Laboratory Manual

THERMODYNAMICS LAB

for

B. Tech.
Mechanical Engineering

Department of Mechanical Engineering

Rukmani & Sons

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Prepared by

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LABORATORY OBJECTIVE

Thermodynamics deals with the study of energy in its various forms or types. It is the science of conversion of heat into mechanical energy. The science of thermodynamics is used often by engineers & technologists in very practical design problem of the operation of large or complicated system.

The scope of applied thermodynamics is restricted to the study of heat & work & its conversion. The application of thermodynamics are found in the many fields like

- Measurement of temperature & humidity in the air, as in the design of a heating or air conditioning system.
- Engines of automobile tractor, trucks are designed by using the concept of thermodynamics.
- Also Jet engine & rocket are also analyzed by using principles of thermodynamics.
- Most of the power plant are dependent on thermodynamics law like Central power plant, captive power plants based on coal, nuclear power plants etc.

So a good knowledge of thermodynamics is very necessary for an engineer so that he can use of fundamental ideas of thermodynamics & applications of those ideas to engineering problems. So this thermodynamics lab is also play an important roll to make a useful significance.

ABOUT THE LABORATORY

This laboratory contains the following setups and equipments:

1. Multi-Cylinder Petrol Engine.
2. Model of Cochran Boiler.
3. Model of Babcock & Wilcox Boiler.
4. Old Working Boiler Model.
5. Diesel Engine.
6. Model of Lancashire Boiler.
7. Model of Locomotive Boiler.
8. Model of Two Stroke Petrol Engine.
9. Model of Four Stroke Petrol Engine.
10. Model of Four Stroke Diesel Engine.
11. Model of Compound Steam Engine.
12. Model of Steam Injector.
13. And some tools & other equipments like tachometer also present in the lab.

GUIDELINES FOR TEACHERS/TECHNICAL ASSISTANTS

1. Know the laboratory: The teacher is expected to understand the layout of laboratory, specifications of equipments/instruments/materials, procedure of experiments, method of working in groups, planning time etc.
2. Ensure that required equipments are in working condition before start of experiment and also keep the operating or instruction/user manuals of equipments/instruments and this laboratory manual available.
3. On the first day of the lab, inform the students about the importance of subject/laboratory, various equipments/instruments that will be used in the lab etc. Also instruct them how to make the practical record file for this lab.
4. Explain the theoretical concepts, relevant to the experiment, to the students before start of each practical.
5. Demonstrate the experiment(s) clearly to the students group-wise.
6. Instruct the students to perform the practical. While taking reading/observation, each student must get a chance to perform or observe the experiment.
7. If the experimental setup has variations in the specifications of the equipment, the teachers are advised to make the necessary changes.
8. Teacher shall assess the performance of students by observation or by asking viva related questions to the students to tap their achievements regarding related knowledge/skills so that students can prepare accordingly.
9. The teacher must check carefully and sign the practical record file of the students periodically.
10. Teacher shall ensure that the industrial/site/plant visits recommended as per the syllabus of laboratory are covered.
11. Teacher should ensure that the respective skills and competencies are developed in the students after the completion of the practical exercise.
12. Teacher may provide additional knowledge and skills to the students albeit not covered in the manual but are expected from students by the industries.
13. Teacher may suggest the students to refer additional related literature of the technical papers, reference books, seminar proceedings etc.
14. Teacher can organize group discussions/brain storming sessions/seminars to facilitate the exchange of practical knowledge amongst the students.

GENERAL PRECAUTIONS AND SAFETY PROCEDURES

1. Teacher/technical assistant must ensure that all the electrical equipments/ instruments are used and periodically performance tested as per manufacturer's recommendations (permissible electrical and ambient temperature ratings).
2. Before use, the electrical equipment, extension cords, power tools etc. must be inspected for any damage (worn insulation, bent/missing pins, etc.). Any equipment found to be damaged or otherwise unsafe must be removed from service.
3. The mains plug of equipments must only be inserted in a socket outlet provided with a protective earth contact.
4. **WARNING**: The protective earth connection inside or outside the equipments/instruments must NEVER be interrupted or tampered. **IT CAN MAKE THE EQUIPMENT DANGEROUS**.
5. If an instrument shows visible damage or fails to perform the intended measurements, it is likely that the protection has been impaired. In such case the instrument must be made inoperative and the necessary repairs should be carried out.
6. Extension cords or power strips must not be plugged into one another so as to increase the overall reach.
7. Report all problems with building electrical systems to the teacher/technical assistant/maintenance for corrective action.
8. In case of any electrical hazard/fire reach out for the nearest fire-extinguisher or sand and use it for putting out the fire. Report immediately to the teacher/ technical assistant nearby.
9. For reasons of safety, every student must come to the laboratory in shoes (covering the whole feet).
10. Avoid wearing garments with loose hanging parts. The students should also ensure that floor around the equipment/machine is clear and dry (not oily) to avoid slipping. Please report immediately to the lab staff on seeing any coolant/oil spillage.
11. The student should take the permission and guidance of the lab staff/teacher before operating any equipment/machine. Unauthorized usage of any machine without prior guidance may lead to fatal accidents and injury.
12. The student will not lean on the equipment/machine or take any kind of support of the machine at any point of time.

INSTRUCTIONS FOR STUDENTS

1. Listen carefully to the lecture and instructions given by the teacher about importance of subject/laboratory, curriculum structure, skills to be developed, information about equipment and instruments, procedure, method of continuous assessment, tentative plan of work in laboratory and total amount of work to be done in the semester/session.
2. Read and understand the theory of each experiment to be performed, before coming to the laboratory.
3. Understand the purpose of experiment and its practical implications. Observe carefully the demonstration of the experiment. When you perform it, organize the work in your group and make a record of all observations.
4. In case of absence, the student must perform the experiment(s) on the next turn or in his/her spare time with permission from the teacher/lab assistant.
5. Student should not hesitate to ask any difficulty faced during conduct of practical/exercise.
6. The student shall study all the questions given in the laboratory manual or asked by the teacher and know the answers to these questions properly.
7. The required instruments/tools will be issued from the laboratory store. They must be returned to the store on the same day at the end of lab hours.
8. Laboratory reports (practical file) should be submitted in a bound file or on A4 size sheets, properly filed, on the next turn completed in all respects i.e. with experiment(s) written, graphs attached (if applicable) and entries made in the list of contents of the file and get them checked from your laboratory teacher. Laboratory reports have associated grades/marks.
9. Student should not bring any food or drink item to the laboratory.
10. Student should develop habit of group discussion related to the experiments/exercises enabling exchange of knowledge/skills.
11. Student shall gain knowledge and develop required practical skills and competencies as expected by the industries.
12. Student shall develop the habit of evolving more ideas, innovations, skills etc. than included in the scope of the manual.
13. Student shall refer technical magazines, proceedings of the seminars; refer websites related to the scope of the subjects and update their knowledge and practical skills.

EXPERIMENT – 1

OBJECTIVE:

To study the Fire tube boiler.

APPARATUS USED:

Model of Lancashire boiler.

THEORY:

A closed vessel in which steam is produced from water by combustion of fuel. According to A.S.M.E, “combustion of apparatus for producing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vaporized.

The primary requirements of steam generator or boiler are:

1. Water
2. Water drum
3. Fuel for heating

Types of Boilers:

a. Water tube boiler
b. Fire tube boiler

In the fire tube boilers, the fire are inside the tube & water surrounds the tubes. The various fire tube boiler are following:

(i) Lancashire boiler
(ii) Locomotive boiler
(iii) Scotch marine
(iv) Cochran boiler
(v) cornish boiler

Introduction:

It is a stationary, fire tube, internally fired, horizontal and natural circulation boiler. It is used where working pressure and power required are moderate.

Construction:

These boilers have a cylindrical shell of 1.75 m to 2.75 m diameter. Its length varies from 7.25 m to 9 m. It has two internal flue tubes having diameter about

0.4 times that of shell. This type of boiler is set in brickwork forming external flue so that part of the heating surface is on the external shell.

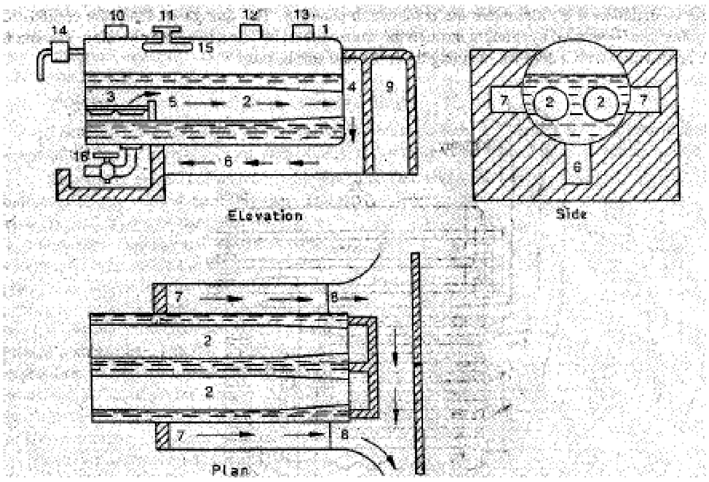


Fig. 1.1: Lancashire Boiler

WORKING:

This boiler consist of a long cylindrical external shell (1) built of steel plates, in sections riveted together. It has two large internal flue tubes (2). These are reduced in diameter at the back end to provide access to the lower part of the boiler. A fire grate (3) also called furnace, is provided at one end of the flue tubes on which solid fuel is burnt. At the end of the fire grate, there is a brick arch (5) to deflect the flue gases upwards. The hot flue gases, after leaving the internal flue tubes pass down to the bottom tube (6). These flue gases move to the front of the boiler where they divide and flow into the side flue (7). The flue gases then enter to the main flue (9), which leads them to chimney.

APPLICATIONS:

1. It is used in Sugar Mills and chemical industries.
2. This boiler is commonly employed where we need large reservoir of water & steam.

PRECAUTIONS:

1. Do not feed water fully the drum.
2. Water level should be checked properly.
3. Pressure should not be over the rating pressure.
4. Clean the boiler time to time.
5. Boiler operator should be present there.

EXPERIMENT – 2

OBJECTIVE:

To study the Water tube boiler.

APPARATUS USED:

Model of Babcock & Wilcox Boiler.

THEORY:

A closed vessel in which steam is produced from water by combustion of fuel. According to A.S.M.E, “combustion of apparatus for producing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vaporized.

The primary requirements of steam generator or boiler are:

1. Water
2. Water drum
3. Fuel for heating

The various water tube boiler are following:

(i) Babcock & Wilcox boiler
(ii) Sterling boiler
(iii) Lamont boiler
(iv) Loeffler boiler
(v) Benson boiler
(vi) Velox boiler

BABCOCK & WILCOX BOILER:

The water tube boilers are used exclusively, when pressure above 10bar and capacity in excess of 7000kg/hr. is required.

Dimension & Specifications:

Diameter of the drum	1.22 to 1.83m.
Length of the drum	6.096 to 9.144m.
Size of the water tubes	7.62 to 10.16cm.
Size of the super heater tubes	3.84 to 5.71cm

Working pressure	40bar (max.)
Steaming capacity	40000kg/hr.(max.)
Efficiency	60-80%

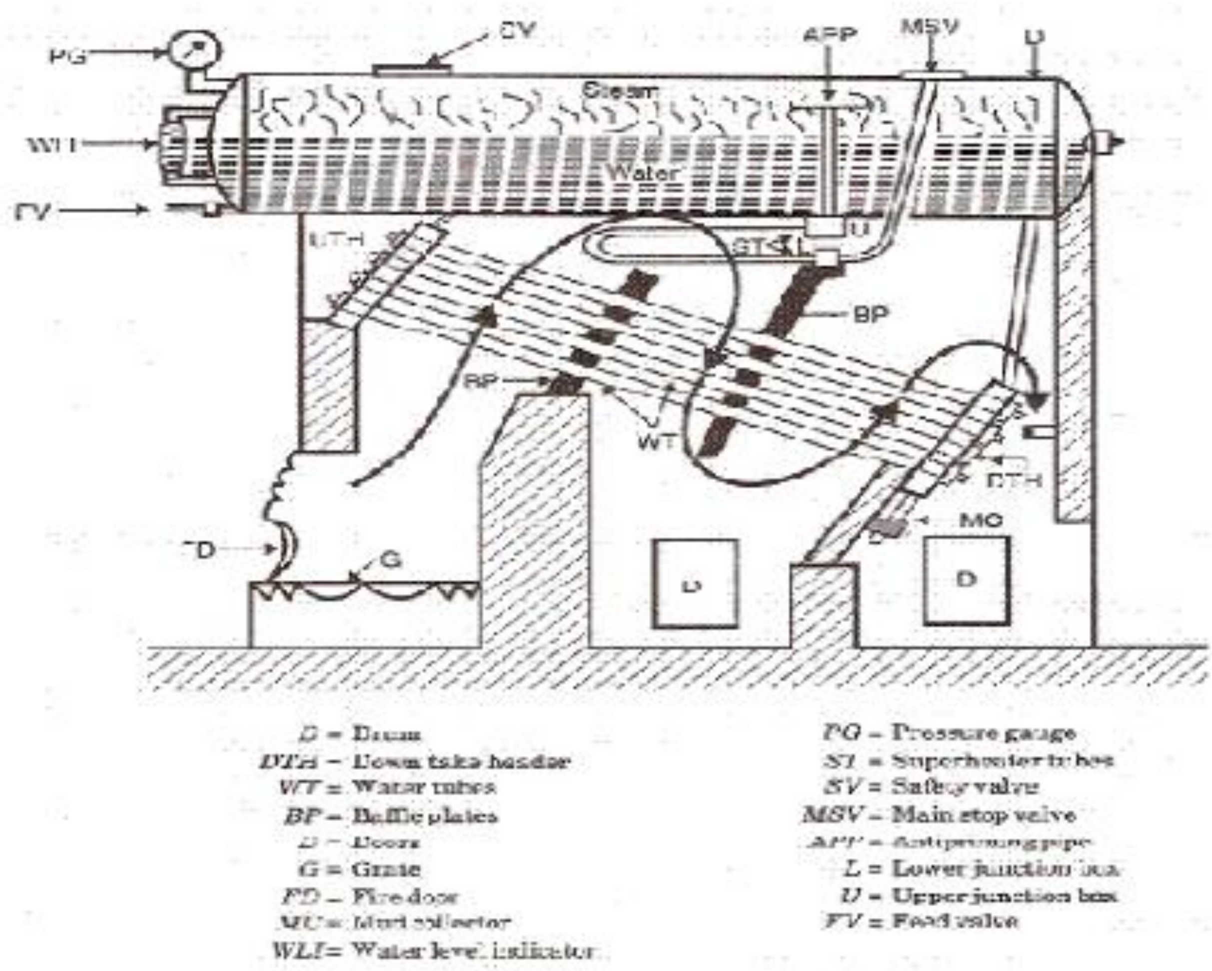


Fig. 2.1. Babcock & Wilcox Boiler

Construction & Working:

Babcock & Wilcox boiler with longitudinal drum. It consists of a drum connected to a series of front end and rear end header by short riser tubes. To these headers are connected a series of inclined water tubes of solid drawn mild steel. The inclination of tubes to the horizontal is about 15 degree or more. A hand hole is provided in the header in front of each tube for cleaning & inspection of tubes. A feed valve is provided to fill the drum and level of water indicates by water level indicator. Fire is burnt on the grate. The hot gases are forced to move upwards between the tubes by baffle plates provided. The water from the drum flows through the inclined tubes via down take header & goes back into the steam the steam space of the drum. The steam then enters through the anti-priming pipe and flows in the super heater tubes where it is further heated and is finally taken out through the main stop valve and supplied to the engine when needed. In the cross drum there is no limitation of the number of connecting tubes. In case of cross drum: Pressure upto100 bar Steaming capacity upto 27000kg./hr.

APPLICATIONS:

The steam generated is employed for the following purpose:

1. For generating power in steam engines or steam turbines.
2. In the textile industries for sizing & bleaching etc. and many other industries like sugar mills, chemical industries.
3. For heating the building in cold weather & for producing hot water supply.
4. Steam turbine propelled ships and other marine vessels.
5. Agriculture field machineries saw mills etc.
6. Steam locomotive.
7. To study steam to the steam engine for driving industries hoists, road rollers, in road constructions, pumps in coal mine.

PRECAUTIONS:

1. Do not feed water fully the drum.
2. Water level should be checked properly.
3. Pressure should not be over the rating pressure.
4. Clean the boiler time to time. Boiler operator should be present there.

EXPERIMENT – 3

OBJECTIVE:

To study the two stroke petrol engine.

EQUIPMENTS:

Model of two stroke petrol engine.

THEORY:

Any type of engine or m/c which drives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a heat engine.

Heat engines may be classified into two main classes as follows:

1. Internal combustion engine
2. External combustion engine.

Main Parts of the Petrol Engine:

1. Cylinder & Cylinder Head
2. Piston
3. Piston Rings
4. Gudgeon Pin
5. Connecting Rod
6. Crank Shaft
7. Crank
8. Engine Bearing
9. Crank Case
10. Fly Wheel
11. Governor
12. Valves
13. Spark Plug
14. Carburetor
15. Cam & Cam Shaft

Working Process of Two Stroke Petrol Engine:

In two stroke engine, the working cycle is completed into two stroke of the piston or one revolution of crankshaft. In two stroke engine the intake and compression processes are completed during the inward stroke and Expansion & exhaust process during the outward stroke. In figure shows a two stroke petrol engine the cylinder L is connected to a closed crank chamber, during the upward stroke of the piston M, the gases in L are compressed and at the same time fresh air and fuel (petrol) mixture enters the crank chamber through the valve V. when the piston moves down wards, V closes and the mixture in the crank chamber is compressed (in fig.)

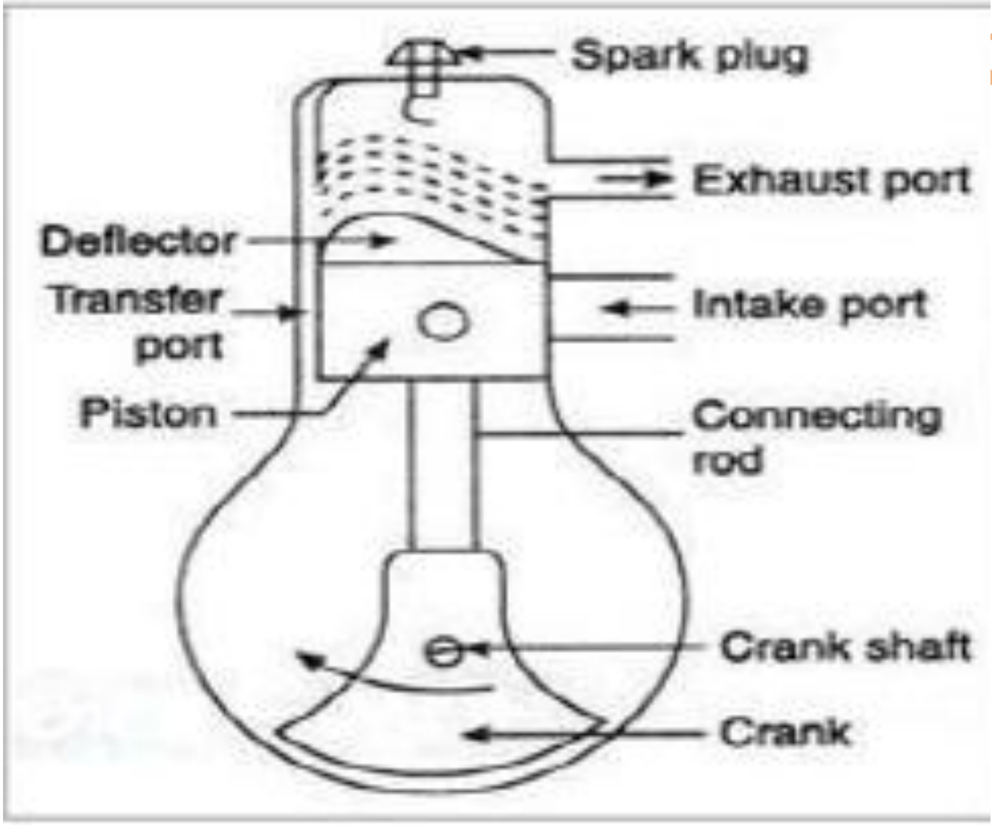


Fig. 3.1 Two Stroke Petrol Engine

1. The piston is moving upwards & is compressing an explosive charge which has previously been supplied to L. Ignition takes place at the end of the stroke. The piston then travels downwards due to expansion of the gases.
2. And near the end of this stroke the piston uncovers the exhaust port (E.P) and the burnt exhaust gases escape through this port.
3. The transfer port (T.P) then is uncovered immediately and the compressed charge from the crank chamber flows into the cylinder and is deflected upwards by the hump provided on the head of the piston. It may be noted that the incoming air petrol mixture helps the removal of gases from the engine cylinder, if in case these exhaust gases do not leave the cylinder the fresh charge gets diluted and efficiency of the engine will decreases. The piston then again starts moving from B.D.C to T.D.C and the charge gets

compressed when E.P and T.P are covered by the piston, thus the cycle is repeated.

APPLICATIONS:

1. I.C. engine are used in all road vehicles i.e. automobiles trucks, tractors etc.
2. I.C. engine are widely used in rail road, aviation & marine.
3. I.C. engine are extensively used in lawn movers boats, concretes mining equipments etc.
4. Petrol engine are used in light motor vehicles like scooty.

PRECAUTIONS:

1. Fuel supply should be controlled.
2. It requires running maintenance.
3. Maintain constant speed for better controlled.

EXPERIMENT – 4

OBJECTIVE:

To study the four stroke petrol engine.

APPARATUS USED:

Model of four stroke petrol engine.

THEORY:

Any type of engine or m/c which drives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a heat engine.
Heat engines may be classified into two main classes as follows:

1. Internal combustion engine
2. External combustion engine

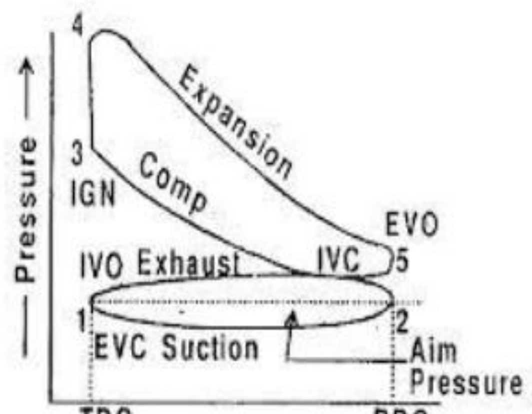
Main Parts of the Petrol Engine:

1. Cylinder & Cylinder Head
2. Piston
3. Piston Rings
4. Gudgeon Pin
5. Connecting Rod
6. Crank Shaft
7. Crank
8. Engine Bearing
9. Crank Case
10. Fly Wheel
11. Governor
12. Valves
13. Spark Plug
14. Carburator
15. Cam & Cam Shaft

Working Process of Otto Four Stroke Engines:

The various stroke of a four stroke (Otto) cycle engine are given below:

Suction Stroke: During this stroke the piston moves from TDC to BDC, the inlet valve open and proportionate fuel-air mixture is sucked in the engine cylinder. In fig. shown by line 5-1.



Indicator Diagram For A Four Stroke Cycle Petrol Engine.

Compression Stroke: In this stroke, the piston moves (1-2) towards TDC and compressors the enclosed fuel air mixture drawn in the engine cylinder during suction. Both the inlet and exhaust valves remain closed during the stroke.

Expansion Stroke: When the mixture is ignited by the spark plug the hot gases are produced which drive or through the piston from T.D.C to B.D.C and thus the work is obtained in this stroke. A spark plug which ignites the mixture & combustion takes place at constant volume (2-3). Both the valves remain closed during the start of this stroke but when the piston just reaches the B.D.C the exhaust valve opens.

Exhaust Stroke: This is the last stroke of the cycle. Here the gases from which the work has been collected become useless after the completion of the expansion stroke and are made to escape through exhaust valve to the atmosphere. This removed of gas is accomplished during this stroke. The piston moves from B.D.C to T.D.C and the exhaust gases are driven out of the engine cylinder. This is also called scavenging. This is represented by the line (1-5).

APPLICATIONS:

1. I.C. engine are widely used in bikes.
2. I.C. engine are extensively used in lawn movers boats etc.
3. Petrol engine are used in light motor vehicles like bike etc

EXPERIMENT – 5

OBJECTIVE:

To study the two stroke diesel engine.

EQUIPMENTS:

Model of two stroke diesel engine.

THEORY:

Any type of engine or m/c which drives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a heat engine.
Heat engines may be classified into two main classes as follows:

1. Internal combustion engine
2. External combustion engine

Main Parts of the Diesel Engine:

1. Cylinder & Cylinder Head
2. Piston
3. Piston Rings
4. Gudgeon Pin
5. Connecting Rod
6. Crank Shaft
7. Crank
8. Engine Bearing
9. Crank Case
10. Fly Wheel
11. Governor
12. Valves
13. Fuel Pump & Injector Unit
14. Cam & Cam Shaft

Working Process of Two Stroke Diesel Engine:

In two stroke engine, the working cycle is completed into two stroke of the piston or one revolution of crankshaft. In two stroke engine the intake and compression processes are completed during the inward stroke and Expansion & exhaust process during the outward stroke. In figure shows a two stroke diesel engine the cylinder L is connected to a closed crank chamber, during the upward stroke of the piston M, the gases in L are compressed and at the same time fresh air enters the crank chamber through the valve V. When the piston moves down wards, V closes and the air in the crank chamber is compressed (in fig.).

1. The piston is moving upwards & is compressing air which has previously been supplied to L. Injector inject and Ignition takes place at the end of the stroke. The piston then travels downwards due to expansion of the gases.
2. And near the end of this stroke the piston uncovers the exhaust port (E.P) and the burnt exhaust gases escape through this port.
3. The transfer port (T.P) then is uncovered immediately and the compressed air from the crank chamber flows into the cylinder and is deflected upwards by the hump provided on the head of the piston. It may be noted that the incoming air helps the removal of gases from the engine cylinder. The piston then again starts moving from B.D.C to T.D.C and the charge gets compressed when E.P and T.P are covered by the piston, thus the cycle is repeated.

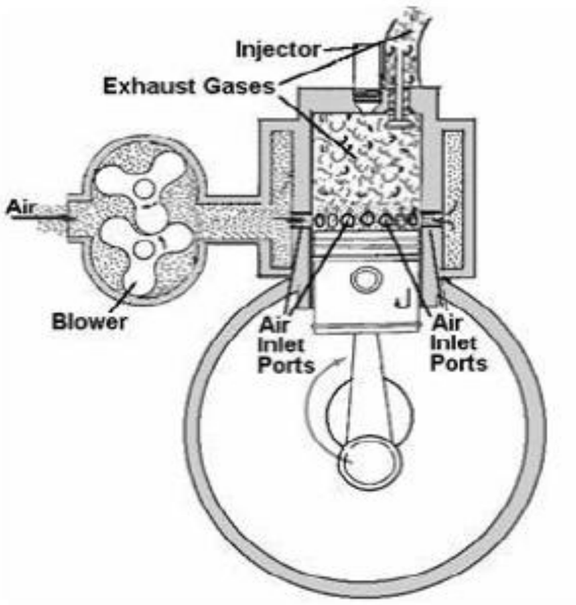


Fig. 5.1: 2 Stroke diesel engine

APPLICATIONS:

1. I.C. engine are used in steamers etc.
2. I.C. engine are widely used in small engines.
3. I.C. engine are extensively used in lawn movers boats, concretes mining equipments .

EXPERIMENT – 6

OBJECTIVE:

To study the four stroke diesel engine.

APPARATUS USED:

Model of four stroke diesel engine.

THEORY:

Any type of engine or m/c which drives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a heat engine.
Heat engines may be classified into two main classes as follows:

1. Internal combustion engine
2. External combustion engine

Main Parts of the Diesel Engine:

1. Cylinder & Cylinder Head
2. Piston
3. Piston Rings
4. Gudgeon Pin
5. Connecting Rod
6. Crank Shaft
7. Crank
8. Engine Bearing
9. Crank Case
10. Fly Wheel
11. Governor
12. Valves
13. Fuel Pump & Injector Unit
14. Cam & Cam Shaft.

Working Process of Four Stroke Diesel Engines:

The various stroke of a four stroke diesel cycle engine are given below:

Suction Stroke: During this stroke the piston moves from TDC to BDC, the inlet valve open and proportionate air is sucked in the engine cylinder. In fig. shown by line 5-1.

Compression Stroke: In this stroke, the piston moves (1-2) towards TDC and compressors the enclosed fuel air drawn in the engine cylinder during suction. Both the inlet and exhaust valves remain closed during the stroke.

Expansion Stroke: When the fuel is ignited by the spark plug the hot gases are produced which drive or through the piston from T.D.C to B.D.C and thus the work is obtained in this stroke. A injector which inject and & combustion takes place at constant pressure (2-3). Both the valves remain closed during the start of this stroke but when the piston just reaches the B.D.C the exhaust valve opens.

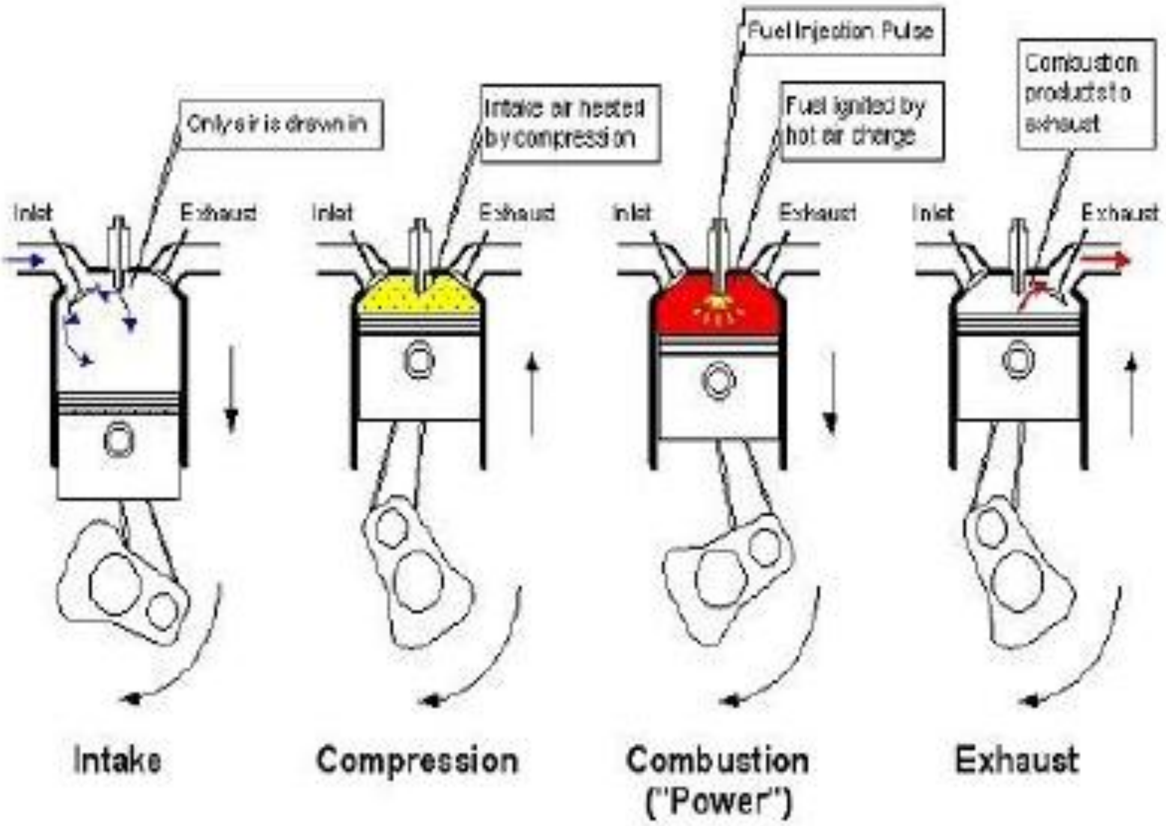


Fig. 6.1: 4-Stroke Diesel Engine

Exhaust Stroke: This is the last stroke of the cycle. Here the gases from which the work has been collected become useless after the completion of the expansion stroke and are made to escape through exhaust valve to the atmosphere. This removed of gas is accomplished during this stroke. The piston moves from B.D.C to T.D.C and the exhaust gases are driven out of the engine cylinder. This is also called scavenging. This is represented by the line (1-5).

APPLICATIONS:

1. I.C. engine are used in all road vehicles i.e. automobiles trucks, tractors etc.

2. I.C. engine are widely used in rail road, aviation & marine.
3. I.C. engine are extensively used in lawn movers boats, concretes mining equipments.

EXPERIMENT – 7

OBJECTIVE:

To study of compound steam engine.

APPARATUS USED:

Model of compound steam engine.

THEORY:

A compound steam engine unit is a type of steam engine where steam is expanded in two or more stages. A typical arrangement for a compound engine is that the steam is first expanded in a high-pressure (HP) cylinder, then having given up heat and losing pressure, it exhausts directly into one or more larger volume low-pressure (LP) cylinders. Multiple-expansion engines employ additional cylinders, of progressively lower pressure, to extract further energy from the steam.

Compound Systems:

There are many compound systems and configurations, but there are two basic types, according to how HP and LP piston strokes are phased and hence whether the HP exhaust is able to pass directly from HP to LP (Woolf compounds) or whether pressure fluctuation necessitates an intermediate "buffer" space in the form of a steam chest or pipe known as a receiver (receiver compounds).

In a single-expansion (or 'simple') steam engine, the high-pressure steam enters the cylinder through a cut-off valve (archaically known as a regulator). The piston moves down the cylinder, and when it is at about 25%–33% of its stroke, the cut-off valve shuts and the steam expands, pushing the piston to the end of its stroke, the exhaust valve opens and expels the depleted steam to the atmosphere, or to a condenser. As steam expands in a high-pressure engine, its temperature drops; because no heat is released from the system, this is known as adiabatic expansion and results in steam entering the cylinder at high temperature and leaving at low temperature. This causes a cycle of heating and cooling of the cylinder with every stroke which is a source of inefficiency. The steam cut-off point when using a slide valve is less than 30% of the stroke. Early cut-off causes the turning moment on the shaft to be more uneven, requiring a larger flywheel to smooth this out.

Compounding Engines:

A method to lessen the magnitude of this heating and cooling was invented in 1804 by British engineer Arthur Woolf, who patented his Woolf high pressure compound engine in 1805. In the compound engine, high-pressure steam from the boiler first expands in a high-pressure (HP) cylinder and then enters one or more subsequent lower pressure (LP) cylinders. The complete expansion of the steam occurs across multiple cylinders and, as there is less expansion in each cylinder, less heat is lost by the steam in each. This reduces the magnitude of cylinder heating and cooling, increasing the efficiency of the engine.

There are other advantages: as the temperature range is smaller, cylinder condensation is reduced. Loss due to condensation is restricted to the LP cylinder. Pressure difference is less in each cylinder so there is less steam leakage at the piston and valves. The turning moment is more uniform, so balancing is easier and a smaller flywheel may be used. Only the smaller HP cylinder needs to be built to withstand the highest pressure, so reducing the overall weight. Similarly, components are subject to less strain so can be lighter. The reciprocating parts of the engine are lighter reducing the engine vibrations. The compound could be started at any point in the cycle, and in the event of mechanical failure the compound could be reset to act as a simple, and thus keep running.

To derive equal work from lower pressure steam requires a larger cylinder volume as this steam occupies a greater volume. Therefore the bore, and often the stroke, are increased in low-pressure cylinders resulting in larger cylinders. Double-expansion (usually just known as 'compound') engines expand the steam in two stages. The pairs may be duplicate or the work of the large LP cylinder can be split across two smaller cylinders, with one HP cylinder exhausting into either LP cylinder, giving a 3-cylinder layout where the cylinder and piston diameter of all three are about the same making the reciprocating masses easier to balance.

Two-cylinder compounds can be arranged as:

Cross-compound – the cylinders are side-by-side.
Tandem compound – the cylinders are end-to-end, driving a common connecting rod
Angle-compound – the cylinders are arranged in a vee (usually at a 90° angle) and drive a common crank.

The adoption of compounding was widespread for stationary industrial units where the need was for increased power at decreasing cost, and almost universal for marine engines after 1880. It was not widely used in railway locomotives where it was often perceived as complicated and unsuitable for the harsh railway operating environment and limited space afforded by the loading gauge (particularly in Britain). Compounding was never common on British railways and not employed at all after 1930, but was used in a limited way in many other countries. However, the first successful attempt to fly a heavier-than-air fixed-wing aircraft solely on steam power occurred in 1933, when George and William Besler converted a Travel Air 2000 biplane to fly on a 150 hp angle-compound V-twin steam engine of their own design instead of the usual Curtiss OX-5 inline or radial aviation gasoline engine it would have normally used.

Fig 7.1: Multiple expansion engines

An animation of a double-acting inverted triple-expansion marine engine. High-pressure steam (red) enters from the boiler and passes through the engine, exhausting as low-pressure steam (blue) to the condenser.

It is a logical extension of the compound engine (described above) to split the expansion into yet more stages to increase efficiency. The result is the multiple-expansion engine. Such engines use either three or four expansion stages and are known as triple- and quadruple-expansion engines respectively. These engines use a series of double-acting cylinders of progressively increasing diameter and/or stroke and hence volume. These cylinders are designed to divide the work into three or four equal portions, one for each expansion stage. The image to the right shows an animation of a triple-expansion engine. The steam travels through the engine from left to right. The valve chest for each of the cylinders is to the left of the corresponding cylinder.

APPLICATIONS:

1. In pumping engines.
2. In Mill engines.
3. Marine steam engines

PRECAUTIONS:

1. Steam supply should be controlled.
2. Operated pressure & temperature should not be higher than rated limit.
3. Proper maintenance also required.

EXPERIMENT – 8

OBJECTIVE:

To study of steam injector.

APPARATUS USED:

Model of steam injector.

THEORY:

An injector, ejector, steam ejector, steam injector, eductor-jet pump or thermo compressor is a type of pump. There are two varieties of injector, non-lifting and lifting

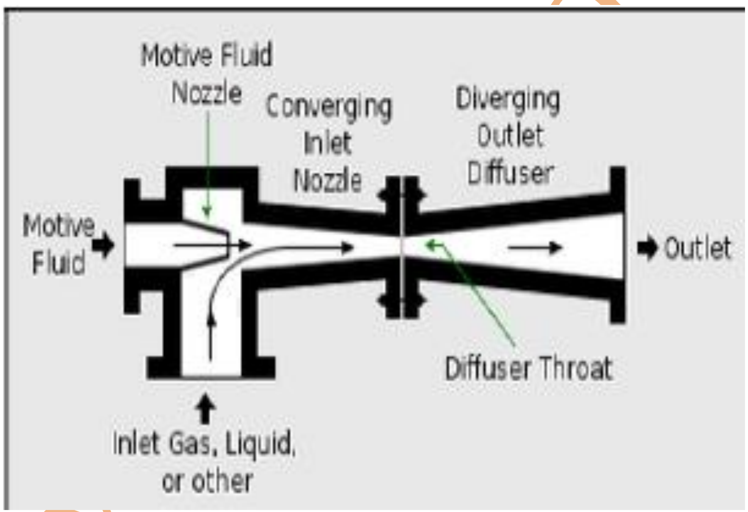


Fig. 8.1: Diagram of a typical modern injector

The non-lift1ing injector cold water input is fed by gravity. It uses the principle of induced current (Impulse (physics)) to push water up to the boiler check valve. It avoids the premature boiling of feed water at very low absolute pressure, by avoiding the Venturi effect. The steam cone minimum orifice diameter is kept larger than the combining cone minimum diameter. [1] The non-lifting Nathan 4000 injector used on the Southern Pacific 4294 could push 12,000 gallons per hour at 250 psi.

The lifting injector uses the Venturi effect of a converging-diverging nozzle to convert the pressure energy of a motive fluid to velocity energy which creates a low pressure zone that draws in and entrains a suction fluid. After passing through the throat of the injector, the mixed fluid expands and the velocity is reduced which results in recompressing the mixed fluids by converting velocity energy back into pressure energy. The motive fluid may be a liquid, steam or any other gas. The entrained suction fluid may be a gas, a liquid, a slurry, or a dust-laden gas stream.

The adjacent diagram depicts a typical modern injector. It consists of a motive fluid inlet nozzle and a converging-diverging outlet nozzle. Water, air, steam, or any other fluid at high pressure provides the motive force at the inlet.

The Venturi effect is a particular case of Bernoulli's principle. Fluid under high pressure is converted into a high-velocity jet at the throat of the convergent-divergent nozzle which creates a low pressure at that point. The low pressure draws the suction fluid into the convergent-divergent nozzle where it mixes with the motive fluid.

In essence, the pressure energy of the inlet motive fluid is converted to kinetic energy in the form of velocity head at the throat of the convergent-divergent nozzle. As the mixed fluid then expands in the divergent diffuser, the kinetic energy is converted back to pressure energy at the diffuser outlet in accordance with Bernoulli's principle. Steam locomotives use injectors to pump water into the steam-producing boiler and some of the steam is used as the injector's motive fluid. Such steam injectors take advantage of condensation of the motive steam resulting from the mixing with cold feed water.

Depending on the specific application, an injector can take the form of an eductor-jet pump, a water eductor, a vacuum ejector, a steam-jet ejector, or an aspirator.

Fig. 8.2: Exhaust steam injector

Exhaust Steam Injector

Efficiency was further improved by the development of a multi-stage injector which is powered not by live steam from the boiler but by exhaust steam from the cylinders, thereby making use of the residual energy in the exhaust steam which would otherwise have gone to waste. However, an exhaust injector also cannot work when the locomotive is stationary; later exhaust injectors could use a supply of live steam if no exhaust steam was available.

APPLICATIONS:

The use of injectors (or ejectors) in various industrial applications has become quite common due to their relative simplicity and adaptability. For example:

- To inject chemicals into the boiler drums of small, stationary, low pressure boilers. In large, high-pressure modern boilers, usage of injectors for chemical dosing is not possible due to their limited outlet pressures.
- In thermal power stations, they are used for the removal of the boiler bottom ash, the removal of fly ash from the hoppers of the electrostatic precipitators used to remove that ash from the boiler flue gas, and for drawing a vacuum pressure in steam turbine exhaust condensers.
- Jet pumps have been used in boiling water nuclear reactors to circulate the coolant fluid.
- For use in producing a vacuum pressure in steam jet cooling systems.
- For enhanced oil recovery processes in the oil & gas Industry.

PRECAUTIONS:

1. Take control volume of steam for injecting.
2. Require proper maintenance.
3. Operated properly in presence of operator.

EXPERIMENT – 9

OBJECTIVE:

To study the working and function of mountings & accessories in boiler.

APPARATUS USED:

Model of Mounting & accessories in boiler.

THEORY:

Boiler:

It is a closed vessel in which steam is produced from water by combustion of fuel.

Classification of Boilers:

1. **According to their Axis (Horizontal, Vertical or Inclined).**
   If the axis of the boiler is horizontal, the boiler is called as horizontal.
   If the axis is vertical, it is called vertical boiler.
   If the axis is inclined it is known as inclined boiler.
2. **Fire Tube and Water Tube.**
   In the fire tube boilers, the hot gases are inside the tubes and the water surrounds the tubes.
   Examples: Cochran, Lancashire and Locomotive boilers.
   In the water tube boilers, the water is inside the tubes and hot gases surround them.
   Examples: Babcock and Wilcox boiler.
3. **Externally Fired and Internally Fired.**
   The boiler is known as externally fired if the fire is outside the shell.
   Examples: Babcock and Wilcox boiler.
   The furnace is located inside the boiler shell.
   Examples: Cochran, Lancashire boiler etc.
4. **Forced Circulation and Natural Circulation.**
   In forced circulation type of boilers, the circulation of water is done by a forced pump.
   In natural circulation type of boilers, circulation of water in the boiler takes place due to natural convention currents produced by the application of heat.
   Examples: Lancashire, Babcock and Wilcox boiler etc.

5. **High Pressure and Low Pressure Boilers.**
   The boilers which produce steam at pressures of 80 bar and above are called high pressure boilers.
   Examples: Babcock and' Wilcox boilers.
   The boilers which produce steam at pressure below 80 bar are called low pressure boilers.
   Examples: Cochran, Lancashire and Locomotive boilers.
6. **Stationary and Portable.**
   Primarily, the boilers are classified as either stationary (land) or mobile (marine and locomotive) Stationary boilers are used for power plant-steam, for central station utility power plants, for plant process steam etc. Mobile boilers or portable boilers include locomotive type, and other small units for temporary use at sites (Large Ships).
7. **Single Tube and Multi-tube Boilers.**
   The fire tube boilers are classified as single tube and multi-tube boilers, depending upon whether the fire tube is one or more than one.

MOUNTINGS:

These are the fitting and devices which are necessary for the operation and safety of a boiler.

Types of Mountings:

1. Safety valves
2. Water level indicator
3. A pressure gauge
4. A steam stop valve
5. A feed check valve
6. A Fusible plug
7. A blow-off cock

Safety Valves: It is use for release the excess steam when the pressure of steam inside the boiler exceeds the rated pressure.
Types of safety valve are the following:

1. Dead weight safety valve
2. Lever safety valve
3. Spring loaded safety valve
4. Gravity safety valve

Water Level Indicator: It is use to indicate the level of water in the boiler constantly.

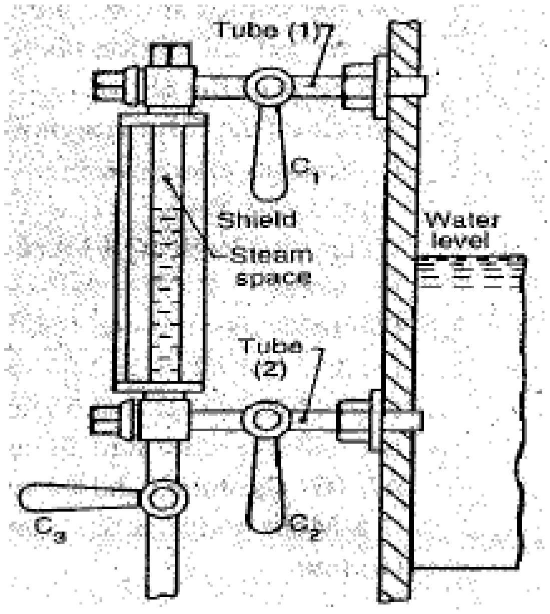


Fig. 9.1: Water level indicator

Pressure Gauge: It is use to measure the pressure exerted inside the vessel.

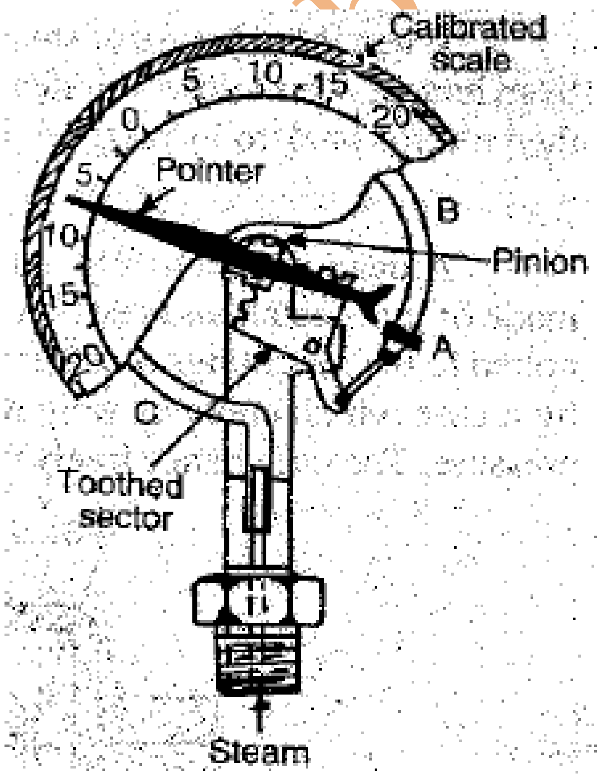


Fig. 9.2: Pressure Gauge

Steam Stop Valve: It is use to regulate the flow of steam from the boiler to the steam pipe.

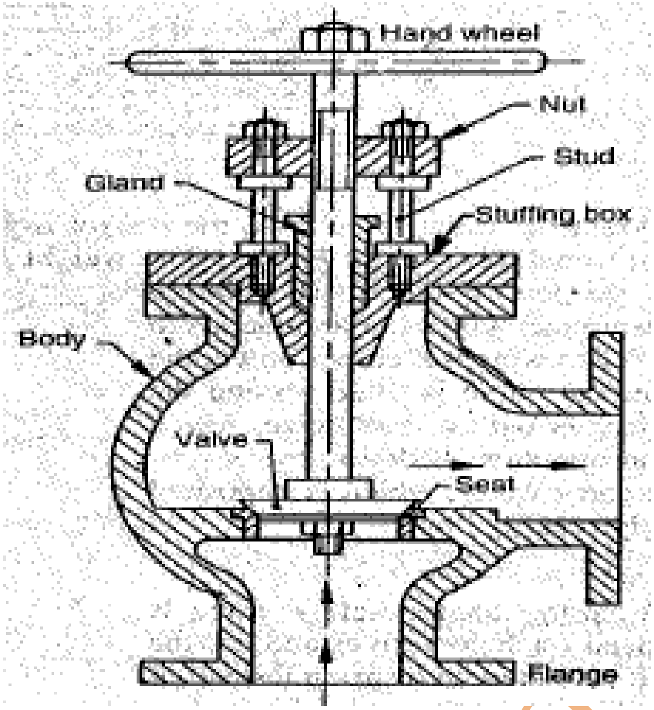


Fig. 9.3: Steam Stop Valve

Feed Check Valve: It is use to control the supply the water to the boiler and to prevent the escaping of water from the boiler when the pump is stopped.

Fusible Plug: It is use to protect the boiler against damage due to overheating for low water level.

Blow-Off Cock: It is use to discharge a portion of water when the boiler is empty when necessary for cleaning, inspection, repair, mud, scale and sludge.

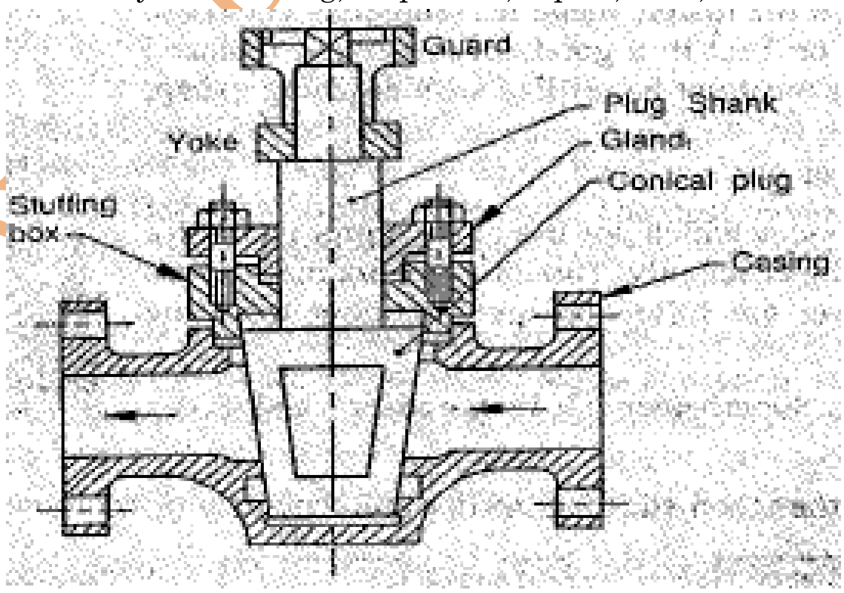


Fig. 9.4: Blow-off Cock

ACCESSORIES:

These are auxiliary plants required for steam boilers for the proper operation and for the increase of their efficiency.

Types of Accessories:

1. Feed pumps
2. Injector
3. Economizer
4. Air-preheater
5. Super heater
6. Steam separator

Feed Pumps: It is used to deliver feed water to the boiler by the pump.

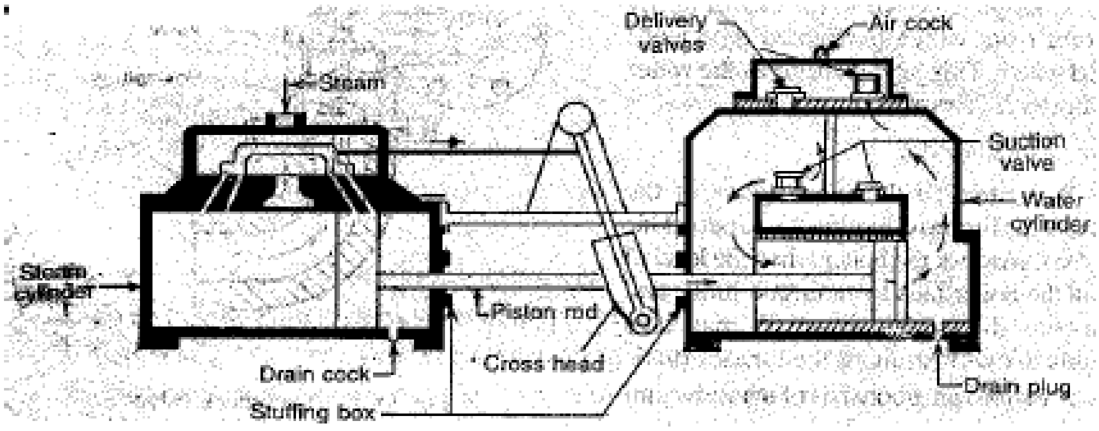


Fig. 9.5: Feed Pump

Injector: The water is delivered to the boiler by steam pressure; The Kinetic energy of steam issued to increase the pressure and velocity of feed water.

Air Pre-Heater: It is use to increase the temperature of air before it enters the furnace.

Economizer: It is a device in which the waste heat of flue gases is utilized for heating the feed water.

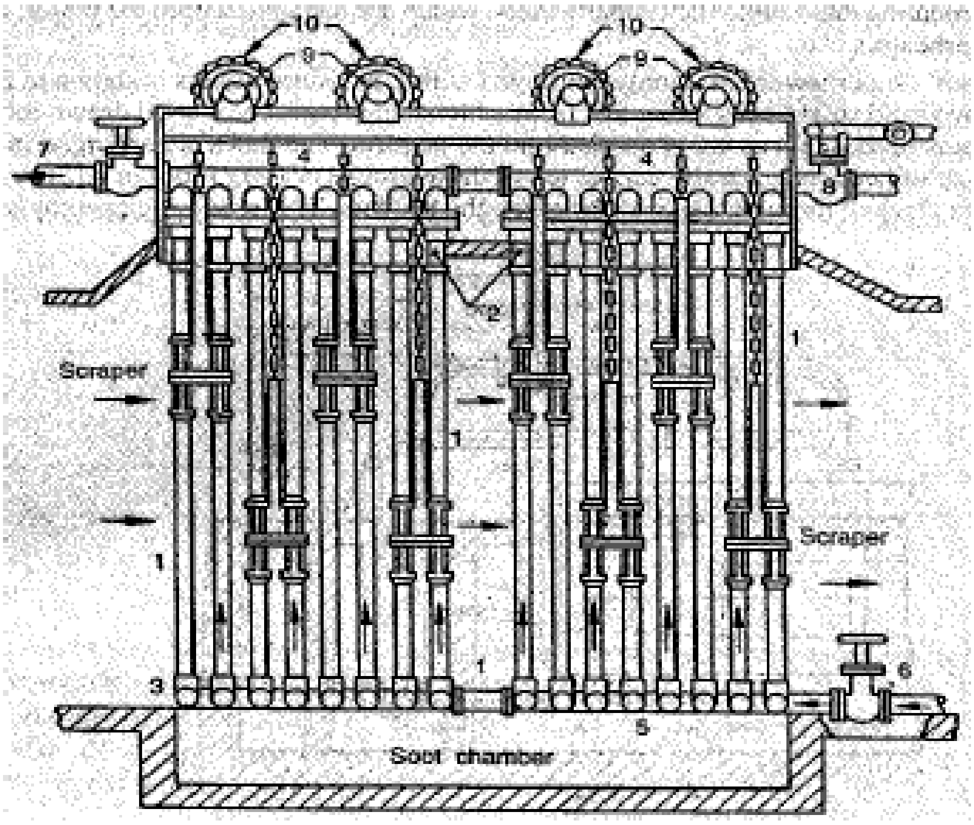


Fig. 9.6: Economizer

Super Heater: It is use to increase the temperature of steam above it saturation point.

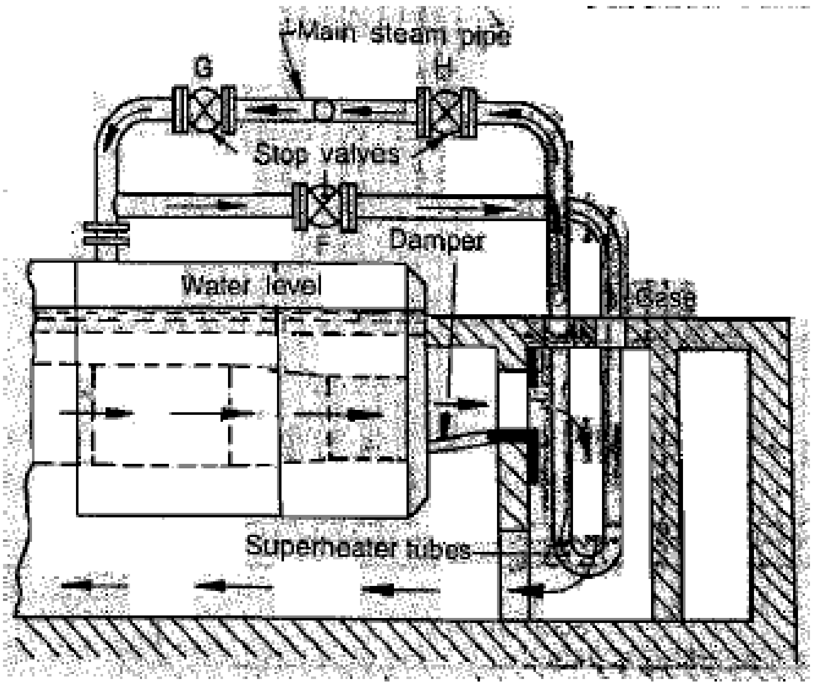


Fig. 9.7: Super heater

Steam Separator: It is use to separate the water particles from the steam to the steam engine or steam turbine.

APPLICATIONS:

1. It is used in thermal power plants..
2. It is used in different types of device.
3. It also used in other machining devices which is used automatically controlled.

EXPERIMENT – 10

OBJECTIVE:

To prepare heat balance sheet for given boiler data.

DATA USED:

Pressure of steam	=	10 bar
Steam condenser	=	540 kg/h
Fuel used	=	65 kg/h
Moisture in fuel	=	2% by mass
Mass of dry flue gases	=	9 kg/kg of fuel
Lower calorific value of fuel	=	32,000 kJ/kg
Temperature of the flue gases	=	325° C
Temperature of boiler house	=	28° C
Feed water temperature	=	50° C
Mean specific heat of flue gases	=	1 kJ/kg K
Dryness fraction of steam	=	0.95

SOLUTION:

Given: p = 10 bar, m_s = 540 kg/h, m_f = 65 kg/h, m_m= 0.02 kg/kg of fuel, m_g = kg/kg of fuel, C = 32,000 kJ/kg, t_g = 325° C, t = 28° C, $t_{1,}$= 50° C, c_{pg} = 1 kJ/kg K, x = 0.95.

First of all, let us find the heat supplied by 1 kg of fuel. Since the moisture in fuel is 0.02 kg, there for heat supplied by 1kg of fuel

$$= (1 – 0.02) \times 32{,}000 = 31\ 360 \text{ kJ}$$

1. **Heat utilized in raising steam per kg of fuel.**

   We know that the mass of water actually evaporated per kg of fuel,

   $$m_e = m_s/m = 540/65 = 8.31 \text{ kg}$$

   From steam tables, corresponding to a feed water temperature of 50° C, we find that

   h_{f1} = 209.3 kJ/kg

   and corresponding to a steam pressure of 10 bar, we find that

   h_f = 762.6 kJ/kg; h_{fg} = 2013.6 kJ/kg

   Heat utilized in raising steam per kg of fuel

$$= m_e (h - h_{fi}) = m_e (h_f + h_{fg} - h_{f1})$$

$$= 8.31(762.6 + 0.95 \times 2013.6 - 209.3)$$

$$= 20{,}495 \text{ kJ}$$

2. **Heat carried away by dry flue gas.**

   We know that heat carried away by dry flue gas

$$= m_g c_{pg} (t_g - t_b)$$

$$= 9 \times 1 (325 - 28) = 2673 \text{ kJ}$$

3. **Heat carried away by moisture in fuel per kg of fuel.**

   From steam tables, corresponding to a temperature of 28° C, we find that $h_b = 117.3$ kJ/kg
   We know that heat carried away by moisture in fuel

$$= m_m [2676 + c_p(t_g - 100) - h]$$

$$= 0.02 [2676 + 2.1(325 - 100) - 117.3]$$

$$= 60.6 \text{ kJ}$$

   (Taking c_p for superheated steam = 2.1 kJ/kg K)

4. **Heat lost by radiation etc.**

   We know that heat lost by radiation etc. (by difference)

$$= 31{,}360 - (20{,}495 + 2673 + 60.6)$$

$$= 8131.4 \text{ kJ}$$

Now complete heat balance sheet per kg of fuel is given below:

Heat supplied	kJ	Heat expenditure	kJ	%
Heat supplied by 1kg of fuel	31360 kg	1. Heat utilized in raising steam	20,495	65.35
		2. Heat carried away by dry flue gases	2,673	8.53
		3. Heat carried away by moisture in fuel	60.6	0.19
		4. Heat lost by radiation etc. (by difference)	8131.4	25.93
Total	31 360kg	**Total**	31,360 kg	100

PRECAUTIONS:

1. Note the value carefully.
2. Make the calculation accurately.
3. Applying the formula suitable to calculate the value.