Temperature of main T_1 ($^{\circ}\text{C}$)			
Temperature after throttling T_3 ($^{\circ}\text{C}$)			
Quantity of separated water m_1 (kg)			
Quantity of condensate m_2 (kg)			
Atmospheric pressure P_a (bars)			

Calculations:

Alternate method:

m_s = mass of steam condensed and collected from the condenser.

m_w = mass of water collected from separating calorimeter.

x = actual dryness fraction of steam in the main pipe.

x_1 = apparent dryness fraction of steam measured by separating calorimeter assuming that the steam coming out of separating calorimeter is completely dry.

x_2 = actual dryness fraction of steam entering into the throttling calorimeter

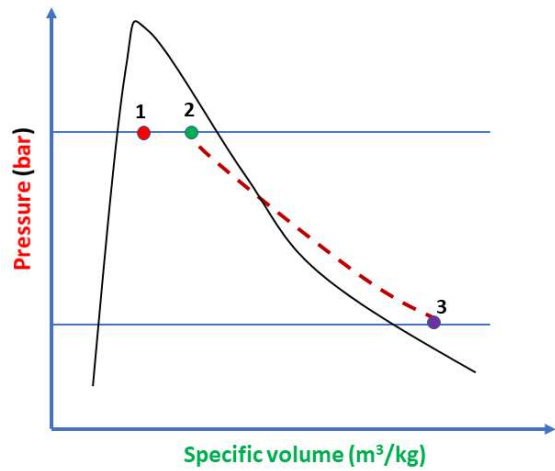


Figure 4: Separating and throttling process on p-v plot

Conclusions:

Questions:

1. What happens in the throttling process?
2. What is the function of separating calorimeter?
3. What is the function of the throttling calorimeter?
4. What is the dryness fraction?
5. Give the range of this fraction.

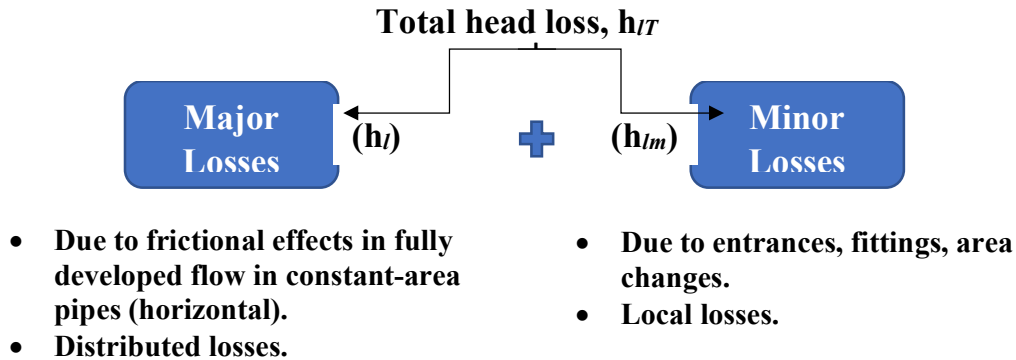
Experiment no. 6

Title: Determination Darcy's friction co-efficient

Objective: To determine and compare the value of Darcy friction factor, f , with Moody chart.

Introduction

Liquid or gas flow through pipes or ducts is commonly used in heating and cooling applications and fluid distribution networks. It is observed that when a fluid is flowing through a pipe, it is subjected to resistance. This resistance depends upon the velocity of flow, area of surface in contact and also type of flow, i.e. laminar or turbulent. The fluid in given applications is usually forced to flow by a fan or pump through a flow section. This experiment pay particular attention to friction, a major factor contributing to the energy loss which is directly related to the pressure drop and head loss during flow through pipes. The pressure drop is then used to determine the pumping power requirement.



Total head loss (h_{IT}) is regarded as the sum of major losses (h_f) and minor losses (h_{lm}). The present experimental setup will demonstrate the **major losses** only. From the engineering point of view, our sole purpose is to estimate and overcome the frictional losses to maintain the constant pressure gradient. The head loss represents the additional height that the fluid needs to be raised by a pump in order to overcome the losses in the pipe. The designing of the pipes for the long distance transportation is mainly depends upon the friction factor.

Experimental setup and apparatus

Schematic diagram of the experimental setup is shown in Fig. 1. The apparatus consists of four pipes so that loss of head can be compared for different diameters and different materials.

- | | | |
|---|---|---|
| <ul style="list-style-type: none">• Copper pipe : 16.6 mm• Aluminum pipe : 17.0 mm• G.I. pipe : 17.0 mm• G.I. pipe : 22.0 mm | } | All of them are internal diameters ID of pipe. Length of each pipe is 1 m . |
|---|---|---|

A flow control valve is provided at outlet of pipe which enables experiments to be conducted at different flow rates, i.e. at different velocities. Tappings are provided along the length of pipes, so that drop of head can be measured and visualized along the length of pipe. Each pipe is provided with valve at outlet which enables head to be controlled.

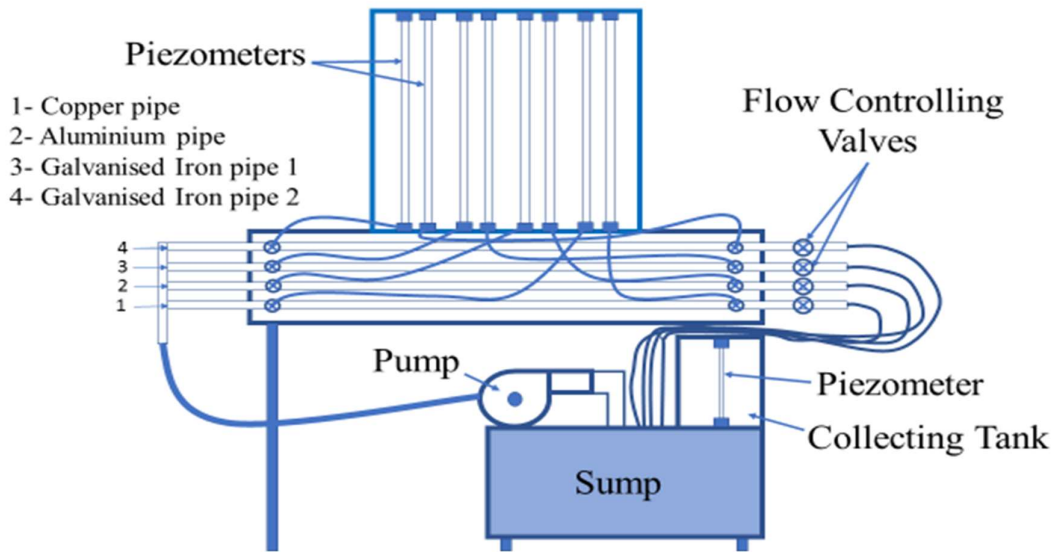


Fig. 2.1 Schematic diagram of experimental setup.

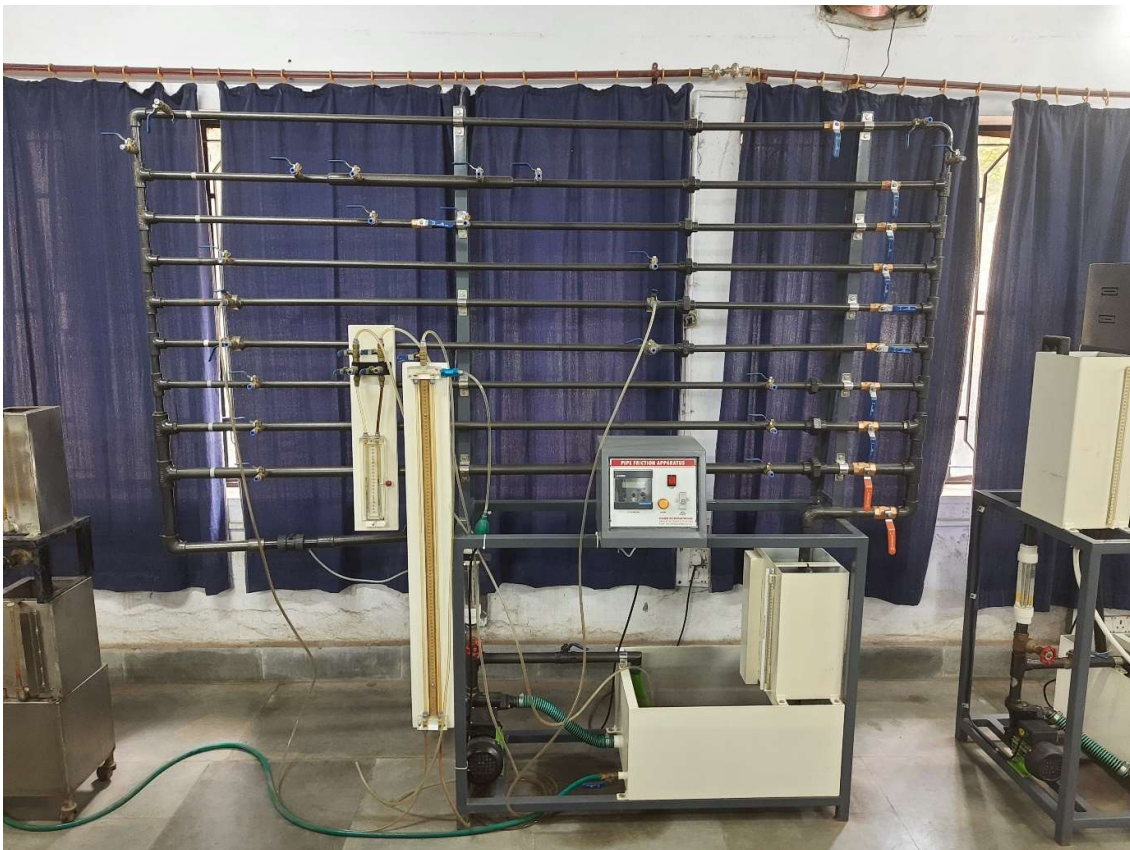


Fig. 2.2 Experimental setup of pipe friction.

Experimental procedure

1. Fill up clean water in the sump up to the mark.
(This water should be free of any oil content)
2. Open the priming bolt (near the delivery pipe) by using the screwdriver. Fill the water and remove all the air. Then tighten the priming bolt.
3. Open bypass valve approximately half.
4. Open all the pipe outlet valves and connect the electric supply (1-ph. A.C.). Start the pump.
5. Check for leakage by closing outlet valves for each pipe and correct leaks, if any.
6. Select the first pipe and open its outlet valve. Keep other three pipes outlet valve in close position.
7. Removed all the air bubbles from manometer by small closing of outlet valve.
8. Adjust outlet valve so that water head in piezometer tubes are to the readable height.
(Do not consider water head in piezometers of other pipes). Note down water head difference.
9. Close the discharge valve of measuring tank so that water collects in the measuring tank. Start stopwatch and measure time required to fill the tank for the given volume in liters.
10. Open the drain valve of measuring tank.
11. For next readings change by pass valve position (i.e. change flow rate) so that head difference in manometer changes. Note down the manometer difference and measure time required for the given volume in liters.
12. Repeat the same procedure for other pipes.
13. After completion of the experiment drain all the water. (Drain plug is fitted at the bottom of the sump tank).

Note: During measuring the heads, slight variation may occur due to voltages etc. in such cases, average readings may be taken.

Observation Table

Sr. No.	Pipe material	Head drop h_l in (mm)	Time (t) for fill 2 Lit. volume in (sec)
1.			
2.			
3.			
4.			

Calculation Steps

1. Area of a pipe, $A_p = \frac{\pi}{4} D^2 \quad (m^2)$

where, D is the internal diameter of the pipe.

2. Discharge of a pipe, $Q = \frac{V_T}{t} \quad (m^3/s)$

where, V_T is the volume of the measuring tank.

3. Average flow velocity of a pipe, $V_{avg} = \frac{Q}{A_p} \quad (m/s)$

4. Type of flow,

Reynolds Number is the ratio of inertial forces to viscous forces in the fluid.

$$Re = \frac{\rho V_{avg} D_c}{\mu}$$

$$Re \leq 2300$$

Laminar flow

$$2300 \leq Re \leq 4000$$

Transitional flow

$$Re > 4000$$

Turbulent flow

where, D_c is the characteristics length of the geometry (m) $D_c = \frac{4A_c}{P}$.

A_c is the cross-sectional area of the pipe (m^2).

P is its wetted perimeter (m).

ρ is the density of the fluid (kg/m^3).

μ is the dynamic viscosity of the fluid = 8.9×10^{-4} ($Pa-s$).

5. Head Loss, h_l ,

According to Darcy-Weisbach equation, the head loss, valid for both laminar and turbulent flows in both circular and noncircular pipes is given as:

$$h_l = \frac{f L V_{avg}^2}{2 g D}$$

where, f – Darcy friction factor

L – Effective length of the pipe, here 1 m
 g – Gravitational acceleration = 9.81 (m/s²)

Then,
$$f = \frac{h_l 2 g D}{L V_{avg}^2}$$

For **Laminar Flow**, $f = \phi(Re)$

For **Turbulent Flow**, $f = \phi(Re, \frac{\varepsilon}{D})$

- $f = \frac{64}{Re}$
- Relative Roughness = $\frac{\varepsilon}{D}$
- Given formula is valid only for circular pipes
- ε – Absolute Roughness

Note down the value of friction factor obtained from the experiment and compare it with the value of Moody chart (Fig. 2) by using the values of relative roughness (can be obtained by using the Absolute roughness Table) and Reynolds number. The value of Darcy friction factor, f , is not constant and depends upon inside surface roughness of the pipe and Reynolds number. Any oil content in water also affects the value of f .

[Repeat the same procedure for other pipes]

Results Data

Sr. No.	Pipe material	Type of Flow (Re)	Darcy friction factor obtained experimentally, f	Darcy friction factor from Moody chart, f_M
1.				
2.				
3.				
4.				

Conclusions

- Loss of head due to friction is directly proportional to length of pipe and square of velocity.
- Loss of head is inversely proportional to inside diameter of pipe.

Remarks (if any)

Questions

1. What is head loss? What are the types?
2. What is major loss? Is major loss is greater or lesser than minor losses?
3. What is piezometer?
4. What is the difference between pipe, duct, tube and conduit?
5. What is laminar flow and turbulent flow?
6. What is Reynolds number? What is inertial force and viscous force? Characteristics length of geometry?
7. Moody chart
8. Many more.... Keep asking yourself.

References

- [1] Fox, R., and A. McDonald. Introduction to fluid dynamics, vol. I. 1982.
- [2] Yunus, A. Cengel. Fluid Mechanics: Fundamentals and Applications (SI Units). Tata McGraw Hill Education Private Limited, 2010.

Absolute Roughness Table

Sr. No.	Type of Pipe	Absolute Roughness, ϵ (mm)
1.	Copper Pipe	0.0015
2.	Aluminum Pipe	0.002
3.	Galvanized Iron	0.15

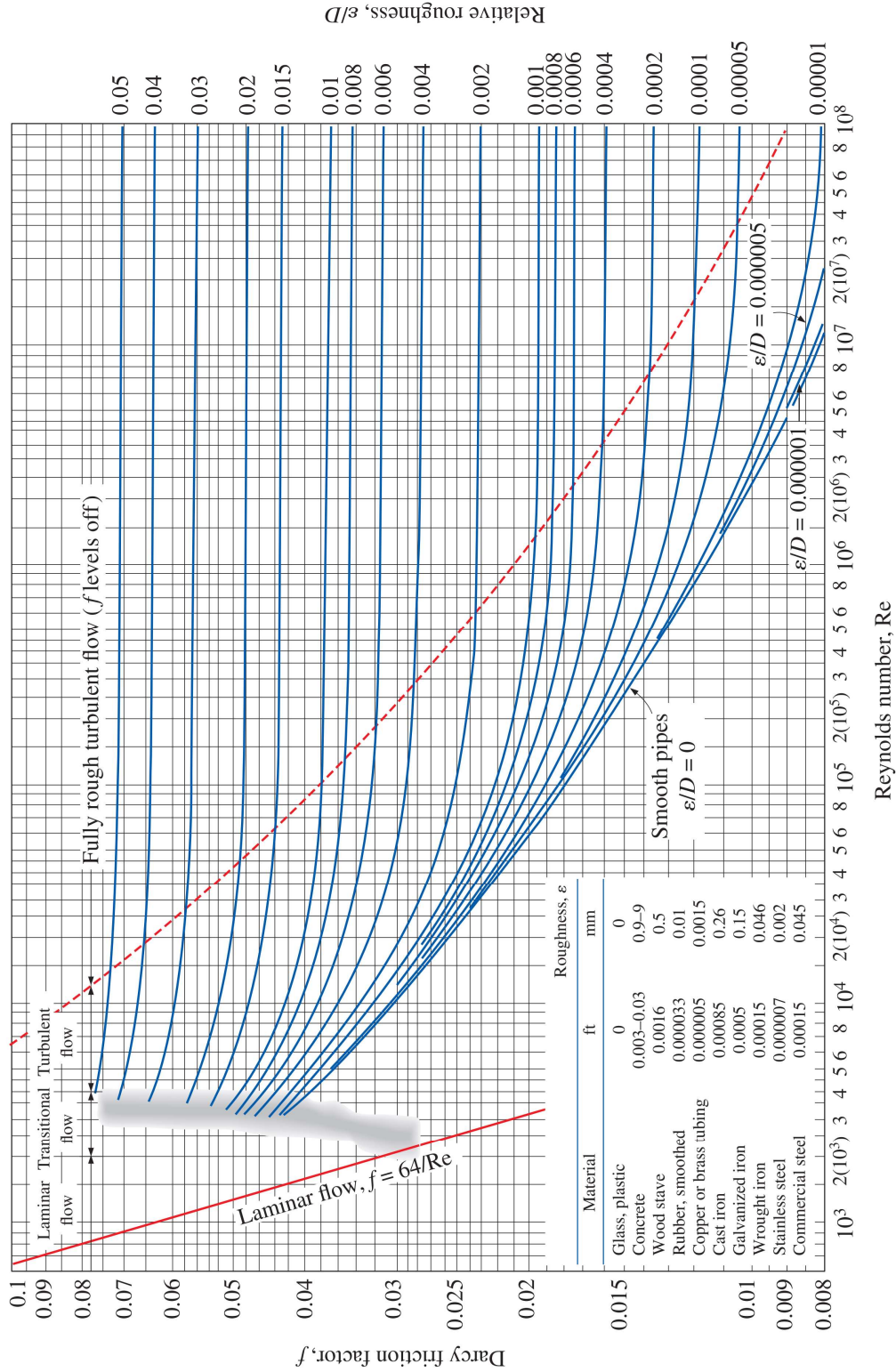


FIGURE A-12

The Moody chart for the friction factor for fully developed flow in circular pipes for use in the head loss relation $h_L = f \frac{L}{D} \frac{V^2}{2g}$. Friction factors in the turbulent flow are evaluated from the Colebrook equation $\frac{1}{\sqrt{f}} = -2 \log_{10} \left(\frac{\epsilon/D}{3.7} + \frac{2.51}{Re \sqrt{f}} \right)$.

Experiment no. 7

Title: Verification of Bernoulli's Theorem

Objective: To verify Bernoulli's Theorem

Introduction:

Bernoulli's theorem, in fluid dynamics, relation among the pressure, velocity, and elevation in a moving fluid. First derived (1738) by the Swiss mathematician Daniel Bernoulli, the theorem states, in effect, that the total mechanical energy of the flowing fluid, comprising the energy associated with fluid pressure, the kinetic energy of fluid motion, and the gravitational potential energy of elevation, remains constant under the following assumptions.

1. Steady flow: Steady - state flow refers to the condition where the fluid properties at any single point in the system do not change with respect to time.
2. Incompressible flow
3. Frictionless flow or inviscid flow
4. Irrotational flow
5. Flow along a single streamline: different streamlines may have different Bernoulli constants ($\frac{p}{\rho g} + \frac{v^2}{2g} + z$) but this is rare. In most cases, a frictionless flow region is irrotational; that is, $\text{curl}(\mathbf{V}) = 0$. For irrotational flow, the Bernoulli constant is the same everywhere.
6. No heat addition, no external work addition

The Bernoulli's principle also states that the sum of pressure energy and the kinetic energy and the potential energy of a fluid per unit weight flowing through a duct is constant

$$\frac{P}{\rho g} + \frac{V^2}{2g} + z = \text{constant}$$

Where P is static pressure, ρ is fluid density, V is fluid speed, Z is height above some datum, and g is the acceleration of gravity. The three terms in Bernoulli's equation represent energy per unit weight is also called head. Where $\frac{P}{\rho g}$ is pressure head or static head, $\frac{V^2}{2g}$ is kinetic head or velocity head and Z is gravitational head or potential head.

Experimental setup and apparatus:

The following equipment is required to complete the demonstration of the Bernoulli equation experiment:

- Hydraulics bench,
- Bernoulli's apparatus test equipment,
- A stopwatch for timing the flow measurement
- Scale for measuring the height of water level.

A Schematic diagram of experimental setup is shown in Fig.1. The dynamic apparatus consists of a rectangular duct which is tapered along the length. Flow area at inlet is maximum and it

goes on reducing towards outlet. Water is fed to duct via inlet tank with the help of a centrifugal pump and then water is collected in measuring tank through outlet tank. 14 piezometers is attached to the duct for measuring pressure head.

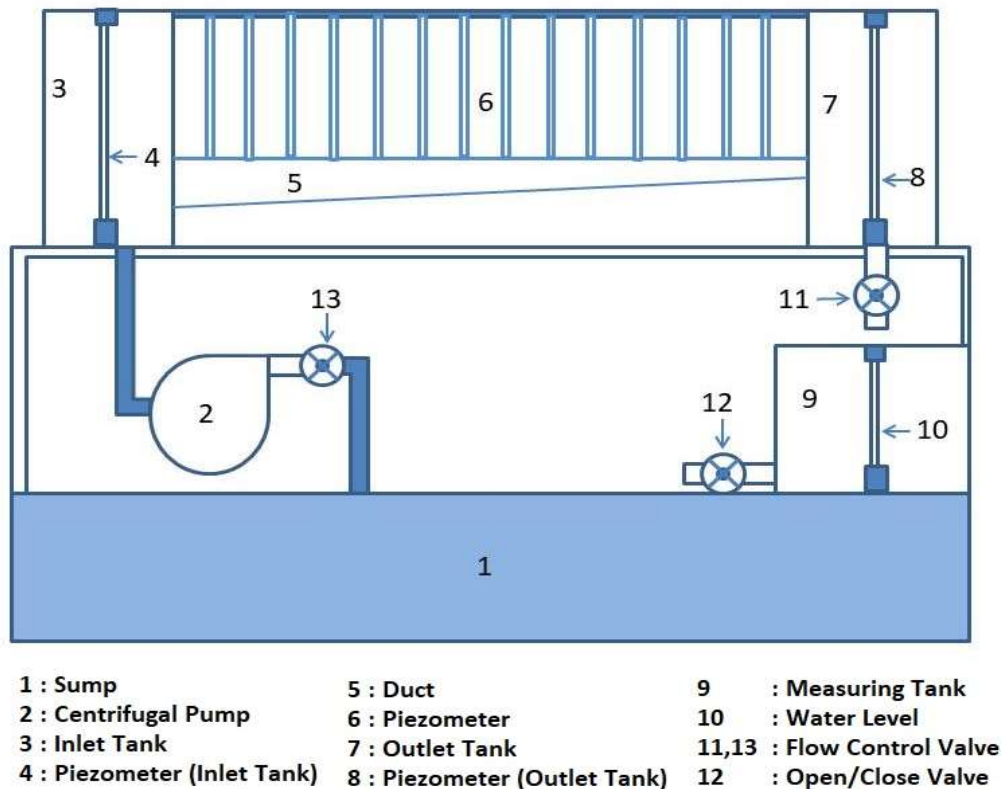


Fig .1.1: Schematic diagram of experimental setup

Procedure:

1. Open the inlet valve slowly and allow the water to flow from the supply tank (sump).
2. Now adjust the flow to get a constant head in the supply tank to make flow in and out flow equal.
3. Under this condition the pressure head will become constant in the piezometer tubes.
4. Measure the height of water level (above the arbitrarily selected plane or datum) in 14 different piezometric tubes.
5. Note down the quantity of water collected in the measuring tank for a given interval of time.
6. Change the inlet and outlet supply and note the reading.
7. Take at least three reading for three different volumetric flow rate.



Fig. 1.2 Experiment setup of Bernoulli's theorem

5. Observations and calculations:

Area of measuring tank, A : $200 \times 200 \text{ mm}^2$

Height of water level in measuring tank, Δh : mm

Time to rise water level Δh , t : sec

Discharge, Q : $\frac{A \times \Delta h}{t}$ mm³/Sec

Velocity of water : $\frac{Q}{a}$ mm/sec

Where a is the cross section area under each piezometer and given in table 3.

Velocity Head : $\frac{V^2}{2g}$ mm

Piezometric Head : $\frac{P}{\rho g} + Z$ mm

Table 1.1 Observations Data

Tapping S.No /Piezometric head in mm	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Discharge in mm ³ /sec
$\frac{P}{\rho g} + z$															
$\frac{P}{\rho g} + z$															
$\frac{P}{\rho g} + z$															

Table 1.2. Results Data

Tapping S. No	Piezometric head, ($\frac{P}{\rho g} + z$) in mm	Velocity of flow under each piezometer (mm/sec)	Velocity head, $\frac{v^2}{2g}$ in mm	Total head (mm)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

6. Conclusions:

- According to the Bernoulli principle, total energy per unit weight along the length of the duct should be remains constant but based on the results (Table 2) of this experiment, total energy per unit weight along the duct is decreasing due to various losses such as friction, leakage etc but these losses are negligible.

- Negligible change in total energy is observed along the length of duct.
- As velocity of flow increases, pressure head drops.
- Hence, Bernoulli equation is verified.

7. Questions:

1. What is the statement of Bernoulli's theorem?
2. Explain the various terms involved in Bernoulli's equation?
3. What are the different assumption made to get Bernoulli's equation from Euler's equation?
4. What are the differences between Bernoulli equation and total energy equation?
5. Why are incompressible fluid and frictionless flow taken in the Bernoulli equation?
6. What is piezometer tube?
7. What is the function of inlet and outlet tank?
8. Why is Bernoulli's equation valid along a streamline for rotational flow?
9. Is there Bernoulli's equation for rotational flow?
10. Can we use Bernoulli equation between any point before the pump and any point after the pump regardless the height, velocity and pressure in such points?

Reference

F. M. White, "Fluid Mechanics," 7th Edition, McGraw- Hill, New York, 2011.

David E. Alexander, in Nature's Machines, 2017

<https://www.britannica.com/science/Bernoullis-theorem>

Table 1.3. Cross section area under each piezometer in mm²

Tapping S. No	Cross section area under each piezometer in mm ²
1	9.6 x 10 ²
2	9.2 x 10 ²
3	8.8 x 10 ²
4	8.4 x 10 ²
5	8.0 x 10 ²
6	7.6 x 10 ²
7	7.2 x 10 ²
8	6.8 x 10 ²
9	6.4 x 10 ²
10	6.0 x 10 ²
11	5.6 x 10 ²
12	5.2 x 10 ²
13	4.8 x 10 ²
14	4.4 x 10 ²

Experiment no. 8

Title: Determination of coefficient of discharge (C_d) for venturimeter

Objective: The objective of this experiment is to obtain the coefficient of discharge (C_d) from experimental data by utilizing venturimeter and also to find the relationship between Reynolds number and the coefficient of discharge.

Theory:

A venturimeter is a device that is used for measuring the volumetric flow rate of fluid through a pipe. Venturimeter consists of a converging section, throat, and a gradually diverging section. The inlet section of the venturimeter is of the same diameter as that of the pipe. At the inlet and at the throat of the venturimeter are provided to connect a differential manometer. In the converging section, acceleration of the flowing fluid is allowed to take place under the favourable pressure gradient in a relatively small length, without appreciable loss of energy. However, in the diverging section, retardation of flow is allowed to take place and to prevent the boundary layer separation and consequently formation of the eddies that result in excessive loss of energy, the divergent section is made longer with a divergence angle of 6° (approx). The convergent section of a venturimeter has a convergent angle of 21° (approx). The throat portion of the venturimeter acts as a bridge between the convergent and divergent section. The diameter of the throat (D_2) is reduced considerably for greater accuracy in the pressure measurement, but it has to be limited to avoid the cavitation. In general, the diameter of the throat may vary from $1/3$ to $3/4$ of the pipe diameter and more commonly the diameter of the throat is kept equal to $1/2$ of the pipe diameter.

Principle of venturimeter:

Venturimeter is based on the **Bernoulli's theorem** that is the conservation of the mechanical energy between two points. The assumptions of the **Bernoulli principle** are:

- 1: Flow is steady and irrotational.
- 2: Flow is incompressible.
- 3: Fluid is the ideal fluid.(ie,viscous effects are negligible).
- 4: Flow along the streamline.

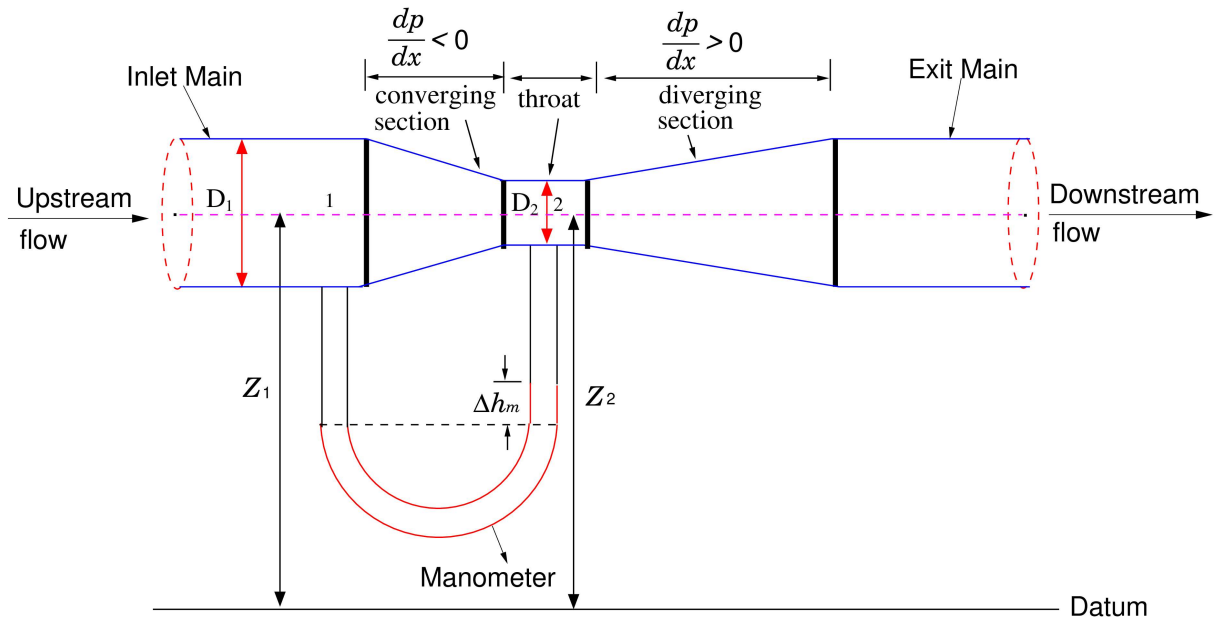


Figure 3.1 Schematic diagram of the venturimeter connected with differential U-tube manometer at pipe(1) and throat(2), respectively.

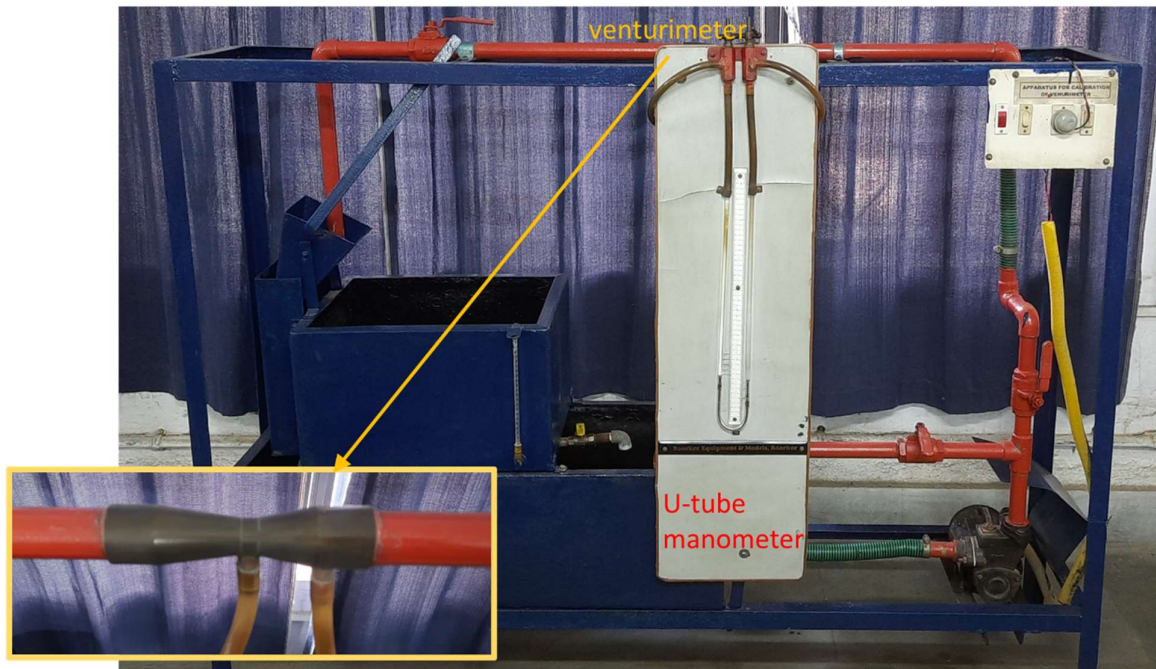


Figure 3.2 Experiment setup of the venturimeter connected with differential U-tube manometer

Let the velocity and pressure at the inlet (Sec. 1) are v_1 and p_1 respectively, while those at the throat (Sec. 2) are v_2 and p_2 . Now, applying Bernoulli equation between 1 and 2, we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + gz_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + gz_2 \quad (\text{i})$$

Neglecting change in the energy due to potential head between 1 and 2, so

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \quad (\text{ii})$$

$$\frac{p_1}{\rho g} - \frac{p_2}{\rho g} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \quad (\text{iii})$$

It is observed that change in pressure head corresponding to the gain in the kinetic head between the inlet main and the throat of the venturimeter. But the velocities v_1 and v_2 are unknown. The unknown velocities can find out by conservation of the mass flow rate ie

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \quad (\text{for compressible flow}) \quad (\text{iv})$$

$$A_1 v_1 = A_2 v_2 \quad (\text{For incompressible flow}) \quad (\text{v})$$

$$v_1 = \frac{A_2 v_2}{A_1} \quad (\text{vi})$$

By substituting the equation (vi) in the (iii). The velocity of the throat (v_2) is giving by:

$$v_2 = \frac{A_1 \sqrt{2g \Delta h_w}}{\sqrt{A_2^2 - A_1^2}} \quad (\text{vii})$$

Now, theoretical discharge (Q_t) can be given by:

$$Q_t = \frac{A_1 A_2 \sqrt{g \Delta h_w}}{\sqrt{A_1^2 - A_2^2}} \quad (\text{viii})$$

Equipment:

- 1: Venturimeter with a differential U-tube manometer connected to the pipe.
- 2: Measuring tank
- 3: Storage tank and pump to maintain the continuous supply of the flow.

Experimental procedure:

- 1: Adjust the flow rate of the water in the main pipe by controlling the flow in the secondary pipe using the bypass valve.
- 2: Take the reading of manometric deflection in the differential U-tube manometer caused by the flow rate in the main pipe, which is connected to the venturimeter.
- 3: Note the initial reading of the water level in the measuring tank. Now collect the water in the measuring tank for a given time (20 seconds). Again note the reading of the water level. The difference between the two readings gives the rise in the water level during the given time. Knowing the area of the measuring tank, calculate the actual discharge (Q_a), i.e. Discussed in the next section.
- 4: Now, C_d can be calculated as

$$C_d = \frac{\text{Actual rate of discharge}}{\text{Theoretical rate of discharge}}$$

$$C_d = \frac{Q_a}{Q_t} \quad (\text{ix})$$

- 5: Repeat the above steps for four different flow rates in the pipe by controlling the flow in the main pipe by the bypass valve.

OBSERVATION TABLE:

SI No	Manometer reading (cm)	Venturi head (cm)	Rise of the water column in the measuring tank(cm)			Actual discharge (cm ³ /s)	Theoretical discharge (cm ³ /s)	Coefficient of discharge	Reynolds no
	Δh_m	Δh_w $=12.6 \times \Delta h_m$	h_1	h_2	$\Delta h_w = h_1 - h_2$	Q_a	Q_t	C_d	Re
1									
2									
3									
4									

GIVEN DATA AND SAMPLE CALCULATION:

1: Diameter of pipe (D_1) = 2.5cm

$$\frac{\pi D_1^2}{4}$$

2: Area of the pipe (A_1) = $\frac{\pi D_1^2}{4} = 4.9 \text{ cm}^2$

3: Dia at throat (D_2) = 1.25cm

$$\frac{\pi D_2^2}{4}$$

4: Area at throat (A_2) = $\frac{\pi D_2^2}{4} = 1.22 \text{ cm}^2$

5: Manometer deflection (Δh_m) = ...cm

6: Venturi head (Δh_w) = $12.6 \times \Delta h_m = \dots\dots\dots \text{cm}$

7: Area of Coll. Tank $A = L \times B = 40 \text{ cm} \times 50 \text{ cm} = 2000 \text{ cm}^2$

8: Rise of the water level x in the t sec =

9: Actual discharge (Q_a) = Area of Coll. Tank $\times$ Rise of the water level x in the t sec

10: Reynolds number (Re) = $\frac{\rho_w v_1 D_1}{\mu}$ (based on pipe velocity and pipe dia)

Note: 1: Dynamic viscosity of water at $25^\circ \text{C} = 8.9 \times 10^{-4} \text{ Pa-sec}$

2: We are measuring the pressure head in terms of the manometric head. So we have to convert manometric head in terms of the water head to calculate velocity at the throat and this can be given by following equation:

$$\Delta h_w = \Delta h_m \left[\frac{\rho_m}{\rho_w} - 1 \right] \quad (x)$$

CONCLUSIONS:

Experimental value of coefficient of discharge (C_d) of the venturimeter is

QUESTIONS:

- 1: What is venturimeter?
- 2: Define the coefficient of discharge (C_d) and why the actual discharge is less than the theoretical discharge?
- 3: Why the throat diameter is limited to a certain diameter in the venturimeter?
- 4: What is the effect of the flow rate on coefficient of discharge?
- 5: Why, the cone angle at the diverging section is significantly less than the converging section?
- 6: Define the manometric principle?
- 7: Which fluid material has been used in the manometer for the present set up and Why?
- 8: What is the Bernoulli principle? and state its assumptions.
- 9: Explain the term $p/\rho g$.

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- [1] F. M. White, "Fluid Mechanics," 7th Edition, McGraw- Hill, New York, 2011.
- [2] Yunus, A. Cengel. "Fluid Mechanics: Fundamentals and Applications (SI Units)". Tata McGraw- Hill Education Private Limited, 2010.
- [3] S. K. Som, G. Biswas, "Introduction to Fluid Mechanics and Fluid Machines" Tata McGraw- Hill Limited, 2011.

Experiment no. 9

Title: Determination of hydraulic coefficients C_v , C_d and C_c for an Orifice

Objective: To determine the hydraulic coefficients C_v , C_d and C_c for a circular edged orifice.

THEORY:

Orifice is an opening on the side wall or bottom wall of a tank used for discharging fluid out of the tank or an opening on a plate which may be fitted in a pipe such that the plate is normal to the axis of the pipe. The flow is into and out of the tank is to be adjusted such that the rate of flow into the tank is equal to the rate of flow out of the tank, thus, establishing a steady flow condition so that the Bernoulli's equation is valid. The discharging fluid from the tank comes out through the orifice into the atmosphere in the form of a free jet. In the process, the total energy of the fluid in the tank is converted to kinetic energy as the fluid issues out into the atmosphere. The cross-sectional area of the jet after coming out from the orifice contracts to a minimum partly due to the viscous resistance offered by the surrounding atmosphere and partly due to the inertia of the fluid particles. The cross-section with the minimum area is known as the *vena-contracta* and this location is assumed to be around $0.5D$ downstream of the orifice where D is the diameter of the orifice. Due to this sudden contraction and expansion of the jet, loss of energy takes place. Further losses like the frictional losses occurring at the orifice edges cause the actual velocity of the water jet to be less than the theoretical velocity at the orifice. The ratio between the actual velocity and the theoretical velocity is known as the Coefficient of velocity C_v . The value of C_v also depends on the size and shape of the orifice.

The actual velocity of the jet is determined experimentally by measuring the horizontal and vertical coordinates of the issuing jet. The water flows through the orifice at a constant H . Let V be the actual velocity (which is horizontal) of the jet. Consider a liquid particle in the jet which is at vena-contracta at any instant in time and in time t , it is carried along the jet. Let x and y are respectively the horizontal and vertical distance of the final point from the vena-contracta. X is the horizontal distance and Y is the vertical distance covered under the influence of gravity. If air resistance is negligible, the horizontal component of velocity remains unchanged and the horizontal distance covered by particle is

$$X = Vt \quad \dots(i)$$

In the vertical direction, since there is uniform downward acceleration g , and the vertical component of velocity is initially zero for horizontal discharge, the vertical distance travelled by particle in time t is

$$Y = \frac{1}{2}gt^2 \quad \dots(ii)$$

By eliminating 't' in the equations (i) and (ii), we have

$$V = \sqrt{\frac{gX^2}{2Y}}$$

But the theoretical velocity is given by $V = \sqrt{2gH}$

The coefficient of velocity is the ratio of actual velocity from the orifice to the theoretical velocity at the orifice. Thus, the coefficient of velocity is given by

$$C_v = \frac{\sqrt{\frac{gX^2}{2Y}}}{\sqrt{2gH}} = \sqrt{\frac{X^2}{4YH}}$$

Since, the actual velocity of the jet at the vena-contracta is less than the theoretical velocity, the actual discharge will also be less than the theoretical discharge. The ratio between the actual discharge and theoretical discharge is called Coefficient of discharge C_d .

$$C_d = \frac{Q_a}{a\sqrt{2gH}}$$

Where

$a\sqrt{2gH}$ = theoretical discharge

a = orifice area

Q_a = actual discharge

The Coefficient of contraction C_c is defined as the ratio of the cross-sectional area at the vena-contracta to the cross-sectional area at the orifice.

$$C_c = \frac{a_{vena}}{a_{orifice}}$$

Since,

The actual discharge passing through orifice = Actual velocity at vena-contracta
× Area of jet at vena-contracta.

$$Q_a = C_v \sqrt{2gH} C_c a$$

Thus,

$$C_d = \frac{C_v \sqrt{2gH}}{a \sqrt{2gH}} C_c a = C_v C_c$$

$$C_d = C_v C_c$$

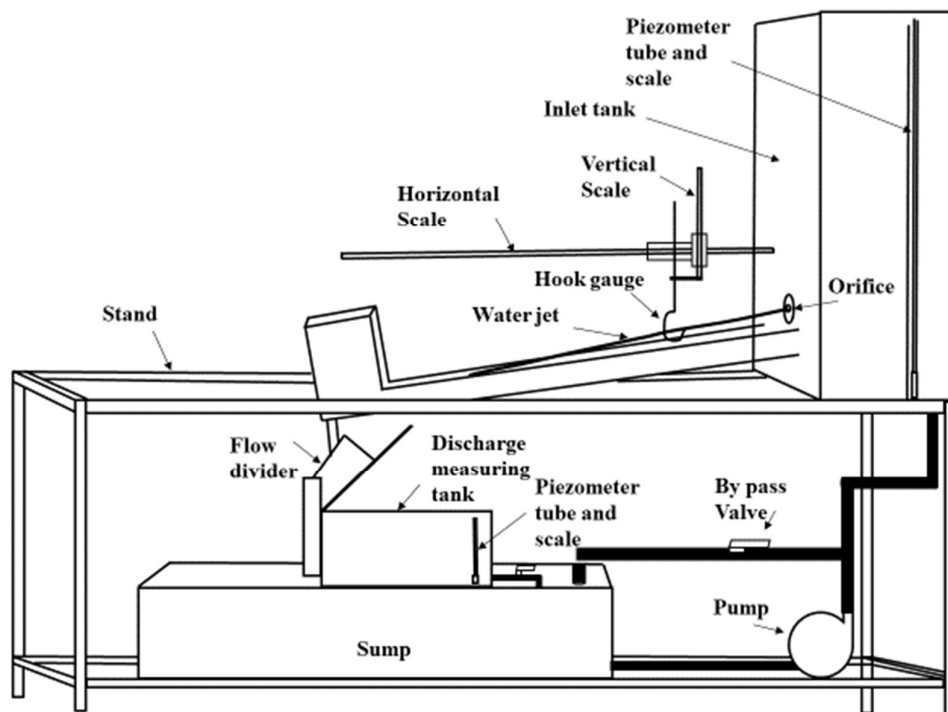


Fig. 1 Schematic diagram of experimental setup.



Fig 4.2 Experiment setup

APPARATUS REQUIRED:

1. Supply tank fitted with circular orifice,
2. Piezometer tubes and scales,
3. Sliding arrangement (hook gauge),
4. Discharge measuring tank,
5. Sump tank,
6. Pump for supply to inlet tank.

PROCEDURE:

1. Control the flow rate into the inlet tank through by-pass valve till the steady state condition is achieved. Steady state condition is achieved when the flow rate through orifice is equal to the inlet flow of the water into the tank. The steady state condition gives the effective head 'H' which is measured by the piezometric tube.

2. Using the hook gauge, measure the x and y coordinates at two different points. First point just near the outlet of orifice and second point at a significant distance from orifice outlet by just touching the hook tip to the circumference of water jet.
3. The difference of these two points gives the displacement of liquid particle $X = x_2 - x_1$ and $Y = y_2 - y_1$ in the horizontal and vertical direction respectively. Thus, the coefficient of velocity C_v calculate from the formula.

$$C_v = \sqrt{\frac{X^2}{4YH}}$$

4. To measure the actual discharge from the orifice, first measure the initial level of the discharge tank. After that, divert the flow into the discharge measuring tank. Note down the time taken to raise the water level by 2 cm by stopwatch. Thus, the actual discharge is given by

$$\text{Actual discharge } Q_a = \frac{\text{area of the discharge tank} \times \text{rise of water level}}{\text{time}}$$

5. The coefficient of discharge C_d is measured by the following formula

$$C_d = \frac{Q_a}{a\sqrt{2gH}}$$

6. Finally, the coefficient of contraction C_c is calculated by

$$C_c = \frac{C_d}{C_v}$$

Repeat the above steps for five different head 'H'.

OBSERVATION:

S. N o.	Head 'H' (cm)	X = ($x_2 - x_1$) Horizontal Gauge reading (cm)	Y = ($y_2 - y_1$) Vertical Gauge reading (cm)	C_v	Rise in Discharge measuring tank 'h' (cm)	Time to Rise in Discharge measuring tank (s)	Q_a . (cm ³ /s)	Q_{th} . (cm ³ /s)	C_d	C_c
1.										
2.										
3.										
4.										
5.										

CALCULATION:

Diameter of circular orifice = $D = 1 \text{ cm}$

Area circular orifice = $a = \frac{\pi D^2}{4} \text{ cm}^2$

Area of discharge measuring tank = $40 \text{ cm} \times 50 \text{ cm}$

$$C_v = \sqrt{\frac{X^2}{4YH}}$$

$$C_d = \frac{Q_a}{a\sqrt{2gH}}$$

$$C_c = \frac{C_d}{C_v}$$

Range of values

$C_d = 0.60 - 0.65$

$C_v = 0.90 - 0.98$

RESULTS:**CONCLUSION:**

PRECAUTIONS:

1. Head should always be constant during taking the readings.
2. Hook tip should always just touch the circumference of water jet.
3. Maintain the sufficient amount of water in sump.

QUESTIONS

1. What is a Vernier coincidence?
2. How to control constant pressure head?
3. When will we achieve constant pressure head?
4. What is the problem if pressure head not constant?
5. What is a free jet?
6. Why hook tip should just touch the water jet?
7. Why vena-contracta forms downstream from orifice ?
8. Difference between Orificemeter and Venturimeter.
9. Why is the coefficient of discharge of venturimeter greater than that of orificemeter?
10. What is the purpose of finding out the hydraulic coefficients and what do they signify?