# 10

# Hydraulic Machines

## Contents

## 10.1 Introduction to Hydraulic Systems

A hydraulic system is a circuit in which the forces and power are transmitted through a liquid. The hydraulic system may be divided into two groups: 1) Hydrostatic System and 2) Hydrodynamic System.

In the hydrostatic system, the force and power will be transmitted by the hydrostatic pressure of the fluid.

In the hydrodynamic system, the force and power will be transmitted by changing the velocity and direction of the fluid.

## 10.2 Hydraulic Press

**Function:**

*"The hydraulic press is a device used for lifting heavy weights by the application of a much smaller force."*

**Principle:**

The hydraulic press is based on *Pascal's law*, which states that the intensity of pressure in a static fluid is transmitted equally in all the directions.

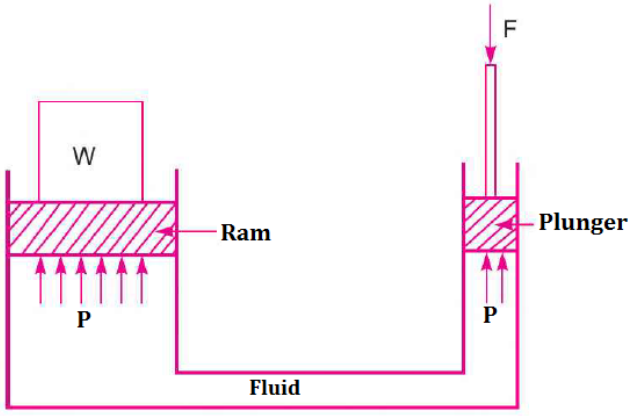


*Fig.10.1 – Hydraulic Press*

**Construction & Working:**

It consists of two cylinders of different diameters.

The cylinder with a larger diameter has a sliding **ram**, the load to be raised or lowered is placed on it.

The cylinder with a smaller diameter has a **plunger** that moves upwards or downwards when a force is applied to it as shown in *Fig.10.1*. Sometimes a lever arrangement is used to increase the mechanical advantage as shown in *Fig.10.2*.

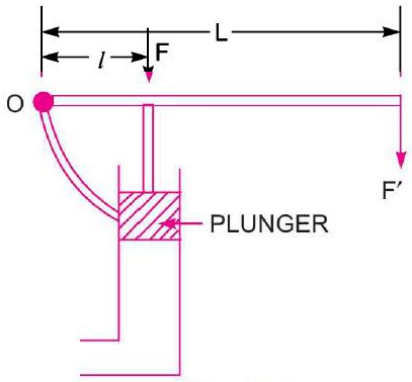


*Fig.10.2 – Lever arrangement*

The two cylinders are interconnected at the bottom and are filled with a liquid (i.e oil) through which pressure is transmitted.

Let,

$W$ = Weight to be lifted

$F$ = Force applied on a plunger

$A$ = Cross-sectional area of the ram

$a$ = Cross-sectional area of the plunger

$P$ = Intensity of pressure produced inside the cylinder

When a small force $(F)$ is applied on the plunger in the downward direction, a pressure $(P)$ is produced on the liquid in contact with the plunger, this pressure is transmitted equally in all directions and acts on the ram in the upward direction and the heavier weight placed on the ram is lifted. Thus,

$$P = \frac{F}{a} = \frac{W}{A}$$

$$\therefore F = W\frac{a}{A}$$

Since $A$ is greater than $a$, the load raised $(W)$ is always greater than the force $(F)$.

**Applications:**

Hydraulic presses may be employed in metal presswork, bending and straightening any metal piece, cotton press, forging press, plate press, packing press, etc.

## 10.3 Hydraulic Accumulator

**Function:**

*"The hydraulic accumulator is a device which stores or accumulates the energy of the fluid in the form of pressure energy when it is not needed and supplies the energy for any sudden or intermittent requirement."*

The hydraulic accumulator works like the flywheel of an engine or electric storage batteries.

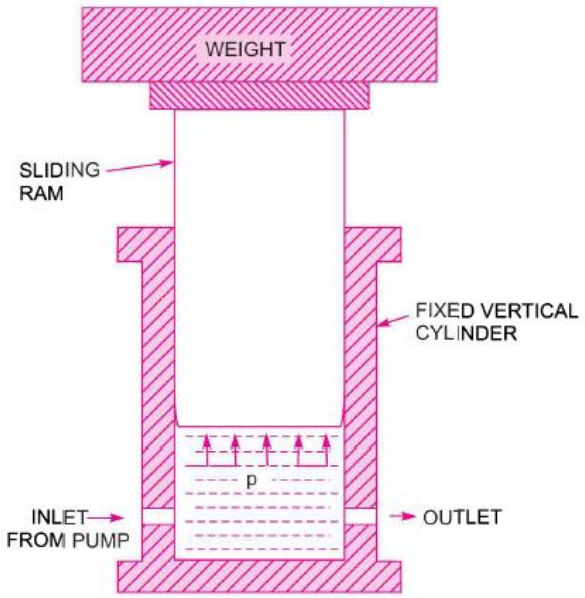


*Fig.10.3 – Simple Hydraulic Accumulator*

**Construction & Working:**

- The hydraulic accumulator consists of a sliding ram, which slides in a fixed vertical cylinder. A heavy weight is placed on the ram as shown in *Fig.10.3*.
- The inlet of the cylinder is connected to the pump, which continuously supplies fluid under pressure to the cylinder and the outlet of the cylinder is connected to the machine (which may be lift, crane, etc.).
- When the machine connected with the accumulator is idle and the pump is running, the high-pressure liquid enters the fixed cylinder from the bottom and it raises the ram.
- This flow of liquid continues until the ram reaches its extreme upper position. As the load is applied on the ram, pressure of the liquid is maintained. Thus the maximum amount of pressure energy is accumulated.
- When the need arises the accumulated energy is discharged to the machine by lowering the ram. When the machine needs the maximum amount of energy it receives pressurised fluid from the pump and accumulator both as discussed above.

**The capacity of Accumulator:**

"It is defined as the maximum amount of hydraulic energy stored in the accumulator."

Let,

$A =$ Area of the sliding ram

$L =$ Stroke or lift of the ram

$P =$ Intensity of water pressure supplied by the pump, and

$W =$ Total weight of ram and load

- An upward force acting on the ram,

$$W = P \times A$$

- The energy stored in the accumulator *or* the maximum work done in lifting the ram *or* capacity of accumulator is given by,

$$= Force \times Distance$$

$$= W \times L$$

$$= P \times A \times L$$

**Applications:**

Generally, the stored energy is used to run hydraulic machines like the hydraulic crane, hydraulic lift, etc. where a high-pressure liquid is needed to supply the energy for lifting the load in upward directions.

## 10.4 Hydraulic Intensifier

**Function:**

*"It is the device, which is used to increase the intensity of pressure using the hydraulic energy available from a large quantity of fluid at low pressure."*

The intensifier is located between the pump and the machine (press, crane, lift, etc.) that needs high-pressure liquid for its operation.

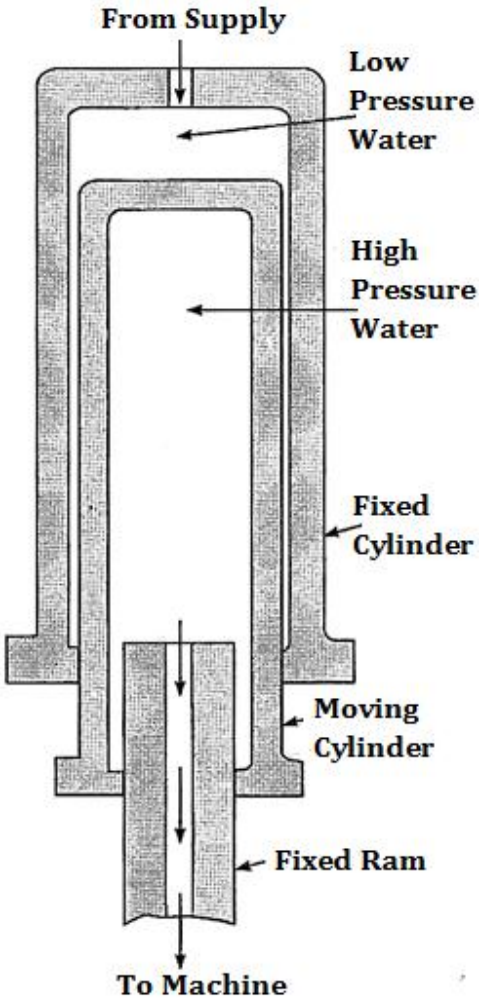


*Fig.10.4 –Hydraulic Intensifier*

**Construction & Working:**

- A hydraulic intensifier consists of a fixed cylinder and the other moving cylinder. It also consists of a fixed ram. The sliding cylinder slides between a fixed ram and the fixed cylinder as shown in *Fig.10.4*.
- Fixed ram has a central passage through which the fluid under high pressure flows to the machine.
- A hollow inverted sliding cylinder, containing fluid under high pressure is mounted over the fixed ram; which is surrounded by another fixed inverted cylinder which contains fluid from the main supply at low pressure.
- A large quantity of fluid at low pressure from supply enters the inverted fixed cylinder. The weight of this fluid moves the sliding cylinder in the downward direction.
- The fluid in the sliding cylinder gets compressed due to the downward movement of the sliding cylinder and its pressure is thus increased. The high-pressure fluid is forced out of the sliding cylinder through the fixed ram, to the machine.

**Applications:**

It is used to run the hydraulic machines such as hydraulic press, lift and crane; which requires fluid at very high pressure; which cannot be obtained from the main supply directly.

## 10.5 Hydraulic Crane

**Function:**

*"Hydraulic crane is a device, used for raising or transferring heavy loads."*

**Construction & Working:**

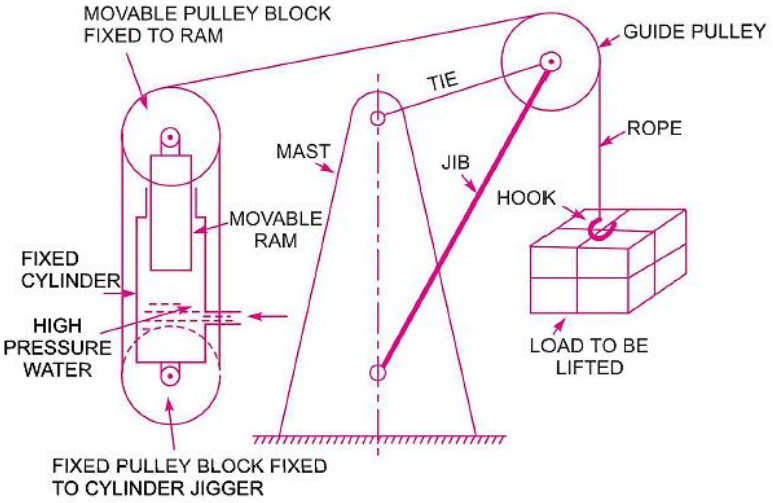


*Fig.10.5 –Hydraulic Crane*

- A hydraulic crane comprises two elements: Craning arrangement and the hydraulic jigger.
- ***Craning arrangement*** consists of a mast, tie, jib and guide pulley as shown in *Fig.10.5*.
- The jib and tie are attached to the mast; the jib can be raised or lowered to decrease or increase the radius of action of the crane.
- The mast along with the jib can revolve about a vertical axis and thus the load attached to the rope can be transferred to any place within the area of the crane's action.
- ***The hydraulic jigger***, which consists of a movable ram sliding in a fixed cylinder, is used for lifting or lowering the heavy loads.
- One end of the ram is in contact with the fluid (water or oil) and the other end is connected to set of movable pulley block and another pulley block, called the fixed pulley block is attached to the fixed cylinder.
- The pulley block, attached to the ram, moves up and down while the pulley block, attached to the fixed cylinder is not having any movement.
- A wire rope, one end of which is fixed to a movable pulley is taken round all the pulleys of the two sets of the pulleys and finally passes over the guide pulley, attached to the jib as shown in *Fig.10.5*.
- The other end of the rope is provided with a hook, for suspending the load.
- For lifting the load by the crane, the fluid under high pressure is admitted into the cylinder of the jigger.
- This fluid forces the sliding ram to move vertically up and due to the movement of the ram in the upwards direction, the movable pulley block attached to the ram also moves upward.
- This increases the distance between two pulley blocks and hence the wire passing over the guide pulley is pulled by the jigger and thus raises the load attached to the hook.

**Applications:**

- It is used in warehouses, workshops, docks, etc. to lift heavy weights.

## 10.6 Hydraulic Lift

**Function:**

*"The hydraulic lift is a device used for carrying passenger or goods from one floor to another in the multi-storeyed building."*

**Construction & Working:**

- A hydraulic lift comprises two elements: Cage and the hydraulic jigger.
- ***Cage*** is suspended from a wire rope using guide pulleys as shown in *Fig.10.6*.
- ***The hydraulic jigger***, which consists of a movable ram sliding in a fixed cylinder.
- One end of the ram is in contact with the fluid and the other end is connected to set of movable pulley block and another pulley block, called the fixed pulley block is attached to the fixed cylinder.

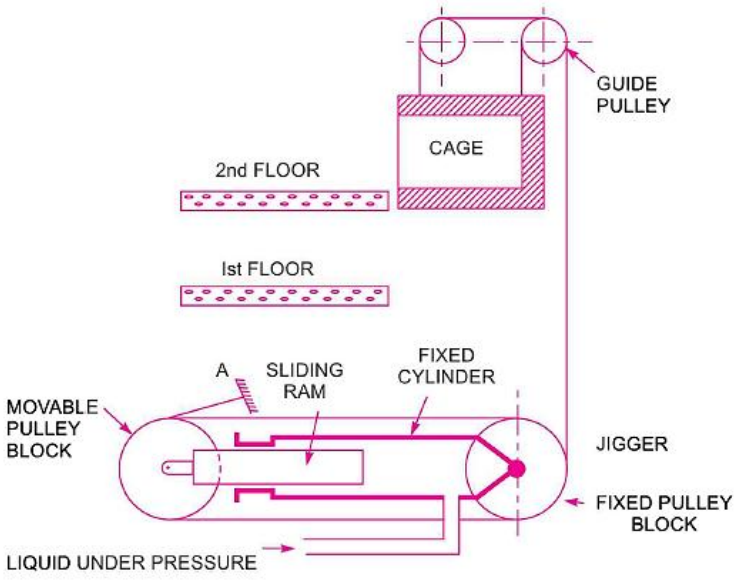


*Fig.10.6 –Hydraulic Lift*

- A wire rope, one end of which is fixed at 'A' and the other end is taken round the movable and fixed pulley blocks and finally passes over the guide pulleys.
- The other end of the rope is provided with a hook, for suspending the cage.
- ***For lifting the cage*** by the lift, the fluid under high pressure is admitted into the cylinder of the jigger. This fluid forces the sliding ram to move towards left and due to the movement of the ram, the movable pulley block attached to the ram also moves towards left. This increases the distance between two pulley blocks and hence the wire passing over the guide pulleys is pulled by the jigger and thus the cage is to be lifted.
- ***For lowering the cage***, water from the fixed cylinder is taken out; thus the sliding ram moves towards the right and hence movable pulley blocks and the cage is lowered due to increased length of the rope.

## 10.7 Hydraulic Ram

**Function:**

*"The hydraulic ram is a device which is used to lift a small quantity of water to a greater height using the energy of a large quantity of water available at low heads."*

It works on the principle of the water hammer effect.

**Construction & Working:**

- *Fig.10.7* shows the construction of a hydraulic ram. It consists of a supply pipe, closed chamber, waste valve (B), delivery valve (C), air vessel and a delivery pipe.

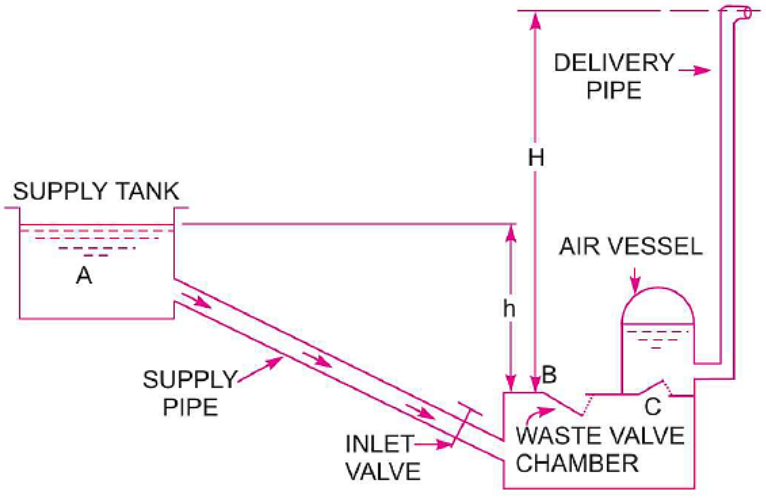


*Fig.10.7 –Hydraulic Ram*

- When the inlet valve fitted to the supply pipe opens, water starts flowing from the supply tank to the chamber, and the level of water rises in the chamber and waste valve 'B' starts moving upward and the stage comes, when the waste valve 'B' suddenly closes.
- This sudden closure of waste valve 'B' creates high pressure inside the chamber and this high-pressure force opens the delivery valve 'C'; thus the water from chamber enters the air vessel and compresses the air inside the air vessel.
- This compressed-air exerts a force on the water in the air vessel and a small quantity of water is raised to a greater height.
- When the water in the chamber loses its momentum, the waste valve 'B' opens in the downward direction and the flow of water from supply tank starts flowing to the chamber and the cycle will be repeated.

**Advantages:**

- No moving parts
- No power requirement
- Inexpensive & less maintenance cost
- Pumping continuously over a longer period of time.

## 10.8 The Fluid or Hydraulic Coupling

**Function:**

*"The fluid or hydraulic coupling is a device used for transmitting power from driving shaft to driven shaft with the help of fluid; without any mechanical connection between the two shafts."*

**Principle:**

It works on the principle of change in the velocity of the working fluid.

**Construction & Working:**

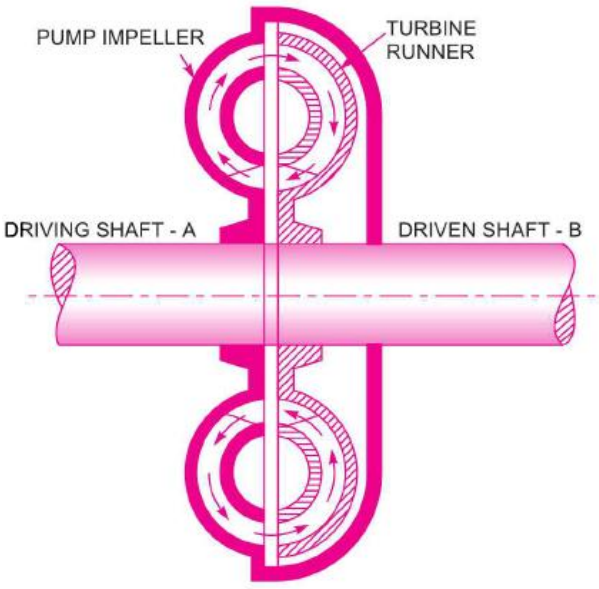


*Fig.10.8 –Hydraulic Coupling*

- It consists of a radial-pump impeller mounted on a driving shaft 'A' and a radial flow reaction turbine mounted on the driven shaft 'B' as shown in *Fig.10.8*.
- Both the impeller and runner are identical in shape and they together form a casing which is completely enclosed and filled with oil. There is no mechanical connection between driving and driven shaft.
- In the beginning, both the shafts 'A' and 'B' are at rest; when the driving shaft 'A' is rotated, the oil will pass through the impeller blades and will flow radially outwards with high energy.
- The fluid will then strike the turbine runners and, while flowing radially inwards, transfer power to the turbine blades.
- With the increase in the speed of shaft 'A', sufficient head is developed in the fluid at the outlet of pump impeller so that the power transferred to the turbine rotor becomes high enough to set the driven shaft 'B' in motion.

- The oil from the runner then flows back into the pump impeller, thus having a continuous circulation.
- Due to slip, the two shafts rotate at different speeds. If both shafts rotate at the same speed, the circulation of oil stops, oil circulates in the system due to the difference of centrifugal force set up in the driver and the driven.
- The slip of the fluid coupling is given by,

$$S = \frac{N_1 - N_2}{N_1}$$

- The efficiency of fluid coupling is given by,

$$\eta = \frac{Output}{Input} = \frac{T_2\omega_2}{T_1\omega_1}$$

Where,
$N_1, \omega_1$ & $T_1$ = Speed, angular velocity and torque of the pump impeller
$N_2, \omega_2$ & $T_2$ = Speed, angular velocity and torque of the turbine runner

- The efficiency of fluid coupling is about 98%.

**Applications:**

- It is used when the driven shaft is required to run at a speed close to that of the driving shaft.
- The large initial loads are involved and smooth free operations are required.
- It is used in automobiles, marine engine and ropeway cable drive units.

## 10.9 Hydraulic Torque Converter

**Function:**

*"The hydraulic torque converter is a device used for transmitting increased or decreased power from driving shaft to driven shaft with the help of fluid."*

**Principle:**

The main difference in the principle of operation between a fluid coupling and fluid torque converter is that while the coupling transmits power with the same torque on driving and a driven shaft, the converter provides for torque multiplication with the same power (neglecting the losses) on driving and driven shaft.

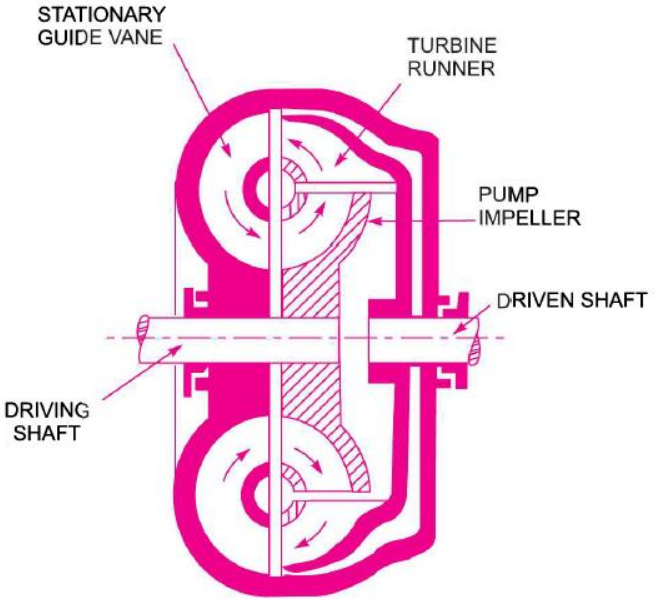


*Fig.10.9 –Hydraulic Torque Converter*

**Construction & Working:**

- In a torque converter, a stationary guide vane (stator) is incorporated between the pump impeller and the turbine rotor as shown in *Fig.10.9*.
- The function of the stator is to increase the torque produced by the driving shaft and then to transmit the increased torque to driven shaft.
- The stator consists of a series of guide vanes through which the fluid flows.

- For a greater torque on the driven shaft, the change in angular momentum in the turbine runner should be greater than that in the pump.
- The stationary blades are so shaped that they increase the angular momentum of fluid and thus it multiply the torque.
- The efficiency of the torque converter is 85 – 87%. The operation of the torque converter is analogous to that of a gearbox in an automobile.
- The increase of torque depends on the design of stationary blades and the speed ratio.

**Applications:**

It is used in diesel locomotives, earthmoving machinery and automobile power transmitting units.

## 10.10 Air Lift Pump

**Function:**

*"It is used to lift water from a deep well or sump by using compressed air."*

**Principle:**

The compressed air is mixed with water and hence the density of the air-water mixture is reduced. The density of this air-water mixture is very much less than that of pure water. Hence a very small column of pure water can balance a very long column of the mixture. This is the principle on which the air lift pump works.

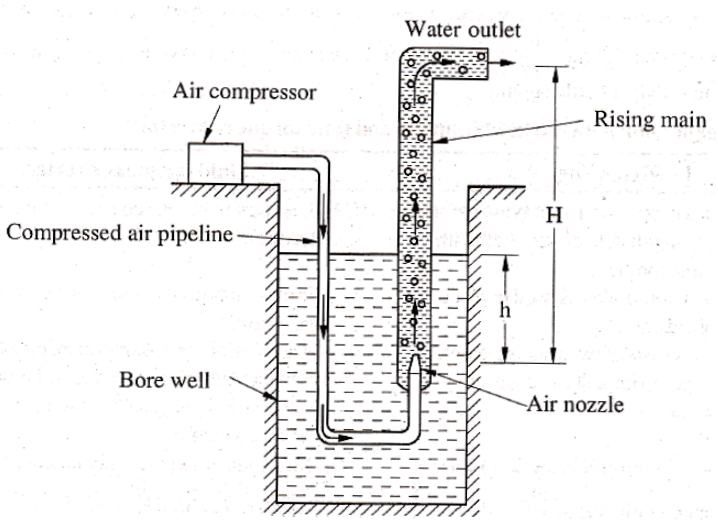


*Fig.10.10 –Air Lift Pump*

**Construction & Working:**

- It consists of 1) an air compressor to supply the compressed air, 2) an air pipe fitted with one or more air nozzles and 3) the delivery pipe as shown in *Fig.10.10*.
- The lower portion of the delivery pipe dips into well and water gets discharged from the upper end of the delivery pipe.
- The compressed air from the compressor is introduced at the bottom end of the delivery pipe through one or more nozzles.
- In the delivery pipe, a mixture of air and water is formed. The density of this air-water mixture becomes very less compared to the density of pure water. Hence a small column of pure water will balance a very long column of the air-water mixture.
- This air-water mixture will be discharged out of the delivery pipe. The flow will continue as long as there is a supply of compressed air.

  Let,

  $h =$ Height of the static water level above the tip of the nozzle

  $H =$ Height to which water is lifted above the tip of the nozzle

- The $(H - h)$ is known as a useful lift. For best results, the useful lift $(H - h)$ should be less than the height of static water $(h)$.

**Advantages:**

- It has no moving parts below water level and hence there are no chances of suspended solid particles damaging the pump.
- It can raise more water through a borehole of given diameter than any other pump.
- Compare to centrifugal pump it is:
  - ✓ Robust, versatile and flexible
  - ✓ Substantially cost-effective (≈50-70% in energy savings)
  - ✓ Lower capital, operation and maintenance costs
  - ✓ Lower operating noise and vibration

**Disadvantages:**

- It has very low efficiency, only 20 to 40% energy available in the form of useful water horse-power.
- It cannot lift water when the level of water in deep well goes down below the limit.
- Quantity of air to compress is high compared to the liquid flow required.
- Suitable only if the head is relatively low. To obtain a high head, one has to choose a conventional pumping system.

**Applications:**

- Mostly used in agriculture.

## 10.11 References


1) R. K. Bansal, "Fluid Mechanics & Hydraulic Machines", 3rd Edition, 2007, Laxmi Publications (P) Ltd.
2) V. L. Patel & Dr. R. N. Patel "Fluid Power Engineering", 4th Edition, 2010-11, Mahajan Publishing House.
3) S. K. Som & G. Biswas, "Introduction to Fluid Mechanics and Fluid Machines", 2nd Revised Edition, 2008, McGraw-Hill Education (India) Pvt. Ltd.
4) D. S. Kumar, "Fluid Mechanics & Fluid Power Engineering", S. K. Kataria & Sons.