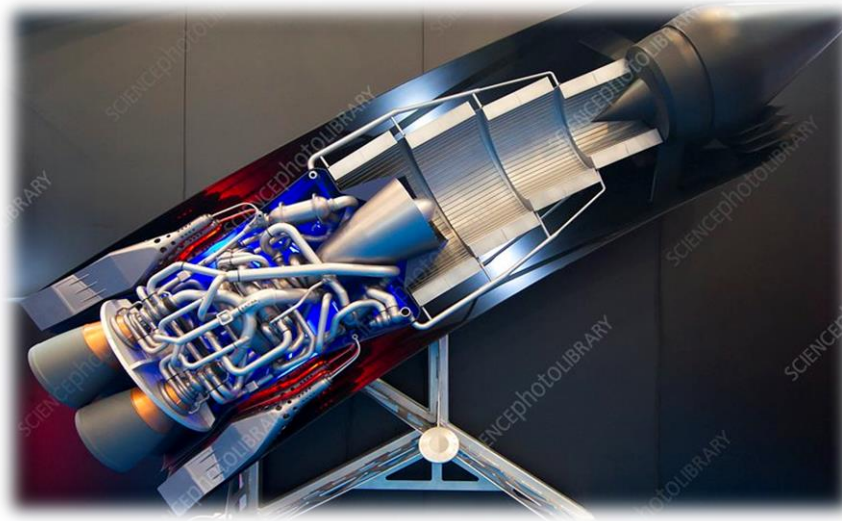


# ACS COLLEGE OF ENGINEERING

## DEPARTMENT OF AEROSPACE ENGINEERING



# Propulsion Lab Manual

(Department of Aerospace Engineering)

NAME OF THE FACULTY : SIVA J

BRANCH : AEROSPACE ENGINEERING

SEMESTER & YEAR : \_\_\_\_\_

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## STUDY OF FORCED CONVECTIVE HEAT TRANSFER OVER A FLAT PLATE

**Aim:** To determine the forced convective heat transfer coefficient for flow of air inside a horizontal pipe.

**Theory:** Convective heat transfer between a fluid and a solid surface takes place by the movement of fluid particles relative to the surface. If the movement of fluid particles is caused by means of external agency such as pump or blower that forces fluid over the surfaces, then the process of heat transfer is called forced convection.

In convection heat transfer there are two flow regions named laminar and turbulent. The non-dimensional number called Reynolds number is used as criterion to determine change from laminar to turbulent flow. For smaller value of Reynolds number viscous forces are dominant and the flow is laminar and for larger value of Reynolds numbers the inertia forces become dominant and the flow is turbulent. Dittus-boelter correlation for fully developed turbulent flow in circular pipes is:  $\mathbf{Nu} = 0.023(\mathbf{Re})^{0.8} (\mathbf{Pr})^n$

Where: n = 0.4 for heating of fluid

n = 0.3 for cooling of fluid

Nu = Nusselt number =  $\frac{hD}{k}$

Re = Reynolds Number =  $\frac{Vd}{\gamma} = \frac{\rho Vd}{\mu}$

Pr = Prandtl Number =  $\frac{\mu C_p}{k}$

**Description of The Apparatus:** The apparatus consists of a blower to supply air. The air from the blower passes through a flow passage, heater and then to the test section. An orifice meter placed near the test section measures airflow. A heater placed around the tube heats the air, heat input is controlled by a dimmer stat. Temperature of the air at inlet and at outlet are measured using thermocouples. The surface temperature of the tube wall is measured at different sections using thermocouples embedded in the walls. Test section is enclosed by a water jacket where the circulation of water removes heat from outer surface tube.



**Procedure:**

1. Start the blower after keeping the valve open, at desired rate.
2. Put on the heater and adjust the voltage to a desired value and maintain it as constant.
3. Start the water circulation.
4. Allow the system to stabilize and reach a steady state.
5. Note down all the temperatures  $T_1$  to  $T_7$ , Voltmeter reading Ammeter reading flow rate of water and manometer readings.
6. Repeat the experiment for different heat input and flow rate.

**Observations & Tabulation:**

Sl. No	Heat input			Diff. In Manometer reading $h_w$ mm	Air Temp In °C		Thermocouple Readings°C					
	V Volts	I Amps	V X I Watts		In $T_1$	Out $T_7$	$T_2$	$T_3$	$T_4$	$T_5$	$T_6$	

**Specimen Calculations:**

1. Mass density of air:  $e_a = \frac{P}{RT_a}$  kg/m<sup>3</sup>

Where  $P$  = Atmospheric pressure = 101325 N/m<sup>2</sup>

$R$  = Gas constant for air = 287 J/kg-K

$T_a$  = Room temperature in K

2. Pressure drop across orifice meter in 'm' of air:  $h_a = \frac{\rho_w h_w}{P_a}$

Where  $\rho_a$  = Mass density of water = 1000 kg/m<sup>3</sup>

$h_w$  = Differential manometer reading in 'm' of mercury

$d_0$  = Dia of the orifice

$d_p$  = Dia of the pipe

3. Velocity of air at the orifice:  $V_0 = C_d \sqrt{\frac{2gh_a}{\left[1 - \frac{d_0}{d_p}\right]^4}} \times 1000$  m/s  $d_0 \rightarrow$  dia of the orifice

$d_p \rightarrow$  dia of the pipe.

Where  $C_d = 0.62$

4. Velocity of air in the tube:  $V_a = \frac{V_0 \pi d_0^2}{\pi d_p^2} = \frac{V_0 d_0^2}{d_p^2}$

5. Average surface temperature of the tube:  $T_s = \frac{T_2 + T_3 + T_4 + T_5 + T_6}{5} \text{ } ^\circ\text{C}$

6. Mean temperature of air:  $T_f = \left[ \frac{T_1 + T_7}{2} \right] \text{ } ^\circ\text{C}$  or  $= \left[ \frac{T_i + T_o}{2} \right] \text{ } ^\circ\text{C}$

Properties of Air are taken at  $T_f$

At temperature  $T_f$ , kinematic viscosity  $\nu$ , Prandtl Number  $Pr$  and thermal conductivity  $K$  are taken from properties of air table

7. Reynolds Number:  $Re = \frac{V_0 d}{\gamma \times 1000}$

8. Nusselt number:  $Nu = 0.023 Re^{0.8} Pr^{0.3}$  (When  $Re > 2300$  flow is turbulent)

9. Nusselt number:  $Nu = \frac{hD}{k}$

Forced convective heat transfer  $h = \frac{Nu \times k}{D}$  W/m<sup>2</sup>-K

10. Rate of heat transfer:  $Q = hA (T_f - T_s)$   
 $Q = \frac{h \pi d L (T_f - T_s)}{10^6}$  Watts

**Result:**

## STUDY OF FREE CONVECTIVE HEAT TRANSFER OVER A FLAT PLATE

### Aim:

To determine the heat transfer co-efficient in natural convection for Flat Plate

### Introduction:

Heat transfer can be defined as the transmission of energy from one region to another as a result of temperature difference between them. There are three different modes of heat transfer; namely conduction, convection and radiation

**Conduction:** The property which allows passage for heat energy, even though their parts are not in motion relative to one another.

**Convection:** is the transfer of heat within the fluid by mixing one portion of fluid with another.

**Heat Radiation:** The property of emit or to absorb different kind of ratio of electromagnetic waves. Out of these types of heat transfer the convective heat transfer which of concern, divides into two categories viz.,

**Natural Convection:** If the motion of fluid caused only due to difference in density resulting from temperature gradients without the use of pump or fan, then the mechanism of heat transfer is known as "natural or free convection".

**Forced convection:** If the motion of fluid is induced by some external means such as a pump or blower.

The Newton's law of cooling in convective heat transfer is given by

$Q = h A \Delta T$ , where  $Q$ =heat transfer rate in watts

- $A$ =surface area of heat flow in  $m^2$
- $\Delta T$ =overall temperature difference between the wall and fluid
- $h$ = convection heat transfer co-efficient in watts
- This setup has been designed to study heat transfer by natural or free convection

### Apparatus:

1. A metallic tube of diameter ( $d$ ) 45 mm and length ( $L$ ) 450mm with a electrical heater coil along the axis of the tube.
2. Seven thermocouple are fixed on the tube surface.
3. Control panel instrumentation consists of multichannel digital display
  - a. Temperature indicator to measure surface temperature  $T_1$  to  $T_7$  of the tube and ambient temperature  $T_8$ .
  - b. Digital ammeter and voltmeter to measure power input to the heater.
  - c. Regulator to control the power input to the heater.
4. Front transparent acrylic enclosure for safety of the tube when not in use.

**Operational Procedure:**

1. Switch ON the mains and the control.
2. Set the regulator to set the heat input.
3. Wait for sufficient time to allow temperature to reach steady values.
4. Note down temperatures T1 to T8 using channel selector and digital temperature indicator.
5. Note down the Ammeter and Voltmeter readings.
6. Tabulate the heat input and transfer co-efficient using the procedure.
7. Calculate the convection heat transfer co-efficient using the procedure given below.
8. Repeat the experiment by changing the heat input.

**Tabulation:**

Sl.NO	Heat Input			Temperature along the tube							Average tube Temperature	Ambient Temperature	Convective heat transfer coefficient	
	V	I	Q	T1	T2	T3	T4	T5	T6	T7	T <sub>av</sub>	T8	h <sub>th</sub>	h <sub>ex</sub>
1														
2														
3														

**Calculations:**

Determination of experimental heat transfer co-efficient: For steady state condition, heat given to heater = Heat lost from the tube surface by natural convection.

$$\text{Therefore, } Q = h A_s (T_s - T_\infty)$$

Where,

$Q = (\text{Ammeter reading}) \times (\text{Voltmeter reading}), \text{ in watts}$

$D = \text{Diameter of tube} = \quad \text{mm}$

$L = \text{length of the tube} = \quad \text{mm}$

$A_s = \text{surface area} = \pi D L = \quad \text{m}^2$

$T_s = (T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7) / 7 = \quad ^\circ\text{C}$

$T_\infty = T_8 = \text{Ambient air temperature} = T_8 = \quad ^\circ\text{C}$

Therefore,

$$\text{Heat transfer co-efficient, } h_{\text{expt}} = Q / A_s (T_s - T_\infty) = \quad \text{W/m}^2\text{K}$$

Determination of Theoretical heat transfer co-efficient: The theoretical value of the natural heat transfer co-efficient is calculated given by: Note down the properties of air t from data hand book

$$T_m = (T_s + T_\infty)/2 = \quad ^\circ\text{C}$$

At mean temperature properties of air should be noted down from the HMT data hand book.  $\nu =$   
m<sup>2</sup>/s

$$k = \quad \text{W/mK}$$

$$\text{Pr} =$$

$$\beta = 1/(T_m + 273) = \quad \text{K}^{-1}$$

$$\Delta T = (T_s - T_\infty) = \quad ^\circ\text{C}$$

$$g = 9.81 \text{ m/s}^2$$

$$\text{Gr (Groshoff No.)} = (g \beta L^3 \Delta T) / \nu^2 =$$

$\text{Nu} =$  choose the equation from data book based on Gr.Pr

$$\text{Nu} = hL/k,$$

$$h_{th} = \quad \text{W/m}^2\text{K}$$

## **RESULTS**

$$h_{exp} = \quad \text{W/m}^2\text{K}$$

$$h_{th} = \quad \text{W/m}^2\text{K}$$

## BOMB CALORIMETER

**AIM:** To determine the calorific value of solid fuels

**APPARATUS:** The Bomb Calorimeter mainly consists of the following:

1. Stainless steel Bomb
2. Calorimeter Vessel with Bomb support and insulating base
3. Water Jacket with outer body
4. Lid for water Jacket
5. Stirrer assembly with F.H.P. motor
6. Bomb firing unit with Electronic Digital Temperature Indicator
7. Pellet Press
8. Stand and dial pressure gauge
9. Connecting tubes(copper tubes O2 Cylinder to pressure gauge & pressure gauge to bomb)
10. Connecting electrical leads(Firing unit to water jacket & water jacket to bomb)
11. Crucible Stainless steel
12. Gas release valve
13. Oxygen cylinder valve

**EXPERIMENTAL SETUP:**

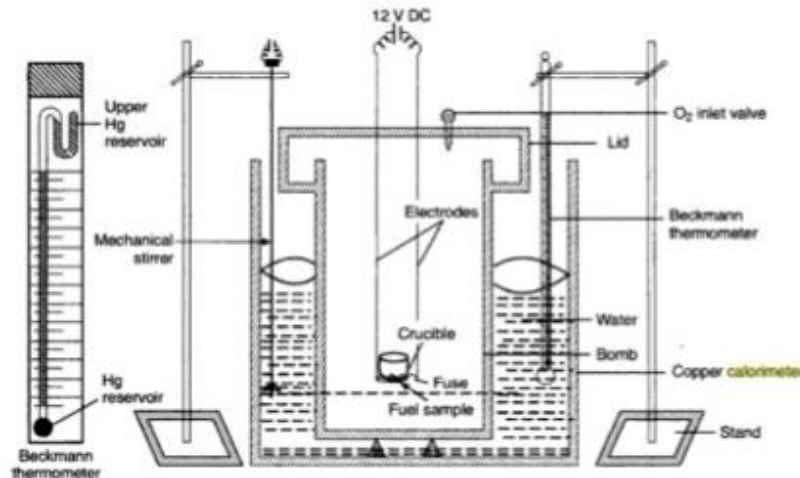


Figure: Experimental setup of Bomb Calorimeter

**DISCRIPTION:**

A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The temperature of the water allows for calculating calorie content of the fuel.

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.

**GIVEN DATA:**

- |   |           |
|---|-----------|
| 1. Weight of nichrome wire taken (10 cm weighs aprox) | = 18.4 mg |
| 2. Weight of the cotton thread (10 cm weighs aprox)   | = 5 mg    |

**OBSERVATION:**

- |   |                  |    |
|---|------------------|----|
| 1. Weight of the empty SS crucible,                                 | m <sub>1</sub> = | gm |
| 2. Weight of the Benzoic acid sample taken,                         | m <sub>2</sub> = | gm |
| 3. Weight of Benzoic acid sample pallet and weight of the crucible, | m <sub>3</sub> = | gm |
| 4. Initial temperature of water before firing,                      | T <sub>1</sub> = | °C |
| 5. Final temperature of water after firing (after 8 to 10 min),     | T <sub>2</sub> = | °C |

**CALCULATION:**

Actual weight of the sample (M) = m<sub>3</sub>-m<sub>1</sub>=                      gm

Maximum rise in temperature (T) = T<sub>2</sub>-T<sub>1</sub> =                      °C

**To calculate water equivalent of calorimeter:**

$$W = \frac{H \times M + (E_1 + E_2)}{T}$$

Where;

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

Calorific value of Standard Benzoic Acid (H) = 6319 Cal /gram

Heat liberated by Nichrome wire (E<sub>1</sub>) = 0.335 Cal/mg X weight of Nichrome wire

Heat liberated by cotton thread (E<sub>2</sub>) = 4.180 Cal/mg X weight of cotton thread

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

A Bomb Calorimeter will measure the amount of heat generated when matter 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 the heat absorbed by calorimeter assembly and the rise in temperature enables to calculate the heat of combustion of the sample.

The water equivalent is calculated using the formula

$$H \times M = W \times T$$

Where

- W** Water equivalent of the calorimeter assembly in calories per degree centigrade (2330 cal / °C)  
**T** 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

#### 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 (Oxygen cylinder is not in the scope of supply).
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.
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.

**OBSERVATION:**

Diameter of smaller hole of burner = 1.8 mm (6 No.)

Diameter of larger hole of burner = 2.5 mm (1 No.)

**TABULAR COLUMN:**

S.N.	Flow rate of air in LPM	Flow rate of gas in LPM	Cone angle, $\alpha$
1			
2			
3			
4			

**CALCULATIONS:**

$$1) \text{ Effective area of burner } A_e = \frac{\pi d^2}{4} \text{ m}^2$$

Where d= Diameter of burner :  $\Phi 2.5\text{mm}$  hole 1No. +  $\Phi 1.8\text{mm}$  6 No.

$$A_e = \frac{\pi}{4} \left[ (2.5 \times 10^{-3})^2 + 6(1.8 \times 10^{-3})^2 \right] = 2.0179 \times 10^{-5} \text{ m}^2$$

$$2) \text{ Total mass flow rate to the burner, } Q_{\text{total}} = Q_{\text{air}} + Q_{\text{gas}} = \quad \text{m}^3/\text{s}$$

$$3) \text{ Mass flow rate of air, } Q_{\text{air}} = \frac{\text{Volume of air supplied in LPM}}{60 \times 1000} = \quad \text{m}^3/\text{s}$$

$$4) \text{ Mass flow rate of gas, } Q_{\text{gas}} = \frac{\text{Volume of gas supplied in LPM}}{60 \times 1000} = \quad \text{m}^3/\text{s}$$

$$5) \text{ Flow velocity, } V_u = \frac{Q_{\text{total}}}{A_e} = \quad \text{m/s}$$

$$6) \text{ Burning Velocity of flame, } S_{L,u} = V_u \sin \alpha$$

Where  $\alpha$  = Semi included angle of flame in degrees**RESULTS:**

Burning velocity of flame = m/s

**CONCLUSIONS:**

## MEASUREMENT OF BURNING VELOCITY OF PREMIXED FLAME

### Aim:

To measure the burning velocity of the premixed flame.

**Apparatus:** Small Gas cylinder with gas, Bunsen burner, Air flow rotameter, Glass chamber, flame cone angle measurement protractor, mixing chamber, gas rotameter.

### Theory:

The Laminar burning velocity

The classical device to generate a laminar premixed flame is Bunsen burner shown in figure (a). Gaseous fuel from the fuel supply enters through an orifice into the mixing chamber into which air is entrained through adjustable openings from outside. The cross sectional area of fuel orifice may be adjusted by moving the needle through an adjustment screw into the orifice. Thereby the velocity of the jet entering into the mixing chamber may be varied and entrainment of the air and the mixing can be optimized. The mixing chamber must be long enough to generate a premixed gas issuing from the Bunsen tube into the surroundings. If the velocity of the issuing flow is larger than the laminar burning velocity to be defined below, a Bunsen flame tube cone establishes itself at the top of the tube. It represents a steady premixed flame propagating normal to itself with the burning velocity into the unburnt mixture.

The kinematic balance of this process is illustrated for a steady oblique flame as shown in the figure(b). The oncoming flow velocity vector  $V_u$  of the unburnt mixture (subscript  $u$ ) is split into a component  $V_{t,u}$  which is tangential to the flame and into a component  $V_{n,u}$  normal to the flame front. Due to a thermal expansion within the flame front the normal velocity component is increased, since the mass flow " $\rho v$ " through the flame must be the same in the unburnt mixture and in the burnt gas (subscript  $b$ ).

$$\rho (V_n)_u = \rho (V_n)_b, \quad \text{-----1}$$

$$V_{n,b} = V_{n,u} (\rho_u / \rho_b) \quad \text{-----2}$$

The tangential velocity component  $V_t$  is not affected by gas expansion and remains the same

$$V_{t,b} = V_{t,u} \quad \text{-----3}$$

Vector addition of the velocity components in the burnt gas in figure(b) then leads to  $V_b$  which points into a direction which is deflected from the flow direction of the unburnt mixture. Finally, since the flame front is stationary in this experiment the burning velocity,

$$S_{L,u} = V_{n,u} \quad \text{-----4}$$

With the Bunsen flame cone angle in fig 6.1 denoted by  $\alpha$  the normal velocity is

$$V_{n,u} = V_u \sin \alpha \text{ and it follows, } \quad S_{L,u} = V_u \sin \alpha \quad \text{-----5}$$

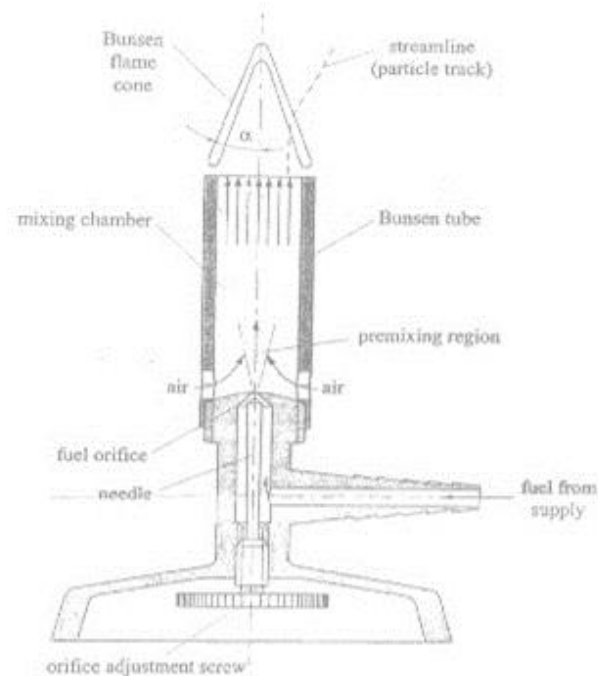


Figure (a): The Bunsen burner.

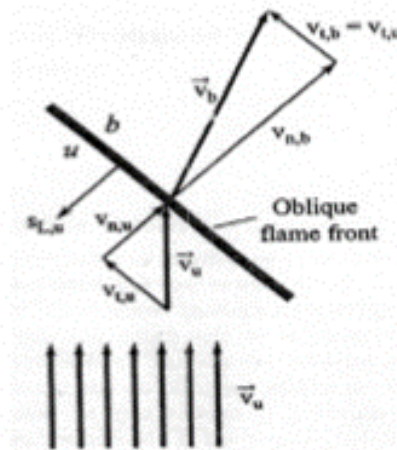


Figure (b): Kinematic balance for a steady oblique flame.

This allows to experimentally determine the burning velocity by measuring the cone angle  $\alpha$  under the condition that the flow velocity  $V_n$  is uniform across the tube exit. If this is not the case the flame angle also varies with radial distance since the burning velocity  $S_{L,u}$  is essentially constant.

A particular phenomenon occurs at the flame tip. If the tip is closed which is in general the case for hydrocarbon flames the burning velocity at the tip being normal and therefore equal to the flow velocity, is by a factor  $(1/\sin\alpha)$  larger than the burning velocity through the oblique part of the cone. This analysis also includes the effect of non-unity Lewis number by which, for instance, the difference between lean hydrogen and lean hydrocarbon flames can be explained. Finally, it is shown in figure (b)

that flame is detached from the rim of the burner. This is due to conductive heat loss to the burner which leads in regions very close to the rim to temperatures at which combustion cannot be sustained.

Another example for an experimental device to measure laminar burning velocities is the combustion bomb within which the flame is initiated by a central spark. Spherical propagation of flame then takes place which may optically be detached through quartz windows and the flame propagation velocity ( $dr/dt$ ) may be recorded. Now the flame front is not stationary. If the radial flow velocities are defined positive inward direction, the velocities of the front must be subtracted from these in the mass flow balance.

**Procedure:**

1. First ensure all the valves of the rotameter, gas cylinder, and compressor are all closed.
2. Then open regulator valve of the LPG cylinder slightly.
3. Simultaneously open the rotameter valve, fire the burner using the matchstick or lighter.
4. By observing the flame through the glass window, adjust the rotameter valve so as to get the quality blue flame (Ensure the laminar flow condition).
5. Now the flame cone is established
6. Measure the cone angle with respect to the centerline of the cone (flame) by using angle protractor (First set the angle protractor to 90 degrees position and by holding in same position bring the protractor arm tangential to the flame boundary the lock the scale by turning the locking knob on the protractor, now observe & note down the reading from the circular scale).
7. Repeat the same procedure by changing the gas and airflow rate.
8. After the reading are taken, ensure that all the valves (LPG cylinder, rotameter, etc. are closed).

**Formulas used:**

1) Mass flow of air ( $m^3/s$ ) = Air flow Rota meter reading in LPM / (1000\*60)

2) Velocity of air ( $V_u, m/s$ ) = Mass flow of air / Area of burner

3) Area of burner =  $\pi * d^2 / 4$

Where d = diameter of burner, d = 5mm

Area of burner =  $\pi * (0.005)^2 / 4 = 1.9637e10^{-5} m^2$

**Tabulation:**

S.No	LPG flow rate in LPM	Air flow rate in LPM	Cone angle
1	0.01	0.5	3degrees (Laminar flow, blue flame)

**Calculations:**

Mass flow of air = Air flow Rota meter reading in LPM / (1000\*60)

$$= 0.5 / (1000 * 60) \text{ m}^3/\text{s}$$

$$= 8.333 \times 10^{-6} \text{ m}^3/\text{sec}$$

Velocity of air = mass flow rate of air / Area of burner (m<sup>3</sup>/sec)

$$= 8.33 \times 10^{-6} / 1.9637 \times 10^{-6}$$

$$= 0.4243 \text{ m/sec}$$

**Results:** The semi cone angle of the premixed flame was found to -----degrees and hence the burning velocity was calculated to be ----- m/sec.

## STUDY OF FREE JET

**AIM:** To determine the velocity profile (or decaying velocity) of the free jet of different sizes

### INTRODUCTION:

A high velocity fluid stream, forced under pressure, out of a small diameter opening such as a nozzle is called a jet. The Jet of the fluid has been extensively studied for its numerous occurrences in the engineering system including flow through an opening. The flow, of jet differs from the other kind of fluid flow because of jet is surrounded in one or more sides by a free boundary of the same fluid. The free air jet is a term used to describe a flow of air using an opening or a nozzle into an air space where the static pressure to influence the flow pattern and the static pressure of surrounding space. As the jet leaves the opening, a shear layer develops around its boundary. This is usually referred to as "free stream layer".

Velocity of the jet is calculated using in the formula,  $V = \sqrt{2gh}$

In general, the free jet is formed when fluid is discharged from a nozzle or slot into large stagnant environments. The entrainment of the jet on the stagnant environments makes the jet width grow along the stream wise direction to some distance and finally dissipate.

The development of the free jet can be divided into four different zones according to the decay of centerline velocity, as shown in Figure. In the first zone (potential core), the centerline velocity is equal to inlet jet velocity where uniform velocity is assumed. The second zone is called the developed zone where the centerline velocity begins to decrease. Beyond these zones is a fully developed or established zone. Note that the irregularities of the edges are due to the mixing process and entrainments of the flow from the still ambient air. The last zone is called the terminal zone in which the centerline velocity rapidly decreases.

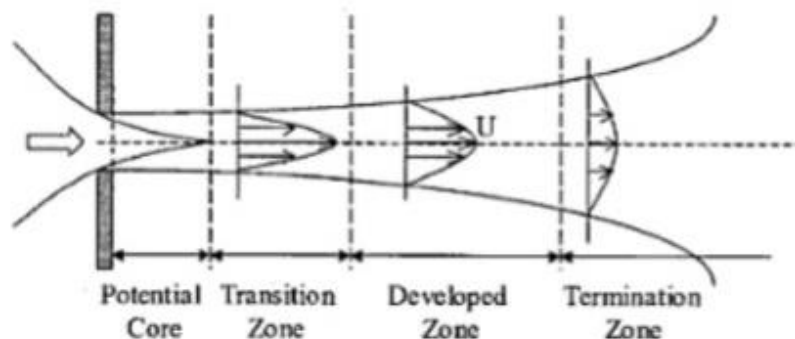


Fig. Sketch of the free jet

### DISCRIPTION ABOUT THE SETUP

The setup basically consists of blower unit, a venture section (test section), orifice arrangement, wall jet arrangement, and flow measurement on control panel consisting of blower starter console, Mains ON Indicator, Differential manometer & multibank manometer & discharge measurement with orifice plate. The blower unit coupled to A.C motor and discharge can be controlled by Inlet valve plate closing. This blower unit is fixed below the control panel and it is connected to the section by a rubber hose and pipe line. The venture section or test section unit consists of an inlet and outlet conical section in between settling chamber with a Honeycomb and mesh so that a laminar and constant air velocity is achieved.

2) Velocity of the jet is calculated using the formula,  $V = \sqrt{2gh_a}$

$$\text{Here, } h_a \rho_a = h_{\text{mercury}} \rho_{\text{mercury}} \text{, or } h_a = \frac{h_m \rho_m}{\rho_a}$$

Where,  $\rho_m$  = Density of mercury = 13550 Kg/m<sup>3</sup>

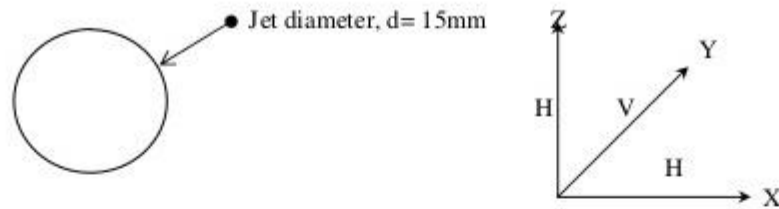
### TABULAR COLUMN:

S. N.	Distance from jet in mm	Mercury manometer reading at different distances along Y direction ( $h_{\text{mercury}}$ ) in mm		
		$h_1$	$h_2$	$h = h_1 - h_2$
1	X=0mm	At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
2	X=20mm	At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
3	X=40mm	At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
4	X=60mm	At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		
		At y=		

### RESULTS:

- 1) Discharge through the orifice,  $Q_{in} =$  m<sup>3</sup>/s
- 2) Velocity of the jet at the centre line,  $V_{center} =$  m/s

Nozzle with pressure tapings (10no) & connected to multibank manometer. The velocity of jet is measured by a pitot tube with X-Y-Z co-ordinate measurement arrangement. The wall jet consists of a M.S plate with adjustable positioning to the orifice.



### PROCEDURE:

- 1) Switch on the mains and observe the red indicator is ON, then Switch on console and blower.
- 2) Then slowly operate the inlet plate and lock to some position.
- 3) Then scan the pitot tube across the orifice & note down the readings.
- 4) Then move the pitot tube in X direction slowly and note down the flow readings.
- 5) Repeat the experiment for different flow.
- 6) Repeat the procedure for different values of Y axis also.
- 7) For wall jet experiments bring the wall near the orifice and note down the force exerted by the jet on the wall at different positions of X axis.
- 8) Draw a graph of velocity Vs X distance, at different values of Y- axis.

### OBSERVATION:

Water tube manometer reading,	$h_1 =$	mm
Water tube manometer reading,	$h_2 =$	mm
Difference in water column of water tube manometer:	$h_w = h_1 - h_2 =$	_____ in meters
Atmospheric pressure,	$p_a = 1.01325$ Bar =	$1.01325 \times 10^5$ N/m <sup>2</sup>
Real gas constant,	$R = 287$ J/Kg <sup>o</sup> K	
Room temperature,	$T_a =$	_____ <sup>o</sup> C
Acceleration due to gravity,	$g = 9.81$ m/s <sup>2</sup>	

### CALCULATIONS:

$$1) \text{ Discharge through the orifice } Q_{in} = C_d \frac{\pi d^2}{4} \sqrt{2gh_a} \text{ m}^3/\text{s}$$

where  $d = 25 \text{ mm} = .025 \text{ m}$   
 $g = 9.81 \text{ m/s}^2$

$$h_a = \frac{h_w \rho_w}{\rho_a} \text{ in meters of air}$$

$$\rho_{air} = \frac{p_a}{RT_a}$$

Where  $\rho_{air}$  = Density of air in Kg/m<sup>3</sup>

$p_a$  = Atmospheric pressure = 1.01325 Bar =  $1.01325 \times 10^5$  N/m<sup>2</sup>

$R$  = Real gas constant = 287 J/Kg<sup>o</sup>K

$T_a$  = Room temperature

Water equivalent of calorimeter is found to be  $W = 2330 \text{ Cal/}^\circ\text{C}$  under standardization experiment.

**To find the calorific value of given sample:**

$$CV_s = \frac{(W \times T) - (E_1 + E_2)}{M}$$

Where CVs is Calorific value of given sample in  $\text{Cal/}^\circ\text{C}$

**RESULT:**

Calorific value of given sample is CVs=                       $\text{Cal/}^\circ\text{C}$

## MEASUREMENT OF NOZZLE FLOW

**Aim:** - To calculate the co-efficient of discharge ( $c_d$ ) of the given Nozzle (venturimeter)

**Theory:** - A Venturimeter is a device used for measuring the rate of flow of a fluid through a pipe. It consists of three parts (1) A short converging part (2) throat (3) Diverging part. It is based on the principle of Bernoulli's equation applied along a stream line.

### Apparatus:

1. Venturimeter with pressure tapings at the entrance (mouth) and at the throat installed in a horizontal pipeline
2. U-tube mercury filled manometer to measure the difference across the topplings.
3. A constant steady of water with a means of varying the flow rate.
4. Measuring tank and stop watch to measure to measure the flow rate.

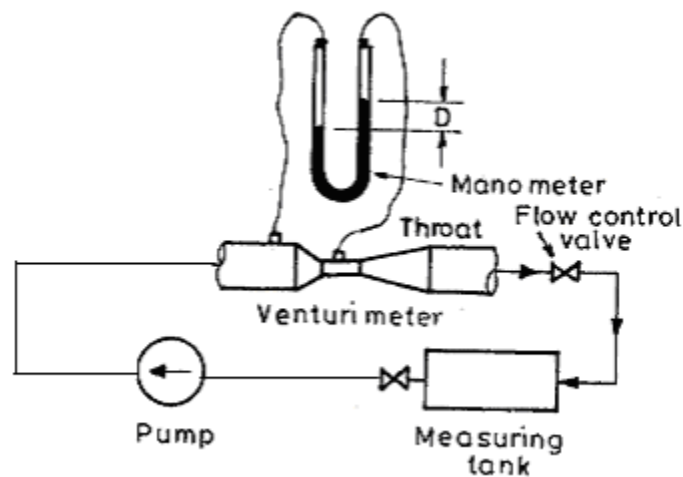


Figure : Venturimeter

- Precautions:**
1. Venturimeter should be horizontal.
  2. The air bubbles in the manometer tubes should be removed.

### Procedure:

1. Measure the diameter of the venturimeter at the mouth  $d_1$ , and the throat  $d_2$ .
2. Connect the pressure tapings to the U-tube manometer and expel any air trapped In the system.
3. Adjust the flow control valve to give the maximum possible flow through the Venturimeter.
4. Record the difference in mercury level 'D' within the manometer limbs.
5. Collect the water discharging from the venturimeter in a measuring tank of Known dimensions and measure the rise of water level R in the measuring tank for Certain period of time t sec.

6. Reduce the discharge in steps by adjusting the flow control valve and record the Series of reading D, t and R at each stage.

**Observations & Tabulation:**

Diameter of the pipe (D) =25mm

Area of measuring tank (A) =0.125m<sup>2</sup>

Mouth diameter d1 (m) = 25mm =0.025m

Area at the mouth a1 (m) =  $\pi d^2/4 = 4.91 \times 10^{-4} \text{ m}^2$

Throat diameter d2 (m) = 12mm = 0.012mts

Area at the throat a2 (m) =  $\pi d^2/4 = 1.13 \times 10^{-4} \text{ m}^2$

**Tabulation:**

Sl. No	Manometer Reading			Head of water (H) in mts=Diff x 12.6/100	$Q_{TH} = \frac{a_1 a_2 \sqrt{2gH}}{\sqrt{a_1^2 - a_2^2}}$ In m <sup>3</sup> /sec	Rise of water in measuring tank 'R' in mts	Time taken for 'R' mts Rise in t sec	Discharge Q <sub>a</sub> = $\frac{AR}{T}$ (m <sup>3</sup> /sec.)	Coefficient of discharge C <sub>d</sub> = Q <sub>act</sub> /Q <sub>the</sub>
	Left cm	Right cm	Diff cm						
01									
02									
03									
04									
05									

**Graphs:** Draw the following graphs: Q<sub>act</sub> v/s Q<sub>the</sub>

**Results:** - The co-efficient of discharge of venturimeter is.....

## PREPARATION OF PROPELLANT

### Aim:

To prepare 200 gm of solid rocket propellant of three different compositions.

### Materials Required

1. Ammonium perchlorate
2. Hydroxy Terminated Polybutadien
3. DioctylAdipate
4. Toluene Diisocyanate
5. Ethylene Glycol
6. Microwave Oven
7. Glass Rod
8. Beaker
9. Aluminium Powder
10. Spatula

### Procedure:

1. Weigh the chemical constituents as shown in the table below

S.No	Composition 1 (65%HTPB + 35% HTPB)		Composition 2 (65%HTPB + 25% HTPB + 10% Aluminium powder)		Composition 3 (65%HTPB + 35% HTPB + 5% Ferric Oxide)	
1	Ammonium Perchlorate	130	Ammonium Perchlorate	130	Ammonium Perchlorate	130
2	HTPB	50	HTPB	35	HTPB	35
3	DioctylAdipate	10.5	DioctylAdipate	7.5	DioctylAdipate	7.5
4	Toluene Diisocyanate	4.5	Toluene Diisocyanate	2.5	Toluene Diisocyanate	2.5
5	Ethylene Glycol	5	Aluminium Powder	20	Ferric Oxide powder	20
6			Glycerol	5	Glycerol	5

2. Mix the Ammonium Perchlorate and HTPB into the beaker.
3. Add pre-weighed DioctylAdipate(Plasticizer) to the mixture and stir for 3 minutes.

4. Add pre-weighed Toluene Diisocyanate(Curing agent) to the mixture and stir for 3 to 4 minutes.
5. Add pre-weighed Ethylene Glycol to the mixture and stir it for 3 minutes.
6. Pour the mixture on to aluminium plate with aluminium foil grease with metrox grease.
7. Place the aluminium plate into a microwave oven and set the temperature to 60°C for curing.
8. After one week take out the mixture from the oven.

**Result:**

The solid propellant with three different compositions has been prepared and cured.

## COMPUTATION OF BURNING RATE OF PROPELLANT

**Aim:**

To compute the burning rate of solid rocket propellant

Materials Required:

**Materials Required**

1. Wooden Box
2. Ohmic Igniter
3. Solid rocket propellant of different compositions

**Procedure:**

1. Cut the propellant strips into 6 cm length and 1 cm width.
2. Mark the propellant strips with two lines 5 cm apart.
3. Place the marked propellant strips into the Wooden box and use the ohmic igniter to ignite the strips.
4. Note down the time the fire takes to cover 5cm distance using a stop watch.
5. Divide the 5cm length by the noted time; will give the burning rate in cm/sec.
6. Repeat the above procedure for other compositions.

**Result:**

Thus the burning rate of propellant has been evaluated.

## MEASUREMENT OF IGNITION DELAY OF A SINGLE PROPELLANT WITH DIFFERENT SHAPES

### Aim:

To measure the ignition delay of a single propellant with different shapes.

### Materials Required:

1. Sugar
2. Ferric Oxide
3. Potassium Nitrate
4. Pan
5. Spoon
6. Water
7. Induction stove
8. Nichrome wire SWG 34
9. Variable Transformer
10. Corn Syrup

### Procedure:

1. Weigh the chemicals as shown in the table below

S.No	Chemicals	Percentage	Weight (gm)
1	Potassium Nitrate	60%	120
2	Sugar	30%	60
3	Ferric Oxide	7.5%	15
4	Corn Syrup	2.5%	5

2. Only induction stove to be used; no open fire heating should be used during the preparation.
3. Pour the water and potassium nitrate into the heating pan and stir well.
4. Once the potassium nitrate dissolves, add powdered sugar and stir well.
5. Subsequently add Ferric Oxide to the mixture and stir well using the big spoon.
6. Add corn syrup to the mixture and occasionally add water to prevent the mixture from drying up.
7. Cast the propellant with micro shapers and insert the nichrome wire 34 SWG into the propellant and smoothen the surface.
8. Hang the prepared propellant on the string and leave it to dry for three days.
9. After 3 days take out the dried up propellant and connect the two leads to 12 V Variable Transformer.
10. Switch on the variable transformer and record the timing it takes from the moment of switching on to the instant of visible fire.
11. Tabulate the readings.

**Result:** Thus, the ignition delay of a single rocket propellant with different shapes has been evaluated.

## PERFORMANCE STUDY OF HYBRID ROCKET MOTOR USING A THRUST STAND

### Aim:

To study the performance of hybrid rocket motors using a thrust stand.

### Materials Required:

1. Pyrometer
2. Gaseous Oxygen Cylinder
3. Propellant Fuel
4. Chart paper
5. Igniter
6. Nichrome Wire 34 SWG
7. Solenoid Valve
8. Pressure Gauge
9. Load Cell

### Procedure:

- 1) Weigh the propellants as shown below.

S.No	Composition 1 - 100% HTPB	Weight(gm)	Composition 2 - 90% HTPB + 10% Al	Weight(gm)	Composition 3 - 50%HTPB+50% Paraffin Wax	Weight(gm)
1	HTPB	800	HTPB	700	HTPB	420
2	DOA	150	Aluminium Powder	100	Paraffin Wax	500
3	TDI	50	DOA	150	DOA	60
4	Glycerol	4	TDI	50	TDI	20
5			Glycerol	4	Glycerol	4
<b>Total</b>		<b>1004</b>		<b>1004</b>		<b>1004</b>

- 2) Theoretical calculation has been done to evaluate the adiabatic flame temperature, nozzle dimension, exhaust temperature, exit mach number for the above propellant combinations. The resulting highest exhaust flame temperature has been used for nozzle fabrication. For simplicity straight cone nozzle is being used for this experiment.
- 3) Propellant Preparation
  - i) Composition 1 – 100% HTPB
    1. Mix weighed quantities of HTPB and DOA into the beaker and stir for 3 minutes using a glass rod.
    2. Mix weighed quantity of TDI to the mixture and stir for 2 to 3 minutes and add Glycerol to the mixture.
  3. Assemble the Mould, Mandrel and Mould bottom and apply metrox grease to the mould walls.

4. Slowly and steadily pour the mixture into the mould.
5. After filling the mould with mixture, place the mould into the Microwave Oven setting the temperature to 60 °C. Leave for 5 days.
6. Take out the mould from the oven and remove the cured propellant.
7. Weigh the cured propellant before loading it into the combustion chamber.
8. Prepare inhibitor and igniter and fix igniter at the head end and apply inhibitor at the fuel end near the nozzle side.

ii) Composition 2 – 90%HTPB + 10% Aluminium powder

1. Mix weighed quantities of HTPB and DOA into the beaker and stir for 3 minutes using a glass rod.
2. Add weighed quantity of aluminium powder to the mixture and stir.
3. Mix weighed quantity of TDI to the mixture and stir for 2 to 3 minutes and add Glycerol to it.
4. Assemble the Mould, Mandrel and Mould bottom and apply metrox grease to the mould walls.
5. Slowly and steadily pour the mixture into the mould.
6. After filling the mould with mixture, place the mould into the Microwave Oven setting the temperature to 60 °C. Leave for 5 days.
7. Take out the mould from the oven and remove the cured propellant.
8. Weigh the cured propellant before loading it into the combustion chamber.

iii) Composition 3 – 50% HTPB + 50% Paraffin Wax

1. Mix weighed quantities of HTPB and DOA into the beaker and stir for 3 minutes using a glass rod.
  2. Take weighed quantity of Paraffin Wax and heat it in a water bath until all of the solid wax turns to liquid.
  3. Add the HTPB mixture to the liquid Paraffin Wax and stir the mixture by periodically heating in a water bath.
  4. Mix weighed quantity of TDI to the mixture and stir for 2 to 3 minutes and add Glycerol to it.
  5. Assemble the Mould, Mandrel and Mould bottom and apply metrox grease to the mould walls.
  6. Slowly and steadily pour the mixture into the mould.
  7. After filling the mould with mixture, place the mould into the Microwave Oven setting the temperature to 60 °C. Leave for 5 days.
  8. Take out the mould from the oven and remove the cured propellant.
  9. Weigh the cured propellant before loading it into the combustion chamber.
3. Wrap the cured propellant in a chart paper and load it into the combustion chamber.
  4. Apply inhibitor to the propellant end near the nozzle.
  5. Fix the igniter in the head end of the propellant near the injector.
  6. Connect the assembled combustion chamber (Injector + Combustion Chamber + Nozzle) to the oxidizer feed line.
  7. The igniter leads are connected to a Variable Transformer.
  8. Required injection pressure is set in the oxidizer feed line.
  9. The igniter is switched on and after predetermined ignition delay, the oxidizer is injected at pre-set injection pressure using a solenoid ball valve.
  10. The solenoid ball valve is kept open for 10 to 12 seconds and switched off.

11. The exhaust temperature is measured by using a non-contact pyrometer kept at a distance.
12. The exhaust plume is recorded using a digital camera
13. The oxidizer feed line is then disconnected from the thrust stand.
14. Requisite thrust reading from load cell is noted down.
15. After cooling the combustion chamber the propellant is taken out and weighed to determine the amount of propellant consumed.
16. The propellant is then cut into four segments with each segment marked from 0 to 30 cm.
17. The local regression rate for each segment is measured by using a screw gauge and the values are tabulated.
18. The above procedure is repeated for two more propellant compositions to infer the variation in regression rate, exhaust temperature, thrust and exhaust plume characteristics.

**Result:**

Thus the performance studies of hybrid rocket motor have been studied using a thrust stand.

**VIVA-QUESTIONS**

SI NO	QUESTION
1	What is a fluid
2	What is subsonic flow
3	What is nozzle
4	What is choked flow in nozzle
5	What is aeronautics
6	What is afterburner
7	What is analysis
8	What is boundary layer
9	What is laminar flow
10	What is flow separation
11	What is boundary layer thickness
12	What is turbulent flow
13	What is by pass ratio
14	What is propulsion
15	Define thrust augmentation
16	Name thrust augmentation devices
17	What is do you mean by premixed flame
18	Define Lewis number
19	Define total pressure ,total temperature
20	How nozzles are specified? Explain