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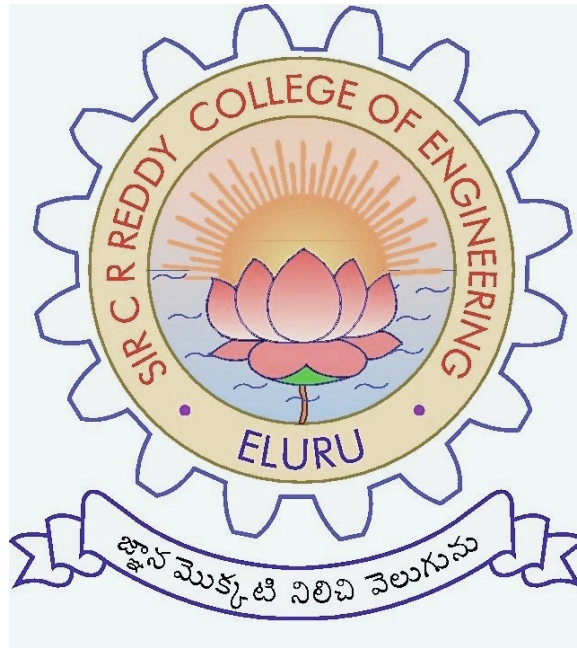# ELURU-534 007

MECHANICAL ENGINEERING LAB-I
MANUAL

DEPARTMENT OF MECHANICAL ENGINEERING

SIR C.R.REDDY COLLEGE OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

MECHANICAL ENGINEERING LAB-I

LIST OF EXPERIMENTS

1.MASS MOMENT INERTIA OF A FLYWHEEL

AIM

To determine the mass moment of inertia of a flywheel about its own axis of rotation.

APPARATUS REQUIRED

Flywheel, Weights, String, Vernier Calipers, Meter scale and Stop watch.

DESCRIPTION OF FLYWHEEL:

The flywheel is a disc, usually made of a heavy metal like steel, having a large diameter and fitted with an axle having comparatively smaller diameter. The ends of the axle are mounted on ball bearings rigidly supported against the wall. For counting the rotations made by the flywheel, a red mark on the periphery of the disc and a pointer are provided.

BACKGROUND THEORY: One end of a string carrying a suitable weight at the other end is loosely fastened to the peg mounted on the flywheel axis. The flywheel is then slowly rotated so that the string gets wound to the axis. Let the number of turns be n_1. Let the weight freely fall through a height **h** due to gravity so that the string starts unwinding itself round the axle and the flywheel starts rotating with increasing angular velocity. After n_1 rotations the fastened string slips off the peg and from now on flywheel starts rotating on its own. According to the law of conservation of energy,

Potential Energy lost by the falling weight = Kinetic Energy gained by the falling weight + Kinetic Energy gained by the flywheel + Work done against the friction at the two ball bearings.

Mathematically, $mgh = \frac{1}{2} mv^2 + \frac{1}{2} I \omega^2 + n_1 F$

Where **v** is the velocity of the mass **m** (of falling weight), **I** is the mass moment of inertia of the flywheel disc, ω is the angular velocity of the flywheel about its own axis, **F** is work done against friction per each turn of the flywheel at both the ball bearings and **g** is acceleration due to gravity. The flywheel will possess maximum kinetic energy, $\frac{1}{2} I \omega^2$, at the time of the separation of the string from its axle. The flywheel will continue to rotate through n_2 revolutions in time **t** seconds before this energy is dissipated in overcoming the friction at the ball bearings and flywheel coming to complete rest.

Hence, $\frac{1}{2} I \omega^2 = n_2 F$ ⟷ $F = \frac{1}{2} I \omega^2 / n_2$

Therefore, $mgh = \frac{1}{2} mv^2 + \frac{1}{2} I \omega^2 + \frac{1}{2} I \omega^2 n_1 / n_2$

⟷ $I = (2mgh - mv^2)/\omega^2 (1 + n_1 / n_2)$

$= (2mgh - m(r\omega)^2)/\omega^2 (1 + n_1 / n_2)$ since v= rω, r being the radius of the flywheel axle.

$= m((2gh/\omega^2) - r^2)/ (1 + n_1 / n_2)$

At the instant when the string leaves off the axle the flywheel has the maximum angular velocity ωand after making n_2 revolutions in time **t** seconds its velocity reduces to zero. Assuming that the friction is steady throughout the motion of the flywheel the average angular velocity during **t** seconds will be $(\omega+0)/2 = \omega/2$.

That is, $\omega/2 = 2\Pi n_2 / t$ ⟷ $\omega = 4\Pi n_2 / t$

Therefore, $I = m(2ght^2 / 16 \Pi^2 n_2^2 - r^2)/ (1+ n_1/ n_2)$

Thus, by knowing **m, g, h, t, r, n$_1$ and n$_2$** from the experiment the mass moment of inertia **I** can be calculated.

PROCEDURE

1. A string shorter than the height of the axle from the floor of the laboratory is taken and loosely fastened to the peg of the axle by forming a loop at one of its end. A mass **m** is then tied to the other end. The string is wound uniformly over the axle and the number of revolutions **n$_1$** is noted. The height **h** of the weight above the ground must be measured and noted.

2. The mass **m** is now released and as soon as the loop of the string slips off the peg of the axle the stopwatch is started. The number of revolutions **n$_2$** made by the flywheel in time **t** seconds before it come to complete rest are noted.

3. The above procedure is repeated for three different weights, three times for each weight varying the height. The observations are noted in tabular form.

OBSERVATIONS: Least Count of Vernier Calipers :

Table for the determination of diameter of the axle:

Sl. No.	Reading Along Any Diameter D_1 m	Reading Perpendicular to axle D_2 m	Mean observed diameter D_0 m $(D_1+D_2)/2$
1.			
2.			
3.			
4.			
5.			

Mean Corrected Diameter D m

Table for the measurement of h, n$_1$, n$_2$, and t, and computation of I.

Sl No	Mass **m** **Kgs**	**n$_1$**	Height **t h** m	Number of revolutions before flywheel came to rest **n$_2$**	Time taken for n$_2$ rotations **t** Sec	Mean value **n$_2$**	Mean value **t** sec	Angular velocity $\omega=4\Pi$ n_2/t rad/sec	I Kgs m^2
1.				(i) (ii) (iii)					
2.				(i) (ii) (iii)					

PRECAUTIONS

1. The string should be light and strong enough to sustain the weight attached to it.

2. The string should be wound on the axle in such a way so that there should not be overlapping.

3. The height h should be measured correctly.

4. The stopwatch should be started exactly at the moment when the string slips off the peg of the axle lest this will be a serious source of error.

5. In the derivation of the formula it has been assumed that the frictional force remains constant while the angular velocity of the flywheel changes from ω to 0. But this assumption is not correct because the friction depends on the magnitude of the angular velocity of the flywheel, and therefore it constitutes another source of error.

RESULT: The mass moment of inertia of the given flywheel about its own axis of rotation, **I** is …..   kg m^2.

VIVA QUESTIONS

1. Give the difference between Mass moment of Inertia & area moment of Inertia?

2. What is parallel axis theorem?

3. What is perpendicular axis theorem?

4. What is radius of Gyration?

5. What is polar moment of Inertia?

6. Give the equation for Mass moment of Inertia for flywheel?

7. What is the use of Vernier Callipers?

8. What is the least count of Vernier Callipers?

2.TORSION PENDULUM

AIM

To determine the modulus of rigidity, **N**, of the material of the given wire by dynamic method (i.e., by torsional oscillations) using torsional pendulum.

APPARATUS REQUIRED

A circular metallic disc provided with a chuck at its center, steel or brass wire the modulus of rigidity of whose material is to be determined, a chuck fixed to a wall bracket or held in a rigid clamp, stopwatch, a vertical pointer, screw gauge, Vernier calipers.

THEORY

Modulus of Rigidity, N, is the ratio of shear stress to the shear strain within elastic limit. Modulus of rigidity of a given material can be determined using several methods, torsional pendulum being one of them. The torsional pendulum consists of a uniform metallic disc suspended by means of a wire. The lower end of the wire is gripped in a chuck at the center of the disc, and the upper end is gripped in another chuck, which is fixed to a wall bracket. Let the disc be turned through a small angle so that the wire is twisted. On being released the disc performs torsional oscillations about the axis of the wire. Due to torsional oscillations the wire gets twisted and untwisted alternatively thereby inducing shear stresses in it. Assuming the motion to be simple harmonic, the time period, T, of torsional oscillation is given by

$$T = 2\Pi (I/C)^{1/2} \quad ..... (i)$$

Where, **I** is moment of inertia of the disc about the axis of rotation, and **C** is the couple per unit twist of the wire. If **r** is the radius of the wire, *l* is its twisted length and **N** is the rigidity modulus of the material of the wire then,

$$C = N\Pi r^4 /2l \quad ....(ii)$$

From equations *(i)* and *(ii)* we get,

$$N = 8\Pi I \, l \, / \, r^4 \, T^2 \quad ....(iii)$$

In the case of a circular disc (or a cylinder) whose geometric axis coincides with the axis of rotation, the moment of inertia, **I**, is given by

$$I = MR^2/2 \quad ....(iv)$$

Where **M** is the mass and **R** the radius of the disc. On substituting the value of **I** from equation *(iv)* in equation *(iii)*, we get

$$N = 4\Pi MR^2 \, l \, / \, r^4 \, T^2 \quad ....(v)$$

By knowing the values of **M, R, *l*, r** and **T** from experiment **N** can be computed.

PROCEDURE

1. Remove the kinks, if any, in the wire and suspend the given disc. Adjust the length , *l,* of the wire between the chucks to be say, 50 cm. When the disc is in its equilibrium position, make a chalk mark on the curved edge of the disc facing you and keep a vertical pointer in front of the disc so that when you look straight, the pointer screens the chalk mark from view.

2. Set the disc to oscillate by gently turning the disc through a small angle and then release it. There should not be any up and down, and lateral movements of the disc. If there are any such movements, damp the oscillations and once again set the disc to oscillate strictly in the horizontal plane. Leave off the first few oscillations and find out the time for 20 oscillations by means of a stopwatch.

3. Again by a second trial find time for 20 oscillations for the same length and find the mean time for 20 oscillations. Hence calculate the time period of each oscillation **T**.

4. Repeat the experiment for four or five different lengths, by increasing the length of the wire in steps of 10 cm and tabulate the readings.

OBSERVATIONS

Table for determination of radius of wire.

Least count of screw gauge: …. mm

Sl No	Reading along any diameter D_1 mm	Reading perpendicular to the axis D_2 mm	Mean diameter $D = (D_1 + D_2)/2$ Mm
1.			
2.			
3.			
4.			
5.			

Mean corrected diameter of the wire is   mm

Average radius of the wire **r**   mm

Table for determination of radius of disc.

Least count of Vernier calipers: …mm

Sl No	Reading along any diameter D_1 mm	Reading perpendicular to the axis D_2 mm	Mean diameter $D = (D_1 + D_2)/2$ Mm
1.			
2.			
3.			
4.			
5.			

Mean corrected diameter of the wire   mm

Mean radius of the disc **R**   mm.   Mass of the disc **M**   kg

Table for determination of average time period of oscillations of disc.

Sl No	No of oscillations N	Time taken for oscillations (t) Seconds	Mean time period of oscillations **T** Seconds
1.			
2.			
3.			
4.			
5.			

PRECAUTIONS

1. Since the radius **r** of the wire occurs to the fourth power in the formula, it must be measured as accurately as possible, lest the error also will be raised to its fourth power. So with a screw gauge determine the diameter of the wire at 3 or 4 places equally spaced along its length and at each place measure it in two mutually perpendicular directions. Thus find the mean value of the radius a of the wire.

2. Find the mass **M** of the disc with a simple balance. Measure the average diameter of the disc with vernier calipers, and hence its radius **R**.

3. The time period also must be measured very accurately since it occurs in second power in the formula.

4. The wire should not be twisted beyond the elastic limit otherwise the torsional couple will not be proportional to the twist.

RESULT: The modulus of rigidity of the material of the given wire **N** is measured as …….kg/m^2

VIVA QUESTIONS
1. Define Modulus of rigidity?

2. Give the range of modulus of rigidity for different materials?

3. Define shear stress?

4. Define Shear strain?

5. What is difference between Modulus of elasticity , modulus of rigidity and bulk modulus?

3.ABEL'S APPARATUS

AIM: To determine the flash point of the given sample of oil using ABEL's apparatus.

APPARATUS REQUIRED

ABEL's apparatus, heating element, autotransformer or rheostat, a sample of oil.

THEORY

The flash point is the minimum temperature at which an oil gives out sufficient vapor to form an ignitable mixture with air, and gives a momentary flash on application of a small pilot flame. Flash point gives idea about:

- Nature and range of boiling point diagram of the oil.
- Amount of low boiling fraction present in the liquid fuel or lubricant.
- Volatility of the liquid fuels, and
- Potential for explosion hazards.

Flammable liquids are usually volatile, and rate of evaporation increases appreciably with rise in the temperature of liquid. The vapors being heavier than air they get accumulated at the lower level traps such as pits or empty pockets in the storage tanks etc., where their concentration reaches so high as to easily explode in the presence of an active ignition source. Providing mechanical ventilation in storage tanks can prevent this by increasing the rate of diffusion of vapors, and concentration of vapors remains within the explosive range. Knowledge of flash and fire points of oils is crucial for providing safeguards against fire hazards during their storage, handling, transportation and use. For example the coolant oil used in electric transformers must have as high a flash and fire points as possible to prevent fire hazards. Similarly for safe usage of illuminating oils, such as kerosene, the average maximum atmospheric temperature of the geographic region must be less than the flash point of the oil, otherwise safety mechanisms must be incorporated in the gadgets. Although flash and fire points are by no means sufficient as the sole indices of fire hazards, they can be effectively used for comparative ratings of the fire hazard potential of different flammable liquids and for labeling their containers accordingly. Liquids having flash points less than 140°F are called *flammable* liquids and those with flash points above 140°F are called *combustible* liquids. Fire insurance companies are concerned about flash points of oil stocks held by their policyholders. Usually higher premiums are charged for flammable liquids with lower flash points. Likewise Railways are also concerned about the flash points of the flammable liquids they carry for safety reasons. The volatility of a liquid markedly increases when heated to or above its flash point. Therefore, a low flash point indicates appreciable evaporation losses and possibility of formation of gas-locks in fuel pipes. Flash and fire points have also been used to detect solvent contamination and to determine the extent of dilution of the lubricating oils. Flash point is higher for the oils of paraffin base than oils of naphta base. The test is therefore a rough guide to the base of oil and is also useful to refiners in controlling the manufacturing process. Flash point less than 23^{0}C is dangerous and highly inflammable. The safe value is 60^{0}C or more. The permissible conditions of storage, transportation and use are different for products with flash points below 23^{0}C (like gasoline), between 23^{0}C and 66^{0}C (like kerosene) and above 66^{0}C (like fuel oils and gas oils). The oils of first category are regarded as dangerous and highly inflammable for transport and storage, and are subject to strict government regulations. Flash points of some commonly used liquid fuels are:

DESCRIPTION OF APPARATUS

It consists of an oil cup, which is about 5 cm in diameter and 5.5 cm deep. The level of the oil to be filled is marked inside the cup. The cup lit is provided with four openings of standard sizes. Thermometer is inserted in one of the openings, the second opening is used for introducing the test flame, third opening carries stirrer with four blades and the last opening is meant for air inlet. Shutter is provided at the top of the cup. Flame exposure device is connected to the shutter by a lever mechanism. Oil cup is supported by flange in the water bath, which is heated by an electric heater. It is an indirect heating system i.e., the water bath is heated first and later the heat is transferred to the oil in cup ensuring uniform heat transfer and temperature distribution.

PROCEDURE

1. Clean the oil cup thoroughly and fill it with the given sample of oil up to the given mark.
2. Insert the thermometer into the oil cup through the clamp. The thermometer indicates the oil temperature.
3. Connect the heater to the mains through autotransformer and adjust the rate of heating.
4. The oil sample is tested for the flash point with atest flame for every 2^0C rise in temperature.
5. When the oil gives a momentary flash on the application of the test flame the corresponding temperature is recorded as the flash point of the oil.
6. Repeat the experiment with fresh oil sample three times to increase the accuracy.

OBSERVATIONS

Room temperature: ___ ^0C

Trial No	Given sample of oil	Observed flash point ^0C

PRECAUTIONS

1. As the moisture affects the flash point the cup and its accessories coming in contact with oil should be dried.

2. No oil should remain between the sliding and fixed plates forming the cover of the cup. If present it must be cleaned. Care should be taken to prevent wetting of the cup above the pointer tip.

3. Always a fresh sample of the oil should be used. A second determination on the same used oil shows higher flash point.

4. Thermometer should be inserted carefully through the clamp. The thermometer bulb should never touch the bottom of the oil cup. Thermometer should never be in line with the stirrer plates.

5. Stirrer should be disconnected during the application of the test flame. During the application of the test flame the slide should be open slowly but closed quickly.

RESULT:

The flash point of the given oil sample using ABEL'S apparatus is found to be _____ ^0C

VIVA QUESTIONS

1. What is Flash point and its importance in applications point of view?

2. What is Fire point and its importance in applications point of view?

3. Constructional difference between Pensky martin & Abel's apparatus, which is the best one?

4. Why stirring is done in fire and flash point measuring apparatus?

4.PENSKY MARTIN'S APPARATUS

AIM

To determine the flash point of the given sample of oil using PENSKY MARTIN's apparatus.

APPARATUS REQUIRED

PENSKY MARTIN's apparatus, heating element, auto-transformer or rheostat, a standard thermometer and a sample of oil whose flash point is to be determined.

THEORY

The flash point is the minimum temperature at which an oil gives out sufficient vapor to form an ignitable mixture with air, and gives a momentary flash on application of a small pilot flame. Flash point gives idea about:

- Nature and range of boiling point diagram of the oil.
- Amount of low boiling fraction present in the liquid fuel or lubricant.
- Volatility of the liquid fuels, and
- Potential for explosion hazards.

Flammable liquids are usually volatile, and rate of evaporation increases appreciably with rise in the temperature of liquid. The vapors being heavier than air they get accumulated at the lower level traps such as pits or empty pockets in the storage tanks etc., where their concentration reaches so high as to easily explode in the presence of an active ignition source. Providing mechanical ventilation in storage tanks can prevent this by increasing the rate of diffusion of vapors, and concentration of vapors remains within the explosive range. Knowledge of flash and fire points of oils is crucial for providing safeguards against fire hazards during their storage, handling, transportation and use. For example the coolant oil used in electric transformers must have as high a flash and fire points as possible to prevent fire hazards. Similarly for safe usage of illuminating oils, such as kerosene, the average maximum atmospheric temperature of the geographic region must be less than the flash point of the oil, otherwise safety mechanisms must be incorporated in the gadgets. Although flash and fire points are by no means sufficient as the sole indices of fire hazards, they can be effectively used for comparative ratings of the fire hazard potential of different flammable liquids and for labeling their containers accordingly. Liquids having flash points less than $140^{o}F$ are called *flammable* liquids and those with flash points above $140^{o}F$ are called *combustible* liquids. Fire insurance companies are concerned about flash points of oil stocks held by their policyholders. Usually higher premiums are charged for flammable liquids with lower flash points. Likewise Railways are also concerned about the flash points of the flammable liquids they carry for safety reasons. The volatility of a liquid markedly increases when heated to or above its flash point. Therefore, a low flash point indicates appreciable evaporation losses and possibility of formation of gas-locks in fuel pipes. Flash and fire points have also been used to detect solvent contamination and to determine the extent of dilution of the lubricating oils. Flash point is higher for the oils of paraffin base than oils of naphta base. The test is therefore a rough guide to the base of oil and is also useful to refiners in controlling the manufacturing process. Flash point less than $23^{0}C$ is dangerous and highly inflammable. The safe value is $60^{0}C$ or more. The permissible conditions of storage, transportation and use are different for products with flash points below $23^{0}C$ (like gasoline), between $23^{0}C$ and $66^{0}C$ (like kerosene) and above $66^{0}C$ (like fuel oils and gas oils). The oils

of first category are regarded as dangerous and highly inflammable for transport and storage, and are subject to strict government regulations. Flash points of some commonly used are

- Crude oil : -10 to 0 ^{0}C
- Gasoline : -40 to 30 ^{0}C
- Kerosene : 28 to 55 ^{0}C
- Diesel   : > 30 ^{0}C
- Lube oil   : 130 to 300 ^{0}C
- Furnace oil : > 66 ^{0}C

Besides oil's volatility and the inflammability limits of the vapor-air mixture, the flash point also depends upon the design of the apparatus, the test procedure and the barometric pressure. ABEL's closed cup apparatus is used for more volatile oils with flash point below 50^{0}C and PENSKY MARTIN's apparatus is used for flash points above 50^{0}C. Kerosene is tested in ABEL's, and furnace oil, diesel fuels and gas oils in PENSKY MARTIN's closed cup type apparatus.

DESCRIPTION

It consists of an oil cup, which is about 5 cm in diameter and 5.5 cm deep. The level of the oil to be filled is marked inside the cup. Four openings of standard sizes are provided in the lid of the cup. Thermometer is inserted in one of the openings, the second opening is used for introducing the test flame, third opening carries stirrer with four blades and the last opening is meant for air inlet. Shutter is a lever mechanism, provided at the top of the cup. Flame exposure device is connected to the shutter by a lever mechanism. A flange supports oil cup over a water bath, which is heated by an electric heater. It is an indirect heating system i.e., the water bath is heated first and later the heat is transferred to the oil in cup ensuring uniform heat transfer and temperature distribution.

PROCEDURE

1. Clean the oil cup thoroughly and fill it with the given sample of oil up to the mark given.

2. Insert the thermometer in to the oil cup through the clamp. The thermometer indicates the oil temperature.

3. Connect the heater to the mains through autotransformer and adjust the rate of heating.

4. The oil sample is tested for the flash point with a test flame for every 2^{0}C rise in temperature.

5. When the oil gives a momentary flash on the application of the test flame the corresponding temperature is recorded as the flash point of the oil.

6. Repeat the experiment with fresh oil sample three times to increase the accuracy.

OBSERVATIONS

Room temperature: ___ ^{0}C

Trial No	Given sample of oil	Observed flash point ^{0}C

PRECAUTIONS

1. As the moisture affects the flash point the cup and its accessories coming in contact with oil should be dried.

2. No oil should remain between the sliding and fixed plates forming the cover of the cup. If present it must be cleaned. Care should be taken to prevent wetting of the cup above the pointer tip.

3. Always a fresh sample of the oil should be used. A second determination on the same used oil shows higher flash point.

4. Thermometer should be inserted carefully through the clamp. The thermometer bulb should never touch the bottom of the oil cup. Thermometer should never be in line with the stirrer plates.

5. Stirrer should be disconnected during the application of the test flame. During the application of the test flame the slide should be open slowly but closed quickly.

6. Flash points of lubricating oils, some crude oils and residues are often determined by the open cup tests. Either PENSKY MARTIN's or CLEVELAND open-cup is used. The open-cup method is liable to error and gives only approximate values. The open cup flash point is higher than the closed cup value for the same sample.

RESULT

The flash point of the given oil sample using PENSKY MARTIN's apparatus is found to be _____ ^{0}C

VIVA QUESTIONS

1. What is Flash point and its importance in applications point of view?

2. What is Fire point and its importance in applications point of view?

3. Constructional difference between Pensky martin & Abel's apparatus, which is the best one?

4. Why stirring is done in fire and flash point measuring apparatus?

5.CLEVELAND OPEN CUP APPARATUS

AIM

To determine the flash and fire points of the given sample of oil using CLEVELAND open-cup apparatus.

REQUIRED APPARATUS

CLEVELAND's open-cup apparatus, heating element, auto-transformer or rheostat, a standard thermometer and a sample of oil whose flash point is to be determined.

THEORY

The flash point is the minimum temperature at which an oil gives out sufficient vapor to form an ignitable mixture with air, and gives a momentary flash on application of a small pilot flame. Flash point gives idea about:

- Nature and range of boiling point diagram of the oil.
- Amount of low boiling fraction present in the liquid fuel or lubricant.
- Volatility of the liquid fuels, and
- Potential for explosion hazards.

Flammable liquids are usually volatile, and rate of evaporation increases appreciably with rise in the temperature of liquid. The vapors being heavier than air they get accumulated at the lower level traps such as pits or empty pockets in the storage tanks etc., where their concentration reaches so high as to easily explode in the presence of an active ignition source. Providing mechanical ventilation in storage tanks can prevent this by increasing the rate of diffusion of vapors, and concentration of vapors remains within the explosive range. Knowledge of flash and fire points of oils is crucial for providing safeguards against fire hazards during their storage, handling, transportation and use. For example the coolant oil used in electric transformers must have as high a flash and fire points as possible to prevent fire hazards. Similarly for safe usage of illuminating oils, such as kerosene, the average maximum atmospheric temperature of the geographic region must be less than the flash point of the oil, otherwise safety mechanisms must be incorporated in the gadgets. Although flash and fire points are by no means sufficient as the sole indices of fire hazards, they can be effectively used for comparative ratings of the fire hazard potential of different flammable liquids and for labeling their containers accordingly. Liquids having flash points less than 140°F are called ***flammable*** liquids and those with flash points above 140°F are called **combustible** liquids. Fire insurance companies are concerned about flash points of oil stocks held by their policyholders. Usually higher premiums are charged for flammable liquids with lower flash points. Likewise Railways are also concerned about the flash points of the flammable liquids they carry for safety reasons. The volatility of a liquid markedly increases when heated to or above its flash point. Therefore, a low flash point indicates appreciable evaporation losses and possibility of formation of gas-locks in fuel pipes. Flash and fire points have also been used to detect solvent contamination and to determine the extent of dilution of the lubricating oils. Flash point is higher for the oils of paraffin base than oils of naphta base. The test is therefore a rough guide to the base of oil and is also useful to refiners in controlling the manufacturing process.

PROCEDURE

1. Support the apparatus on a level steady table in a draught-free room or compartment.

2. Clean the test cup thoroughly with an appropriate solvent to remove traces of oil or residue from previous test and fill it with the given sample of oil up to the mark given.

3. Support the thermometer in a vertical position with the bottom of the bulb at least 6 mm above the bottom of the cup.

4. Connect the heater to the mains through autotransformer and adjust the rate of heating. Apply initially heat so that temperature rises at the rate of 14 to 16 ^{0}C per minute.

5. When the sample temperature is approximately 60% of the expected flash point temperature the rate of rise in sample temperature must be brought down to 5 to 6 ^{0}C per minute. The oil sample is tested for the flash point with a test flame for every 2^{0}C rise in temperature.

6. When the oil gives a momentary flash on the application of the test flame the corresponding temperature is recorded as the flash point of the oil.

7. Repeat the experiment with fresh oil sample three times to increase the accuracy.

8. Continue the heating of sample at the rate of 5 to 6 ^{0}C per minute and apply the test flame at 2 ^{0}C intervals until the vapors ignite and continue to burn for at least 5 seconds. Record this temperature as the fire point of the oil.

OBSERVATIONS

Room temperature: ____ ^{0}C

Trial No	Given sample of oil	Observed flash point ^{0}C	Observed fire point ^{0}C

PRECAUTIONS

1. This test shall not be performed where draught occurs.

2. As the moisture affects the flash point the cup and its accessories coming in contact with oil should be dried.

3. No oil should remain between the sliding and fixed plates forming the cover of the cup. If present it must be cleaned. Care should be taken to prevent wetting of the cup above the pointer tip.

4. Always a fresh sample of the oil should be used. A second determination on the same used oil shows higher flash point.

5. Thermometer should be inserted carefully through the clamp. The thermometer bulb should never touch the bottom of the oil cup. Thermometer should never be in line with the stirrer plates.

6. Stirrer should be disconnected during the application of the test flame. During the application of the test flame the slide should be open slowly but closed quickly.

7. Flash points of lubricating oils, some crude oils and residues are often determined by the open cup tests. Either PENSKY MARTIN's or CLEVELAND open-cup is used. The open-cup method is liable to error and gives only approximate values. The open cup flash point is higher than the closed cup value for the same sample.

RESULT

The flash and fire points of the given sample of oil using CLEVELAND's open cup apparatus is found to be _____ ^{0}C and _____ ^{0}C respectively.

VIVA QUESTIONS

5. What is Flash point and its importance in applications point of view?
6. What is Fire point and its importance in applications point of view?
7. What is the disadvantage of Cleveland open cup apparatus?
8. Why stirring is done in fire and flash point measuring apparatus?

6.CALIBRATION OF PRESSURE GUAGE

AIM

To calibrate the given pressure gauge by dead weight method, and to draw its calibration curves.

APPARATUS REQUIRED

One dead weight pressure gauge testing cum calibration machine, a set of standardized weights to reach the maximum capacity of the gauge being tested, two pressure gauge adopters, two spanners and one needle puller.

THEORY

Pressure intensity is defined as force per unit area and its measurement is quite commonplace in most mechanical applications and accouterments. Pressure due to ambience is called atmospheric pressure and pressure measured over and above the atmospheric pressure is called gauge pressure. If pressure is measured with respect to absolute vacuum it is called absolute pressure. Obviously absolute pressure is the sum of atmospheric pressure and gauge pressure. The gadget used for pressure measurement is called pressure gauge. Broadly they are two types, manometers and mechanical gauges. Manometers are liquid columns, usually of mercury, wherein pressure is measured in terms of height of liquid column. This does not pose any calibration problems as it involves measurement of height only. On the other hand mechanical gauges such as bourdon gauge, diaphragm gauge, bellows gauge etc., must be calibrated before use. Besides, in the course of their usage due to loss of mechanical properties they lose their accuracy and required to be re-calibrated at regular intervals. A number of methods exist for their calibration and dead weight method using standard weights is one of them.

DESCRIPTION OF APPARATUS

The apparatus consists of a priming-pump, a pressure-pump, an isolating valve, a loading head with hydraulic ram and two pressure gauge adopters, all assembled to a common base plate with leveling screws. The priming-pump is used to develop small initial pressure to begin with the test. It also serves as a reservoir of hydraulic liquid required for testing. The isolating valve isolates the priming-pump from rest of the hydraulic system after a small initial pressure has been built up in the system. A thrust ball bearing is used in the pressure-pump operating mechanism to minimize the effort required to operate it. The loading head houses a precision ground and lapped hydraulic ram to facilitate movement without friction in its guide. The ram carries a loading platform on top of which standardized weights can be placed. The pressure developed due to self-weight of loading ram and loading platform is marked on the platform itself. Each of the standardized weights is also marked with the additional pressure that it builds up when placed on the loading platform. Two pressure gauge adopters are provided with the unit. When testing an already calibrated gauge, one adopter must be closed with a dead plug, and when comparing or calibrating a new gauge both adopters must be used simultaneously. A needle puller is proved for pulling out the pressure gauge needles during calibration and testing.

PROCEDURE

1. The apparatus should be set up on a firm flat table or platform to provide convenient operating height for the apparatus. Place a spirit level on the top of the loading head and level the apparatus adjusting the leveling screws.

2. Pour hydraulic oil through the hole on top of the priming-pump while rotating its handle in anti-clockwise direction until the handle is completely taken out.

3. Now rotate the priming-pump slowly in clockwise direction with its isolating valve open until oil starts coming out of pressure gauge adopter. Fit the gauge in the adopter.

4. Rotate pressure-pump handle in clockwise direction till it stops. Rotate priming-pump handle in anti-clockwise direction until it is taken out, and add oil if required in to the priming-pump.

5. Place weights on the loading head up to the full capacity of the apparatus and see that a pressure gauge of capacity slightly higher than the total capacity of weights is fitted in the adopter.

6. Open the isolating valve and fix the priming-pump handle simultaneously unscrewing pressure-pump so that it is unscrewed completely.

7. Screw in the priming-pump tightly and close the isolating valve. Then move the pressure-pump handle clockwise to build up pressure in the system.

8. Check for any leaks at the pressure gauge fitting adopter etc.

9. Build up pressure to the full capacity of weights and rotate the weights gently by hand. It is necessary to rotate the weights to minimize the friction between the hydraulic ram and its guide so that the loaded ram just floats on the oil surface.

10. Rotate the handle of pressure-pump and open the isolating valve. Also rotate the priming-pump handle in the anti-clockwise direction until the pressure comes to zero.

11. Repeat this process 5 to 10 times to completely let out air in the system.

12. Remove the weights from the loading plat form and fit the pressure gauge to be tested in the pressure gauge adopter. A sealing washer should be used in the joint to prevent leakage.

13. Select about ten points at equal intervals to reach the full capacity of the gauge. Select the corresponding weights from the set of weights supplied.

14. After priming and closing the isolating valve for priming-pump add weights on the loading head step by step and operate the pressure-pump clockwise so that the loading platform remains lifted up to the red mark on the guide.

15. Rotate the weights gently by hand and see that the platform remains moving in the red band range.

16. Similarly go on increasing the weights and balancing the hydraulic ram in the red band range.

17. Compare the pressure shown by the pressure gauge needle with the sum of pressure intensities marked on the weights at various selected points and make necessary adjustments in the pressure gauge mechanism.

OBSERVATIONS

The observed valued are recorded in tabular form as following

Sl No	Actual pressure Based on weights Kg/cm^2	Pressure as per pressure gauge Kg/cm^2	Error	Correction	Percentage correction %
1					
2					
…					
…					
20					

GRAPHS: The observed data as recorded in the above table is presented in the following two graphs:

- A graph drawn between pressure as read from pressure gauge on X-axis and the percentage correction on Y-axis.

- A graph drawn between actual pressure based on weights on X-axis and the pressure as shown by gauge being tested/calibrated on Y-axis.

PRECAUTIONS

1. Keep the apparatus along with the weights clean and tidy. The loading head is the most delicate and sensitive part of the apparatus and therefore care should be taken in its handling. The weights should be placed very gently over it, and removed one by one carefully.

2. The oil inlet of the priming-pump should be kept covered with the plug to prevent foreign matter like dust from entering into it.

3. If the needle of the pressure gauge is to be removed, it should be done with the help of needle puller only, and not by force to avoid damage to the gauge spindle.

RESULT

The given pressure gauge has been calibrated using dead weight pressure gauge and calibration curves have been drawn.

VIVA QUESTIONS

1. What is calibration?
2. What is an error?
3. Difference between error & % of error?
4. What is absolute pressure, atmospheric pressure & gauge pressure?
5. What is calibration curve?
6. What are different types of pressure measuring instruments?
7. What is correction and % of correction?

7.REDWOOD VISCOMETER-I

AIM

To determine the kinematic viscosity and dynamic viscosity of a given sample of oil at different temperatures using REDWOOD-I viscometer.

REQUIRED APPARATUS

REDWOOD – I viscometer, heating element, autotransformer, standard thermometer, stopwatch, 50cc gravity bottle, simple balance, sample of oil whose viscosity is to be determined.

THEORY

By definition, a fluid is a substance that continuous to deform so long as a shear force is acted upon it. An ideal fluid is one, which continuously deforms i.e., flow, however negligible the applied shear force may be. However, the real fluids offer some resistance before they deform. This resistance to flow is due to its property, called viscosity of the fluid. In solids the induced stress is directly proportional to the resulting strain within the elastic limit, and this is true for all types of stresses, be it tensile, compressive or shear stress. According to Newton's law of fluids, however, in fluids the shear stress, τ, is proportional to *time rate* of strain, $d\theta/dt$.

$$\text{Mathematically, } \tau \propto (d\theta/dt)$$
$$\Leftrightarrow \quad \tau = \mu \, (d\theta/dt)$$

Where the constant of proportionality μ is called coefficient of dynamic viscosity and it is measured in *poise*. Thus, absolute or dynamic viscosity is the tangential force per unit area required to move one horizontal plane of the fluid at unit velocity with respect to another maintained at a unit distance apart by the fluid. When the force is 1 dyne/cm^2, the distance between the layers or planes 1cm and the velocity gradient 1 cm/sec, the viscosity is 1poise. This being a large unit, absolute viscosity is more commonly expressed as one hundredth of a poise called centipoise. The viscosity of water, for example, at 20^0C is 1.002 centipoise. The coefficient of kinematic viscosity, ν, is defined as the ratio of dynamic viscosity fluid to its density. Fluids, which obey Newton's law, are called Newtonian fluids and those, which do not obey, are called Non-Newtonian fluids. All gasses, water etc., are examples of Newtonian fluids while visco-elastic materials like tar, molasses, honey, blood etc., and mixtures of fluids and solids such as slurries are examples of non-Newtonian fluids.

Some of the reasons why measurement of viscosity is vital in most engineering applications of fluids are:

- Viscosity of fuel oils influences the ease of handling, transportation and nature of storage. High viscosity fuel oil cannot be properly atomized leading to incomplete combustion and loss of fuel. Fuel oils are usually pre-heated to reduce viscosity and above 120^0C viscosity are almost constant. Maximum viscosity for easy atomization in conventional burners is 25 centistokes (100 seconds Redwood I). A higher preheating temperature decreases the oil density causing lesser weight of oil delivered to the burner, thereby reducing burner output. Hence, accurate value of viscosity of oil is required for optimum burner output.
- High viscosity lubricating oil reduces its fluidity besides causing undue friction. Indeed, viscosity of lubricants determines the bearing friction, heat generation and fluidity under conditions of load and speed. Only lubricants of rated viscosity as per design parameters must be used.

- In case of diesel fuels, too low viscosity causes excessive leakage at the injection pistons while too high viscosity produces coarse droplets leading to incomplete combustion.
- Viscosity determines the pressure drop in pumping of fluids through open or closed channels. For easy and economic pumping the maximum viscosity should be 12 stokes (486 seconds Redwood II) in closed channels.
- Viscosity of oil blends must be experimentally determined since viscosity is neither an addictive property nor can be calculated using blending charts.

Though the units of kinematic and dynamic viscosity are stokes and poise respectively, the commonly used methods in engineering industry measure the viscosity in *arbitrary units,* using commercial viscometers. Commercial viscometers work on the following principle.
When a liquid is made to flow through a capillary tube by a pressure gradient, and the time for a given volume to flow along the tube is measured, then at a constant temperature, the coefficient of viscosity, μ, is given by Poiseuille's equation as:

$$\mu = \Pi PR^4T/8VL$$

Where P = pressure difference between the ends of the tube
L = length of the tube
R = radius of the tube
T = time in seconds
V = volume of the liquid flowing through the tube in T seconds

When the 'Inlet correction' and the 'kinetic energy correction' are incorporated, the above equation takes the form:

$$\mu = (\Pi PR^4T)/(8V(L + k_1R)) - (V\rho k_2)/ (8\Pi(L + k_1R)T)$$

where ρ is the density of the liquid and k_1 and k_2 are constants which depend on the form of the apparatus and are determined experimentally. The driving force is provided by the head of the test oil flowing vertically down the tube and is given by:

$$P = h \rho g$$

where h is the mean height of the oil. The tube dimensions are so chosen that k_1R in the above equation becomes negligible as compared to L, so that

$$\mu = (\Pi h\rho gR^4T/8VL) – (V\rho k_2/8\Pi LT)$$

For a given viscometer the head of the oil is maintained at the same height h. The time T in seconds is measured for flow of a fixed volume of the oil through the capillary of fixed dimensions. Then h, g, R, V and L all become constant and the above equation is reduced to

$$\mu = A\rho T – (B\rho/T)$$

where A and B are constants. Dividing both sides by ρ, we get

$$\mu/\rho = At – B/t \quad \Leftrightarrow \quad \nu = At – B/t$$

The above equation is called viscometer equation because all the commercial viscometers are based on this equation. The time t in seconds measured experimentally is reported as relative viscosity and its magnitude depends on the viscometer used and the volume of the liquid that flows through the tube of the viscometer. Therefore, while reporting the viscosity of oils using commercial viscometers, the viscometer used must be specified. Most commercial viscometers express viscosity in terms of number of seconds of time required for a fixed volume of fluid at a certain temperature to flow through a standard orifice. The measured time is then converted into corresponding stokes or poise using empirical formulae i.e., **A** and **B** in the above equation, supplied with the viscometer. Three makes of commercial

viscometers, REDWOOD, SAYBOLT and ENGLER, are popularly used in engineering applications. The time measured in seconds by these viscometers is usually post-fixed with the name of the viscometer itself. The REDWOOD viscometer is widely used in commonwealth countries including India. In REDWOOD viscometer viscosity is measured in number of seconds required for a fixed quantity of oil, usually 50 c.c., to flow. Two types of REDWOOD viscometers are used, REDWOOD I viscometer is used for low viscosity oils whereas REDWOOD II viscometer is used for high viscous oils. Oil flow port area for REDWOOD II viscometer is larger than that of REDWOOD I viscometer to facilitate quicker flow of high viscous oils. Consequently the empirical formulae are different for each of them. The time required for a standard volume of oil to flow from REDWOOD II viscometer is 1/10 of that require for an equal volume of same oil at the same temperature to flow from REDWOOD I viscometer. Viscosity measured by REDWOOD viscometers are reported as " n seconds of REDWOOD I or II", as the case may be, at a given temperature. SAYBOLT viscometer is the standard equipment for measuring viscosity in U.S.A. Similar to REDWOOD viscometers I and II, SAYBOLT also uses two standards, SAYBOLT UNIVERSAL and SAYBOLT FUROL. In SAYBOLT viscometers viscosity is measured in number of seconds required for a fixed quantity of oil, usually 60 ml, to flow through a calibrated universal/furol orifice under specified conditions. The SAYBOLT FUROL viscosity is approximately one tenth the SAYBOLT UNIVERSAL Viscosity and is recommended for those liquids having viscosity more than 1000 SECONDS SAYBOLT UNIVERSAL such as fuel oils and other residual materials. The word FUROL is a contraction of *fu*el and *ro*ad oi*l*s. ENGLER viscometer is popular in Europe. In the ENGLER viscometer the viscosity is expressed as the ratio of the time periods of flow of equal volumes of oil and water, and is called degree ENGLER (^{0}E). The empirical formulae for converting the measured time into poise or stokes differ from viscometer to viscometer. The following table gives the conversion formulae.

Viscometer Name	Range of flow time, T, seconds	Kinematic viscosity, ν, stokes
Saybolt universal	T=32 to 100	0.00226T-1.95/T
	T≥ 100	0.00220T-1.35/T
Saybolt furol	T=25 to 40	0.0224T-1.84/T
	T≥ 40	0.0216T-0.60/T
Redwood I	T=34 to 100	0.00260T-1.79/T
	T≥ 100	0.00247T-0.50/T
Redwood II	--	0.027T-20/T
Engler	--	0.00147T-3.74/T

DESCRIPTION

REDWOOD – I viscometer consists of a metal cup with an axially placed orifice in the base. A metal ball or a rod can be used to close the hole. The metal cup can be heated and the oil stirred to ensure uniform temperature throughout the oil. When the ball is removed, a thin stream of oil runs into a small graduated glass flask and the time to fill the flask is recorded. This time in seconds is called "seconds REDWOOD I" and is a measure of viscosity. These seconds REDWOOD I are converted into stokes of kinematic viscosity using the empirical formula $\nu = AT - (B/T)$ where A and B are viscometer constants and T is seconds REDWOOD I. The difference between REDWOOD I and REDWOOD II

viscometers lies in the dimensions of the discharge capillary (either tube, jet or orifice) as given below:

VISCOMETER	DIAMETER OF FLOW PORT	LENGTH OF FLOW PORT
REDWOOD I	1.62 mm	10 mm
REDWOOD II	3.8 mm	50 mm

As per the equipment manufacturer's recommendations, the viscosity for petroleum products must be determined at the temperatures of 21^0C, $37.8\ ^0C$, 50^0C, 93^0C, 121^0C, 149^0C, and 204^0C. For fuel oils the minimum temperature is 49^0C. For flux oils the temperature of the test be 93^0C. When an oil of unknown viscosity is given it must always be tested with REDWOOD – I viscometer. If the viscosity exceeds 2000 SECONDS REDWOOD – I then the REDWOOD – II be used.

PROCEDURE

1.   Level the apparatus by using spirit level and adjusting the leveling screws.

2.   Clean the oil cup thoroughly and place the ball valve in its position.

3.   The cup must be filled with the given sample of oil up to the mark.

4.   Fill the heating bath with water up to the marked level.

5.   Heat the oil sample in the cup until the required temperature is attained.

6.   Place the gravity bottle just below the oil jet and lift the ball valve.

7.   Note down the time taken for collecting 50cc of the given oil in seconds.

8.   Continue heating the water bath and repeat the experiment for every 5^0 C rise in temperature at different temperatures by finding the time taken for the collection of 50cc oil each time and tabulate the readings.

OBSERVATIONS

Weight of empty gravity bottle W_1 = _____ grams
Weight of oil + gravity bottle W_2 =_____ grams

Volume of the gravity bottle = _____ ml
Density at room temperature = _____ grams/ml

Sl No	Temperature of oil ^{0}C	Density of oil gm/ml	Time for collecting 50cc of oil in seconds REDWOOD -I	Kinematic viscosity ν Centi stokes	Dynamic viscosity μ Centi poise
1.					
2.					
3.					
4.					
5.					

GRAPHS The above results must be graphically presented by drawing the following graphs:

- Temperature on X-axis and Time in seconds REDWOOD I on Y-axis.
- Temperature on X-axis and log seconds REDWOOD I on Y-axis on a semi-log graph sheet.
- Temperature on X-axis and kinematic viscosity, ν, on Y-axis.
- Temperature on X-axis and dynamic viscosity, μ, on Y-axis.

PRECAUTIONS

1. Ensure proper sitting of the ball valve to avoid leakage.
2. Stir the water bath continuously during heating for homogenous rise in temperature.
3. Oil should be free from suspended particles.
4. The jet should be clear.

RESULT

1. The kinematic viscosity of the oil sample at ____ ^{0}C is _____ centi strokes.
2. The dynamic or absolute viscosity of the oil sample at ___ ^{0}C is _____ centi poise.

VIVA QUESTIONS

1. What is Viscosity?
2. What are different types of viscosity explain them and write the units?
3. What are factors effecting viscosity?
4. Mention some applications where viscosity is considered?
5. Relation between density and viscosity?
6. Mention different types of oils used in lubricating purposes?
7. How does SAE grade differ in lubricants oils used summer and winter?
8. How the power consumptions varies with viscosity of lubricant in rotation of shaft?
9. Selection of viscometers based on grading or viscosity of oil?
10. Which constructional feature of viscometer varies with the viscosity of oil?
11. Why stirring is done in viscometer and fire and flash point measuring apparatus?
12. Properties of good lubricant?
13. How does viscosity effects lubricants?
14. What is the temperature range for Redwood – I viscometer?

8.REDWOOD VISCOMETER-II

AIM

To determine the kinematic viscosity and dynamic viscosity of a given sample of oil at different temperatures using REDWOOD-II viscometer.

APPARATUS REQUIRED

REDWOOD – II viscometer, heating element, auto transformer, standard thermometer, stopwatch, 50cc gravity bottle, simple balance, sample of oil whose viscosity is to be determined.

THEORY

By definition a fluid is a substance that continuous to deform so long as a shear force is acted upon it. An ideal fluid is one, which continuously deforms i.e., flow, however negligible the applied shear force may be. However, the real fluids offer some resistance before they deform. This resistance to flow is called viscosity of the fluid. In solids the induced stress is directly proportional to the resulting strain within the elastic limit, and this is true for all types of stresses, be it tensile, compressive or shear stress. According to Newton's law of fluids, however, in fluids the shear stress, τ, is proportional to *time rate* of strain, $d\theta/dt$.

$$\text{Mathematically, } \tau \propto (d\theta/dt)$$
$$\Leftrightarrow \quad \tau = \mu\,(d\theta/dt)$$

Where the constant of proportionality μ is called coefficient of dynamic viscosity and it is measured in *poise*. Thus, absolute or dynamic viscosity is the tangential force per unit area required to move one horizontal plane of the fluid at unit velocity with respect to another maintained at a unit distance apart by the fluid. When the force is 1 dyne/cm^2, the distance between the layers or planes 1cm and the velocity gradient 1 cm/sec, the viscosity is 1poise. This being a large unit, absolute viscosity is more commonly expressed as one hundredth of a poise called centipoise. The viscosity, also known as coefficient of viscosity, *n*, of water at 20^0 C is 1.002 centipoise. The coefficient of kinematic viscosity, ν, is defined as the ratio of dynamic viscosity fluid to its density. Fluids, which obey Newton's law, are called Newtonian fluids and those, which do not obey, are called Non-Newtonian fluids. All gasses, water etc., are examples of Newtonian fluids while visco-elastic materials like tar, molasses, honey, blood etc., and mixtures of fluids and solids such as slurries are examples of non-Newtonian fluids.

Some of the reasons why measurement of viscosity is vital in most engineering applications of fluids are:

- Viscosity of fuel oils influences the ease of handling, transportation and nature of storage. High viscosity fuel oil cannot be properly atomized leading to incomplete combustion and loss of fuel. Fuel oils are usually pre-heated to reduce viscosity and above 120^0C viscosity are almost constant. Maximum viscosity for easy atomization in conventional burners is 25 centistokes (100 seconds Redwood I). A higher preheating temperature decreases the oil density causing lesser weight of oil delivered to the burner, thereby reducing burner output. Hence, accurate value of viscosity of oil is required for optimum burner output.
- High viscosity lubricating oil reduces its fluidity besides causing undue friction. Indeed, viscosity of lubricants determines the bearing friction, heat generation and fluidity under conditions of load and speed. Only lubricants of rated viscosity as per design parameters must be used.
- In case of diesel fuels, too low viscosity causes excessive leakage at the injection pistons while too high viscosity produces coarse droplets leading to incomplete combustion.

- Viscosity determines the pressure drop in pumping of fluids through open or closed channels. For easy and economic pumping the maximum viscosity should be 12 stokes (486 seconds Redwood II) in closed channels.
- Viscosity of oil blends must be experimentally determined since viscosity is neither an addictive property nor can be calculated using blending charts.

Though the units of kinematic and dynamic viscosity are stokes and poise respectively, the commonly used methods in engineering industry measure the viscosity in *arbitrary units,* using commercial viscometers. Commercial viscometers work on the following principle.
When a liquid is made to flow through a capillary tube by a pressure gradient, and the time for a given volume to flow along the tube is measured, then at a constant temperature, the coefficient of viscosity, μ, is given by Poiseuille's equation as:

$$\mu = \Pi\, PR^4 T / 8VL$$

Where P = pressure difference between the ends of the tube
L = length of the tube
R = radius of the tube
T = time in seconds
V = volume of the liquid flowing through the tube in T seconds

When the 'Inlet correction' and the 'kinetic energy correction' are incorporated, the above equation takes the form:

$$\mu = (\Pi\, PR^4 T)/(8V(L + k_1 R)) - (V\rho k_2)/(8\Pi(L + k_1 R)T)$$

where ρ is the density of the liquid and k_1 and k_2 are constants which depend on the form of the apparatus and are determined experimentally. The driving force is provided by the head of the test oil flowing vertically down the tube and is given by:

$$P = h\, \rho g$$

where h is the mean height of the oil. The tube dimensions are so chosen that $k_1 R$ in the above equation becomes negligible as compared to L, so that

$$\mu = (\Pi h\rho g R^4 T / 8VL) - (V\rho k_2 / 8\Pi LT)$$

For a given viscometer the head of the oil is maintained at the same height h. The time T in seconds is measured for flow of a fixed volume of the oil through the capillary of fixed dimensions. Then h, g, R, V and L all become constant and the above equation is reduced to

$$\mu = A\rho T - (B\rho/T)$$

where A and B are constants. Dividing both sides by ρ, we get

$$\mu/\rho = At - B/t \Leftrightarrow \nu = At - B/t$$

The above equation is called viscometer equation because all the commercial viscometers are based on this equation. The time t in seconds measured experimentally is reported as relative viscosity and its magnitude depends on the viscometer used and the volume of the liquid that flows through the tube of the viscometer. Therefore, while reporting the viscosity of oils using commercial viscometers, the viscometer used must be specified. Most commercial viscometers express viscosity in terms of number of seconds of time required for a fixed volume of fluid at a certain temperature to flow through a standard orifice. The measured time is then converted into corresponding stokes or poise using empirical formulae i.e., **A** and **B** in the above equation, supplied with the viscometer. Three makes of commercial viscometers, REDWOOD, SAYBOLT and ENGLER, are popularly used in engineering applications. The time measured in seconds by these viscometers is usually post-fixed with the name of the viscometer itself. The REDWOOD viscometer is widely used in commonwealth countries including India. In REDWOOD viscometer viscosity is measured in

number of seconds required for a fixed quantity of oil, usually 50 c.c., to flow. Two types of REDWOOD viscometers are used, REDWOOD I viscometer is used for low viscosity oils whereas REDWOOD II viscometer is used for high viscous oils. Oil flow port area for REDWOOD II viscometer is larger than that of REDWOOD I viscometer to facilitate quicker flow of high viscous oils. Consequently the empirical formulae are different for each of them. The time required for a standard volume of oil to flow from REDWOOD II viscometer is 1/10 of that require for an equal volume of same oil at the same temperature to flow from REDWOOD I viscometer. Viscosity measured by REDWOOD viscometers are reported as " n seconds of REDWOOD I or II", as the case may be, at a given temperature. SAYBOLT viscometer is the standard equipment for measuring viscosity in U.S.A. Similar to REDWOOD viscometers I and II, SAYBOLT also uses two standards, SAYBOLT UNIVERSAL and SAYBOLT FUROL. In SAYBOLT viscometers viscosity is measured in number of seconds required for a fixed quantity of oil, usually 60 ml, to flow through a calibrated universal/furol orifice under specified conditions. The SAYBOLT FUROL viscosity is approximately one tenth the SAYBOLT UNIVERSAL Viscosity and is recommended for those liquids having viscosity more than 1000 SECONDS SAYBOLT UNIVERSAL such as fuel oils and other residual materials. The word FUROL is a contraction of *fu*el and *ro*ad oi*ls*. ENGLER viscometer is popular in Europe. In the ENGLER viscometer the viscosity is expressed as the ratio of the time periods of flow of equal volumes of oil and water, and is called degree ENGLER (^{0}E). The empirical formulae for converting the measured time into poise or stokes differ from viscometer to viscometer. The following table gives the conversion formulae.

Viscometer Name	Range of flow time, T, seconds	Kinematic viscosity, ν, stokes
Saybolt universal	T=32 to 100 T≥ 100	0.00226T-1.95/T 0.00220T-1.35/T
Saybolt furol	T=25 to 40 T≥ 40	0.0224T-1.84/T 0.0216T-0.60/T
Redwood I	T=34 to 100 T≥ 100	0.00260T-1.79/T 0.00247T-0.50/T
Redwood II	--	0.027T-20/T
Engler	--	0.00147T-3.74/T

DESCRIPTION

REDWOOD – II viscometer and REDWOOD I viscometer differ only in oil flow port areas. It consists of a metal cup with an axially placed orifice in the base. A metal ball or a rod can be used to close the hole. The metal cup can be heated and the oil stirred to ensure uniform temperature throughout the oil. When the ball is removed, a thin stream of oil runs into a small graduated glass flask and the time to fill the flask is recorded. This time in seconds is called "seconds REDWOOD II" and is a measure of viscosity. These seconds REDWOOD II are converted into stokes of kinematic viscosity using the empirical formula $ν = AT – (B/T)$ where A and B are viscometer constants and T is seconds REDWOOD II. The difference between REDWOOD I and REDWOOD II viscometers lies in the dimensions of the discharge capillary (either tube, jet or orifice) as given below:

VISCOMETER	DIAMETER OF FLOW PORT	LENGTH OF FLOW PORT
REDWOOD I	1.62 mm	10 mm
REDWOOD II	3.8 mm	50 mm

As per the equipment manufacturer's recommendations, the viscosity for petroleum products must be determined at the temperatures of 21^0C, 37.8 ^{0}C, 50^0C, 93^0C, 121^0C, 149^0C, and 204^0C. For fuel oils the minimum temperature is 49^0C. For flux oils the temperature of the test be 93^0C. When an oil of unknown viscosity is given it must always be tested with REDWOOD – I viscometer. If the viscosity exceeds 2000 SECONDS REDWOOD – I then the REDWOOD – II be used.

PROCEDURE

1. Level the apparatus by using spirit level and adjusting the leveling screws.

2. Clean the oil cup thoroughly and place the ball valve in its position.

3. The cup must be filled with the given sample of oil up to the mark.

4. Fill the heating bath with water up to the marked level.

5. Heat the oil sample in the cup until the required temperature is attained.

6. Place the gravity bottle just below the oil jet and lift the ball valve.

7. Note down the time taken for collecting 50cc of the given oil in seconds.

8. Continue heating the water bath and repeat the experiment for every 5^0 C rise in temperature at different temperatures by finding the time taken for the collection of 50cc oil each time and tabulate the readings.

OBSERVATIONS

Weight of empty gravity bottle W_1 = _____ grams
Weight of oil + gravity bottle W_2 = _____ grams

Volume of the gravity bottle = _____ ml

Density at room temperature = _____ grams/ml

Sl No	Temperature of oil ^{0}C	Density of oil gm/ml	Time for collecting 50cc of oil in seconds REDWOOD –II	Kinematic viscosity ν Centi stokes	Dynamic viscosity μ Centi poise
1.					
2.					
3.					
4.					
5.					

GRAPHS The above results must be graphically presented by drawing the following graphs:

- Temperature on X-axis and Time in seconds REDWOOD II on Y-axis.
- Temperature on X-axis and log seconds REDWOOD II on Y-axis on a semi-log graph sheet.
- Temperature on X-axis and kinematic viscosity, ν, on Y-axis.
- Temperature on X-axis and dynamic viscosity, μ, on Y-axis.

PRECAUTIONS

1. Ensure proper sitting of the ball valve to avoid leakage.
2. Stir the water bath continuously during heating for homogenous rise in temperature.
3. Oil should be free from suspended particles.
4. The jet should be clear.

RESULT

1. The kinematic viscosity of the oil sample at _____ ^{0}C is _____ centi strokes.
2. The dynamic or absolute viscosity of the oil sample at ___ ^{0} C is _____ centi poise.

VIVA QUESTIONS

1. What is Viscosity?

2. What are different types of viscosity explain them and write the units?

3. What are factors effecting viscosity?

4. Mention some applications where viscosity is considered?

5. Relation between density and viscosity?

6. Mention different types of oils used in lubricating purposes?

7. How does SAE grade differ in lubricants oils used summer and winter?

8. How the power consumptions varies with viscosity of lubricant in rotation of shaft?

9. Selection of viscometers based on grading or viscosity of oil?

10. Which constructional feature of viscometer varies with the viscosity of oil?

11. Why stirring is done in viscometer and fire and flash point measuring apparatus?

12. Properties of good lubricant?

13. How do viscosity effect lubricants?

14. What is the temperature range for Redwood – I viscometer?

9.SAYBOLT VISCOMETER

AIM

To determine the kinematic viscosity and dynamic viscosity of a given sample of oil at different temperatures using SAYBOLT UNIVERSAL viscometer.

APPARATUS REQUIRED

SAYBOLT UNIVERSAL viscometer, heating element, auto transformer, standard thermometer, stopwatch, 50cc gravity bottle, simple balance, sample of oil whose viscosity is to be determined.

THEORY

By definition a fluid is a substance that continuous to deform so long as a shear force is acted upon it. An ideal fluid is one, which continuously deforms i.e., flow, however negligible the applied shear force may be. However, the real fluids offer some resistance before they deform. This resistance to flow is called viscosity of the fluid. In solids the induced stress is directly proportional to the resulting strain within the elastic limit, and this is true for all types of stresses, be it tensile, compressive or shear stress. According to Newton's law of fluids, however, in fluids the shear stress, τ, is proportional to *time rate* of strain, **dθ/dt**.

$$\text{Mathematically, } \boldsymbol{\tau \propto (d\theta/dt)}$$
$$\Leftrightarrow \quad \boldsymbol{\tau = \mu \, (d\theta/dt)}$$

Where the constant of proportionality μ is called coefficient of dynamic viscosity and it is measured in *poise*. Thus, absolute or dynamic viscosity is the tangential force per unit area required to move one horizontal plane of the fluid at unit velocity with respect to another maintained at a unit distance apart by the fluid. When the force is 1 dyne/cm^2, the distance between the layers or planes 1cm and the velocity gradient 1 cm/sec, the viscosity is 1poise. This being a large unit, absolute viscosity is more commonly expressed as one hundredth of a poise called centipoise. The coefficient of kinematic viscosity, ν, is defined as the ratio of dynamic viscosity fluid to its density. Fluids, which obey Newton's law, are called Newtonian fluids and those, which do not obey, are called Non-Newtonian fluids. All gasses, water etc., are examples of Newtonian fluids while visco-elastic materials like tar, molasses, honey, blood etc., and mixtures of fluids and solids such as slurries are examples of non-Newtonian fluids.

Some of the reasons why measurement of viscosity is vital in most engineering applications of fluids are:

- Viscosity of fuel oils influences the ease of handling, transportation and nature of storage. High viscosity fuel oil cannot be properly atomized leading to incomplete combustion and loss of fuel. Fuel oils are usually pre-heated to reduce viscosity and above 120^{0}C viscosity are almost constant. Maximum viscosity for easy atomization in conventional burners is 25 centistokes (100 seconds Redwood I). A higher preheating temperature decreases the oil density causing lesser weight of oil delivered to the burner, thereby reducing burner output. Hence, accurate value of viscosity of oil is required for optimum burner output.
- High viscosity lubricating oil reduces its fluidity besides causing undue friction. Indeed, viscosity of lubricants determines the bearing friction, heat generation and fluidity under conditions of load and speed. Only lubricants of rated viscosity as per design parameters must be used.
- In case of diesel fuels, too low viscosity causes excessive leakage at the injection pistons while too high viscosity produces coarse droplets leading to incomplete combustion.

- Viscosity determines the pressure drop in pumping of fluids through open or closed channels. For easy and economic pumping the maximum viscosity should be 12 stokes (486 seconds Redwood II) in closed channels.
- Viscosity of oil blends must be experimentally determined since viscosity is neither an addictive property nor can be calculated using blending charts.

Though the units of kinematic and dynamic viscosity are stokes and poise respectively, the commonly used methods in engineering industry measure the viscosity in *arbitrary units,* using commercial viscometers. Commercial viscometers work on the following principle.
When a liquid is made to flow through a capillary tube by a pressure gradient, and the time for a given volume to flow along the tube is measured, then at a constant temperature, the coefficient of viscosity, μ, is given by Poiseuille's equation as:

$$\mu = \Pi\, PR^4 T/8VL$$

Where P = pressure difference between the ends of the tube
L = length of the tube
R = radius of the tube
T = time in seconds
V = volume of the liquid flowing through the tube in T seconds

When the 'Inlet correction' and the 'kinetic energy correction' are incorporated, the above equation takes the form:

$$\mu = (\Pi\, PR^4 T)/(8V(L + k_1 R)) - (V\rho k_2)/ (8\Pi(L + k_1 R)T)$$

where ρ is the density of the liquid and k_1 and k_2 are constants which depend on the form of the apparatus and are determined experimentally. The driving force is provided by the head of the test oil flowing vertically down the tube and is given by:

$$P = h\, \rho g$$

where h is the mean height of the oil. The tube dimensions are so chosen that $k_1 R$ in the above equation becomes negligible as compared to L, so that

$$\mu = (\Pi h\rho g R^4 T/8VL) - (V\rho k_2/8\Pi LT)$$

For a given viscometer the head of the oil is maintained at the same height h. The time T in seconds is measured for flow of a fixed volume of the oil through the capillary of fixed dimensions. Then h, g, R, V and L all become constant and the above equation is reduced to

$$\mu = A\rho T - (B\rho/T)$$

where A and B are constants. Dividing both sides by ρ, we get

$$\mu/\rho = At - B/t \quad \Leftrightarrow \quad \nu = At - B/t$$

The above equation is called viscometer equation because all the commercial viscometers are based on this equation. The time t in seconds measured experimentally is reported as relative viscosity and its magnitude depends on the viscometer used and the volume of the liquid that flows through the tube of the viscometer. Therefore, while reporting the viscosity of oils using commercial viscometers, the viscometer used must be specified. Most commercial viscometers express viscosity in terms of number of seconds of time required for a fixed volume of fluid at a certain temperature to flow through a standard orifice. The measured time is then converted into corresponding stokes or poise using empirical formulae supplied with the viscometer. Three makes of commercial viscometers, REDWOOD, SAYBOLT and ENGLER, are popularly used in engineering applications. The time measured in seconds by these viscometers is usually post-fixed with the name of the viscometer itself.   The REDWOOD viscometer is widely used in commonwealth countries including India. In REDWOOD viscometer viscosity is measured in number of seconds required for a fixed

quantity of oil, usually 50 c.c., to flow. Two types of REDWOOD viscometers are used, REDWOOD I viscometer is used for low viscosity oils whereas REDWOOD II viscometer is used for high viscous oils. Oil flow port area for REDWOOD II viscometer is larger than that of REDWOOD I viscometer to facilitate quicker flow of high viscous oils. Consequently the empirical formulae are different for each of them. The time required for a standard volume of oil to flow from REDWOOD II viscometer is 1/10 of that require for an equal volume of same oil at the same temperature to flow from REDWOOD I viscometer. Viscosity measured by REDWOOD viscometers are reported as " n seconds of REDWOOD I or II", as the case may be, at a given temperature. SAYBOLT viscometer is the standard equipment for measuring viscosity in U.S.A. Similar to REDWOOD viscometers I and II, SAYBOLT also uses two standards, SAYBOLT UNIVERSAL and SAYBOLT FUROL. In SAYBOLT viscometers viscosity is measured in number of seconds required for a fixed quantity of oil, usually 60 ml, to flow through a calibrated universal/furol orifice under specified conditions. The SAYBOLT FUROL viscosity is approximately one tenth the SAYBOLT UNIVERSAL Viscosity and is recommended for those liquids having viscosity more than 1000 SECONDS SAYBOLT UNIVERSAL such as fuel oils and other residual materials. The word FUROL is a contraction of *fu*el and *ro*ad oi*l*s. ENGLER viscometer is popular in Europe. In the ENGLER viscometer the viscosity is expressed as the ratio of the time periods of flow of equal volumes of oil and water, and is called degree ENGLER (^{0}E). The empirical formulae for converting the measured time into poise or stokes differ from viscometer to viscometer. The following table gives the conversion formulae.

Viscometer Name	Range of flow time, T, seconds	Kinematic viscosity, ν, stokes
Saybolt universal	T=32 to 100	0.00226T-1.95/T
	T≥ 100	0.00220T-1.35/T
Saybolt furol	T=25 to 40	0.0224T-1.84/T
	T≥ 40	0.0216T-0.60/T
Redwood I	T=34 to 100	0.00260T-1.79/T
	T≥ 100	0.00247T-0.50/T
Redwood II	--	0.027T-20/T
Engler	--	0.00147T-3.74/T

DESCRIPTION

 The SAYBOLT UNIVERSAL viscometer consists of a cylindrical oil cup having a prolonged tubular like base with a provision for axially fixing the jets to drain out the oil. The construction features of both SAYBOLT UNIVERSAL and SAYBOLT FUROL are identical except for variation in jet sizes. The upper portion of the cup is larger in diameter and the interior of the bottom of the cup is concave in shape for complete and easy draining of its contents. Oil shall be filled up to the mark provided for the purpose. The oil cup and silver plate are fixed to the bottom of the securely held heating bath. An immersion heater is fixed inside the periphery of the heating bath and is connected to the autotransformer for temperature control. Stirring of the bath is effected by means of a cylinder with vanes surrounding the oil cup. A flat shield is fixed to the upper edge of the cylinder in order to provide an insulated handle for rotating the stirrer. A thermometer support is provided for holding the thermometer.

As per the equipment manufacturer's recommendations, the SAYBOLT UNIVERSAL viscometer determinations must be made at the temperatures of 21^0C, 37.5 ^{0}C, 54^0C and 98^0C, and the SAYBOLT FUROL viscometer determinations must be made at the temperatures of 25^0C, 37.5 ^{0}C, 50^0C and 98^0C. In testing road oils and paving material determinations must also be made at 60^0C and 82^0C.

PROCEDURE

1. Level the apparatus by using spirit level and adjusting the leveling screws.
2. Clean the oil cup thoroughly and place the ball valve in its position.
3. The cup must be filled with the given sample of oil up to the mark.
4. Fill the heating bath with water up to the marked level.
5. Heat the oil sample in the cup until the required temperature is attained.
6. Place the gravity bottle just below the oil jet and lift the ball valve.
7. Note down the time taken for collecting 50cc of the given oil in seconds.
8. Continue heating the water bath and repeat the experiment for every 5^0 C rise in temperature at different temperatures by finding the time taken for the collection of 50cc oil each time and tabulate the readings.

OBSERVATIONS

Weight of empty gravity bottle W_1 = _____ grams
Weight of oil + gravity bottle W_2 = _____ grams

Volume of the gravity bottle = _____ ml

Density at room temperature = _____ grams/ml

Sl No	Temperature of oil ^{0}C	Density of oil gm/ml	Time for collecting 50cc of oil in seconds SAYBOLT UNIVERSAL	Kinematic viscosity ν centi stokes	Dynamic viscosity μ centi poise
1.					
2.					
3.					
4.					
5.					

GRAPHS The above results must be graphically presented by drawing the following graphs:

- Temperature on X-axis and Time in seconds SAYBOLT UNIVERSAL on Y-axis.
- Temperature on X-axis and log seconds SAYBOLT UNIVERSAL on Y-axis on a semi-log graph sheet.
- Temperature on X-axis and kinematic viscosity, ν, on Y-axis.
- Temperature on X-axis and dynamic viscosity, μ, on Y-axis.

PRECAUTIONS

5. Ensure proper sitting of the ball valve to avoid leakage.
6. Stir the water bath continuously during heating for homogenous rise in temperature.
7. Oil should be free from suspended particles.
8. The jet should be clear.

RESULT

3. The kinematic viscosity of the oil sample at _____ ^{0}C is _____centi strokes.
4. The dynamic or absolute viscosity of the oil sample at ___ ^{0} C is _____ centi poise.

VIVA QUESTIONS

9. What is Viscosity?

10. What are different types of viscosity explain them and write the units?

11. What are factors effecting viscosity?

12. Mention some applications where viscosity is considered?

13. Relation between density and viscosity?

14. Mention different types of oils used in lubricating purposes?

15. How does SAE grade differ in lubricants oils used summer and winter?

16. How the power consumptions varies with viscosity of lubricant in rotation of shaft?

17. Selection of viscometers based on grading or viscosity of oil?

18. Which constructional feature of viscometer varies with the viscosity of oil?

19. Why stirring is done in viscometer and fire and flash point measuring apparatus?

20. Properties of good lubricant?

21. How does viscosity effects lubricants?

22. What is the temperature range for Say Bolt viscometer?

10.CLOUD AND POUR POINT

AIM

 To determine the cloud and pour points of the given sample of oil.

APPARATUS REQUIRED

 Cloud and pour point apparatus consisting of bath, jar, jackets, corks and gaskets, NaCl, $CaCl_2$, Acetone, ice and thermometers.

THEORY

 Lubricating oils derived from petroleum usually contain dissolved paraffin wax and other asphaltic or resinous impurities, their amounts depending on the efficiency of de-waxing and refining process used. These impurities tend to separate out of the oil at lower temperatures. When a petroleum oil is chilled under specified conditions, the temperature at which dissolved paraffin wax or other solidifiable materials, begin to separate out in the form of minute crystals, causing the oil to become less transparent, cloudy or hazy in appearance, is known as the cloud point of the oil. If the cooling is continued further, the amount of the separating material increases and a stage is reached when the oil solidifies and stops flowing. The lowest temperature, at which the oil will just start to flow or pour under prescribed conditions, when it is cooled undisturbed at a fixed rate, is called its pour point. The cloud point determination is limited only to transparent oils; otherwise there may be slight variation in results due to the human error involved, since the decrease in transparency is to be visually observed.

Cloud point of a lubricant to be applied by a capillary feed system or wicking arrangement must be low so that the oil flow does not cease due to deposition of crystals of wax in the capillary or interstices of wick. Cloud point is helpful in identifying the temperatures at which wax separation may clog the filter screens in the fuel intake system of diesel engines. Oils of naphtha base, which are almost wax-free, show very low cloud points and this fact may be useful in identifying the source of the oil. Pour point is more important since in the lubrication of any machine subjected to low temperature, the lubricant must flow freely, especially during the start-up period. A high pour point may lead to solidification of the lubricant that may cause jamming of the machine. Pour point also establishes the lowest temperature at which the oil can be transferred by pouring or below which, because of extremely poor mobility of the oil, lubrication by gravity flow process is less reliable.

DESCRIPTION

 It consists jar with cork for placing thermometer and jacket with gasket both placed in a cooling bath with an opening for placing a thermometer. Jar is a flat-bottomed cylindrical vessel made of glass. It is fitted with a cork, which carries a thermometer for measuring the temperature of the oil being cooled in the jar. Jacket is a watertight flat-bottomed cylindrical vessel made of steel. Gasket is fitted around the jar and then the jar is placed in the jacket. Gasket prevents the jar from touching the jacket. Bath is an insulated metallic vessel placed on a tripod, and is used to support the bank of jackets in vertical position. Cooling mixture is placed in the bath to bring about the required lower temperatures around the jackets carrying oil filled jar. Temperatures of cooling mixture and the oil in the jar can be recorded.

PROCEDURE

Determination of cloud point of an oil:

1. Bring the oil sample to be tested to temperature at least 10^0C above the expected cloud point. If the sample contains moisture, dry it by shaking with a little anhydrous sodium sulfate followed by filtration through dry lint less filter paper.
2. Pour the clear oil into the test jar up to the etched mark.
3. Tightly close the jar with a cork carrying a thermometer with its bulb touching the bottom of the jar.
4. Insert the test jar inside a holding jacket made of glass or copper, in freezing mixture suitable for obtaining the desired temperature.
5. After every 1^0C fall in temperature of the oil, take out the test jar from the jacket, inspect for cloudiness and immediately replace it in the jacket. Record the temperature at which such inspection first reveals a distinct cloudiness in the oil near the bottom of the jar and report it as the cloud point.

Determination of pour point of an oil:

1. Proceed as in the cloud point test with the difference that the thermometer bulb is just completely immersed in the oil, instead of touching the bottom.

2. Starting at a temperature of about 5^0C above the expected pour point, take out the jar after every 2^0C fall in temperature and tilt it just enough to see any movement of the oil. Immediately replace the jar in the jacket.

3. At a point where the oil in the jar shows no movement on tilting, hold the jar in a horizontal position for 5 seconds. If there is some movement of the oil, replace the jar immediately in the jacket and repeat the test for flow after further 1^0C fall in temperature.

4. Continue the test until no movement of the oil is observed when the test jar is held in a horizontal position for exactly 5 seconds. Record the reading on the test thermometer as *solid point*. Add 5^0C to this temperature to get the pour point

OBSERVATIONS

Room temperature = _____ ^{0}C

TABLE FOR DETERMINATION OF BATH TEMPERATURE:

Cooling mixture	Temperature obtained ^{0}C
Ice + Water	
Ice + NaCl	
Ice + CaCl$_2$	
Ice + Acetone	

TABLE FOR DETERMINATION OF CLOUD AND POUR POINT TEMPERATURE:

Sl No.	Sample of oil	Cloud point ^0C	Pour point ^0C
1			
2			
3			

PRECAUTIONS

1. As per the equipment suppliers recommendations cloud point of oils which are transparent in layers of 40 mm thickness and having cloud point below 49^0C must be used for reliable results. The equipment can be used for determining the pour point of any petroleum oil.

2. The bath temperature must be at least 10^0C below the expected pour point. A suitable cooling mixture must be used.

3. For black oil, cylinder stock and non-distillate fuel the result obtained by the above procedure gives upper pour point. Lower pour point can be determined by heating the sample to 105^0C, and then pouring it into the jar and repeating the above procedure.

4. Certain lubricating oils tend to move as a whole. The point at which they cease to flow is consequently more difficult to detect.

RESULT

The cloud and pour points of the given sample of oil are found to be _____ ^0C and _____ ^0C respectively.

VIVA QUESTIONS

1. What is cloud point and significance of estimating cloud point?
2. What is pour point and significance of estimating pour point?
3. What are properties of fuel?

11.VOLUMETRIC EFFICIENCY OF 2-STAGE AIR COMPRESSOR

AIM

To determine the volumetric efficiency of a two stage air compressor by (i) Tank Capacity method, and (ii) Plate Orifice method.

APPARATUS REQUIRED

Stopwatch, Two stage air compressor with tachometer, U–tube manometer and plate orifice.

THEORY

In engineering applications it is often required to increase the mechanical energy level i.e., head, velocity or pressure, of the working fluid by employing head or pressure producing machines called pumps, compressors, fans, blowers and propellers. Broadly, they are of two types viz., rotary and reciprocating machines. The reciprocating machines, also called positive displacement machines, trap the working fluid, whose energy level is to be raised, inside a cylinder and impart work to it through the motion of a piston, and then release it. They are driven by prime movers such as turbines or electrical motors for supplying the power required for imparting the work required to increase the energy level of the fluid. Reciprocating machines are inherently of low speed machines on account of mechanical and volumetric efficiency considerations, resulting in much smaller fluid flow rates when compared to rotary machines. Reciprocating compressors are suited for low volume and high-pressure ratio applications. The delivery rate is not steady, and therefore a storage tank is used as a reservoir to get smooth delivery of the fluid. Thus, storage tank ensures continuous supply of fluid flow at the required pressure. The actual volume of air delivered, referred to atmospheric or inlet conditions, is generally less than the displacement volume of the compressor. ***Displacement volume*** is the volume swept over by the piston in the process of imparting work to the working fluid, and is equal to the product of stroke volume and the number of strokes during a given time. Compressors are specified using the volume of air that they can deliver at the required pressure. Since the volume varies with the temperature and pressure, compressors with different outlet pressures cannot be compared purely based on delivery volumes. In order to standardize the volume, the "***FREE AIR DELIVERY (FAD)***" conditions are defined. The volume of air delivered per unit time at FAD conditions is called the capacity of the compressor. It is represented as m^3/s of FAD or m^3/min of FAD. Each country's standard defines the free air conditions. In India, Standard Temperature and Pressure are FAD conditions. Volumetric efficiency of a reciprocating compressor is defined as:

$$\eta_{Vol.} = (\text{Volume delivered per unit time as converted to FAD}) \div (\text{displacement volume per unit time})$$

In case of multi-stage compressors, the displacement volume is the volume swept by the low-pressure cylinder. The actual volume is less due to several reasons, some of the important ones being:

1. **Clearance Volume** is the volume of the clearance space between cylinder cover and piston when piston reaches its top most position, called Top Dead Center (TDC). This clearance is required to avoid mechanical impact of piston onto the cylinder. The trapped air in the clearance volume is not pushed out of the cylinder, and expands during the following suction stroke. During the suction stroke until this air expands to inlet pressure

suction valve cannot open. This effectively reduces the suction volume. The actual volume sucked in will, therefore, be less then the stroke volume.

2. **Resistance of Flow-passages** Frictional resistance in the various inlet passages causes pressure drops and so the pressure in the cylinder at the end of suction is lower than the atmospheric pressure. The mass filling the volume is lower due to the lower pressure.

3. **Heating of air over the cylinder surface** as the surface of the cylinder is warmer, the air in the cylinder during suction gets heated increasing its volume and reducing the amount of air taken in.

There are two methods by which the volumetric efficiency of a reciprocating compressor can be experimentally determined viz., tank capacity method and plate orifice method.

TANK CAPACITY METHOD

The volume of the receiver tank into which the compressed air is pumped is constant, and the other characteristics such as mass, pressure and temperature change as more and more of compressed air is pumped into it. This fact coupled with the characteristic gas equation form the basis of this method. In this method the mass of air in the receiver tank is calculated by knowing the pressure and temperature. Now the compressor is started and run for a period of time at a constant speed. The mass of air in the receiver tank is again computed as before. The difference of the two masses is the mass of the air compressed by the compressor in a known time and at a known speed. The volume of the compressed mass of air at NTP may be computed by applying the characteristic gas equation. Knowing the swept volume of the low-pressure cylinder per each stroke of the piston, the compressor speed and time of compression, the volume of air displaced by the low-pressure cylinder is calculated. The ratio of the volume of the air compressed at Standard Temperature and Pressure to the displacement volume of the low-pressure cylinder gives the volumetric efficiency of the reciprocating compressor by the tank capacity method. In this method, however, it may be observed that the delivery pressure of the compressor will be continuously increasingly because the tank is completely closed.

PLATE ORIFICE METHOD

In this method the velocity of the air flowing into suction chamber of the low-pressure cylinder is calculated using an orifice. Once the velocity of the air is known, the quantity of air passing per unit time is determined since the cross-sectional area of the passage is known. The volume of air displaced by the low-pressure cylinder per unit time is computed as in the tank capacity method. The ratio of the two values represents the volumetric efficiency of the compressor by plate orifice method. In this method constant delivery pressure can be maintained in the receiver tank by letting out as much air as pumped into it by the compressor.

DESCRIPTION

 A typical reciprocating compressor consists of a cylinder and piston with pressure or spring actuated valves. The valves are of reed type, balanced by the pressures on either side. The inlet valve opens when the suction caused by the piston motion reduces the pressure in the cylinder to a value lower than the inlet pressure. The outlet valve is kept closed by the pressure on the delivery side. When the pressure in the cylinder exceeds the pressure at the outlet, the valve opens and delivery of air starts. This is different from the valve arrangement in steam engines and IC engines. When high delivery pressure is required, multi stage

compression with inter cooling between stages is used. Direct electrical drive is rarely used. Belt drive is used for speed reduction. The compressor available in the laboratory is a two-stage air compressor with open belt drive from an electric motor. It is equipped with air-cooled inter-cooler and after-cooler. The speed of the compressor is directly read by a tachometer, which is driven by 1:1 ratio pulleys coupled by a belt. On the suction side there is a plate orifice of 10mm diameter. A U–tube manometer is fitted across the orifice to measure the pressure drop across the orifice. The compressed air is sent into a receiver tank after the third stage of compression. There is a provision on the receiver tank to read the pressure of air inside it.

PROCEDURE

TANK CAPACITY METHOD

1. All the openings of the compressor receiver tank are closed. The initial pressure and temperature of the air in the receiver tank are recorded.

2. Start the compressor and stopwatch, and run the compressor until the receiver tank pressure reaches the required value then stop it. Record the temperature of the air in the receiver tank, the rpm of the compressor and time of compression. The pressure and temperature are regarded as the initial pressure and temperature for the next set of observations.

3. Repeat the above procedure at various tank pressures.

PLATE ORIFICE METHOD

1. Start the compressor and open the receiver tank outlet valve in such a way that a constant pressure is maintained in the receiver tank.

2. When the pressure gauge on the tank shows a constant value, the temperature of the air in the receiver tank and the pressure difference in the U–tube manometer are recorded.

3. Repeat the above procedure at various delivery pressures.

OBSERVATIONS

Characteristic gas equation PV = m RT.
Where characteristic gas constant of air R = 29.27 kgf m/kg K

TECHNICAL DATA OF THE GIVEN TWO STAGE AIR COMPRESSOR:

Bore of the low pressure cylinder D = _____ mm
Stroke of the piston of the low pressure cylinder L = _____ mm
Speed of the compressor N = _____ rpm
Displacement volume of low pressure per minute cylinder V_d = _____ m^3
Maximum pressure P_{max} = _____ kg/cm^2.
Tank length L_{tank} = _____ m.
Tank diameter D_{tank} = _____ m
Tank Volume V_t = _____ m^3

TANK CAPACITY METHOD:

Initial temperature of air in the tank T_1 = ____ ^{0}C

Initial pressure of the air in the tank P_1 = ____ kgf/cm^2

Initial mass of air in the tank $M_1 = (P_1 \times V_t) \div (R \times (273+T_1))$

Final temperature of air in the tank T_2 = ____ ^{0}C

Final pressure of the air in the tank P_2 = ____ kgf/cm^2

Final mass of air in the tank $M_2 = (P_2 \times V_t) \div (R \times (273+T_2))$

Mass of air compressed $M = M_2 - M_1$ = ____ kg.

Time of compression t = ____ min

Volume of air sucked at NTP per minute V_{NTP} = MT/Pt m^3/min

Where, P = 1.0332 kgf/cm^2 = 1.0332 × 10^4 kgf/m^2

$\quad\quad$ T = 0^{0}C= 273K

Volumetric Efficiency $\eta_{vol} = V_{NTP}/V_d$

TABLE: VOLUMETRIC EFFICIENCY WITH RESPECT TO TANK PRESSURE

Sl. No	Initial Tank Temperature T_1 ^{0}C	Initial Tank pressure P_1 kgf/cm^2	Final Tank Temperature T_2 ^{0}C	Final Tank pressure P_2 kgf/cm^2	Speed of compress or N rpm	Time of compression t min	Volumetric Efficiency η_{vol}

PLATE ORIFICE METHOD:

Manometer reading h_W = ____mm = ____ m

Head of suction air h_a = h_w × (Density of water/ Density of air) m

Velocity of air passing through orifice = $(2gh_a)^{1/2}$ m/sec

Area of orifice meter A = ____ m^2

Coefficient of discharge of orifice meter C_d = ____

Volume of air passing through the orifice per second V = $C_dA (2gh_a)^{1/2}$ m^3/sec

Volume of air passing through orifice at NTP V_{NTP} = V × 60 × (Ts / T) m^3/min

Volumetric Efficiency $\eta_{vol} = V_{NTP}/V_d$

TABLE: VOLUMETRIC EFFICIENCY WITH RESPECT TO DELIVERY PRESSURE

Sl. No	Delivery pressure P_2 kgf/cm^2	Manometer reading h_W m	Head of suction air h_a m	Velocity of air passing through orifice m/sec	Volume of air passing through orifice at NTP V_{NTP} m^3/min	Volumetric Efficiency η_{vol}

GRAPHS

The above results may be graphically presented by drawing the following graphs:

- Tank pressure on X-axis and volumetric efficiency on Y-axis.
- Delivery pressure on X-axis and volumetric efficiency on Y-axis.

PRECAUTIONS

1. In conducting the tank capacity method all the valves of receiver tank must be closed.

2. During the plate orifice method, receiver tank outlet valve must be opened so as to maintain constant tank pressure. Fluctuations in tank pressure must be avoided.

3. The rpm of the compressor must be kept fluctuation-free throughout the test.

RESULT

The volumetric efficiency of the given two-stage air compressor is _____.

12.JUNKER'S GAS CALORIMETER

AIM

To determine the calorific value of given gas using JUNKER's GAS CALORIMETER.

APPARATUS REQUIRED

JUNKER's gas calorimeter assembly, Gas flow meter, a source of continuous supply of water, four thermometers, a source of gas whose calorific value is to be determined.

THEORY

Calorific value, also called heating value, is defined as the quantity of heat liberated by the complete combustion of unit quantity of fuel. There are two types of calorific values, higher or gross calorific value and the lower or net calorific value. Hydrogen is found in almost all fuels, and when the calorific value of such fuel is determined by completely burning a unit quantity of it, hydrogen is converted into steam. When the products of combustion are condensed to room temperature, that is to about 25^0C, the latent heat of condensation of steam shall also be included in the measured heat resulting in a higher value. The total value thus calculated is called *higher or gross calorific value,* which may be defined as the total amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are cooled to room temperature. In actual practice, however, the water vapor escapes along with hot combustion gasses and thus is not condensed. As a result a lesser amount of heat is accounted for. The amount of heat so available per unit of fuel is called as *lower or net calorific value,* which may be defined as the amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are allowed to escape. Higher or gross calorific value and lower or net calorific value are thus related as:

Net Calorific Value = Gross Calorific Value – Latent heat of water vapor formed.

Since one part by weight of hydrogen gives nine parts by weight of water the above equation becomes,

Net Calorific Value = Gross Calorific Value – (Weight of $H_2 \times 9 \times$ Latent heat of steam)

Units of calorific value are different for solids and liquids on one hand and gasses on the other. In case of solid and liquid fuels, since they are measured in terms of mass, their calorific values are expressed as calories/gm in CGS system of units, kilo calories/kg in MKS system of units and British Thermal Units (BTU)/lb., in FPS system of units. Since gasses are measured in terms of volumes, their calorific values are expressed as calories/cubic centimeter in CGS system of units, kilo calories/cubic meter ($Kcal/m^3$) in MKS system of units and British Thermal Units/cubic feet ($B.T.U./ft^3$) in FPS system of units. However, the volume of gasses varies with temperature and pressure. Therefore, volume at normal temperature and pressure are considered. The apparatus used for determining the calorific value is called calorimeter. It operates on the principle that heat liberated from a known quantity of fuel burnt in an atmosphere of pure oxygen in the sealed and thoroughly insulated chamber of calorimeter can be completely utilized for raising the temperature of the calorimeter and a known quantity of water in the calorimeter. By considering that the heat absorbed by the calorimeter and water and the heat given out by the fuel are equal the calorific value of the fuel can be determined.

DESCRIPTION

 JUNKER's gas calorimeter consists of an inner combustion chamber in which the gas burns. This chamber is surrounded by a water jacket through which a number of tubes, called flues, pass. Water enters the calorimeter at a constant head and steady flow rate. Its inlet and outlet temperatures are recorded. The gas whose calorific value is to be determined is made to pass through a gas meter, which records its volume at room temperature, and burns in the inner combustion chamber. The gas on combustion heats the water jacket and then passes down the flues in the water jacket, thus complete transfer of the heat of combustion to water is ensured. The hot products of combustion move upward in the chamber and then downward through the flues provided in the water jacket and escape through the exit. A thermometer at the exit indicates its temperature, which should be as near the room temperature as possible so that the transfer of heat to water is complete. Water, moving in a direction opposite to that of the gases in the flues, goes out from the upper portion. Its temperature and volume are recorded. Water formed by the condensation of steam is also collected. The volume of gas burnt during the experiment is converted to NTP volume (at 0^0C and 760 mm high of mercury column pressure). Knowing the weight of the water flowing and the rise in its temperature, the heat given out by the gas is known.

PROCEDURE

1. Place the apparatus preferably at the end of the test bench and nearer to sink so that there will be space to keep the measuring jar beneath the swinging outlet arm and the sink can be used to drain the over flowing water.

2. Adjust the leveling screws of the calorimeter so that the entire apparatus is in vertical position. Insert the thermometers in such a way that the scales are visible conveniently to observe.

3. Level gas flow meter using the spirit lever by adjusting the leveling screws. Connect the outlet of the gas flow meter to the burner.

4. Pour water through the holder provided for inserting the thermometers till it reaches the mark on the window. If water level is above the mark in the window drain the excess water by opening the cock provided beneath the glass window.

5. Also drain out any excess water in the meter by opening the screw provided on the rear side of the meter. Replace the screw tightly and insert thermometer in the flow meter. Connect the inlet tube to the outlet of pressure governor by rubber tube.

6. Remove the knurled head screw from the over flow tube of the governor. Lift the float slightly by holding the thread and pour water till the water over flows through the sidewall tube. Replace the knurled head screw tightly. Connect the inlet of the governor to the gas source. Ensure that the outlet nose cock and the cover is closed.

7. Connect the water supply from water tap to water inlet. Connect the rubber tube to the water over flow tube and place its other end in the sink. Insert the thermometer.

8. Turn on the water mains. Adjust the water supply in such a way that there will be only a small amount of over flow of excess water to sink. This lets out the air bubbles inside the water circulating system.

9. Remove the burner from the calorimeter. Open the outlet tap of the governor and the gas tap on the burner.

10. Allow the gas to pass for two or three revolutions as indicated by the flow meter. Then light the burner and adjust the air regulator sleeve and the gas tap to get a non luminous flame. Clamp the burner keeping it to the top most position.

11. Adjust the flow of water to get a temperature difference of 12 to 15°C between the water inlet and outlet temperatures. This is important because if water flow is less than what is required then some of the water may escape as steam.

12. Allow the water outlet thermometer to indicate a steady temperature, which may take 20 to 30 minutes.

13. Keep 2000ml measuring jar beneath the swinging water outlet tube and simultaneously count the number of revolutions made by the gas flow meter pointer to find the volume of gas consumed during the test period.

14. When the pointer has made 2 to 3 revolutions swing the water outlet back to waste. Immediately note the temperatures of water inlet, outlet and the gas flow meter.

15. Repeat the experiment three or four times.

OBSERVATIONS

Volume of water collected during the test period V_W = _____ m^3.

Specific weight of water γ = 1000 kg/m^3

Room temperature T = _____ ^{0}C

Volume of gas burnt at room temperature and pressure during the test period V_G = _____ m^3.

Average water inlet temperature T_1 = _____ ^{0}C

Average water outlet temperature T_2 = _____ ^{0}C

Equivalent Volume of V_G at Normal Temperature and Pressure V_{NTP} = K_M × K_N × V_G m^3

K_M is called *meter constant* and is equal to 1 when water level is set for front window mark, and

K_N is *correction factor* for reducing the V_G to V_{NTP}. Its value varies with ambient temperature and pressure, and it can be read from the table supplied by the gas flow meter manufacturer.

Gross Calorific value of the gas C.V.= $\gamma \times V_W \times C_V \times (T_2 - T_1) / V_{NTP}$ KJ / m^3

Trial number	Volume of water collected during the test period V_W m^3.	Volume of gas burnt during the test period. V_G m^3	Correction factor K_N	Equivalent volume of gas burnt at NTP V_{NTP}	Water outlet temperature T_2°C	Water inlet temperature T_1°C	Gross Calorific value of the gas C.V. KJ / m^3

AVERAGE VALUE OF CALORIFIC VALUE OF THE GIVEN FUEL:

PRECAUTIONS

1. The gas flow meter should be kept perfectly horizontal and there should not be excess or insufficient water. The armored thermometer should be kept tightly over the water lever indicator to avoid leakage of water.

2. If the flow is not proper it may be due to clogging of dust in the adjusting hole on the tapered position of the cock. Remove the hexagonal nut and take the tapered position out.

3. Do not rotate the pointer of the gas flow meter by hand especially when there is water inside the meter as it may damage the equipment.

4. Test readings are to be taken only after the steady state conditions are reached i.e., inlet and outlet temperatures and gas flow rates remain constant.

5. Formation of steam should not be allowed. If steam formation is observed then increase the water flow or reduce the gas flow and wait until steady state conditions are reached.

6. Water must flow at uniform rate and any fluctuations in rate of flow must be avoided.

7. During the initial stages air bubbles can be easily removed by opening the stopcock at the bottom of the gas calorimeter and letting out certain quantity of water through it. If the flow to the outlet funnel is irregular it indicates there is air locking or there is considerable variation in variation in velocity of the tap water.

RESULT

The gross calorific value of the given gas is found to be _____ KJ/ m^3.

VIVA QUESTIONS

1. Explain the working principle of Calorimeter?

2. Define Calorific value, Define HCV & LCV

3. Bomb Calorimeter is used to find the calorific values of which fuels?

4. Junker's calorimeter is used to find the calorific value which fuels?

5. Units of Calorific value?

6. Relation between Calorie and Joule?

7. What are the properties required for a good fuel?

8. What are the advantages, disadvantages of solid, liquid & gaseous fuels?

13.VALVE TIMING DIAGRAM OF A 4-STROKE DIESEL ENGINE

AIM

 To draw the valve timing diagram of the given four-stroke diesel engine, and to determine the periods of intake, fuel injection, exhaust and valve over-lap in terms of crank angle.

APPARATUS REQUIRED

Four stroke diesel engine, Measuring tape, a piece of chalk, and a piece of thin paper.

THEORY

  The four-strokes of a typical diesel engine are suction stroke, compression stroke, power stroke and exhaust stroke. During the suction stroke, the inlet valve opens to admit air into the cylinder. The air is drawn into the cylinder due to rapid decrease of pressure in it as the piston moves away from its head. Theoretically, the inlet valve opens and closes instantly at the beginning and the end of the suction stroke respectively. However, the inlet valve opens slightly *before* the piston starts downward on the suction stroke, and closes slightly *after* the end of suction stroke for the following reasons:

1.   At the high speeds at which the diesel engines run, the piston will reach the end of the suction stroke before air has enough time to enter through the small inlet valve opening and completely fill the space above the piston.

2.   The column of air in the inlet pipe needs to overcome its inertia, and be accelerated, and thus the suction pressure needs to exert this force also.

3.   Due to inertia and mechanical friction, the opening and closing of inlet valve is very slow. Hence, it must be open sufficiently in advance of the suction stroke. The valves are also made to open and close slowly to provide quiet operation under high-speed conditions.

4.   At the end of the suction stroke, the pressure in the cylinder will still be below atmospheric and the incoming air will be moving in the direction of the motion of the piston with high velocity. If the inlet valve is closed at this point less air will remain in the cylinder leading to incomplete combustion. The inlet valve, therefore, must remain open until the piston reaches a point in its next stroke at which the pressure in the cylinder equals pressure outside. Thus, this closing point also coincides with the point when the motion of the rushing air would otherwise reverse its direction. Also, the momentum of the rushing air will enable more quantity to be induced.

        Similarly, the exhaust valve opens slightly *before* the piston reaches the end of the power stroke, and closes slightly *after* the beginning of the suction stroke for the following reasons:

1.   By opening the exhaust valve before the piston reaches the end of its power stroke, the flue gases have an outlet for expansion and begin to rush out of their own accord. This removes the greater part of the burnt gases reducing the amount of work to be done by the piston on its return stroke. Early release of expanding gasses causes loss

of some of the work of the expansion. However, the work to be done by the piston in driving the flue gasses out of the cylinder during the exhaust stroke is considerably reduced. This reduction may more than compensate the loss of work due to early release of gases.

2.   During the exhaust stroke the remaining flue gases are forced out through the open exhaust valve as the pressure in the cylinder exceeds the pressure in the exhaust manifold. This causes a slight compression of the gases ahead of the piston, and when it reaches the end of the exhaust stroke, there still will be certain amount of compressed exhaust gases in the clearance space. If the exhaust valve is closed at this point significant portion of the gases may be retained in the cylinder. The best results are obtained by not closing the exhaust valve at the end of the exhaust stroke, but a short time after the piston has begun to move outwards on the next suction stroke. It might appear that this would result in drawing the exhaust gases back into cylinder. However, this does happen because the pressure of the outgoing flue gases exceeds the pressure in the exhaust manifold, and will continue to flow out because of this difference in pressure. In addition, the piston moves very little for 10 to 15 degrees movement of the crankshaft, and the combustion space does not increase significantly.

The valve timings of each engine is decided on the basis of speed of operation, type of fuel used and minimum compression ratio required for giving the rated output. The timings are based on the experience of the manufacturer and depend on the service to which the engine is put. Further, a small charge in any one of the events due to wear and tear in the valve operating mechanism will affect the performance. Therefore, it is necessary to specify the events by a valve-timing diagram by the manufacturer so that these conditions can be resorted after several hours of running if necessary

DESCRIPTION

This is a four-stroke, water cooled, cold start, compression ignition, single vertical cylinder, high speed diesel engine of Kirloskar make. The following are the specifications of the engine:

MAKE:	**KIRLOSKAR**
BORE:	80 mm
STROKE:	110 mm
SPEED:	1500 rpm
POWER:	5 bhp
COMPRESSION RATIO:	16.5:1
FUEL:	HIGH SPEED DIESEL

PROCEDURE

1. The first step is to identify the correct direction of rotation of the flywheel of the engine. The correct direction is the one that gives about one revolution of the wheel in between the inlet valve closing and exhausts valve opening.

2. The flywheel in now to be rotated in the correct direction and when each of the events like inlet valve opening, inlet valve closing, exhaust valve opening, exhaust valve closing, fuel injection beginning, fuel injection closing.

3. Measure half the circumference of the flywheel along the circumference of the flywheel starting from Top Dead Center (TDC) and then mark it as Bottom Dead Center (BDC) on the flywheel.

4. A mark is to be made on the flywheel against the fixed reference mark on the body of the engine.

5. Inlet valve opening occurs when the valve stem cap of the inlet valve (which can be freely rotated by hand) is arrested from its free movement by the rocker arm.

6. When the valve stem cap becomes free it indicates the closure of inlet valve.

7. The opening and closing of exhaust valve are also recorded similarly.

8. The beginning and ending of fuel injection can be identified by observing the fuel pump or by observing the movement of the plunger of the fuel pump.

OBSERVATIONS

Circumference of the flywheel, L = _____ m

TABLE: OPENING AND CLOSING EVENTS OF VALVES AND FUEL INJECTION PUMP

SL NO	EVENT	PISTON W.R.T. TDC or BDC (nearest dead center)	DISTANCE MEASURED ALONG THE CIRCUMFERENCE OF THE FLYWHEEL X m	CRANK ANGLE $(X/L) \, 360^0$
1	IVO			
2	IVC			
3	FIB			
4	FIC			
5	EVO			
6	EVC			

Where,

IVO : Inlet Valve Opening
IVC : Inlet Valve Closing
FIB : Fuel Injection Begins

FIC : Fuel Injection Completed
EVO: Exhaust Valve Opening
EVC: Exhaust Valve Closing

PRECAUTIONS

1. Correct direction of rotation of the engine must be carefully determined.

2. Marking of the events must be done carefully and correctly.

RESULT
The periods of suction, exhaust, fuel injection and angular over-lap are listed.

1. The period of suction is the crank angle between the opening and closing of the inlet valve. It is found to be _____ ^{0}.

2. The crank angle between the opening and closing of the exhaust valve represents the period of exhaust, and it is found to be _____ ^{0}.

3. The fuel injection period is the crank angle between the beginning and the end of fuel pump, and it is found to be _____ ^{0}.

4. The angular overlap is the crank angle during which the exhaust valve remains opened during the suction period i.e., the angle between inlet valve opening and the exhaust valve closing, and it is found to be _____ ^{0}.

14.BOMB CALORIMETER

AIM

To determine the gross and net calorific values of given sample of fuel using BOMB CALORIMETER.

APPARATUS REQUIRED

BOMB calorimeter assembly, oxygen cylinder, Beckmen thermometer, fuse wire, a pellet press, a sample of fuel whose calorific value is to be determined.

THEORY

Calorific value, also called heating value, is defined as the quantity of heat liberated by the complete combustion of unit quantity of fuel. There are two types of calorific values, higher or gross calorific value and the lower or net calorific value. Hydrogen is found in almost all fuels, and when the calorific value of such fuel is determined by completely burning a unit quantity of it, hydrogen is converted into steam. When the products of combustion are condensed to room temperature, that is to about 25^0C, the latent heat of condensation of steam shall also be included in the measured heat resulting in a higher value. The total value thus calculated is called *higher or gross calorific value,* which may be defined as the total amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are cooled to room temperature. In actual practice, however, the water vapor escapes along with hot combustion gasses and thus is not condensed. As a result a lesser amount of heat is accounted for. The amount of heat so available per unit of fuel is called as *lower or net calorific value,* which may be defined as the amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are allowed to escape. Higher or gross calorific value and lower or net calorific value are thus related as:

Net Calorific Value = Gross Calorific Value – Latent heat of water vapor formed.

Since one part by weight of hydrogen gives nine parts by weight of water the above equation becomes,

Net Calorific Value = Gross Calorific Value – (Weight of $H_2 \times 9 \times$ Latent heat of steam)

Units of calorific value are different for solids and liquids on one hand and gasses on the other. In case of solid and liquid fuels, since they are measured in terms of mass, their calorific values are expressed as calories/gm in CGS system of units, kilo calories/kg in MKS system of units and British Thermal Units (BTU)/lb., in FPS system of units. Since gasses are measured in terms of volumes, their calorific values are expressed as calories/cubic centimeter in CGS system of units, kilo calories/cubic meter ($Kcal/m^3$) in MKS system of units and British Thermal Units/cubic feet ($B.T.U./ft^3$) in FPS system of units. However, the volume of gasses varies with temperature and pressure. Therefore, volume at normal temperature and pressure are considered. The apparatus used for determining the calorific value is called calorimeter. It operates on the principle that heat liberated from a known quantity of fuel burnt in an atmosphere of pure oxygen in the sealed and thoroughly insulated chamber of calorimeter can be completely utilized for raising the temperature of the calorimeter and a known quantity of water in the calorimeter. By considering that the heat absorbed by the calorimeter and water and the heat given out by the fuel are equal the calorific value of the fuel can be determined.

DESCRIPTION

The calorific value of a solid or non-volatile liquid fuel can be satisfactorily determined with a high-pressure oxygen bomb calorimeter. It consists of a strong cylindrical vessel made of stabilized corrosion resistant austenitic steel called bomb, which is designed to withstand a pressure of at least 50 atmospheres. The capacity of bomb is designed to be large enough to store enough oxygen for complete burning of the sample. The bomb is provided with a gas-tight screw cap to which a couple of stainless steel electrodes and a release valve are fitted. One of these electrodes is tubular and can also as an oxygen inlet. A small ring is attached to this electrode for supporting the crucible carrying a known quantity of fuel whose calorific value is to be determined. The bomb is placed in a copper calorimeter having a known weight of water. The copper calorimeter is surrounded by an air-jacket and water-jackets to prevent loss of heat due to radiation. An electrical is stirrer provided for stirring the water in the calorimeter at a uniform rate. A Beckmen thermometer is provided for temperature measurement. During complete combustion of the fuel sample nitrogen and sulfur present in it are also oxidized. Due to the presence of water vapor these gases are then converted into nitric acid and sulfuric acid. Hence, the interior of the calorimeter is provided with lining resistant to acidic or basic ash and is corrosion proof. Water equivalent of the calorimeter is optimized to ensure maximum rise in temperature of water following ignition. In addition all surfaces have high reflectance to minimize radiation losses.

PROCEDURE

1. An accurately weighed amount of the fuel is placed in the crucible. The crucible is supported over the ring. A fine magnesium wire is stretched across the electrodes so that it touches the fuel sample.

2. About 10 ml of distilled water is introduced into the bomb to absorb vapors of sulfuric and nitric acids formed during the combustion and the lid of the bomb securely fixed.

3. The calorimeter vessel is then kept in the outer jacket on the insulating feet provided. The bomb is then lowered in the calorimeter.

4. The stirrer and the lid of the calorimeter vessel are placed in position and the Beckman thermometer is adjusted.

5. The stirred is started. Oxygen supply is forced into the bomb till a pressure of 25-30 atmospheres is reached. Initial temperature of water in the calorimeter is noted to the nearest 0.002^0C after thorough stirring and five more readings are taken at one-minute intervals.

6. The current is switched on and the magnesium wire ignites the fuel in the crucible thereby releasing heat.

7. Temperature readings are recorded continuously at one-minute intervals. The heat produced by burning of the fuel in the crucible is transferred to the water, which is stirred continuously throughout the experiment by the electric stirrer. Maximum temperature shown by the thermometer is recorded.

8. After the maximum temperature is attained, readings are still noted until the rate of fall is uniform. The stirrer is stopped and the bomb removed from the calorimeter.

9. After allowing for about half an hour for the settlement of the acid mist within the bomb, the contents of the bomb are washed into a beaker and the amounts of H_2SO_4 and HNO_3 present in this solution are determined through titration analysis.

OBSERVATIONS

Weight of the fuel taken in crucible, **X** = _____ kg

Weight of water in the calorimeter, **Y** = _____ kg

Water equivalent of the calorimeter, stirrer, thermometer and bomb, **Z** = _____ kg

Calorific Value of Fuse wire CV_{fw} = _____ kcal/kg

Mass of fuse wire burnt M_{fw} = (Mass of fuse – Mass of unburned fuse) kg

Pressure of oxygen = ___ atm

Initial temperature of the water in calorimeter, t_1 = _____ ^0C

TABLE FOR RECORDING TEMPERATURE VARIATION WITH RESPECT TO TIME:

TIME (min)	1	2	3	4	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
TEMP ^0C																				

Final temperature of water in calorimeter, t_2 = _____ ^0C

CALCULATIONS

Calculations of higher or gross calorific value

Heat gained by water $= Y \times (t_2 - t_1)$ kcal

Heat gained by calorimeter $= Z \times (t_2 - t_1)$ kcal

∴ Total heat gained $= (Y + Z) \times (t_2 - t_1)$ kcal

Heat liberated by fuel $= X \times C + M_{fw} \times CV_{fw}$ kcal

Now, heat liberated by the fuel = Heat gained by water and calorimeter.
i.e., $X \times C + M_{fw} \times CV_{fw} = (Y + Z) \times (t_2 - t_1)$

∴ Gross calorific value $C = \{(Y + Z) \times (t_2 - t_1) - M_{fw} \times CV_{fw}\} / X$ kcal/kg

Calculations of lower or net calorific value

Let the percentage of hydrogen in fuel = H

Weight of water produced from 1 gram of fuel = 9H/100 gm.

= 0.09H gm.

$\therefore$ Heat taken by water in forming steam = 0.09H X 587 kcal

(Because latent heat of steam = 587 kcal/kg)

Hence, lower (or net) calorific value of fuel = Higher calorific value – Latent heat of water formed

$$= (C - 0.09H \times 587) \text{ kcal/kg.}$$

CORRECTIONS In addition to the hydrogen correction, following other corrections must be considered while calculating the calorific value of a fuel.

i) **Cooling correction**. Rate and time taken for cooling the water in calorimeter from maximum temperature to room temperature must be considered. From the rate of cooling dt^0/minute and the actual time taken for cooling (t minutes), the cooling correction (dt×t) must be added to the rise in temperature (t_2 - t_1).

ii) **Acid correction**. During ignition, sulfur and nitrogen (if present) in the fuel are oxidized to the corresponding acids along with the evolution of heat.

$S + 2H + 2O_2 \rightarrow H_2 SO_4 + \text{Heat}$

$2N + 2H + 3O_2 \rightarrow 2HNO_3 + \text{Heat}$
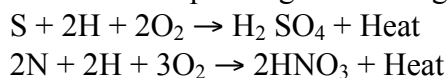
So this heat is also included in the measured heat and hence must be subtracted. The amount of these acids are analyzed from washings of bomb by titration, while sulfuric acid alone is determined by precipitation as $BaSO_4$. Correction for 1 mg of S is 2.25 cal, while for 1 ml of N/10 HNO_3 formed it is 1.43 cal.

iii) **Fuse wire correction**. The measured heat also includes the heat given by ignition of the fuse wire and hence must be subtracted from the total value.

Thus, higher (gross) calorific value (C)

C = (y + z) (t_2 - t_1+ Cooling correction) – (Acid + Fuse correction) / x kcal/kg.

PRECAUTIONS

1. Too much sample should not be used. The bomb cannot be expected to withstand the effects of combustible charges, which liberate more than 10,000 calories. This limits the total weight of combustible material, i.e., sample plus gelatin, firing oil or any combustion aid, to not more than 1100 gm.
2. Do not charge with more oxygen than necessary and do not fire the bomb if an overcharge of oxygen should accidentally be admitted.
3. Do not fire the bomb if gas bubbles are leaking from the bomb when it is submerged in water.

4. Stand back from the calorimeter for at least 15 seconds after firing and above all keep clear of the top of the calorimeter. Should the bomb explode it is most likely that the force of explosion be directed upward.

5. Rapid admission of gas to the bomb during charging may cause part of the sample to be blown out of the cup and result in poor combustion and erratic results.

6. If sample is in loose or powdery condition part of it may be ejected due to violence of combustion leading to poor combustion and erratic results. At the same time if the sample pellet is made too hard it may lead to sapling and the ejection of fragments of during heating. This too is not desirable.

7. The fuse wire must either barely touch the surface of the sample or freely hang slightly above the surface but should never be inserted below the sample.

8. Lack of sufficient quantity of oxygen or use of very high initial gas pressure that retards development of required turbulence causes incomplete combustion.

9. The stirrer unit should not generate excessive heat and the motor heat should not reach the calorimeter for accurate results.

RESULT

The gross calorific value and the net calorific value of the given sample of given fuel are found to be _____ kcal/kg and _____ kcal/kg respectively.