

A Text Book Of Water Supply Engineering

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Water Supply

I

INTRODUCTION

1.1 General Considerations :

Water is absolutely essential to all life, both animal and plant. In order to survive, all animals and plants must have ample supply of water. A water supply which is differ for human consumption is essential to all life.

It is difficult to imagine any clean and sanitary environment without water. Invariably, the progress of sanitation throughout the world has been closely associated with the availability of water ; and, the larger the quantity and the better the quality of the water, the more rapid and extensive has been the advance of public health. The history of public health is filled with both tragic and glorious milestones in which water was the important factor.

Man uses water not only for drinking and curlinary purposes, but also for bathing, washing, laundering, heating and air-conditioning, for agricultures, stock raising and gardens, for industrial processes and cooling, for water power and steam power, for fire protection, for disposal of wastes, for fishing, swimming, boating and other recreational purposes, for fish and wild life propagation, for navigation and for engineering constructions. Therefore, every activity of man involves some use of water. Yet man's assessment of the value of water is very low until he finds himself without it.

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While man has always recognized the importance of water for his internal bodily needs, his recognition of its importance to health is a more recent development, dating back only a century or so. Since that time, much has been learned about the role of inadequate and contaminated water supplies in the spread of water-borne diseases. Among the first diseases recognized to be water-borne were cholera and typhoid fever. Later, dysentery, gastro-enteritis and other diarrhoeal diseases were added to the list. More recently, water has also been shown to play an important role in the spread of certain virus diseases such as infectious hepatitis (Jaundice).

Water is involved in the spread of communicable diseases in essentially two ways. The first is the well known direct ingestion of the infectious agent when drinking contaminated water (e.g. dysentery, typhoid and other gastro-intestinal diseases). The second is due to a lack of sufficient water for personal hygiene purposes. Inadequate quantities of water for the maintenance of personal hygiene and environmental sanitation have been shown to be major contributing factors in the spread of epidemic diseases. Adequate supplies of water for personal hygiene also diminish the probability of transmitting some of the gastro-intestinal diseases mentioned above. The latter type of interaction between water and the spread of diseases has been recognized by various public health organizations in

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developing countries which have been trying to provide adequate quantities of water of reasonable, though not entirely satisfactory, quality.

Health problems related to the inadequacy of water supplies are universal but, generally, of greater magnitude and significance in the underdeveloped and developing nations. It has been estimated that about two-thirds of the population of the developing countries obtain their water from contaminated sources. The World Health Organization (WHO) estimates that each year 500 million people suffer from diseases associated with unsafe water supplies. Due largely to poor water supplies, an estimated 5,000,000 infants die each year from diarrhoeal diseases.

In addition to the human consumption and health requirements, water is also needed for agricultural, industrial and other purposes. Though all of these needs are important, water for human consumption and sanitation is considered to be of greater social and economic importance since the health of the people influences all other activities.

1.2 Engineering Aspects of Water Supply :

The planning, design, construction, supervision and maintenance of water supply systems to supply potable water to communities have long been the responsibility of Civil Engineers in every country of the world. Civil Engineers with an understanding of water quality manage-

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ment and sewage treatment and disposal, are known as Sanitary Engineers, but they are also called Public Health Engineers or Environmental Engineers.

The important role that the Public Health Engineers have to play is to provide communities with adequate potable water supplies, facilities for sewage and refuse collection, treatment and disposal, safe recreational areas, and a healthy environment within homes and the places of employment. Many other factors concerned with aesthetics, economic, recreation, and other elements of better living are important consideration and have become part of the responsibilities of the modern Public Health Engineers.

Even in its most specific sense in an engineering enterprise, satisfactory development of water supply and waste-water schemes depends upon hydrologic, and geologic information that can be made available only by decades of institutionalization, orderly observations, recording, and analysis, and also upon the sound knowledge of hydraulics, structural engineering chemistry and microbiology. The planning, design, construction and operation of modern urban water supply and wastewater systems are complex undertakings. The entire works must legally, hygienically, aesthetically and economically defined. Since science, engineering and technology have advanced very much there must be support from teaching research and professional institutions deeply concerned with the advancements of the

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underlying sciences, engineering and technologies of water supply for the successful planning, design, construction, and operation of modern water supply systems.

1.3 History and Development of Water Supplies:

Water supply has its history, its archeology, its literature, its science, its engineering and technology. There was no truer sign of civilization and culture without good water supply. A knowledge of history and development of water supplies is highly desirable to emphasize changes in practice. The story of water supply begins with the growth of ancient capital cities, or religious or trade centres. Constructed as works of considerable magnitude and complexity, their remnants are monuments to sound, yet daring feats of early Civil Engineers. The relatively recent development of present day water supply systems is as ancient as the history of man. Water-works structures are found in excavation of prehistoric ruins. The remains of Lake Moeris in Egypt indicates its construction about 2000 B.C. It was the largest of the reservoirs of the Nile Valley which is believed to supply water for 20,000,000 people.

The water supply of towns in very early times was derived from large tanks excavated on minor drainage lines which collected and stored the rainfall in the wet season to provide a supply during the dry periods. Especially notable are the structures of water supply, drainage, sewerage and

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swimming pool of Mohenjodaro civilization in the Indus Valley. In Egypt, Babilonia, and Assyria flat countries traversed by rivers subject to floods, water was supplied by means of open canals with large storage basins. Wells were also used in many countries in ancient times to utilize the underground waters which were collected from them by simple mechanical devices, still to be seen in Egypt and India. Wells are also known to have been used at remote periods in ancient Greece and Italy and artesian wells were sunk in China in very early times. Ancient China possesses the deepest well in the world as it was known to be 1500 ft deep. In ancient Greece and Egypt, deep wells as deep as 300 ft below ground level and wells ranging in depth from 100 to 200 ft even now exist in India.

The numerous conduits which supplied water to ancient Jerusalem are very old, no exact date can be assigned to their construction but they probably go back to the times of the Kings of Judah, 600 to 900 B.C. The two most important of these conduits were carried at different levels to the city from a large reservoir consisting of the three pools of Solomon, built in three terraces, the height was 40 ft. above the ground level. The conduits were rock-cut canals partly built in masonry. Valleys were crossed by syphons formed of large pierced stones embedded in rubble masonry.

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The water supply for the city of Rome is one of the marvels of ancient times. The water was brought from the surrounding hills in aqueducts totalling about 385 miles in length. The first aqueduct, the Appia, was 10 miles long and was built in 312 B. C. All of these aqueducts were constructed along the hydraulic grade line in order to avoid the necessity for building pressure conduits. Iron pipe was unknown at that time. Lead was the only material available to carry water under pressure as lead was not suitable for high pressure, it was necessary to convey water at atmospheric pressure in aqueducts. The Greeks were very skilful in their methods of bringing water to their towns in conduits along the contour, lines of hills or through tunnels. Distribution through pipes was probably unknown to the ancients. London was perhaps the first modern city in the world which at the end of the 16th century used lead pipes for conveyance or distribution of water. After this, for many years wood pipes bored out of logs came to be used and in some parts of Europe such pipes are still in use.

Most of the early water supplies were contaminated by various impurities and the people did not know the science and technology required to purify water to make it safe. People suffered much from various water-borne diseases. The men who first raised the objection to drink impure water and tried to purify it included engineers, scientists, doctors, lawyers, writers and statesmen. Notable among

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engineers were John Gibb (designed and constructed the first water filter at Paisley in Scotland, U.K. in 1804). James Simpson (designed and built a sizeable water filter for the Chelsea Water Company to improve its supply from the Thames River, England, in 1829) and James P. Kirkwood (designed and built the first sizeable water filter at Poughkeepsie in New York: USA, in 1871).

Among the lawyers were Sir Edwin Chadwick (England, 1842) and Lemuel Snattuck (Boston, USA, 1850: who first told the public not to drink polluted water.

Famous among the doctors were Sir (Dr.) John Simon (first medical officer of health of London City, 1842) and Dr. Stephen Smith (general practitioner of New York City, 1850) who demanded the purity of public water supplies. Two researchers of medical profession of England also accelerated the revolution against drinking of polluted waters: they were Dr. John Snow who in 1849 demonstrated to the world not yet blessed by the discoveries of Louis Pasteur, the role of faecal pollution of drinking water in the epidemics of cholera and Dr. William Budd who from 1857 onward investigated the water-borne diseases specially, Typhoid fever, its nature, mode of spreading and prevention.

Among writers, Charles Dickens commented on the polluted water of the Thames River and urged the

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government to adopt necessary steps to purify the water supplied to the public in England (1850).

Therefore, the science, engineering and technology of modern water supply systems were contributed by the combined efforts of engineers, chemists, biologists, doctors, geologists, economists and other specialists in the natural and social sciences.

The modern renaissance in water-works design, construction and operation was marked at the start of the nineteenth century by invention of steam-driven pumping machinery and of cast iron. The first steam-driven pumping engine is said to have been installed in London in 1887. Previous to this, pump-driven by the river current have been used. The first steam-pumping engine in the United States was installed in Philadelphia water-works in 1800. Cast iron pipe conveyance of water was laid in Philadelphia in 1804 and in London in 1807. Public water supplies in the United States date from 1652 at Boston.

Ancient water supply systems did not have proper treatment methods. Although some cities were able to collect safe water from uninhabited regions and thereby reduce water-borne diseases to some extent ; many others found their supplies dangerously polluted and that the danger was increasing as population increased upon watersheds. Accordingly, some treatment methods, such as sedimentation, were developed, which when properly

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applied, eliminated the hazard to some extent. The theory of water filtration was conceived by the engineers early in the 19th century, but city councils were slow to be convinced of the necessity for spending money to save lives, and the water treatment methods were not widely adopted until about 1909. When slow-sand filters were introduced in England in 1906, an immediate reduction in Typhoid fever occurred. This epidemic was further checked by disinfection of filtered water with chlorine. A still greater decrease was accomplished after 1920 by careful control over infected persons, who had become carriers.

As progress and civilization advance, the difficulty of obtaining water becomes greater, because the population of towns increases to such an extent that the existing sources of natural supplies are neither within an easy reach of the majority of the public, nor are they sufficient. The requirements for municipal, trade and manufacturing purposes grow considerably. The sources were inadequate and got contaminated in dry season and became sources of danger. Cholera, typhoid, dysentery and diarrhoea were found in epidemic form. Hence, public water supply schemes, which could deliver pure water to the houses, industries, public places and trade centres, were urgently felt by the authority concerned to be installed.

In our country, water supply on modern lines is comparatively of recent origin. The first water works for the

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supply of water to Dacca City was completed by the Nawab of Dacca (Sir Nawab Abdul Ghani) in early eighteenth century. After this, water-works were constructed by the Government at Chandpur, Chittagong and other places. The water-works in Calcutta was completed in 1870 and those of Barmby, Madras and Poona 1875, 1880, 1890 respectively.

1.4 Objectives of Water Supply Systems:

The broad objectives underlying any water supply system are: (1) to supply safe and wholesome water to consumers; (2) to supply water in adequate quantity; (3) to make water easily available to consumers so as to encourage personal and household cleanliness.

In order that water should be safe and wholesome it, must satisfy the criteria of being, least harmful upon consumption. A wholesome water is usually one which is unpolluted, free from toxic substances as well as excessive amounts of mineral and organic matter that may impair the quality of water. Standards of quality for drinking water have been established by many countries now to ensure that the water supplied is really safe and wholesome. The first objective as outlined above is fairly satisfying. To supply water in adequate quantity would mean that the source of water supply must be so selected as to ensure that quantities of water as required by the community would be amply available. further, capacities of units required to store

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requisite quantity of water for continuous supply must be sufficient. To make water within the easy reach of consumers, would mean planning a well laid-out system of distribution involving pipes, valves and other fixtures of adequate design and capacity so that the system could be fully relied upon to meet the continual requirements of consumers at all hours of the day.

1.5 Elements of Water Supply System :

The water requirement of a modern city is so great that a system capable of supplying a sufficient quantity of potable water is necessary. The first step in the design of a water supply system is the determination of the quantity of water that will be required with provision for the estimated requirements of the future. Next a reliable source of water must be located, and finally a collection system, a treatment plant and a distribution system must be provided.

Water use varies from city to city depending on the population, climatic conditions, industrialization and other factors. In a given city, water use varies from season to season and even from hour to hour. The planning of a water supply system requires that the probable water use and its variation be estimated as accurately as possible.

The essential elements of a water supply system are as follows : ~~1~~ Source of supply : ~~2~~ Collection system: ~~3~~ Treatment or purification plant; and ~~4~~ Distribution system.

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1) **Source of Supply** : All waters come in the form of precipitation. It is evaporated from the ocean, condenses to form clouds and finally precipitates over land. As the water falls in the form of rain or snow or sleet or hail, it acts as a vacuum cleaner picking up all the dusts and dirt particles in air. Needless to say, the first water that falls from the clouds picks up the greatest concentration of contaminants. After a short period of all, the precipitation is relatively free of contaminants. When the water hits the ground, a portion of its runoff across the surface of the ground and a portion of it sinks into the ground. Therefore, the source of supply is of two types : a) Surface water supply and (b) Ground water supply.

(a) **Surface Water Supply** : The water running across the surface of the ground has been designated as surface water. It picks up many substances as it flows back to the ocean like Micro-organisms, organic matter, minerals and other polluting substances. Surface supply is generally obtained from streams, lakes, ponds, reservoirs and oceans. Since surface water is highly polluted it needs extensive treatment.

(b) **Ground Water Supply** : The surface water which seeps into the ground is designated as ground water or sub-surface water. As it travels through the surface layers of the earth, it picks up some minerals and a few organics in solution. The micro-organisms and particulate matter find themselves being filtered out in the upper layers. Thus, it is found that

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most ground waters taken far below the earth's surface are free of microorganisms. These waters are usually relatively low in mineral and organic contaminants. Needless to say ground waters are usually preferred as sources of drinking water to surface waters. Springs, wells and galleries form the chief ground water supply.

Suitability of Sources with Regards to Quantity and Quality :

Quantity : As the effect of rainfall is most direct on the surface sources of water supply, the quantity of water available is abundant. However, since the rainfall may not be uniformly spread throughout the year especially in the case of tropical countries like Bangladesh and India, considerable variations in the flow of surface waters are likely. Thus, the flow in the streams or rivers may vary from a maximum during the rainy season, ancient to result in floods to a minimum during dry months, sufficient to cause long droughts. In case of impounding reservoirs, in addition to the rainfall and run off, the topography of the catchment area is important. It should be such as to drain off water from all remote points.

As regards the underground sources, the quantity of water available is usually less than that in the case of surface sources : the effect of rainfall now being most indirect, and depending upon the available underground storage and the

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geological formations of the substrata i.e. permeable or non-permeable. In case of shallow wells and springs, it is easier to get supplies by tapping the upper water bearing strata but such a storage may be temporary and fall off during dry season resulting in the failure of the source. The underground supplies drawn from greater depths i.e. deep wells, are more constant in their yield and hence more reliable.

Quality : Impurities in water normally are of two types, suspended and dissolved. The surface waters are characterized by the suspended impurities whereas the ground waters are generally free from the suspended matter but are likely to contain a large amount of the dissolved impurities, which they gather during the course of their travel in the underground strata comprising of rocks and minerals. The suspended matter often contains the pathogenic or diseases producing bacteria ; as such surface waters are not considered to be safe for water supply without the necessary treatment. Ground waters are comparatively safer and fit for use with or without minor treatment only.

The rain water is soft, has a flat taste and is free from contamination. As, however, rain falls through the air, it collects dusts and gases from atmosphere and becomes impure. Where rain water is collected in storage tanks, it may pick up impurities and therefore requires to be

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disinfected before use or drinking. However, because of the soft nature of the water, it finds an excellent use for washing purposes.

The river water varies in quality. This variation is caused by the great difference in the maximum and minimum flow. The maximum flow is caused by high floods, resulting in an increase in turbidity and bacteria due to the surface wash brought into the river. The minimum flow is due to the flow of ground water into the river, resulting in the decrease of turbidity but increase of dissolved impurities. The river water is also usually found to be contaminated with sewage or industrial wastes from towns and cities. The river water, therefore, must be thoroughly treated before supplying for public use.

An impounding reservoir stores water by the construction of a dam across a natural water course. The storage provided may be as much as 60 days or less. This long storage enables the suspended matter to settle down and be removed. There is also considerable reduction in harmful bacteria and in colours present. Long storage is, however, objectionable in one way and this is that it creates growth of microscopic organisms in water impairing its general quality. Aeration and chlorination are thus normally required before water is considered fit for supply.

The quality of ground water is comparatively much better. This is due to the fact that water gets strained during its

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passage through the porous underground strata. The geological formations with which water comes into contact also impart to it certain qualities like softness or hardness. The bacterial content of waters from springs, infiltration galleries and deep wells is usually low due to the straining action involved. In general, ground water is good in quality but may require some treatment to improve its chemical characteristics.

Choice of a Source for Water Supply : Considerations in the selection of a particular source for supplying of water are : (a) Quantity, (b) Quality and (c) Cost

The quantity of water available from the source should be sufficient to cater for the needs of the town or city regarding domestic service, industrial demands, fire fighting requirements and other public uses. The quantity of water supplied should also include the design requirements, which means the calculated quantity would be somewhat higher than the bare needs.

The quality of water should be wholesome, safe and free from pollution of any kind. The health of the public should in no way be endangered due to epidemics associated with water-borne diseases.

The quantity and quality of water are prime considerations in the selection of any source of supply. Cost considerations regarding the development and operation of water supply are also significant. The cost of supply would depend

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whether the system of supply is such that the water flows by gravity from the source or it has to be pumped first before supplying. Cost would, naturally, be less in the first case. The cost shall also depend upon the distance between the source of supply and the distribution system. Longer distance means water cost of conduits and other appurtenances required. In short, the cost of water supply must be reasonable compared to the number of people served and must bear a fair relation to the value of property served so that by equitable taxes and reasonable charges for water, the original cost of the system can be repaid at the end of the design period, which is usually 20 to 30 years.

(2) **Collection systems** : The collection system is a sort of engineering works designed to convey from a source to a treatment plant. The following are essential units in a collection system: ~~(a)~~ Intake, ~~(b)~~ Intake main, ~~(c)~~ Aqueduct or Transmission main, and ~~(d)~~ Pumping station.

Intake : An intake is a device or a structure placed in a surface water source to permit the withdrawal of water from this source and its discharge into an intake conduit or pipe (intake main) through which it will flow into the water-works system. Intakes are of primary importance. In general, they consist of the opening protected by a strainer or grating through which the water enters to the intake main. Types of intake structures consist of intake towers submerged intakes, intake pipes or conduits, movable intake

and shore intakes. Intake structures of the inlet end of inlet conduit is necessary to protect against current and wave action, floods, stoppage, navigation, pollution and other interference with the proper functioning of the intake. Intake should be so located and designed that the possibility of interference with the supply is minimised to the greatest possible extent. Where uncertainty of continuous serviceability exists intakes should be duplicated. The following factors must be considered in designing and locating intakes : (i) Location of the best quality of water available, (ii) Possibility of wide fluctuations of water level, (iii) Characteristics of intake surrounding, i.e., depth of water, character of the river bottom, navigation requirements, the effects of waves, currents, floods and storms upon the intake structure and in scouring the river bed and banks, (iv) Formation of shoals and bars, (v) Possible sources of pollution, and (vi) Provision for excluding possible floating materials like logs and vegetations.

Intake Main and Transmission Main : A pipe line must be used to deliver the water from the source to the treatment plant. The kind of pipe to be used—cast iron steel, concrete, asbestos cement or even wood will depend to some extent on local conditions and local costs, which should be determined on an engineering basis. Similarly, the size of the pipe is fixed by the volume of water to be delivered and

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the pressure or head of water. In general, the design of the pipe line will be governed by the principles of engineering economics, perhaps to a great extent than any other part of the water supply system.

✓ **Pumping Station :** A pumping station is essential for pumping water from the source through the intake to allow water to flow by gravity through the transmission main to the treatment plant.

✓ **(3) Treatment Plant :** Water, as it is drawn from streams, reservoirs, or wells, is rarely suitable for use. It must usually be treated before it reaches the consumers. In case of surface waters, the treatment procedure may involve the removal of turbidity, colour, taste, odour and bacteria. Ground water from wells may be treated to reduce hardness, iron, corrosive qualities, and sometimes bacteria. The methods used for treatment include screening, sedimentation, treatment with chemicals, filtration through sand beds, and disinfection to kill microorganisms. Most streams are polluted by industrial or domestic wastes to some degree and treatment of the water from a stream must be designed to provide a safe, clear and palatable water under any condition. The engineer must, on the basis of a careful examination of local data and conditions, plan, design and supervise the construction of a plant that is capable of producing satisfactory water. He must also so design the plant that the correct operation is easiest and

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most logical. Adequate treatment is necessary because the use of polluted water can be an important factor in the spread of many diseases.

4) **Distribution System:** The distribution system is needed to deliver water to the individual consumer in the required quantity and under a satisfactory pressure. The distribution system is often a major investment of a municipal waterworks. This includes: (a) Various pipes that convey the water to the consumer, (b) Storage Reservoirs that are provided to aid in the distribution of water, (c) Pumps and necessary equipments, and (d) Fire hydrants, valves, meters and other appurtenances.

✓ **Classification of Distribution Systems :** There are three general methods or systems for furnishing satisfactory water pressure in the distribution pipes, namely, the gravity system, the distributing reservoir system, and the direct pressure system. In a gravity system the source of supply is at such an elevation with respect to the community to be served that adequate pressure in the pipe is obtained directly from the head. In a distributing reservoir system the water is pumped to a reservoir called a storage reservoir or distributing reservoir which is at such an elevation that the water flows by gravity through the mains. In a direct pressure system, the water is pumped directly into the mains. These methods may be combined, or may merge into one another and therefore, the classification is not absolute.

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The procedure in designing a distribution system is essentially the same in each case. The details of the system are determined largely by cost and local topographic characteristics.

Pressure Requirements in Distribution Pipes : For general domestic purposes, the necessary pressure of water in the pipes, which is usually indicated by an ordinary pressure gauge is about 50 to 60 psi. However, in communities built in hilly or mountainous districts, considerable variation in pressure may be necessary in the pipe lines. In general, the pressure for domestic purposes should not fall below 20 psi and should not exceed, 120 psi. Where the conditions are such that, variation in pressure would otherwise exceed the given limits, it is necessary to layout the distribution system in separate districts of high and low pressure. To supply water to all floors in a very high multi-storied building, it is necessary to install separate pumps and roof top tanks in the building.

Fire service requires pressure higher than that provided for domestic use because the water is used at a greater rate and, to be effective in fighting fire the water must issue from the nozzle of a fire hose with a sufficient velocity to a considerable height. When the pipe pressure is dependent on the forcing water through a hose to a fire, a pressure of at least 80 to 100 psi is needed in the pipes. Therefore it is often cheaper, especially in large cities, to use fire engines

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for providing extra pressure in case of fire, and to provide a lower pressure in the pipes for ordinary occasions. Like many other engineering problems, the question of pipe pressure requires for its solution a careful weighing of conditions and costs.

Distribution Reservoirs : These reservoirs provide storage of treated water to meet the water requirement of the consumers and also to provide fire storage and to stabilize pressures in distribution system. The reservoir of steel or concrete. They may be cylindrical, rectangular or square. The reservoirs should be located a close to the centre of use as possible. The water level in the reservoir must be high enough to permit gravity flow at satisfactory pressures to the pipe system it serves.

Pumping Station: A pumping station is needed to pump water to the reservoir (overhead water tank) to allow the water to flow by gravity to the distribution system.

Distribution Pipes : The basic requirements of distribution system are adequate strength and maximum corrosion resistance. Cast iron, concrete, asbestos-cement, PVC / polyvinyl chloride) and G.I. (Galvanized Iron) pipes compete in smaller sizes, while steel, and R.C.C. (Reinforced Cement Concrete) pipes compete in larger sizes.

All the Essential elements of a water supply system for a city in diagrammatically shown in the Fig. 1.1.

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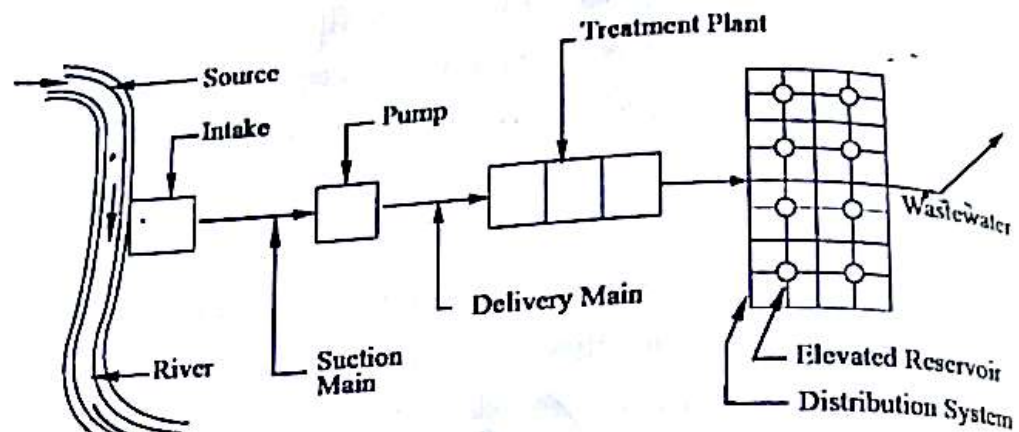


Fig. 1.1 Essential Elements of a Water Supply System

1.7 Planning a Municipal Water Supply System :

In general the following must be done in planning a municipal water supply system;

- (1) Estimate of the future population of the community and study of local conditions to determine the quantity of water which must be provided.
- (2) Location of a reliable source of water of adequate quality.
- (3) Design of a suitable collection system.
- (4) Provision for the necessary storage of water, and design of the works required to deliver the water from its source to the community.
- (5) Determination of the physical, chemical and biological characteristics of the water.
- (6) Design of various units of the treatment plant.

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(7) Design of the distribution system, including distribution reservoirs, pumping station, elevated storage, layout and location of fire hydrants.

(8) Provision for the establishment of an organization which will maintain and operate the supply, distribution and treatment facilities.

1.8 Conclusion :

Modern civilization is far more dependent on water than were the civilization of the past. Modern water supply and sewerage engineering together with modern medical science reduced death rates and increased life expectancy. Modern standard of living requires much more water than was used only hundred years ago. Increasing population demands more attention to water supply, storm drainage and sewerage. Industrial Progress finds increasing uses of water in process industries, for steam generation, and also for electric power production. The emphasis of water supply engineering shifts more or less steadily and continuously.

The development of civilization has increased the importance of water supply engineering and there is no prospect of a line of activity in this field in the foreseeable future. More efficient methods in planning and design and better construction materials and process for water supply systems for urban and rural areas must be utilized to make the systems more efficient and to reduce costs so that water supply projects may become economically feasible.

Water Supply

QUESTIONS

1. Explain the importance of water supply engineering upon city life. BUET, 1962, 68.
2. Write a short essay on the history and development of water supply engineering. BUET, 1965.
3. Discuss briefly the engineering aspects of water supply. BUET, 1964.
4. Enumerate and explain briefly the essential elements of a water supply system for a city with the help of a neat sketch. BUET, 1963, 66, 69, 70, 72.
5. Enumerate the factors to be considered in planning a municipal water supply system. BUET, 1970, 72.
6. Write an essay on "Water Supply Engineering and Public Health". BUET, 1966, 69, 70, 73.

SURFACE WATER COLLECTION AND TRANSPORTATION

4.1 Introduction :

Surface water is collected from rivers, lakes, reservoir, canals, ponds and seas. The collection system is a set of engineering works designed to convey water from a source to a distribution system via treatment plant and includes intakes, suction pipes, delivery pipes and pumping stations.

4.2 Intakes :

The intake is a device placed in a surface water source to permit the withdrawal of water from the source and then discharge it into intake pipe through which it will flow into the water-works system. There are mainly two types of intakes :(1) River intakes, and (2) Lake and reservoir intakes.

River Intakes : Understandably, river intakes are constructed well upstream from points of discharge of sewage and industrial wastes. Optional location will take advantage of deep water a stable bottom, and favourable water quality, all with proper reference to protection against floods, debris and river traffic. Where the river bed shifts or depth of flow varies greatly, intake pumps may be mounted on carriages that are moved up and down on the river bank

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to stay within desired suction lift as flows the and fall. A typical river intake is shown in the Fig. 4.1.

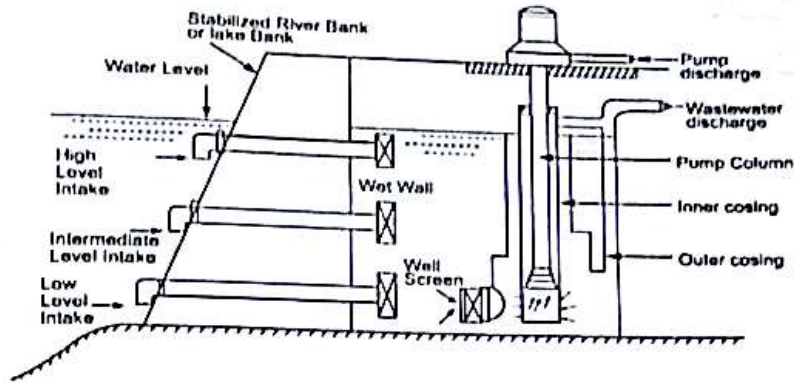


Fig. 4.1 River or Lake intake with vertical pump

Lake and Reservoir Intakes : Lake intakes are sited with due reference to sources of pollution, prevailing winds and surface currents. Reservoir intakes resemble lack intakes but generally lie closer to bank in the deepest part of the reservoir They are often incorporated into the impounding structure itself (Fig 4.2).

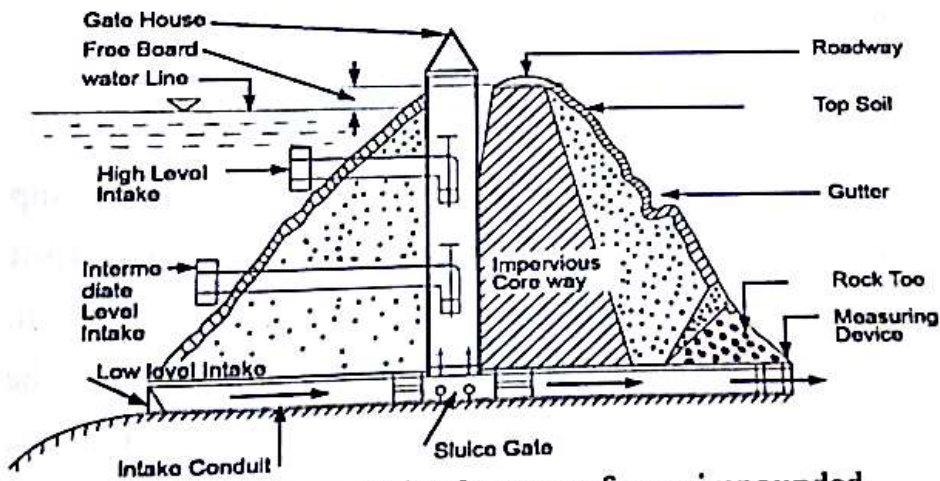


Fig. 4.2 Dam and intake tower for an impounded Surface water Supply

Water Supply

Intake Velocities and Depths : Intake entrance should lie 10 to 15 ft below the water surface but 4 to 6 ft above the river, lake or reservoir floor to keep bottom sediments out of intakes and entrance velocities are kept down to 3 or 4 inch per sec. At such low velocities, vegetation debris and other materials are not entrained in the flowing water, fish and other aquatic lives are well able to escape from the intake current. Gratings or screens of 2 to 8 mesh to an inch are provided at the intake-entrance.

Intake Pipe and Pumping Station : Intakes are connected to the banks of rivers or to the shores of lakes and reservoirs (1) by pipe lines (often laid with flexible joints) or (2) by tunnels blasted through rock beneath the floor. The pipe lines are generally laid in a trench on the river bank or on the lake or reservoir floor and covered after completion. Pipe passing through the foundation of dam are subjected to heavy loads and to stresses caused by consolidation of the foundation.

Intake pipe are designed to operate at self cleansing velocities, 3 to 4 fps. Flow may be by gravity or by suction. Pump wells are generally located on shore or banks. Suction lift including friction should not exceed 15 to 20 ft. Accordingly, pump wells are often quite deep. The determining factor is the elevation of water level in the river, lake or reservoir in times of drought.

Intake Design Considerations : The following are important considerations for designing an intake :

- (1) Selection of a particular type for the given source.
- (2) The magnitude of the external forces (waves, currents and blows from floating and submerged objects) to be resisted by the intake.
- (3) Consideration of the total lift from the source to the treatment plant and selection of a suitable pumping unit.
- (4) Determination of the total length of suction and delivery mains, head losses due to friction and small bends, enlargement and reduction.
- (5) Selection of a suitable screen to provide around the intake pipe not to permit entry of large and small objects, such as logs, stones, aquatic lives and vegetation.
- (6) Installation of intake valves or port holes at 2 or 3 different levels to get the best available quality of water, eliminating seasonal fluctuation of water levels.
- (7) Determination of cost-benefit ratio. To reduce the cost, the intake elevation is often made higher so that the water flows to the treatment plant by gravity.
- (8) Assurance of the safety of the intake structure, provision future extension and installation of standby units of pumps.

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4.3 Transportation of Water :

The arrangements for the transportation of water from the source of supply to the treatment plants and subsequent distribution to the consumers form an important part of the water-works system. The source of supply usually being at some distance away from towns and cities, it is necessary to construct structures for the transportation of water. These structures are known as pipes or conduits. There are two general classes of pipes; (1) Pressure pipes in which the water flows under hydraulic pressure, and (2) Gravity pipes (open channels) in which the water flows by gravity.

A pressure pipe is also defined as a pipe flowing full. Such pipes are often less costly than open channels (canals and flumes) because they can generally follow a shorter route. If water is scarce, pressure pipes may be used to avoid loss of water by seepage and evaporation which generally occurs in open channels. Pressure pipes are preferable for public water supplies because of the reduced opportunity for pollution.

The open channel may take the form of a canal, flume, tunnel, aqueduct or partly filled pipe. Open channels are characterized by a free water surface, in contrast to pressure pipes, which are always full.

4.4 Pressure pipes:

The desirable qualities of pressure pipes are as follows:

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- (1) They should be made of durable materials so that no leakage develop causing wastage of water.
- (2) They should be strong and of sufficient thickness to withstand both internal and external stresses.
- (3) The inner surface of the pipe should be very smooth so that the resistance to flow is minimum.
- (4) The pipe materials should not impart any physical or chemical effects to water.
- (5) The pipes should be light so that transporting, handling and laying the pipe under different conditions of topography, geology, and communication become easier
- (6) Low initial cost and maximum service period of pipes are desirable.
- (7) The pipe materials should be so selected that annual maintenance cost is low, joints can be made easily, offer adequate resistance to the corrosive characteristics of soil and water and highly skilled labour is not required for their laying and construction.
- (8) The pipe sections should possess good hydraulic properties.

Materials for Pressure Pipes: The principal pipe materials are steel, cast iron, concrete, wood, asbestos-cement, and vitrified clay, PVC, etc. Relative economy plays a large part in the selection of pipe materials but availability of skilled

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labour for construction and accessibility of the site may be influencing factors.

Steel Pipe : Steel pipe has been used in all sizes upto more than 20. ft. in diameter. Steel pipe in sizes of 1 to 12 inch in diameter is often a continuous tube formed by drawing over a mandrel. In sizes under 42 inch. steel pipes are often made of long, narrow steel plates which are bent to shape and welded or riveted along a spiral joint. This type of pipe has considerable flexural strength. Larger sizes are built on the job by welding or riveting steel plates. Steel bands or stiffening rings are sometimes provided on larger steel pipes to aid resisting bursting, pressures. The working stress for steel is usually taken as 16,000 psi. Steel pipes are made much thinner than cast iron pipes because the material is stronger, is more uniform and can be more easily inspected and the defects are more readily located.

Buried steel pipes are not usual provided with expansion joints since they are not subject to large temperature changes. Pipes exposed to the atmosphere may, however, require expansion joints to minimise temperature stresses. In the range of sizes encountered in engineering practice, steel; pipe sizes vary by 3 inch increments from 12 to 30 inch diameter and by 6 inch increments from 30 to 72 inch in diameter. The internal diameter of steel pipe depends on the wall thickness. The life of any pipe material depends

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very much on the conditions to which it is exposed, but properly protected steel pipe should have a life of at least 40 years under ordinary conditions. Protection is commonly provided both internally and externally. The internal coating is applied centrifugally and the external coating is painted or sprayed on at the same time the internal lining is placed.

Cast-iron Pipe : Cast-iron pipe is widely used for city water supplies because of its high resistance to corrosion and consequent long life. Under normal conditions, cast iron pipe can be expected to last 100 years. Standard pipe sizes are 2, 3, 4, 6, 8, 9, 12, 15, 18, 21, 24, 27, 30, 36, 42, 48, 54, 60, 66, 72 inch in diameter. The usual length of a pipe section is 12 ft but lengths upto 20 ft can be obtained. Cast-iron pipe is made in several thickness classes for various pressures upto a maximum of 350 psi. Its main advantages are durability, resistant to corrosion, ease of laying, joining and admitting of junctions. Cast-iron pipes are usually dipped in a bituminous compound for protection against corrosion and to improve their hydraulic qualities; larger size are provided with a lining of cement mortar.

Concrete Pipe : Reinforced cement concrete pressure pipe is generally used for large water supply systems. Such pipe has the advantage of good hydraulic properties and the pipe is resistant to tuberculation and corrosion. When the pipe is properly made and laid, the leakage is small.

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Precast concrete pipe is available in sizes upto 72 inch in diameter and sizes upto 180 inch have been reported to have made on special order. All concrete pipes are reinforced except in sizes under 12 inch in diameter. The reinforcement may take the form of spirally wound wire or elliptical hoops. In large pipes the reinforcement usually consists of two cylindrical cages. Because of the better control in its manufacture, precast pipe is usually of higher quality and need not to be so thick as cast-in-situ pipe of the same size. Because of the need to move plant and forms over long distances, cast-in-situ pipe is relatively expensive and is normally used only for pipe sizes not available in precast form or where transportation difficulties make use of precast pipes impossible. Concrete pipes should at least last 40 to 60 yrs under average conditions. Alkaline water may cause rapid deterioration of thin concrete sections. Concrete pipes carrying waste water may be subject to sulphide corrosion and may be short lived unless proper precautions are taken. Nowadays, prestressed concrete pressure pipes are used in water supply systems. This pipe withstands veiy high pressure and is advantageous because it requires less steel and weighs less. But it is costlier because special high strength steel and techniques are required in its manufacture.

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Asbestos cement Pipe : Asbestos-cement pipe is made from asbestos, silica, and cement converted under pressure to a dense, homogeneous material possessing considerable strength. The asbestos fibre is thoroughly mixed with the cement and serves a reinforcement. Asbestos-cement pipes are available in diameters from 3 inch to 36 inch in 10 to 15 ft lengths. The pipe is manufactured in three different grades intended for internal pressures of 100, 150 and 250 psi. Asbestos-cement pipe is assembled by means of a special coupling which consists of a pipe sleeve and two rubber rings which are compressed between the pipe and the interior of the sleeve. The joint is as resistant to corrosion as the pipe itself and is flexible enough to permit as much as 12 deflection in laying pipe around curves. Asbestos-cement pipe is light in weight and can be assembled without skilled labour. It can be joined to cast-iron pipe with lead or sulphur-base compounds. It is easily cut and tapped, drilled and treated for service connections. The hydraulic efficiency of this pipe is high. It is highly resistant to tuberculation, incrustation, and corrosion, The pipe is easily damaged by excavation tools and does not have much strength in bending.

Vitrified-clay-Pipe: Clay pipe is not often used as pressure pipe but widely used in sewerage and drainage systems for flow at partial depth. The main advantage of clay pipe is that it is virtually free from corrosion, has a long life and its

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smooth surface provides high hydraulic efficiency. Use of clay pipe under pressure is usually prevented by its low strength in tension and the difficulty of securing water tight joints.

Clay pipe is most commonly made in 3 to 5 ft lengths. Inside diameters vary by 2 inch increments from 4 to 12 inch diameters. greater than 36 inch is rarely used.

PVC (Poly vinyl Chloride) Pipe: PVC pipe is manufactured from poly vinyl chloride, resin and some stabilizer. It is manufactured for wide range of dimensions and pressures. These are specified by the manufacturer and have to be strictly followed. The pipe material does not have any detrimental effects on the water flowing through it. These pipes are very light and easy to handle.

They are highly resistant to tuberculation, incrustation and corrosion, but not resistant to temperature exceeding 150° C. Because of their adaptability, use and serviceability, PVC pipes are nowadays preferred to steel, cast iron, or concrete both in water supply and sewerage systems.

G. I. (Galvanized Iron) Pipe : G. I. pipes are generally used for service connections from distribution branch lines. They offer great facilities for fitting and fixing branches, bends, for reduction in sizes, for fitting and fixing taps, cocks, etc. Pipe diameter varies from 1/4 inch to 12 inch.

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larger diameter pipes up to 18 inch are available but they are very costly. For acidic water, these pipes may cause lead poisoning.

Miscellaneous Pipes : Other materials used for pipe include-copper, wrought iron, plastics, asphaltic fibre and lead. Copper and wrought iron are used for small diameter pressure pipes. Copper is quite expensive but may be advantageous in situations, where corrosion is likely to occur. Plastic pipe is corrosion free and light in weight. Its low strength, however, does not permit it to be used in large sizes. It is mainly used for washing purposes. Asphaltic fibre pipe is sometimes used as house connections to sewers. Lead pipe is used as pressure pipe in house plumbing.

4.5 Corrosion of Metal Pipes :

Metal pipes are subject to corrosion. Corrosion is a phenomenon by which metals and their alloys are attacked by the environment consisting of chemicals. There are mainly two types of corrosion in pressuse water pipes. (1) External corrosion and (2) Internal corrosion. External corrosion is caused by external agents like biological action, oxygen, etc., and the internal corrosion is generally attributed primarily to the nature of water which flows through pipes.

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The chemical attack of an environment upon a metal results in the oxidation of the metal and the formation of corrosive products, usually the oxides, hydroxides, carbonates, sulphides, etc. In most cases, corrosion product is insoluble in the environment and forms a separate phase on or adjacent to the metal. Hence, corrosion may be defined simply as the process by which the metals and their alloys are destroyed by chemical or electrochemical means. So, according to reaction with metals, corrosion is of two types: (1) Chemical corrosion, and (2) Electro-chemical corrosion (Electrolysis). In its simplest form, chemical corrosion occurs when iron enters solution as positive ions and combines with the negative ions of water to form ferrous hydroxide. If the water contains oxygen, the ferrous hydroxide is oxidised to ferric hydroxide, an insoluble, red-brown precipitate. The initial rust-coating which forms on the pipe tends to protect it from further corrosion, but the coating is not impermeable and some corrosion usually continues. Water, with a large amount of dissolved carbon dioxide is an active corrosive agent. Corrosion of metal pipes results in the formation of tubercles of ferric hydroxide on the inside of the pipe. This deposit (known as tuberculation) decreases the pipe area and increases the pipe roughness, thus greatly-reducing the hydraulic carrying capacity. Cast-iron pipes of smaller diameter have had their

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capacities reduced as much as 50 percent in 5 year by tuberculation.

Corrosion of metal pipes may result from electrolysis. Electrolysis is often caused by the galvanic action resulting when two dissimilar metals are immersed in water. The rate of electrolysis depends on the dissimilarity of the two metals as indicated by their relative position in the electrochemical series. A metal which is high in the series is dissolved and deposited on the other metal. This type of corrosion may occur in water supply systems between pipes and fittings of different metals or between the pipe metal and the impurities in the pipe metal. Pipes laid in soil that has a high electrical conductivity are principally vulnerable to electrolysis.

The following are some of the important causes of corrosion of metal pressure pipes :

(1) **Pitting** : Localized pitting is usually caused in metal pipes by the concentration of electric currents resulting from the potential differences on the metal surface which accelerates. This process is also accelerated by dissolved oxygen content of flowing water.

(2) **Influence of Acids and Alkalies** : Acidity or alkalinity of water passing through pipes will help vigorously to corrode pipes.

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✓ (3) **Influence of Sulphur Compounds:** The influence of sulphur compounds on metal pipes is harmful. It has been reported that the presence of sulphide particles raised the proportions causing rust from 22 to 90 per cent. The effect of sulphide is almost due to the liberation of hydrogen sulphide which accelerates the attack of acids on the pipe metal.

✓ (4) **Biological Action:** Soil contains various types of bacteria both aerobic and anaerobic. Certain anaerobic bacteria are capable of rendering the oxygen present in sulphates, nitrates and carbonates available for the free oxygen and thereby corrosion will proceed pace. The most important sulphate reducing bacteria (Vibrio desulphuricans; which can cause serious attack on buried pipes when three conditions are satisfied : (a) Absence of oxygen as in many clayey soils (b) Presence of proper food (organic matter) and other environmental conditions needed for the growth of bacteria and (c) Presence of large amount of sulphates. These conditions occur in many clayey soils and lead to intense corrosion product is black iron sulphide. If subsequently the conditions become aerobic the iron sulphide is oxidised to ferric sulphate, which accelerates the corrosion by acting as an oxygen carrier, acid is said to be liberated in the oxidation process giving pH values as low as 3-5-which may also stimulate the attack. Sulphate

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reducing bacteria cause corrosion of ferrous metals. They work in absence of oxygen to react with sulphates and with organic compounds containing sulphur in the soil to produce hydrogen sulphide. Bacteria do not attack the pipe directly. The hydrogen sulphide combines with irons to form compounds of sulphur iron or it combines with water to form sulphurous or sulphuric acid which corrodes the pipe materials.

✓ (5) **Cavitation** : The effects of cavitation are similar to those of corrosion but are due more to erosion. The sudden and alternate making and breaking of high vacuum and the creation and condensation of water vapour cause a bombardment of the surrounding surfaces with particles of water and water vapour moving at a high velocity thereby accelerating corrosion.

✓ (6) **Temperature**: The increase in temperature accelerate the rate of corrosion. The rate of corrosion in water pipes may be increased three or four fold by raising the temperature from 60 to 150°F.

✓ (7) **Velocity of Flowing Water**: As the velocity of the water in the pipe increases from linear to turbulence type, the rate of corrosion is sharply increased.

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Effects of Corrosion : Corrosion in water pipes causes a great economic loss. Both direct and indirect losses resulting from corrosion are vast and undesirable. Replacing a corroded leaky-water main by the road side is very difficult and costly. Corrosion greatly reduces the pressure head and results in increased cost of pumping and short life of the water mains. Leakage in domestic plumbing fixtures due to corrosion involves not only the replacement but also repairing damages to walls, floors, etc. Rusty water due to corrosion causes strain in cloth after washing, produces unsightly marks on the plumbing fixtures and unsuitable for domestic uses.

Control of Corrosion : Corrosion of metal pipes may be reduced or eliminated by protection coatings of paint, galvanizing, bituminous compounds, or cement linings. Red lead paint or zinc pigments, offer some protection and are used on the exterior of exposed metal pipes. Other metallic protective coatings are tin coatings,, nickel coatings, chromium coatings and copper coatings. Galvanizing by dipping the pipe in molten zinc is an effective corrosion control except for highly acid waters. Galvanized pipe is widely used for small service lines in distribution systems but is too expensive for large pipes.

Large pipes are usually protected by non-metallic coatings, such as bituminous coatings or cement linings. Numerous

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commercial bituminous compounds are available for both hot and cold application.

4.6 Scale Formation In Pressure Pipes :

Scale formation in water pipes is mainly due to the presence of dissolved mineral matter and gases under favourable conditions of temperature and pressure. Scale formation caused water pipes to wear out and burst out very soon as the cross-sections of the pipes are reduced and this *also* causes insufficient discharge through pipes. Scaling also causes water unfit for domestic and industrial uses.

The impurities which are mainly responsible for scale formation in water pipes may be classified under two heads:

(1) Dissolved mineral matter, and (2) Dissolved gases.

Dissolved mineral matter include the hardness producing substances, i.e., carbonates, bicarbonates, sulphates and chlorides of calcium and magnesium, and silica. Dissolved gases include carbon dioxide, oxygen, nitrogen, hydrogen sulphide and methane.

Control of Scale Formation : To control scale formation in pressure pipes, water is softened. The chief objective of water softening is to remove dissolved mineral compounds which constitute the hardness and which deposit scales in water pipes, boilers and hot water heating system. Cause serious difficulties in many processes including textile

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finishing, dyeing, canning, paper making, cold drinks preparation, tanning and others.

The following are the effective processes by which scale forming minerals and gases are removed from water : (1) Lime-Soda process, (2) Zeolite process, (3) Phosphate process, and (4) Lime process. All these processes are discussed in chapter 8 (water purification).

4.7 Forces Acting on Pipes :

Pipes carrying water under pressure must be designed to withstand stresses caused by internal and external loads, and temperature changes, and to satisfy the structural and hydraulic requirements. The forces are :

1. Internal force; due to static head
2. Internal forces due to water hammer
3. Forces at bends and changes in Cross-section
4. Forces due to temperature changes
5. External forces in the form of backfill, traffic and own weights.

Internal Forces due to Static Head : Internal forces due to static head create hoop stress (transverse stress or circumferential stress and longitudinal stress.

$$\text{Hoop stress, } S_h = pd/2t. \quad (4.1)$$

where S_h = hoop stress per linear length in inch of the pipe.

p = intensity of static pressure in psi = wh , in which

h is the static head and w is the unit wt of water.

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d = pipe diameter in inch,

t = thickness of the pipe shell in inch.

Longitudinal (tensile) stress, $S_t = \frac{pd^2}{4t(d+t)}$ (4.2)

$= \frac{pd}{4t}$ (approximately) (4.3)

Water Hammer : One of the most damaging factors to a water piping system is water hammer action. In addition to its effect on the piping system, water hammer causes banging noises in the system that are very disagreeable to occupants in the building. Water hammer occurs when a column of water flowing through a pipe line and discharging at an open outlet, is suddenly stopped by closing the outlet. Since flowing water has force, tremendous pressures result at the point of closure and pressure surges move along the pipe. The manner in which water hammer occurs is illustrated in Fig. 4.3.

Phase 1 : The valve on the line is closed and the water contained in the line is at rest. Water pressure is thus exerted in all directions in an equal way.

Phase 2 : The valve on the line is open and water flows freely through the open outlet. Now the water pressure is utilized to force the water out of the open end of the pipe. Arrows indicate the direction of force in the column of water.

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Phase 3 : When the valve is quickly closed, the column of freely flowing water is suddenly stopped ; excessively high pressures are generated at the point of stoppage. This reaction is the same as would result of a steel bar moving through the line at the velocity of water were suddenly stopped by the valve.

Phase 4: In an effort to equalize the pressure build-up of the water, a shock wave will travel back along the branch line until a larger diameter pipe is reached. This will allow the shock wave to dissipate itself. Arrows denote the direction of force toward the valve and then its reversal as a shock wave toward the point of relief. Since the shock wave travels at speeds in excess of 4000 fps, it causes a piping clatter all along its route. Often the shock wave will oscillate back and forth between the valve and the point of relief until the pressure is stabilized with the branch line.

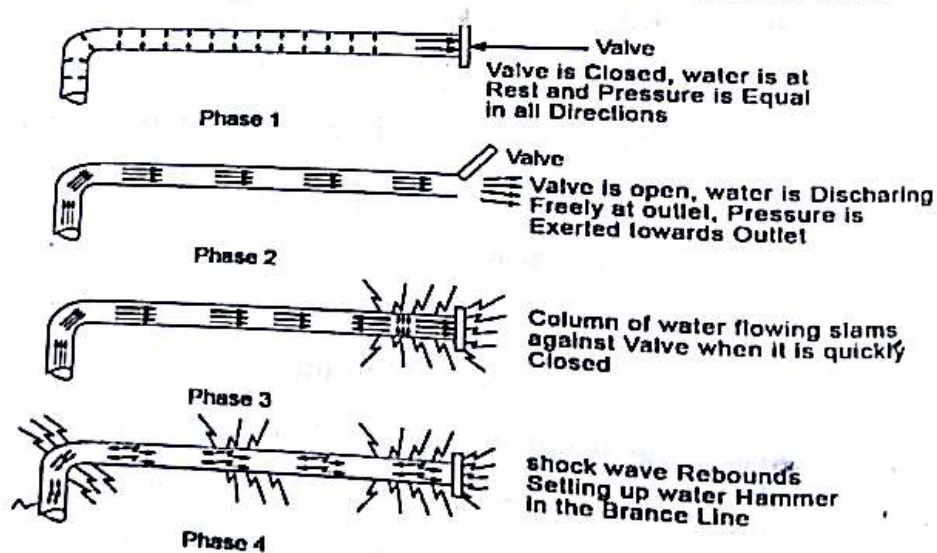


Fig. 4.3 How water hammer can Develop in a Pipe Line

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The pressure generated by the shock wave can expand and often rupture the piping. Although piping clatter is normally associated with water hammer, you cannot assume that when these noises do not occur, that the shock wave is non-existent. Quite often, water hammer takes place without any physical sounds. Therefore, it is very important that piping systems be designed with all due consideration given to the means that compensate for the action of water hammer.

Causes of Water Hammer: Not all the noises heard in the piping system can be attributed to water hammer. Loose faucet or valve washers can cause a pounding or chattering in the piping. Improperly supported and secured piping can create noises as the flowing water causes the piping to vibrate and thus rattle, against steel members. This noise is easily transmitted through the piping system, undersized water piping with excessive pressures will produce shrill sounds. Then of course, there is certain equipment, as pumps, that will produce noises unless the pumps are insulated and the piping connections are equipped with flexible piping connectors.

As for water hammer, it is generally impossible to predict just where in the piping system that water hammer will occur. There may be a small diameter branch line in the system which by the nature of its length and the fixture it supplies should produce water hammer, yet it does not. On

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the other hand a larger diameter line which should not cause water hammer often will cause such noise.

- One of the basic causes of water hammer is quick closing of valves. These include any valve or faucet that is closed rapidly. If the same valve were closed slowly, then the flowing water would have the chance to stabilize without producing the shock waves of water hammer. However, since these valves must Junction in the manner intended, other means must be employed to minimize the violent action of water hammer.

Other factors that contribute to the positive occurrence of water hammer are excessive water pressuers, inadequate piping sizes and water piping that is improperly installed.

Methods of controlling water hammers. In order to eliminate the danger and piping clatter that results from water hammer, it is important that certain steps be taken in piping system design to compensate for the excessive pressures that are generated when a column of flowing water is suddenly stopped.

The consideration needed is some means or device that will provide flexibility in the system to absorb the initial Shock wave of water flexibility thereby confining the action to a given section of piping.

Air is the most effective medium for absorbing the shock wave caused by water hammer for (1) water is non-

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compressible; (2) air can be compressed to considerable pressure when the water compresses the air, it also fills the void offered by the displaced air. Because water has this flexible means to expend its force, the shock wave that would otherwise result, is quickly absorbed. The manner in which air serves to eliminate water hammer is shown in

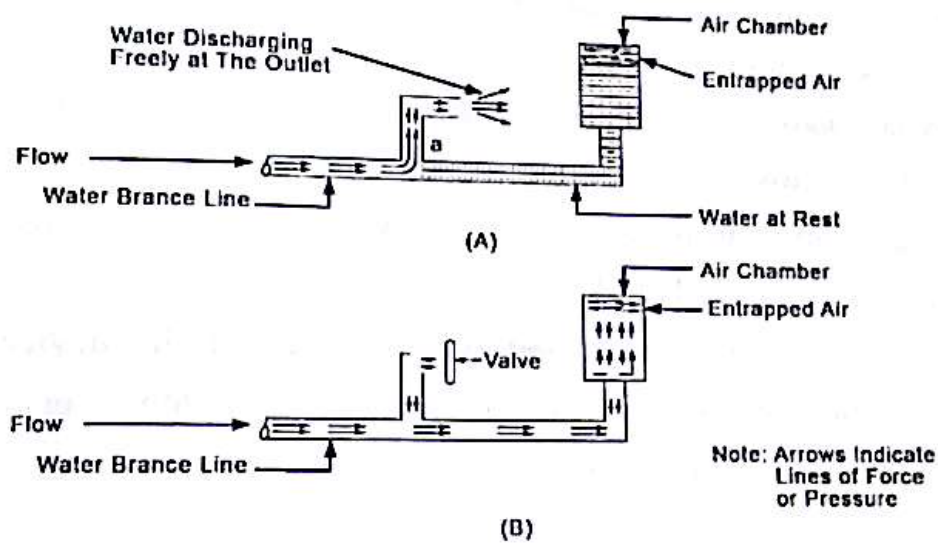


Fig. 4.4 How Air Chambers cushion the initial shock wave generated by water hammer

The Fig 4.4 (A) shows water flowing in a branch line and discharging at an open outlet. Water in the line from a to b is at rest with very little pressure exerted on the air that is contained to the chamber. The Fig. 4.4 (B) illustrates the condition when the following water is suddenly stopped by the valve. The shock wave generated rebounds but is absorbed by the air in the chamber. Thus by absorbing the

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initial shock wave, the water pressure is stabilized and the occasion of water hammer has been removed. Both details are diagrammatic and have been used only for example in showing how the phenomenon of water hammer can be properly controlled.

The extent of water pressure in a given line and the required sizes of air chambers to absorb the resultant shock waves can be computed.

Water hammer pressures can also greatly be reduced by the use of slow-closing valves, automatic relief valves and surge tanks. It is seldom that any two cause of water-hammer are exactly alike.

Each must be studied, and one or more of the devices available for its suppression must be used alone or in combination with others.

Forces at bends and changes in cross-section : A change in direction or magnitude of flow velocity is accompanied by a change in the momentum of water. The force required to produce this change: in momentum covers from pressure variation within the water and from the forces transmitted to the water from the pipe walls. For a pipe bend of uniform section.

$$\text{Longitudinal force} = s (\pi d) t \dots\dots\dots(4.4)$$

4.9 Pipe Joints :

The pipes are required to joint together pipes which are available in smaller lengths, say 6, 10, 12, 15 and 20 ft. only. The requisites of a jointing material are (1) imperviousness, (2) elasticity, (3) strength, (4) durability, (5) adhesiveness, (6) availability, (7) workability, and (8) economy.

There are various types of joints of which the powered joint, spigot and socket joint, flanged joint, screwed and socketed joint are important.

4.10 Pipe Laying :

Operation involved in the laying of pipe-frames include the following steps :

(1) Preparation of detailed maps of roads and streets :

Showing position of curbs, gutters, other unground service lines-sewers, existing water pipe (if there is any), gas pipes, telephone and electric conduits.

(2) Locating the proposed alignment on the ground :

The trench line is marked by driving centrally stakes 100 ft apart on straight reaches and 25 to 50 ft apart on curves.

(3) Excavating Trenches : With width sufficient to allow

The pipes to be properly laid and jointed, and with depth sufficient to give adequate protection to the pipes

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against impact of traffic and other factors. Width is usually, kept 12" to 18" more than the outside diameter of the pipe and depth such as to give a ground cover of about 3 ft. from the top of the barrel of the pipe.

- (4) **Preparation of the bottom of the trench excavated :** the bottom of the trench should be carefully prepared so that the barrel of the pipe can be bedded true to line and gradient for its entire length on a firm surface. In many cases, a bed of concrete 6" thick would provide a hard and even surface and adequate protection against possible settlement. Joint-holes should be left in the bed at suitable intervals to assist in the jointing of pipes where necessary.
- (5) **Lowering of pipes into the trench :** Pipes stacked on either side of the trench after transported to the site should be gently and carefully lowered into the trench so as not to damage thin outer protective coatings or their ends. Before lowering, pipes should be wiped clean to remove any dirt or foreign matter sticking to them.
- (6) **Laying of Pipes :** Pipes are seldom laid with a flat slope parallel to the hydraulic gradient. This is to avoid any air lock troubles. Every pipe length should, therefore, be laid either with a continuous rise to high points or continuous fall to low points. Pipe laying should proceed in an uphill direction to facilitate joint-making.

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Water Supply

- (7) **Jointing Pipes** : It should conform to the operation and specification of pipe jointing.
- (8) **Anchoring of Pipes** : At all bends, tees, valves and other branch connections, it should be necessary to provide thrust blocks of concrete to transmit the hydraulic thrust and distribute it over a wider area of the ground. Where the hydraulic thrust is upwards as in case of pipes on sloping grounds, anchor Mocks of concrete would be required to be provided at regular intervals and pipes should be firmly secured to them with steel straps.
- (9) **Back Filling or Refilling the Trench with the Excavated material**: The material surrounding the pipes must be soft and laid preferably in layers of 6" to 12" thickness, well rammed so as to resist subsequent movement of the pipes. The remaining upper portion of the trench may be refilled as before with the excavated material and the top brought flush with the road level or a little projecting above it for later consolidation by the traffic.
- (10) **Pipe Testing** : After laying and jointing and before backfilling the pipe is required to be tested under pressure. The test consists of filling the pipe-line with water expelling all air from within, allowing it to stand full for some time and then applying the test pressure of about 70 psi. The pressure is applied by means of a

Water Supply

manually operated test pump fitted with a pressure gauge. The test is generally carried out in sections as the pipe-laying proceeds. The open end of the pipe is closed for testing by fitting a suitable watertight plug.

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PUMPS AND PUMPING MACHINERY

5.1 Purposes :

Pumps and pumping machinery serve the following purposes in water supply systems :

- (1) Lifting water from the source so that the water will flow into the mains by gravity.
- (2) Boosting water from low service to high service areas, to separate the fire supplies, and to the upper floors of multistoried buildings.
- (3) Transporting water through treatment plant, draining component settling tanks, filter beds and other treatment units, withdrawing deposited solids, supplying water (especially pressure water) to operating equipment and pumping chemical solutions to treatment units
- (4) Lifting water to the overhead water tanks or reservoirs to flow by gravity to the distribution systems.

5.2 Types of Pumps :

Pumps may be classified according to the service for which they intended in water-works, the power by which they are driven, or the mechanical principles on which their operation is based. The following is a brief description of each type :

Water Supply

(i) **Pumps on the Basis of Type of Service** : These may be (a) deep well pumps, (b) low lift pumps, (c) high lift pumps, (d) booster pumps, (e) fire service pumps, and (f) stand-by pumps.

(a) **Deep Well Pumps** : These operate in tube-wells and pump water into service reservoirs or directly into the distribution system.

(b) **Low Lift Pumps** : These operate for small heads such as at treatment plants for pumping water from one unit to another and also for pumping water from river source or reservoir source to the treatment plant.

(c) **High Lift Pumps** : These operate under large heads for pumping water from clear water-reservoir to the elevated water tanks or directly into the distribution system.

(d) **Booster Pumps** : These pumps are used to increase pressures in parts of the distribution system where adequate pressure cannot be obtained either because of greater elevation or excessive loss of head in the distribution pipes. These are also used to supply water in the upper stories of tall buildings.

(e) **Fire-Service Pumps** : These are used to build up pressure to the extent required for effective fire-fighting in factories and multi-storied buildings.

(f) **Stand-by Pumps** : These are used for large pumping installations where auxiliary forms of power are also

available. In failure, the s etc.

(2) **Pumps**
These pump gasoline pu

(a) **Steam**
where prior low cost. operation.

(b) **Gasol**
high cost suitable heads.

(c) **Diesel**
pump speeds. water-v

(d) **Electric**
modern smoke and e Disad of pre

Water Supply

available. In case of temporary power (electric power) failure, the stand-by units can be driven on steam, diesel, etc.

(2) Pumps on the basis of Power used to Drive Them : These pumps may be classed as (a) steam pumps, (b) gasoline pumps, (2) diesel pumps, and (d) electric pumps.

(a) Steam Pumps : These are used in large pumping plants where prime considerations are (i) production of power at low cost, (ii) durability of service, and (iii) flexibility in operation.

(b) Gasoline Pumps : These are seldom used because of high cost in continuous operation. They are, however, suitable for stand-by service and are efficient for moderate heads.

(c) Diesel Pumps: These are reliable and economical for pump drives but not commonly used because of lower speeds. These are suitable for use only in small capacity water-works and as stand-by units.

(d) Electric Pumps: These pumps are generally used in all modern water-works. Advantages include freedom from smoke and dust, quiet operation, economical supervision, and economy of floor space for pumps and motors. Disadvantages include frequent power failure and necessity of providing stand-by units.

Water Supply

(3) **Pumps on the basis of Mechanical Principles of operation** : The common types are (a) displacement pumps, (b) centrifugal pumps, and (c) airlift pumps.

(a) **Displacement Pumps** : These pumps work on the principle of mechanically inducing vacuum in a chamber thereby drawing in a vacuum of water which is then mechanically displaced and forced out of the chamber. These are of two types : (i) Reciprocating pumps, and (ii) Rotary pumps.

In reciprocating pumps, a plunger or piston is operated so as to draw water into a closed chamber and to expel it into the pressure mains. The rotary pumps has cams or gears that revolve in a Close-fitting case and force the water around and out of each revolution, but this type is seldom used in water-works.

(b) **Centrifugal Pumps** : These pumps employ the principles of centrifugal force to impart energy to the water. Water entering into the pump-casing is revolved by a wheel called impeller which discharges it in a direction at right angles to its original direction of flow. In doing so, the kinetic energy of water is converted into static or pressure-head. Centrifugal pumps are extensively used in all types of modern water supply systems.

The centrifugal pumps may be classified as follows :

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Water Supply

(i) According to the system of rotation as right-handed or left-handed.

(ii) According to the manner of conversion of kinetic energy into static head as volume pumps, diffuser pumps, turbine pumps, and axial flow pumps.

(iii) According to the number of stages as single-stage, two stage or multiple-stage pumps etc, depending upon the number of stages of pressure developed by impeller. Each stage of the pressure head is added together by leading the discharge from one impeller into the suction of another and this when added to the initial pressure at the inlet, results in an increased discharge-pressure of the centrifugal pump.

Characteristics of Centrifugal Pumps: The centrifugal pumps is essentially a high-speed pump, normally operating at speeds more than 1,000 rpm; in some cases, efficient speeds of 3,500 rpm are possible. The discharge is uniform and consequently the power requirements also are uniform/Because of high speed of the pump, its direct connection to an electric motor is possible.

Water Supply

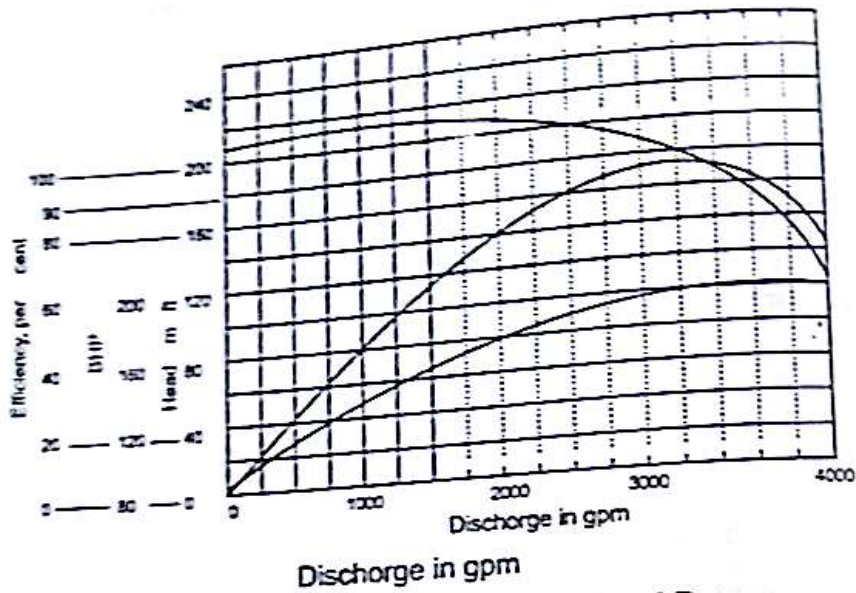


Fig. 5.1 Operating Curves for Centrifugal Pumps

The discharge of centrifugal pump is fixed by the design and by the speed. In Fig. 5.1. are shown typical operating curves for a centrifugal pump operating at a constant speed under various conditions. The pump was designed to deliver 3,000 gpm against a 185 ft. head with an efficiency of 85 percent. It is observed from the curves in Fig. 5.1 that (a) the discharge of the pump increases with the decrease in head, maximum discharge being limited by a certain minimum head below which the pump will not operate. The head increases to a maximum at zero-discharge with the discharge valve being closed. This condition is called shot-off head and should not be permitted to last long; otherwise pressure will abnormally rise above the design head. (b)

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Water Supply

Maximum efficiency is obtained with moderately low head and high discharge and decreases with lesser or greater discharge a fact greatly utilized in rating pumps. (c) The power required from the prime mover to drive the pump increases with increase in discharge, this being maximum at the shut-off head, but as the discharge valve is closed under this condition, the prime mover will not be over-loaded. However, this centrifugal pumps are much easier to shaft than other types of pump.

Advantages of Centrifugal Pumps : The centrifugal pumps has a wide range of usefulness in water supply systems, as it is relatively cheap, compact and simple, and is adaptable in various kinds of power.

(4) Pumps according to the position of pump-shaft : Pumps may also classified as horizontal shaft and a vertical shaft pumps. Horizontal shaft pumps have such characteristics as larger required head-room, less of corrosion and abrasion and higher efficiency. Vertical shaft pumps are commonly used as deep-well pumps and have such characteristics as lesser floor-space requirement, positive suction, easy priming, higher discharge head, higher initial cost and difficulty in maintenance.

Well Pumps : These include deep well turbine pumps, air lift pumps and submersible pumps.

Deep Well Turbine Pumps : A deep well turbine pump operates in the same way as a centrifugal pump but the

Water Supply

channel into which the water is discharged by the impeller is of uniform cross-section. While somewhat higher efficiencies are obtained with a turbine pump than with ordinary centrifugal pump, the initial cost is higher and the cost of maintenance is greater for the turbine pump. The turbine pump is particularly adapted to deep well pumping. In Fig. 5.2 is shown a common type of deep well turbine pump.

Air Lift Pumps : The air lift pump is particularly adapted for use in wells that are drilled through is at a considerable depth below the surface of the ground. In Fig. 5.3 are shown the main parts of an air lift pump. Compressed air from an air pipe is admitted into the education pipe at its lower end through a foot-piece or air diffuser. The mixture of air and water so created has a lower specific gravity than that of water alone and thus rises to the surface. With the continued supply of air, the column of water in the education pipe is forced upwards ultimately discharging from an outlet of the top. The effectiveness of this pump is dependent upon a factor called percentage submergence which is the ratio

$$\frac{D}{H+D} \times 100$$
 ; where H being the effective lift of the pump and D, the depth of submergence, and H+D representing the effective length of the education pipe. Its value should be at least 25 per cent for the pump to operate at all and 70 per cent to operate of best efficiency.

Water Supply

The advantages of the air lift pump are (a) freedom from submerged moving parts making them useful to handle corrosive or gritty materials, (b) ease of operation and maintenance the compression unit being located on the ground surface, (c) increased yield caused by forcing greater air pressure into the pumps, and (d) its suitability for installation in crooked holes where other types of pumps are least suitable.

Disadvantages are (a) greater depth of submergence necessitating wells to be made deeper, (b) low efficiency, 20 to 45 per cent, and (c) little flexibility in muting variations in demands.

Submersible Pumps : They differ from the usual deep well pumps in respect that the motor here is below the turbine bowls of the

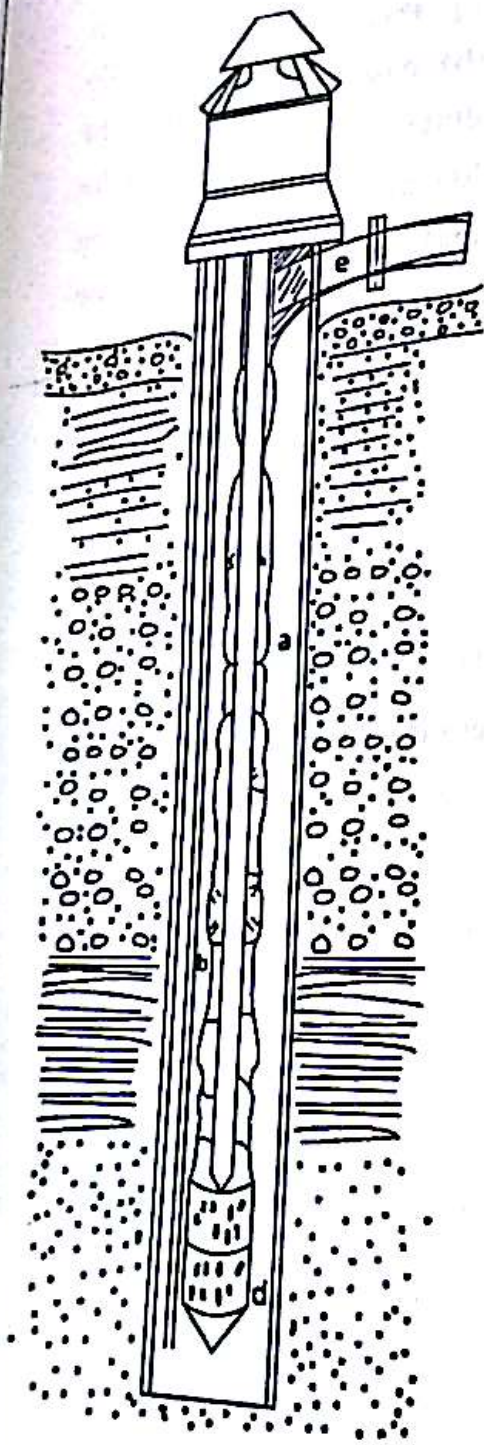


Fig. 5.2 Turbine Pump

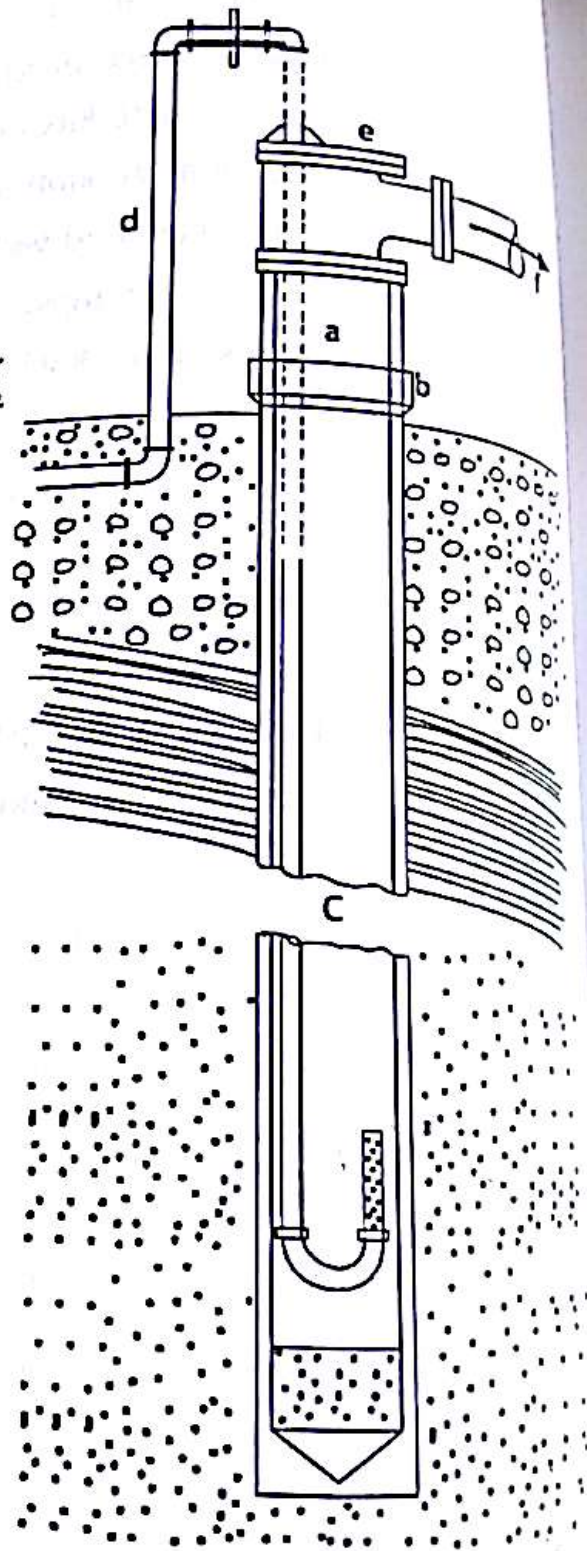



Fig. 5.3 Air Lift Pump

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Water Supply



pump and submerged at all times in the well. The water pumped may be prevented from coming into contact with the electrical parts or the motor bearings by enclosing in an oil-filled case with a mercury seal where the shaft passes through the top, though modern practice is to allow the windings to be surrounded by the well water which is considered to act as a coolant and bearing lubricant. Motors (usually squirrel cage induction type) used with these pumps are designed for long service without attention should a motor failure occur, the entire pump must be lifted from the well, a disadvantage in extremely deep-well. Submersible pumps are extremely useful both for shallow and deep wells and especially where the well is poorly aligned or crooked. They are easy to install and can be made of smaller diameter. Their efficiency, however, is comparatively less.

5.3 General Considerations For Pumping Installations :

Suction Lift: The theoretical maximum suction lift for pumps is approximately 34 ft.; but, because of various losses, such as friction losses in the pipe and strainer, and loss due to velocity head, this limit can never be reached in practical works. The elevation of any pump above the source of water supply should not exceed 22ft. and for a centrifugal pump, the practical limit is about 15 ft. The suction pipe should be short, straight and of ample diameter. Strainers, when used should have a clear waterway area that

Water Supply

is at least $1\frac{1}{2}$ times the cross-sectional area of the suction pipe.

Power for Pumps : The cost of pumping is mainly the cost of power to operate the pump, so that in areas of limited economic means the use of power is of utmost importance. Steam engines, the gasoline engines, diesel engines, and electric motors are commonly used to drive pumps. Electricity is to be preferred if it is available at reasonable cost. Electric motors are reasonably low in original cost and are cheap to operate.

Stand-by or Reserve Power : No matter what type of power employed, it is desirable to provide some extra pump units for use in case of breakdown or when repairs to the regular pumps are necessary.

Size of Units: A water-work pumping station is not operated at full capacity all the time. This factor has considerable bearing on the sizes of the pumps that are installed in any particular station. As previously explained, the efficiency of pumping engines varies with the amount of load. For example, the full load efficiency of the pump may be 80 per cent, the half-load efficiency, not greater than 75 per cent and the quarter-load efficiency not greater than 50 per cent. Consequently, the complete pump installation

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should be so designed that some of the pump units may be operated of the full capacity at all times, regardless of the variation in demand. When the demand is increased, additional pumps may be started, and when the demand is decreased, some pumps may be stopped.

Total Lift of Pump : The total lift of pump or the total head against which the pump must operate, is the algebraic sum of the following quantities: The discharge lift or the vertical distance from the centre of the pump to the level to which the water is to be raised; the suction lift or the vertical distance from the level of the source of water supply to the centre of the pump; the friction head and the minor losses in the discharge and suction pipes, the velocity head.

The suction lift may be positive or negative, depending upon whether the pump is above or below the level of the source of water supply. Thus, if the pump is set 6 ft. above the surface of the source the suction lift of 6 ft. is positive and is to be added to the discharge lift in determining the total lift. But if the pump is 6 ft. below the surface of the source, the suction lift of 6 ft. is negative and is to be deducted from the discharge lift.

5.4 Horsepower Required :

When the volume of discharge and the total lift or head of the pumps are known, the theoretical horsepower required may be found by the formula.

Water Supply

$$P = \frac{HQ}{3,960} \dots\dots\dots (5.1)$$

in which P = theoretical horsepower required to operate the pump (W.H.P. = Water Horse Power);

H = total lift or head of the pump;

Q = volume of water to be pumped, gpm.

If the head to be pumped against is given in psi, the formula becomes.

$$P = \frac{QP}{1,715} \dots\dots\dots (5.2)$$

in which P = intensity of pressure, psi.

The actual horsepower required depends on the efficiency of the pump and may be found by relation.

$$P_1 = \frac{P}{E} \dots\dots\dots (5.3)$$

in which P₁ = actual horsepower required to operate the pump (B.H. P = Break Horse Power)

E = efficiency of the pump.

PROBLEM 1 : It is required to pump water at the rate of 6,750 gpm from a reservoir whose surface is at an elevation of 180 ft. to a tank whose bottom is at an elevation of 372 ft. The pump is placed at an elevation of 192 ft., the diameter of the suction pipe is 30 inch, the length of the pipe from the pump to the tank is 290ft. and the estimated size of this pipe is 24 inch. The sum of the minor head losses in the suction and discharge pipe may be taken as 1.5 ft. If the maximum

depth of water
horsepower
per cent ?

Assume head
Neglect all

Solution :

Elevation of

Discharge

pump to the

Suction line

in the reservoir

Since the head

is positive.

Total head

$$P = \frac{HQ}{3,960}$$

$$P_1 = \frac{375}{0.6}$$

PROBLEM 2 :

deliver

the tank

intake

head is

Assume

friction

efficiency

Water Supply

depth of water in the tank is to be 25 ft., what is the required horsepower of a pump for which the overall efficiency is 67 per cent ?

Assume head loss due to friction in 290 ft.+1.5 ft.

Neglect all other head losses.

Solution :

Elevation of water surface in the tank = 372 + 25 = 397 ft.

Discharge lift or the vertical distance from the centre of the pump to that surface = 397 - 192 = 205 ft.

Suction lift, or the vertical distance from the water surface in the reservoir to the centre of the pump = 192 - 180 = 12 ft.

Since that pump is above the water surface this lift is positive.

Total head $H = 205 + 12 + 1.5 + 1.5 = 220$ ft.

$$P = \frac{HQ}{3,960} = \frac{220 \times 6,750}{3,960} = 375 \text{ (W.H.P)}$$

$$P_1 = \frac{375}{0.67} = 560 \text{ (BHP) Ans}$$

PROBLEM 2 : Design a suitable set of pumping unit to deliver 4,50,000 gph from an intake well of a river bank to the treatment plant. Total length of rising main from the intake well to the treatment plant is 800 ft. and the static head is 60 ft-Design also the cast iron main.

Assume: Velocity of water = 12 fps

friction factor = 0.0075

efficiency = 70%

Water Supply

Solution.

$$Q = 4,50,000 + 60 = 7,500 \text{ gpm}$$

$$\text{again } Q = \frac{4,50,000}{60 \times 60 \times 6.24} = 20 \text{ cfs}$$

$$\text{Cross-sectional area} = \frac{20}{12} = 1,667 \text{ sq. ft.}$$

$$\frac{\pi d^2}{4} = 1,667 \quad (d = \text{diameter of pipe})$$

$$d = \sqrt{\frac{1,667 \times 4}{\pi}} = 1.5 \text{ ft} = 18 \text{ inch}$$

Frictional head loss h_f

$$= \frac{4 f l v^2}{2 g d} = \frac{4 \times 0.0075 \times 800 \times (12)^2}{2 \times 32.2 \times 1.5} = 36 \text{ ft.}$$

$$\text{Velocity head, } h_v = \frac{v^2}{2g} = \frac{(12)^2}{2 \times 32.2} = 2.24 \text{ ft.}$$

$$\text{Total head } H = h_s + h_f + h_v = 60 + 36 + 2.24 = 98.24 \text{ ft}$$

$$P = \frac{HQ}{3,960} = \frac{98.24 \times 7,500}{3,960} = 188 \text{ (WHP)}$$

$$P_1 = \frac{180}{0.70} = 265 \text{ (BHP) Ans.}$$

PROBLEM 3 : Water is supplied from an impounding reservoir 30 miles away to a service reservoir near the town. A cast iron main is to be designed to supply 425 mgd. Loss of head due to friction in the pipe is estimated to be 300 ft. All other head losses are neglected. What size cast iron pipe would you use?

Assume $f =$

Solution :

$$h_f = \frac{4 \times 0.0075 \times 800 \times (12)^2}{2 \times 32.2 \times 1.5} = 36 \text{ ft.}$$

$$\frac{v^2}{2g} = 2.24 \text{ ft.}$$

Again, $Q = av = \frac{\pi d^2 v}{4}$

[1 mgd = 1.547 cfs]

$$Q = av = \frac{\pi d^2 v}{4}$$

$$\therefore v^2 = \frac{4Q}{\pi d^2}$$

Substituting

$$\therefore \frac{16Q}{\pi^2 d^4} = \frac{4Q}{\pi d^2}$$

$$d^2 = \frac{4Q}{\pi^2 d^4}$$

$$\therefore d = 1.5 \text{ ft}$$

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Water Supply

Assume $f = 0.0075$

Solution :

$$h_f = \frac{4 \times 0.0075 \times (30 \times 5280) \times v^2}{2 \times 32.2 \times d} = 300$$

$$\frac{v^2}{d} = 4.06 \therefore v^2 = 4.06 \times d \dots (1)$$

Again, $Q = 425 \text{ mgd} = 425 \times 1.547 = 787 \text{ cfs}$

[1 mgd = 1.547 cfs]

$$Q = av = \frac{\pi d^2}{4} \times v \therefore v = \frac{4Q}{\pi d}$$

$$\therefore v^2 = \frac{16Q^2}{(\pi d)^2}$$

Substituting the value of v^2 from Eq. 2 to Eq. 1.

$$\therefore \frac{16Q^2}{\pi^2 d^5} = 4.07$$

$$d^5 = \frac{16 \times (787)^2}{\pi^2 \times 4.07^2} = 246,800$$

$$\therefore d = 11.98 \approx 12 \text{ ft. Ans.}$$

Problem 4 : Design a pumping unit capable of lifting 5 mgd of water from an intake well to the treatment plant against a static head of 60 ft ; length of suction main is 120 ft and that of rising main is 400 ft. The pump will work in two shifts of eight hours each.

Assume : velocity of flow = 6 fps

ending
town.
Loss
30 ft.
pipe

Water Supply

$$\text{friction factor} = 0.01$$

$$\text{efficiency} = 75\%$$

Solution :

$$\text{Total length of pips} = 120 + 400 = 520 \text{ ft.}$$

$$\text{Discharge, } Q = 5 \text{ mgd} = \frac{5 \times 10^6}{6.24} = 8 \times 10^5 \text{ cu ft/day}$$

Since total pumping time is 16 hrs/day,

$$\text{Pumping capacity} = \frac{8 \times 10^5}{16} = 50,000 \text{ cu ft/hr.}$$

$$= \frac{50,000}{60 \times 60} = 13.9 \text{ cfs}$$

$$Q = \frac{\pi d^2}{4} = 13.9$$

$$\therefore d = \sqrt{\frac{4 \times 13.9}{\pi \times 6}} = 1.7 \approx 21.75 \text{ ft} = 21 \text{ inch}$$

$$h_f = \frac{4 \times 0.01 \times 520 \times 6^2}{2 \times 32.2 \times 1.75} = 6.7 \text{ ft}$$

$$h_v = \frac{6^2}{2 \times 32.2} = 0.56 \text{ ft}$$

$$H = h_s + h_f + h_v = 60 + 6.7 + 0.56 = 67.26 \text{ ft}$$

$$Q = \frac{50,000,000}{16 \times 10} = 5,220 \text{ gpm}$$

$$P = \frac{HQ}{3,960} = \frac{67.26 \times 5,220}{3,960} = 88.5 \text{ (WHP)}$$

$$P_1 = \frac{P}{E} = \frac{88.5}{0.75} = 118 \text{ (BHP) Ans.}$$

Problem 5 : Design the transmission main and the pumping unit from the following data :

Water Supply

Water supply rate = 40 gpd

Estimated population = 85,000

Ground R. L. = at the pump house = 102.50 ft.

Treatment plant R. L. = 193.00 ft.

Velocity through pipes = 8 fps

Pumping time = 10 hrs. daily

Total length of pipe = 3,500 ft.

Friction factor = 0.01

Efficiency = 65%

Solution :

Total water required = $40 \times 85,000 = 34,00,000$ gpd

$$= \frac{34,00,000}{6.24} = 5.45 \times 10^5 \text{ cuft/day}$$

$$\text{Pumping rate} = \frac{5.45 \times 10^5}{10} = 5.45 \times 10^4 \text{ cuft/day}$$

$$= \frac{5.45 \times 10^4}{60 \times 60} = 15.15 \text{ cfs}$$

$$Q = \frac{\pi d^2}{4} \times v = 15.15$$

$$\therefore d = \sqrt{\frac{4 \times 15.15}{\pi \times 8}} = 1.56 \text{ ft.}$$

Use a 21 inch diameter pipe $d = 1.75$ ft.

Static head = $193.00 - 102.50 = 90.50$

$$\text{Friction head} = \frac{4 \times 0.01 \times 3,000 \times 8^2}{2 \times 32.2 \times 1.75} = 80.0 \text{ ft}$$

$$\text{Velocity head} = \frac{v^2}{2 \times 32.2} = 1.0 \text{ ft}$$

Water Supply

$$\text{Total head. } H = 90.5 + 80.0 + 1.0 = 171.5 \text{ ft}$$

$$\text{Discharge. } Q = \frac{34,00,000}{10 \times 60} = 5,667 \text{ gpm}$$

$$\therefore P = \frac{HQ}{3,960} = \frac{171.5 \times 5667}{3,960} = 246 \text{ (WHP)}$$

$$\therefore P_1 = \frac{P}{E} = \frac{246}{0.65} = 380 \text{ (BHP) Ans.}$$

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Water Supply

QUESTIONS

1. State the purposes of pumps and pumping machinery in water supply systems.

Water supply to a small town with ultimate population of one lakh (1,00,000) supplied with 60 gpd has to be arranged from a river flowing nearby. Design the economical section of the rising main and the necessary pumping unit from the following data:

Static head	60 ft
Total length of pipe	520 ft.
Coefficient of friction	0.01
Velocity of water in the pipe	6 ft/sec
Pump efficiency	70%

The pumps will work in two shifts of six hours each in a day, (BUET, 1972)

2. Write the characteristics of centrifugal pumps. Design a suitable pumping unit and the size of the transmission main delivering water from a source 500 yds. away to a treatment plant or a small town having the design. Population of 2.5 millions supplied with 50 gpd against a frictional head of 70ft. The pump will operate only 8 hrs. in a day. Take pump efficiency =65% and $f=0.01$. Neglect all other head losses. (BUET, '71).
3. State the general considerations for pumping installation. What is the theoretical horsepower required for a pump to

Water Supply

raise 1800 gpm of water against a total head of 150 ft. including all losses ?

Which type of pump do you suggest and why? (BUET, '68)

4. What is the total lift of a pump ?

Design a pumping unit to transmit water from a source to a treatment plant of a small town having ultimate population of 80,000 supplied with 50 gpd of water.

Given : R. L. of the ground at pump house = 98.20 ft.

R. L. of the entry site ground to a treatment plant = 154.60 ft.

Length of pipe line = 2000 ft.

Velocity of water through the pipe = 8 fps.

Friction factor = 0.0075

Pump efficiency = 65% (BUET, '67)

5. A multistoried building requires 15,000 gpd of water. The water will be supplied by a 3 inch diameter well. Design a suitable pumping unit from the following data : Suction head = 12 ft. Delivery head = 180 ft. Size of the suction and delivery pipe = 2 inch Velocity of water through pipes = 6 ft/sec. Friction factor = 0.01 Assume reasonable values of data not supplied. (BUET, 1972)
6. Write explanatory notes on :
Deep well turbine Pump, Air Lift Pump, Submersible pump.
Suction lift.

DISTRIBUTION SYSTEM

9.1 Definition :

The distribution system is that part of the water works which receives the water from the pumping station or from conduits by the gravity flow and delivers it throughout the district to be served.

It includes, as such, reservoirs for purposes of storage equalizing pressures and subsequent distribution, together with pipes, valves, hydrants and other appatenances for carrying water, services pipes, meters etc.

9.2. General Requirements :

A distribution system should satisfy the following general requirements :

- (a) The distribution system should, be such as to furnish water in adequate quantities and pressures to all parts of the district served. This would include all demands such as water supply for domestic and industrial use and for fire-fighting purposes.
- (b) The distribution system should be thoroughly reliable. This would involve (i) interconnecting all the water mains and controlling flow through shuice valves located at suitable points, so as to ensure an uninterrupted supply of water to all other sections when one of the sections has to be cut out of service following breakdown and consequent

Water Supply

repair; (ii) protecting the following supply mains, valves and other appurtenances. The main would normally be required to be laid with a sufficient cover of about 3 ft under roads and streets, so that they are not open to any damage because of any hazard of passing traffic. At such points as stream crossings, rail-roads etc., the pipes need to be amply protected by carrying them on concrete trestles or similar supports.

(c) The distribution system should be economical in its design, lay-out and construction; this being considered to be the costliest part of the water supply scheme. It is estimated that the ratio of the cost of the distribution system to the overall cost in case of a large scheme is 50 to 75 per cent and for a small scheme as much as 90 per cent.

9.3 Classification:

A distribution system is classified depending upon the method of distribution involved as (1) Gravity system, (2) System with direct pumping and (3) System with pumping and storage.

Gravity System : A gravity system is adopted where the source of supply such as a lake or an impounding reservoir, is at a sufficient elevation with respect to the city in order to produce adequate pressures for fire and domestic service. This method, evidently, is the safest and most reliable.

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System with direct pumping : In this, water is directly pumped into the mains. Consumption is the only outlet. This method is least desirable, a failure in the power supply means breakdown of the system. Also, pressures in the mains vary with the consumption, so that under varying consumption, several pumps may be required to conform to the supply, adding to cost.

System with pumping and storage : This is also called the direct-indirect or dual system. In this, when the demand-rate exceeds the rate of pumping, the flow into the distribution system is both from the pumping-station as well as the elevated reservoir. When, however, the reverse condition exists i.e., pumping is more than the demand, the excess of water is stored in the reservoir. This system, obviously, is the most economical and reliable. It provides for a uniform rate of pumping. The pumps can be operated at their rated capacities, resulting in higher efficiency and economy of operation. Also, the water stored serves as a reserve to take care of fire demands and pump breakdowns.

9.4 Methods of Supply :

Water may be supplied to the consumer either intermittently i.e., for a few fixed hours of the day say 5 A.M. to 11 A.M. and 3 P.M. to 9 P.M., or continuously i.e., for all the twenty-four hours of the day. A continuous method of supply is

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always better than the intermittent method because of the following reasons.

- (1) When the supply of water is only for a few fixed hours of the day, consumers are compelled to store water for use during the non-supply hours. The domestic storage tanks built for the purpose may suffer for want of proper maintenance and attention for a long time, resulting in a possible contamination of the water supply.
- (2) The unused water of storage tanks is most likely to be thrown out to be replaced, during the supply hours, by fresh supply of water. Evidently, this is a wasteful use of water. Also, where the supply is not metered, there is a tendency on the part of consumers to leave the taps open for all hours, resulting in additional wastage of water. The receptacles so left under public hydrants and faucets may remain overflowing, without being attended to, for a long time.
- (3) In case a fire breaks out during the non-supply hours, considerable damage would have resulted before the supply could be turned on and fire extinguished.
- (4) During the non-supply hours, pressures in the distribution mains may fall below atmospheric pressures, causing partial vacuum, sucking in air or other harmful gases from sewers running close-by and resulting in a possible contamination of water supply.

9.5 Pressure Requirements in Water Distribution System:

In designing water-distribution systems pressure requirements for ordinary use, and for fire fighting must be considered. In residential districts fire pressures of 60 psi at the hydrant are recommended. In commercial districts minimum pressure of 75 psi is tolerable, but higher pressures must be provided in districts with tall buildings. The American Water Works Association recommends a normal static pressures of 60 to 75 psi is throughout a system. Many cities use fire-department motor pumpers to develop the necessary fire pressure so that normal operating pressure can be less than that quoted above. The maintenance of high pressure in mains means increased pumping costs and usually also increased leakage. Some large cities have installed dual systems in business districts, a low-pressure system for ordinary use and a high-pressure system (150 to 300 psi) for fire fighting only. Other cities use standby pumps to raise the pressure in the entire system whenever a fire occurs.

Faucet pressures of 5 psi are satisfactory for most domestic needs. Assuming a maximum pressure loss of 5 psi in the meter the main about 5 ft below ground level, a total pressure of about 35 psi in the main is adequate for residential districts with one and two storey houses. Allowing about 5 psi for additional storeys, a pressure of 75 psi should be satisfactory for buildings upto 10 storey in

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Water Supply

height. Many cities require owners of tall buildings to install booster pumps in order to avoid the need for very high pressures in the mains.

9.6 Distribution System Components:

Pipes, gates and hydrants are the basic elements of distribution systems. Their dimensioning and spacing rest upon experience normally precise enough in its minimum standards to permit roughing in all but the main 'arteries and feeders. Common standards include the following :

Pipes

Smallest pipes in grid iron	6 inch
Smallest branching pipes (dead ends)	8 inch
Largest spacing of 6 in, grid (8 inch pipe used beyond this value)	600 ft
Smallest pipes in high-value district	8 inch
Smallest pipes on principal streets in central district	12 inch
Largest spacing of supply mains for feeders	2,000 ft

Gates

Largest spacing on long branches	800 ft
Largest spacing in high-value district	500 ft

Hydrants

Areas protected by hydrants	50,000-70,000 sqft each
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Water Supply

Largest spacing when fire flow exceeds 5,000 gpm 200ft
Largest spacing when fire flow is low as 1,000 gpm 300 ft

9.7 Distribution Reservoirs (TANKS) :

Distribution reservoirs are used to provide storage to meet fluctuations in use, to provide fire storage, and to stabilize pressure in the distribution system.

The reservoir should be located as close to the center of use as possible. The water level in the reservoir must be high enough to permit gravity flow at satisfactory pressures to the system which it serves. In large cities several distribution reservoirs may be located at strategic points throughout the city. Water is usually pumped into a distribution reservoir when the demand is low and withdrawn by gravity flow during periods of high demand. The required capacity of a distribution reservoir is established by the use of characteristics of the district which it serves.

Types of Reservoirs : The storage reservoirs are commonly built up in four different types: (1) R.C.C. tank on R.C.C. staging (2) Steel tank on brick ower, (3) steel tank on steel staging, (4) Prestressed steel tanks on steel staging.

The R.C.C. tanks are commonly used in our country. The reservoirs may be of various shapes like square, rectangular, cylindrical, cylindrical with conical base (Inze type)

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Cylindrical with hemispherical base, etc. Cylindrical type is most economical.

Accessories: The following are the main accessories of an overhead reservoir: (1) Inlet and outlet pipes fitted with valve control. (2) Overflow and wash-out pipes combined with valve control. (3) Ladder and manhole for cleaning and inspection. (4) Water level indicator. (5) Ventilators and lightning arresters.

A. Typical Intze type R.C.C. cylindrical overhead water tank is shown in Fig. 9.1,

Most Economic Dimensions of a Cylindrical Water Tank
Dimensions of tank may be determined by applying the simple principle of calculus, Maxima and minima. Since the tank is cylindrical, minimum surface area that will be required to contain a constant volume of water by the condition of maxima and minima.

(See Fig. 9.2)

Assuming floor thickness is equal to that of the wall.

$A = A_1 + A_2$, where A_1 = Area of the base

A_2 = Area of the shell-surface

A = Total Area

$$A = \pi r^2 + 2\pi rh$$

V = Volume of the tank

$$= \pi r^2 h$$

$$\therefore h = \frac{V}{\pi r^2}$$

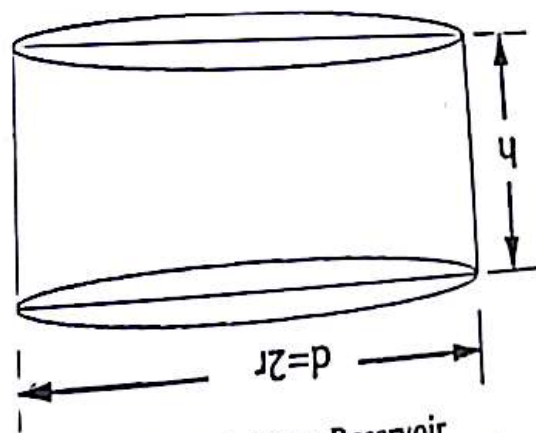


Fig. 9.2 Water Reservoir

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$$\begin{aligned} A &= \pi r^2 + 2\pi r \frac{V}{\pi r^2} \\ &= \pi r^2 + \frac{2V}{r} \end{aligned}$$

Differentiating with respect to r

$$\frac{dA}{dr} = 2\pi r - \frac{2V}{r^2}$$

From the condition of Maxima and Minima : $\frac{dA}{dr} = 0$

$$\therefore 2\pi r = \frac{2V}{r} = 0$$

$$\text{or, } 2\pi r = \frac{2V}{r^2}$$

$$\text{or, } 2\pi r = \frac{2\pi r^2 h}{r^2}$$

$$\text{or, } r = h$$

Hence, for economical dimension of a cylindrical tank radius of the tank must be equal to the height of the tank.

Example : Calculate the economic dimension of a cylindrical: water tank for one lakh gallons.

Solution : capacity of the tank = $\frac{1,00,000}{7.48} = 13,370$ cuft.

$$V = \pi r^2 h = 13,370$$

$$\therefore r = h.$$

$$\therefore \pi r^3 = 13370$$

$$r^3 = \frac{13370}{\pi} = 4258$$

$$r = 16.5 \text{ ft.}$$

Dimensions : Diameter = 33 ft.

Water Supply

Height = 16.5 ft.

Example : In constructing an elevated circular R.C.C. tank if the cost per sq ft of the shell is 1.5 times to that of the floor, what be the most economical dimensions of the tank : Assume thickness of the floor thickness of the shell.

Let C = cost, and A = surface area.

$C \propto A$ constant

$$C = K(A) = K[\pi r^2 + 1.5(2\pi rh)]$$

$$C = K(\pi r^2 + 3\pi rh), \quad V = \text{Volume of the tank}$$

$$C = K\left(\pi r^2 + 3\pi \frac{V}{\pi r^2}\right), \quad V = \pi r^2 h$$

$$= K\left(\pi r^2 + \frac{3V}{r^2}\right), \quad h = \frac{V}{\pi r^2}$$

Differentiating cost with respect to radius

$$\frac{dc}{dr} = K\left(2\pi r - \frac{3V}{r^2}\right)$$

for minimum condition:

$$\frac{dc}{dr} = 0, \quad \text{Hence, } K\left(2\pi r - \frac{3V}{r^2}\right) = 0$$

$$\text{or, } 2\pi r^3 = 3V$$

$$\text{or, } 2\pi r^2 = 3\pi r^2 h$$

$$\text{or, } 2r = 3h$$

$$\text{or, } r = 1.5h$$

9.8 Pipe Systems : The pipe system comprises of the following four units (See Fig. 9.3) :-

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(i) The supply main, (ii) the sub-mains, (iii) minors distribution and (iv) valves.

The supply main or main is the direct conveyor of water for the pumping plant or the gravity conduit. It should be of sufficient size to carry the flow.

The sub-mains are the secondary feeders connected to either side may be placed at about 1000 ft apart and should be of sufficient size to discharge domestic supply and fire flow.

The minor distributors or branches make up the grid irons of pipes and supply water to the fire hydrants and service pipes of the residences and other buildings. For fire service, minimum

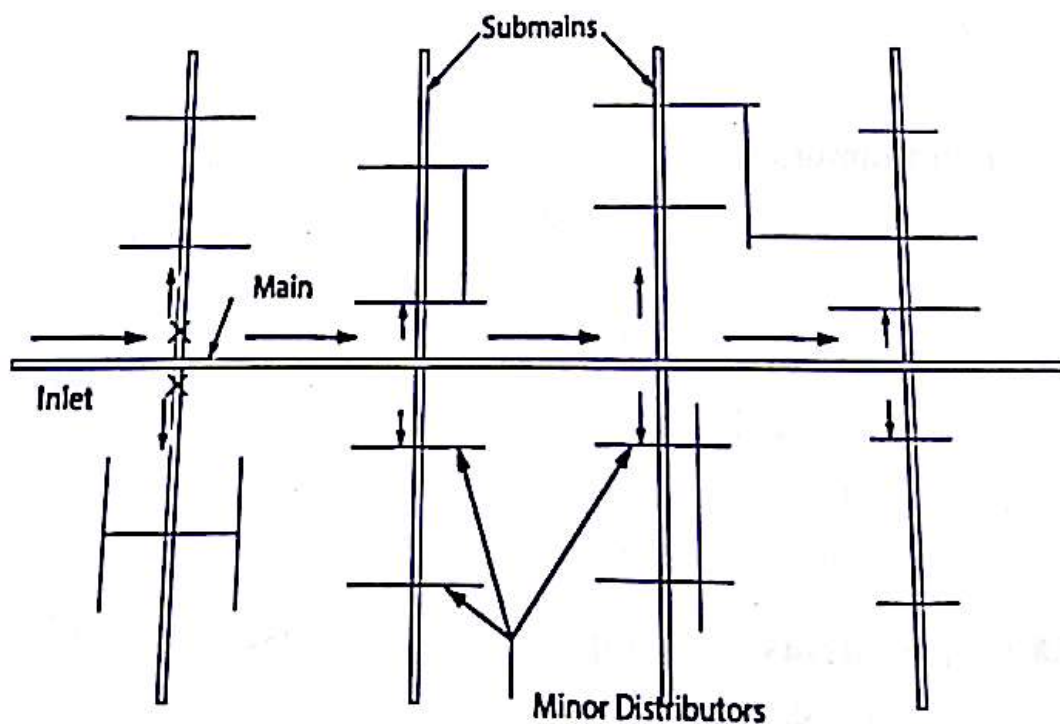


Fig. 9.3 Components of the Pipe System

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diameter of pipe should be 6 inch and for domestic service alone 4 inch and less.

Valves are needed to operate and control the pipe system. These should be sufficient in number and suitably located.

9.9. Layout of Distribution System:

There are four different systems of distribution depending upon the methods of layout of the pipe-system. These are (1) Dead End (2) Grid Iron System (3) Circle or Ring System, (4) Radial System.

Dead End System comprises of a supply main starting from the service reservoir and laid along the main road, with submains running at right angles to it in both directions and laid along other roads joining the main road. Across the submains run the minor distributors or branches, laid along streets and connecting buildings and houses (Fig. 9.3).

This system is suitable to old towns and 'cities which have been irregularly developed having no definite pattern of roads and streets. Its advantages are (i) its relative cheapness and (ii) easy determinations of discharge and pressure at any point in the system. By suitably locating valves, water supply can be so regulated that by closing any valve say at A, a section of the system can be cut out for repairs without affecting the rest.

Its disadvantages are (i) each pipe has a dead end where the water becomes stagnant and sediment accumulates.

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requiring the provision of blow-off or drain valves to remove the same. (ii) A large district is to be cut out when repairs have to be made to an important pipe.

Grid Iron System is an improvement over the Dead End System, caused by connecting the ends of the various mains so as to eliminate the dead ends. The water then circulates freely throughout the system. Such a system is very useful for a city laid out on a rectangular plan (Fig. 9.4); the connections of the dead end producing a grid iron pattern, with mains running in one direction or in perpendicular direction and submains also running alike on minor roads and streets.

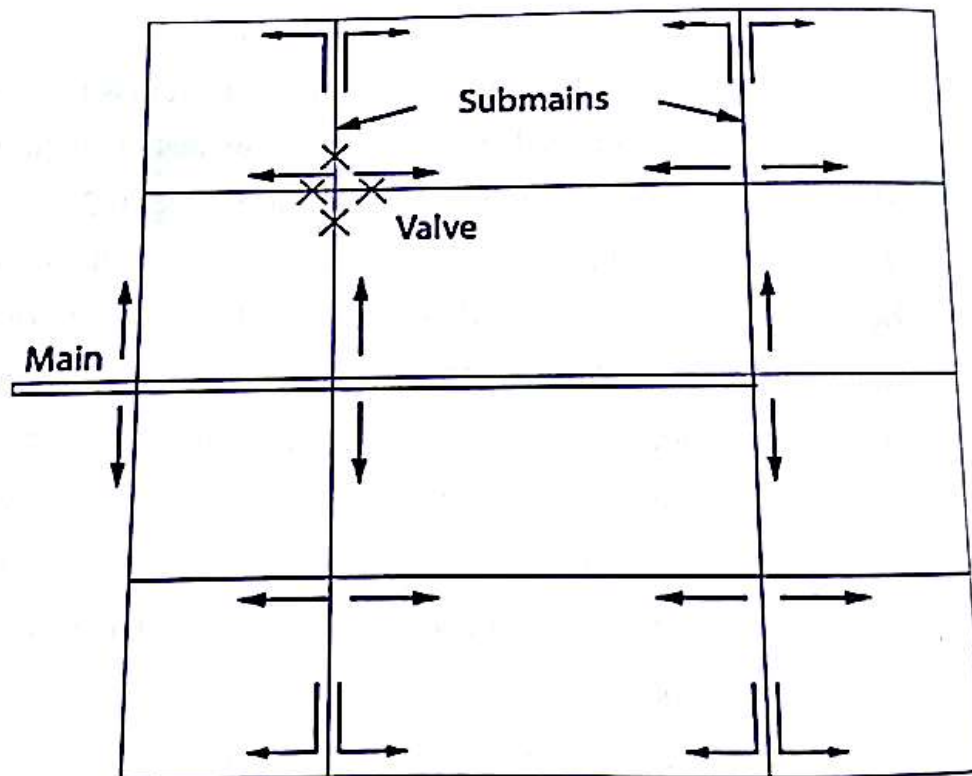


Fig. 9.4 Grid Iron System

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Advantages to be gained with this system are (i) avoidance of any stagnation due to water circulating continually, and (ii) absence of the discontinuity of water supply anywhere in the system in the event of any repair-work to a main or submain, water being easily available from another main or submain. Disadvantage is the provision of a very large number of valves. At every junction of two roads, four valves are required (see at B, Fig. 9.4). The system is, therefore, costlier.

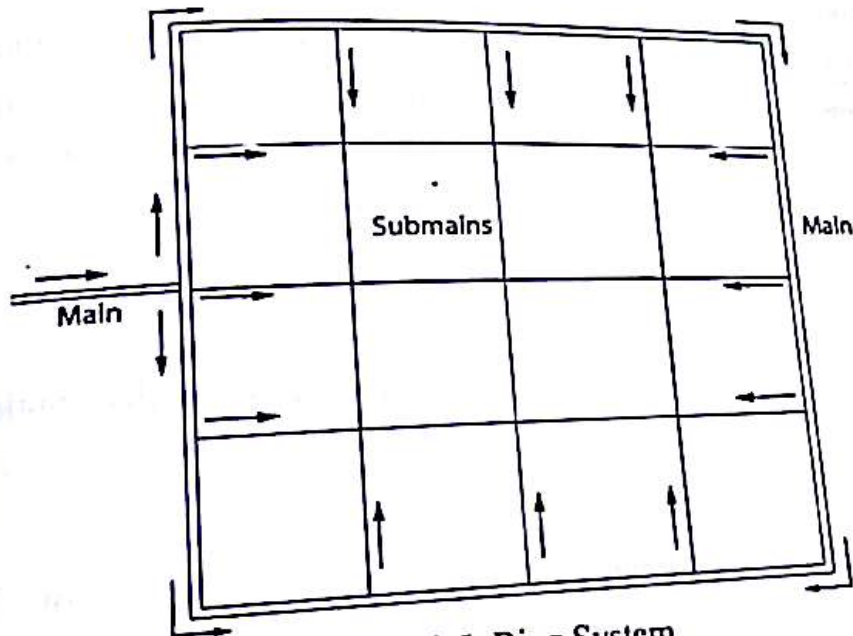


Fig. 9.5 Ring System

Circle or Ring System (Fig. 9.5) : This consists of cutting the entire district into circular or rectangular blocks and then laying the mains all along the peripheral roads with submain branching out from the mains and running on the

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inner roads and streets. Thus this system also follows the Grid-Iron pattern with the difference that the flow pattern is now similar in character to that of the Dead End System. That makes the determination of discharge or size of pipe easier. Also, water can be supplied to any point from at least two directions. This shows that this system possesses the advantages of both of the previous systems.

Radial System (Fig. 9.6) : This system is the reverse instead of from it. The entire district is divided into a number of distribution zones AEKH, EBKH etc., and a distribution reservoir is placed in the centre of each zone. The supply pipes are laid radially away towards the periphery. This system is most advantageous with the "direct-indirect system" for obvious reasons.

9.10. Design of Distribution System :

Factors to be considered in the design of a distribution system are

- (a) Type of flow-whether continuous or intermittent.
- (b) Method of distribution-whether by gravity or by pumping.
- (c) Probable future demand based on prospective increase in population. This also includes the industrial demand as well as the fire fighting requirements.

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- (d) Period to be considered to be the life of pipes used. The system should be designed anticipating the future for the condition that will obtain near the end of the time when the amounts set aside for depreciation would have returned the first cost.
- (e) The flow-formulae used in the design have been discussed in Chapter 6.

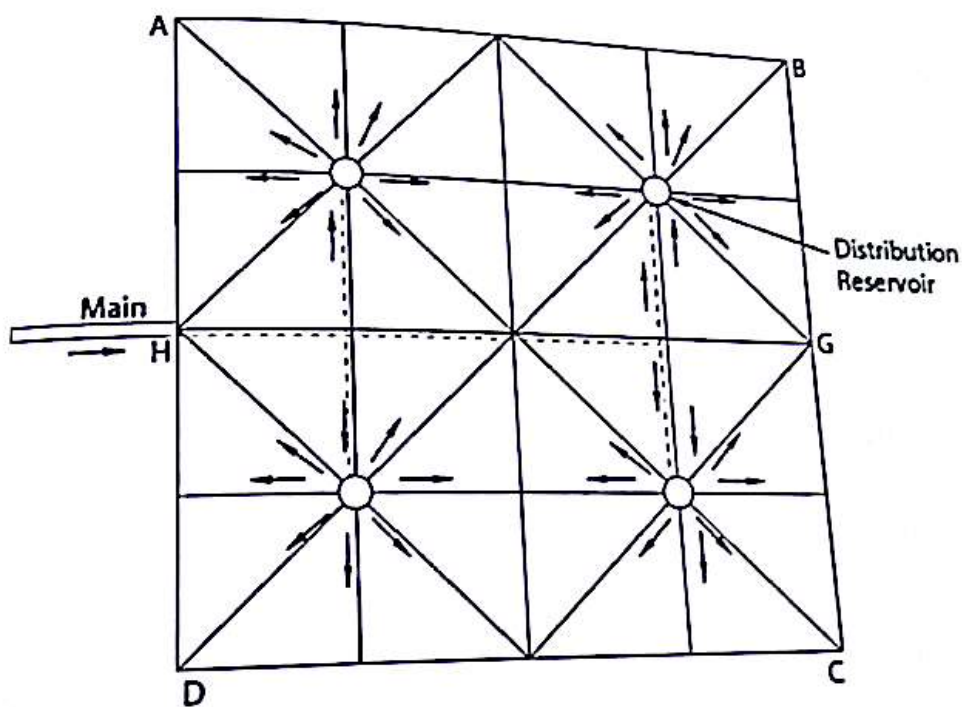


Fig. 9.6 Radial System

The principle involved in the design is to assume the pipe size-and then to work out the terminal pressure heads which could be made available at the end of each pipe section after allowing for the loss of pressure-head in the pipe section

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when discharging the peak flow. The peak or maximum flow in the pipes is taken as 3 times the average daily flow. Factors causing loss of pressure-head include size of pipe, rate of flow, and friction. Usually losses due to friction in the pipes are considered.

The available pressure heads as calculated are checked up to see if they correspond to the permissible residual pressure-heads. If not, the pipe size is changed and the system reinvestigated until satisfactory conditions are obtained.

The design-procedure may now be outlined as below :

(a) Prepare a contoured plan of the city or town, locating on it the positions of districts or distribution zones with their population, service reservoirs, pumping stations, main roads and streets, existing main-lines and other similar features. A

small scale (say $\frac{1}{10,000}$) may be used

(b) Prepare detailed map of each district, showing in addition to the aforesaid information for the particular district, location of all principal and minor streets. The tentative alignment of all mains, sub-mains and branches as well as position of valves and other appurtenances should be marked. Probable population to be served by each section of

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pipe-line should be indicated. Choose a bigger scale (say $\frac{1}{2,000}$).

(c) Estimate the rate of demand for all purposes including the fire-demand and determine the quantity flowing in each section of the pipe length. This gives the average daily flow in the pipe. The maximum flow will be 3 times of this.

(d) Assume pipe sizes. The velocity of flow varies 3-4 ft/sec.

(e) Find loss of head due to friction in the pipe-length. Use in made of the Hazen-Williams formula because of the ease with which calculation can be made due to the availability of Nomograph (Fig. 6.1). Usual value of C taken is 100. Alternatively the friction-flow formula viz,

$$h_f = \frac{4fLv^2}{2gd} \text{ may also be used (} f = 0.01 \text{)}$$

(f) Determine the available terminal pressure-heads. Starting, from the service reservoir of the pumping station where the total pressure-head is known, the pressure-head at the end of any line would be determined by allowing for the frictional loss of head and any rise or fall due to slope of the pipe line and the ground levels.

(g) In case of difference between the available terminal pressure-head and the permissible pressure-head, revise the assumed pipe-size.

9.11 Analysis of Distribution System:

Frequently it becomes necessary to analyse a given distribution system in order to determine through a quick and approximate check, the pressures and flows available in any section of the system and to suggest ways to improve upon the same, if found inadequate. A few important methods, their principles and methods of determination are briefly discussed as below.

Equivalent Pipe Method : This method is useful in rendering a complex network of pipes into an equivalent pipe system giving the same discharge and loss of head as in the complex system.

For purposes of analysis, the entire network of pipes is considered to be split up into two portions : (i) pipes in series and (ii) pipes in parallel.

Pipes in Series : Pipes carry arbitrarily chosen values of discharge Q_1 , flowing through branches AB and BD and Q_2 , flowing through AC and CD (See Fig. 9.7) It is assumed that the loss of head for pipes in series is additive.

Knowing discharge (say Q_1) and diameters of pipe-lines AB and BD through which it flows, it is possible to determine the loss of head H , in their total length (AB+BD) Here, use is made of the nomograph as discussed in Fig. 6.1. A single length of equivalent pipe AD of

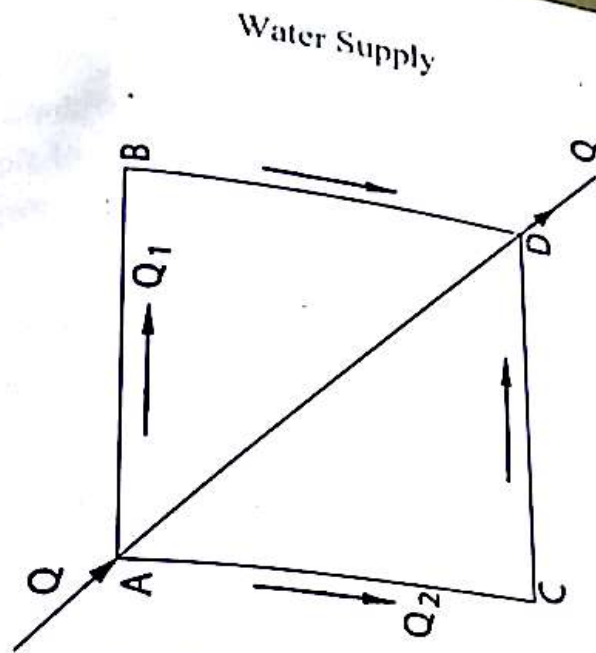


Fig. 9.7 Equivalent Pipe

known diameter can then be selected to give the same values of discharge Q_1 and loss of head H_1 .

Pipes in Parallel : In this head through pipes in parallel i.e., ABD and ACD is the same.

If a certain loss of head (say H_1) is one assumed to occur in either arm length ABD and ACD flows through the arms can be worked out and added together to see that the total flow corresponds nearly to the original flow Q . The size and length of a single pipeline can then be calculated to give the same discharge and loss of head.

Method of Sections : This is an approximate method but gives a quick check and is simple to follow.

The method may be described in the following steps :

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- (i) Cut the network of pipes by a number of sections aa, bb, cc, at right angles to the assumed direction of flow (see Fig. 9.8). Consider a proper sequence of pipes and character of district served (residential or commercial).
- (ii) Calculate the quantity of water to be supplied beyond each section.
- (iii) Study the average available gradient. Velocity allowed in pipes is 2 to 4 ft/sec. Permissible gradient should be between 1 to 3 ft per 100ft. .
- (iv) Find out the number of pipes cut by each section.
- (v) Calculate the total discharge of water available at the end of each section by determining the discharge capacities and number of pipes cut at a section and summing these up.

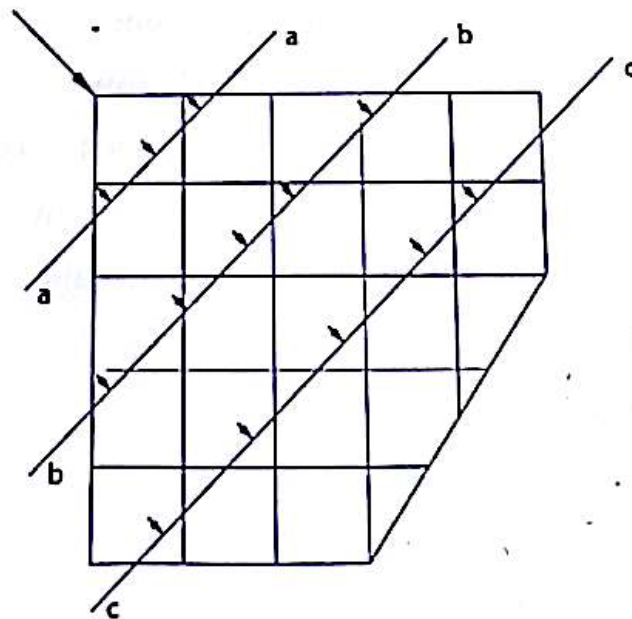


Fig. 9.8 Method of Sections

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- (iv) Difference between the required discharge and the calculated discharge are made up by providing suitable number of additional pipes at allowable gradients at each end of section.

Hardy-Cross Method of Analysis of Flow in a Pipe Network : City water distribution systems are composed of inter connected pipes in branches and loops, and the flow to given outlet may come from several pipes. The determination of the probable flow in each pipe of a network requires complicated and tedious trial and error solution.

In any pipe network two conditions must be satisfied : (1) the flow entering a junction must equal the flow leaving it, and (2) the algebraic sum of the pressure drops (head losses) around any closed loop must be zero. The first condition is a statement of the law of continuity. The second condition states that there can be no discontinuity in pressure, i.e., the pressure drop (head loss) through any route between two junctions in a loop must be the same

Pipe network problems in water distribution systems are usually solved by methods of successive approximation since any analytical solution requires the use of many simultaneous equations, some of which are nonlinear. It is convenient to express head loss as a function of discharge, i.e.,

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$$H = KQ^x \quad (9.1)$$

in which H is the head loss in the pipe, Q is the discharge, K is the constant depending upon length, diameter and roughness of the pipe as well as the fluid properties, and x is the exponent. On the basis of the Manning equation the value of x would be 2, while for the Hazen-Williams equation, $x=1.85$. The Darcy-Wesbach formula gives values of x varying from 1.75 for smooth pipes to 2 for rough pipes. In pipe net-work, the value of x is usually taken as 1.85.

Hardy Cross (USA) developed a method of successive approximations in which the circuits are balanced, distribution of flow is determined and the two conditions of flow are satisfied. The solutions for pipe network problems suggested by Hardy cross requires that the flow in each pipe be assumed so that the principle of continuity is satisfied at each junction. A correction to the assumed flow is computed successively for each pipe loop in the network until the correction is reduced to an acceptable magnitude. If Q_a is the assumed flow and Q is the true flow in a pipe, then the correction is $Q-Q_a$ and $Q=Q_a+\Delta$ (9.2)

Expressing head loss by Eq. 9. 1 the condition that the head loss around any closed loop be zero gives

$$\sum K(Q_a+\Delta)^x = 0$$

Expanding this Summation

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$$\sum KQ_a^x + \sum xK \Delta Q_a^{x-1} + \frac{x-1}{2} \sum xK \Delta^2 Q_a^{x-2} + \dots = 0 \quad (9.4)$$

If Δ is small compared to Q the third and all succeeding terms of the expansion may be neglected. Hence,

$$\sum KQ_a^x + \Delta \sum xKQ_a^{x-1} = 0 \quad (9.5)$$

where Δ has been removed from the summation since it is the same for all pipes of the loop. Solving for Δ gives

$$\Delta = - \frac{\sum KQ_a^x}{\sum xKQ_a^{x-1}} \quad (9.6)$$

$$\text{or } \Delta = - \frac{\sum H}{\sum xKQ_a} \quad (9.7)$$

Inflow

Inflow

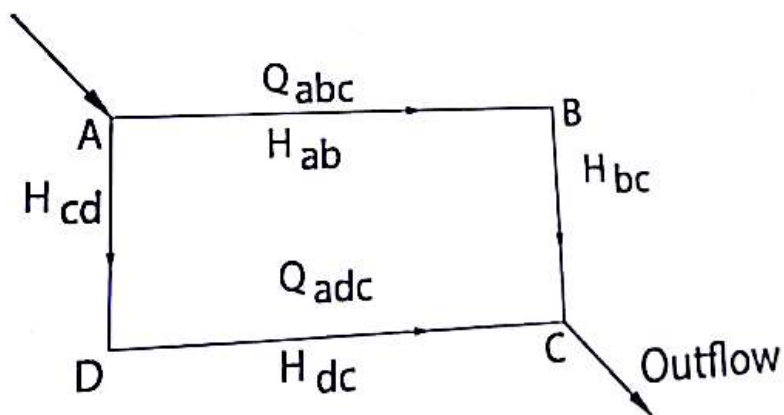


Fig. 9.9

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Consider the simple loop shown in Fig. 9.9, the arrow heads showing the assumed direction of flow. Two conditions must be satisfied.

(1) Inflow at the junction A must equal outflow at the junction

(2) Head losses due to flow in the clockwise direction (in pipes ab and bc) must equal head losses in the counterclockwise direction (in pipes ad and dc) at the junction C. The flow correction Δ can be computed by

$$\Delta = \frac{(H_{ab} + H_{bc}) - (H_{ad} + H_{dc})}{\times [(H_{ab} + H_{bc}) / Q_{abc} + (H_{ad} + H_{dc}) / Q_{adc}]} \quad 9.8$$

where Δ = flow correction in gpm or cusec.

Q_{abc} = assumed flow in the clockwise direction in pipes ab and bc in gpm or cusec.

Q_{adc} = assumed flow in the counterclockwise direction in pipes ad and dc in gpm or cusec.

H_{ab} = head loss in the pipe ab in ft.

H_{bc} = head loss in the pipe bc in ft.

H_{ad} = head loss in the pipe ad in ft.

H_{dc} = head loss in the pipe dc in ft

x = exponent = 1.85

In practice, the Hardy Cross method is usually applied by the following procedure :

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- (a) Carefully examine the network and assume reasonable rates of flow in each pipe such that inflow equals outflow at each junction.
- (b) In each loop determine the head loss, H and H/Q for each pipe.
- (c) With due attention to sign, compute the total head loss around each circuit.
- (d) Compute, without regard to sign, for the same circuit the sum : $\Sigma H/Q$.
- (e) Δ , the correction, is computed for each loop by the Eq. 9.7. The minus sign can be disregarded since the correction so obtained is made by inspection.
- (f) Apply corresponding correction to each pipe in each loop. When the sign of Δ is positive (+), decrease the clockwise flows and increase counterclockwise flows. Where sign is negative (—), increase clock-wise flows and decrease counterclockwise flows. Pipes that are common to two loops require a double correction.
- (g) With adjusted flows, repeat the procedure for the second approximation. The procedure is continued until the desired accuracy is attained.

Electrical Network Method : An electrical analogy is sometimes used to solve complex pipe-network problems. Ohm's law is not applicable to turbulent flow in pipes since it makes discharge (current) a function of the first power of the potential gradient. Special tubes, called fluistors, have

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been developed which cause voltage to vary with the 1.85 power of the current. With these tubes in the circuit, the pressure (voltage) and flow (current) distribution can be determined by measuring voltage and current at the desired junctions.

Computer Method : Another method of solving a pipe-network problem is to use a computer. Programming takes time and care, but once set up, there is great flexibility. The effect of changing a pipe size, for example, can be readily determined by simply replacing the old data card for that pipe with a new one. The speed of the computer and the accuracy that can be obtained are the outstanding advantages of this approach.

Example: Given Pipe network shown in Fig. 9.10 with inflow of 3500 gpm at the junction A and outflows as follows : junction C-700 gpm, junction E-2,100 gpm, and junction K-700 gpm. Use Williams and Hazen formula, $C=120$ and determine the rate of flow in each pipe when the pipe network is properly balanced.

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First Trial

denoted by (1)

Loop	Pipe	H	H/Q
Loop 1	bc	10.0	0.0053
	cd	6.0	0.0067
Loop 2	cd	15.0	0.0100
	de	3.7	0.0051
		18.7	0.0279

$$\Delta Q = \frac{18.0 - 18.7}{1.85 \times 0.0279} = -54.0$$

Loop	Pipe	H	H/Q
Loop 1	bc	3.5	0.0032
	cd	2.8	0.0051
Loop 2	cd	7.6	0.0030
	de	6.0	0.0067
		6.0	0.0224

$$\Delta Q = \frac{7.6 - 6.0}{1.85 \times 0.0224} = 39.0$$

Loop	Pipe	H	H/Q
Loop 1	bc	17	0.0053
	cd	4.6	0.0058
Loop 2	cd	4.6	0.0053
	de	4.1	0.0073
		10.3	0.0252

$$\Delta Q = \frac{17.0 - 10.3}{1.85 \times 0.0252} = 182.0$$

Loop	Pipe	H	H/Q
Loop 1	bc	2.3	0.0077
	cd	1.3	0.0033
Loop 2	cd	3.6	0.0030
	de	0.3	0.0088
		4.2	0.0138

$$\Delta Q = \frac{3.6 - 4.2}{1.85 \times 0.0138} = -14.0$$

SECOND TRIAL denoted by (2)

Loop	Pipe	H	H/Q
Loop 1	bc	11.2	0.0055
	cd	7.0	0.0071
Loop 2	cd	14.0	0.0090
	de	5.0	0.0060
		19.0	0.0283

$$\Delta Q = \frac{18.2 - 19.0}{1.85 \times 0.0283} = -15.0$$

Loop	Pipe	H	H/Q
Loop 1	bc	3.3	0.0031
	cd	3.3	0.0092
Loop 2	cd	6.7	0.0021
	de	3.0	0.0071
		7.0	0.0275

$$\Delta Q = \frac{6.7 - 7.0}{1.85 \times 0.0275} = -8.0$$

Loop	Pipe	H	H/Q
Loop 1	bc	5.0	0.0060
	cd	3.0	0.0049
Loop 2	cd	3.0	0.0049
	de	0.50	0.0022
		6.5	0.0253

$$\Delta Q = \frac{5.0 - 6.5}{1.85 \times 0.0253} = -45.0$$

Loop	Pipe	H	H/Q
Loop 1	bc	2.6	0.0083
	cd	0.50	0.0022
Loop 2	cd	3.0	0.0021
	de	2.00	0.0091
		1.60	0.0217

$$\Delta Q = \frac{3.0 - 1.60}{1.85 \times 0.0217} = 12.0$$

Water Supply

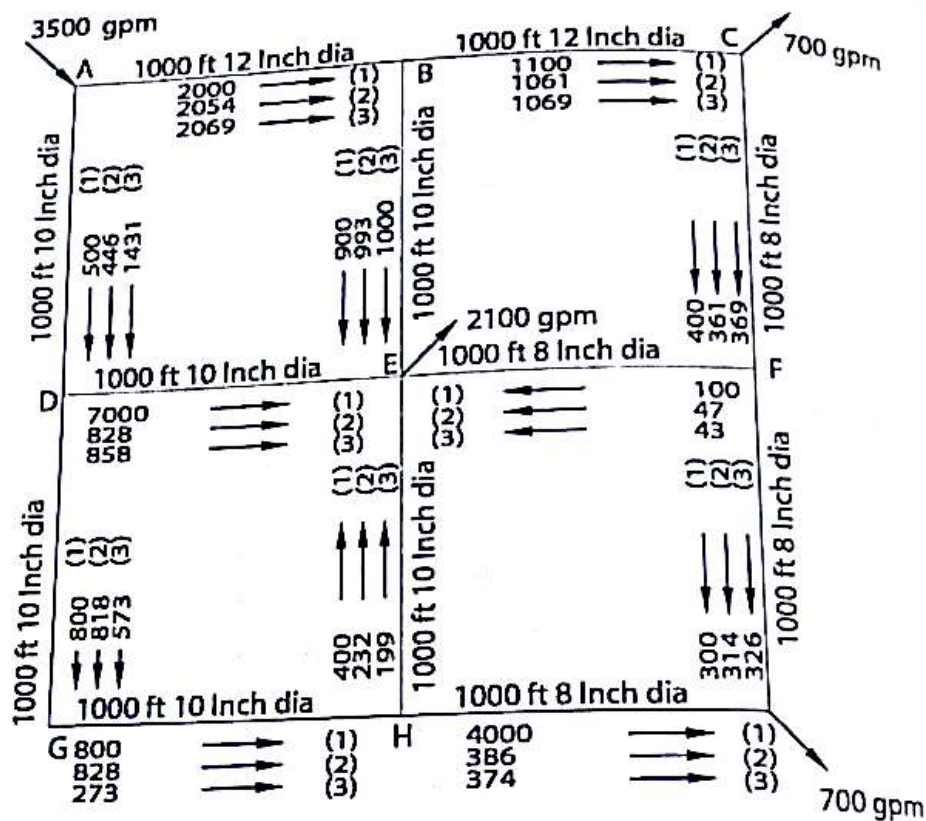


Fig. 9.10

Third trial denoted by (3): Detailed calculations have not been shown but the results have been shown on the Fig. 9.10.

After third trial it is seen that the rate of flow in various pipes of the network has been approximately balanced.

9.12 Appurtenances in the Distribution System :

The various appurtenances commonly used in a distribution system are:-

Water Supply

(1) Sluice valves or shut-off valves. (2) Check valves or non return valves. (3) Air valves. (4) Drain valves. or Scour valves. (5) Hydrants and (6) Meters. They are described in brief as follows

Sluice Valves : These are used to control the flow of water through pipe-lines and are frequently used in mains and submains to isolate certain sections enabling repairs to be carried out therein without affecting supplies in the rest of the sections. These may be placed at intervals of about 500 to 800 ft. and invariably provided at every point of intersection.

A vertical section through a screw-down sluice valve, commonly used is shown in Fig. 9.11. It consists of a wedge-shaped gate which is raised or lowered on grooves with gunmetal faces through a spindle by turning a hand wheel or by turning the cast iron cap with a wrench, thereby opening or closing the passage of water through the pipe on which it is fixed. The direction of rotation for closing the valve is usually clockwise.

Water Supply

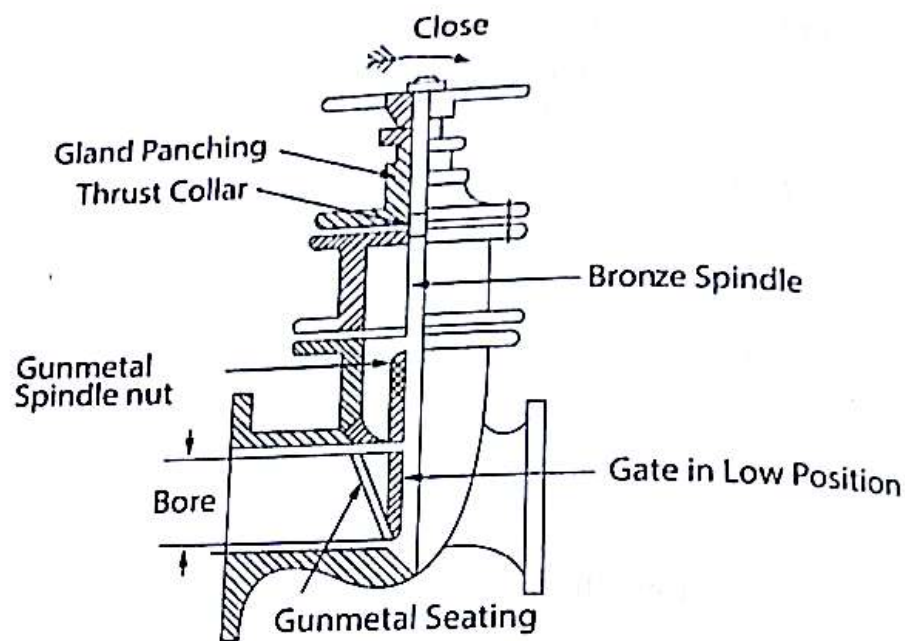


Fig. 9.11 Screw-down Sluice Valve

Stop Cock: Stop cock is another type of screw down valve only in smaller sizes in the case of a bib tap. The body of the valve is so cast that the water must pass through an orifice which is normally arranged in the horizontal plane. A plug or a 'jumper' can then be forced down on to this orifice by a screwed handle, shutting off the water flow as shown in Fig 9.12. Stop cocks extensively used in case of service pipes for sizes up to 2 inch.

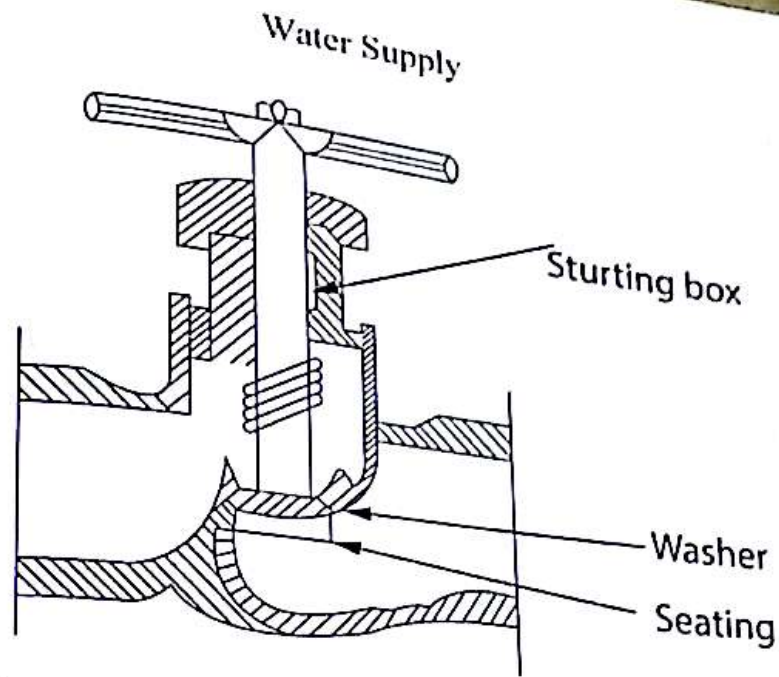


Fig. 9.12 Screw-down Stop Cock

Check Valves : Also called reflex valve or nonreturn valve, as valve is an automatic type of valve which allows the water to flow through in one direction and prevents it from flowing back.

It consists of a flat disc or door within the pipe line, pivoted so that it is forced open when flow of water is in one direction, and forced shut against a gunmetal seating when flow tries to be in the reserve direction (see Fig. 9.13). It will be observed that the seating is normally arranged slightly out of perpendicular. This enables the disc to close automatically by gravity when there is no flow, with the valve fixed in a horizontal pipe.