Text/Reference Book Series No. 14
May 1980. Reprinted, March 1987.

INTRODUCTION TO ENGINES

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This "COMBINED EDITION OF TECHNICAL PAPERS" was printed with the kind assistance of the Japan International Cooperation Agency, Tokyo.

FOREWORD

The present textbook has been prepared by Mr. Hiroshi Mizuno, who was an instructor of Marine Engineering, Training Department, Southeast Asian Fisheries Development Center from April 1972 to March 1975. During his stay in the Department, he had given various valuable lectures to our trainees of Marine Engineering Course. Unfortunately, however, a textbook based on his lectures has not been issued earlier because a publishing system for textbooks has only recently been instituted in the Department.

Mr. H. Mizuno kindly accepted the request from the Editor in 1979 to prepare the present book which, although based on his original lecture notes, has been completely rearranged and expended.

The Department would like to extend its heartfelt thanks to Mr. H. Mizuno for having prepared the book for our Department in spite of his busy schedule in his present post in Japan.

Editor of Technical Paper
Training Department

PREAMBLE

The purpose of this textbook is to assist the engineering course trainees in the initial stage of their studies, as well as the fishing course trainees. Most of our attention will be devoted to those engines which are generally employed on board fishing boats.

Fishing boats may range in size from small vessels manned by one or two persons for coastal fishing to large vessels manned by a large number of crew members who navigate the high seas to catch tuna, whales, etc.

Nowadays most of the fishing boats are driven by a motor. The type of motor is determined by taking into account various factors, e.g., fuel consumption, weight, size, economical factors (initial cost, maintenance cost, engine service life), reliability, convenience of operation and purpose of the ship. Most fishing boats are fitted with internal combustion engines, especially the diesel engine, spark ignition engine or hot bulb engine, for the propulsion of the ship or as the prime mover of the auxiliary machinery. Steam engines are not popular among small-scale fishermen, even though these engines, which are used on the large merchant ships, are technically available to them.

The first engine ever to be installed in a ship for propulsion purposes was the plant consisting of a steam boiler and a steam reciprocating engine. This dates back some 200 years. As engines were developed further, the use of the boiler and steam reciprocating engine plant for the propulsion of ships was replaced by the boiler and steam turbine plant, and later by the spark ignition engine, diesel engine, etc.

The present textbook is mainly concerned with the internal combustion engine. However, it also comprises the steam engine for the purpose of giving the students the whole spectrum of engines.

The various engines for marine and land use are categorized from the functional and structural standpoints, as follows:

External combustion engine

- Steam boiler and steam reciprocating engine
- Steam boiler and steam turbine

Internal combustion engine

Spark ignition engine

Hot bulb engine

Diesel engine

Gas turbine

Rotary engine

Nuclear reactor plant

Pressurized water reactor and steam turbine

Other types of nuclear reactors and steam turbine

Electrically driven ships may be equipped with any type of engine to generate electricity, which is fed to the electric motor to turn the propeller.

This textbook follows, in general, the above categorization, in the same sequence. Early types of engine or those not commonly used (geothermal plant, sterling engine) have been omitted.

The author wishes to record his appreciation for the cooperation given by the Tokyo University of Merchantile Marine, and the Science and Technology Museum. Thanks are also due to Miss B. Mountfield, who worked on the collation of the text, and Mr. Issara Sricha-um for handling the reproduction of the photographs and diagrams.

Tokyo, Nakano-ku
May, 1980

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1. EXTERNAL COMBUSTION ENGINE

1.1 General

The external combustion engine can be defined as an engine, the fuel of which is burnt externally in separate equipment such as a boiler, where the working substance, that is highly pressurized hot steam or gas, is produced. This working substance is then fed into the machinery (e.g., a steam turbine) where the energy is released and turned into mechanical work.

In the case of the conventional steam engine, the steam is generated in the steam boiler, while in the case of the nuclear propulsion plant, the steam is generated in the nuclear reactor in which nuclear fuel is used. The nuclear power plant will be covered in section 3.

The conventional steam engine consists of two parts: the steam generating part (boiler) and the work producing part (steam turbine, steam reciprocating engine). Both the cylindrical boiler and water tube boiler are available for marine propulsion proposes. Some boilers are exclusively used for miscellaneous purposes such as room heating, which is not necessary for tropical navigation, and galley use.

A boiler requires fuel and water to produce pressurized steam. Any fuel may be used, depending on the design of the boilers: fuel oil; coal; a mixture of the two, etc.

Freshwater must be supplied by means of a feed water pump. The water should be properly purified. The fuel is burnt in the boiler and steam is generated, which is led from the boiler to the engine, such as a steam reciprocating engine or a steam turbine, in which it expands and work is done. For the sake of economy, the thermal energy and water should be conserved as far as practical, as follows: after the work is finished, the steam from the engine outlet is collected in a condenser where it is condensed into water to be fed into the boiler again. The plant comprising this system is called condensing engine.

Cylindrical boilers are divided into several kinds: the Scotch boiler, the dry combustion (chamber) boiler and others. Water tube boilers are of diverse designs, but only the typical design will be described in sub-paragraph 1.2.2.

Some 20 or more years ago, the steam reciprocating engine was generally used for steam locomotives and ships. The use of steam locomotives is now on the decrease, and ships propelled by a steam reciprocating engine are almost obsolete.

The steam locomotive is designed so that the steam expands once only to do work, whereafter it is discharged into the atmosphere. There is no condenser. The steam engine of this type is called non-condensing engine.

The steam turbine is now utilized on large ships and is generally used in oil- or coal-fired power stations. The thermal efficiency of the steam turbine plant is far greater than that of the steam reciprocating engine plant. (Thermal efficiency means the ratio of the heat liberated from the fuel to the heat equivalent of the work done by the engine.) The thermal efficiency of the steam reciprocating engine plant may range from less than 10 percent to 20 percent, while the steam turbine plant may range from 25 to 40 percent.

The gas turbine of the external combustion type is dealt with in paragraph 2.5.

1.2 Boiler

As water is heated under atmospheric pressure, the water temperature rises and boiling starts at 100°C. (Atmospheric pressure is the pressure of the air, at sea level, pressing down on the earth.) Under the same atmospheric pressure the water continues to boil, but the temperature remains unchanged, the reason being that the heat added to the body of boiling water causes the water to change from the liquid state to the gaseous state (steam), and is, therefore, unable to increase the temperature. The steam thus produced is called saturated steam. In other words, by heating the water under a certain pressure, boiling takes place at a certain temperature, and the temperature of the steam remains the same as long as the pressure remains the same, both the water and the steam being in equilibrium. When such evaporation takes place continually in a finite space, the pressure in the space tends to rise higher than the atmospheric pressure. As the pressure rises, the boiling temperature also rises. Under such higher pressure, the boiling takes place with an increase in the boiling temperature. The steam thus produced is also saturated steam.

The required temperature of the steam is determined by the purpose to be served. For hotel use such as cooking and room heating, the required temperature is very low and accordingly the corresponding pressure of the steam is low, as can be seen from the table which shows the relationship between the temperature and pressure (absolute) of saturated steam.

Table of pressure (Ps) and temperature (Ts) of saturated steam

Ps kg/cm^2ab	Ts ^oC	Ps kg/cm^2ab	Ts ^oC	Ps kg/cm^2ab	Ts ^oC	Ps kg/cm^2ab	Ts ^oC	Ps kg/cm^2ab	Ts ^oC
0.01	6.7	3.0	132.9	9.0	174.5	20	211.4	60	274.3
0.05	32.5	4.0	142.9	10	179.0	25	222.9	70	284.5
0.1	45.4	5.0	151.1	12	187.1	30	232.8	80	293.6
0.5	80.9	6.0	158.1	14	194.1	35	241.4	90	301.9
1.0	99.1	7.0	164.2	16	200.4	40	249.2	100	309.5
2.0	119.6	8.0	169.6	18	206.1	50	262.7	225.65	374.15

Steam is liable to contain a certain amount of water. In other words it includes moisture. Such steam is called wet steam, while saturated steam free of water content is called dry steam.

The general principle of the functioning of a boiler is that the combustion of fuel takes place within the furnace of the boiler, and the boiler water, inside the boiler, absorbs the heat liberated from the fuel, and steaming occurs. As steaming continues and the steam is fed to the engine, the water level in the boiler tends to lower. Therefore, the boiler has to be designed so as to maintain the proper level of water. To do this, a feed water system is provided to pump into the boiler as much water as is continually being used up.

There exist various types of boilers whose design depends on the purpose to be served. They can be classified according to structure, use, fuel, draught method, water treatment method, pressure, capacity, temperature, etc.; however, to follow the aim of this textbook, boilers are dealt with here by dividing them into two groups from the standpoint of marine application: cylindrical boiler and water tube boiler. These are briefly described in the following paragraphs.

1.2.1 Cylindrical boiler

The cylindrical boiler used to be widely applied on board ships. It has now been replaced by the water tube boiler, for various reasons such as the large size, low pressure and low thermal efficiency of the former.

In the early days of the cylindrical boiler, the Scotch boiler (wet combustion boiler) was commonly used for marine propulsion. Later, the dry combustion boiler was developed and became more popular than the Scotch boiler for installation on board ships.

The cylindrical boiler contains a comparatively large quantity of water, which enables it to withstand a sudden change in steam demand and avoid sharp pressure fluctuations. The structure is not complicated, and operation and maintenance are comparatively easy.

However, the maximum pressure which the cylindrical boiler can produce is fairly low (i.e., 18 kg/cm^2), and the steam generation capacity is also limited (i.e., 12 tons/hr.). Therefore, the tendency has recently been to use this type of boiler as an auxiliary boiler on board ships.

1.2.1.1 Scotch boiler

The general structure of a Scotch boiler is as shown in Fig. 1.2 - 1. The principal parts of the Scotch boiler are (1) the boiler shell, which is a cylindrical outer structure, (2) end plates, which are the covers fixed at both ends of the boiler shell, (3) furnace, structured like a large horizontal corrugated tube, which passes through the front end plate and enters the boiler, (4) combustion chamber, structured like a vertical box, to receive the combustion gas coming from the furnace, (5) a great number of smoke tubes, which connect the combustion chamber to the front end plate, and (6) accessories attached to the boiler such as stop valve, feed valve, safety valve, glass water gauge, pressure gauge, blow-off valve, and valves for salinometer, drain, steam siren, and whistle.

The water entering the boiler from the feed water valve is fed by the outside feed water pump up to a level above the smoke tubes and combustion chamber. The fuel is fed into the furnace from the front end manually or mechanically. The air is also introduced by natural draught or by forced draught. The fuel is ignited and combustion takes place; the heat thus generated is transferred to the water through the corrugated wall of the furnace. The combustion gas goes into the combustion chamber to undergo further combustion and then enters a great number of smoke tubes, where the remaining heat is transmitted to the water. Finally the gas leaves the boiler at the front end plate and is released to the atmosphere through the funnel.

The water is heated and steam rises from the surface of the water. Steam leaving the boiler through the main stop valve, which is placed at the top of the boiler shell, is fed to various machiner.

As the steam is consumed the water decreases and the water level tends to lower. The water level is important and has to be kept constantly at the normal level to cover the heating surface so that it will not get overheated and melt. Thus water has to be supplied as it is being used up.

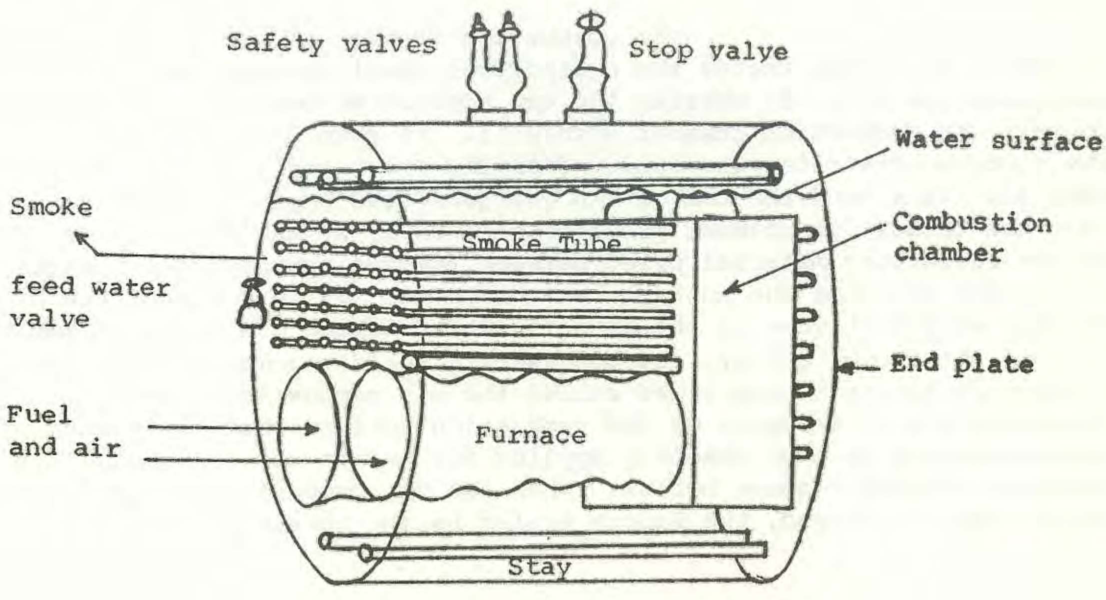


Fig. 1.2 - 1 Scotch boiler

The safety valve is a spring loaded valve, which automatically opens to release the excessive pressure building up in the boiler due to excess ste-m generation, and prevents the boiler from bursting.

The glass water gauge is an instrument to show the position of the boiler water surface.

The pressure gauge is an instrument to show the steam pressure of the boiler.

The blow-off valve is a valve to enable blow-off of the surface or bottom water to expel the impurities.

The boiler needs some separate devices such as oil burner and feed water pump. If the boiler is oil burning, an oil burner is necessary. It sprays oil into the furnace. If the boiler applies forced draught, a draught fan is needed to send air forcibly into the furnace in order to produce more active combustion than by natural draught.

1.2.1.2 Dry combustion boiler

The combustion chamber of the Scotch boiler is contained inside the cylindrical shell as mentioned in sub-paragraph 1.2.1.1, whereas the dry combustion boiler does not contain the combustion chamber within it. As seen in Fig. 1.2 - 2, the furnace penetrates the boiler from the front end plate to the back end plate, and the combustion gas generated in the furnace goes into the combustion chamber provided separately at the reaf of the boiler refractory material piled between the two equipments. The gas turns back to enter the smoke tubes and passes to the front of the boiler, whence it goes to the funnel. The detailed structure resembles that of the Scotch boiler. In contrast to the dry combustion boiler, the Scotch boiler is sometimes called the wet combustion boiler. There exist several types of dry combustion boilers, but the Howden Johnson boiler is most commonly applied for marine use. Fig. 1.2 - 2 shows the Howden Johnson boiler. When the dry combustion chamber boiler was introduced, the Scotch boiler became obsolete.

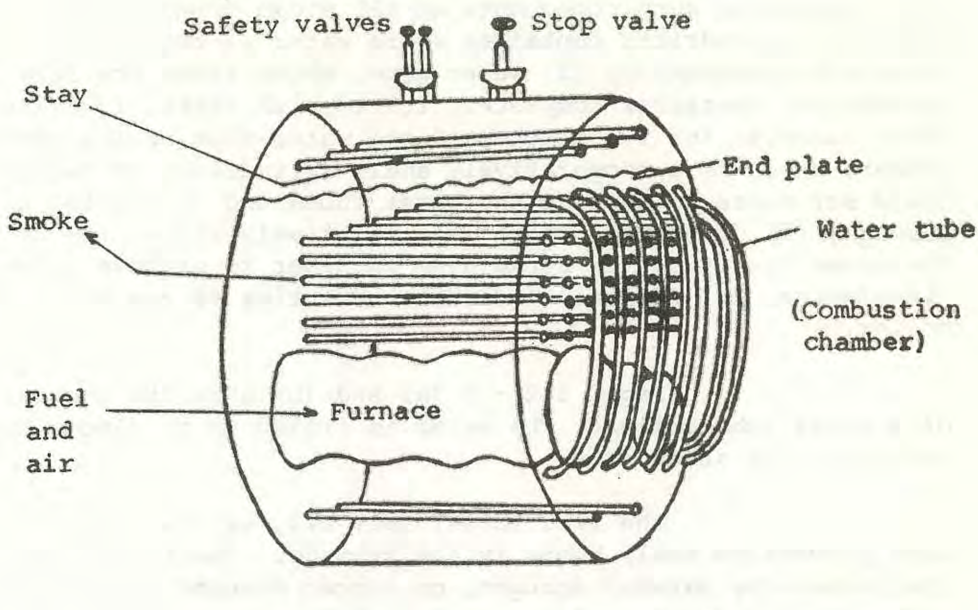


Fig. 1.2 - 2 Dry combustion boiler

1.2.1.3 Other types

There are other types of cylindrical boilers, some of which are the vertical boiler, furnace boiler and smoke tube boiler.

A vertical boiler is vertically positioned and so structured as to include a furnace and smoke tubes. This type of boiler is installed in a ship as an auxiliary boiler (not for main engine).

The main component of a furnace boiler is a cylindrical furnace, installed horizontally. It does not have any smoke tube.

A smoke tube boiler, installed horizontally, consists mainly of a cylindrical shell, a furnace, and a great number of smoke tubes. This boiler is applied to a locomotive engine.

1.2.2 Water tube boiler

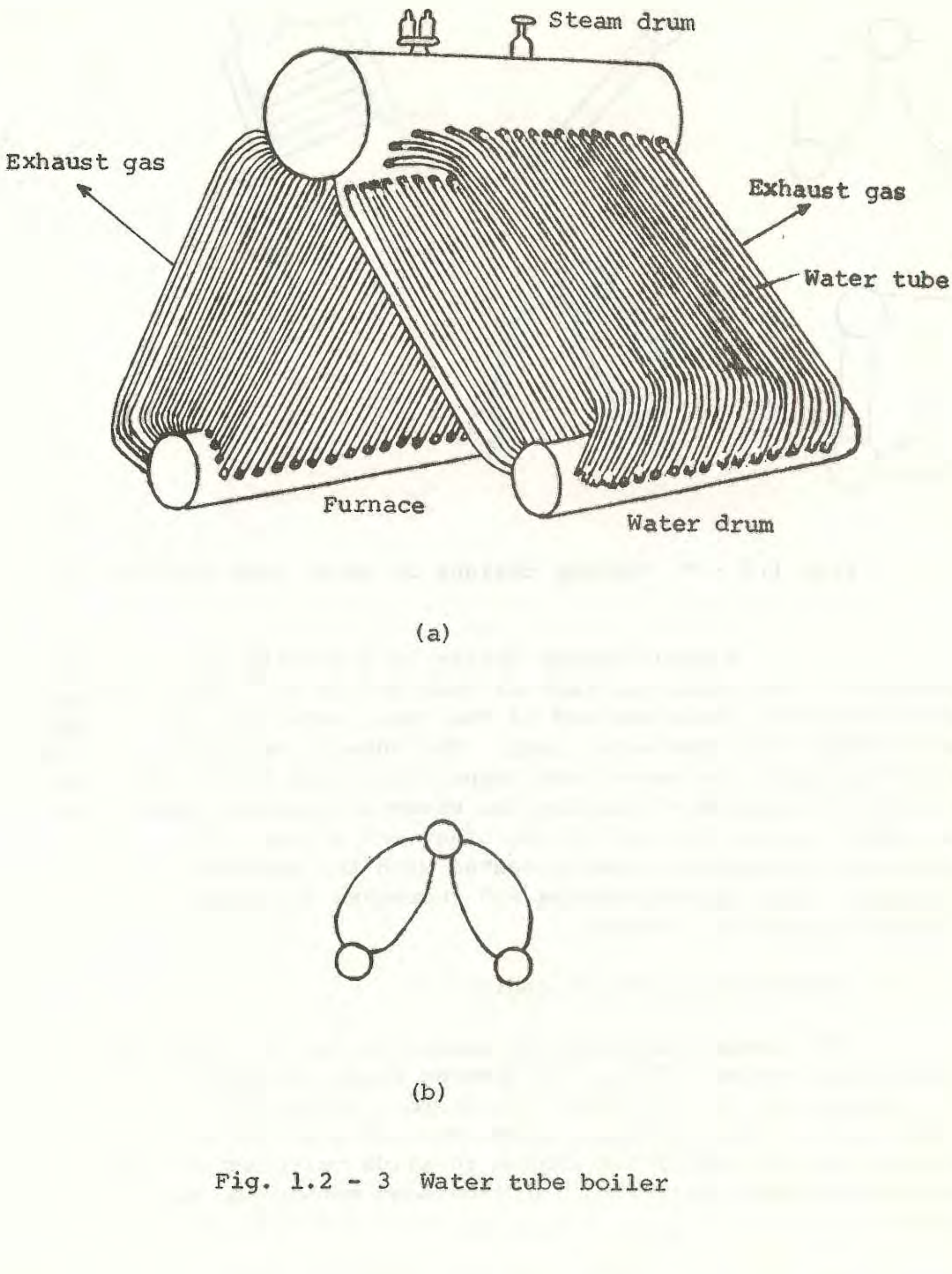
There exist various types of water tube boilers and it is difficult to generalize their structure. Broadly speaking, they consist of such components as (1) steam drum, which takes the form of a cylindrical container where water is kept at a given level for steam evaporation, (2) water drum, which takes the form of a cylindrical container completely filled with water, (3) water tube, which connects the steam drum and the water drum or the header, (4) header, which is a comparatively small cylindrical or rectangular solid structure to receive the water tubes and to provide water passage, (5) downcomer, which is a relatively thick pipe to lead the water down from the steam drum in order to promote water circulation, (6) furnace, and (7) accessories as for the cylindrical boiler.

Figs. 1.2 - 3 (a) and (b) show the general design of a water tube boiler. The water is filled up to almost half the height of the steam drum.

The fuel (coal, fuel oil, or a mixture of the two with pulverized coal) burns in the furnace. The air is supplied to the furnace by natural draught, or forced draught if provided. The combustion gas heats a large number of long water tubes containing the boiler water. The combustion gas passes through the water tube nest to reach the funnel, from which it is expelled into the atmosphere.

The boiler water inside the water tubes is heated by the combustion gas and turns into a mixture of water and steam. Then natural convection in this case induces the water-steam mixture to flow up to enter the steam drum, in which the steam is separated from the water surface. The steam thus produced is provided for outside consumption through the stop valve. The water which has not evaporated passes down the downcomer to the water drum, from which it flows into the water tubes to be heated once more. This process is repeated continuously during the boiler operation. As in the case of the cylindrical boiler, the water level in the steam drum should be kept at an appropriate level to prevent drying up of the boiler, which would result in meltdown, rupture of the water tubes, etc. A separate feed water pump assumes the function of sending the amount of water necessary to replace consumption.

Fig. 1.2 - 4 shows some other types of water tube boilers with a steam drum.



(a)

(b)

Fig. 1.2 - 3 Water tube boiler

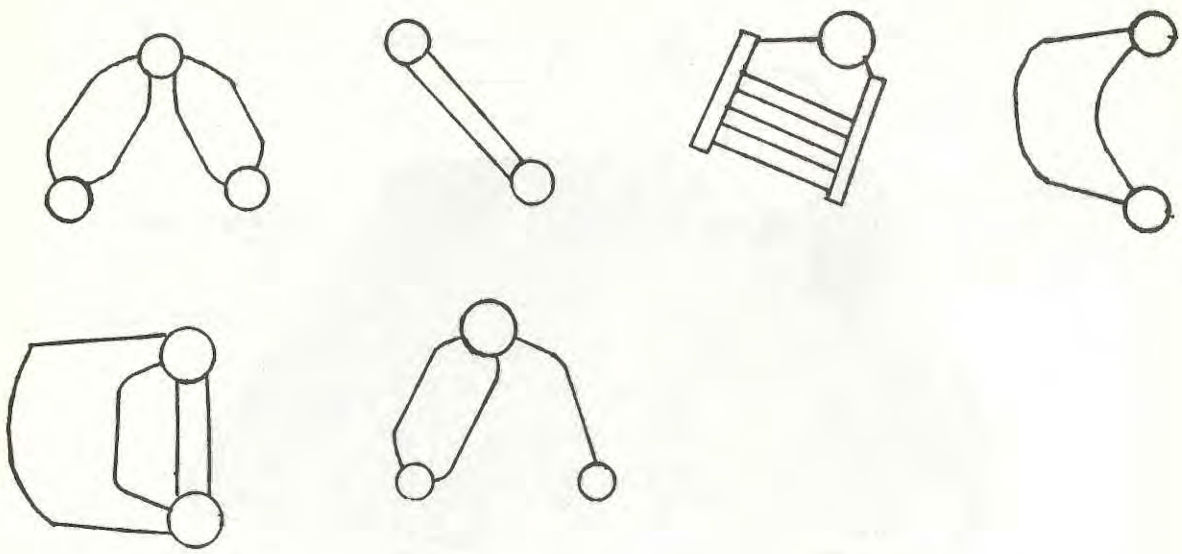


Fig. 1.2 - 4 Various designs of water tube boilers

A once-through boiler is a special type of water tube boiler. The principal part of this boiler is a long tube. No drum is attached. From one end of the tube, water is fed into the tube by means of a feed water pump. The tube is heated by burning fuel and the water is heated and turns into steam inside the tube. The boiler is capable of heating the steam to produce superheated steam, which can be let out of the other end of the tube. (Note: When the dry saturated steam is heated with the pressure unchanged, it becomes higher in temperature and increases in volume. Such steam is called superheated steam.)

1.3 Steam reciprocating engine

The steam reciprocating engine is, as the name implies, a piston type engine. There are diverse kinds of design, one of which consists of (1) cylinder, (2) piston, (3) slide valve, which provides the control of steam inlet, cut-off and release, (4) link mechanism, which enables the change in slide valve stroke and go-ahead/go-astern switching, (5) crosshead mechanism, and (6) crankshaft.

Fig. 1.3 - 1 shows a single cylinder, double acting steam reciprocating engine, which means that the engine is equipped with

one cylinder only and the piston receives live steam alternatively on both sides. The alternative supply of live steam into the cylinder is made by the slide valve, which slides over the steam port of the cylinder.

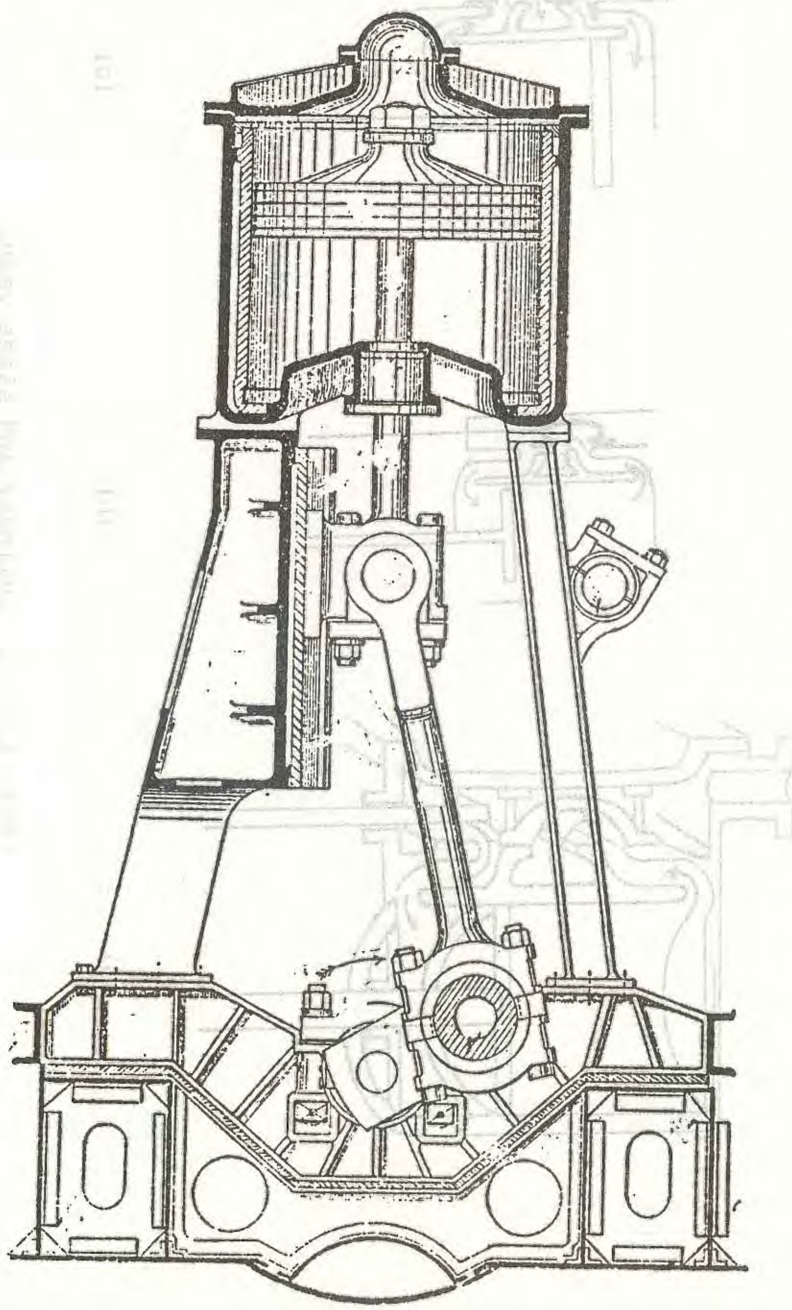
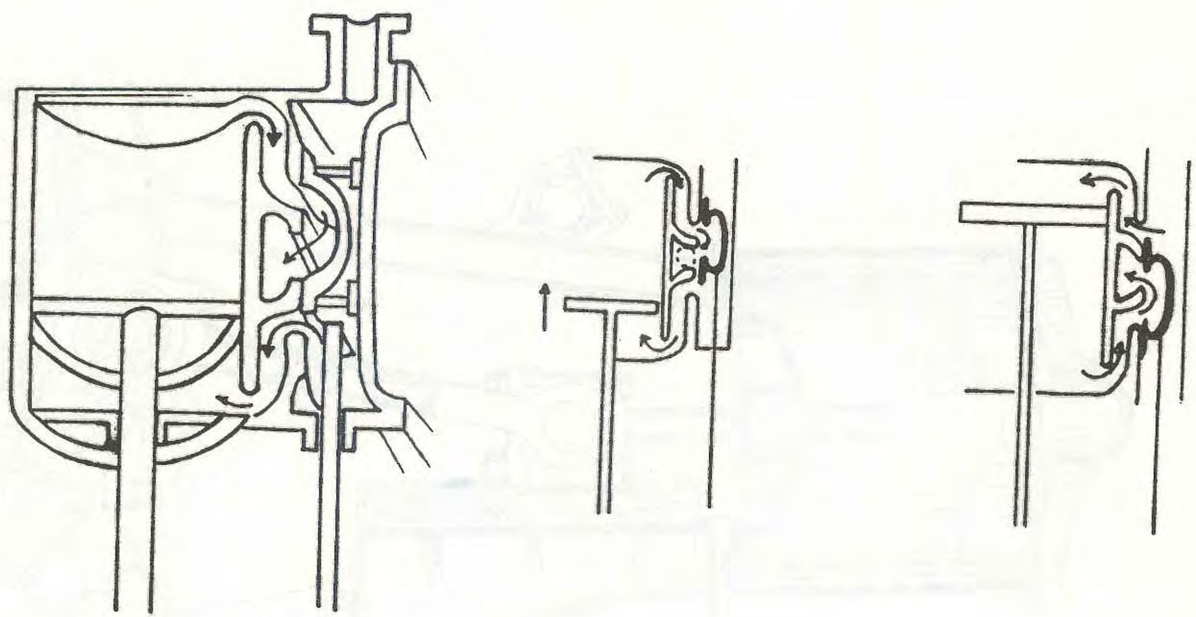


Fig. 1.3 - 1 Cutaway view of a reciprocating engine

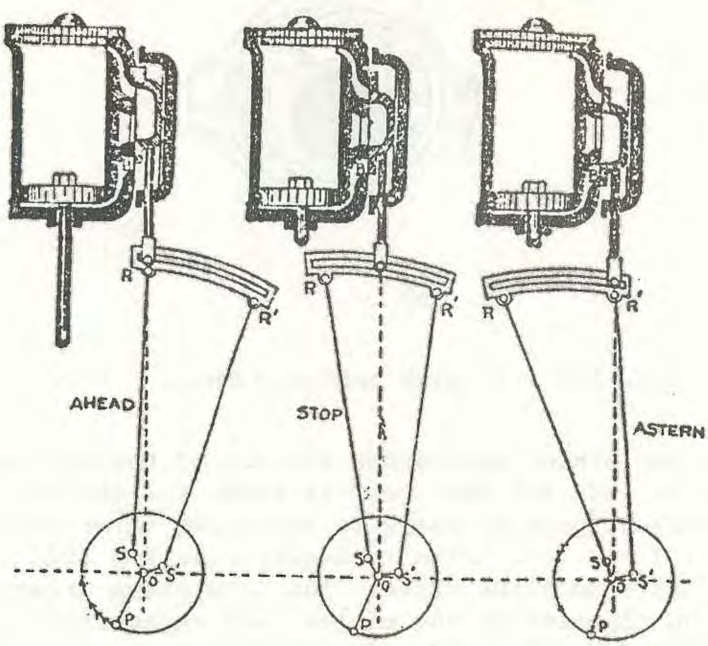


(a) (b) (c)

Fig. 1.3 - 2 Cylinder and slide valve

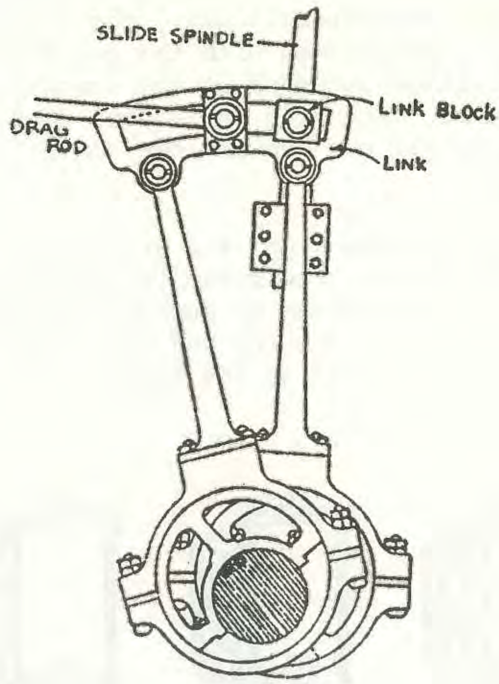
This is how it works: the slide valve is assumed, at first, to be positioned as shown in Figs. 1.3 - 2 (a) and (b), and the steam port is opened to the live steam, which goes into the bottom part of the cylinder. Then the steam pushes the piston upwards as it enters and, automatically, the slide valve, the movement of which is interlocked with the piston movement by means of an eccentric mechanism attached at the crankshaft, is made to operate. The eccentric mechanism and a link system connected thereto (as seen in Fig. 1.3 - 3) can provide the control of the engine including reversing.

As the piston moves up, the steam port is completely covered by the slide valve. The steam is isolated and set free for expansion in the cylinder bottom by pushing the piston. The piston does work by pushing the piston rod and connecting rod to rotate the crankshaft, which is connected to the load.



(a)

Fig. 1.3 - 3 Link motion



(b)

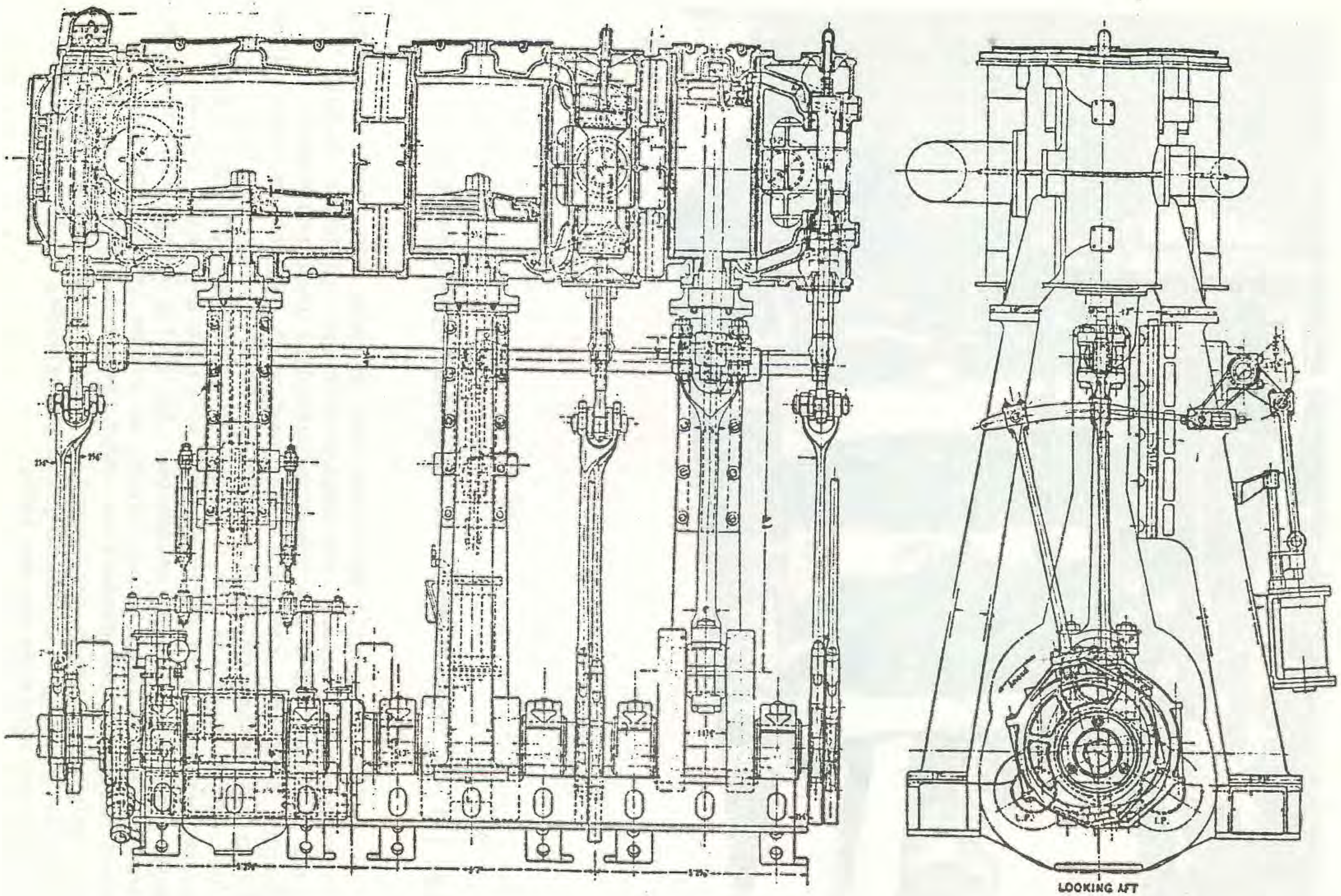
Fig. 1.3 - 3 Link motion (cont.)

As the piston approaches the top of the cylinder, the expansion almost ends and the steam is ready for discharge, by opening the exhaust port by means of the slide valve movement, as seen in Fig. 1.3 - 3 (c). Simultaneously, the top side steam port is opened by the same slide valve. The live steam enters the cylinder at the top side of the piston, and expansion of the steam occurs to produce the downward piston motion.

In other designs of the engine, the slide valve is replaced by different types of valves.

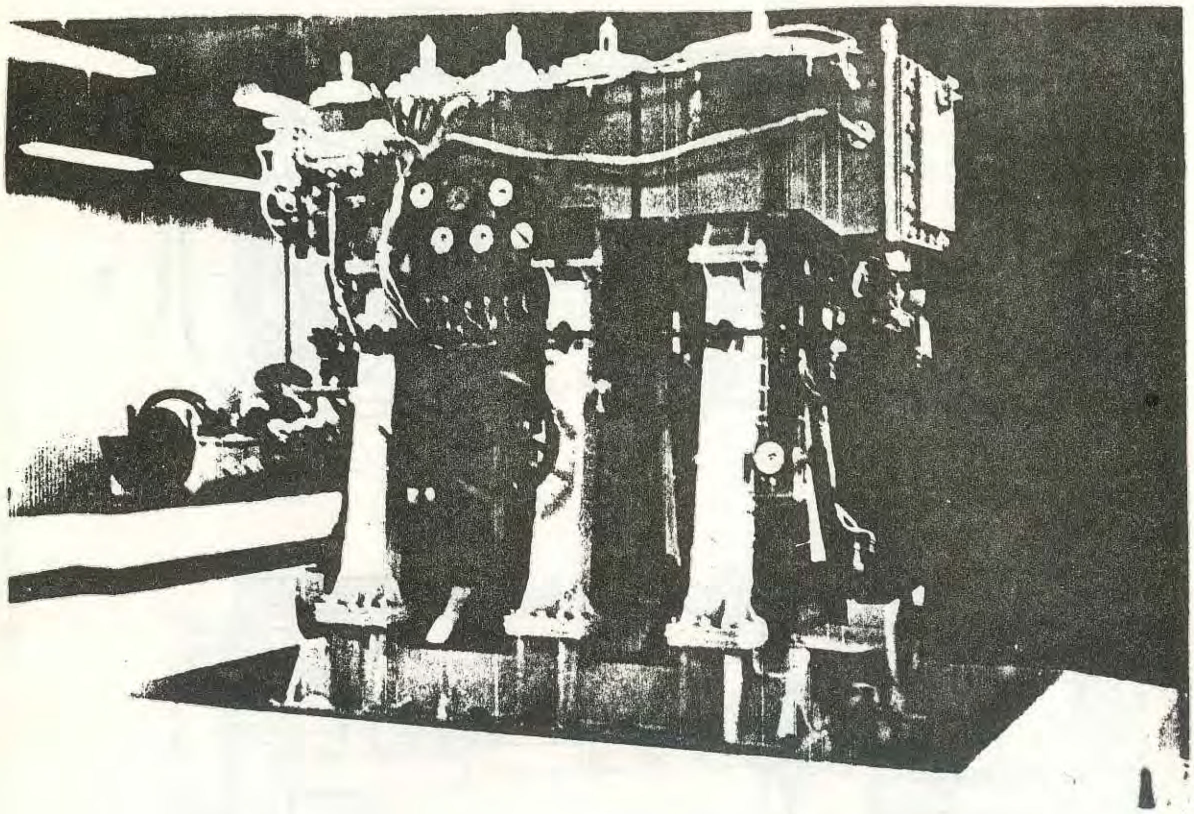
Figs. 1.3 - 3 (a) and (b) show the link motion to operate the slide valve function for go-ahead, go-astern and stop.

The single acting reciprocating steam engine receives the steam supply on the top of the piston only. This type of design in far less popular than the double acting type.



(a) (b)

Fig. 1.3 - 4 Triple expansion reciprocating engine



(c)

Fig. 1.3 - 4 Triple expansion reciprocating engine (cont.)

The engine with more than one cylinder can perform double, triple or more expansions. The engine with two cylinders (a high pressure cylinder and a low pressure cylinder) performs double expansion. At first, the primary expansion of live steam takes place in the high pressure cylinder. Then the steam leaves the high pressure cylinder and is led into the low pressure cylinder, where the second expansion is carried out. A triple expansion engine performs three-stage steam expansion. In multiple-expansion engines, the lower pressure cylinder is larger in volume because of the expanded volume of the steam at a lower pressure. Fig. 1.3 - 4 (a) shows a triple expansion reciprocating engine with a high pressure cylinder on the right, a medium pressure cylinder in the middle and a low pressure cylinder on the left.

1.4 Steam turbine

A steam turbine is supplied with the steam raised in a boiler. The steam entering the turbine expands to produce a fast flow of steam, which acts to turn the turbine rotor to deliver work to the outside. The steam turbine is classified into three kinds from the standpoint of function, namely (1) impulse turbine, (2) reaction turbine and (3) combination turbine.

The principal stationary parts of these steam turbines are (1) turbine casing, which is an external structure, and (2) nozzle and fixed blade which provide a passageway where the steam expands or deflects. The moving parts are a rotor with a shaft and moving blades. The moving blades are arranged at the circumference of the rotor to receive the steam coming out of the nozzle or through fixed blades, and develop power.

Fig. 1.4 - 1 shows a steam turbine plant in a laboratory for training purposes.

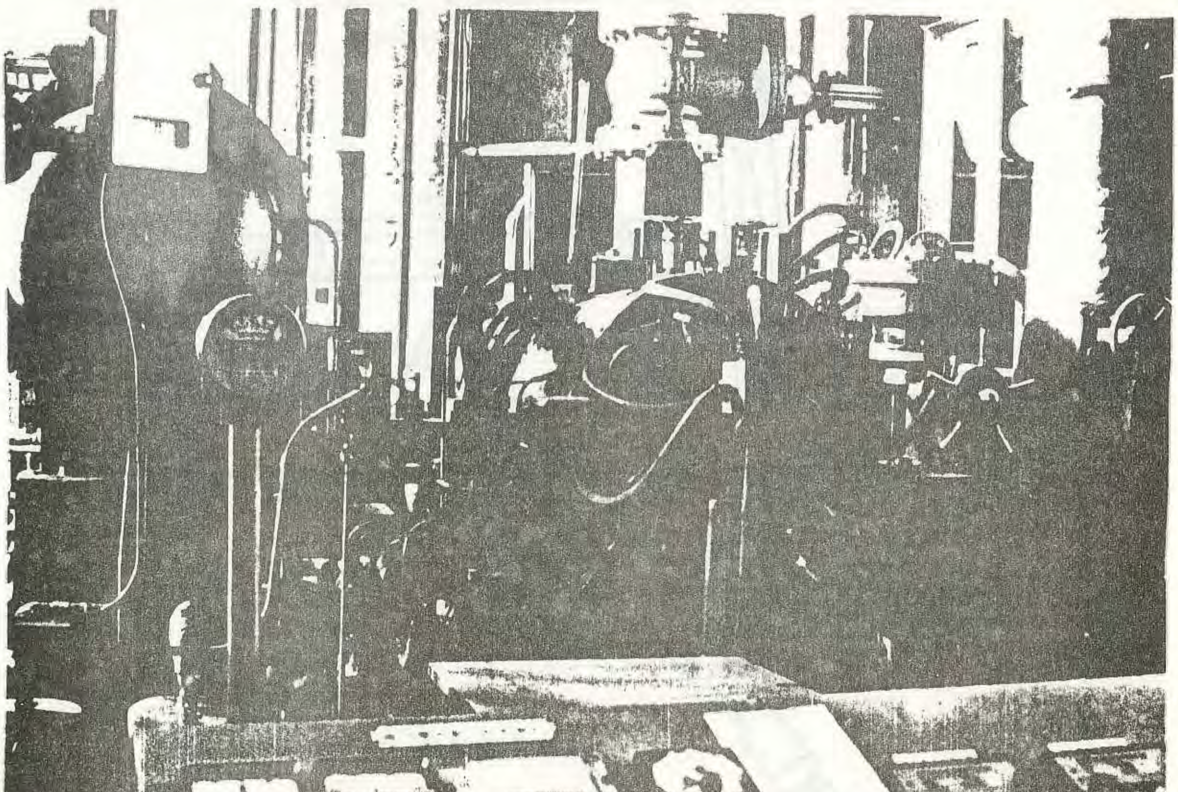


Fig. 1.4 - 1 Turbine plant in a laboratory

1.4.1 Impulse turbine

An impulse turbine is provided with nozzles fixed inside the turbine casing so that they are facing the moving blades. The nozzles, as seen in Fig. 1.4 - 2 (a) and (b), are designed to allow the incoming steam to expand in them while passing through the divergent section and increase the speed of the steam flow. The steam mass impinges at a high speed on the moving blades arranged at the circumference of the rotor, thus transmitting the kinetic energy of the expanded high speed steam to the rotor and, consequently, to the load.

There are various kinds of impulse turbines. The following are the basic types.

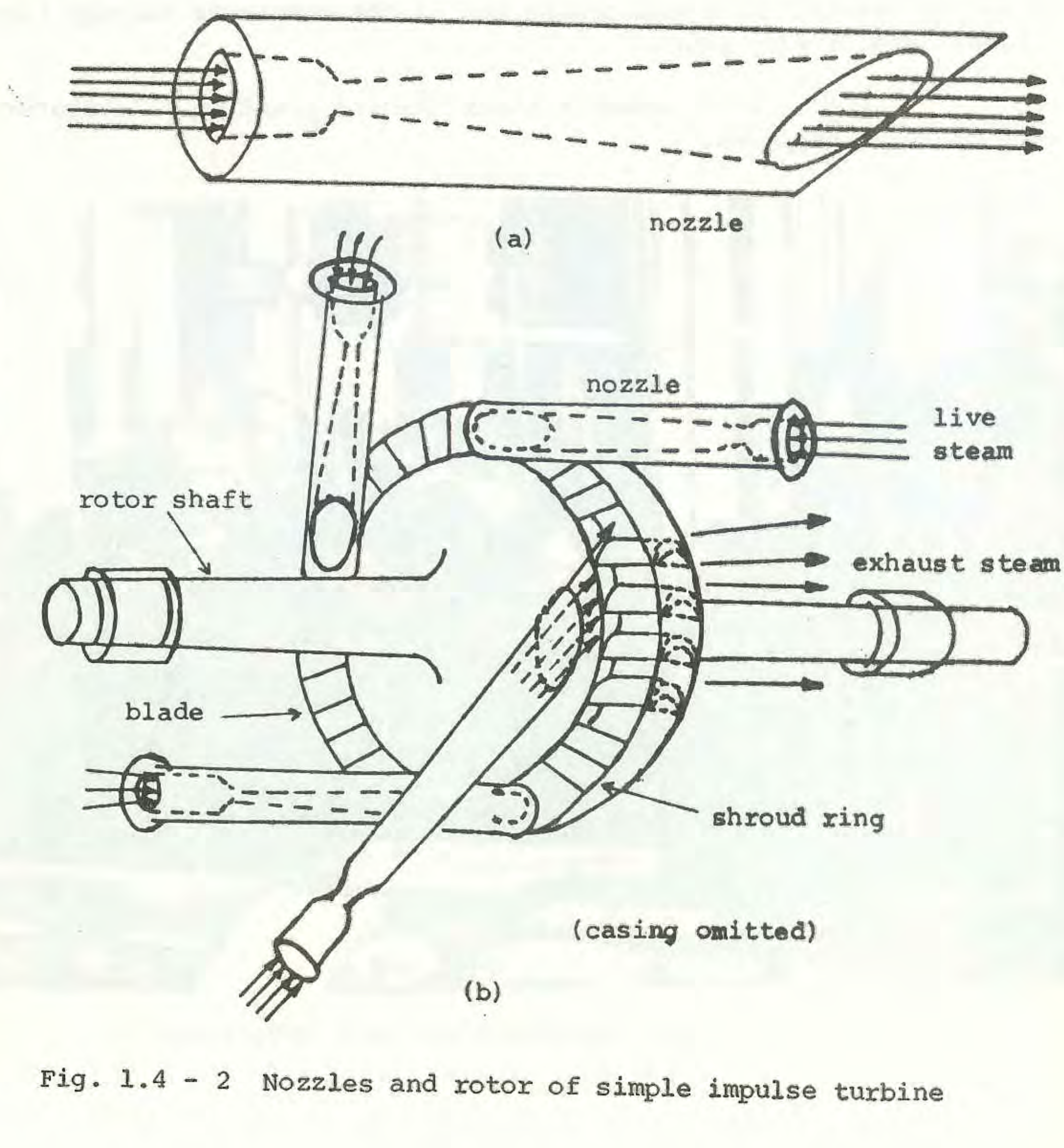


Fig. 1.4 - 2 Nozzles and rotor of simple impulse turbine

(1) Simple impulse turbine

A simple impulse turbine (single stage) is the simplest in structure among turbines. As described above, it has nozzles, arranged inside the turbine casing, and moving blades, arranged circumferentially at the rim of one rotor. Fig. 1.4 - 3 (a) and (b) show the relative positions of these components.

Steam expands continuously from the initial pressure to the final pressure while it passes the nozzles. The steam which has expanded has a high velocity and impinges on the moving blades. This type of turbine is very high in speed and is applied for small output use.

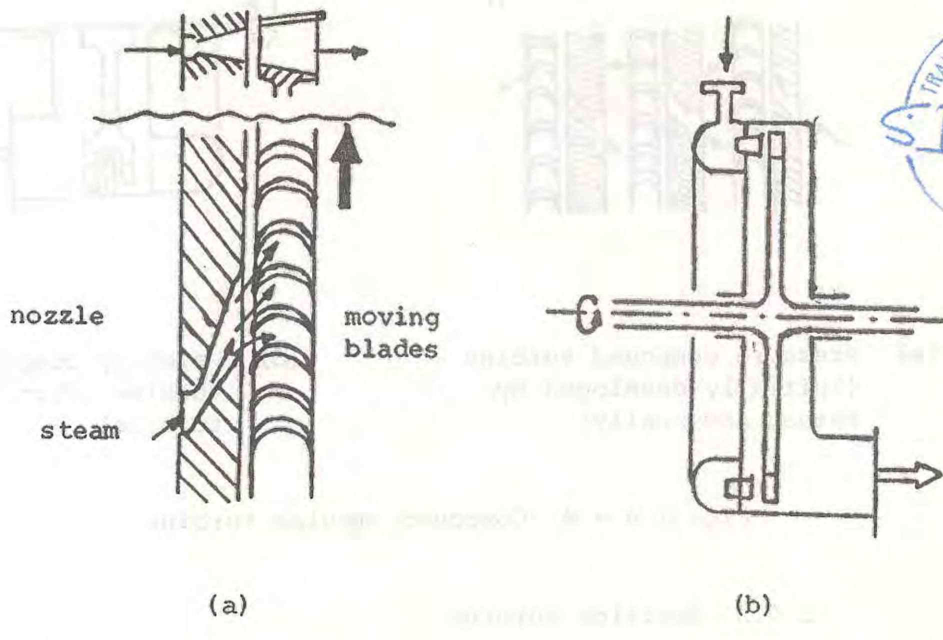
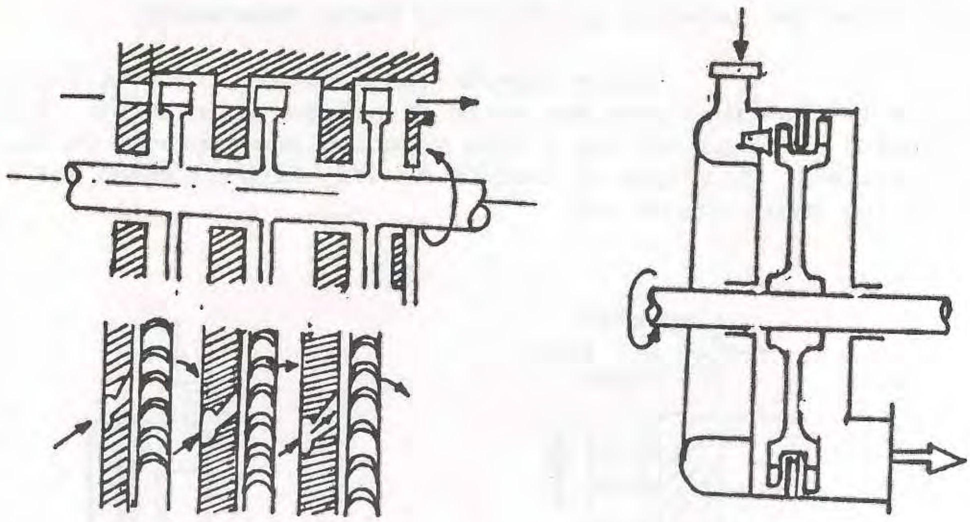


Fig. 1.4 - 3 Simple impulse turbine (De Laval turbine)

(2) Compound impulse turbine

The turbine casing of a compound impulse turbine (multistate) is, as shown in Fig. 1.4 - 4, partitioned into several compartments (stages), and each stage is installed with nozzles, which face moving blades fitted on the circumference of a rotor. These blades receive the steam jetting from the nozzles. The steam expands gradually as it passes through the nozzles from one stage to another, enabling the rotor speed to be more appropriate than is the case in the single stage turbine.



(a) Pressure compound turbine (initially developed by Rateau and Zoelly)

(b) Velocity compound turbine (Curtis turbine)

Fig. 1.4 - 4 Compound impulse turbine

1.4.2 Reaction turbine

There exist various types of reaction turbines. The following are some of the basic types.

1. Axial flow reaction turbine

An axial flow reaction turbine is installed with fixed blades, which are arranged at the turbine casing side, instead of nozzles as in the impulse turbine, as seen in Fig. 1.4 - 5. These fixed blades form the passage way through which the steam expands about 50 percent. The expanded steam impinges on the moving blades to do work and undergoes a further expansion, while passing through the moving blades. The steam kicks back the moving blades giving a reactionary force to them, thus doing further work (the remaining 50 percent).

Fig. 1.4 - 6 shows a cross-sectional view of a kind of reaction turbine.

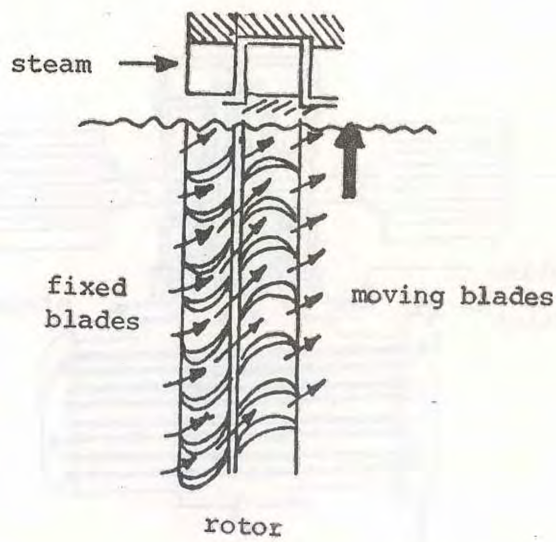


Fig. 1.4 - 5 Reaction turbine

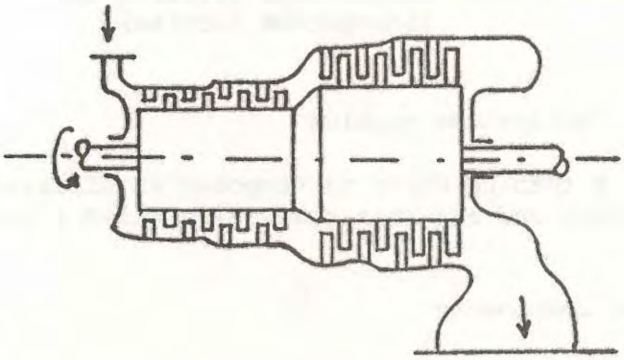


Fig. 1.4 - 6 Axial flow reaction turbine (Parsons turbine)

2. Radial flow reaction turbine

In a radial flow reaction turbine, there are two rotors with rows of blades facing each other as shown in Fig. 1.4 - 7. Steam passes as indicated by the arrows in the figure, causing the shafts to turn in opposite directions from each other. Two consumers (2 electric generators, in the figure) are mounted at the two rotor shafts. No fixed blades are needed.

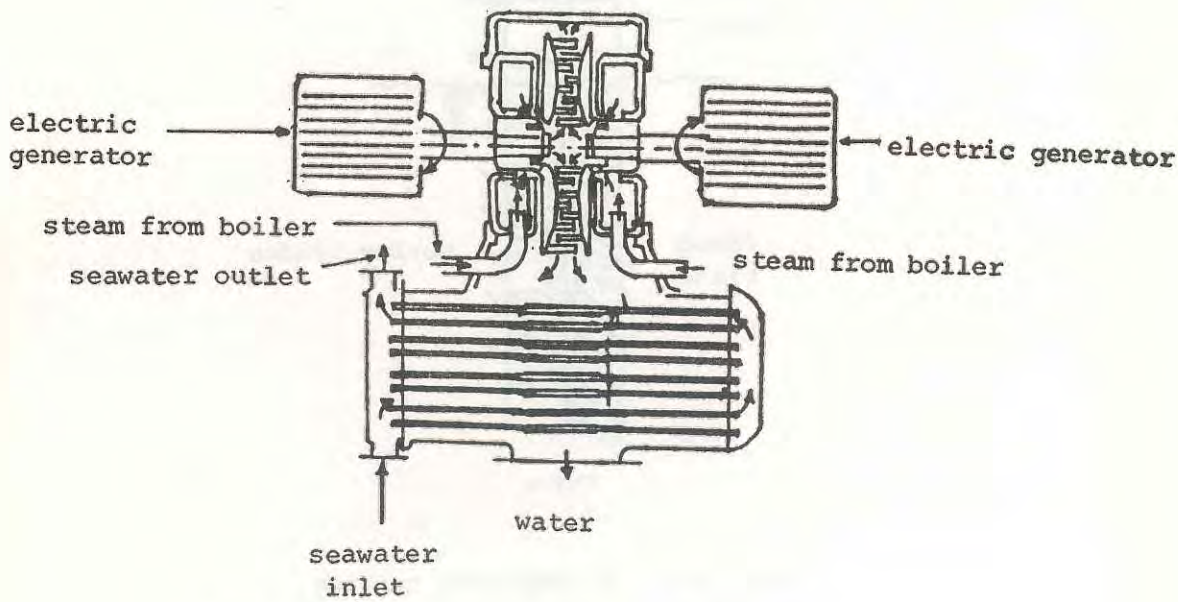


Fig. 1.4 - 7 Radial flow reaction turbine (Ljungström turbine)

1.4.3 Combination turbine

A turbine which is composed of different stages, such as impulse stage and reaction stage, is called a combination turbine.

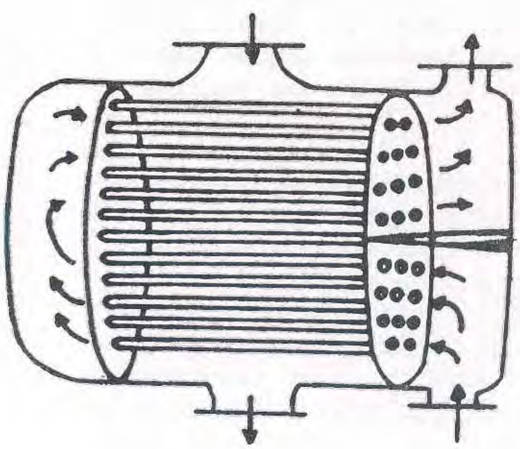
1.5 Related components

(a) Steam condenser

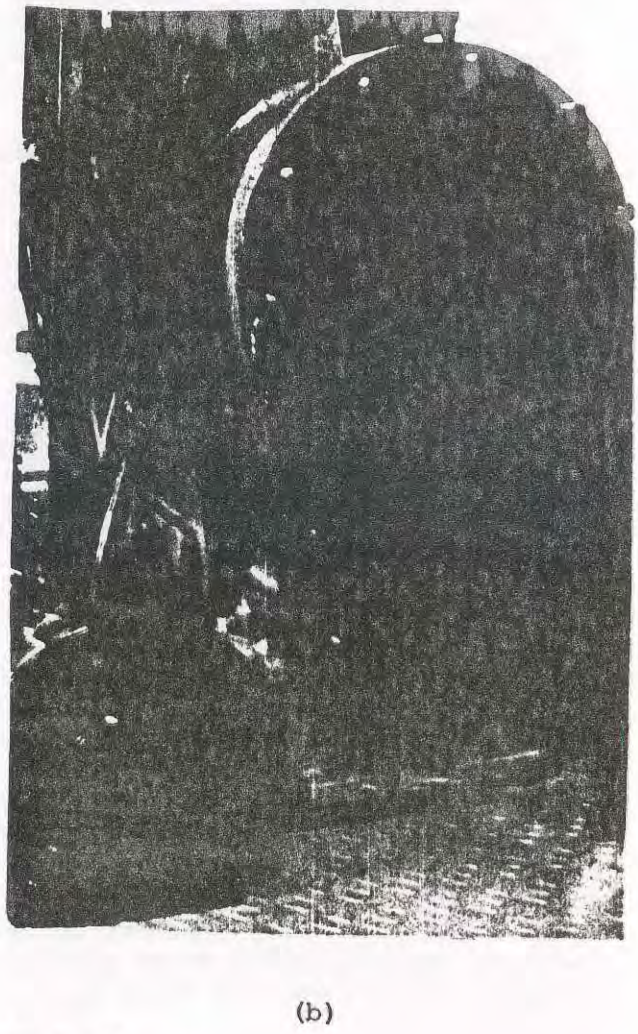
The exhaust steam coming out of the engine can be introduced into a steam condenser, in which the steam is cooled and turns to water for re-use, as mentioned in paragraph 1.1 in the case of the condensing engine. The structure of the condenser is simple. It is a mere heat exchanger. As shown in Fig. 1.5 - 1, it is a vessel in which many tubes are placed. Sea water passes through these tubes for cooling purposes. The exhaust steam enters the condenser from the top and filters through the tubes to be cooled down and condensed to a liquid state.

(b) Reduction gear

A turbine is equipped with a reduction gear, which connects the high speed mover to the consumer (propeller) and enables the consumer to be run at a reduced speed.



(a)



(b)

Fig. 1.5 - 1 Condenser

2. INTERNAL COMBUSTION ENGINE

2.1 General

(a) The internal combustion engine is a heat engine which burns fuel as the working substance to produce thermal energy. (The heat engine is a prime mover, which converts thermal energy to mechanical work.) The diesel engine, spark ignition engine, hot bulb engine, gas turbine (internal combustion type), etc., belong to this category.

(b) These engines are classified from the mechanical standpoint into two groups: the reciprocating type in which the output is developed in the form of a reciprocating motion in the cylinder and then converted into rotary motion by means of the connecting rod and crankshaft mechanism as in the case of the steam reciprocating engine, and the other type which causes the combustion of fuel and produces power (output), which is converted directly into rotary motion. The diesel engine, spark ignition engine and hot bulb engine belong to the former category, and the gas turbine and rotary engine to the latter.

In addition to the above classification, the internal combustion engines can be classified in terms of their specific features, such as kind of fuel used, ignition method, fuel supply, combustion method, operating cycle, acting scheme, engine speed, piston-crank connection, use of engine, arrangement of cylinders, cylinder cooling, starting method, cooling medium, combustion chamber mechanism, output, etc. Some of these features are summarized in the succeeding sub-paragraphs to give a general concept of engines.

(c) Starting method

The internal combustion engine must be provided with a starting device. It needs initial air supply, air compression and ignition, which have to be produced by an external force.

In the case of manual start, some simple device is provided and human power must give the required inertial force to the engine.

For start-up by battery, the engine is equipped with an electric motor which gives sufficient inertial force to the engine. In the case of start-up by compressed air, there must be an air compressor, an air reservoir and the appropriate components and mechanism to produce the compressed air and supply it to the engine for starting.

Manual starting is used only for small engines, up to about 10 ps ("ps" is the abbreviation of Pferdestärke meaning meaning horsepower in German). Starting by battery is also used for small engines but it can be applied to more powerful engines for which manual starting is not appropriate. Technically it is possible to use this method for large engines, but from the standpoint of facility and maintenance it is not the best method for engines of any output; therefore, the air starting method is wedely applied.

(d) Kind of fuel

An engine is a device for liberating the thermal energy stored in the fuel to do work. The fuel for the internal combustion engine should be either liquid fuel or gas. Liquid fuels such as heavy oil, gasoline and kerosene, and any gaseous fuel such as liquefied petroleum gas are actually available. In special cases liquefied coal, alcohol, etc., can be used as fuel, either singly or by mixing with another fuel.

The characteristics of the engine are the principal factor for determining the kind of fuel to be used, but other factors such as cost, convenience of handling, safety (accidents caused by a gasoline explosion on board ships installed with a spark ignition engine, which is operated on gasoline, have been reported), and availability should also be considered.

A brief list of fuels for use in internal combustion engines is included here merely for reference purposes. (The values given below as regards temperature and specific gravity are not necessarily rigid.)

Gasoline - obtained by distillation (distillation temperature: 200°C or less) of crude oil, or other methods; specific gravity about 0.7.

Kerosene - obtained by distillation (distillation temperature: 150 - 300°C) of crude oil; specific gravity about 0.8.

Gas oil - obtained by distillation (distillation temperature: 300 - 350°C) of crude oil; specific gravity about 0.85.

Heavy oil - obtained by distillation (distillation temperature: more than 350°C) of crude oil; specific gravity about 0.9.

Liquefied petroleum gas (LPG) - produced during the process of crude oil distillation, etc., as a by-product; mainly composed of propane and butane.

Natural gas - combustible gas issuing from the earth; locally available.

Alcohol - rarely used after mixing with another fuel to meet fuel shortage; expensive.

(e) Fuel supply

For releasing thermal energy, the fuel is supplied to the interior of the engine to burn. There are two types of fuel supply methods: one is the suction type, and the other is the injection type. The suction type engine draws the fuel into the cylinder when the cylinder is negative in pressure. Injection is done by a fuel injecting mechanism, which sprays the fuel into the cylinder.

(f) Ignition

The fuel supplied to the interior of the engine must be ignited. As regards ignition, engines are grouped into two types: the spark ignition type (spark ignition engine) and the compression ignition type (hot bulb engine, diesel engine). In a spark ignition engine the fuel is ignited by an electric spark, and in the diesel engine by the compression temperature of the air.

(g) Operating cycle

The fuel combustion takes place in the engine during its cycle, which consists of several phases such as fuel combustion, exhaust, air suction and compression.

The reciprocating type internal combustion engine is subdivided into two types according to the number of strokes in a cycle: the two-stroke engine and the four-stroke engine. The word stroke means the complete travel of a piston sliding in the cylinder. The two-stroke engine completes its combustion cycle in two strokes (one rotation of the crankshaft), while the four-stroke engine completes it in four strokes (two rotations of the crankshaft.) A further, more detailed discussion of this process appears in sub-paragraphs 2.2.1 and 2.2.2.