CHAPTER 3

BASIC PNEUMATIC AND HYDRAULIC SYSTEMS

INTRODUCTION TO FLUID POWER

A fluid power system transmits and controls energy through the use of pressurized fluid. The term *fluid power* applies to both hydraulics and pneumatics. With hydraulics, that fluid is a liquid such as oil or water. With pneumatics, the fluid is typically compressed air or inert gas. Hydraulics uses oil or liquid as the medium that cannot be compressed and pneumatics, which involves gases, uses air or gas as the medium that can be compressed. It is a term, which was created to collect the generation, control, and application of smooth, effective power of pumped or compressed fluids (either liquids or gases). This power is used to provide force and motion to various mechanisms. This force and motion may be in the form of push, pull, rotate, regulate, or drive.

Fluid power is one of three commonly used methods of transmitting power in an industry; the others are electrical and mechanical power transmission. Electric power transmission uses an electric current flowing through a wire to transmit power. Mechanical power transmission uses gears, pulleys, chains, etc. to transmit power. Fluid power's motive force comes from the principle that pressure applied to a confined fluid is transferred uniformly and undiminished to every portion of the fluid and to the walls of the container that holds the fluid. A surface such as a cylinder piston will move if the difference in force across the piston is larger than the total load plus frictional forces. The resulting net force can then accelerate the load proportionately to the ratio of the force divided by the mass.

Fluid power encompasses most applications that use liquids or gases to transmit power in the form of mechanical work, pressure, and/or volume in the system. This definition includes all systems that rely on pumps and compressors to transmit specific volumes and pressures of liquids or gases within a closed system. Fluid power is used in the steering, brake system, and automatic transmissions of cars and trucks. In addition to the automotive industry, fluid power is used to control airplanes and spacecraft, harvest crops, mine coal, drive machine tools, and process food. Fluid power can be effectively combined with other technologies through the use of sensors, transducers, and microprocessors.

BASIC ELEMENTS OF FLUID POWER SYSTEM

The basic elements of fluid power system are:

- Power device: Pump or Compressor
- Control valves
- Actuators: Cylinders or Motors

Figure 3.1 shows the basic elements of a fluid power system connected by fluid power lines. These elements are discussed in detail in next chapters.

ADVANTAGES AND DISADVANTAGES OF FLUID POWER

Advantages

There are few advantages, which make fluid power so popular. These are listed below:

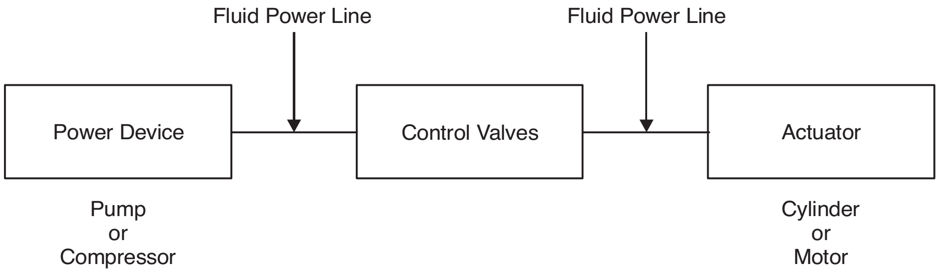

FIGURE 3.1 Elements of Fluid Power System.

- **No need of intermediate equipment:** They eliminate the need for complicated systems of gears, cams, and levers. Motion can be transmitted without the slack inherent in the use of solid machine parts.
- **Less wear and tear:** The fluids used are not subject to breakage as are mechanical parts, and the mechanisms are not subjected to great wear.
- **Multi-function control:** A single hydraulic pump or air compressor can provide power and control for numerous machines or machine functions when combined with fluid power manifolds and valves.
- **Constant force or torque:** This is a unique fluid power attribute.
- **Flexibility:** Hydraulic components can be located with considerable flexibility. Pipes and hoses instead of mechanical elements virtually eliminate location problems.
- **Comparatively small pressure losses:** The different parts of a fluid power system can be conveniently located at widely separated points, because the forces generated are rapidly transmitted over considerable distances with small loss. These forces can be conveyed up and down or around corners with small loss in efficiency and without complicated mechanisms.
- **Multiplication and variation of force:** Very large forces can be controlled by much smaller ones and can be transmitted through comparatively small lines and orifices. Linear or rotary force can be multiplied from a fraction of an ounce to several hundred tons of output.
- **Accurate and easy to control:** We can start, stop, accelerate, decelerate, reverse, or position large forces with great accuracy.
- **High horsepower and low weight:** Pneumatic components are compact and lightweight.
- **Smoothness:** Fluid systems are smooth in operation. Vibration is kept to a minimum.

- **Overload protection:** In case of an overload, an automatic release of pressure can be guaranteed; automatic valves guard the system against a breakdown from overloading so that the system is protected against breakdown or strain.
- **Wide variety of motions:** Fluid power systems can provide widely variable motions in both rotary and straight-line transmission of power.
- **Low speed torque:** Unlike electric motors, air or hydraulic motors can produce large amounts of torque (twisting force) while operating at low speeds. Some hydraulic and air motors can even maintain torque at zero speed without overheating.
- **Less human intervention:** The need for control by hand can be minimized.
- **Low operating costs:** Fluid power systems are economical to operate their high efficiency with minimum friction loss keeps the cost of a power transmission at a minimum.
- **Safety in hazardous environments:** Fluid power can be used in mines, chemical plants, near explosives, and in paint applications because it is inherently spark-free and can tolerate high temperatures.
- **Better force control:** Force control is much easier with fluid systems than for electric motors. Fluid actuators, either hydraulic or pneumatic, are well suited to walking robots because they are high force, low speed actuators. They provide much higher force densities than electric systems.
- **Simpler design:** In most cases, a few pre-engineered components will replace complicated mechanical linkages.

Disadvantages

The main disadvantage of a fluid system is maintaining the precision parts when they are exposed to bad climates and dirty atmospheres. Protection against rust, corrosion, dirt, oil deterioration, and other adverse environmental conditions is very important.

APPLICATIONS OF FLUID POWER

Mobile

Fluid power is used to transport, excavate, and lift materials, as well as control or power mobile equipment. End use industries include construction, agriculture, marine, and the military. Applications include backhoes, graders, tractors, truck brakes and suspensions, spreaders, and highway maintenance vehicles.

Industrial

Fluid power is used to provide power transmission and motion control for the machines of industry. End use industries range from plastics to paper production. Applications include metal working equipment, controllers, automated manipulators, material handling, and assembly equipment.

Aerospace

Fluid power is used for both commercial and military aircraft, spacecraft, and related support equipment. Applications include landing gear, brakes, flight controls, motor controls, and cargo loading equipment.

PNEUMATICS VS. HYDRAULICS

Fluid power can be broadly divided into two fields: *pneumatics and hydraulics*. Both pneumatics and hydraulics are applications of fluid power.

Pneumatic systems use compressed gas such as air or nitrogen to perform work processes whereas hydraulic systems use liquids such as oil and water to perform work processes. Pneumatic systems are open systems, exhausting the compressed air to the atmosphere after use whereas hydraulic systems are closed systems, recirculating the oil or water after use.

A fluid power system uses hydraulics or pneumatics to deliver extremely powerful pushing and pulling forces to machinery. Much of the factory equipment used to lift and move large components is powered by hydraulics. For example, forklift trucks, opencast mining equipment, and multi-purpose agricultural spraying equipment all use hydraulic systems to operate their lifting arms. Pneumatics, on the other hand, are used for a variety of purposes that include delivering power to tools like jack hammers, air guns, and complex industrial equipment for conveying, separating, and air handling goods.

The extensive use of hydraulics and pneumatics to transmit power is due to the fact that properly constructed fluid power systems possess a number of favorable characteristics. They eliminate the need for complicated systems of gears, cams, and levers. The fluids used are not subject to breakage as are mechanical parts, and the mechanisms are not subjected to great wear.

Some points of difference between hydraulics and pneumatics are shown in Table 3.1.

TABLE 3.1 Difference between Hydraulics and Pneumatics.

	Pneumatics	*Hydraulics*
Pressure level	5–10 bar	Up to 200 bar
Actuating forces	Pneumatic actuators can produce only low or medium size forces.	Hydraulic actuators are suitable for very high loads.
Element cost	Pneumatic elements such as cylinders and valves are less costly as compared to hydraulic elements.	Hydraulic elements can cost from 5 to 10 times more than similar size pneumatic elements.
Transmission lines	Transmission lines in pneumatics are made up of inexpensive flexible plastic tubing. Only single line is needed in pneumatics to simply exhaust the air into atmosphere.	Transmission lines in hydraulics are made up of metal tubing with expensive fittings to withstand high working pressure and to avoid leaks. Also return lines are needed in hydraulics to return the oil from each cylinder back to reservoir.
Stability	Low stability because air is compressible.	High stability because oil is incompressible.
Speed control	Difficult to control the speed of pneumatic cylinders or motors.	Easy to control the speed.

ADVANTAGES AND DISADVANTAGES OF PNEUMATICS

Advantages

- Pneumatic systems are clean because they use compressed air. If a pneumatic system develops a leak, it will be air that escapes and not oil.
- Pneumatic systems are cheaper to run than other systems.
- Inherently modulating actuators and sensors.
- Explosion proof components.
- High efficiency, example, a relatively small compressor can fill a large storage tank to meet intermittent high demands for compressed air.
- Ease of design and implementation.

- High reliability, mainly because of fewer moving parts.
- Compressed gas can be stored, allowing the use of machines when electrical power is lost.
- Easy installation and maintenance.

Disadvantages

- Low accuracy and control limitation because of compressibility.
- Noise pollution.
- Leakage of air can be of concern.
- Need for a compressor producing clean and dry air.
- Cost of air piping.
- Need for regular component calibration.

ADVANTAGES AND DISADVANTAGES OF HYDRAULICS

Advantages

- Through the use of simple devices, an operator can readily start, stop, speed up, slow down, and control large forces with very close and precise tolerance.
- High power output from a compact actuator.
- Hydraulic power systems can multiply forces simply and efficiently from a fraction of an ounce to several hundred tons of output.
- Force can be transmitted over distances and around corners with small losses of efficiency.
- There is no need for complex systems of gears, cams, or levers to obtain a large mechanical advantage.
- Extreme flexibility of approach and control. Control of a wide range of speed and forces is easily possible.
- Safety and reliability.
- Hydraulic systems are smooth and quiet in operation. Vibration is kept to a minimum.

Disadvantages

- Hydraulic systems are expensive.
- System components must be engineered to minimize or preclude fluid leakage.

- Protection against rust, corrosion, dirt, oil deterioration, and other adverse environment is very important.
- Maintenance of precision parts when they are exposed to bad climates and dirty atmospheres.
- Fire hazard if leak occurs.
- Adequate oil filtration must be maintained.

APPLICATIONS OF PNEUMATICS

- Operation of heavy or hot doors
- Lifting and moving in slab moulding machines
- Spray painting
- Bottling and filling machines
- Component and material conveyor transfer
- Unloading of hoppers in building, mining, and chemical industry
- Air separation and vacuum lifting of thin sheets
- Dental drills

APPLICATIONS OF HYDRAULICS

- Machine tool industry
- Plastic processing machines
- Hydraulic presses
- Construction machinery
- Lifting and transporting
- Agricultural machinery

BASIC PNEUMATIC SYSTEM

Pneumatic systems use pressurized air to make things move. A basic pneumatic system consists of an air generating unit and an air-consuming unit. Air compressed in a compressor is not ready for use. The air has to be filtered, the moisture present in air has to be dried, and, for different applications in the plant, the pressure of air has to be varied. Several other treatments are given to the air before it reaches finally to the actuator. Figure 3.2 gives an overview of a basic pneumatic system. Some accessories are added for economical and efficient operation of system.

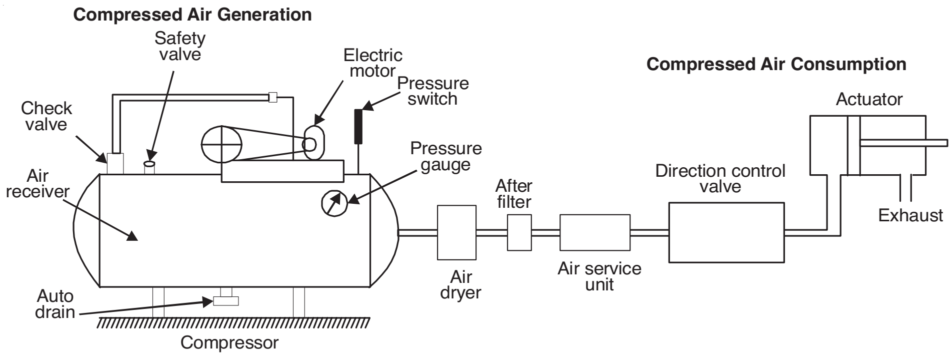

FIGURE 3.2 Basic Pneumatic System.

A typical pneumatic power system includes the following components:

1. Compressor	2. Electric motor
3. Air receiver	4. Pressure switch
5. Safety valve	6. Auto drain
7. Check vlve	8. Pressure gauge
9. Air dryer	10. After filter
11. Air service unit	12. Direction control valve
13. Pneumatic actuator	

1. **Compressor:** A device, which converts mechanical force and motion into pneumatic fluid power, is called a compressor. Every compressed-air system begins with a compressor, as it is the source of airflow for all the downstream equipment and processes.

2. **Electric Motor:** An electric motor is used to drive the compressor.

3. **Air Receiver:** An air receiver is a container in which air is stored under pressure.

4. **Pressure Switch:** A pressure switch is used to maintain the required pressure in the receiver. It adjusts the *high pressure limit* and *low pressure limit* in the receiver. The compressor is automatically turned off when the pressure is about to exceed the high limit and it is also automatically turned on when the pressure is about to fall below the low limit.

5. **Safety Valve:** The function of the safety valve is to release extra pressure if the pressure inside the receiver tends to exceed the safe pressure limit of the receiver.

6. **Auto Drain:** Air condenses to give out water in the receiver and a device called auto drain directs this water out.
7. **Check Valve:** The valve enables flow in one direction and blocks flow in a counter direction is called check valve. Once compressed air enters the receiver via check valve, it is not allowed to go back even when the compressor is stopped.
8. **Pressure Gauge:** The pressure gauge tells us the pressure inside the compressor receiver.
9. **Air Dryer:** A device for reducing the moisture content of the working compressed air.
10. **After Filter:** A filter that follows the compressed air dryer and usually used for the protection of downstream equipment from desiccant dust, etc. is called an after filter. The name filter refers to a device whose primary function is the removal of insoluble contaminants from a liquid or a gas with the help of porous media.
11. **Air Service Unit:** Filter, regulator, and lubricator combined in one device is popularly known as an air service unit or F.R.L unit. Its purpose is to supply air to other successive applications in the line. It provides clean air at the required pressure with lubricant added to it to increase the life of equipment.
12. **Direction Control Valve:** Directional-control valves are devices used to change the flow direction of fluid within a pneumatic/hydraulic circuit. They control compressed-air flow to cylinders, rotary actuators, grippers, and other mechanisms in packaging, handling, assembly, and countless other applications. These valves can be actuated either manually or electrically.
13. **Pneumatic Actuator:** A device in which power is transferred from one pressurized medium to another without intensification. Pneumatic actuators are normally used to control processes requiring quick and accurate response, as they do not require a large amount of motive force. They may be reciprocating cylinders, rotating motors, or may be robot end effectors.

A few more components can be added to the system; first, an air intake filter and second, an air intercooler (if a multistage compressor is used). The function of the former is to prevent the entry of vast quantities of dust and dirt along with air and the latter is to cool the air again to room temperature after it is discharged from the low-pressure compressor.

BASIC HYDRAULIC SYSTEM

Figure 3.3 gives an overview of a basic hydraulic system.

A typical hydraulic power system includes the following components:

1. Electric motor
2. Hydraulic pump
3. Strainers and filters
4. Pressure gauge
5. Pressure relief valves
6. Check valve
7. Direction control valve
8. Hydraulic actuator
9. Reservoir

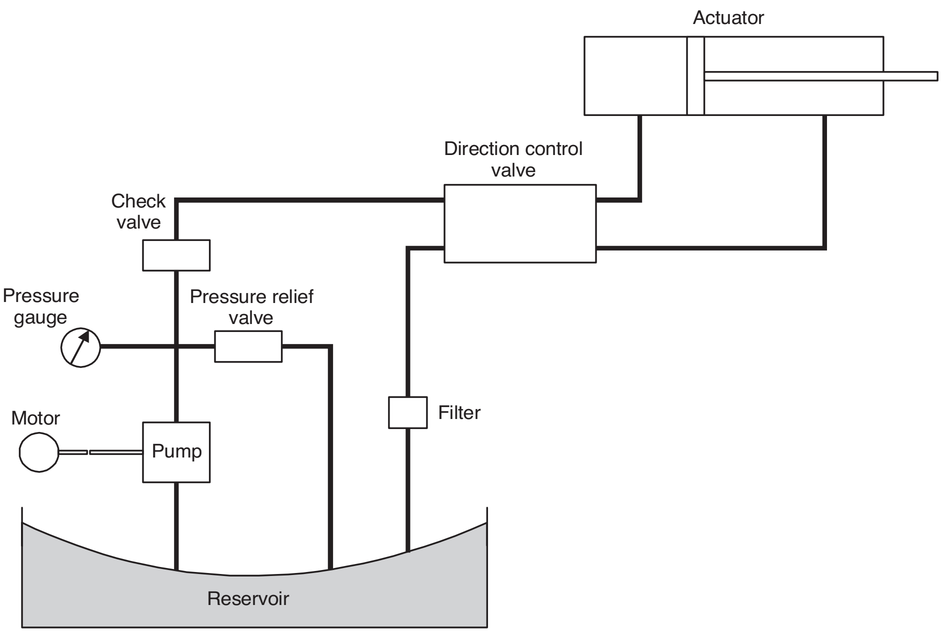

FIGURE 3.3 Basic Hydraulic System.

1. **Electric Motor:** An electric motor is used to drive the pump.
2. **Hydraulic Pump:** Hydraulic pumps convert mechanical energy from a prime mover (engine or electric motor) into hydraulic (pressure) energy.

The pressure energy is used then to operate an actuator. Pumps push on a hydraulic fluid and create flow.

3. **Strainers and Filters:** To keep hydraulic components performing correctly, the hydraulic liquid must be kept as clean as possible. Foreign matter and tiny metal particles from normal wear of valves, pumps, and other components are going to enter a system. Strainers, filters, and magnetic plugs are used to remove foreign particles from a hydraulic liquid and are effective as safeguards against contamination.

***Strainers*:** A strainer is the primary filtering system that removes large particles of foreign matter from a hydraulic liquid. Even though its screening action is not as good as a filter's, a strainer offers less resistance to flow.

***Filters*:** A filter removes small foreign particles from a hydraulic fluid and is most effective as a safeguard against contaminates. They are classified as full flow or proportional flow:

(*a*) *Full-Flow Filter*: In a full-flow filter, all the fluid entering a unit passes through a filtering element. Although a full-flow type provides a more positive filtering action, it offers greater resistance to flow, particularly when it becomes dirty.

(*b*) *Proportional-Flow Filters*: This filter operates on the venturi principle in which a tube has a narrowing throat (venturi) to increase the velocity of fluid flowing through it. Flow through a venturi throat causes a pressure drop at the narrowest point. This pressure decrease causes a sucking action that draws a portion of a liquid down around a cartridge through a filter element and up into a venturi throat.

4. **Pressure Gauge:** A pressure gauge tells us the pressure of fluid going into the valve.

5. **Pressure Relief Valves:** Relief valves are the most common type of pressure-control valves. The relief valves function may vary, depending on a system's needs. They can provide overload protection for circuit components or limit the force or torque exerted by a linear actuator or rotary motor. The internal design of all relief valves is similar. The valves consist of two sections: a body section containing a piston that is retained on its seat by a spring(s), depending on the model, and a cover or pilot-valve section that hydraulically controls a body piston's movement. The adjusting screw adjusts this control within the range of the valves. Valves that provide emergency overload protection do not operate as often

because other valve types are used to load and unload a pump. However, relief valves should be cleaned regularly by reducing their pressure adjustments to flush out any possible sludge deposits that may accumulate. Operating under reduced pressure will clean out sludge deposits and ensure that the valves operate properly after the pressure is adjusted to its prescribed setting.

6. **Check Valve:** Check valves are the most commonly used in fluid-powered systems. They allow flow in one direction and prevent flow in the other direction. They may be installed independently in a line, or they may be incorporated as an integral part of a sequence, counterbalance, or pressure-reducing valve. The valve element may be a sleeve, cone, ball, poppet, piston, spool, or disc. Force of the moving fluid opens a check valve; backflow, a spring, or gravity closes the valve.

7. **Direction Control Valve:** Directional-control valves are devices used to change the flow direction of fluid within a pneumatic/hydraulic circuit. They control compressed-air flow to cylinders, rotary actuators, grippers, and other mechanisms in packaging, handling, assembly, and countless other applications.

8. **Hydraulic Actuator:** A hydraulic actuator receives pressure energy and converts it to mechanical force and motion. An actuator can be linear or rotary. A linear actuator gives force and motion outputs in a straight line. It is more commonly called a cylinder but is also referred to as a ram, reciprocating motor, or linear motor. A rotary actuator produces torque and rotating motion. It is more commonly called a hydraulic motor or motor.

9. **Reservoir:** A reservoir stores a liquid that is not being used in a hydraulic system. It has many other important functions as well.

- It also allows gases to expel and foreign matter to settle out from a liquid.
- It functions as a cooler.
- It functions as a “coarse strainer,” providing sedimentation of impurities.
- It functions as an air and water separator.
- It functions as a foundation for pumps, etc.

A properly constructed reservoir should be able to dissipate heat from the oil, separate air from the oil, and settle out contaminates that are in it. It should be high and narrow rather than shallow and broad. The oil level should be as high as possible above the opening to a pump’s suction line. This prevents the vacuum at the line opening from causing a vortex or whirlpool effect, which would mean that a system is probably taking in air. Most mobile equipment reservoirs are located above the pumps. This creates a flooded-pump-inlet condition. This condition reduces the possibility of pump cavitation; a condition where all the available space is not filled and often metal parts will erode. Most reservoirs are vented to the atmosphere. A vent opening allows air to leave or enter the space above the oil as the level of the oil goes up or down. This maintains a constant atmospheric pressure above the oil.

HYDRAULIC SYSTEM DESIGN

Each component in the system must be compatible with and form an integral part of the system. Example, an inadequate size filter on the inlet of a pump can cause cavitation and subsequent damage to the pump. Each component in the system has a maximum rated speed, torque, or pressure. Loading the system beyond the specifications increases the possibility of failure.

All lines must be of proper size and free of restrictive bends. An undersized or restricted line results in a pressure drop in the line itself. Some components must be mounted in a specific position with respect to other components or lines. The housing of an in-line pump, for example, must remain filled with fluid to provide lubrication.

Systems should be designed for correct operating pressures. The correct operating pressure is the lowest pressure, which will allow adequate performance of the system function and still remain below the maximum rating of the components and machine. Always set and check pressures with a gauge.

FLUIDS USED IN HYDRAULICS

The oil in a hydraulic system must first and foremost transfer energy, but the moving parts in components must also be lubricated to reduce friction and consequent heat generation. Additionally, the oil must lead dirt particles and friction heat away from the system and protect against corrosion. Oil requirements include:

- Good lubricating properties.
- Good wear properties.

- Suitable viscosity.
- Good corrosion inhibitor.
- Good anti-aeration properties.
- Reliable air separation.
- Good water separation motor oil.

Liquids being used include mineral oil, water, phosphate ester, water-based ethylene glycol compounds, and silicone fluids. The three most common types of hydraulic liquids are petroleum-based, synthetic fire-resistant, and water-based fire-resistant.

Petroleum-Based Fluids

The most common hydraulic fluids used are the petroleum-based oils. These fluids contain additives to protect the fluid from oxidation (antioxidant), to protect system metals from corrosion (anticorrosion), to reduce tendency of the fluid to foam (foam suppressant), and to improve viscosity.

Synthetic Fire-Resistant Fluids

Petroleum based oils contain most of the desired properties of a hydraulic liquid. However, they are flammable under normal conditions and can become explosive when subjected to high pressures and a source of flame or high temperatures. Nonflammable synthetic liquids have been developed for use in hydraulic systems where fire hazards exist.

Water-Based Fire-Resistant Fluids

The most widely used water-based hydraulic fluids may be classified as water-glycol mixtures and water-synthetic base mixtures. The water-glycol mixture contains additives to protect it from oxidation, corrosion, and biological growth and to enhance its load-carrying capacity. Fire resistance of the water mixture fluids depends on the vaporization and smothering effect of steam generated from the water. The water in water-based fluids is constantly being driven off while the system is operating. Therefore frequent checks to maintain the correct ratio of water are important.

EXERCISES

1. Define fluid power.
2. What are the different fluid power elements? Discuss.

3. What is the difference between fluid power and hydraulics and pneumatics?
4. Discuss the basic elements of an automated system.
5. What are the advantages and disadvantages of fluid power?
6. Distinguish between hydraulic and pneumatic systems.
7. What are the properties of pneumatic energy that make it a fit for the engineering applications?
8. What are the advantages of hydraulics over pneumatics?
9. Discuss the application of hydraulics in automation.
10. Compare the different features of a hydraulic system with those of a pneumatic system.
11. Draw a sketch of a hydraulic system and explain its components.
12. Draw a sketch of a pneumatic system and explain its components.
13. List the applications of hydraulics and pneumatics.
14. Discuss the various types of fluid used in hydraulics.
15. What are the reasons for pressure drop in hydraulics?