Sultanate of Oman

Ministry of Electricity and Water

Design Guidelines and Standards for Water Supply Systems

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1. INTRODUCTION

1. INTRODUCTION

The objective of these Design Guidelines is to establish uniform procedures for design and engineering of water supply systems in the Sultanate of Oman.

This Manual includes information, data, criteria and practices which are applicable for undertaking public water supply projects for the Ministry of Electricity and Water.
Practices and standards which are dealt with in this manual can be subject to changes. Issue date of this manual is September 1987.

2. BASIC DESIGN CRITERIA

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2.1 Water requirements

2.1.1 General

The most fundamental factor for planning and designing water supply works is the projection of the water requirements. There is a distinct difference between water demand, which is the quantity of water required by the consumers to satisfy all their normal water needs, and water consumption, which is the actual quantity of water supplied to consumers.
The price of potable water in a metered water supply system can affect the actual consumption.
In an inadequate water supply system the water demand is suppressed.

Water consumption can be divided into categories according to the type of users:
- domestic
- industrial
- commercial (shops, restaurants)
- institutional (government establishments, schools, hospitals, etc.)
- agricultural, landscaping, irrigation, etc.
- wastage and leakage.

The water demand forecast must therefore identify the magnitude and type of consumer. The basic factors which determine the forecast are population, per capita demands, and served area.

The period of planning usually covers 10 to 15 years, sometimes 25 to 30 years for new systems.

2.1.2 Population

There are no official census data for the present population of the Sultanate of Oman, and other methods must be used to estimate the population. The trend of population growth is difficult to assess because of the lack of past census data.

The present natural growth rates of other Arab communities vary between 2.5 and 3.5% per annum.

Due consideration must be given to the fact that Oman has a high influx of non-nationals, which has resulted in a large foreign component in the population.

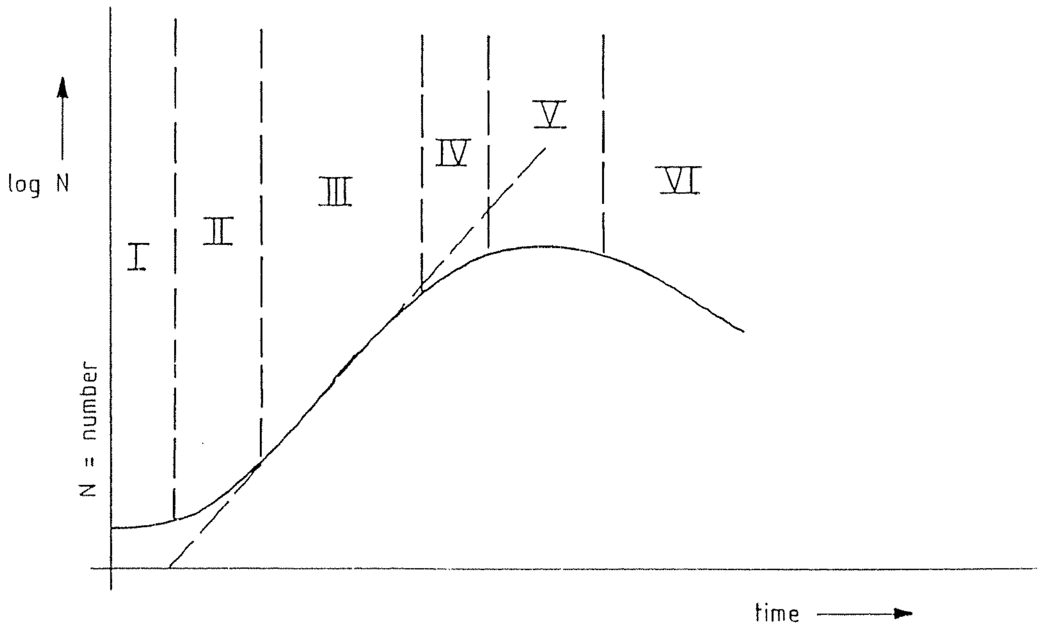
Population growth rate in urban areas during the last decade was in the range of 10-20%. However, it is not likely that the population growth in Oman will take place at this same pace, but at a lower level as indicated in Table 2.1.

TABLE 2.1 : OMAN POPULATION GROWTH PROJECTION

Area	Growth rate	
Urban areas in interior	3- 5%	(low/possible)
Small rural villages	3%	(high rate increase)
Capital Area villages	5-10%	(depending on rate of increase of G.N.P.)

Population growth is sensitive to the level of economic activities.

For normal cases, populations would follow the growth curve characteristics of living matter within limited space or with limited economic opportunity. The curve is S-shaped (figure 2.1), early growth taking place at an increasing rate and late growth at a decreasing rate as a saturation value or upper limit is approached.



phase I + II : the lag-phase

I : preamble phase

II : growth acceleration phase

III : exponential growth phase

IV : negative acceleration phase

V : stationary phase

VI : die-off phase

FIG 2.1 GROWTH CURVE LIVING MATTER

Following formula gives logarithmic growth:

$$P_n = P_o (1 + i)^n$$

where

P_n = future population
P_o = present population
i = yearly increase rate (%)
n = the period of forecast (years)

2.1.3 Unit consumption

The required per capita water demand of human beings can vary between 1.4 and 20 litres per day, depending on age, physical activities and climatic conditions. Average daily in-house water demand ranges from 15 to 20 litres in rural areas if water is supplied by public wells, and upto 150 litres or more in residential urban districts supplied through house connections from distribution mains. This results in a total demand of 200 litres per capita per day in highly developed urban areas. The domestic water consumption in the U.S.A., United Kingdom and The Netherlands roughly had the following values in 1983 respectively: 350, 125 and 150 litres per capita per day.

The specific consumption is also dependent on the type of living accomodation (low cost houses, appartments, villas) and will gradually increase due to improvement of living conditions.

The following table shows some values of unit consumption.

TABLE 2.2: UNIT CONSUMPTION

Category	Average per capita consumption (l/c/d)
Public tap	50
Tanker supply	100-150
Rural areas	100-150
Low cost houses	150-200
Apartment/villa	200-250
Public office	60 (6d/wk)
Hospital	400-1000 l/bed/day
School	20 l/pupil/day (5d/wk)
Hotel	200-500 l/person/day
Restaurant	100 l/person/day
Cattle breeding	6-10 l/animal/day
Standpipe supply	4000-5000 l/tap/day
Gardens/plantations*	3-10 l/m² /day

* to be considered separately for offices, schools, hospitals, public buildings, etc.

In addition to the above an allowance of 25 to 33% shall be made for leakage, wastage and unaccounted - for water.

The requirements for fire fighting shall be determined as follows:

- the characteristics of the city or village, its facilities for fire fighting, density of population and type of buildings define the basic data for planning fire demand planning.
- the fire demand reservoir capacity of water to be provided in addition to the basic capacity of the storage reservoirs is as follows:

TABLE 2.3: ADDITIONAL RESERVOIR CAPACITY FOR FIRE FIGHTING

Population (persons)	Additional reservoir capacity m^3
less than 5,000	50
10,000	100
20,000	200
30,000	300
40,000	350
50,000	400

- when designing the flow capacity of a distribution system, the following fire flows shall be incorporated, depending on the population of the area served.

TABLE 2.4: FIRE FLOW REQUIREMENTS

Population (persons)	Fire flow m^3/min
less than 5,000	not less than 1
10,000	2
20,000	4
40,000	6
60,000	8
80,000	9
100,000	10

2.2 Demand fluctuations

The daily demand throughout the year varies with the character and climate of the served areas being considered.
Also factors such as work situation, cultural or religious considerations influence the demand pattern.
Demand fluctuations must be determined statistically. As an indication the following values may be used:

Monthly

The maximum monthly consumption = 110-125% mean monthly
The minimum monthly consumption = 90% mean monthly

Daily

Maximum day = 150% average day
Minimum day = 80% average day

Hourly

Maximum hour = 150-250% average hourly consumption
Minimum hour = 30-60% average hour

2.3 Water supply schemes

Water supply schemes can be characterized by:

- water source
- distribution system

The source determines the treatment that is necessary to obtain a clean, safe potable water, that does not endanger public health. The two main sources that are used in water supply schemes are groundwater and surface water. In general groundwater has a better quality. In Oman fresh groundwater is an important source, which needs little treatment, whilst seawater needs desalination which is a costly treatment.

A distinction must be made between rural and urban areas.
The water supply systems for small towns and rural communities are different from urban facilities. Usually the number of people to be served is small and often the local conditions make piped distribution of the water very costly.
Planning and design for such small communities should therefore be based on appropriate technology, simple, yet reliable and adapted to the available technical and organizational skills.

Water supply schemes for urban areas, such as the Capital Area and bigger towns may comprise:

-	production	:	ground water wells desalination plants blending facilities with 1 day's storage of blended water
-	transmission	:	pumping stations transmission pipelines
-	storage	:	local distribution reservoirs (2 day's storage)
-	distribution	:	distribution pipelines, house tanks (1 day's storage), house connections.

The smaller water supply systems may include:

-	production	:	ground water wells
-	storage	:	ground level tank
-	distribution	:	pumpstation with elevated tank public taps, tankerpoints Some direct connections to public buildings.

For large urban water supply, complete distribution is taken as a matter of course, in view of large amount of house connections, public and communal buildings, industries, which all may be expected to contribute the largest share of the capital investments involved.

In rural water supplies, however, distribution should be considered from a different point of view. Important reason for promoting the construction of rural supplies is the provision of safe water in adequate quantity and in a convenient way to villagers.
Rural water supply systems are more simple and may comprise:

- groundwater well, provided with a diesel driven or solar well pump
- suitable disinfection facilities, if required
- small capacity elevated tank, at 5-6 m above groundlevel
- central public stndpipes
- tanker filling point.

Such schemes should be considered as a first step towards complete water distribution and should be upgraded and extended in step with further development of the village.

In the following chapters the various components of such water supply systems will be discussed in greater detail.

3. WATER SOURCE

3. WATER SOURCE

3.1 General

The main sources for water supply are:

- groundwater
- surface water

The quality of the source determines whether it is suitable for potable water supply.
In the Sultanate of Oman (fresh) groundwater is the main source, while in the Capital area and some remote places, where there is a lack of sufficient fresh groundwater, surface water, i.e. the sea, is used for the drinking water production, based on desalination methods.

3.2 Groundwater

3.2.1 Introduction

To determine whether or not water of acceptable quality can be extracted from an aquifer in sufficient quantity and for a sufficiently long period requires a thorough analysis of the underground stratification, the buried topography, inflow and outflow, rainfall, evaporation etc. of the related area. Such analysis, however desirable, is often impossible due to lack of sufficient reliable data and underground strata complexity. Consequently a study of existing well fields will often yield only approximate conclusions after a number of reasonable assumptions have been introduced in the groundwaterflow model. These assumptions relate to thickness and continuity of waterbearing layers, permeability, gradient, storage, draw-down, etc. and such data should be systematically obtained. Up to date methods, such as computer models and reliable data should be utilized in the design of wellfield development schemes. Reliable and consistent feedback of information will also play a major role and is a prerequisite for the predictability of any future development.

3.2.2 Selection of promising areas

Selection and use of existing and/or proposed developments of well-fields require a sub-division of areas being made along the following lines.

- potential but untapped fresh water aquifers.
  The frequency of such aquifers is likely to increase in the more mountainous areas. However the size of the reservoirs is likely to decrease in conjunction with an increased susceptibility for seasonal variations in precipitation.

- areas supported by single wells.
  Their location often coincides with either remote or small catchments in mountainous regions. They are designed to fulfill local needs but may be prone to yield and/or quality variations under influence of seasonal fluctuations. In some areas holes have been drilled already but pumps have not been installed as yet.

- areas in which well-fields can be developed.
  These areas are characterized by a relatively thick waterbearing layer. Feasible areas are encountered in the foothills and adjoining the gravel plains.

Serious attention should be paid to the fact that water is a precious mineral being extracted with often only the consumers own interest in mind. As long as extractions are small with respect to availability no conflict of interest will rise. However upstream extraction (and pollution) will have its eventual impact downstream. This means that though minor developments in the mountainous areas may have no noticeable direct impact on the downstream aquifers, changes may take place in time.

3.2.3 Wellsite location

One of most important activities in wellfield development is locating a wellsite. With relatively small numbers of potential well sites being developed the chance will remain that a succesfull well will be sunk without extensive investigation. This should be regarded as a disadvantage in the process of a well development policy as it presents

the excuse of drilling without proper investigation. However it should be mentioned that the costs for a detailed hydrogeological site investigation are approximately equal to the costs of drilling two successful wells. With such a site survey a more technical and scientific approach for wellfield design and development could be utilized and the chances of drilling unsuccessful wells, thus wasting investment costs, are minimized.
Every envisaged wellsite should be judged on its own characteristics. The sequence of activities that will lead up to the final location are as follows:

1. Desk study
2. Site check and/or confirmation
3. Site investigation
4. Drilling of well and testing.

1. The desk study may comprise review and assessment of the following data:
   - Existing data on wells and/or boreholes (borelogs)
   - Aerial photography
   - Geo-hydrological information
   - Groundwatertable contours
   - Salinity contours
   - Geological and seismic survey information.

2. During the second stage, having developed certain ideas on the envisaged location, desks study results need to be checked in the field. This check may cover:
   - Accessibility for drilling rigs
   - Presence of water for drilling
   - Height of well-head with respect to users and/or reservoir
   - Geotechnical and geological features
   - Geophysical survey
   - Coordination with authorities (right-of-way, ownership, other users, etc.)

The geophysical survey in this respect is of major importance. This survey will provide information on the extent of the aquifer, the location of fresh water - sea water interface. With the results the location, number and depth of future drillings (both observation wells and production wells) can be optimized.

3. After the second stage investigation the choice of the well location can be made. To allow proper design of a well, site work will start with drilling of a 100 mm reconnaissance borehole. From this borehole soil layering, permeability and salinity can be established. Figure 3.1 shows samples of boring logs.

4. Provided the results are positive the fourth stage can now be carried out with:
   - Designing and drilling of test-well to a predetermined depth
   - Drilling of observation wells
   - Pumptest and pumptest analysis.

The scope of a hydrogeological investigation of course may differ from site to site. Such a survey should be defined for each specific area, region, with its own boundary conditions and local circumstances.

3.2.4 Hydrogeology

In a hydrogeological water-resource evaluation the object of data collection is to locate deposits of waterbearing materials of relatively high permeability.
In order to classify them as potential aquifers the deposits should meet to the following requirements.

- occurrence in sufficient thickness
- enough areal extent to provide large storage volumes
- enough annual recharge

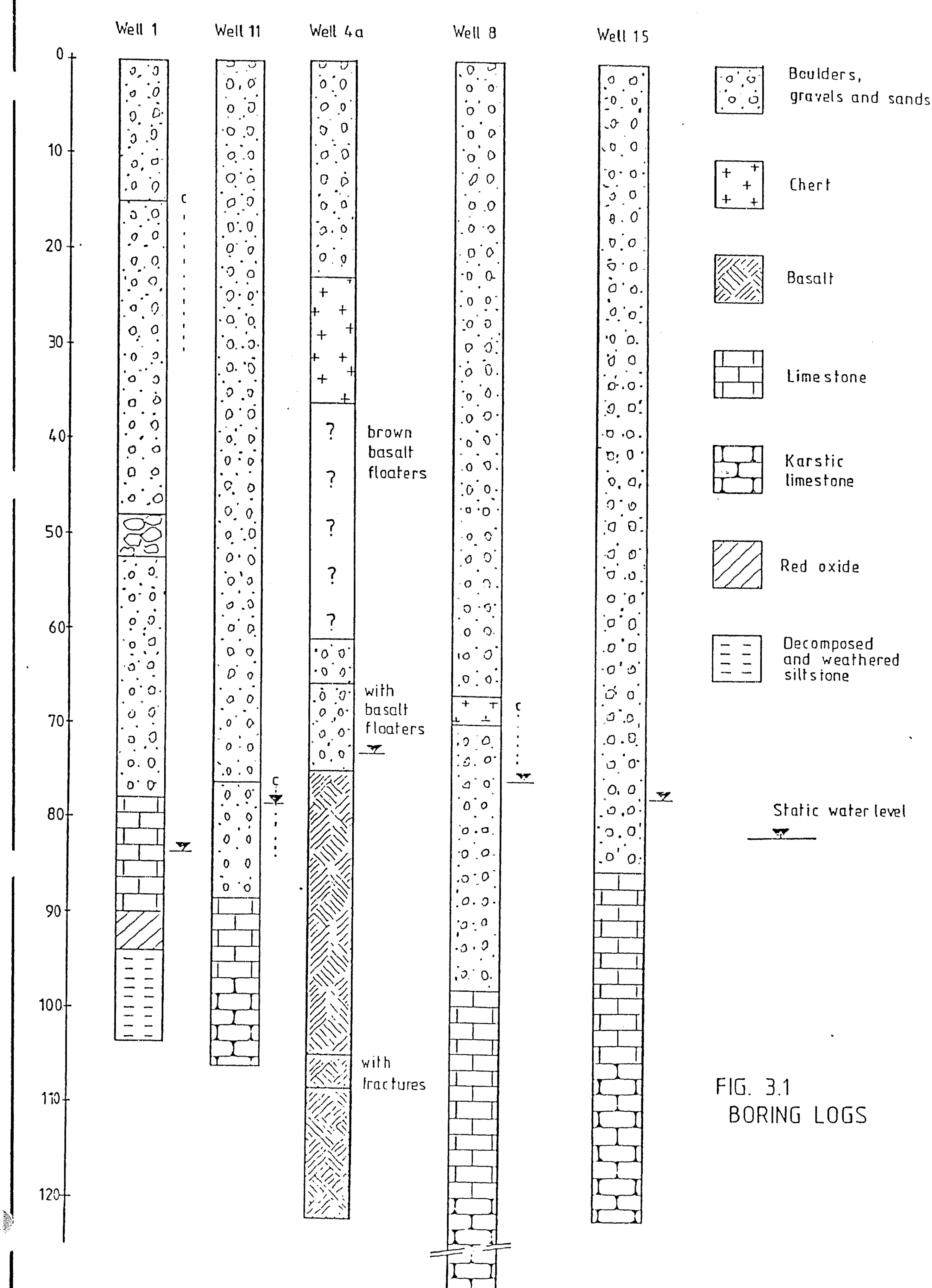


FIG. 3.1
BORING LOGS

The ways and rates at which an aquifer is recharged are primarily dependent upon its structure or geological formation.
Of first concern are the geological conditions of an area as they apply to locating test holes.
A knowledge of the geological structure of the general area will enable one to determine the water-bearing formations, their locations and their depths.

3.2.5 Geophysical methods

Geophysical survey is of major importance to extend the information based on test drilling and adequate sampling. The following geophysical methods are used:

Seismic

This method is dependent upon the fact that the velocity of shock waves is different in materials of different composition.
Its success is limited to areas where water is obtained from highly permeable sandstone or limestone underlaid and overlaid by materials with sharply contrasting physical properties. The determination of bedrock surface elevations where the bedrock surface lies beneath a blanket of unconsolidated material is an application of this method.

Resistivity

This method is an application of the fact that under saturated conditions the coarse-grained, permeable materials offer greater resistance to the passage of an electric current than do fine-grained, dense materials of lower permeabilities.
Four electrodes are driven into the ground along a straight line. By applying current to the two outer electrodes and observing the voltage drop between the inner electrodes, one determines the apparent resistivity of the earth material to a depth equal to the distance between two electrodes.

The use of this method is limited to the following two conditions:

- the mathematical interpretation permits only a general comparative classification of earth materials profiles.
- the depth to which accurate work can be done is limited to about 45 meters.

Electric logging

Electric logs, representing a resistivity survey of the bore hole, are made by lowering a set of electrodes into the hole and observing the variation in resistivity throughout the depth. Coupled with the surface resistivity survey, electric logging has proved to be a very effective method for locating shallow aquifers.

Gamma-ray logs

The geologic occurrence of radioactive isotopes (e.g. of potassium) are indicative of the material classifications.
By lowering a probe containing a Geiger-Muller tube into a well and recording the rate of gamma emission at regular intervals of depth, the construction of a gamma profile of subsurface conditions can be accomplished.
An advantage over electric logging is the possibility of logging the cased portion of a hole as well.

3.2.6 Pumping tests

The objectives of water well pumping tests are twofold. First of all to obtain information about the performance and efficiency of the well being pumped. This results in values for the yield, observed drawdown and specific capacity. The productive capacity of the completed well can be estimated and pumping equipment can be selected. A second aim of pumping tests is to provide data from which the principal factors of aquifer performance can be calculated. (Aquifer performance test). The parameters to be assessed include the coefficient of transmissibility KD (in m^2/day), the coefficient of storage S in artesian aquifers and the specific yield μ in water-table aquifers.

During the test the pumping rate has to be measured and must be kept constant. A control valve in the discharge line of the pump can keep this rate constant. The drawdown or lowering of the groundwater table has to be measured in the well tested and observation wells.

If no existing wells can be used test wells and observation wells need to be drilled.
At least three observation wells at different distances from the test well are necessary. The diameter of an observation hole is about 200 mm, while the top has a 300 mm outer casing embedded with concrete with a protective cover. The test well has a diameter of about 400 mm and must be provided with casing and screen of a suitable material. A gravel pack may be necessary.
After installation of the casing, screens and gravel pack, the test wells must be developed e.g. by means of high pressure water jetting with simultaneous air lifting. Upon completion of this well development the following pump tests can be carried out, by means of a submersible pump. Simultaneously the water level in the observation holes must be monitored.

Pumping tests can be executed in several ways. Two examples of tests are:

a. Step drawdown test
b. Constant discharge test

Step drawdown test (S.D.T.)

A step draw-down test of 4 steps, 100 minutes each step, to be performed at pump discharge of 50, 100, 150 and 200 m^3 hour.
The draw-down in the test well and the observation holes are to be measured at 0, 1, 2, 3, 4, 6, 8, 10, 15, 20, 30, 35, 40, 45, 50, 60, 70, 80, 90 and 100 minutes from the start. After completion of the step draw-down test and prior to starting the next contant discharge test the water level must be allowed to return to its original level.

The recovery must be measured at the moment the pump stops and at the same time intervals as specified for the draw-down test. Temperature conductivity, salinity and pH of the water must be measured during each step.

Constant discharge test (C.D.T.)

Upon evaluating of the results of the step draw-down tests one has to decide upon the discharge to be used for carrying out the constant discharge test. The constant discharge test must be continued without any interruption for a maximum of 84 hours or till the draw-down does not increase further. The draw-down in the well and the observation holes is to be measured at:
0, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 35, 40, 45, 50, 55, 60, 70, 80, 90, 100, 110, 120, 150, 180, 240, 270, 300, 360, 420, 480, 540, 600, 720, 840, 960, 1080, 1200, 1320, 1440, 1680, 1920, 2160, 2400, 2640, 2880, 3240, 3600, 3960, 4320, 4680 and 5040 minutes from the start of the test.

Methods to measure discharge

1. Container method

   Simple and accurate. Observe the time required to fill a container of known volume.
2. Water meter

   Substracting two readings of a commercial type water meter taken exactly one minute (or other unit of time) apart gives the pumping rate.
3. Circular orifice weir (see Figure 3.2).

   A continuous flow can be measured (not suitable for the pulsating flow from a piston pump).

   A circular orifice, which consists of a round hole in the centre of a circular steelplate, and a piezometer tube are essential parts of this measuring device. Water discharge takes place into the open air, or otherwise a second piezometer tube is necessary.

   The flow rate can be calculated using the following formula:

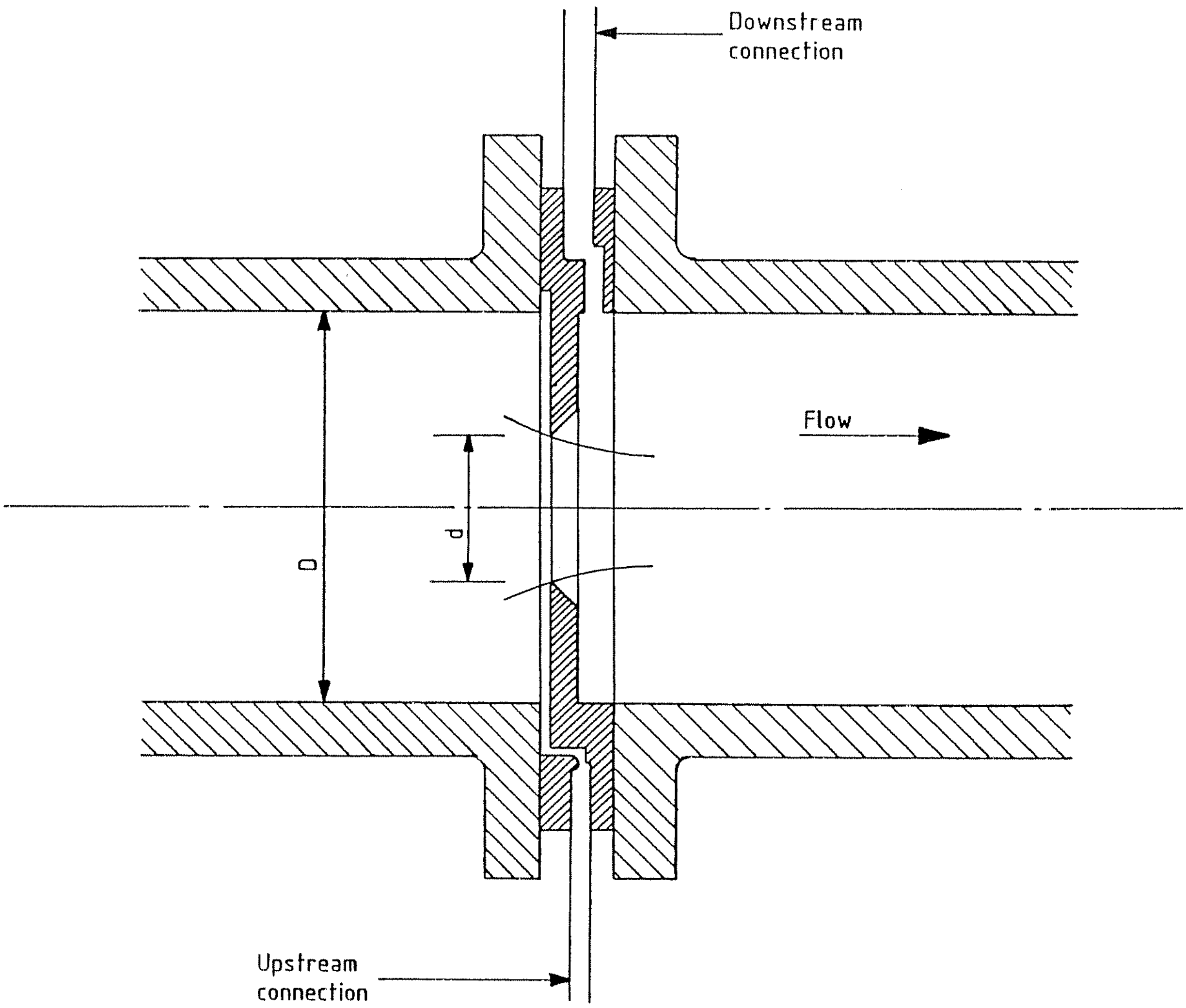


FIG. 3.2 ORIFICE METER

$$Q = K.A. (2.g.h.)^{\frac{1}{2}}$$

where

Q = flow per unit of time
A = area of the orifice
K = discharge factor (K = 0.6 ... 1.0)
g = acceleration due to gravity
h = pressure drop (m.w.c.)

4. Venturi meter (see Figure 3.3)
The water flows through a constriction in a pipeline, while two piezometers register the waterhead upstream and at the throat.
5. Ninety-degree V-notch weir (see Figure 3.4)
For flowing measurements in open channels a 90°V-notch weir can be used. The weir is well adapted to recording wide variations in flow.
Discharge can be calculated using the following formula:

$$Q = 1.4\ H^{5/2}$$

where

Q = flow in m^3/s
H = head in m

3.2.7 Drilling, casing, well head installation

3.2.7.1 Methods of well construction

The construction of a hole for the purpose of obtaining water can be performed in different ways, according to which wells are commonly classified as dug, bored, driven, jetted, or drilled wells. The choise of method depends upon factors such as cost of construction, need for specialised equipment, formations that can be penetrated, depth that can be reached, storage capacity obtained, protection against pollution, safeguard against rapid clogging, etc.

CALCULATION OF CLASSICAL VENTURI ACC. TO ISO - 5167 FOR LIQUID SERVICE.

$$Q = C \cdot \frac{D^2 - d^2}{\sqrt{D^4 - d^4}} \cdot \frac{\pi}{4} \cdot \sqrt{2 \cdot \Delta P \cdot \rho}$$

ΔP : IS DIFFERENTIAL PRESSURE BETWEEN UPSTREAM CONNECTION AND THROAT CONNECTION

$\rho = \left[\frac{kg}{m^3}\right]$ MASS DENSITY OF LIQUID

$Q = \left[\frac{kg}{s}\right]$ MASS RATE OF FLOW

C = DIMENSIONLESS DISCHARGE COEFFICIENT (APPROXIMATELY 0.98)
TO BE DETERMINED ACC. TO ANNEX B OF ISO - 5167

d = (m) THROAT DIAMETER

D = (m) UPSTREAM INTERNAL PIPE DIAMETER

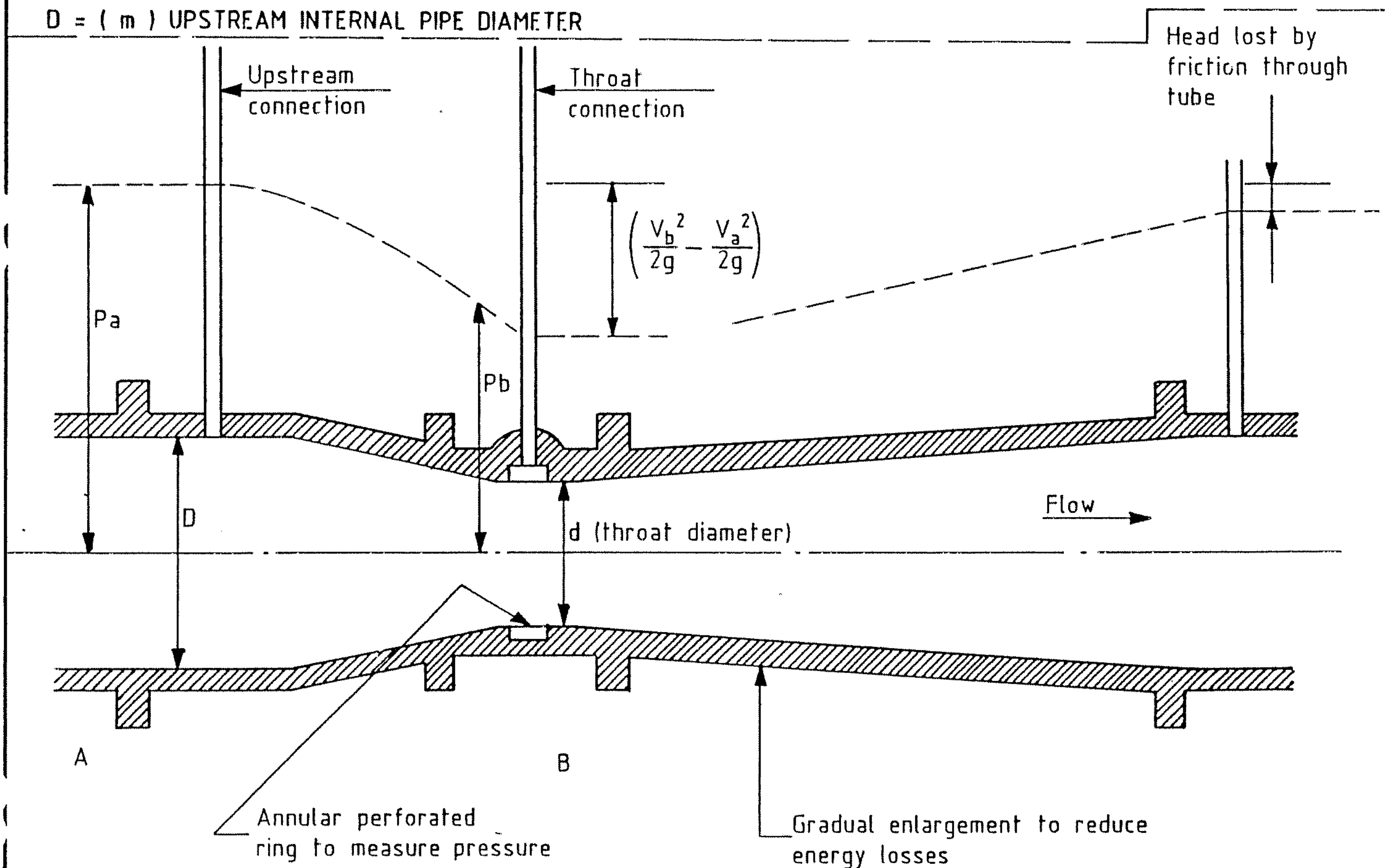


FIG. 3.3 VENTURI METER

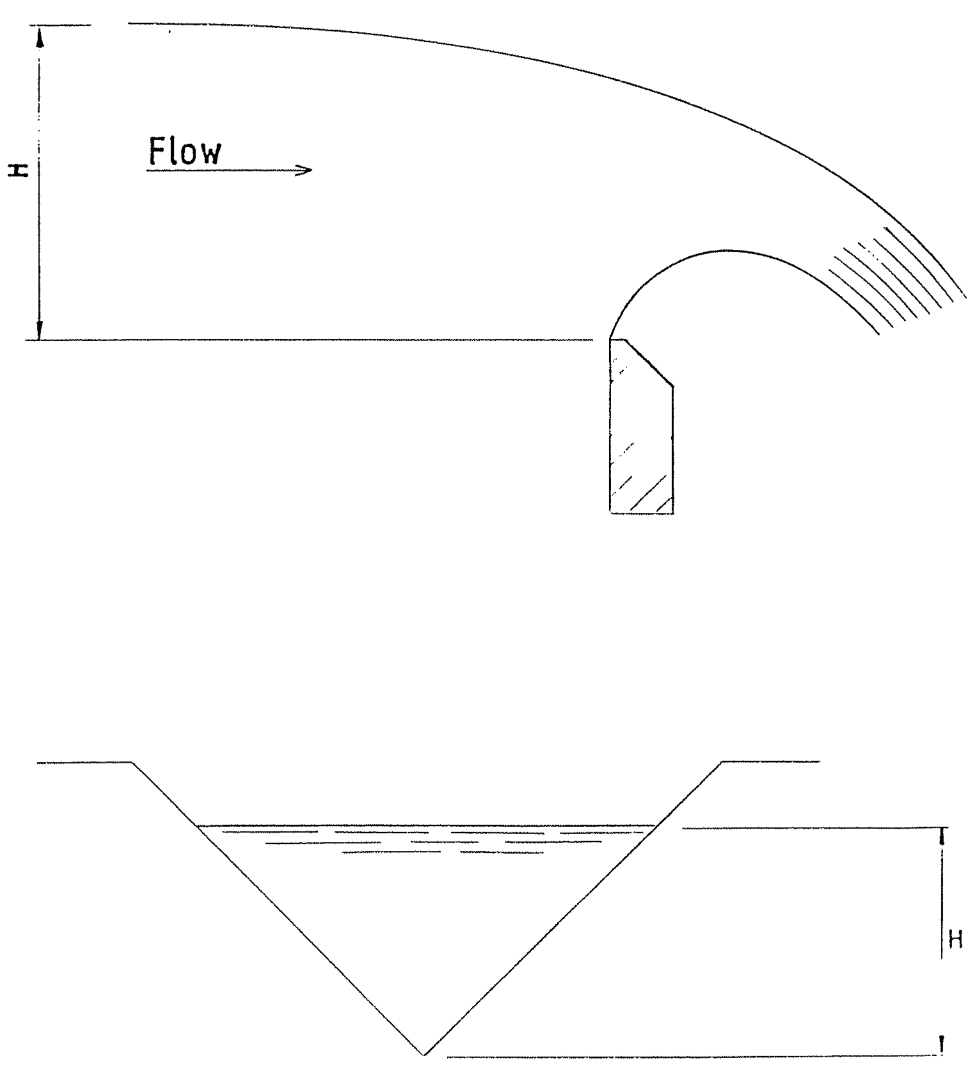


FIG. 3.4 NINETY DEGREE V-NOTCH WEIR

The majority of wells constructed today are drilled wells, which can be used for small and large diameter holes, in any formation, and with depths varying from a few tens to many thousands of metres.
Dug wells are only used for private and other small-capacity water supplies. The same holds true for driven and jetted wells.
Boring is no longer used as an independent method of sinking a well.

3.2.7.2 Drilled wells

For drilled wells a drilling rig is used to excavate or drill the hole and then a casing or tubular pipe is forced down to prevent it from collapsing or caving in.
When a water-bearing stratum or formation of sufficient capacity is found, a screen is set in place to permit the water to flow into the casing and to hold back the fine material.
When the drilled well terminates in rock, no screen is used.
The hole is made by cutting the formation material at the bottom and subsequent removal of the disintegrated fragments to ground surface. With drilling the functions of cutting and removal are separated. Regarding cutting, a further subdivision can be made between percussion drilling (by alternately raising and dropping the tools) and rotary drilling (by rotating suitable tools that chip and abrade the formation). For removal of the disintegrated material two methods are in use: a periodic removal with the help of a bailer or sand pump, and a continuous removal by means of a stream of water.
Following are the four methods for drilling:

- percussion drilling with bailer
- hydraulic percussion drilling
- rotary drilling with bailer
- hydraulic rotary drilling.

3.2.7.3 Well casing

The well casing is merely a lining for the drilled hole and, as such, maintains the open hole from the land surface to the water-bearing formation. It also seals out contaminated water from the land surface and other undesirable water from formations above the aquifer wherein the well is developed.

For the casing to be entirely effective, it must be constructed of suitable materials, such as wrought iron, alloyed steel or ingot iron, and must be properly installed so as to be watertight for its entire depth. The watertight construction in channelled or creviced formations is effected by drilling the hole in the revised rock 5 cm larger than the OD of the casing couplings and filling the annular space between drill hole and the outside of the casing with cement grout.

Water wells are cemented, or grouted and sealed:

- to protect the supply against pollution
- to seal out water of an unsatisfactory chemical quality
- to increase the life of the well by protecting the casing against exterior corrosion
- to stabilize soil or rock formations of a caving nature.

At the top of the casing a cover is necessary to prevent foreign material from entering the well. This cover must be absolutely water-tight to keep all contamination from entering the well.

3.2.7.4 Well screens

Wells completed in unconsolidated formations such as sands and gravels are equiped with screens, devices that allow the maximum amount of water from the aquifer to enter the well with a minimum of resistance and without the passage of sand during pumping.

Several types of screens exist. The two main types are the gauze screen and the slotted screen type. The perforated-slot screens (open area 10-12%) and the continuous-slot wire wound screens (30-50% open area) are used most.

Well screens must be carefully selected.

Among the most important criteria are:

- large percentage of open area
- non clogging slots
- resistance to corrosion
- sufficient column and collapse strength

The percentage of open area should be as high as possible without endangering the collapse strength of the screen.
The percentage of open area should preferably be the same as or greater than the average porosity (p) of the aquifer material:

gravel, p = 25%-35%
sand , p = 30%-40%

Particles that have penetrated the slots during developing the well must not be retained inside the slot. A wedge shaped wire screen is an example of a screen with a non-clogging slot opening.
The materials used for constructing screens are mainly thermoplastics (P.V.C. and A.B.S.) and stainless steels (type 304,316)

Choosing the right size of slot width is essential in well design. With over-sized slots the well will pump sand, whilst in under-sized slots flow resistance is increased and the danger exists that rapid clogging of the screen by small (sand) particles, precipitation of calcium carbonate or growth of bacteria will occur.
Slot openings can be manufactured in the range of about 0.15-6.4 mm, with an accuracy of 0.03-0.05 mm.
Slot openings have been designated by slot numbers.
The slot number divided by 1000 represents the width in inches. Small diameter screens covered with wire mesh are designated by gauze numbers, which represent the number of openings in the mesh per inch (see Figure 3.5).

During the development of a well a specific percentage of the surrounding formation must be removed to increase the permeability of a circumferential zone around the screen. The apertures of the screen must allow the passage of particles of a certain size. The slot size must be based on a size analysis of the formation samples

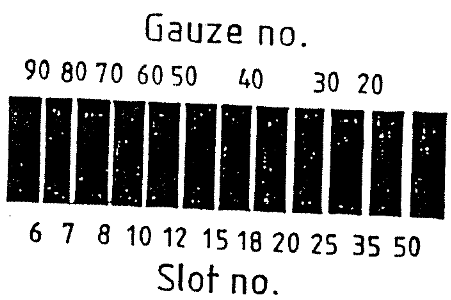


FIG 3.5 SLOT NUMBER

OPEN AREA OF SLOTTED SCREENS - % -										
SLOT TYPE		BRIDGE SLOT			SLOTTED PLASTIC			CONTINUOUS SLOT		
DIAMETER		8"	10"	12"	8"	10"	12"	8"	10"	12"
SLOT SIZE										
SLOT NO	MM									
20	0.5					4		18	18	14
30	0.8	3	2	3	8	6		25	25	16
40	1.0					8	8	30	30	21
50	1.3					10		35	35	24
60	1.5	6	5	6	14	11	11	41	33	28
90	2.3							48	43	37
100	2.5				21	16	16	52	46	39
125	3.2	13	12	13				51	51	45

as represented by grain sizes distribution curves (see Figure 3.6). The slope and shape of these curves give information about the uniformity of the grains.
The uniformity of grains is given by the uniformity coefficient of Hazen (U-Hazen is the 40-percent retained size of the particles divided by the 90-percent retained size).
The amount of material that is allowed into the well is based on the criterion that sufficient material is retained to build up a natural gravelpack without undue time consuming development work.
In less uniform sands (U-Hazen $>$ 6) 30 to 50% of the material should be retained. In uniform sands (U-Hazen $<$ 3) 40-60% should be retained.
With uniform medium sands and with non-uniform fine sands (Figure 3.6 curves b respectively a) the percentage to be retained (40-60%) results in the use of very fine openings with the danger of rapid clogging. Larger openings can be applied when inserting an annular wall of gravel between the well screen and the formation. The desired amount of retention of grains is then effected by the artifical gravelpack.

Commonly used diameters are	:	
Conductor casing	:	16"/400 mm
		20"/500 mm
Casing/screen	:	8"/200 mm
		10"/250 mm
		12"/300 mm
Observation wells	:	4"/100 mm
		6"/150 mm

3.2.7.5 Well head facilities

An example of a standardized well head configuration is given in the Standard Drawings Album.

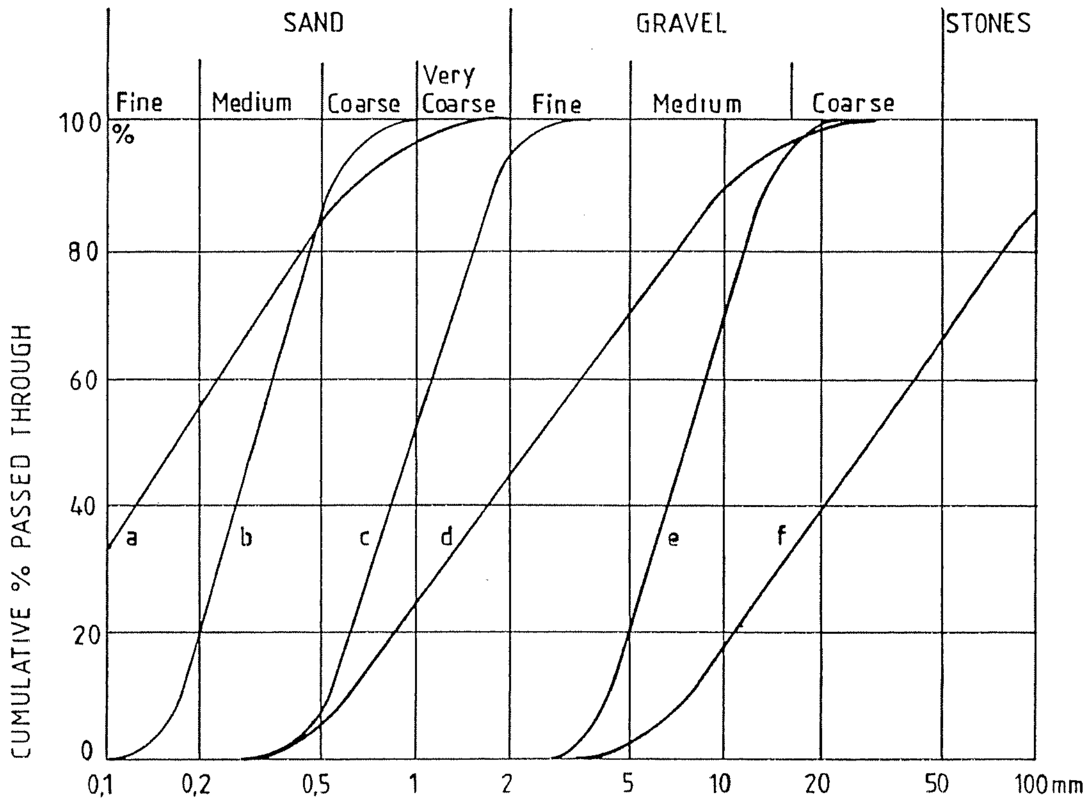


FIG 3.6 GRAIN SIZE DISTRIBUTION

A concrete plinth, 1 x 1 x 1,5 m, extending 500 mm above grade, covers the well conductor/casing. The top of the conductor pipe, installed central to the well casing, shall be at minimal 100 mm above the concrete plinth.
Around the well, the ground shall be levelled up and provided with stone pitching over a distance of 3-5 m from each side of the concrete well plinth.

Well pumping facilities in Wadi areas shall be installed in a covered concrete pit. The cover of the well head facilities should be kept 2 metres above the chamber bottom. The embedment and gabion mattress protection is necessary to protect the well head facilities during floods.

The following instruments and valves are to be installed:

- Pressure indicator
- Flow meter
- Check valve
- Air valves
- Gate valve
- Level probes
- Low level cut off switches
- High pressure cut off switches

Because most wells are located in remote areas, the controlling and monitoring of the well pump facilities must be realized using automatic control systems and telemetry techniques.

3.2.8 Pumping equipment for wells

Types of pumps

A basic classification divides pumps into two groups:

1. Constant displacement pumps
2. Variable displacement pumps

The first group of pumps delivers substantially the same quantity of water against any head delivered (e.g. the rotary pumps). The input of power varies in direct proportion to the pressure.
The second group of pumps delivers water in quantity varying inversely with the head against which they are operating.
The centrifugal pump is an example. The greatest input of power is required at a low head and large discharge.

A further distinction can be made between the shallow well pump and the deep well pump, which refers to the location at which the pump is installed: at surface level (suction lift necessary) or at some depth below the top. The depth of the well itself is not relevant.

With centrifugal pumps one can choose between a surface drive and a submersible pump. In the latter case the pump is closely coupled with an electric motor which can operate when submerged in water.

Pumps in use for the recovery of groundwater are commonly classified as:

1. Reciprocating pumps
2. Impulse pumps
3. Revolving vertical shaft pumps:
    a. deep well centrifugal pumps
    b. rotary positive displacement pumps

Reciprocating pumps only have historic value. The single-acting piston pump is the oldest type of deep-well pump.

Impulse pumps, of which the jet pump and the air-lift pump are examples, have low efficiencies and are used on a small scale only, for instance for cleaning production wells.

Rotary displacement pumps, such as the gear pump, mono pump, propeller and mixed flow pump, are suitable for shallow wells, where heads are limited. Large capacities are possible.

Centrifugal pumps are commonly used.
The deep well centrifugal pump usually has 3, to more than 20, pump bowls. With a surface drive the motor is located at ground level and is coupled to the pump by a spindle. Where electric power is not available, diesel driven pumps shall be installed.
Especially suitable for deep wells is the submersible drive where the electric motor is directly coupled to the pump and is submerged in the water.
Submersible pumps are quickly and more easily installed than the vertical spindle pump.
In Oman submersible pumps are mostly in use. Submersible pumps can be of small diameter, yet sufficient clearance between pump-motor and well screen/casing should be provided for proper motor cooling purposes.
Submersible pump motor capacities for some well diameters are tabulated in Table 3.1.

TABLE 3.1: SUBMERSIBLE PUMP CAPACITIES PER WELL DIAMETER

Well diameter mm	Max. pump motor output kW	Max. pumping capacity m^3/h	
		H = 60m	H = 100m
200	50	180	130
250	60	185	140
300	200	450	400

Well pump sizing

Pump size selection and pump design parameters are discussed in paragraph 4.3.

3.3 Brackish and Saline water

3.3.1 Introduction

The rapid increase in water demand in arid areas, together with a shortage of fresh groundwater has accelerated the development of the technology in brackish/saline water treatment for drinking purposes.
There are various desalination methods to produce potable water, based on different processes such as distillation, reverse osmosis and electrodialysis.

3.3.2 Multi-stage Flash Process

A schematic flow diagram of the multi-stage flash evaporation process is shown in Figure 3.7.
The principle of multi-stage flash evaporation is to heat concentrated sea water (brine) to a certain temperature (top brine temperature) and then to pass it into a series of flash chambers, each consecutive chamber having a lower pressure than the preceeding chamber.
Part of the brine evaporates and the vapour is condensed on a condensor bundle forming distilled water.
The heat of condensation is recovered by heating the recirculation brine flowing through the condensor bundles (heat recovery section).
The required energy to keep the process going is introduced by a steam heated brine heater ahead of the first flash chamber. This heat is finally transferred to sea water through the condensor bundles of the last chambers of the evaporator train (heat reject section).

Major design parameters for the MSF process are:

- The gain ratio.

  This is defined as tons of water produced per ton of steam consumed. Depending on the energy cost this ratio normally will be chosen between 6 and 10.

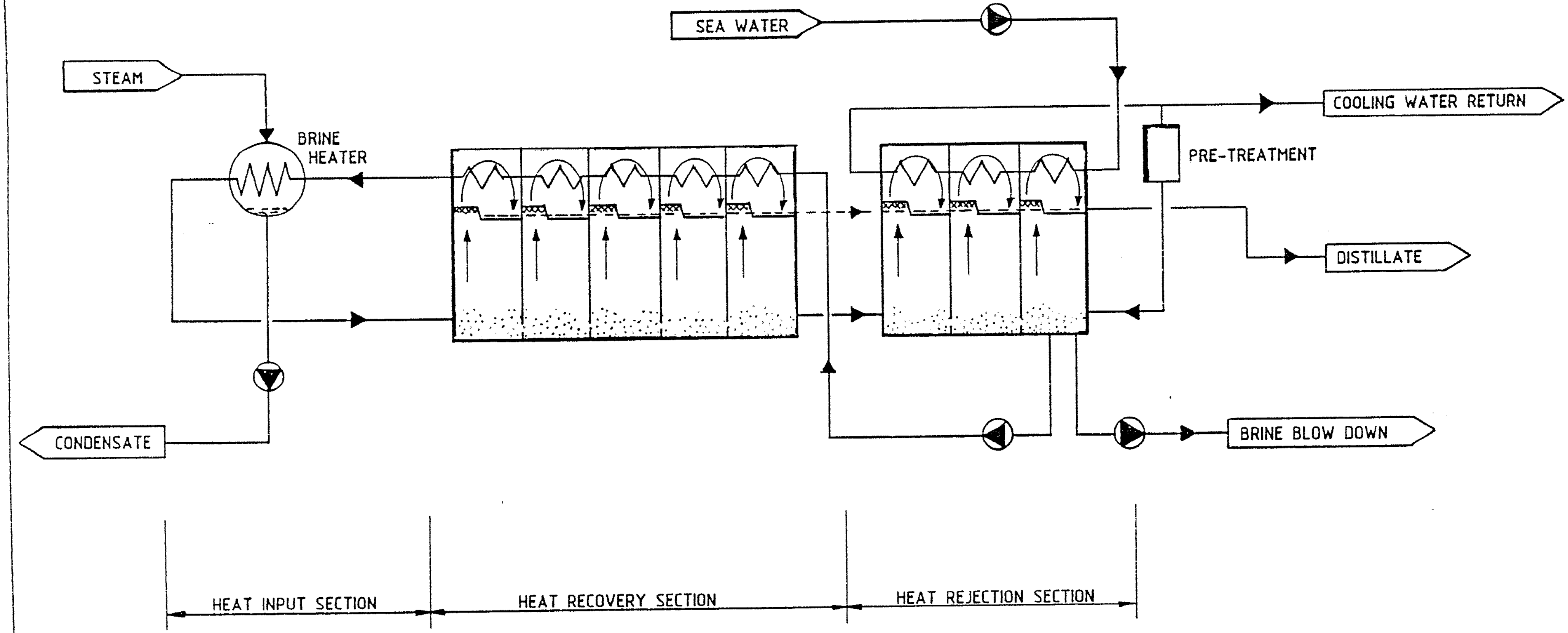


FIG. 3.7 FLOW DIAGRAM MULTI-STAGE FLASH DISTILLATION PLANT

For a single purpose plant the dominant part of the overall water production cost is the generation of steam. Consequently the gain ratio is chosen as high as technically and economically possible. On the other hand the investment cost of an evaporator increases with increasing gain ratio.

- Top brine temperature.

  For a chosen gain ratio the investment of the evaporator decreases with increasing top brine temperature. The maximum allowable top brine temperature is limited by the calcium sulphate scaling threshold. In general the brine in the evaporator is concentrated to 70,000 ppm T.D.S. and the maximum allowable top brine temperature is 110-115°C.

- Scale control.

  Besides calcium sulphate the brine contains other scale forming components such as calcium carbonate, magnesium salts, etc. To prevent scaling the sea water feed is treated by adding chemicals such as sulphuric acid or polyelectrolytes.

The main characteristics of the MSF process are:

- Reliable, well proven process.
- Equipment is not very sensitive to operation errors.
- Product is better than required for drinking water and must be hardened for health requirement and/or protection of the distribution system. Hardening system requires additional installations and supervision.
- High energy requirements; the equivalent of approx. 8 kg of oil per ton product for a single purpose plant.
- Very corrosive, due to high operation temperature.
- Steam boiler plant is required for the single purpose operation.
- High feed rate compared to product rate (approx. 10 times).
- Relatively simple automatic control.

- Construction is heavy and complex due to large dimensions and heavy weights of single items. heavy foundations and deep subsoil constructions for brine recirculation pumps.
- Relatively simple pretreatment.
- Relatively long construction time.

Distillate treatment

The distillate leaving the desalinator has a very corrosive character due to the absence of salts and natural inhibitors. It is therefore required to treat the distillate prior to distribution to the consumers, in order to meet the W.H.O. standards.

To establish whether a water is corrosive or otherwise, the Langelier Index or Saturation Index should be determined. This index is defined as the difference in the actual pH of the water and its equilibrium pH (pHs).

If SI is negative : the water is corrosive,
SI = 0 : the water is in balance,
SI is positive : the water is scale forming.

The Saturation Index is only qualitative and as Langelier emphasised "the Saturation Index is an indication of directional tendency and of driving force, but is in no way a measure of capacity".

This Index, however, is not always reliable in predicting the corrosivity behaviour of a water, because some waters with a positive index actually may be quite corrosive.

In general the best treatment of a distillate is to make the water slightly scale forming by adding an inhibitor. Several inhibitors are available but for potable water an inhibitor must be of proven suitability for human consumption. The obvious choice is the inhibitor found in most natural water: calcium bicarbonate.

There are various methods applicable, such as:

a. Carbon dioxide + hydrated lime
$2CO_2 + Ca\ (OH)_2 \longrightarrow Ca(HCO_3)2$

b. Calcium chloride + sodium bicarbonate
$CaCl_2 + 2\ NaHCO_3 \longrightarrow Ca(HCO_3)2 + 2\ NaCl$

c. Calcium sulphate + sodium bicarbonate
$CaSO_4 + 2NaHCO_3 \longrightarrow Ca(HCO_3)2 + Na_2SO_4$

d. Addition of CO_2 and filtration through beds of limestone or dolomite
$CO_2 + H_2O + CaCO_3 \longrightarrow Ca(HCO_3)2$

e. Sodium carbonate + carbon dioxide
$Na_2CO_3 + CO_2 + H_2O \longrightarrow 2NaHCO_3$

f. Addition of (poly)phosphate

Each method has its advantages and disadvantages.
The final choice of the method is to be done after laboratory tests, and after consideration of the availability of chemicals, assessment of capital and operating costs, etc.

Furthermore blending of desalinated water with brackish well water, if available, should be considered in order to increase the total output of potable water. In practice brackish water, with a T.D.S. content of max. 4000 ppm might be used for blending. The rate of blending should be carefully controlled, with proper pH adjustments.
The blending should take place at the desalination plant as control can be there easily exercised (see also para 3.5.3).

3.3.3 Reverse Osmosis

A schematic flow diagram of the reverse osmosis process is shown in Figure 3.8.

Reverse Osmosis (R.O.) is a membrane process in which water is forced through a membrane by pressure. The membrane is a thin plastic film or hollow fibre which allows water to pass through, but which rejects most of the salts present in the water. In practice the salt water flows along the membrane and is divided into two streams: a product water flow which has passed the membrane, and a concentrated brine flow containing the rejected salts.

A Reverse Osmosis installation consists basically of a high pressure pump which pressurises the pre-treated feedwater and pumps it through a number of membrane modules (permeators) while pressure and water flows are controlled. These modules of permeators incorporate a certain membrane area or a certain number of hollow fibres.

The following parameters govern the performance of the Reverse Osmosis process:

- Salt rejection

  The salt rejection of a membrane is expressed in percentages. For brackish water with a relatively low salt concentration a salt rejection of 90% to 95% is sufficient to produce drinking water, while a salt rejection of 98% and more is required for desalting sea water.

- Production rate and pressure.

  The production rate increases with the applied pressure. The optimum pressure range for operation is 20 to 40 bar for brackish water applications. For sea water treatment the pressure range is much higher, between 55 and 70 bar, due to the high osmotic pressure of the sea water. (Sea water from the Arabian Gulf has an osmotic pressure of approximately 30 bar, while brackish water has an osmotic pressure of approximately 1.5 bar).

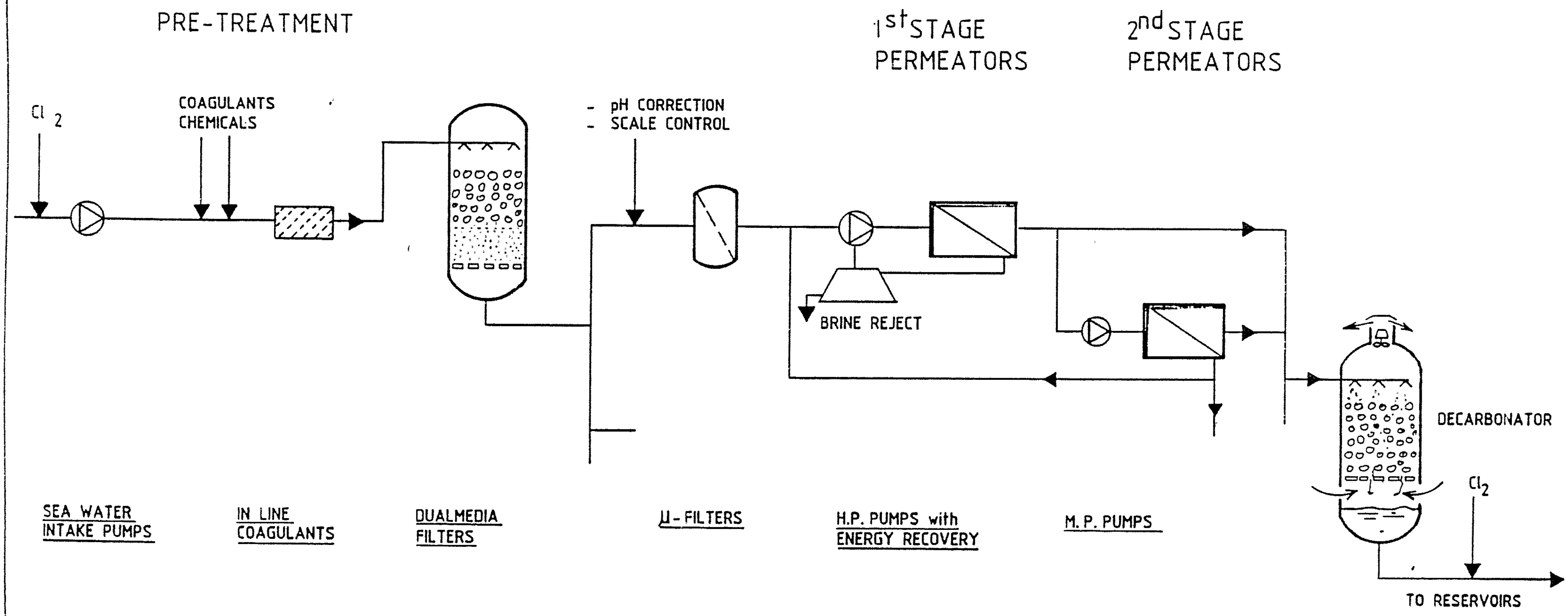


FIG. 3.8 SCHEMATIC FLOW DIAGRAM SEAWATER REVERSE OSMOSIS TREATMENT PLANT

- Conversion.

  The percentage of the salt feed water flow which is obtained as product water is called the conversion. For brackish water installations the conversion is in general 75% to 90%, while in sea water installations the conversion is 20% to 40%.

- Membranes.

  There are mainly two types of membrane designs: the spiral wound module, comprising spirally wound membrane films, and the hollow fibres.
  The main features of the reverse osmosis process for sea water desalination are:

  - In recent years Reverse Osmosis has proven to be a reliable process for the desalination of brackish and sea water, with respect to both large scale operation and product quality within WHO standards.
  - The energy consumption is relatively low: approximately 11 kWh per m^3 product, to be reduced to about 7 kWh per m^3 if an energy recovery system is used, for sea water treatment.
  - The membranes have a limited lifetime and have to be replaced after 3 to 5 years.
  - The process requires clean feed water; in general the available sea water has to be pretreated. Feed water obtained from beach wells need simpler pretreatment.
  - In the Arabian Gulf area it is preferred to have the installation indoors.
  - The corrosion is limited, because many parts are made of plastics and the remaining of stainless steel, while the temperature is ambient.
  - Control and automation are easy.
  - The process is inherently simple and requires limited attendance by skilled operators.
  - The construction is simple and the separate units can be constructed and tested at the manufacturer's site.

- The delivery time is short and mainly limited by the civil works at site.

The most important design parameters for a reverse osmosis plant are type of membrane, salt rejection, conversion, operation, temperature and pressure. The relation between these parameters is of a complex nature.

Furthermore due consideration should be given to the appropriate method of brine disposal, in order to reduce pollution of the underground and natural water sources, especially for brackish R.O. plants, situated in the interior.

The brine disposal can be controled by:

- evaporation ponds with lining
- concentration by a Brine Concentrator

The system choice depends on the local circumstances.

3.4 Disinfection

Potable water shall be free of pathogenic organisms. This can be achieved by disinfection.

The most commonly used disinfectants are chlorine (in several forms), ozone and ultra-violet radiation. Not discussed are less common methods like boiling or freezing, and the use of ionizing radiation, halogen mixtures, silver or chlorine dioxide.

3.4.1 Chlorine

Chlorine is commercially available as liquified gas, as hypochlorites (sodium or calcium hypochlorites) and as bleaching powder (chlorinated lime). Hypochlorites are obtained by reacting chlorine with an alkaline solution, e.g. NaOH or $Ca(OH)_2$.

When using hypochlorites simultaneous alkalinisation takes place by the introduction of NaOH or $Ca(OH)_2$.

The efficiency of disinfection is independent of the type of chlorine used.

3.4.1.1 Liquified Chlorine

Liquified chlorine is available in steel cylinders under a pressure of about 40 bars, with a chlorine content ranging from 40 to 80 kg and in steel containers of 500 to 1000 kg.

In freshly filled containers about 15% of the volume is gaseous chlorine.

The specific gravity of the liquid chlorine is about 1.44 at 20°C decreasing to 1.25 at 70°C. This results in liquid chlorine filling the entire volume of the container at 70°C.

Further rise in temperature may be dangerous also because at higher temperatures chlorine can react explosively with iron. Therefore filled liquid chlorine cylinders and drums shall be adequately protected from direct sun radiation. Gaseous chlorine has a greenish yellow colour and is approximately 2.5 times heavier than air.

Chlorine is toxic; a concentration of 3.5 volume parts per million parts air is already noticeable by its characteristic smell, a 3 times higher concentration irritates the eyes, the respiratory systems etc.

The MAC value (maximum allowable concentration) is 1 ppm, thus it is allowed and safe to work in a room with a chlorine gas concentration of lower than 1 ppm.
A concentration of 1000 ppm chlorine gas in air is lethal even inhaled for a short time.

Gaseous chlorine reacts rapidly with water and kills germs.
After five minutes reaction, oxidation of organic matter uses up most of the chlorine, and the residual chlorine content remains constant. It is therefore a very suitable disinfectant for groundwater.
Since all organic matter, if present, is oxidized first by the chlorine, and chlorinated hydrocarbons which are considered carcinogenic are formed, it is less suitable for surface water containing a lot of organic matter.
Water chlorination chemicals require special care in handling. The handling of compressed chlorine gas in particular is subject to strict rules.

Appropriate equipment should be installed for venting the chlorine dosing and storage rooms and as chlorine vapour is denser than air the ventilation opening shall be located close to groundlevel.
Steel piping can be used for handling liquid chlorine and dry gaseous chlorine, however with the slightest trace of humidity present severe corrosion will occur.
Stainless steel AISI 316 or higher quality, is resistant to drý chlorine.
Teflon is resistant to liquid chlorine attack. PVC should never be used for liquid chlorine or gaseous chlorine at pressures significantly higher than atmospheric pressure, especially in hot climates.
Usually gaseous chlorine is not dosed directly into the water to be treated, but as a concentrated solution in feed water. In these concentrated feed solutions a pH value of 2 is usually attained and therefore the materials used to handle these solutions should be acid and chlorine resistant (Hastelloy, Teflon).
After having obtained chlorine in the gaseous phase, either by evaporation from the containers at room temperatures or through an evaporator, the dissolving and dosing is usually performed under vacuum e.g. with an ejector.

When designing storage and dosing systems of compressed chlorine gas, the following AWWA-safety measures are advisable.

- Chlorine cylinders to be stored in a locked room separated from the room in which the mixing and dosing equipment is installed. The gas containers should never be exposed to temperatures exceeding 60°C, for instance caused by direct sunlight.
- Adequate ventilation must be provided in the chlorine rooms. In small rooms natural ventilation may be sufficient, in larger rooms mechanical ventilation is necessary. Vent openings must be located close to floor levels (150 mm).
- Personnel authorized to working with the chlorination equipment must wear protective clothing, which may consist of p.v.c. overalls and gloves, eye protection devices or masks.

Emergency measures:

- An automatic chlorine leak detector, with visible and audible alarm.
- Emergency showers or eye baths in convenient locations.
- Approved gas masks to be provided for every employee involved with chlorine handling. For rooms where no mechanical ventilations is applied and high contamination levels can occur, self-contained breathing apparatus with compressed air cylinder may be necessary to be located outside the chlorine rooms.
- Gas leaks can be traced with an ammonia saturated cloth (strong ammonia water necessary), as chlorine reacts with ammonia to form dense white fumes. The escaped gas can be neutralized with caustic soda, soda ash or other alkali absorption systems.

3.4.1.2 Sodium hypochlorite

Sodium hypochlorite is commercially available as a solution.
The available chlorine of a hypochlorite solution is usually expressed in a percentage by weight and amounts normally to 5-15% by wt.

Since the concentration to be dosed should be about one percent, the solution must be diluted prior to use.
The available chlorine in the solution reduces quickly with time when exposed to the atmosphere. A quantity sufficient for about one day use must be mixed at any one time. The sodium hypchlorite solution can lose up to half its strength in a year when stored in sealed containers.
Industrial grade hypochlorite is available in 5, 25 and 40 liter containers and in 500 to 2000 liter rubber lined steel drums.

Due to its low toxicity the solution will not harm the respiratory system as chlorine gas does. An installation for dosing of sodium hypochlorite would consist of a storage room, handling equipment, mixing tanks and gravity dosers or dosing pumps.

The safe handling combined with the daily mixing procedures and the reaction time (30 minutes to one hour) makes this process most suitable for small or rural plants.

The atmosphere in the chlorination rooms will be moist and corrosive. The materials best suitable for storage tanks are glass fibre reinforced epoxy, P.V.C. and polyethylene. Recommended piping materials are G.R.P. and P.V.C.

3.4.1.3 Calcium hypochlorite

Dry calcium hypochlorite is available on the market under different trade names, either in powder, granular or agglomerated form.
The content of available chlorine reaches 70% by weight. The granular and powder forms can be purchased in 25 kg and 50 kg drums and/or bags.
The solubility of calcium hypochlorite in water ranges from 215 g/l at 0°C to 234 g/l at 40°C.
Practical working solutions are preferably held at a concentration lower than 100 g Ca (OCl)2 per liter.

The solution is subject to some deterioration in time, but is more stable than sodiumhvpochlorite.
To avoid precipitation of calcium carbonate during dilution of solid calcium hypochlorite in water and during injection of the solution in the water to be disinfected it is recommended to treat the dilution water with at least 1 ppm sodium hexametaphosphate or polyphosphate.
The maintenance of systems using calcium hypochlorite may require periodic flushing with hydrochloric acid to remove deposits of calcium carbonate.
This acid should, however, never be mixed with calcium hypochlorite in uncontrolled conditions, as gaseous chlorine may escape.

3.4.1.4 Bleaching powder

Bleaching powder or chlorinated lime is a white powder with an available chlorine of 30-35 percent.
The content is of a complex nature, also containing calcium-hypochlorite. It is available in 50 kg drums.
Provided that the drums are sealed there is no deterioration with time.
The lime content of the powder is insoluble and the prepared solution must be left to stand for at least 24 hours prior to dosing.
Because some chlorine is lost due to the settling of unsoluble elements an extra 10 percent is needed.
Storing, mixing, handling and dosing facilities are similar to disinfection using sodium hypochlorite.

3.4.1.5 Electrolytic on-site generation of chlorine

The production of active chlorine, in the form of a diluted sodium hypochlorite solution, can be achieved by passing sea water or commercially available brine through electrolyzers. The electrolysers are formed by a number of electrolytic cells, electrically and hydraulically arranged to form a packaged group.

The production rate of active chlorine is directly controlled by adjusting the direct current supplied to the electrolyzers.
The use of the electrolytic sodium hypochlorite is widening due to its advantages of safety and simple operation and control.
The 3% sodium chloride solution, normally sea water is electrolyzed and a final concentration of 0.8–1% sodium hypochlorite is produced. This solution may be used directly or may be stored with little decrease in its effective concentration.
During the electrolysis hydrogen is also produced:

$$2NaCl + 2H_2O \quad\quad Cl_2 + 2NaOH + H_2$$

This hydrogen will be diluted to a safe concentration by a forced stream of air and vented to the atmosphere.
The energy cost for production of hypochlorite range between 4 and 8 kWh/kg active chlorine.
As the hypochlorite solution is prepared from a approx. 3 wt% sodium chloride solution or sea water the total dissolved solids contents of the water to be disinfected will also increase.

3.4.2 Ozonation

When using ozone as a disinfectant no chemicals are needed, and no taste or odor is produced. For the necessary on-site generation only electric current is needed.
Ozone is a powerful disinfecting agent which kills all germs, viruses inclusive, within few seconds. The efficiency in water treatment depends on the mass transfer of ozone from its gaseous state to a liquid where the reactions occur.
Ozone is an unstable gas which must be generated on the site of application. It can not be liquified by compression because of the danger of explosion. Ozone is usually produced by electrical discharge in dry air or oxygen, viz. by circulating dried air or oxygen through a di-electric medium over which a high voltage alternating current is applied.
Basically the overall reaction can be written as follows:

$$3O_2 \longrightarrow 2O_3$$

Although much progress has been made on the construction of ozonators, practically 15 to 20 kWh/kgO_3 are required when starting from air. The yield can be increased when oxygen or air enriched with oxygen is used.

The ozone demand to disinfect drinking water depends greatly on the temperature of the water.

From experience in Europe it appears that a production capacity corresponding to an ozone demand capable of attaining 2 to 4 mg O_3/l water, has generally been sufficient.

Part of this ozone is effectively consumed by the oxidizable impurities present in the water, another part is found as a residual concentration of ozone and finally, part of it is decomposed. Due to decomposition residual ozone concentration cannot be maintained in the water while flowing through a water distribution system.

Ozonated water is therefore subject to easy bacteriological after growth.

An ozone treatment plant shall be equipped with:

- Preliminary air treatment equipment
- Ozone production equipment: high tension transformers and discharge electrodes
- Mixing equipment for injection of ozone.

Because of the complicated installation which needs specialized equipment, high installation costs are to be foreseen.

The gas is highly toxic. A seperate room for the installation of ozone equipment and for the mixing units is recommended.

All gas production and treatment facilities must be gas tight and separated from the control rooms.

3.4.3 U.V. Radiation

Ultra-Violet radiant energy can destroy or inactivate bacterial organism, inhibiting their multiplication. U.V. light is generally obtained by electrical discharge in mercury vapour contained in a

quartz lamp. The technique usually suffers from lack of field tests for establishment of its efficiency and its inability to maintain a disinfecting residual in the water. The germicidal action depends on the intensity, e.g. the density of the U.V. light at the point where the germ is located. Therefore the thickness of the water layer from the surface of the quartz lamp to the wall of the pipe should not exceed approximately 70 mm. The process can be controlled by a continuous measurement of the light intensity.
The obvious advantage of U.V. disinfection is that no chemicals are introduced into the water.
The energy input is in the range of 10 Wh/m^3. The lamps are to be replaced either when the emitted intensity falls below 70% of the rated intensity or after a guaranteed lifetime. The quartz lamps are to be cleaned regularly.
This means that equipment should be designed to allow easy cleaning without having to disassemble the equipment.
The tubes are normally designed in such a way as to protect the operator against electric shocks or U.V. radiation.
Protection of eyes is of primary importance. Prolonged exposure can cause permanent damage to the vision.

3.4.4 Choice of a disinfection system

The main considerations which affect the final choice of a disinfection system are:

1) Ease of operation, reliability and effectiveness of the system
2) Safety of the system to consumers and operators
3) Cost of equipment including maintenance, chemicals and other running costs.
4) Location of water treatment: in rural areas or in (densely populated) urban areas.

ad. 1

All disinfection systems described ensure an effective disinfection provided that the operating personnel is well trained.
Ozone and U.V. systems are dependent on electricity supply, while

the chlorination systems need a regular supply of chemicals. Ozone and U.V. have limited or no residual effect with the consequent danger of bacterial after-growth in the distribution system.
Ozone needs complex equipment and specialist technical assistance, but operation is fairly simple.
The chlorination systems require more attention for routine operation. Sodium hypochlorite is an unstable solution, calcium hypochlorite is fairly stable, chlorine gas has no stability problems.

ad. 2

U.V. and ozone pose no health risks to consumers.
An excess of chlorine in the drinking water is not harmfull in the concentrations that can be produced by the chlorinators, but taste problems can occur.
To operators, U.V. and ozone present no risks of importance.
Chlorine being a very toxic gas presents high risks when leakage occurs. Only when strict rules are obeyed and skilled operators are present, can this disinfection method be applied succesfully. The other chlorination chemicals are also aggressive but less dangerous.

ad. 3

The investment costs of equipment, and the availability of chemicals and running costs in general can also influence the choice of a disinfection system.

Conclusions

Because of the absence of an active residual disinfectant in the distribution system, the use of ozone and U.V. radiation is not advisable.
Where the requirements of skilled personnel and regular maintenance are not always fulfilled, e.g. in rural and remote areas, the use of (liquified) chlorine gas is not advisable.
For large installations the gaseous chlorination systems are preferred.
For rural areas calcium hypochlorite should be used and where not readily available sodium hypochlorite.

3.5 Water quality

3.5.1 Quality standards

Quality standards for potable water can be developed by using the "Guidelines for drinking water quality" published by the World Health Organisation (W.H.O.) 1984.
These guidelines are intended for use by countries as a basis for the development of standards. The levels recommended are not standards themselves, but shall be considered in the context of local prevailing environmental, social, economic and cultural conditions. In this respect reference is made to the Omanian Standards for Drinking Water.

Drinking Water shall be safe for human consumption and palatable, thus free from constituents, detrimental to health and attractive to the senses. The microbiological quality is of the greatest importance and should never be compromised in order to provide aesthetically pleasing and acceptable water.

In the "WHO Guidelines for drinking water quality" the health risks and effects of the various substances in drinking water are discussed in greater detail, reference is made hereto.
The WHO has given following categories of guideline values:

- health aspects:
  - microbiological quality
  - inorganic constituents of health significance (see Table 3.2)
  - organic constituents of health significance
  - radioactive constituents
- palatability
  - aesthetic quality (see Table 3.3)

TABLE 3.2: INORGANIC CONSTITUENTS OF HEALTH SIGNIFICANCE - W.H.O.

Constituent	Unit	Guideline value
arsenic	mg/l	0.05
cadmium	mg/l	0.005
chromium	mg/l	0.05
cyanide	mg/l	0.1
fluoride	mg/l	1.5
hardness	--	no health-related guideline value set
lead	mg/l	0.05
mercury	mg/l	0.001
nitrate	mg/l (N)	10
selenium	mg/l	0.01

TABLE 3.3: AESTHETIC QUALITY - W.H.O.

Constituent or characteristic	Unit	Guideline value
aluminium	mg/l	0.2
chloride	mg/l	250
colour	TCU	15
copper	mg/l	1.0
hardness (as $CaCO_3$)	mg/l	500
hydrogen sulfide	--	not detectable by consumers
iron	mg/l	0.3
manganese	mg/l	0.1
pH	--	6.5-8.5
sodium	mg/l	200
solids-total dissolved	mg/l	1000
sulfate	mg/l	400
taste and odour	--	inoffensive
turbidity	(NTU)	5
zinc	mg/l	5.0

The microbiological guidelines state that water shall have "no" coliform organisms in a random 100 millilitre sample (depending on the method of supply 0-10 coliform organisms/100 ml in 95-98% of samples examined throughout the year).
The organic constituents-values recommend values for chemicals like aldrin/dieldrin, benzene, chloroform, DDT etc.

3.5.2 Water quality control

An adequate water quality control is a necessity in a reliable and safe water supply system.
Even if the water is sufficiently treated, water quality control remains necessary to detect water quality deterioration inside the pipeline system, caused by corrosion, leaks, aftergrowth of microorganisms, etc.
A good water quality must be maintained in the whole system. This requires a systematic way of control, taking samples at several locations in the system (before and after treatment, in reservoirs, in distribution lines).

In controlling the water quality one can ensure the hygienic safety of the water, and corrosion prevention of the system is also possible.

Where no reliable public water supply exists, an improvement of the quality in the public water supply will cause an improvement of public health.
There are many diseases that are water borne, caused by pathogenic bacteria, protozoa, virus or worms, if present in water. Some examples are given in Table 3.4.

TABLE 3.4: WATER BORNE DISEASES

Bacterial diseases	Cholera
	Typhoid fever, para typhiod
	Bacillary dysentery
	Travellers diarrhoea
	Leptospirosis
Protozoal diseases	Amoebiasis
	Amoebic dysentery
Virus diseases	Poliomyelitis
	Infectious hepatitis
Worm diseases	Schistosmiasis (bilharzia)
	Schistosome dermatitis (swimmers itch).

Samples of the water to be distributed must be collected in a representative way. Water quality analyses of the samples must be performed in a water laboratory. For the determination of the water quality the following types of analyses are necessary:

- physical
- chemical
- microbiological.

Physical analyses determine parameters like temperature, colour, turbidity, odour and taste, and specific conductance.

Chemical analyses are necessary to determine a large quantity of chemical substances present in water, which can affect human health or are even toxic. Also parameters that determine the chemical water equilibria, which give information about the corrosiveness of the water or the possibility of scale forming, like pH-value, hardness, bicarbonate, etc.

Microbiological analyses are necessary to determine the most probable number (MPN) of faecal bacteria (coliforms), which indicates excreta pollution and thus the possible presence of pathogenic micro-organisms.

Standard methods of water analyses in laboratories can be found in:

1. Standard Methods for the examination of Water and Sewage - American Public Health Organisation.
2. Laboratory Manual for Chemical and Baterial Analysis of Water and Sewage - F.R. Theroux; Mc.Graw-Hill.

3.5.3 Mixing of waters from different sources

The quality of the water produced in a desalination plant can be classified as agressive, and will cause severe corrosion of unprotected steel pipes. The adding of inhibitors is now necessary to bring the water into "equilibrium". The equilibrium concerned is the $CaO-CO_2$, or calcium-carbon dioxide equilibrium. The stability of a water can be indicated by several indices, such as the Langelier index and Ryznar index. For the Langelier index reference is made to paragraph 3.3.2, and Table 3.5 gives an indication of the Ryznar index, expressed as follows:

$$I_R = 2\ pHs - pH$$

Where I_R = Ryznar index
pHs = Saturation pH
pH = actual pH

Another possibility of obtaining a non-agressive water is the mixing of waters from different sources. Desalinated water can be mixed with groundwater produced by wells, with a higher T.D.S. content (total dissolved solids) than is suitable for drinking water.
The ideal location to blend the waters will be the potable water storage reservoir of the desalination plant.
Control is achieved by measuring the well water quantity.

TABLE 3.5: RYZNAR STABILITY INDEX OF WATERS

Index	Tendency
4-5	Heavy scale forming
5-6	Slight scale forming
6-7	Equilibrium
7-7.5	Slight corrosive action
7.5-8.5	Heavy corrosive action (agressive)

4. PUMPSTATION

4. PUMPSTATIONS

4.1 General

The main pumping duties are:

- pumping from wells
- boosting to increase the flow in a pipeline
- pumping from one level to a higher level for distribution or storage.

Many pumps in waterworks run continuously for long periods of time. High efficiency is therefore very important, and pumps must be reliable in use.
At the wellfield area usually only the wellpump facilities are installed. The water is pumped to a storage facility, located at a more convenient site, where distribution-pumping facilities are located together with other amenities, such as offices, workshop, staff housing.

4.2 Pumping equipment

In waterworks practice centrifugal pumps are used almost exclusively, mostly electrically driven. In this chapter centrifugal pumps will be discussed, other types are also discussed in paragraph 3.2.8.

A centrifugal pump raises a liquid by centrifugal force created by an impeller, revolving in a tight case.
They are available commercially for almost any capacity and for lifts up to 200 m per stage. There is no theoretical limit to the number of stages that can be placed in series to increase the lift.
For waterworks pump speeds of 400 to 3500 r.p.m. are used.
The capacity of the centrifugal pump is determined by its size, pump speed and type of impeller.

The specific speed Ns of a pump is the speed at which the pump would run when discharging 1 m^3/s under a head of 1 m at the highest efficiency.
Following expression may be useful in comparisons:

$$Ns = N. \frac{Q^{\frac{1}{2}}}{H^{\frac{3}{4}}}$$

where

N = actual speed (r.p.m.)
Q = discharge (m^3/s)
H = manometric head (m.w.c.)

The variations of Q,H, and power P, with N are given by following expressions:

$$Q' = \frac{N'}{N}\ Q; \quad H' = \left(\frac{N'}{N}\right)^2 H; \quad P' = \left(\frac{N'}{N}\right)^3 P$$

A wide variety of impeller types is available. Depending on the quality of the fluid, and the Q/H desired a choice must be made.
Centrifugal pumps may be classified as horizontal shaft or vertical shaft pumps.
Horizontal shaft pumps are suitable for large capacities, where adequate floorspace is available and flooding of the motor is improbable.
Vertical shaft pumps are used mostly as deep-well pumps. The motor can be located above the water level, or be submerged in the water.
Horizontal pumps (with horizontal shaft) have higher efficiencies than vertical pumps, maintenance is easier, setting is easier and less expensive.

4.3 Pump Design

4.3.1 Design parameters

The most important data needed for selecting the pump size are:

- pump flow rate, or capacity, Q (in m^3/day, m^3/h)
- pump head H (in m water column)

at the required duty point.
When these variables are determined, the mains frequency must be known. The correct pump size and speed can then be selected from pump group-performance curves. Other parameters such as efficiency η , input power P and N.P.S.H. of the selected pump are known from its individual curves.

The main pump curve of a pump gives the relationship between the two variables Q and H. A typical pump curve of a constant speed centrifugal pump is given in Figure 4.1
The characteristic feature of the pump curve of a centrifugal pump is the increase of the flow rate Q with decreasing head H.
The pump has a self-regulating capacity for varying heads.

The selection of the appropriate pump curve depends on the specific pump duty requirements. With a steep curve the change in capacity (ΔQ) is less than with a flat curve under the same differential head conditions (ΔH). With a steep curve the control characteristics of the pump are better.

To assess the necessary pump head H, the system head, Hs, must be determined,

$$Hs = h_{sta} + \Sigma h_f$$

where

h_{sta} = static head: height difference between the suction and the discharge fluid levels.

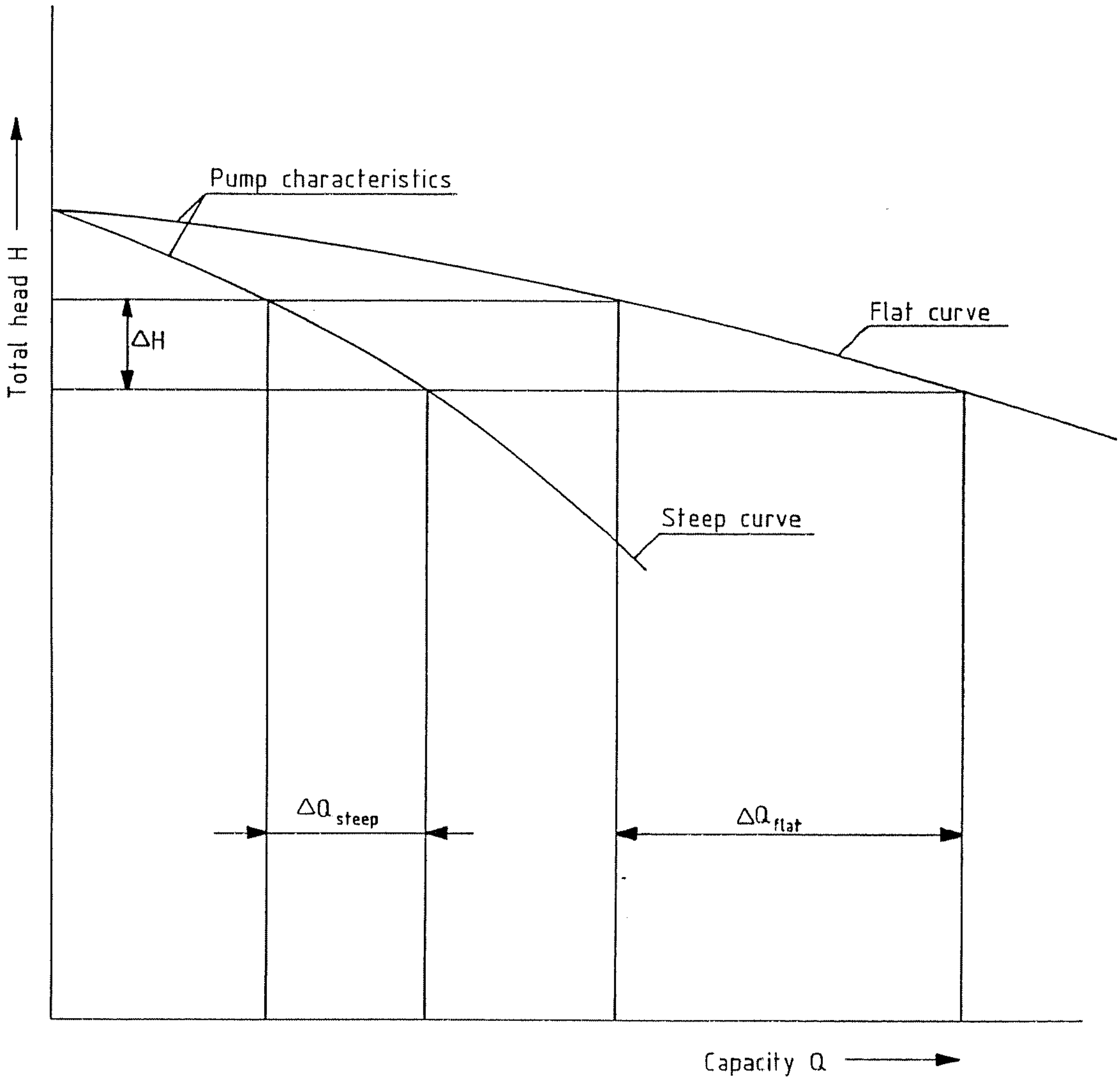


FIG 4.1 PUMP CHARACTERISTIC CURVES

Σh_f = the sum of all pressure head losses caused by friction in pumps and pipeline systems (see also paragraph 5.2)

4.3.2 Operating point

The pump characteristics are known from the pump curve.
The system characteristics, i.e. the Q - H relationship of the pipe system have a form as can be seen in Figure 4.2
The point of intersection between the two curves is the operating point B: the pump will establish flowrate Q_B at a head H_B.
There are several ways to change this operating point.
One way is to change the pump curve. This can be achieved by (see Figure 4.3 and 4.4):

- parallel operation of more pumps (max. output higher,)
- serial operation of more pumps (max. head higher)
- altering pump speed
- altering impeller diameter.

Another way is to change the system characteristics by:

- opening or closing a valve
- changing pipe diameters
- flow control valves.

4.3.3 NPSH and cavitation

Centrifugal pumps will only operate satisfactorily if there is no build up of vapour within the pump.
Cavitation on the impeller blades should always be avoided. This phenomena is caused by entrained air or water vapour being released from the water. The developed bubbles (of very small size) move inside the pump and where entering a higher pressure zone they collapse. The continuous collapsing of bubbles on the tip of an impeller blade causes the metal to be eroded.

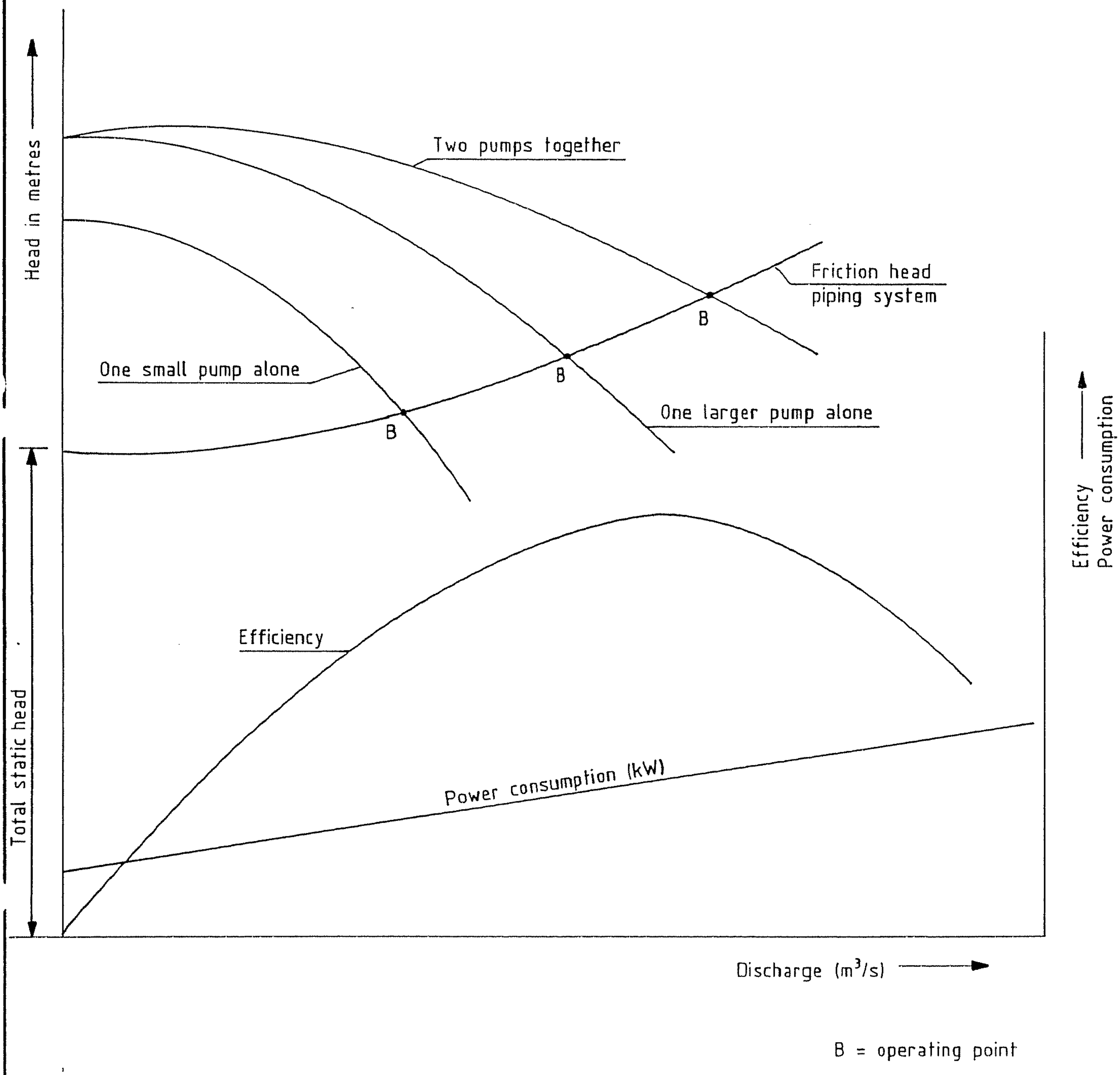


FIG. 4.2 FRICTION HEAD AND PUMP CHARACTERISTIC CURVES

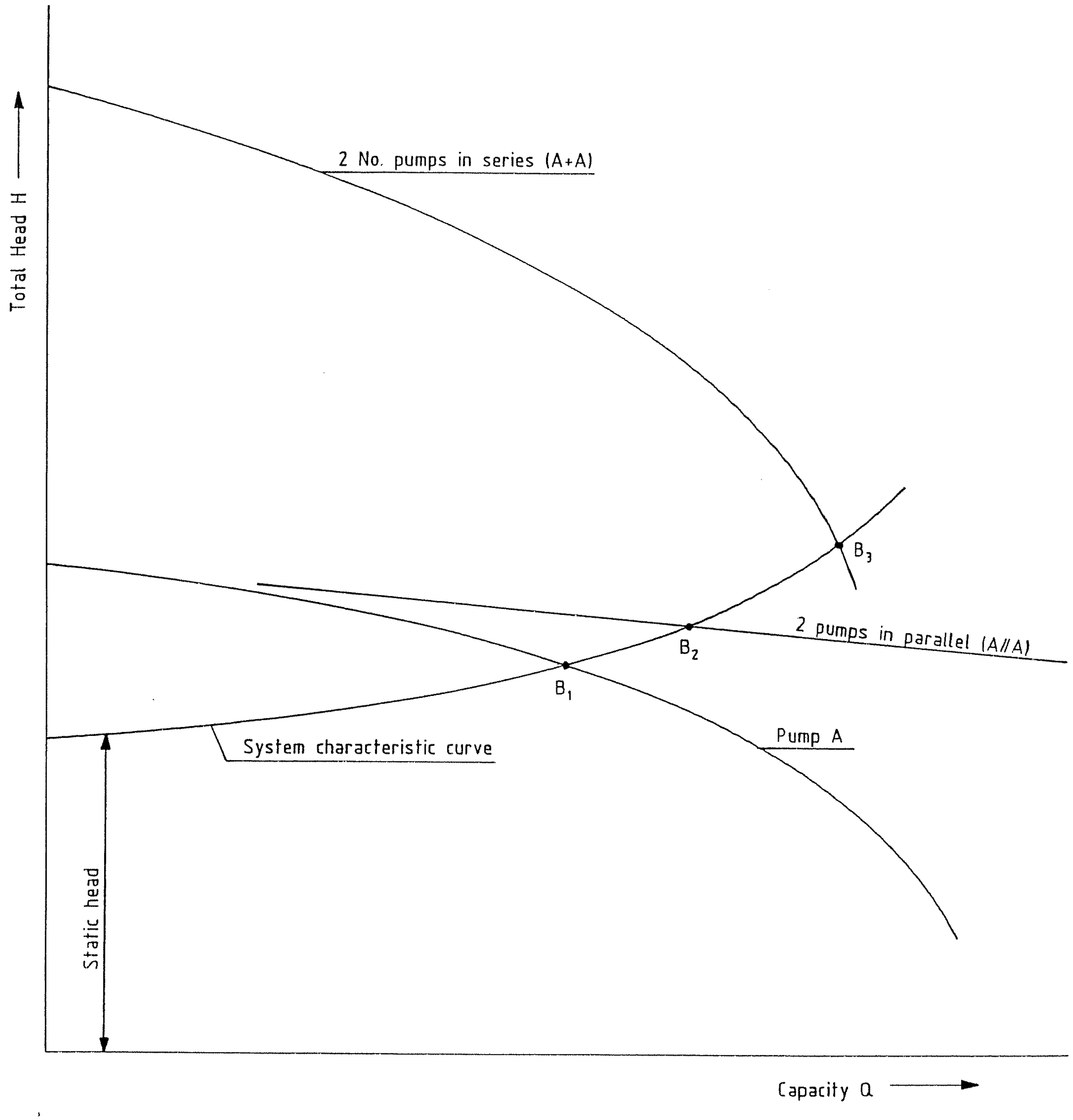
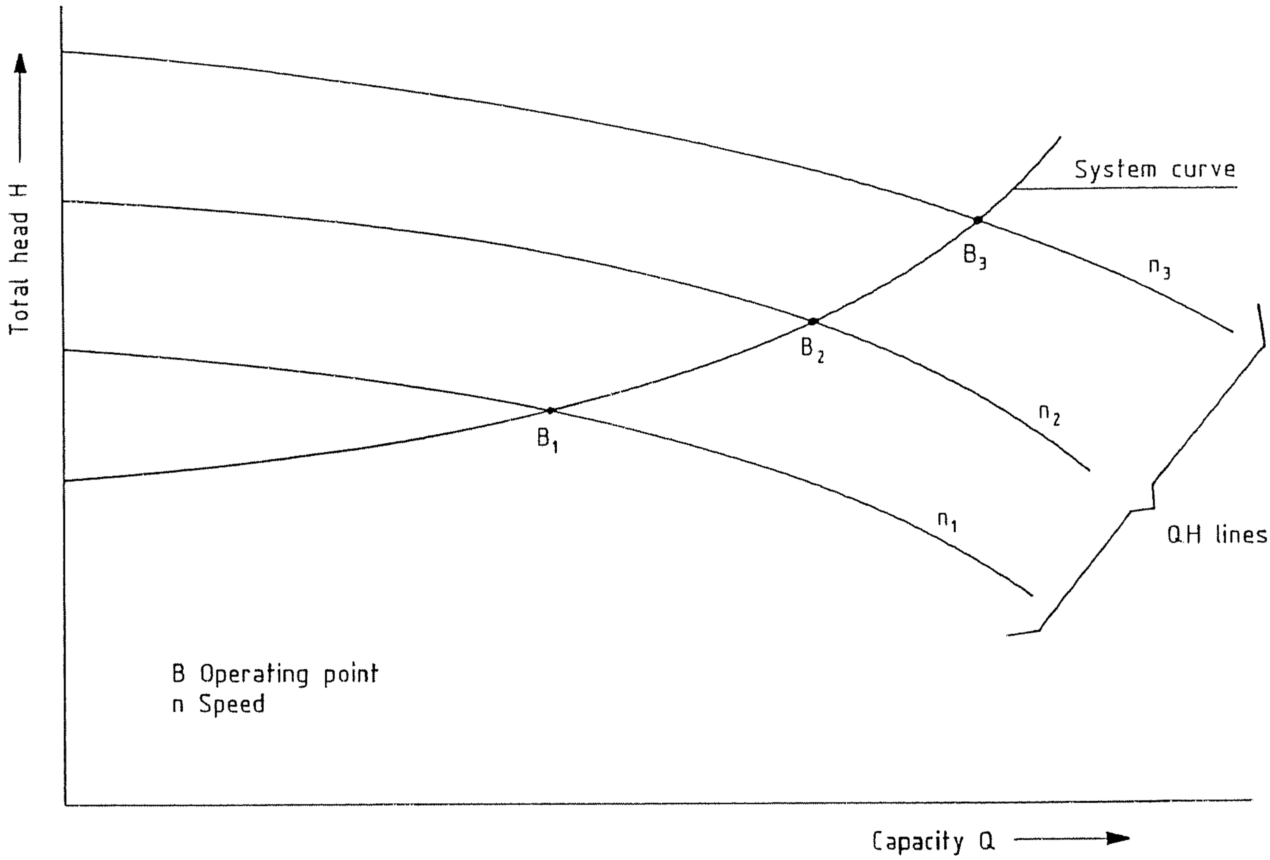
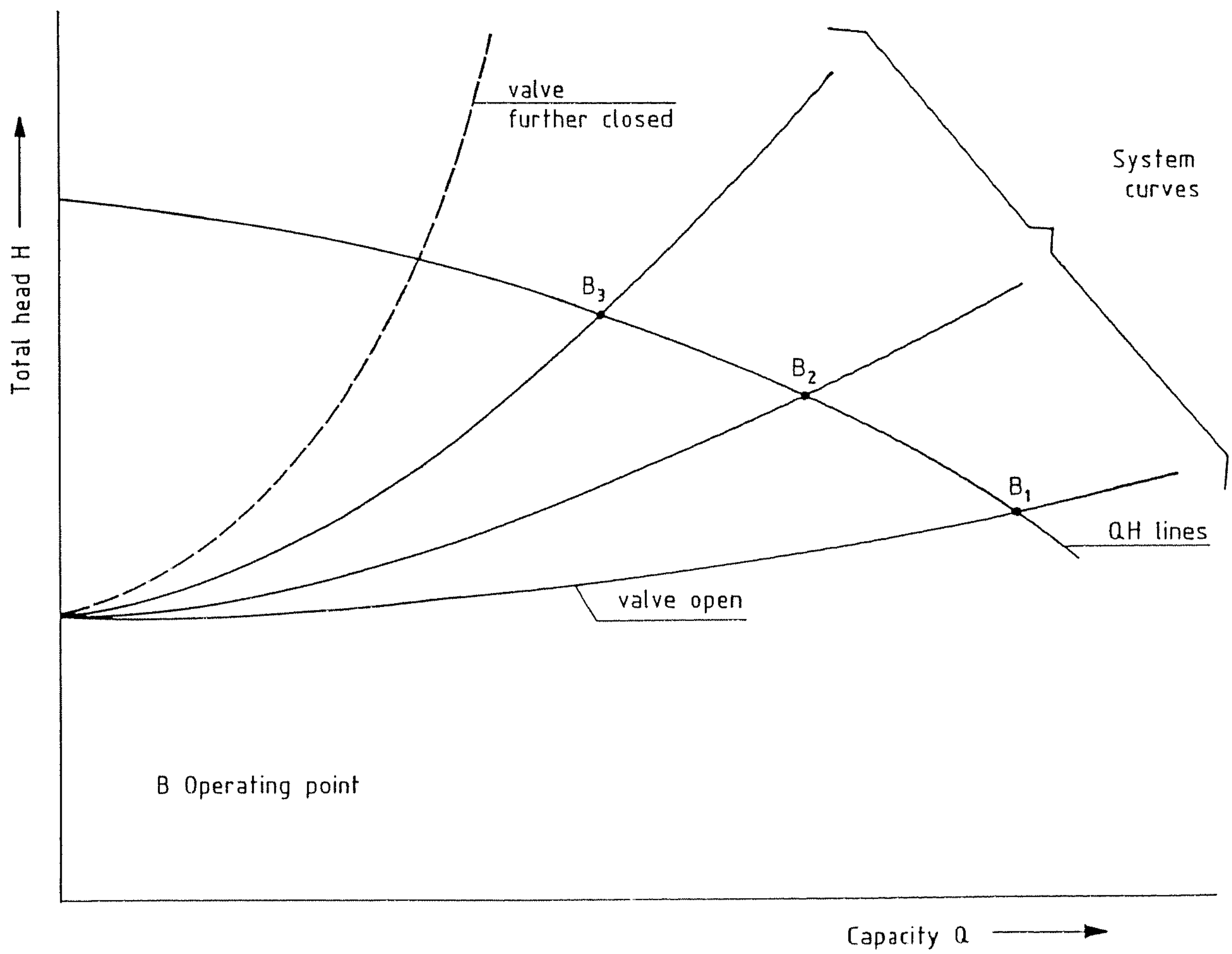


FIG. 4.3 CHANGING OPERATING POINT BY PUMPS IN PARALLEL / IN SERIES



INCREASING PUMP SPEED



CLOSING OF VALVE

FIG. 4.4 CHANGING OPERATING POINT BY CHANGING PUMP SPEED / VALVE POSITION

The lifting of water by suction should be avoided as far as possible. The pump parameter Net Positive Suction Head (NPSH) must be evaluated. The NPSH can be incompletely defined as the static head above vapour pressure. The available NPSH must be greater than the required NPSH.

Where suction lift cannot be avoided, provisions must be made for priming the pumps. Vacuum pumps may be necessary to exhaust the air.

4.3.4 Motor drive

Centrifugal pumps are commonly driven by an a.c. squirrel cage motor. With this type of drive the approximate pump speeds are as in Table 4.1.

TABLE 4.1: PUMP SPEEDS (L/MIN)

no. of poles	2	4	6	8
frequency				
50 Hz	2900	1450	960	725
60 Hz	3500	1750	1160	875

A pump speed of 960 (1/min) is used when pumping large quantities. A speed of 1450 is considered normal, and 2900 is for special applications.

When determining the motor size, safety margins are used because of the possibility of a fluctuating system flow.

Following safety margins are used:

$P < 7.5$ kW : 20%

$7.5 < P < 40$ kW : 15%

$P > 40$ kW : 10%

The pump power input P of the pump is the mechanical energy at the pump coupling or pump shaft absorbed from the drive. P can be calculated using the following formula:

$$P = \frac{\rho . g . Q . H}{1000 . \eta}$$

where

P	= power (kW)
ρ	= density of the fluid (kg/m^3)
g	= gravitational constant (m/s^2)
Q	= pump capacity (m^3/s)
H	= pump head (m)
η	= pump efficiency

When determining the necessary power requirement of the motor drive an overall efficiency must be used:

$$\eta = \eta_{pump} \cdot \eta_{motor} \cdot \eta_{cable} \cdot \eta_{transformer}$$

4.4 Electrical facilities

4.4.1 General

All electrical design equipment and installation shall be in accordance with the requirements contained in the latest editions and supplements of the codes and standards issued by the following organisations:

- Regulations for electrical installation works by the Ministry of Electricity and Water of the Sultanate of Oman.
- International Electrotechnical Commission (IEC)
- International Organization of Standardization (ISO)
- British Standards and British Institute of Electrical Engineers (I.E.E.) regulations

In case of conflict between requirements of above mentioned regulations, the most stringent requirements shall prevail.

The design shall be based on a failsafe system.
Every precaution must be taken to ensure a safe shutdown in case of failure of the power supply and a safe start-up after the power has been reinstated.

In engineering and selecting electrical materials and systems the guiding principle shall be suitability, reliability, ease of operation/maintenance, and costs of supply, installation, operation and maintenance.

The power supply to small stations is generally at the standard 3-phase voltage (415 V). For larger stations it is preferable to use power at higher voltage (6.6 or 11 kV).
In case of high tension being used, an enclosed switchboard and switchgear is necessary.
The transformer facilities must be provided with a switch for opening/closing the circuit and a breaker to disconnect fault currents.

Auxiliary or emergency power facilities are to be provided to maintain operation in case of an electricity break-down. Usually a diesel driven generator is used.

The electrical design is drawn on single-line diagrams showing power system, switchgear, protective devices, feeder panels and wiring and motor controllers diagrams.

Control panels and main switchgear are to be installed for the operation and the monitoring of the pumps. Discharge pressure, flow and pump motor status are to be indicated.

Sensor and alarming may be necessary to indicate chlorine gas leaks or the overheating of pump motors, etc. In some cases a remote control system using telemetry techniques should be considered.

4.4.2 Power transformers

Transformers shall in general conform in design, material construction and performance to the latest editions of the I.E.C. Standards and in particular to the following publications:

- Power transformers — IEC 76
- Recommendations for the classification of materials for the insulation of electrical machinery and apparatus in relation to their thermal stability in service — IEC 85
- Methods for the determination of the electric strength of insulating oils — IEC 156

Transformers kVA and voltage rating shall comply with the preferred values of the standards specified. Unless otherwise specifically stated to the contrary the rated kVA shall be based on natural air cooling. Voltage insulation of windings shall be for unearthed system.

Liquid immersed transformers of ratings higher than 500 kVA shall have provisions for increasing their rated kVA by use of fans. The provisions shall cover the ratings of all current conducting parts and bushing. Fan cooled kVA ratings shall not be less than the following percentages of the natural air cooled ratings:

Naturally cooled kVA	fan cooled ratings
501 - 2499	115%
2500 - 10000	125%
above 10000	133%

Temperature rise of transformers shall not exceed the following values when operating continuously at the maximum kVA ratings, at the rated voltage and frequency.

	Temperate climate	Tropical climate
- Oil immersed type: Top oil temperature rise measured by thermometer	60°C	50°C
Winding temperature rise measured by resistance	65°C	55°C
- Dry type	Dependent on class of insulation	

Unless otherwise specified oil immersed transformers shall be suitable for outdoor installation, while dry type transformers shall be suitable for indoor type of installation.

4.4.3 Cables

Reference is made to the following publications, latest editions:

- Guide to the selection of high-voltage cables	IEC 183
- Conductors of insulated cables	IEC 228
- Rubber insulated cables of rated voltages up to and including 450/750 V	IEC 245
- Calculation of the continuous current rating of cables (100% load factor)	IEC 287

Cables may be run underground or aboveground, but pref should be given to underground cabling for its inherent pro against fire hazards and mechanical damage. When designing cable networks, the cable types and thei shall be determined corresponding to the required duties and in particular taking into account the following:

- Possibility of soil contamination and chemical attack. T not only affect the choice of cable routings and the installation (above or underground), but also the cable
- Voltage drop and short-circuit level.
- Heat dissipation aspects, e.g maximum soil and/or temperature, minimum thermal soil conductivity, cab ping, depth of laying in order to prevent the occu excessive insulation temperatures for each cable.

The sizing of cables for consumers shall be based on their ratings: those for distribution shall be sized in accordance loads.

At an early stage of the area plot plan development, rese appropriate routings and adequate space for undergrou aboveground cable installations shall be made in cooper the other engineering disciplines.

To this end a dimensional cable routing plan shall be prepared, indicating adjacent facilities such as drainage, sewerage, pipe tracks, concrete foundations, instrument cable routings.

Wires in conduits are allowed for indoor lighting installations in utility buildings in safe areas, such as offices, messes, toilets and locker rooms.
Cables in ducts are also allowed in those cases in large buildings.

Main cable routes shall be logical, e.g. alongside the roads, outside the routing of heavy transport.
Furthermore, underground cable routes shall be designed to avoid close pipe crossings and close parallel runs with underground pipelines; a distance of at least 30 cm between cable and pipe (including insulation) shall be maintained.

Cables should preferably be buried directly in the ground at a depth of minimum 90 cm.

Single-core cables pertaining to one 3-phase circuit shall be laid together, separated from multicore cables.

Instrument and telecommunication cables shall not be laid in trenches used for MV and/or LV cables.

MV cables may be laid in the same trench with LV cables, but shall then be separated, e.g. by means of a continuous row of concrete cable tiles placed vertically between the two types of cable or by any other suitable barrier. All cables shall be covered by concrete or PVC tiles. Distance between medium and high voltage cables shall be at least 30 cm.

Aboveground cables shall be supported by cable racks, trays or cable ladders all the way up to their terminations.

Where necessary, e.g. particularly on vertical runs, the cables shall be fixed to the tray by straps.
Cable trays shall be galvanized sheet steel of 1.25 mm and suitable for a load of at least 250 kg/m at a distance between the supports of 2 m.

Individual cables, however, may be fixed directly to the main structures, walls, ceilings or columns by means of proper fixing and supporting materials.
All materials used shall be protected against corrosion.
Bends and corners in the corner racks, trays or ladders shall allow for the minimum cable bending radius.
Cable trays shall be closed by removable top covers allowing adequate ventilation, in the following situations:

- in the pumphouse
- where mechanical damage of the cables is likely to occur during maintenance activities
- where oil or chemical spillages on the trays can be expected
- where sun shielding is required.

Cables on racks or trays may be bunched in more layers as long as the thermal derating factor is not further affected such as with lighting or control cables or where voltage drop considerations are the overriding factor for derating.
MV cables shall be mounted separately from the LV cables at a distance of at least 30 cm.

Multicore cables shall have preference over single-core cables.

However, single-core cables may be preferred for practical and/or economical reasons on short runs, e.g. generator and transformer secondary cables or on long runs in the case of extremely high current ratings, where 2 parallel cables of 3 x 240 mm^2 would not suffice.

All power, lighting, control and earthing cables shall have copper conductors.

Three-core MV cables shall be of the cross linked polyethylene (XLPE) insulated single galvanized steel wire armoured and PVC oversheathed type.

Twin-core and multicore power, lighting and control cables of 600 V/1000 V or 750 V grade shall be of the cross-linked polyethylene (XLPE) insulated, steel wire armoured or braided type. These cables shall be used for aboveground and underground installations, but in the latter case lead-sheathed cables are required in those areas where the subsoil conditions are liable to be severly contaminated by hydrocarbons and/or solvents.

Single-core cables for abovegroudn connections of transformers with LV swithcgear panels should be of the XLPE-insulated, PVC-sheathed type.

Earthing cables, both underground and aboveground, shall be PVC-covered as a protection against electrolytic corrosion.

4.4.4 Motors

In case a three phase induction motor is used, for rating upto and including 200 kW, a standard three phase altering current with working voltage of upto 440 V AC is to be provided.

For pumpmotors with higher ratings, high tension may be used, depending on total power requirements.
Motors shall conform in design, material, construction and performance to the latest editions of the relevant IEC standards (IEC 34, IEC 72).

LV motors shall be capable of continous operation at their max. kW ratings and within their limits of temperature rise at system continuous deviation of up to and including the following percentages of the nominal values.

-	Voltage	: ± 5%
-	Frequency	: ± 2%
-	Absolute voltage and frequency variations	: 5%

The permissible temperature rise under these conditions is stated in IEC 34-1.

LV motors shall be suitable for continuous operation on systems with the neutral at or near earth potential.

They shall also be suitable for operation on unearthed systems with one line at earth potential for infrequent periods of short duration, e.g. as required for normal fault clearance.

Motors shall be suitable for direct on-line starting. Furthermore, unless otherwise specified, also for two successive starts with the motor already at running temperature under the following conditions:

-	motor terminal voltage	:	80% of rated voltage
-	load torque	:	varying with the square of the speed from zero to rated motor torque
-	inertia	:	125% of own inertia

To ensure successful re-acceleration, the motor torque shall be minimum 110% of the torque required by the driven equipment under load conditions, over the entire rpm-range and with the motor terminal voltage at 80% of the rated voltage.

All motors shall be suitable for restarting against full residual voltage.

4.5 Works compound facilities

In a pumpstation the following rooms are to be provided:

- pumphall with control room
- electrical room, substation
- room for disinfection facilities
- office

It may be advisable to plan following rooms:

- maintenance and workshop facilities
- storage yard
- staff housing
- laboratory (for larger plants).

It is necessary to prevent unauthorized entry to the site and the building by chain link fencing and lighting the pumpstation and transformer area.

The lay-out of the pumping equipment with piping determines the area of floor space required. Ample spacing between the pumpsets should be provided, with the valves, instruments suitably placed for ease of operation and control by the operator.
Greatest accessibility to all parts for periodical maintanance should be incorporated including an overhead crane or other form of lifting tackle, with a working platform, for overhaul purposes.
A drainage pumpingsystem shall remove gland water and other incidental leakage water from pumphall floor. It is recommended to install also a high capacity drainage pump which will work in case of emergencies.
Horizontal pumpsets should be placed at least 300 mm above floor level, to prevent flooding.
The pumpinghall and other buildings should have a R.C. roof and be neatly finished, for example with tiles, or properly painted.

The pump control room shall be properly ventilated, slightly over-pressured to prevent ingress of sand, dust and other particles.
Workshop facilities should be within easy access of the pumphall. Stores for spare parts and consumables should be incorporated within, or adjacent to the workshop.

The electrical room/substation accomodates the high tension switch-gear and other electrical equipment. Transformers can be either of the indoor or outdoor type.
The main switch gear and control panels need adequate room both in front and behind.

In case of chlorination being used as the disinfection system, two separate rooms are necessary, one for the chlorinating apparatus, the other for chlorine storage, with direct access to the open air. These rooms need ventilation openings near floor level.

5. WATER TRANSMISSION PIPELINES

5. WATER TRANSMISSION PIPELINES

5.1 Selection of pipeline materials

A major part of the capital investment in water supply (about 60%) is required for the construction of pipeline systems.
Therefore due consideration should be given to the selection of the most suitable pipe materials.
Quality of water to be conveyed, soil conditions around buried pipes, cost and properties of pipe material, pipeline design, internal pressures, external loadings and trench bedding conditions as well as flexibility of installation and handling of pipe materials are factors to be considered in the assessment of the correct pipe material.
In the following sections the main features of the two pipe materials, widely used in the Middle East,ductile iron and asbestos cement, are summarized.

5.1.1 Meteorological conditions

The high ambient temperatures, together with the extremely high relative humidity during a major part of the year promotes chemical reactions and thereby may accelerate corrosion processes of metallic materials, the degradation of cement mortared materials and various types of protective coatings. The deterioration of materials is further accelerated by the saline atmosphere in the coastal regions.

5.1.2 Soil conditions

Wherever possible excavated trench material should be used instead of having to import material for backfill around a pipe.
Most coarse grained soils are suitable for embedment provided stones larger than 30 mm diameter are not placed in contact with the pipe and larger stones up to 80 mm diameter may not be allowed in the remainder of the embedment.
The best material is a mixture of sandy soil with graded gravel that will compact down into a dense mass.

Examples of unsuitable soils are boulder studded soils, clay, recently backfilled and compacted soils, soils containing organic matter or rubbish and unprepared rock.
The soil and underground conditions for pipelines in the Sultanate of Oman are determined by the local geology and geomorphology and can be described in general as follows:

Mountain region

The mountain range is bare and trench excavation has to be carried out in highly weathered rock material.
In this area backfilling material has to be supplied from elsewhere and the upperpart of the backfilled trenches should be adequately protected to prevent washing out of fine backfill material during heavy rainfall and resulting flood spates.
Where steep slopes exist pipes must be firmly anchored.

Gravel Plain - Batina Coast

Close to the mountain range coarse sediments are deposited resulting in gravel plains consisting of gravel and boulders near the mountain and gradually becoming more sandy.
In areas with coarse gravel and boulders the backfilling material should be supplied from elsewhere and the upperpart of the backfilled trenches should be adequately protected to prevent washing out of backfill material in wadi areas.

Tidal flats

The subkhas and low lying tidal flats are mainly composed of calcium carbonate sediments. In this area the groundwater table can reach the surface and will vary with the sea level. The highly aggressive saline soils of the subkha's and tidal flats require special attention to protect the metallic and cement based pipes. The use of reinforced plastic pipes should be considered because of the excellent corrosion resistant properties of these pipes.
Ballasting of these pipes may be necessary in area with high groundwater level to avoid flotation.

5.1.3 Ductile Iron pipes

Ductile Iron was developed from grey iron by changing the laminated structure of the graphite into a spherical shape. This modification of the graphite form resulted in mechanical properties superior to those of grey iron and its ability to withstand high impact loads without fracturing is one of the major advantages of the use of ductile iron as a pipeline material. The strength and impact resistance of ductile iron is higher than of asbestos cement.
Although proper site supervision is recommended during handling and laying of the pipes, ductile iron is less sensitive to damage than asbestos cement during construction.

Like grey iron, ductile iron has a much higher carbon content than steel, about 3.5-3.8%, and has better anti-corrosion properties than steel. Corrosion of ductile iron, both internal and external, can be prevented by the use of hot or cold applied coatings and linings according to the appropriate standard specifications. Normally ductile iron pipes are provided externally with a bituminous or coaltar epoxy coating. Sometimes an extra zinc coating is applied prior to the bitumen coating.
If the pipes are to be buried in aggressive soils additional protection can be provided by using polyethylene sleeving, which prevents groundwater flow along the outerpipe wall. Sometimes suitable tape wrappings are used.

Due to the construction of the joints with a rubber ring, a ductile iron pipeline has no electrical continuity which means that the pipeline is not affected by stray currents. For drinking water purposes the pipes have an internal cement mortar lining.

Due to the spigot and socket joints the relatively low weight per pipe length and the good mechanical strength, handling and laying

operations are simple. Installation of the pipe joints can easily be done by a backhoe which is used for digging the trench, working at the front end and lowering the pipe in place. The total length of open ditch is usually not more than 3 joints, which facilitates laying lines in congested areas.
For the material specification reference is made to MS-1, Material Specification For Ductile Iron Pipe.

5.1.4 Asbestos-Cement pipes

Asbestos-cement (AC) pipes have been used for many years because the pipes are manufactured locally. AC pipes are subject to external attack from the high levels of sulphate and chlorides in the groundwater. Therefore sulphate resisting portland cement should be used for manufacturing AC pipes.
To improve resistance to sulphate attack manufacturers of AC pipes nowadays recommend the use of an epoxy coating or a P.V.C. tape wrap as external protection. Desalinated water will increase in alkalinity if in contact with AC at the expense of cement in the pipe wall.
This process is continuous and could lead to structural breakdown over a number of years.
For transportation of desalinated water, particularly at higher temperatures, manufacturers of AC pipes do not recommend these pipes unless an epoxy lining is used. Such a lining would need to be acceptable from toxicity and taste aspects and must also bond well to the pipewall.
Protection would also have to extend around the pipe ends up to the sealing ring and inside the joint collars.

It should be noted that moisture is retained within the wall of an asbestos cement pipe for a considerable length of time.
Although normal curing would be complete before an epoxy coating or lining is applied, experience has shown that if an asbestos cement pipe is completely coated and lined in epoxy-type material, any retained moisture in the pipe wall causes blistering of the lining and hence, the lining may peel off.

AC pipes are brittle and may suffer during handling, transportation and construction.
Cracks are easily inflicted and will remain unnoticed until the pressure testing results in the need for remedial work.
In hot climates a gap between the pipe ends must be ensured to prevent cracking because of expansion.
Careful site supervision of transport, handling and laying of the pipes is therefore required. The pipeline structure relies on a good side wall support from the trench backfill and a well compacted bed. Reference is made to the Standard Materials Specification MS-2 for Asbestos Cement Pipe.

5.1.5 Alternative materials

In some cases, due to specific requirements or local circumstances, other materials for pipelines should be considered:

- Mild steel.
  Because of the electrical welding of joints very large diameters can be realised. Severe electrochemical corrosion can occur without suitable protection. Epoxy coating on inside and outside of pipe should therefore be an important consideration.
- Prestressed concrete.
  Suitable for pressure pipes in long transport lines (diameters over 600 mm).
- Glass fibre reinforced plastic (G.R.P.)
  This material has a very high resistance against chemical corrosion. No coating or lining is needed when transporting drinking water. Large diameters are possible. Used in coastal areas, the subkas and tidal flats, close to the coast and below sea level.
- Polyethylene (P.E.)
  Excellent resistance against chemical corrosion, but liable to deterioration when exposed to bright sunshine (UV-radiation). High elasticity, suitable for house connection lines (up to DN 80).

- Polyvinyl chloride (P.V.C.)

  Excellent resistance against chemical corrosion, but becomes more brittle with age. High temperatures and bright sunshine have a bad effect on strength properties.

  Suitable for small diameter inside lines.
- Galvanized iron:

  Heavy duty mild steel with heavy zinc coating.

  Used for house connections.

Pipes must be suitably de-rated to suit the high temperatures prevailing in Oman.

Reference is also made to the relevant Standard Materials Specifications, compiled in Section 8.

5.1.6 Corrosion

Corrosion is defined as the destructive attack of metals by chemical and electro-chemical processes.

Forms of corrosive attack:

- Uniform attack

  Loss of material takes place uniformly over the metal surface, with occasional perforation.
- De-zincification

  The selective corrosion of one element of an alloy leaving a weakened residue.
- Contact corrosion

  Bimetallic corrosion near the junction of two different materials. A galvanic cell is set up.
- Pitting corrosion

  Highly localized pitting and perforation
- Stress corrosion

  Cracking induced at highly stressed areas.
- Crevice corrosion

  Corrosion in crevices, in sockets and under gaskets or washers.

Elements in the water that accelerate corrosion are:

- Dissolved carbon dioxide (influences pH-value, concentration of hydrogen ions).
- Dissolved oxygen
- Dissolved hydrogen sulfide
- High total dissolved solids (electrical conductivity is increased by chlorides for instance).
- Flow velocity (in general corrosion increases with velocity)

Depending on the type of material that is corroded, internal and external influences and type of construction, (pipeline, water reservoirs, water well screen, etc.) several methods of retarding the corrosion process exist:

- cathodic protection (induced current, sacrificial anodes, etc.)
- coatings (bituminous, polyethylene, bandages, epoxy, etc.)
- linings (p.v.c., cement, etc.)
- galvanizing
- the use of alloys and corrosion resistant materials.

As an example, a ductile iron transmission pipeline is considered. The concentration of salts in the ground can be high in the Sultanate of Oman. These salts (sulphates, chlorides) create highly aggressive conditions for ferrous and cement based materials. High ambient temperatures accelerate the corrosion process. A bitumen based coating or wrapping or a polyethylene sleeving is therefore used as an external corrosion protection. The pipe material is thus separated from the electrolyte solution. As an extra protection cathodic protection may be necessary.
The pipe has to be internally protected as well. Tuberculation, which is the deposition of iron components on the pipe due to corrosion, increases the friction of the pipe. An internal cement lining is therefore used, which does not endanger the quality of the potable water.

5.1.7 Recommended pipe materials and diameters

As already outlined in the preceeding paragraphs of this chapter there are a number of governing factors in determining the correct pipe material for a particular pipeline structure.

The final pipe material selection can only be made during the engineering stage of a pipeline project when all these factors are known.

At present asbestos cement pipes are widely used for distribution lines in Oman as these pipes are being manufactured locally, while ductile iron pipes are used for transmission pipelines, pump mains, and in distribution systems for special situations, such as road crossings and rocky areas.

In the pressure ranges usually encountered in distribution systems, AC pipes are lower in costs in comparison with DI pipes.

However the construction costs for AC pipe lines will be higher as extra costs will be incurred in handling the pipes and for the supply of suitable backfill materials, in testing and for special fittings.

Therefore the total costs per meter pipeline in AC are only marginally lower than pipes in DI and thus are not the most important factor for the choice of pipeline material.

In comparison with asbestos cement pipes, ductile iron pipes can withstand higher impact loads and are stronger, due to the superior material properties of ductile iron.

Therefore, although proper supervision is required during handling and laying of pipes, ductile iron pipes are much less susceptible to damage than AC pipes to damage, during construction and/or failure during testing.

For pipelines in wadis and areas where the underground consists of cements of coarse gravel and rock material, and in roadcrossings, the use of ductile iron is preferable.

In sandy areas and wherever soil conditions permit, asbestos cement pipes can be used for construction of distribution networks.

As per M.E.W. requirement the following shall be strictly complied with pipematerials to be used for:

- Transmission pipelines : Ductile iron as per Material Specification MS-1 (K9, polyethylene sleeves wrapped)
- Distribution pipelines : Asbestos cement as per MS-2 (class 18) or ductile iron as above
- All road and wadi crossings and in rocky areas : Ductile iron as above

Diameters to be used: 100-150-200-300-400-500-600-800-1000-1200 mm.

5.2 Hydraulic calculation

5.2.1 Basic equations

The most useful of basic equations is Bernoulli's equation:

$$p + \rho.g.z. + \tfrac{1}{2}\rho\, v^2 = \text{constant}$$

where

p = pressure (N/m^2)
ρ = mass density of liquid (kg/m^3)
g = gravitational constant (m/s^2)
z = height above datum line (m)
v = mean velocity of flow (m/s)

The limitation of the equation are:

- water flow is a steady flow along a streamline
- there is no energy lost through friction

In reality however a certain energy loss due to friction, h_f, will occur, and the equation now becomes (see Figure 5.1):

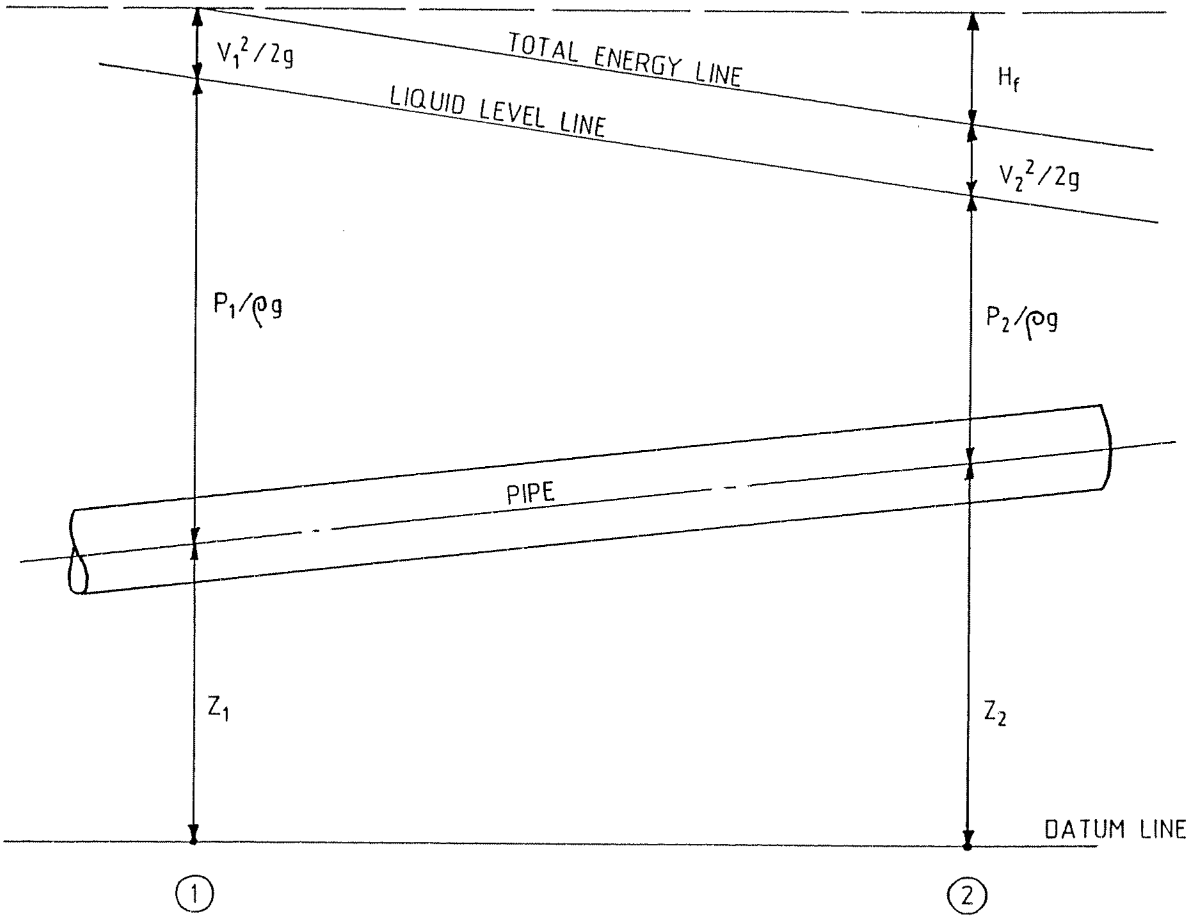


FIG 5.1 HYDRAULIC GRADIENT

$$\frac{p_1}{\rho g} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + z_2 + \frac{v_2^2}{2g} + h_f \quad \text{(m)}$$

where

$v^2/2g$ = the velocity head (kinetic energy of movement)

z = the elevation head (the position energy above some given datum line in a gravitational field)

$p/\rho g$ = the pressure head.

The velocity of flow, v, is the mean velocity. In a pipeline, which is not partially empty its value equals Q/A, which is the discharge (m^3/s) divided by the cross sectional area of the pipe bore (m^2).

The modified equation of Bernoulli can be used for flow in pipelines which are not partially empty. If the pipeline has a uniform diameter throughout the length considered, then v1 = v2 and the kinetic energy term is constant.

The equation reduces to:

$$\frac{p1}{\rho g} + z_1 = \frac{p2}{\rho g} + z_2 + h_f$$

If, furthermore, the pipeline has the same level at point 1 and at point 2 then:

$$\frac{p1}{\rho g} - \frac{p2}{\rho g} = h_f$$

This means that the pressure lost in a straight pipe is equal to the energy lost through friction.

The total loss of head during transportation in a pipeline system is a summation of the following losses:

1. friction losses (f)
2. entrance losses (α1)
3. losses in bends and curves (α2)
4. losses resulting from diameter changes (α 3)
5. losses in valves (α 4)
6. exit losses (α 5).

These losses are proportional to the velocity head $v^2/2g$.

The total loss of head, H, equals:

$$H = (f \cdot \frac{L}{D} + \alpha 1 + \alpha 2 + \alpha 3 + \alpha 4 + \alpha 5) \cdot \frac{v^2}{2g}$$

5.2.2 Darcy-Weisbach equation

The Darcy-Weisbach equation is an expression for the head loss by friction when water flows through a circular pipe. The expression is dimensionally correct as opposed to the empirical formulae which will be discussed in paragraph 5.2.3. The latter type of formula has a lesser accuracy.

$$h_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g}$$

where

h_f = friction loss in metres head of water (m.w.c.)
f = friction factor (dimensionless)
L = length of pipe (m)
D = internal diameter of pipe (m)
v = mean velocity of flow (m/s)
g = gravitational constant (m/s^2)

The friction factor f is dependent on the type of flow, assessed by the Reynolds number (Re), upon the roughness of the interior surface of the pipe or wall-roughness (k), and upon the diameter of pipe (D).
One of the expressions for the determination of the friction factor is the Colebrook expression:

$$(f)^{\frac{1}{2}} = \frac{0.5}{\log \left(\frac{1}{0.4 \; Re \; (f)^{\frac{1}{2}}} + \frac{k}{3.7D}\right)}$$

where

Re = Reynolds number (-)

k = Wall roughness coefficient (m)

The Reynolds number indicates the type of flow, which can be a laminar or smooth type of flow ($Re < 2000$), a turbulent flow ($Re > 4000$), or a transitional type of flow ($Re = 2000-4000$).
For circular pipes which are completely filled, the Reynolds number equals:

$$Re = \frac{v \cdot D}{\upsilon}$$

where

v = mean velocity of flow (m/s)

D = internal diameter of pipe (m)

υ = kinematic viscosity (m^2/s)

Through the kinematic viscosity the Reynolds number is dependent upon the temperature. Figure 5.2 shows the friction factor being dependent upon the Reynolds number and the relative wall-roughness.
The roughness coefficient of several pipe materials is shown in Table 5.1. When using a formula the determination of the friction factor can only be done by iteration because of the Colebrook expression being an implicit expression. As a first estimation of f a value of 0.025 is taken.

In practice two first-estimate values of the roughness coefficient k are used:

1. Smooth non-corroding piping with scaling unlikely, e.g. plastic, asbestos cement, centrifuged cement: theoretical value for materials in new condition, k = 0,03 mm. In practice k = 0,1 mm.

2. Corrodible piping and probable scaling:
   Piping carrying water which is relatively aggressive or corrosive, scale producing, or turbid, k = 2 mm.
   Non-aggressive, non scale forming, k = 1 mm.

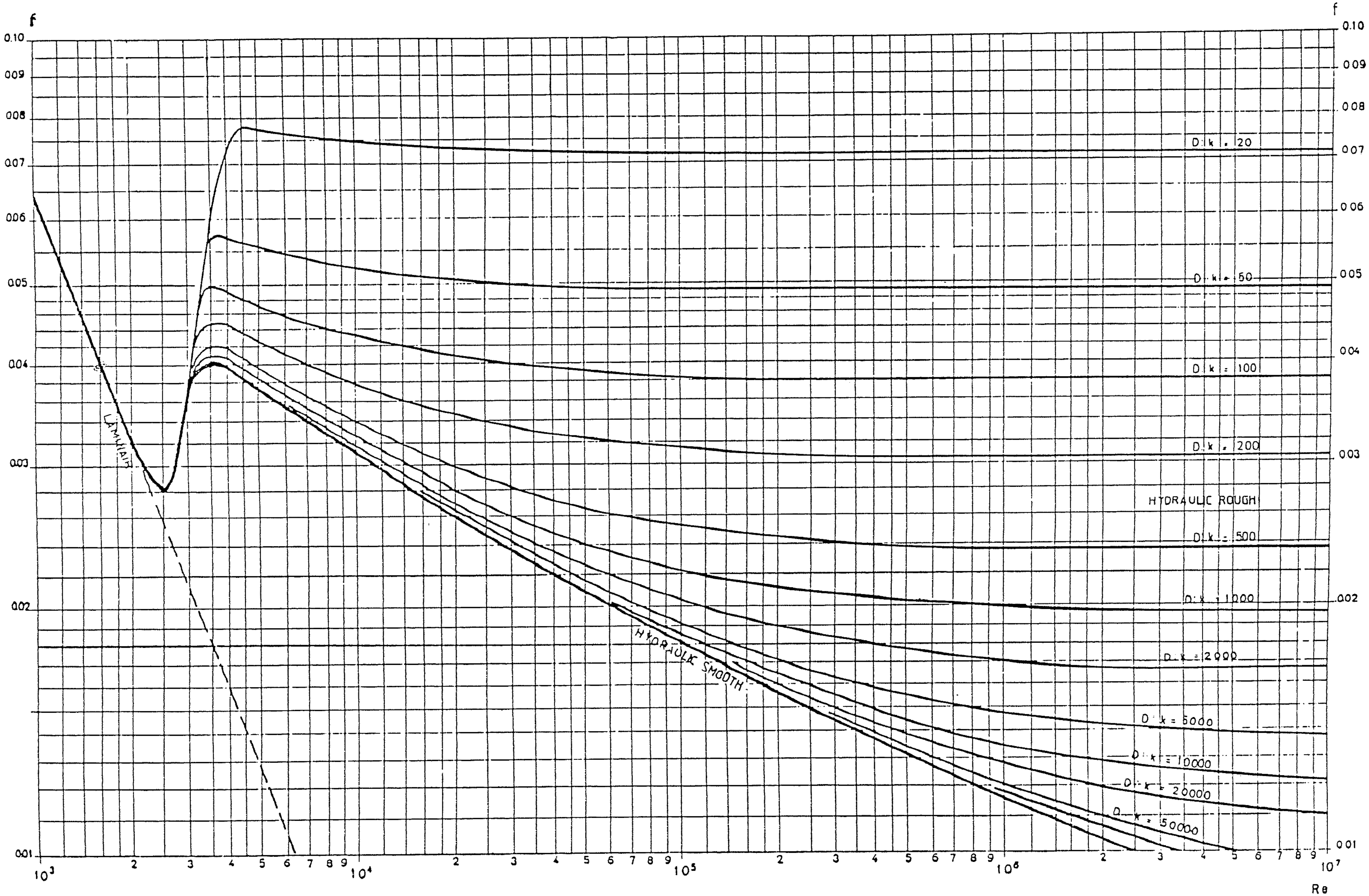


FIG. 5.2 FRICTIONFACTOR f

TABLE 5.1 ROUGHNESS COEFFICIENT k

Nature of wall	k
Drawn tubing of copper, lead, small diameter p.v.c. pipe, asphalted astbestos cement, centrifugal asphalted centrifugal cast iron	0.01 mm
p.v.c. lining, smooth asbestos cement	0.02 mm
new welded steel pipe, large diameter p.v.c. pipe, asphalted centrifugal cast iron	0.05 mm
Asbestos cement pipe, asphalted cast iron, G.R.P. pipe	0.1 mm
Slightly corroded steel pipe, new centrifugal cast iron	0.2 mm
Moderately corroded steel pipe, centrifugal concrete pipe, new cast iron, smooth concrete	0.5 mm
Concrete, heavily corroded steel pipe, slightly corroded cast iron	1 mm
Rough concrete, heavily corroded cast iron	2 mm

A first estimation of the head loss by friction can be obtained using Table 5.2. In this table values are given of the f/D ratio, being the friction factor divided by the pipe diameter. The values can be substituted in the Darcy-Weisbach formula:

$$h_f = \frac{f}{D} \cdot L\frac{v^2}{2g}$$

TABLE 5.2: COEFFICIENT $\frac{f}{D}$

Diameter (mm)	k = 0.1 mm	k = 0.5 mm	k = 1.0 mm	k = 2.0 mm
50	0.528	0.78	0.985	1.30
80	0.290	0.413	0.512	0.660
100	0.222	0.310	0.380	0.490
150	0.133	0.182	0.223	0.280
200	0.0935	0.128	0.153	0.190
250	0.0710	0.096	0.114	0.141
300	0.0573	0.076	0.090	0.110
400	0.0400	0.0530	0.0625	0.0758
500	0.0308	0.040	0.047	0.0566
600	0.0245	0.0322	0.0371	0.0477
800	0.0175	0.0225	0.0260	0.0477
1000	0.0134	0.0170	0.0197	0.0234
range of velocities	1-3 m/s	1-3 m/s	1 m/s	0.5 m/s

Tables in handbooks or manuals in which friction losses are given (in order to avoid calculations) must be carefully interpreted. Most of these tables consider a water temperature of 0°C. The water to be distributed in Oman has a temperature of 40°C or more. Both viscosity and density of water are dependent upon the temperature.

To illustrate the influence of the temperature a calculation is made of the pressure drop caused by friction losses over the full length of a pipeline of 10,000 metres, the flow velocity being 1 m/s, at two diameters (100 and 400 mm), two roughness coefficients (0.1 and 1.0 mm), and three different temperatures (0°C, 40°C, 50°C) causing three different values of the viscosity (1.787, 0.653 and 0.547 mPa.s). The results are given in Table 5.3.

TABLE 5.3: <u>PRESSURE DROP IN m.w.c. (percentage)</u>

For a pipelength of 10,000 m, and a flow velocity of 1 m/s.

	0°C	40°C	50°C
1. Diameter 400 mm Roughness 1 mm	32.3 (100)	31.7 (98)	31.7 (98)
2. Diameter 400 mm Roughness 0.1 mm	21.7 (100)	19.8 (91)	19.5 (90)
3. Diameter 100 mm Roughness 1 mm	201.2 (100)	197.7 (98)	197.4 (98)
4. Diameter 100 mm Roughness 0.1 mm	122.1 (100)	111.4 (91)	110.4 (90)

The Darcy-Weisbach formule can be rewritten into an exponential form:

$$v = C \cdot R^n \cdot J^m$$

using

$J = h_f/L$ (hydraulic gradiënt)

R = wetted section/wetted perimeter (hydraulic radius)

the formula is transformed into:

$$J = f \cdot \frac{1}{4R} \cdot \frac{v^2}{2g}$$

or $v = C \cdot R^{\frac{1}{2}} \cdot J^{\frac{1}{2}}$, with $C = \left(\frac{8g}{f}\right)^{\frac{1}{2}}$

known as the Chezy formula.

5.2.3 Empirical formulae

Several empirical expressions exist to determine the friction loss. This type of expression is more convenient to handle, though less accurate

5.2.3.1 Hazen-Williams formula

$$h_f = \frac{6.78 \ L}{D^{1.165}} \left(\frac{v}{C}\right)^{1.85}$$

or more convenient:

$$v = 0.85 \ . \ C \ . \ R^{0.63} \ . \ J^{0.54}$$

Some values of the coefficient C in the Hazen-Williams formula are given in Figure 5.3 and in Table 5.4.
This formula is easy to handle and has been in use for many years. It is sufficiently accurate for pipe sizes of 150 mm upward, and for values of C not substantially below 100.

TABLE 5.4: VALUES OF THE HAZEN WILLIAMS COEFFICIENT C FOR VARIOUS KINDS OF PIPE

Kind of pipe	C
Cast iron, new	130
Cast iron, old	100
Cast iron, centrifugally lined with cement or bituminous enamel	140
Steel, welded, lined with cement or bituminous enamel	140
Steel, riveted, coated with coal tar	110
Asbestos cement	140
Concrete	120
Wood stave	120

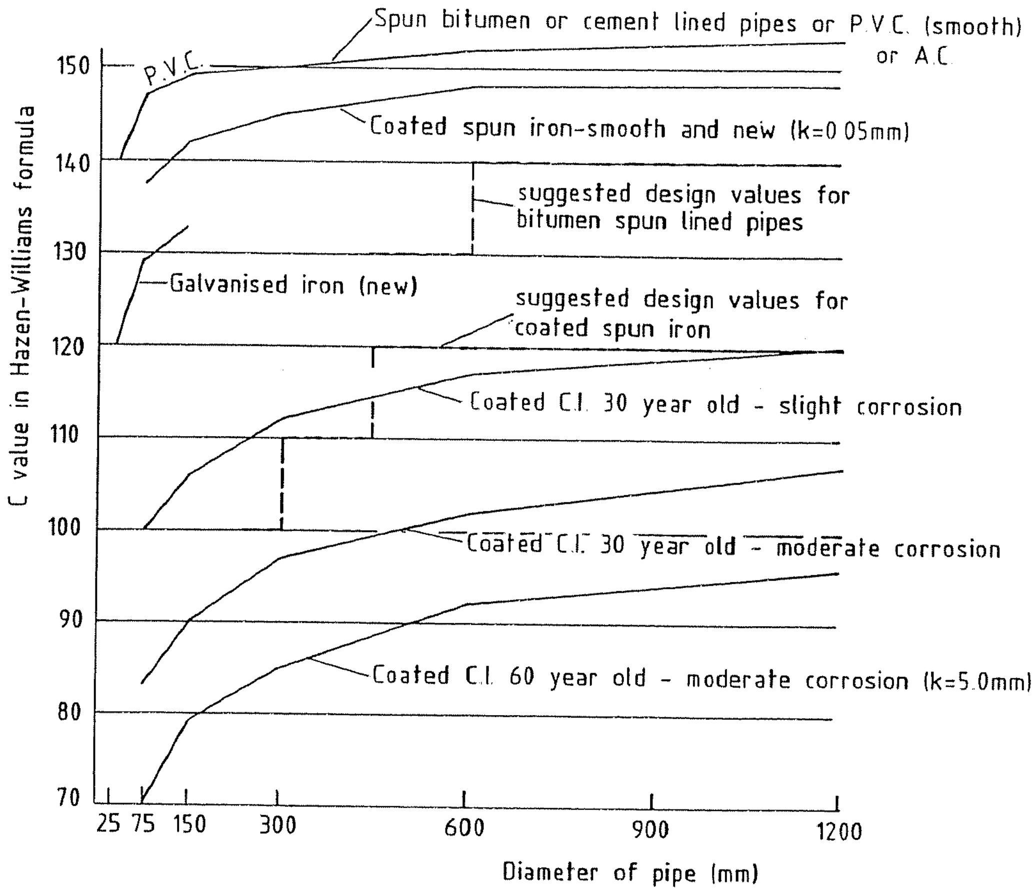


FIG. 5.3 C VALUES IN HAZEN WILLIAMS FORMULA

5.2.3.2 Manning's formula

$$h_f = \frac{n^2}{0.397^2} \cdot \frac{L}{D^{4/3}} \cdot v^2$$

or

$$v = \frac{1.588}{n} \cdot R^{2/3} \cdot J^{1/2}$$

Some values of Manning's coefficient n are set out in Table 5.5. The Manning formula has the advantage that H is proportional to v^2, the coefficient n being constant for a given type of pipe. Since the friction loss caused by fittings is usually expressed as $\alpha \cdot v^2$, this formula is used for lengths of pipelines involving many fittings. Also where the Hazen Williams formula is less accurate, e.g. where high flows are estimated ($v \gg 1$ m/s) and where flows in old rough surfaced pipes ($C < 100$) are concerned.

TABLE 5.5: VALUES OF MANNING'S n FOR VARIOUS TYPES OF PIPE SURFACES

Smooth metallic	0.010
Large welded steel pipes with coal-tar lining	0.011
Smooth concrete or small steel pipes	0.012
Riveted steel or flush-jointed brick	0.015 to 0.017
Rough concrete	0.017
Rubble (fairly regular)	0.020
Old rough or tuberculated C.I. pipes	0.020 to 0.035

5.2.3.3 Head loss through fittings and valves

The head losses due to the flow through bends, tees, entrances, sudden enlargements, sudden contractions, valves etc. are generally expressed as

$$h_f = \alpha \cdot \frac{v^2}{2g}$$

The value of α for various types of obstacles is given in Table 5.6

TABLE 5.4: FRICTION LOSS FACTOR α

Friction loss through constrictions in pipelines. Factor according to: $H = \alpha \cdot v^2/2g$.
The factor is dependent on the Reynolds number and in case of turbulent flow also on the roughness of the material. For smooth surfaces and a turbulent flow some theoretical values of the friction factor are given in this table.

		theoretical value of α	
1.	Entrances/exits		
	Standard bellmouth pipe	0.05	
	Pipe protuding, Borda entrance	1.0	
	Ordinary entrance	0.5	
	Gradual exit	0.15 - 0.75	
2.	Bends		
	r/D	45°	90°
	1	0.14	0.29
	2	0.09	0.14
	3	0.09	0.13
	4	0.08	0.11
3.	Tees; 90°, equal diameters		
	in line flow	0.35	
	branch to line or reverse	1.20	
4.	Sudden enlargements $H = 0.051\ (v_1 - v_2)^2$		
	D2/D1		
	4/3	0.20 (v1)	
	1.5	0.35 (v1)	
	2	0.60 (v1)	
	5	1.00 (v1)	
5.	Sudden contractions		
	D2/D1		
	2/3	0.30 (v1)	
	0.5	0.35 (v1)	
	0.2	0.50 (v1)	
6.	Valves		
	Gate valve fully open	0.17-0.25	
	Butterfly valve open	0.20	
	Swing check valve	0.8 -2.5	
	Nozzle type check valve	0.16-0.23	

5.3 Design of water transmission pipelines

5.3.1 Routing

The ensure sufficient accessibility a transmission pipeline should be located next to a road, following the shortest route between two points. The depth of the pipeline should be chosen in such way that the slope of the pipeline is as constant as possible. Minimum cover over crown on pipe: 0,9 m.

It is desirable to allocate in urban areas corridors for different services, such as water, sewerage, electricity, telephone, gas, etc. The minimum distances between the various service pipelines are governed by size of valve chamber, thrust blocks, anchoring, etc.

5.3.2 Economic diameter

Water transmission lines are necessary for the transportation of raw water from the source to the location of treatment, or for the transportation of treated water to the distribution area. The first type can be constructed as open channel or as closed pipeline.
For the transportation of treated water a closed pipeline is necessary.

In open channels flow velocities in the range of 0.2 to 0.5 m/s are used, whilst the head loss due to friction approximately equals 0.1 m per 1000 m. In closed pipelines flow velocities between 0.5 and 3 m/s are used, whilst the value of friction loss is between 1 and 5 per 1000 m.

Friction losses are proportional to the square of the flow velocity. An economical velocity must therefore be chosen for each line.
Recommended flow velocities are given below:

- drinking water, transmission lines	up to 3 m/s
- drinking water, main lines	1-2 m/s
- drinking water, local nets	0.5-0.8 m/s
- feed water suction mains	0.5-1 m/s
- feed water delivery mains	1.5-3 m/s.

When designing the size of a transmission pipeline parameters such as: total length, static pumphead, quantity of water to be conveyed are known. Only the internal diameter (DN) of the pipe is still to be decided. This diameter must be chosen on economic grounds.

An economic evaluation has to be done concerning the sum of the following costs (see Figure 5.4):

- Pipe material purchase costs
- Laying and maintenance costs
- Energy costs, e.g. operating costs of the pumps for the compensation of friction losses.

The transmission pipeline shall be designed for summer average demand, assuming that pumping is done for 16 hrs per day.

5.3.3 Valves

The valves that are necessary in transmission pipelines, such as isolating valves, air valves, and wash-outs, are discussed in paragraph 7.4.

5.3.4 Thrust blocks

A pipeline must be protected against movement caused by water thrust, produced whenever there is a change of direction of the pipeline, at bends, tees, end plugs, etc. This protection can be achieved by means of appropriate concrete anchor blocks placed between the solid ground and the fitting to be anchored.
The anchor blocks must be designed to withstand the thrust force, either by bearing on the side of the trench if the soil is sufficiently resistant or by their own weight.

The thrust force can be calculated using the following formulae (see Figure 5.5).

bends : $T = 2\ P \times S \sin(\alpha/2)$

where

T = thrust force in Newton (N)

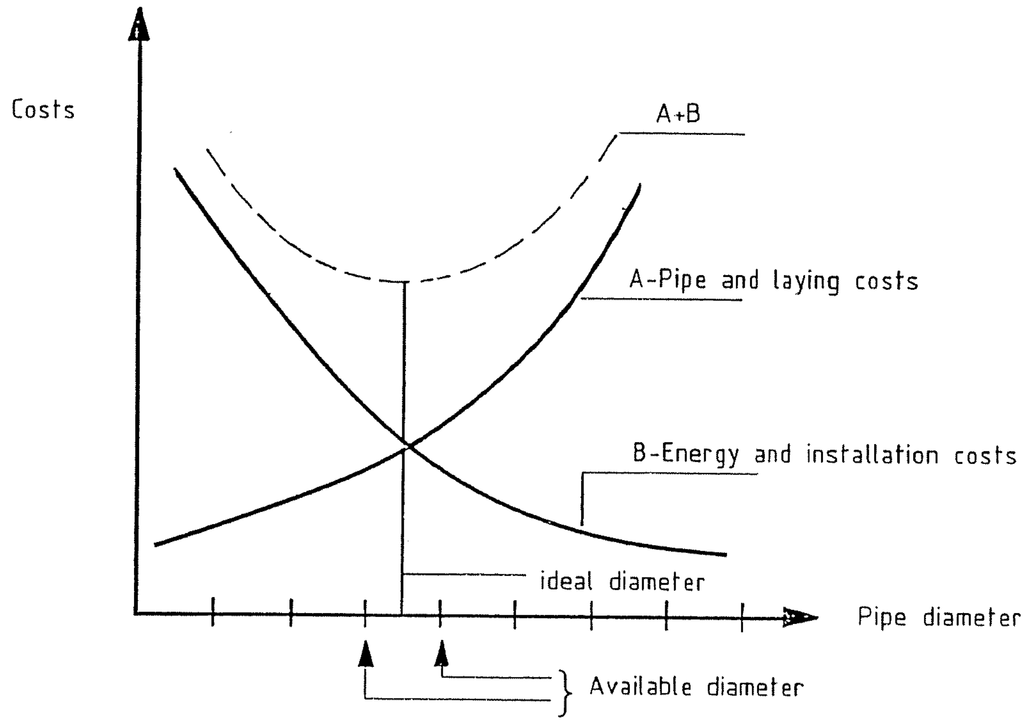
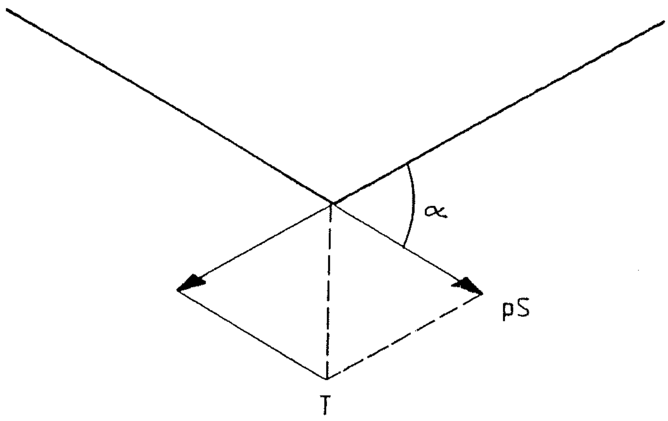


FIG. 5.4 OPTIMIZATION OF PIPE DIAMETER



Thrust T = $2\ pS.\sin \frac{\alpha}{2}$ in which

p = hydraulic test pressure

s = cross sectional area of the pipe

α = angle of the bend

Horizontal reaction force concrete block/soil

U = $\overline{\sigma_b}$. M, in which

$\overline{\sigma_b}$ = allowable horizontal soil pressure

M = area of vertical contact surface of concrete block/soil

Friction concrete block/soil

V = β N, in which

β = friction factor concrete/soil

N = weight concrete block

U + V shall be greater than T

FIGURE 5. 5 - THRUST BLOCK CALCULATION

P = hydraulic (test)pressure in Pa (N/m^2)
S = cross sectional area of pipe (m^2)
α = angle of the bend

tees : T = P x S
reducers : T = P (S1 - S2)

The area of the thrust block (A) required to sustain the thrust force (T) is to be related to the safe bearing capacity (ϕ) of the soil concerned: $A > \frac{T}{\phi}$
When the pipeline lies in a horizontal plane the thrust force is sustained by the horizontal soil pressure together with the friction between the concrete block and the soil.
Standards for anchors and thrust blocks are shown in the Standard Drawings Album.

5.3.5 Waterhammer

When there is a sudden change in flow velocity in a closed line, e.g. when a valve is suddenly closed or opened, or when pumps are switched on or off, a pressure surge will occur.
This phenomena is called waterhammer.

The velocity of the pressure wave can be determined from the formula:

$$c = \left(\frac{1}{\rho(\frac{1}{K} + \frac{D}{t.E})} \right)^{\frac{1}{2}}$$

where
c = velocity of the pressure wave (m/sec)
ρ = density of the fluid (kg/m^3); water: ρ = 1000
K = modulus of compression of the fluid (N/m^2)
K water = $2.03.10^9$ N/m^2
D = inside pipe diameter (m)

t = pipe wall thickness (m)

E = modulus of elasticity of pipe wall material (N/m^2)

TABLE 5.7: MODULUS OF ELASTICITY OF PIPE MATERIALS

E steel	$= 2{,}1.10^{11}$	N/m^2
E ductile iron	$= 1{,}05.10^{11}$	N/m^2
E AC	$= 0{,}20.10^{11}$	N/m^2
E copper	$= 1{,}15.10^{11}$	N/m^2
E p.v.c.	$= 3{,}10^{9}$	N/m^2
E p.e.	$= 1{,}2.10^{8}$	N/m^2

When closing a "quick" closing type of valve, the maximum pressure rise, or head rise, can be determined from:

$$H = \frac{c}{g} \cdot \Delta v \qquad \text{(Joukowsky equation)}$$

where

H = pressure rise (m.w.c.)

c = velocity of pressure wave (m/sec.)

g = gravitational constant (m/sec^2)

Δv = change in velocity (m/sec)

This formula can only be used when the closing time of the valve is shorter than the reflection time of the wave: $t = \frac{2.l}{c}$

The reflection time of the wave is the time necessary for the pressure wave to reach the point where the wave is reflected, e.g. a free water surface, plus the time necessary to return to the closed valve.

When a closing time is longer than the reflection time the maximum head rise will be less.

Waterhammer protection

Although some pipe materials are able to resist certain values of waterhammer surges it is usually more economic to provide the pipe system with waterhammer protection devices or take measures to avoid waterhammer.

Quick closing valves can cause waterhammer. The use of slow closing valves is therefore advisable.

Due to inertia, a pump will continue to rotate after a power failure. The rotational inertia of pump and motor reduces the waterhammer pressure.

A bypass reflux valve is a simple device for waterhammer protection. When pump failure occurs and negative pressure is built up at the discharge side of the pumps, the reflux valve, installed in parallel with the pump, will open allowing water from the source (a suction reservoir) and dissipates the negative pressure.

If the above mentioned measures are not sufficient to prevent unallowable pressure surges, other devices must be applied, such as discharge tanks, air vessels, in-line reflux valves or surge relief valves (see Figure 5.6).

5.4 Pipeline construction guidelines

In this paragraph an example is given of specifications for pipeline construction. These specifications may be used for water supply projects in rural as well as in the Capital Area.

5.4.1 Excavation of trenches and pits

General

Excavation for trenches shall be carried out for a maximum of four lengths in advance of the pipe laying (not exceeding 1 kilometer) or as determined by the Engineer.

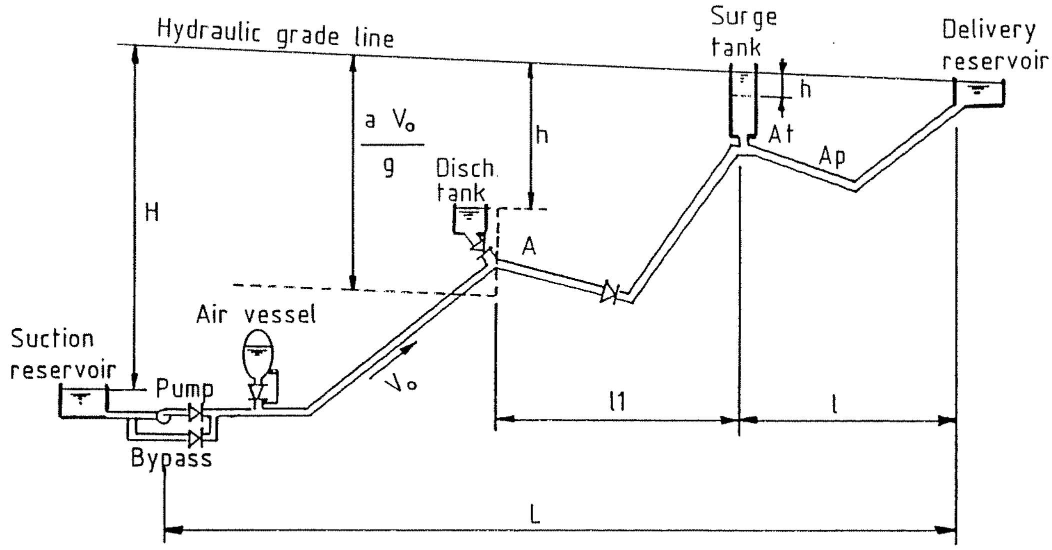


FIG. 5.6 WATERHAMMER PROTECTION DEVICES

The trenches shall be excavated to the required line and level as shown on the approved working drawings or as especially approved by the Engineer, and shall at all times be drained and braced to ensure safe and efficient pipe laying.
In locations, where services, ruins of historical value or other structures are near the pipeline route, only hand excavation will be permitted.

Depth

All pipes shall have a cover of not less than 0.90 m, or as shown on the drawings, measured from the top of the pipe to the finished ground level except where the pipe must be lifted or lowered when crossings other services. In such instances the pipes shall be encased in concrete.
Where trenches are required to be deeper than the general depth mentioned above, the Contractor shall dig the trench to this required depth with a gradual slope necessary for the proper laying of the pipelines.
Pipelines shall in no case be closer than 300 mm to other pipelines, services or structures. Desirable spacing is 1000 mm, especially for larger diameter pipelines.

Width

The width of the trench is dependent on the nature of the ground, depth and pipe size. The clear width of the trench at any level shall be minimum of one pipe diameter plus 400 mm clearance on either side (see Figure 5.7 and 5.8 for reservations for pipelines).
In all cases the trench shall be excavated sufficiently to ensure efficient laying and jointing of the pipes.

Rock excavation

Excavation in rock shall be made to provide a minimum of 150 mm clearance on each side of and below all pipes or fittings.
Excavations below grade shall be backfilled to grade with approved material and thoroughly compacted.

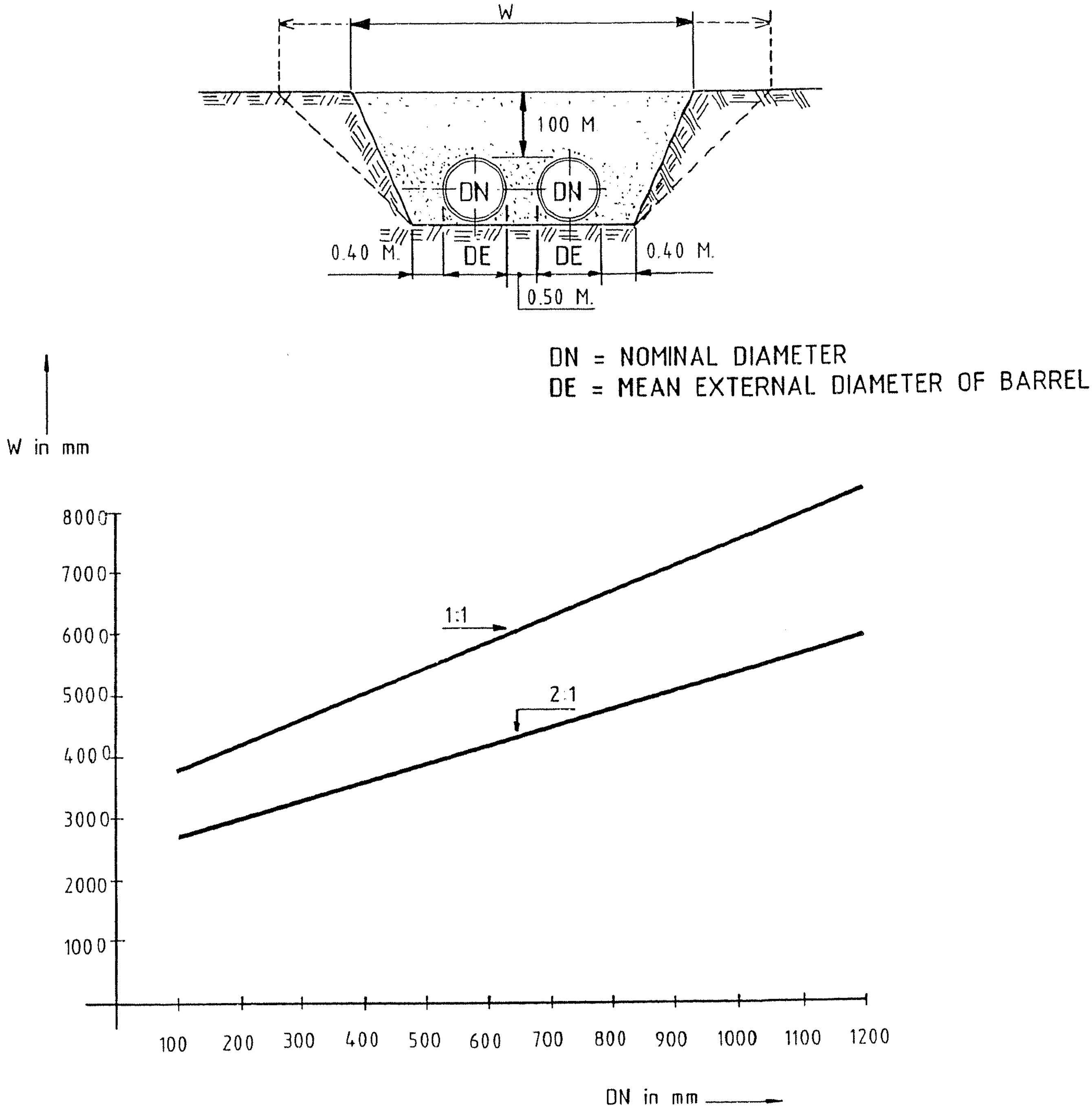
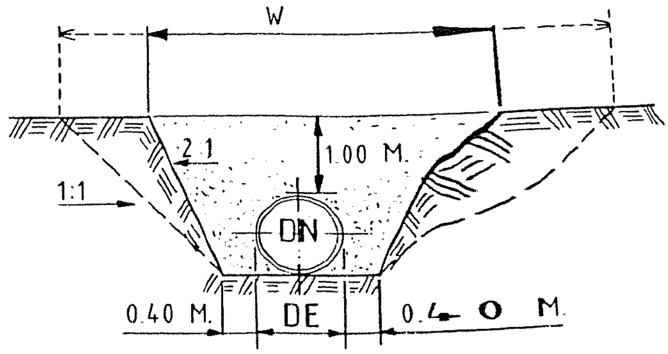


FIG. 5.8 RESERVATION FOR DOUBLE PIPELINES
(OF SAME DIAMETER)



DN = NOMINAL DIAMETER
DE = MEAN EXTERNAL DIAMETER OF BA

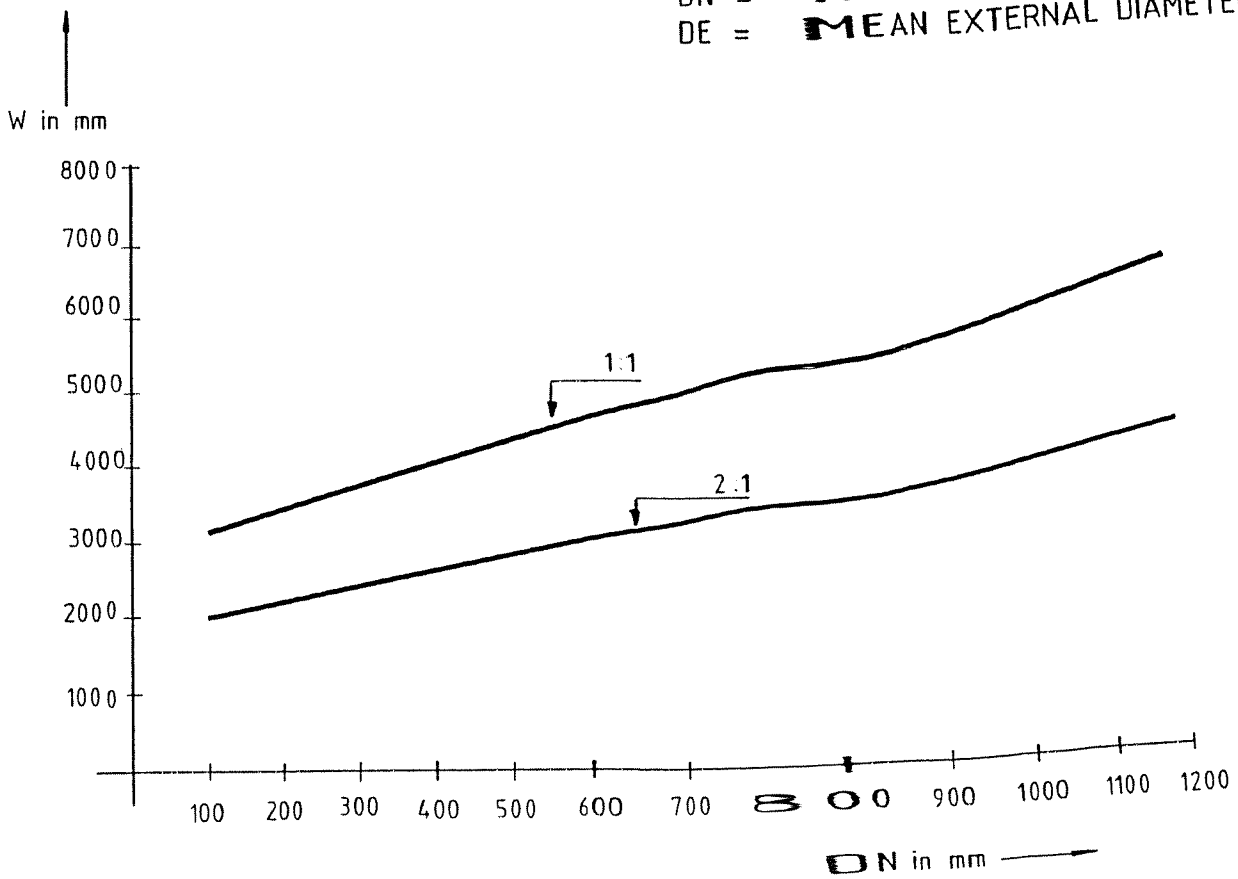


FIG. 5.7 RESERVATION FOR SINGLE PIPELINE

In the events of the use of explosives being permitted, the Contractor shall comply with the requirements of, and give at least 48 hours notice of blasting to all relevant authorities and the Engineer.

Pipeline bedding

If the material in the trench bottom is considered unsuitable by the Engineer to be used as bedding material, it shall be removed and replaced to a depth of at least 150 mm beneath the bottom of the pipe. The bottom of the trench shall then be lined with a layer of suitable approved bedding material to the level required.
Materials generally considered as unsuitable are rock, boulder studded soils, soil high in organic content and clay.

Wet trench

The Contractor shall include in his price for excavation the provision for removing all water from his excavations and he shall provide all the plant and labour necessary for the efficient drainage of the Works.

Methods of excavation

Wherever practical, mechanical excavation methods are to be used, except where such methods may cause damage to existing structures, services or historical ruins. In these locations, the Contractor may only use hand excavation. The Engineer shall decide whether and where hand excavation required.
Where shoring is used to stabilize excavation, the shoring shall be removed progressively to ensure that adequate backfilling is carried out without leaving voids.
All excavated material shall be so placed as to avoid any danger or hindrance to others.

5.4.2 Pipe laying and construction

In general D.I. pipes shall be laid according to approved standards, A.C. pipelines shall be laid according ISO 4483 standard latest issue.

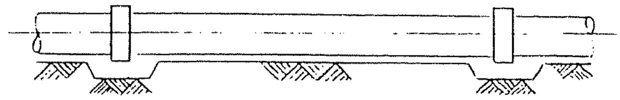
Laying

Before the pipe is lowered into the trench, the suitability of the material in the bottom of the trench shall be inspected and approved by the Engineer and bedding for pipes shall be constructed as previously described.
Additional excavations will have to be carried out to provide extra space around couplings. These coupling pits shall be large enough to allow unhindered jointing of the whole lengths, see Figure 5.9.

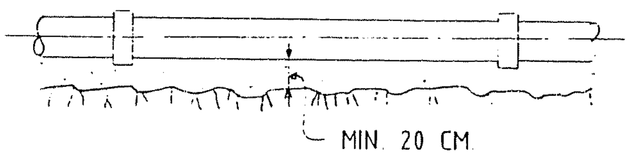
All pipes shall be laid and maintained to the agreed alignments and grades ensuring that the pipe is properly bedded along its whole length. Where ground conditions are suitable for pipe laying, the pipeline is to be laid on undisturbed soil. Fittings and valves shall be at the required locations. No deviation shall be made from the agreed alignment or grade except with the written consent of the Engineer. The maximum allowable deviation angle in horizontal and vertical planes for DI and AC pipes is about 2-5 degrees, see Table 5.8.

Temporary support, adequate protection and maintenance of all underground and surface utilities encountered during construction of the Works shall be furnished by the Contractor.

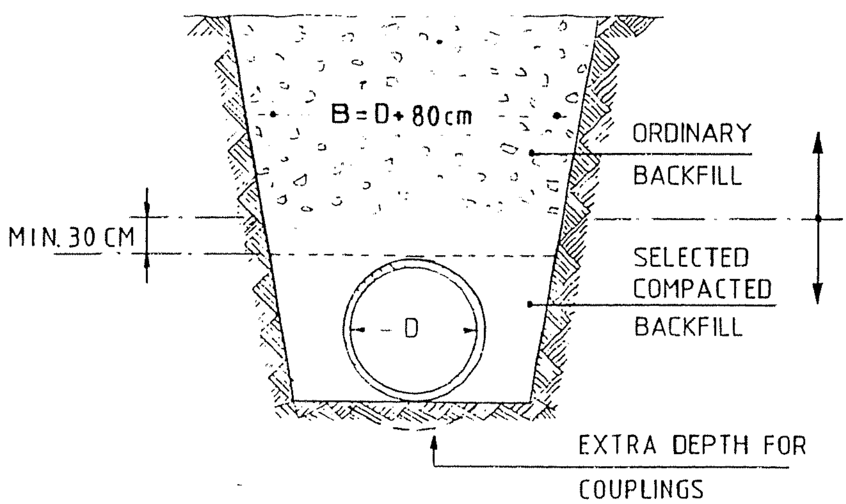
Where the grade or alignment of the pipe is obstructed by existing utilities, such as conduits, ducts, pipes, branch connections, etc., the obstructions shall be supported, relocated, removed or reconstructed by the Contractor, at his own cost, unless otherwise provided to be paid for separately.



ORDINARY LAYING



LAYING PIPES ON A ROCKY BOTTOM



BACKFILLING

FIG. 5.9 INSTALLATION OF PIPES

TABLE 5.8: MAXIMUM ALLOWABLE DEVIATION ANGLE

"Reka"-Coupling for A.C. Pipes

DN	Angular Deflection α	Radius of Curvature (m) L = 3 m	Radius of Curvature (m) L = 5 m
80- 250	5°	34.4	57.3
300- 350	4°	43.0	71.6
400- 600	3°	57.3	95.5
700-1200	2°	85.9	143.2
1300	1°	171.9	286.5

Spigot-socket joint, D.I. pipes

DN	Angular Deflection α	Radius of Curvature (m) L = 6 m
100- 150	5°	68.8
200- 300	4°	86.0
350- 500	3°	114.6
600- 700	2°	171.9
800-1200	1°30'	229.2

Whenever necessary to determine the location of existing underground utilities, the Contractor, after an examination of available records, shall make all explorations and excavations as may be directed by the Engineer to determine these locations.
Only such tools and equipment as have been approved by the Engineer shall be used by the Contractor to execute his work in a safe and efficient manner.
It is the Contractor's responsibility to ensure that the pipeline is clear and free of all foreign matter at all times. All open ends of pipes shall be suitably blanked at the end of each day's work to

prevent ingress of foreign material in the pipeline. Until taken over by the Owner sufficient backfill shall be placed on the pipe to prevent any floatation. Any pipe that has floated shall be removed from the trench and relaid as directed by the Engineer. Trench sections of completed pipelines shall be partially backfilled, as soon as possible to avoid pipeline floatation, leaving joints open.
Completed sections of the pipe shall then be closed by means of blank flanges or inflatable balls and filled with clean fresh water.

5.4.3 Backfilling

Trench sections of completed pipelines shall be backfilled as soon as possible to avoid pipeline flotation. Completed sections of the pipe shall then be closed by means of blank flanges or inflatable balls. Backfilling shall be done in two stages I the first stage of back-filling leaving joints open for testing procedures, and the second stage after succesful testing.
Approved backfill material free from clay, boulders or stones larger than 25 mm, and other unacceptable material shall be compacted around the pipe up to 30 cm above the top of pipe in layers of not more than 15 cm (see Figure 5.9).

The material shall be made damp if necessary to attain adequate compaction around and under the pipes and fitting.
The balance of the backfill to the final ground level shall contain no stones more than 150 mm in their largest dimension and shall not contain more than 25 percent of stones.
The trenches or other excavations shall only be backfilled using approved fill, and shall not be used for dumping unwanted, exca-vated material which should be disposed off from the site as direc-ted by the Engineer.
Any depressions caused by settlements due to trench excavations and backfilling shall be made good by the Contractor using appro-ved fill material.

5.4.4 Road and Wadi crossings

Pipelines under existing roads

The Contractor shall programme the Works to minimize disruption to road traffic and before any work commences in existing roads shall:

(i) Obtain the full permission and approval of all Authorities concerned serving notices of intent to start work as may be necessary and observing all the local Laws and Regulations.

(ii) Submit details of his proposals, and obtain approval from the Engineer.

Pipelines shall cross roads at the angles shown on the drawings.

The bedding and jointing shall be as specified but the first stage of trench re-filling shall be carried out using granular bedding material and compacted at the sides of the pipes to not less than 95% of the modified Proctor maximum dry density as specified in BS 1377, Test 13. Above this layer concrete Grade 15 shall be placed to bring the level of the backfilling up to the underside of the road sub-base. This method of backfilling shall extend at least 5 m either side of the surfaced road carriageway.
The roadway shall be reinstated using the form of construction and materials as ordered by the relevant Authority.

The replacement of the road structure shall be carried out as soon as practicable after backfilling has been completed. Suitable excavated road pavement which complies with the requirements of the Engineer may be used at the sub-base levels. Compaction shall be carried out with approved mechanical compacting equipment.

The edges of the trench shall be cut to a uniform line consistent with the varying width of the trench and the agreed trimming allowances. Any part of the structure of the road which has been damaged beyond the width of the trench must be cut out and made good. The Engineer's prior agreement for such additional work shall have been obtained before payment can be considered.

A vertical joint shall be formed between the new work and the existing road surface and shall be painted with hot bitumen or as approved by the Engineer and the base course and wearing course stepped 75 mm.

The finished levels of the completed reinstatement shall conform with the adjoining carriageway surface.

Reinstatement of wearing courses shall match as nearly as practicable the colour or other characteristics of the existing surface.

Where the carriageway surface adjoining the trench is of rolled asphalt the Contractor shall lay an interim wearing course of bitumen macadam 40 mm thick. At a later date, to be decided by the Engineer, the temporary wearing course may be removed and replaced with 40 mm of rolled asphalt.

Crossings through existing ducts/culverts

Where ducts/culverts have been installed by the responsible Authority, the Contractor shall inform himself about the availability and exact location of mentioned ducts. For the construction of these crossings the pipes, shall be pulled or pushed through the ducts taking special precautions to ensure the integrity of the pipeline.

The Contractor shall provide protection around the pipe to prevent damage to the couplings while being pulled. Also, or in conjunction with, special supports shall be provided to fix the pipe into the duct as well as prevent the pipe from resting on the couplings. Details of proposed arrangement including pipeline support method shall be submitted for approval to the Engineer.

After finishing the pipe sections in the duct and thorough inspection of the work, both ends of the duct shall be sealed by casting lean concrete. Pipe ends protruding from the duct ends shall rest on thoroughly compacted soil.

All works related to construction of pipes in ducts as mentioned here, including excavations and dewatering to provide access to the ducts as well as removal of sand from the ducts, shall be paid under the relevant articles of the Bill of Quantities.

In general wadi crossings shall meet the following requirements:

- Ductile Iron pipes and fittings shall be used over the length of the wadi crossings plus two pipes on either side. The use of restrained joints may be necessary.

- The pipes shall be embedded in concrete grade 20 all around the pipe leaving the joints free by 25 cm on either side.

- Wadi crossings in soft soil will be constructed with a cover of minimal 2.00 metres.

- No valve chambers or marker posts shall be constructed in the wadi bed.

5.4.5 Hydrostatic testing

After a new pipeline has been disinfected by chlorination, hydrostatic tests must be performed to ensure that the pipeline is properly constructed before the acceptance of the pipeline. The hydrostatic testing takes place after field placed concrete (thrust blocks) has had adequate curing time.
Before any testing is commenced, piping and pipelines to be tested shall be filled with water and left to stand for at least 24 hours under a static pressure of upto the intended working pressure in the section of the pipeline. After this, the line shall be subjected to the pressure and leakage tests.

Testing shall be carried out in two stages:

a) test of sections as construction proceeds
1 - 3 km pipeline sections, leaving joints open, with thrust anchoring, if required

b) a final test of the whole system on completion.

The test pressure is applied to the pipeline by means of a continuously operating pump, equipped with a bypass valve for regulating pressure. Attention must be given that the pipeline is filled at a rate which will not cause any surges, and which will ensure a proper air release. All air must be purged through blow-offs or hydrants, or otherwise a tap is required to purge the air.
Leakage shall not exceed 0.1 litre/mm of pipe diameter per kilometre per 24 hours for each 30 m head of pressure applied and shall be measured during a period of steady pressure for not less than 4 hours.

After all visible leaks have been repaired, the full test pressure must be maintained for two continuous hours. Recommended test-pressures are given in table 5.9.

TABLE 5.9: RECOMMENDED TEST PRESSURES

	DI (transmission) line	AC (distribution) line
Max. working pressure	16 bar (163 m.w.c)	9 bar (92 m.w.c)
On-site test pressure	24 bar (245 m.w.c)	13.5 bar (138 m.w.c)

6. WATER RESERVOIRS

6. WATER RESERVOIRS

6.1 General

The various types of reservoirs can be classified according to their location with respect to the ground level:

- underground reservoir (water surface approximately at ground level)
- groundlevel reservoir (water surface above and bottom slightly below ground level).
- elevated tank (water surface and base far above ground level)

and according to their functions:

- receiving and disinfection reservoir
- raw water reservoir
- treated water reservoir
- blending reservoir

The main function of a water reservoir is the storage of water. This storage capacity is necessary to:

- compensate for the difference between inflow and outflow.
- bridge over temporary break-downs (main trunk lines).
- fulfil the water demands for fire fighting.

The water level inside the reservoir determines the pressure in the distribution network.
Furthermore a water reservoir can be used for complementary purposes such as:

- extension of the detention time for effective chlorination
- mixing of different water qualities.

6.2 Capacity

The determination of the capacity of a service reservoir should be according to the following principles:

- The minimum capacity should be at least several hours of water demand during a peak period.
  It is more common to choose a minimum capacity equal to the maximum 24 hour demand of the area supplied.
- For the design-water demand, future developments should be taken into consideration (about 10-15 years).
- The fire fighting capacity should be determined to conform the local rules.

The following storage capacities are recommended:

- at the desalination plant: one day's production of desalinated water/blended water
- in the consumer areas: storage of two day's average summer demand
- in rooftanks of individual houses: one day's average summer consumption.

For determination of distribution reservoir capacity the projected average summer demand soon after the completion of the distribution reservoir is to be considered. In no case shall the capacity be less than 1 day storage of the projected average summer demand .of the area served by the reservoir 10-15 years after completion of the reservoir.

6.3 Design of service reservoirs

Water reservoirs are built of reinforced concrete, prestressed concrete or steel. Their form (rectangular, circular, square, polygonal), type of roof, water depth, etc. are determined by technical-economical and aesthetic considerations, and therefore may vary with time and location.

Shallow reservoirs (water height up to 5 m) are in general preferred to deep tanks in view of reducing fluctuations in pressure.

Main design criteria are:

- the water stored must be protected against contamination
- the quality of the water shall not change, e.g. by heating, stagnation, etc.

Contamination can be prevented by appropriate design of the entrance facilities and of the ventilation systems.
Deterioration in quality due to heating can be prevented by adequate insulation of the external surfaces.
The preservation of water quality requires the use of harmless building materials for the construction and interior lining, in some cases, of the water reservoirs and adequate replacement of water and air.

With regard to the pipeline systems, each water storage reservoir shall be provided with:

- supply or inlet line
- outlet line to pumping facilities/distribution network
- overflow line
- reservoir drainage line

A bypass line may be useful for more flexible pump operations.
The inlet and outlet shall be so arranged that the required replacement of the water is achieved, to prevent short circuiting.
Baffles may be installed in the reservoirs.
The inlet is usually float-level controlled.
A special float type may be used, the float-altitude valve, which only opens when the water level in the reservoir has dropped below a pre-set value, e.g. when tank is filled at 80% capacity.

The water level in the reservoir should be clearly visible by a water level indicator.

A ventilation system is necessary for reasons of hygiene and taste. The vent openings must be provided with screens to prevent the penetration of insect, dust, etc.

Access to the reservoir shall be so designed as to facilitate supervision as well as cleaning or maintenance work.
Number of access openings as few as possible, 600 mm diameter, with access ladder to reservoir including lockable covers.
Some important design aspects, resulting from boundary conditions, are:

- Geotechnical and topographical aspects

  Subsoil conditions of the Arabian Peninsular can in general be characterized as follows.

  - medium dense to dense fine natural sands, often partially cemented, overlying hard rocky layers.
  - loose to very loose wind blown sands, overlying a crust type layer, on its turn underlain by rock or medium dense to dense sandlayers.
  - loose and/or compressible layers of fill, underlain by medium dense to dense sand layers and/or rock.
  - rock at groundlevel.

- Aggressiveness of soil/groundwater

  Soil can be extremely aggressive due to the presence of high quantities of sulphates (or chlorides).
  These conditions may require the use of sulphate resisting portland cement or super sulphated cement and in extreme cases the use of protective coatings.
  Concrete storage tanks for desalinated water require also a dense concrete or in some cases a protective inside lining, such as cement based water proofing coating.

- Foundation method

  The choice of the foundation method is governed by the sub-soil conditions. Some methods are:

  - shallow foundation, slab on the ground
  - soil improvement
  - piled foundation.

- Joints

  Due consideration should be given to the joints.
  Construction joints cannot be avoided, they are essential.
  Where possible, expansion joints should be avoided. If expansion joints must be incorporated, particular attention shall be paid to:

  - the use of a flexible joint seal
  - a construction permitting movement
  - the use of flexible joint - sealing compound, which has been approved for use with drinking water.

6.4 Protection of reservoirs

Concrete reservoirs should be protected against sun exposure. Temperature variations within a structure should be kept to a minimum, walls must be protected against direct sun exposure. This can be achieved by the use of sun retaining walls or by burying the reservoir.
Concrete reservoirs as well as steel reservoirs need some protection against aggressiveness or corrosion.

a. Concrete

Properly manufactured, non porous, smooth and water-tight concrete needs no after-treatment of any kind. In practice these preconditions are not always fulfilled, and it is advisable to line the water chambers using one of the following methods:

- cement plaster (applied in three layers)

- plasters or paints based on cement (light-coloured surfaces)
- chlorinated rubber or epoxy resin paints and coatings (danger of drying-out)
- tile surfacing (expensive)
- multiple-layer coating of glass fibre reinforced polyester (water towers).

Soil covered surfaces have to be protected against soil acids and aggressive groundwater.

b. Steel

All parts of steel or cast iron must be protected against rust. A bright metallic or clean surface, free of mill scale grease or moisture is to be produced prior to painting. The hot galvanizing of steel parts will improve their resistance to corrosion. Pressed steel panel tanks are recommended only for temporary and small (rural) installations.
In general welded steel tanks, suitably protected, are to be used.
Protective coatings in use:

- bitumen based protective paints
- chlorinated rubber paints and single or multiple component paints may also be used, if adequate thickness and non-porosity can be garanteed.
- non toxic epoxy coatings.

7. DISTRIBUTION

7. DISTRIBUTION

7.1 Purpose of a distribution network

The purpose of a distribution network is to distribute the potable water from the storage reservoir over the area to be provided, and deliver it to the individual consumer in such a way that at any tap-point and at any time sufficient water of good quality can be withdrawn.

Apart from distribution pipelines service reservoirs play an important role in the distribution system.
In an economic distribution system the service reservoirs are located as near as possible to the distribution area.
The reservoir evens-out the peak demands for water.
The mains between the service reservoir and the distribution area must be designed for peak rate of flow, and therefore the length of these mains must be kept as short as possible.

7.2 Type of distribution

The pressure needed for the distribution can be obtained by gravity or by pumps, see Figure 7.1.

7.2.1 Gravity-system

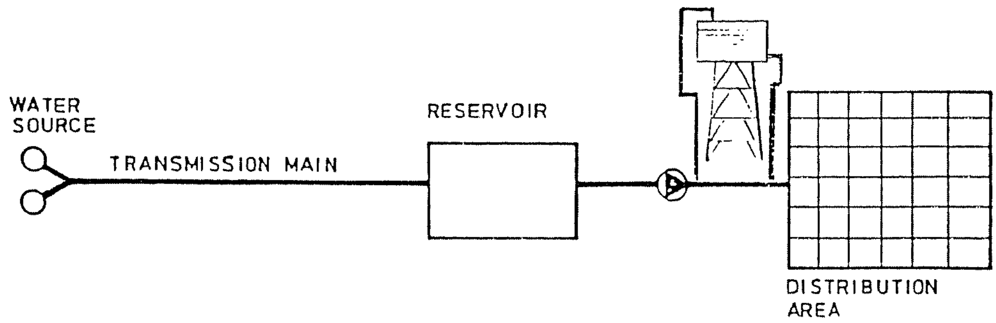
Water reservoirs (service reservoirs) can be elevated or situated on a hillside on such a level that sufficient pressure head is ensured in the distribution area. In these reservoirs the two functions of storage and pressure head are combined.

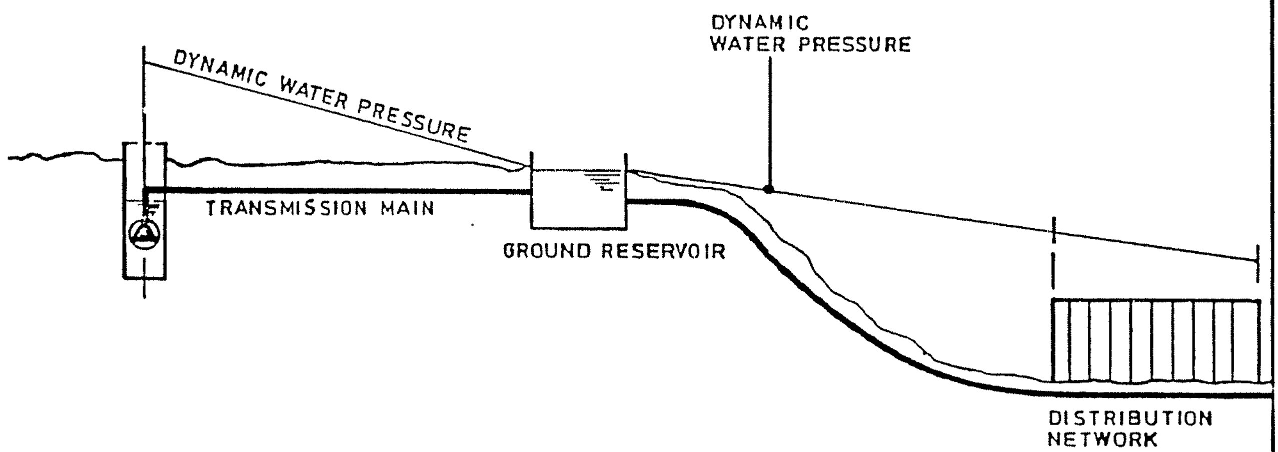
7.2.2 Distribution pumpstation

This system has a low-level groundreservoir and the required pressure is provided by pumps. The functions of storage and pressure are divided.

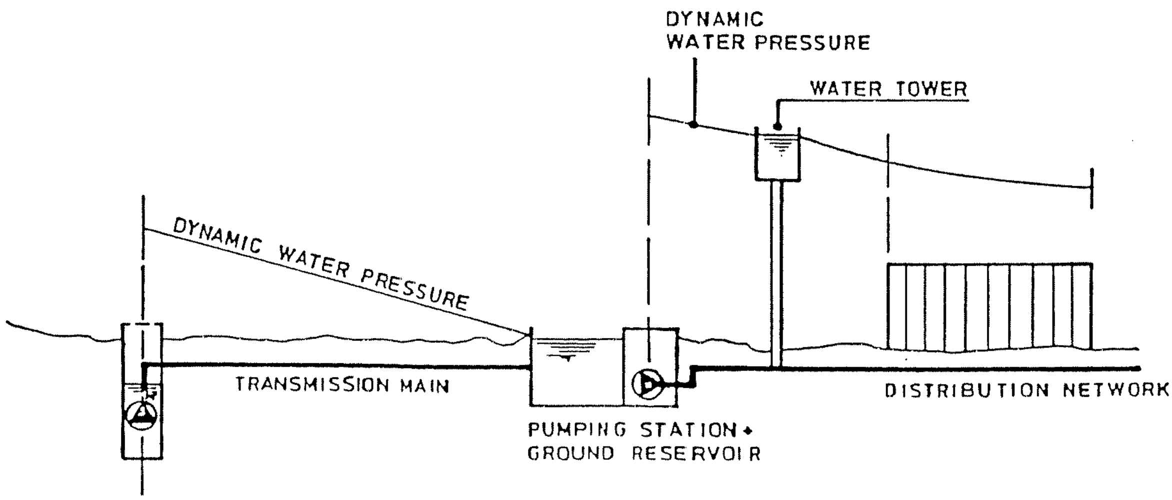
WATER SUPPLY SCHEME

Fig 7.1





DISTRIBUTION FROM GROUND RESERVOIR ELEVATED SITE.



DISTRIBUTION FROM ELEVATED TANK.

7.2.3 Distribution network

There are basically two main types of distribution network systems (Figure 7.2):

- branched or dead end system
- looped network system

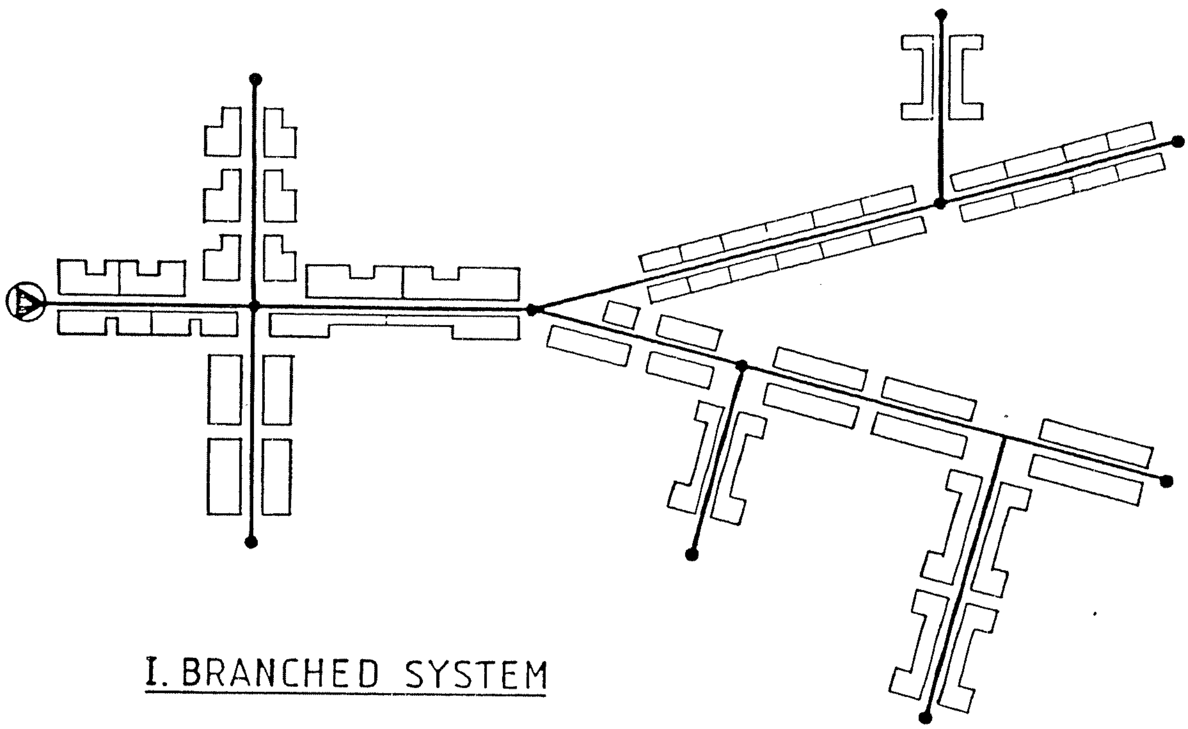
Branched systems are generally used for small community supplies, delivering the water mostly through public standpipes. For larger (urban) distribution systems looped network grids are more common.

The distribution network will be supplied with water under sufficient pressure from the storage reservoir. Public standpipes can operate at a low pressure, say 6 m.w.c. at the tapping point.

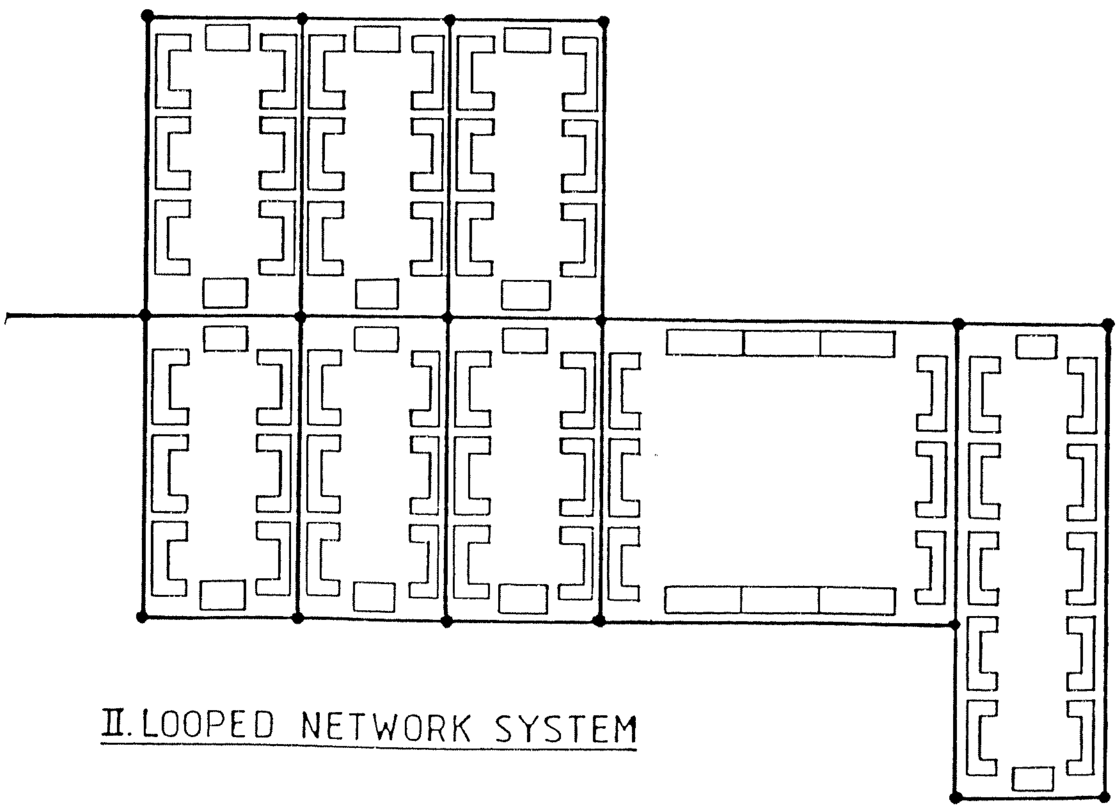
The design of a distribution system is governed by factors such as pipe size, reservoir location, minimum and maximum pressure and pressure variations, and pumpsize. A proper design involves the optimization of investment and operating costs by varying these factors. Furthermore due consideration should be given to possible staged development of the network.
As the cost of a water distribution system depends mainly on the total length of pipes installed and to a lesser extent on the diameter of these pipes, it is advantageous to design the system directly for the ultimate capacity. This argument is valid even when initially only a part of the distribution system is installed for supplying water to a few standpipes.
In subsequent stages additional standpipes are installed, and even more secondary pipes may be layed. When this basic level of water service has spread out throughout the community the installation of house connections or yard taps may follow.
The staged development of such a distribution system would thus go parallel with the actual growth of water use.

Fig. 7.2

TYPE OF DISTRIBUTION SYSTEMS



I. BRANCHED SYSTEM



II. LOOPED NETWORK SYSTEM

7.3 Pressure

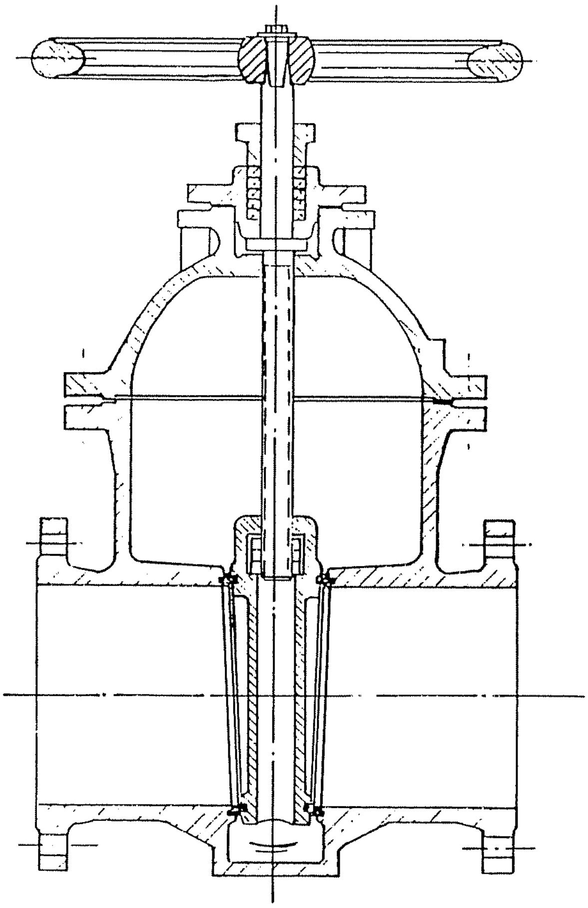
To deliver sufficient quantities of water the pressure head in the network should be at least 15 metres water head (m.w.c.) in all parts of the network, including the remotest and highest points.
The recommended water pressure in a distribution system is 40-55 m.w.c. This level of pressure can provide for the consumption in buildings up to ten stories in height. In higher buildings a booster pump is necessary to ensure sufficient water pressure.
For a residential service connection a pressure of 25 m.w.c. is recommended. Pressure in excess of 60 m.w.c. is undesirable, while the maximum allowable pressure is 90 m.w.c.
At excessive levels leaks occur in domestic plumbing requiring pressure reducers in service connections.
The pressure variations in time and place can be reduced by choosing larger pipe diameters. A suitable location of the reservoir can also reduce pressure differences. In case these differences amount to more than 40 m.w.c. the distribution system must be divided into separate pressure zones. This can be especially useful to prevent excessive pressures in networks in areas with big differences in altitude.

In a gravity-system the reservoir should preferably be located in the centre of the distribution network or as close as possible to the probably centre of the distribution network after allowing for future extensions.
In a branched system the reservoir should be located at the beginning of the distribution network.

7.4 Valves

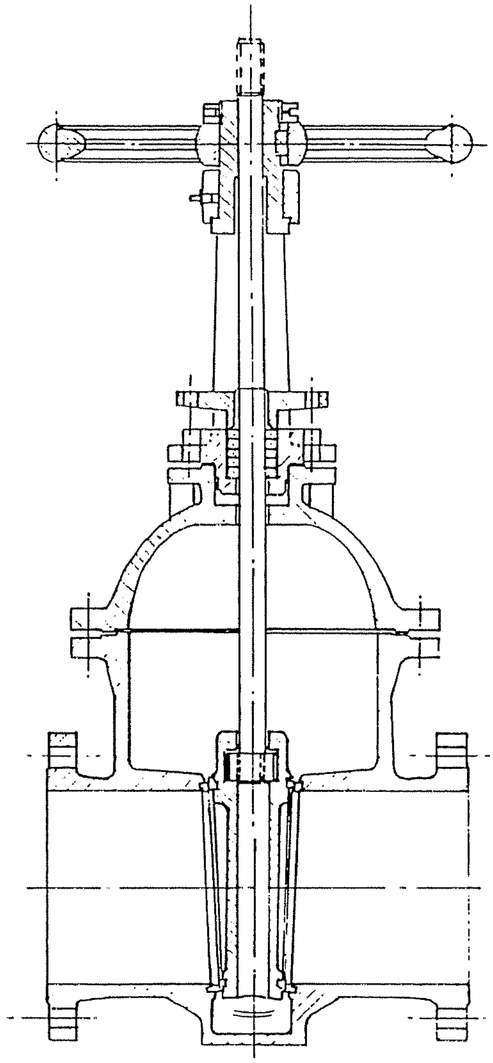
The following types of valves are used in waterworks pipeline systems:

1. Isolating valves
2. Non-return valves
3. Air valves
4. Pressure regulating valves
5. Flow control valves
6. Fire hydrants



inside screw

GATE VALVE



outside screw

GATE VALVE

FIG. 7.3 GATE VALVES

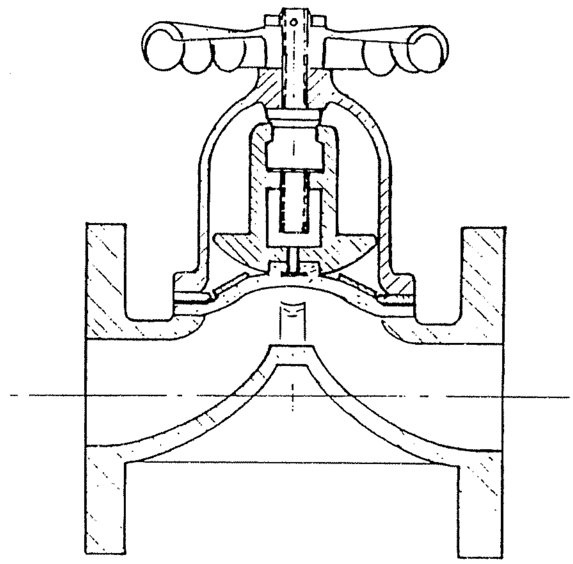


FIG. 7, 4 MEMBRANE VALVE

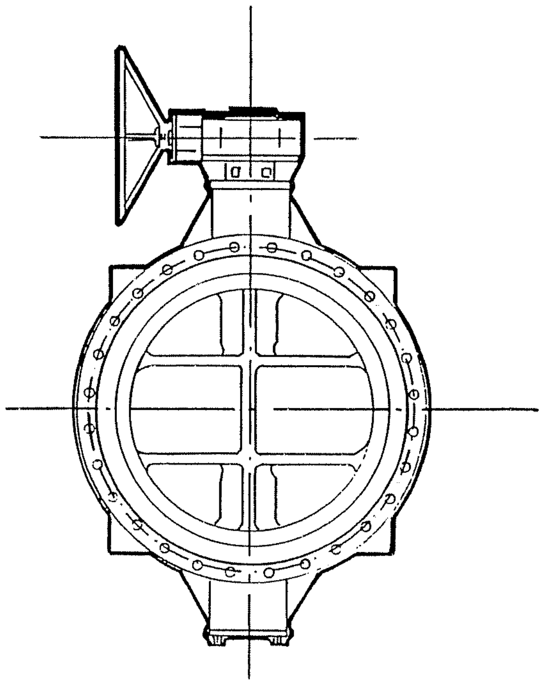
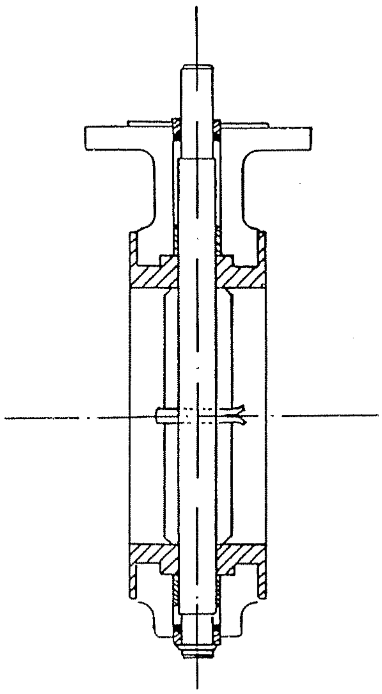
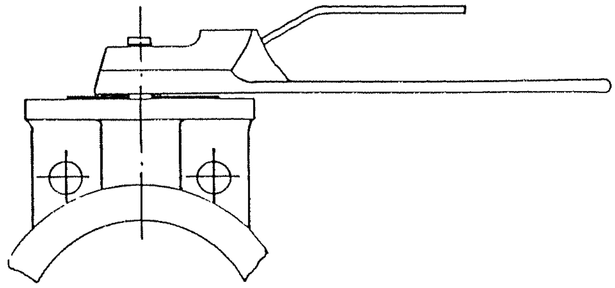
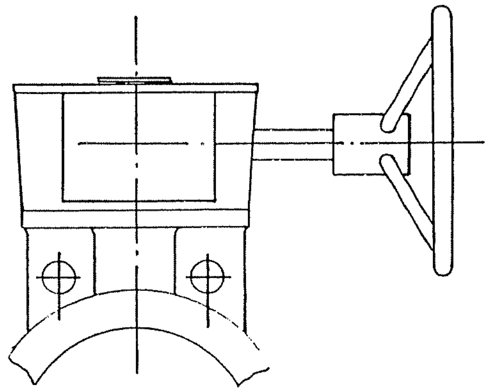


FIG 7.5-A BUTTERFLY VALVE (FLANGED TYPE)

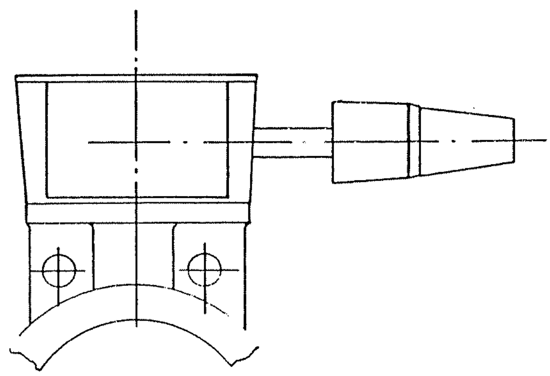




With hand lever



With geared actuator and handwheel



With geared actuator and stem cap

FIG. 7.5-B BUTTERFLY VALVE (WAFER TYPE)

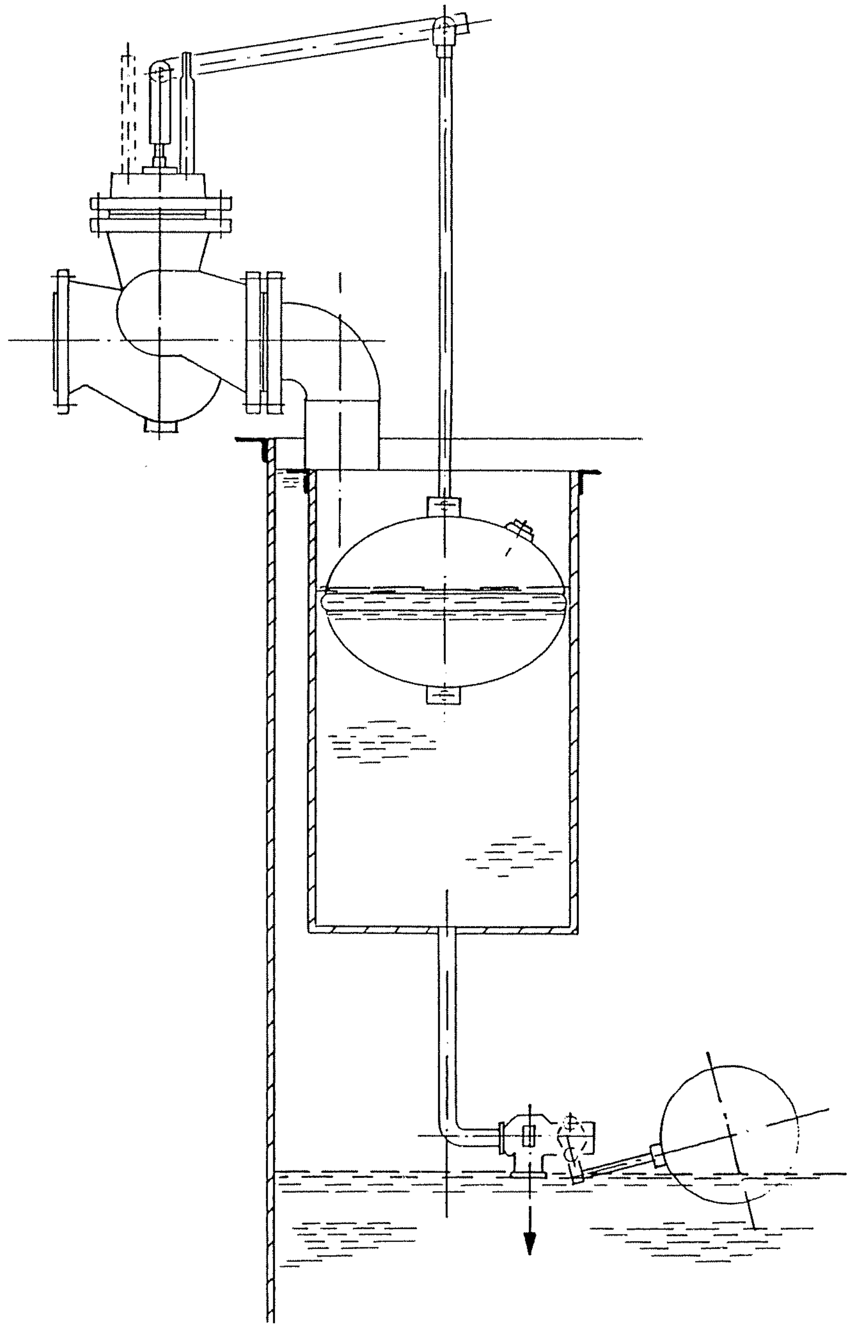


FIG. 7.6 FLOAT VALVE

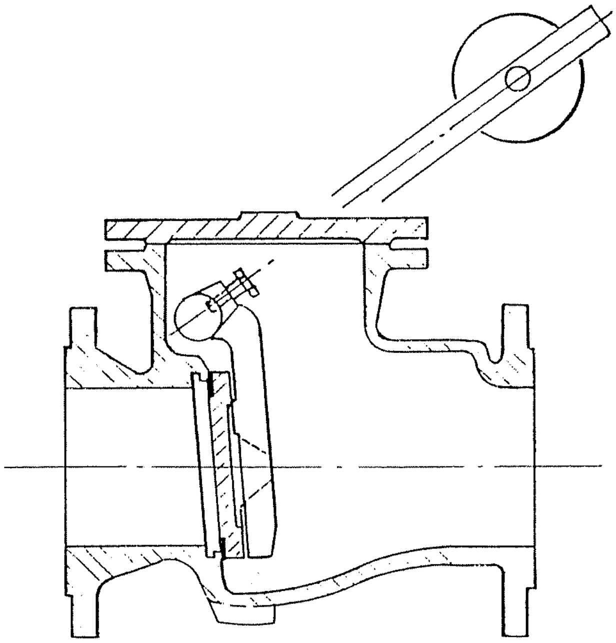


FIG. 7.7 SWING CHECKVALVE

7.4.1 Isolating Valves

Isolating or stop valves are used to isolate sections of transmission systems, distribution networks, pumpstations and as a provision for flushing, testing and maintenance.
The handling of the valves should be easy and fast while the pressure loss in open position should be low.
Isolating valves shall close clockwise and open anti clockwise.
Valves above 300 mm diam. shall be gear operated.

1. Gate valves (Figure 7.3)
   This is a typical on-off valve, being fully open or closed. There are several types which can be subdivided into types with wedges or discs, and with internal or external screws.
2. Diaphragm valve (Figure 7.4)
   A rubber membrane is used which can have the shape of a disc or a cylinder.
3. Butterfly valve (Figure 7.5.a and 7.5.b)
   This shut-off device can also be used for throttling services. The constuction design is rather simple with less weight, space and cost than gate valves.
   The valve is used in larger diameter pipes where a gate valve is not practical anymore and requires a long time to be closed. Several types exist such as the flanged type and the wafer type (flangeless), with hand lever or with geared actuator and handwheel.
4. Float ball valve (Figure 7.6)
   This valve is used in water storage reservoirs to stop the incoming water flow when the reservoir is full. The valve is opened only after a certain drop of liquid level has occured.

7.4.2 Non-Return Valves

This type of valve permits a fluid flow in one direction only. They are used in pumping stations in the pressure line to prevent a reverse flow inside the pumps, in elevated storage reservoirs, and in house connections.

1. Swing check valve (Figure 7.7).
   This valve is closed by the weight of the disc, or by a counterweight connected to the disc through a lever. There are also slow closing types fitted with an oil brake.
2. Nozzle check valve (Figure 7.8).
   With this type a better streamline guidance is accomplished by the shape of the nozzle used, resulting in a low pressure loss. The nozzle is springloaded in order to assure a shock-free closure prior to flow reversal.
3. Flap valve (Figure 7.9).
   Flap valves are applied at the end of drainage lines or overflow lines. They are opened by the water pressure when there is a discharge and are closed when there is no flow.

7.4.3 Air Valves (Figure 7.10)

During filling, the air present in pipelines must be released. Under working conditions air can accumulate at crest points. This air must also be released.

When a pipeline is emptied air must be admitted.

Air valves are designed to perform these duties. They can be single or double acting, permitting air release and/or air admission, with single or double chambers.

Hydrants can also be used as air valves.

Air valves are to be located at crestpoints of pipelines, and in long ascending stretches of moderate slope at 500-1000 m intervals. Also where abrupt changes of slope exist an air valve is to be applied.

7.4.4 Pressure Regulating Valves (Figure 7.11)

Pressure reducing and pressure retaining devices are used in places where the water pressure is higher than desired and where the danger exists that pressure is reduced too much.

In low altitude parts of a distribution network with big differences in altitude, water pressure can be higher than desired.

In branches of transmission lines pressure may also be too high. Pressure reducing valves are therefore required.

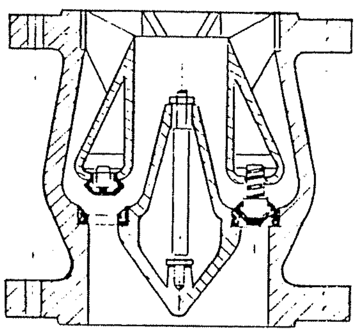


FIG.7.8 NOZZLE CHECKVALVE

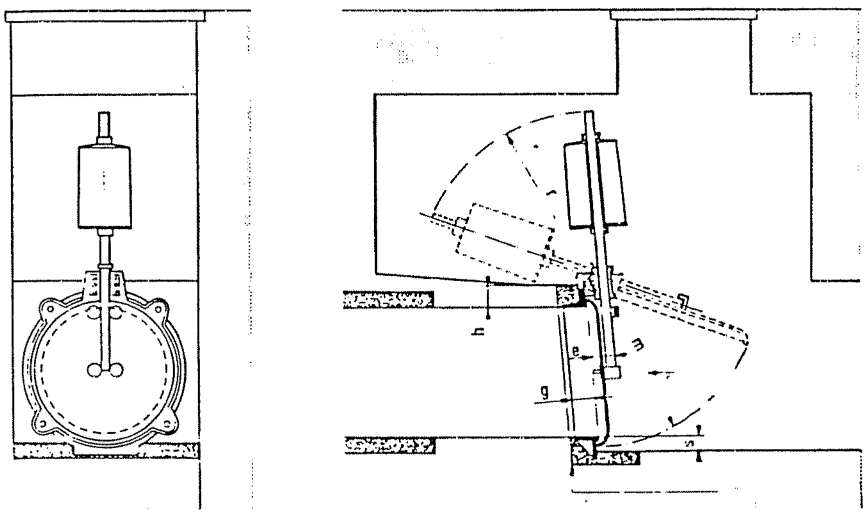


FIG 7.9 FLAPVALVE

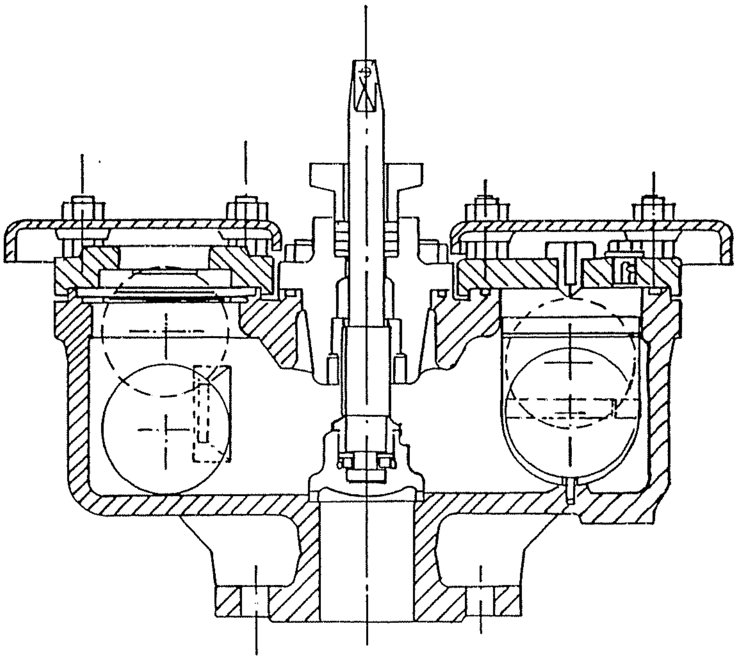


FIG.7.10 DOUBLE ORIFICE AIR VALVE

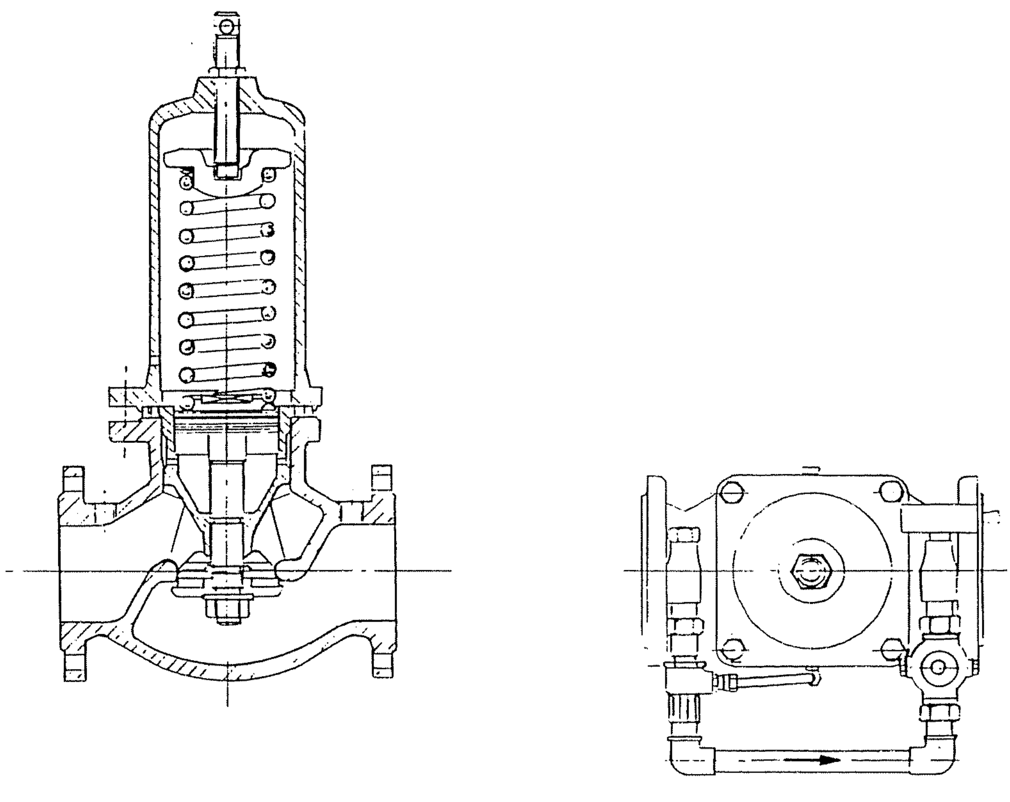


FIG. 7.11 PRESSURE REDUCING VALVE

7.4.5 Flow control valve

Several types of valves can be used for flow control duties, e.g. the butterfly valve and the globe valve (see Figure 7.12). The globe valve, which owes its name to the global shape of the valve body, is mostly used as an on-off valve, but can well be used for flow control. Special applications and automatic models exist of the globe type, which cover a wide range of duties, e.g. pressure control and liquid level control.

7.4.6 Location of valves

Isolating valves in distribution systems should be placed according to following guidelines:

- on all branches from feeder mains
- between feeder pipes and hydrants
- not more than 3 valves at a cross
- not more than 2 valves at a tee
- preferably at an uniform distance from pipe intersections
- not further apart from each other in a line than 500 metres, preferably not more than 400 metres.
- air valves at all crest points
- wash-outs at all valley points

in transmission pipelines:

- isolating valves every 2-3 kilometres
- air valves at crest points, and in constant rising pipelines (of moderate slope) every 1000-1500 m
- wash-outs at the lowest points of the pipelines or section

A valve chamber should be provided for every valve on an underground pipe. Where adequate physical reference points are not available, a valve reference marker post must be installed and reference data recorded.

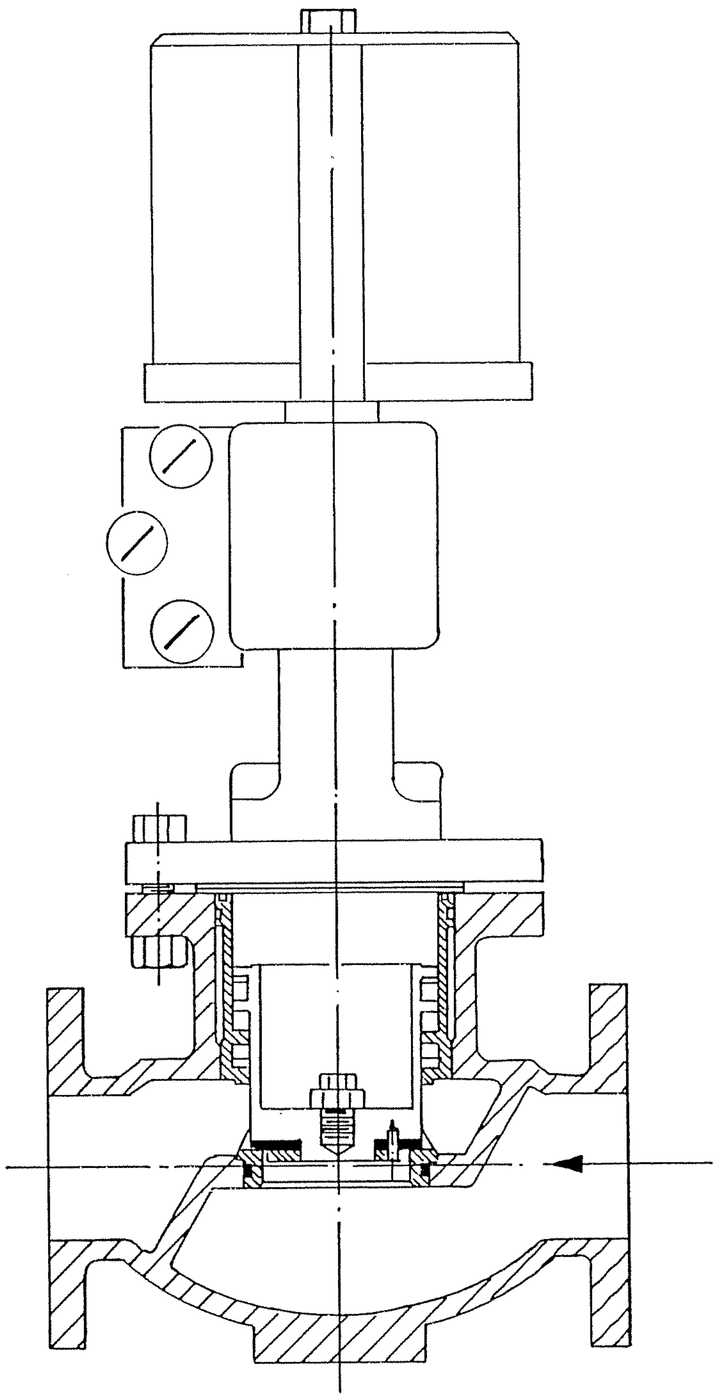


FIG. 7.12 GLOBE VALVE WITH ACTUATOR

7.4.7 Fire hydrants

Fire hydrants should be included in piped water distribution systems, no fire hydrants on transmission pipelines.
In urban areas a spacing of 90-120 m is desired between the hydrants. Their location will be along roads on the distribution mains, and must be determined in coordination with fire department officials and local authorities to prevent interference with pedestrians and vehicular movements.
It is important that fire demands are taken into consideration in the design of water distribution networks.
Flow requirements from a hydrant would be 1.5-2 m^3/min. For major fires the flow requirements may range from 5 to 15 m^3/min from several hydrants.
Fire hydrants shall be located below ground- or pavement level in a chamber. The valve can be of the screwdown type or the wedge gate type.
The cap of the hydrant shall be between 300 to 500 mm. from the pavement level/hydrant chamber top level.

7.5 Methods of supplying potable water

Several ways to deliver the potable water to the consumer are used in Oman:

1. Standpipes
   The water is delivered by pipelines to public standpipes. This system is used mainly in rural areas, and in towns where the design does not provide for individual house connections.
2. Tanker distribution
   Water is made available at tanker points from where it is bowsered to the houses of invidual consumers, and pumped into the rooftanks.
3. House connections
   The water is delivered through a pipe to each house separately. House connections are realised by a service pipeline which branches off from the distribution main.

Standpipes

Public standpipes should be designed and located in such a way that the walking distance of the water users is limited and a proper discharge capacity is provided. Following rules of thumb are to be followed:

- Walking distance of the users should not exceed 200 metres. In sparsely populated rural areas 500 metres may be acceptable.
- Pressure at standpipe should not exceed 20-30 m.w.c. to avoid wastage.
  Discharge capacity ca. 15 litres per minute at each outlet. Water consumption from standpipes generally is not higher than 20 to 30 litres per person per day. One bucket to be filled in 2 minutes.
- A single tap standpipe can serve about 50-100 persons. A multiple tap standpipe may serve up to 200-300 persons. In no case should the number of users dependent on one standpipe exceed 500.
- A drainage system is necessary to carry away the spilled water in order to prevent the stagnation of water with subsequent health hazards.

Tanker filling station

A tankerpoint should have a filling capacity of 40 m^3 in 30 minutes. A two bay tankerpoint serving 2 tankers at a time is usual. Multi-bay tankerpoints are sometimes installed in urban areas with a high population density.

House connections

The service pipeline connects the distribution main to the plumbing inside the house.

A typical house connection is given in Figure 7.13.

A vertical water meter is installed together with a stopcock, attached to the exterior of the outside wall. The service pipe is attached to the water main through the ferrule.

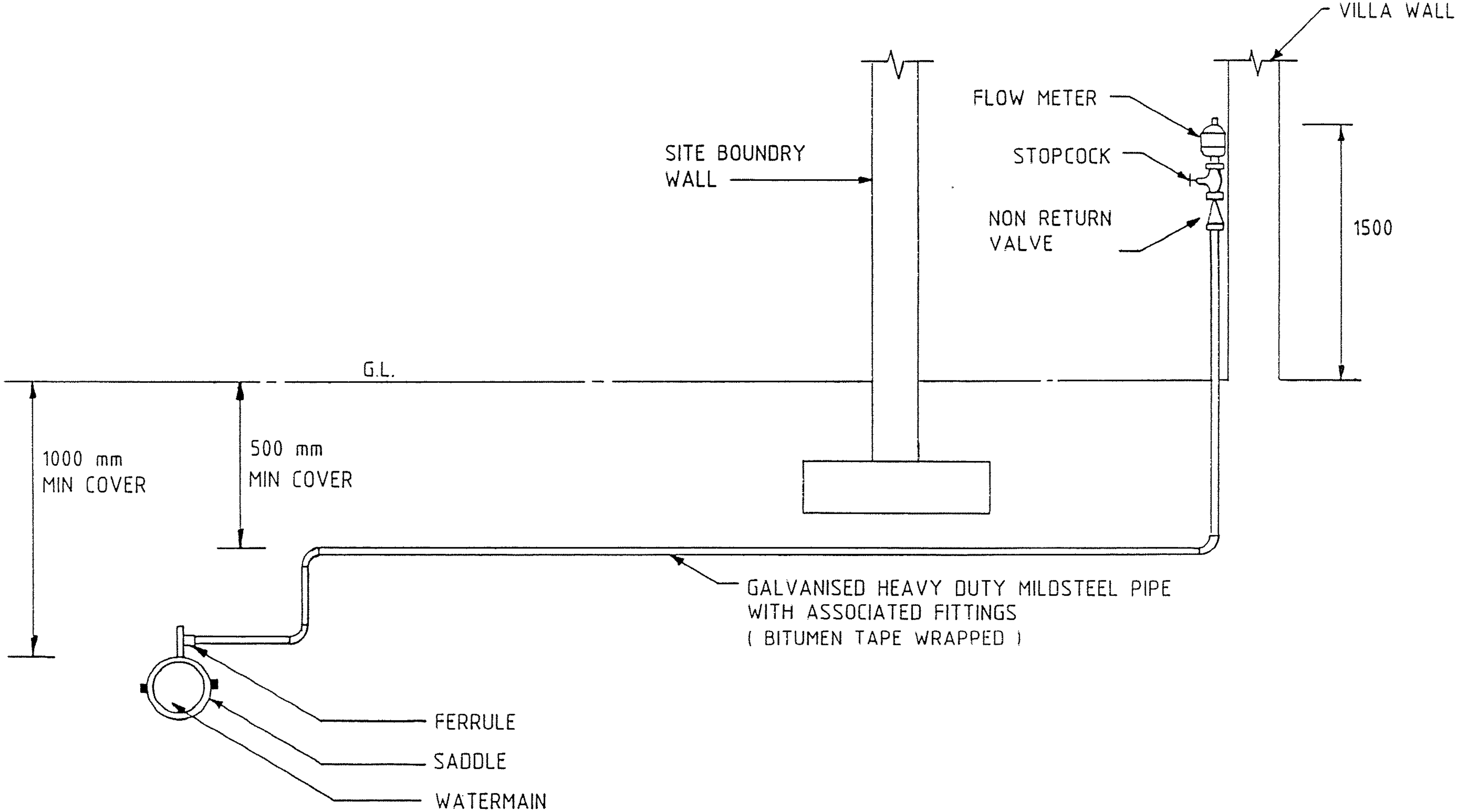


FIG. 7.13 HOUSE CONNECTION DETAIL

It is adviseable to provide the ferrule with a stopcock to facilitate the installation or removal of the service pipe. To prevent the water from flowing back from the house into the distribution main (especially important when the water is polluted), the installation of a check valve is advisable. This valve should be installed next to the flowmeter and stopcock, where it can be inspected.

7.6 Watermeters

Watermeters used in house connections can be subdivided into the following types:

- Inferential type

  This type can be further subdivided into single jet or multi-jet meters. The vane wheel meter is an example.

- Displacement type

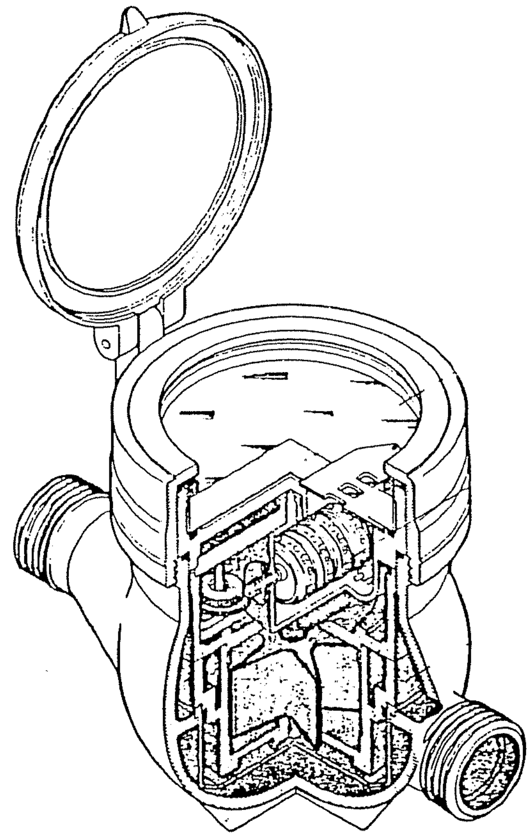
  A further subdivision can be made into the plunger, the cylinder or the screw type. The rotary piston meter is an example.

The meters can have wet or dry dials. The appellation refers to the space in which the parts of the gearing and register are being located.

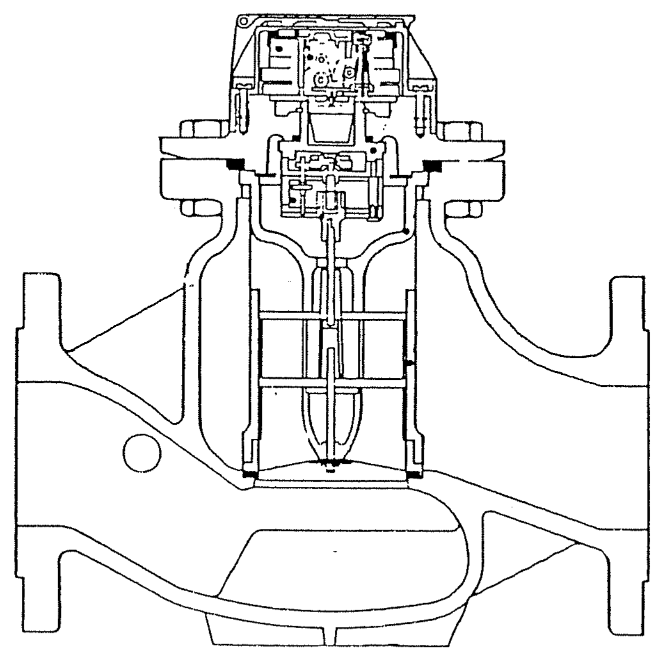
Apart from the type, watermeters are characterised by their capacity, i.e. the amount of water in m^3 per hour that can be measured accurately.

Vane wheel meters (see Figure 7.14.a)

In vane wheel meters a light vane wheel acts as measuring device which actuates via its axis gearing and register. The number of revolutions of the wheel is totalized and will be proportional to the amount of water which flows through.



A. VANE WHEEL METER



B. HELIX TYPE METER

FIG. 7.14 WATER METER

Rotary piston meters (see Figure 7.14.b)

The rotary piston meter is a displacement meter.

At each full revolution of the measuring device, the same amount of water is admitted and forced to the outlet. A piston which rotates in an oscillating movement inside a cylinder shaped chamber, acts as measuring device. For good performance there shall be minimum clearance between piston and chamber. By means of the rotating movement of the piston the gearing and register are actuated.

The error of measurement of the rotary piston meter is lesser than the error of the vane wheel meter, and usually does not exceed ± 2%.

In order to keep the accuracy of measurement at an acceptable level, the meters in use have to be exchanged, cleaned and revised and finally recalibrated, every 3 to 5 years.

7.7 Leakage and wastage control

There is no water distribution system without wastage and leakage. Wastage and leakage of water is considered as the total output of water which is not used by the consumers, thus not accounted for. The water consumption at consumers premises can be counted by totalling the water meter reading. However improper meter readings, data collection, and inadequate billing procedures result in "administrative" unaccounted-for water.

Wastage of water can be caused by the following factors.

- Leakage in production plants, reservoirs, watermains (due to faulty joints, tie-ins, corrosion, fractures), valves, etc.
- Leakage in service pipes and fittings inside consumer's premises.
- Unduly high pressures in distribution systems intensifying leakage and waste.
- Undue high consumption by consumers (garden watering, running taps, overflows)
- Malfunctioning of watermeters

- Unauthorized connections
- Wrong administrative procedures

The percentage of unaccounted for water, due to wastage and leakage, in well maintained systems in Europe and USA ranges from 5 to 20 percent, whereas in developing countries in other parts of the world this percentage may amount 50 percent, or even more, of the total daily flow into a system.

An allowance of 25 to 30% for unaccounter for water and leakage is to be made in estimating water demands.

In general an "unaccounted-for" percentage of about 10-15% may be assumed to be acceptable. This percentage probably could be reduced below 10% with a systematic leakage and waste prevention programme and improvement of the system. However expenses incurred for such a programme should be weighed against cost savings or increased sales.

The following methods of leakage control are in use:

1. Pressure control.
   This is the simplest and most immediate way of reducing leakage, as detection of leaks in not involved. Ways to acomplish pressure reduction are reducing pumping heads, installing break pressure tanks, and the use of pressure reducing valves.
2. Passive leakage control.
   No measuring or detecting of leaks takes place, but self-evident leaks, for instance where water is showing on the ground surface, or after consumers complaints such as poor pressure, are repaired.
3. Routine/regular sounding.
   This involves the systemtically sounding of all stopcocks, hydrants, valves, listening for the characteristic noise of leaking water.

4. District metering.

   Flowmeters are installed at strategic points within the system so that areas of about 2000 to 5000 properties are supplied via meters and the integrated flow into each area measured.

5. Waste metering.

   This involves the setting up of areas between 1000 and 3000 properties such that when appropriate valves are closed these areas can be supplied via a single pipe in which it is possible to site a flowmeter. This meter must be capable of measuring low rates of flow (night flow).

   A waste meter can be permanently installed on a by-pass or be portable on a mobile unit.

8. MATERIALS SPECIFICATION

MS-1: MATERIAL SPECIFICATION FOR DUCTILE IRON PIPE

1. Codes and standards

Ductile iron materials shall meet the test requirements in accordance with ISO 2531, latest edition to be conducted at manufacturer's plant.

Tests quality control etc., at manufacturer's plant shall be as per relevant standards mentioned hereafter.

All pipes and fittings shall have joints as specified hereafter.
The pipes and fittings shall be thoroughly protected, both inside and outside.

The pipeline materials shall meet as a minimum the requirements of the following standards or their latest revisions:

- for ductile iron pipes, fittings and accessories for pressure pipelines : ISO 2531 - BS 4772
- polyethylene sleeves : ANSI A21-5-(AWWA C105)
- rubber gaskets joints : ANSI A21-11 (AWWA C111)
- cement mortar lining : AWWA C104

In case other standards are used, proof shall be given that they fulfill the requirements of the above mentioned standards.

2. Pipes

All pipes shall be truly circular and of uniform thickness and supplied in the longest practicable length (6 m) so as to minimize the number of joints.
Pipe diameters shall be chosen from following diameter series: 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200 mm.

Pipes and fittings to be used shall be internally lined and where laid underground the outside is to be further protected with polyethylene sleeves and/or sheet wrapping, all in accordance with the standards mentioned and specifications of this document.

Only pipes of class K9 or higher shall be used. The thickness of pipes and fittings shall be calculated according to ISO 2531, clause 4.

The pipe shall be hydrostatically tested and certified at manufacturer's plant before application of the lining, at the following hydrostatic test pressures, according to ISO 2531, clause 16.

All the pipes, joints and fittings shall be suitable for a maximum working pressure of 16 bar (absolute)

All the pipes and joints of the socket and spigot "push-on" type are to be factory tested and shall sustain without damage or any leakage a hydrostatic test pressure of 32 bar (absolute). Joints of the flanged type must be able to sustain, without any leakage, a hydrostatic test pressure of 32 bar (absolute).
On-site test pressure shall be 24 bar (absolute).

3. Joints

Flange ended pipes and fittings shall be used for above ground ductile iron piping and valve pits.
Where flanged joints are used, they shall be supplied complete with approved gaskets and hot dipped galvanized or cadmium plated bolts, nuts and washers. Flanges shall be drilled in accordance with the ISO 2531 standard for PN 16.
All other pipes and fittings on the plant site shall have pipe joints of the socket and spigot "push-on" type.
When using pipes with spigot and socket end, an approved type of joints shall be applied (Fastite, Tyton or equivalent).

Rubber ring joints shall be of a type which will not deteriorate under the local conditions either during storage or during operation. The installation of the joints shall be caried out with all due care and shall follow the recommendations of the manufacturer and/or those of the CIPRA (Cast Iron Pipe Research Association).

Where directed by the Engineer pipes and fittings shall be supplied with and be suitable to accept restrained couplings with push-on type joints. This type of coupling shall be equipped to accept axial thrust forces working on bends, valves, tees, reducers and dead ends. The thrust resisting mechanism shall be separated from the sealing action of the rubber ring seals and shall not be in contact with the potable water. It will be considered as an advantage if standard pipes and fittings can easily be modified to restrained pipes and fittings in the field.

4. Fittings

All fittings shall comply with ISO 2531, section 4.

5. Protective coatings

5.1 Internal cement mortar lining

All pipes and fittings shall be internally covered with a cement mortar lining of standard thickness in accordance with AWWA-standard C104.

5.2 Outside coating

All buried pipes and fittings shall have an external coating of coal tar epoxy material of good quality, which shall not deteriorate under temperatures of 100°C. The thickness of the coat shall be at least 300 microns.
In case zinc spray coating of approved quality is applied over the bare metal, a black bituminous coating of tropical standards with a thickness of 100 microns will be acceptable.

The inside of the bell mouth (socket end), as well as the outside of the spigot end which may have contact with the potable water, shall be coated with a suitable non toxic epoxy coating.
Outside coating for above ground piping shall be a coal-tar epoxy coating system according to AWWA standards C210 latest edition or approved equivalent standard.

All pipes and fittings inside buildings, shall be coated with an epoxy coating system according to AWWA standard C210 latest edition and with the following supplementary specifications prevailing over the requirements of the above standard.
Dry-film thickness shall be at least 300 microns. Toplayer of painting shall be according to the colourscheme, as will be specified for each project.

5.3 Polyethylene sleeves

All buried pipes and fittings shall be covered with polyethylene sleeves to prevent direct contact between the backfill material or groundwater and the pipe, fitting or valve, as per ANSI A21.5 (AWWA C105), or equivalent.

The polyethylene material shall be in accordance with ASTM D-1248 or its approved equivalent and shall have a minimum thickness of 0.010 inch (250 microns) with a maximum minus tolerance of 10%.

6. Flanges

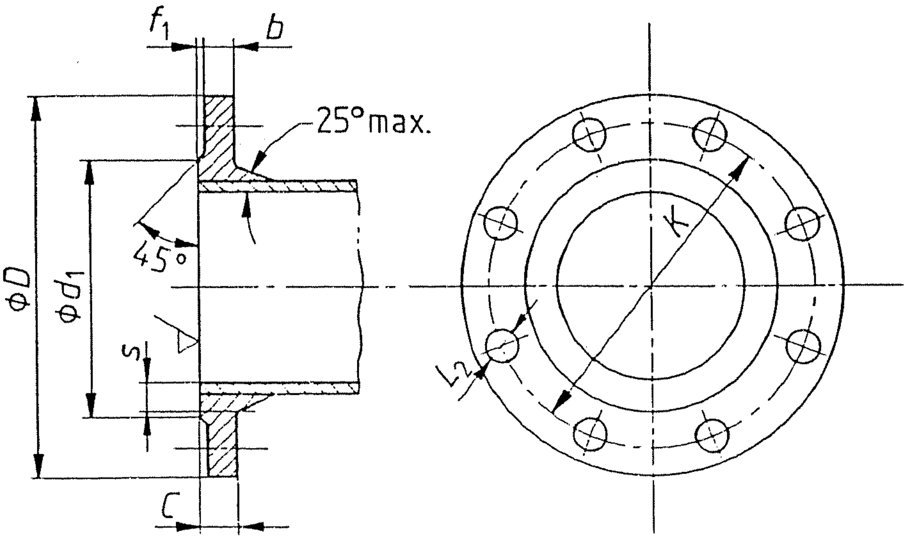
6.1 General

Flange dimensions and drilling details shall be in accordance with ISO 2531, section 3 and which are given in the next pages.
The diameters of bolt holes of the various types of flange are 1 mm larger than those envisaged for pipelines not laid in the ground. This increase makes it easier to assemble the castings, which is sometimes difficult in the case of underground pipelines. It also permits the use of large diameter bolts whenever this is justified by considerations of resistance to corrosion.

6.2 Dimensions and drilling details of PN 10 flanges

$$b = \begin{cases} 10 + 0{,}035\ DN, \text{ with a minimum value of } 16, \text{ for DN 40 to 300} \\ 10 + 0{,}025\ DN, \text{ with a minimum value of } 20{,}5, \text{ for DN 350 to 1 200} \\ 20 + 0{,}015\ DN \text{ for DN 1 400 to 2 600} \end{cases}$$

$$s = \begin{cases} 0{,}8\ C \text{ for DN 40 to 600} \\ 0{,}7\ C \text{ for DN 700 to 2 600} \end{cases}$$



This view may not represent the exact number of holes.

Refer to column "Number of holes" in table 17 to obtain the exact number.

Dimensions in millimetres — Masses in kilograms

Nominal size DN	D	d_1	C	b	f_1	s 1)	Approximate flange mass (hatched part)
40	150	84	19	16	3	15	1,7
50	165	99	19	16	3	15	2,1
(60)	175	108	19	16	3	15	2,2
65	185	118	19	16	3	15	2,5
80	200	132	19	16	3	15	2,9
100	220	156	19	16	3	15	3,3
125	250	184	19	16	3	15	4
150	285	211	19	16	3	15	4,9
200	340	266	20	17	3	16	6,8
250	400	319	22	19	3	17,5	9,6
300	455	370	24,5	20,5	4	19,5	12,8
350	505	429	24,5	20,5	4	19,5	14,1
400	565	480	24,5	20,5	4	19,5	16,3
500	670	582	26,5	22,5	4	21	21,8
600	780	682	30	25	5	24	30,8
700	895	794	32,5	27,5	5	23	40,5
800	1 015	901	35	30	5	24,5	54,8
900	1 115	1 001	37,5	32,5	5	26,5	64,3
1 000	1 230	1 112	40	35	5	28	81,4
1 200	1 455	1 328	45	40	5	31,5	120,9

Dimensions in millimetres

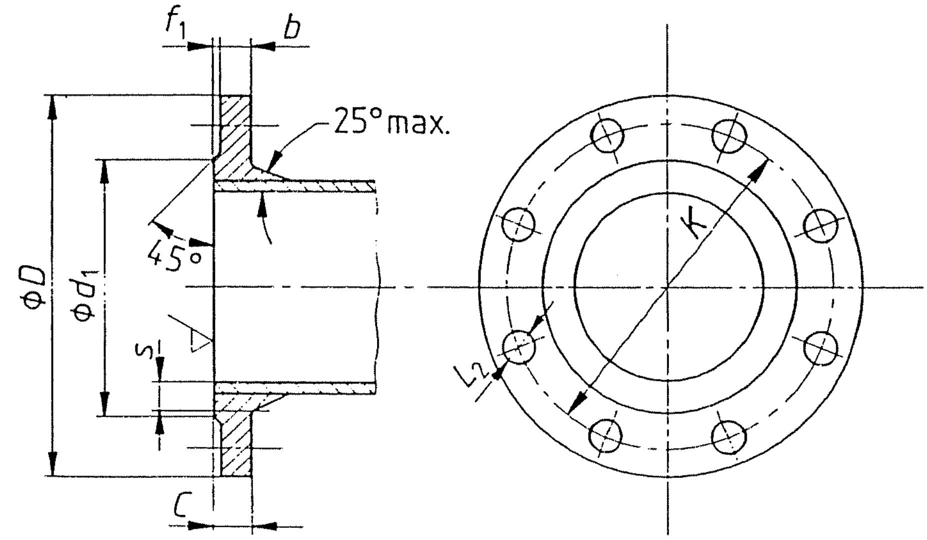
Nominal size: DN	D	K	Holes		Bolts
			Number	Diameter L_2	Nominal diameter
40	150	110	4	19	M16
50	165	125	4	19	M16
(60)	175	135	4	19	M16
65	185	145	4	19	M16
80	200	160	8 1)	19	M16
100	220	180	8	19	M16
125	250	210	8	19	M16
150	285	240	8	23	M20
200	340	295	8	23	M20
250	400	350	12	23	M20
300	455	400	12	23	M20
350	505	460	16	23	M20
400	565	515	16	28	M24
500	670	620	20	28	M24
600	780	725	20	31	M27
700	895	840	24	31	M27
800	1 015	950	24	34	M30
900	1 115	1 050	28	34	M30
1 000	1 230	1 160	28	37	M33
1 200	1 455	1 380	32	40	M36

1) For flanges with nominal diameter DN 80 and nominal pressure PN 10, the number of holes may be reduced to 4 at the purchaser's request, in order to permit coupling with an existing flange of an old pipeline.

6.3 Dimensions of drilling details of PN 16 flanges

$b = \begin{cases} 10 + 0{,}035\ DN, \text{ with a minimum value of 16, for DN 40 to 1 200} \\ 20 + 0{,}025\ DN \text{ for DN 1 400 to 2 600} \end{cases}$

$s = \begin{cases} 0{,}8\ C \text{ for DN 40 to 600} \\ 0{,}7\ C \text{ for DN 700 to 2 600} \end{cases}$



This view may not represent the exact number of holes.

Refer to column "Number of holes" in table 19 to obtain the exact number.

Dimensions in millimetres — Masses in kilograms

Nominal size DN	D	d_1	C	b	f_1	s[1]	Approximate flange mass (hatched part)
40	150	84	19	16	3	15	1,7
50	165	99	19	16	3	15	2,1
(60)	175	108	19	16	3	15	2,2
65	185	118	19	16	3	15	2,5
80	200	132	19	16	3	15	2,9
100	220	156	19	16	3	15	3,3
125	250	184	19	16	3	15	4
150	285	211	19	16	3	15	4,9
200	340	266	20	17	3	16	6,6
250	400	319	22	19	3	17,5	9,2
300	455	370	24,5	20,5	4	19,5	12,4
350	520	429	26,5	22,5	4	21	17,2
400	580	480	28	24	4	22,5	21,9
500	715	609	31,5	27,5	4	25	37
600	840	720	36	31	5	29	57,3
700	910	794	39,5	34,5	5	27,5	55,6
800	1 025	901	43	38	5	30	74
900	1 125	1 001	46,5	41,5	5	32,5	88,2
1 000	1 255	1 112	50	45	5	35	122,9
1 200	1 485	1 328	57	52	5	40	185,2

1) Dimension s is for the sole purpose of calculating the mass.

Dimensions in millimetres

Nominal size DN	D	K	Holes		Bolts
			Number	Diameter L_2	Nominal diameter
40	150	110	4	19	M16
50	165	125	4	19	M16
(60)	175	135	4	19	M16
65	185	145	4	19	M16
80	200	160	8	19	M16
100	220	180	8	19	M16
125	250	210	8	19	M16
150	285	240	8	23	M20
200	340	295	12	23	M20
250	400	355	12	28	M24
300	455	410	12	28	M24
350	520	470	16	28	M24
400	580	525	16	31	M27
500	715	650	20	34	M30
600	840	770	20	37	M33
700	910	840	24	37	M33
800	1 025	950	24	40	M36
900	1 125	1 050	28	40	M36
1 000	1 255	1 170	28	43	M39
1 200	1 485	1 390	32	49	M45

MS-2: MATERIAL SPECIFICATION FOR ASBESTOS CEMENT PIPE

1. Codes and standards

Asbestos cement pipes and collars with rubber rings shall comply to the latest issue of ISO standard 160 (BS 486) and ISO standard 2785.

2. Pipes

The pipes shall be with plain ends to be jointed with "push-on" collars to "Reka" pattern or similar.
All pipes and collars shall be coated internally and externally. Pipes shall be of class 18 or higher.

Pipe bursting pressures and pipe crushing loads as determined by tests prescribed in ISO R160 Clauses 2.6.2 and 2.6.3 respectivily shall at least equal those given in ISO Standard 2785, Annex A, Table 6. The Contractor may be required to demonstrate compliance with this requirement by tests on at least ten pieces prior to full scale manufacture. The results of this initial test and subsequent tests as may be required by the Engineer during manufacture shall be not less than the values referred to above.

The cement used in the manufacture of all asbestos cement pipes shall be sulphate resisting cement complying with BS 4027 or ASTM C150-61 Type V. No admixtures shall be included in the cement without the written approval of the Engineer.

All the pipes, joints and fittings shall be suitable for a maximum working pressure of 9 bar (absolute).

All the pipes and joints shall sustain without damage or any leakage a hydrostatic test pressure of 13.5 bar (absolute).

Hydraulic test pressure applied in the factory shall be 18 bar.

Pipe diameters shall be chosen from following diameter series: 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200 mm.

The external diameters and wall thickness of the pipes at the finished ends where jointing rings are located shall be as follows:

Nominal Diameter mm	Outside Diameter mm		Wall Thickness mm	
	minimum	maximum	minimum	maximum
100	129.4	130.6	11	15
150	181.4	182.6	12	16
200	237.4	238.6	15	19
300	349.4	350.6	19.5	24.5
400	463.2	464.8	25.5	30.5
500	567.2	568.8	27.5	32.5
600	687.0	689.0	31.0	37.0

The length of chamfering at each of the finished ends of the pipe where jointing rings are located shall be equal to or greater than the length of the jointing ring.

Rubber rings should comply with the latest BS 2494 or equivalent standards.

3. Fittings

Fittings for asbestos cement shall be of asbestos cement, ductile iron, or grey cast iron. Grey cast iron is to be preferred.
Grey cast iron fittings shall be manufactured according to B.S. 4622 and suitable for use with asbestos cement pipes.
Fittings with plain ends for use with asbestos cement pipes shall comply with foregoing standard where applicable and with approved manufacturer's standard patterns. All fittings shall be free from blow holes and superficial defects, and the ends shall be suitable

for use with "detachable" type joints, and also with "push-on" type joints. All fittings shall be coated internally and externally.
If detachable joints are required to fit the fittings and/or valves to the asbestos cement pipe network the joints shall be of the Gibault type or similar.
If flanged joints are required these shall be in accordance with latest BS 4504 or equivalent.

4. Coatings and linings

Asbestos cement pipes shall be coated and lined with bitumen in accordance with BS 486 Clause 2.3. The coating shall be applied preferably in two coats.

Fittings shall be lined and coated with cold applied bitumen complying with the requirements of BS 3416 and be suitable for tropical climates.
Application shall be in accordance with the manufacturers instructions.

Damaged areas of coating shall be reapplied on Site after removing any loose coating and wire brushing the affected areas of the pipe.

MS-3: MATERIAL SPECIFICATION FOR GALVANIZED IRON PIPE

Galvanized mild steel pipes shall comply with BS 1387, Class C and shall be of heavy gauge, supplied in maximum possible lengths.

After cutting, pipes shall be reamed, and be free of burrs rust scale and other defects and shall be thoroughly cleaned before erection. Open ends left during progress of the work shall be closed off with purpose made wooden plugs.

Threads cut on site shall be cleaned and coated with a zinc based coating in accordance with BS 2569 before assembly.

Screwed pipe joints shall be taper threaded to BS 21.

Screwed fittings other than sockets shall be malleable cast iron to BS 143.

MS-4: MATERIAL SPECIFICATION FOR CAST IRON WATERWORKS FITTINGS

1. Codes and standards

All cast iron fittings shall be manufactured in accordance with the following standards:

- ISO 2531: d.i. pipes, fittings and accessories
- AWWA C104: Cement Mortar Lining
- AWWA C111: Rubber gasket joints

2. Protective coatings

2.1 Internal lining

All sizes of cast iron sleeves shall be furnished without a cement-mortar lining or a epoxy coating. All other fittings shall be furnished with a cement- mortar lining of standard thickness as defined in referenced specifications and given a seal coat of bituminous material or a epoxy coating.

2.2 Outside coating

All buried fittings shall have an external coating of coal tar epoxy material of good quality, which shall not deteriorate under temperatures of 100°C. The thickness of the coat shall be at least 300 microns.
In case zinc spray coating of approved quality is applied over the bare metal, a black bituminous coating of tropical standards with a thickness of 100 microns will be acceptable.

Outside coating for above ground piping shall be coal-tar epoxy coating system according to AWWA standards C210 latest edition or approved equivalent standard.

3. Joints

Flange ended fittings shall be used for above ground piping and valve pits.
All other fittings on the plant site shall have pipe joints of the socket and spigot "push-on" type.

4. Thickness class

All fittings shall be of class K12 or higher. The thickness shall be calculated according to ISO 2531, clause 4.

MS-5: MATERIAL SPECIFICATION FOR WATERWORKS GATE VALVES

1. Codes and standards

Gate valves shall be used for pipeline sizes of 300 mm and smaller, Gate valves shall meet the minimum requirements of DIN 3225, BS 5163 or equivalent. All valves shall close clockwise and shall be equipped with open/closed position indicator.
The valves shall be of the double disc, non-rising stem type.

2. Materials

Valve materials shall conform to the following specifications:

- body : ductile cast iron
- spindle : stainless steel or forged bronze
- gate : ductile cast iron
- spindle nut : gun metal or zinc free bronze BS1400
- body seat rings : zinc free bronze BS1400

The valves shall be provided internally and externally with a suitable non toxic coating.
O-rings instead of glands are preferred.

3. Service

Valves shall be suitable for frequent operation as well as service involving long periods of inactivity.
The nominal pressure for all sizes shall be PN16 or as otherwise specified.

4. Operation

Manually operated valves shall be provided on pipelines with cast iron caps for key operation requiring forces not greater than 12 kg applied at the opposite ends of a standard key from the closed position. In the pumphouse they shall be provided with cast iron handwheels requiring a force not greater than 20 kg on the outer rim with a balanced head across the valve. The direction of operation shall be clockwise.

MS-6: MATERIAL SPECIFICATION FOR BUTTERFLY VALVES

1. Codes and standards

Butterfly valves shall comply with BS 5155 or other approved standard.

2. Service

Valves shall be suitable for tight shut off application unless a regulating duty is required. Valves shall be suitable for service involving long periods of inactivity.
The maximum static differential pressure across the valve will be 16 bar. At this rated pressure the valve will be bubble light for flows in either direction.

3. Installation

Valves shall be mounted with shaft horizontal unless otherwise specified.
Valves shall be for buried service or for installation in valve chamber.
A by-pass for valves above 300 mm diameter shall be provided.

4. Operation

Valves above 300 mm diameter shall be gear operated.
Where manually operated valves are required they shall be provided with cast iron hand wheels and bevel gearing with indicators to show the position of the disc.
If specified, provision shall be made for initiating the operation of remote indicator lights in the fully OPEN and CLOSED positions.

MS-7: MATERIAL SPECIFICATION FOR SWING CHECK VALVES

1. Codes and standards

Check valves shall comply with BS 5153 or AWWA Standard C508 or other approved standard.

2. Type

Valves shall be iron body, fully bronze-mounted, metal to metal and the disc shall be swing type, for either vertical or horizontal use.

3. Service

Valves shall be suitable for frequent operation as well as service involving long periods of inactivity.
The nominal pressure for all sizes shall be PN16 or as otherwise specified.

4. Operation

The valve design shall ensure closure in the shortest possible time following deceleration of the water column ideally reaching its seat without slamming. This may be achieved with the use of an exterior lever and adjustable spring/weight operation or hydraulic damping equipment.

MS-8: MATERIAL SPECIFICATION FOR PRESSURE REGULATING VALVES

1. Service

The function of this valve is to reduce an existing high pressure to a preadjusted lower downstream pressure for varying rates of flow without causing shock or water hammer on the system. The valve shall be drop tight under no flow conditions.

2. Valve description

The pressure reducing valve shall be hydraulically operated with a free floating guided piston having a seat diameter equal to the size of the valve. The valve shall be fully bronze-mounted and all packing shall have either leather or rubber seals to provide tight closure and prevent metal to metal friction. An indicator rod shall be furnished as an integral part of the valve to show the position of the piston within the valve body. The valve shall be designed to provide an access opening in the valve body for removing the piston and other internal parts without removing the main valve body from the line.

The pilot valve for controlling operation of the main valve shall be a single seated, diaphragm operated and spring loaded type. The pilot valve shall be attached to the main valve with piping and isolation valves so arranged for easy access in making adjustments and also for its removal from the main valve while the main valve is under pressure.

3. Materials

Cast iron body and cover. Internal valve, gunmetal with bronze liner, cups and facing rings in leather. Relay valve, bronze with stainless steel spindle and nylon valve face. Diaphragm reinforced synthetic rubber.

Loading spring, if employed - spring steel. Cylinder and weights, if employed - cast iron. Lever, steel with gunmetal pins and links. Connecting pipework to cylinder - copper. Cylinder, mild steel epoxy lined with internal working parts gunmetal bushed.

4. Valve ends

Body ends shall be flanged and drilled to ISO 2531 PN16 or for the nominal operating pressure required.

MS-9: MATERIAL SPECIFICATION FOR COMBINATION AIR AND VACUUM - AIR RELEASE VALVES

1. General

All combination air and vacuum release valves shall be shop assembled and shipped as a complete unit ready for field installation.
The large orifice of combination air valve shall allow air to escape during pipeline filling and enter during drainage of the pipeline. It shall close water tight when liquid enters the valve. The small orifice shall release small pockets or air after the pipeline is filled and under pressure.

2. Valve body and cover

The combination air valve shall be the single body type. The valve body and cover shall be designed to operate under a maximum working pressure of 16 bar. Materials shall be as follows:

Body cover and cowl	-	cast iron
Small orifice	-	cast iron with gunmetal seat
Small orifice ball	-	rubber covered or other approved
Large orifice	-	cast iron with rubber seat
Large ball	-	vulcanite covered or other approved

3. Operating pressure

The operating pressure shall be PN16.

MS-10: MATERIAL SPECIFICATIONS FOR FIRE HYDRANTS

1. Codes and standards

   Hydrants shall comply with BS 750 or other approved standard.

2. Type

   Hydrants shall be of the captive screw-down type with cast iron stopper håving neoprene rubber face, complete with cap.

3. Nominal pressure

   The nominal pressure shall be PN16.

4. Body ends

   Body ends shall be flanged and drilled to ISO 2531.
   Outlet screwed BS round thread complete with polypropylene protecting cap and sherardised mild steel chain.

5. Materials

   Gunmetal, aluminium bronze or nickel copper alloy may be used for internal components. The body and stopper shall be spheroidal graphite or grey cast iron.

MS-11: MATERIAL SPECIFICATIONS FOR 1/2-INCH WATER METERS

Inferential multijet vane wheel/volumetric rotary piston type 1/2-inch size conforming to the following Specifications.

1. Normal Measuring Range

0.06 to 1.5 m^3/hour with less than approximately 3 meter loss of head at the maximum of the range.

2. Pressure Rating

16 Bar; test pressure: 32 bar.

3. Temperature Rating

Up to 70 degrees C water temperature.

4. Graduation

In cubic meters and decimal parts of a m^3. Shall record quantities of 0.001 m^3. Dry dial type with straight reading.

5. Maximum Error in Normal Flow Range

Plus or minus 2 percent.

6. Materials of Construction

The body top and bottom halves shall be of bronze/brass. Internal gears shall be of corrosion resistant material. The piston or vane wheel mechanism shall be of suitable plastic, capable of withstanding a temperature of 70 degree C. and fitted on self-lubricated bearings. The construction shall be sturdy and capable of withstanding rough use and exposure to sunlight, dust, rain, and other adverse atmospheric conditions.

7. Mounting Position

Vertical with flow from bottom to top (90%) top to bottom (10%).

8. End Connection

Threaded with fixing nuts, 1/2-inch standard pipe threads.

9. Type of Couplings

Magnetic.

10. Metrological Class

B or C.

11. Guarantee

Trouble-free service for 3 years.

The meter shall be supplied with fixing nuts and shall have a suitable tamperproof sealing arrangement for the working parts. Graduations shall be clear and easily readable, black/red on a white background.

MS-12: MATERIAL SPECIFICATIONS FOR 3/4-INCH WATER METERS

Inferential multijet vane wheel/volumetric rotary piston type 3/4-inch size conforming to the following Specifications.

1. Normal Measuring Range

0.10 to 2.5 m^3/hour with less than approximately 3 meter loss of head at the maximum of the range.

2. Pressure Rating

16 Bar; test pressure: 32 bar.

3. Temperature Rating

Up to 70 degrees C water temperature.

4. Graduation

In cubic meters and decimal parts of a m^3. Shall record quantities of 0.001 m^3. Dry dial type with straight reading.

5. Maximum Error in Normal Flow Range

Plus or minus 2 percent.

6. Materials of Construction

The body top and bottom halves shall be of bronze/brass. Internal gears shall be of corrosion resistant material. The piston or vane wheel mechanism shall be of suitable plastic, capable of withstanding a temperature of 70 degree C. and fitted on self-lubricated bearings. The construction shall be sturdy and capable of withstanding rough use and exposure to sunlight, dust, rain, and other adverse atmospheric conditions.

7. Mounting Position

Vertical with flow from bottom to top.

8. <u>End Connection</u>

Threaded with fixing nuts, 3/4-inch standard pipe threads.

9. <u>Type op Couplings</u>

Magnetic.

10. <u>Metrological Class</u>

B or C.

11. <u>Guarantee</u>

Trouble-free service for 3 years.

The meter shall be supplied with fixing nuts and shall have a suitable tamperproof sealing arrangement for the working parts. Graduations shall be clear and easily readable, black/red on a white background.

MS-13: MATERIAL SPECIFICATIONS FOR ONE-INCH WATER METERS

Inferential multijet vane wheel/volumetric rotary piston type one-inch size conforming to the following Specifications.

1. Normal Measuring Range

0.15 to 3.5 m^3/hour with less than approximately 3 meter loss of head at the maximum of the range.

2. Pressure Rating

16 Bar; test pressure: 32 bar.

3. Temperature Rating

Up to 70 degrees C water temperature.

4. Graduation

In cubic meters and decimal parts of a m^3. Shall record quantities of 0.01 m^3. Dry dial type with straight reading.

5. Maximum Error in Normal Flow Range

Plus or minus 2 percent.

6. Materials of Construction

The body top and bottom halves shall be of bronze/brass. Internal gears shall be of corrosion resistant material. The piston or vane wheel mechanism shall be of suitable plastic, capable of withstanding a temperature of 70 degree C. and fitted on self-lubricated bearings. The construction shall be sturdy and capable of withstanding rough use and exposure to sunlight, dust, rain, and other adverse atmospheric conditions.

7. Mounting Position

Vertical with flow from bottom to top.

8. End Connection

Threaded with fixing nuts, one-inch standard pipe threads.

9. Type of Couplings

Magnetic.

10. Metrological Class

B or C.

11. Guarantee

Trouble-free service for 3 years.

The meter shall be supplied with fixing nuts and shall have a suitable tamperproof sealing arrangement for the working parts. Graduations shall be clear and easily readable, black/red on a white background.

9. DOCUMENTATION

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9.1 Standards

Different types of standards can be used in the field of water supply systems:

1. British Standards
   published by the British Standards Institution (B.S.I.)
2. A.W.W.A. Standards
   published by the American Water Works Association (A.W.W.A)
3. American Standards
   published by the American Society for Testing of Materials (A.S.T.M.)
4. International Standards
   published by International Organization for Standardisation (I.S.O.)

For electrical facilities and instrumentation, standards of the following organizations may be applicable:

- International Electrotechnical Commission (I.E.C.)
- Regulations for the Electrical Equipment of Buildings (I.E.E.)
- Regulations for Electrical Installation Works by the Ministry of Electricity and Water.
- Instrument Society of America (I.S.A.)

9.1.1 British Standards

BS	12	-	Portland cement (ordinary and rapid hardening)
BS	21	-	Pipe threads for tubes and fittings where pressure tight joints are made on the treads
BS	143	-	Malleable cast iron and cast copper alloy screwed pipe fittings for steam, air, water, gas and oil
BS	340	-	Pre-cast concrete kerbs, channels, edgings and quadrants
BS	410	-	Test sieves
BS	417	-	Galvanised mild steel cisterns and covers, tanks and cylinders

BS 443	-	Galvanised coatings on wire
BS 449	-	The use of structural steel in buildings
BS 476	-	Fire test on building materials and structures Parts 7 and 8
BS 486	-	Asbestos-cement pressure pipes
BS 497	-	Cast iron manhole covers, road gully gratings and frames, for drainage purposes
BS 534	-	Steel pipes and specials for water and sewage
BS 540	-	Clay drain and sewer pipes including surface water pipes and fittings
BS 587	-	Motor starters and controllers
BS 690	-	Part 3: Corrugated sheets Part 6: Fittings for use with corrugated sheets
BS 729	-	Hot dip galvanised coating on iron and steel articles
BS 747	-	Specification for roofing felts
BS 750	-	Underground fire hydrants and surface box frames and covers
BS 812	-	Methods for sampling and testing of mineral aggregates
BS 879	-	Water well casing
BS 882	-	Aggregates from natural sources for concrete (including granolithic)
BS 890	-	Building limes
BS 952	-	Glass for glazing
BS 1014	-	Pigments for Portland cement and Portland cement products
BS 1186	-	Quality of timber and workmanship in joinery
BS 1191	-	Gymsum building plasters
BS 1194	-	Concrete porous pipes for under-drainage
BS 1199/ BS 1200	-	Building sands from natural sources
BS 1239	-	Linters (cast concrete and natural stone)
BS 1247	-	Manhole step irons
BS 1362	-	General purpose fuse links for domestic and similar purposes (primarily for use in plugs)

BS 1377	-	Methods of test for soil for civil engineering purposes
BS 1387	-	Steel tubes and tubulars suitable for screwing to BS 21 pipe threads
BS 1400	-	Copper alloy ingots and copper alloy castings
BS 1449	-	Steel plate, sheet and strip
BS 1452	-	Grey iron castings
BS 1455	-	Plywood manufactured from tropical hardwoods
BS 1494	-	Fixing accessories for building purposes
BS 1521	-	Waterproof building papers
BS 1564	-	Pressed steel sectional rectangular tanks
BS 1722	-	Fences Parts 1 and Parts 3
BS 1740	-	Wrought steel pipe fittings (screwed BSP thread)
BS 1780	-	Bourbon tube pressure and vacuum gauges
BS 1881	-	Methods of testing concrete
BS 1926	-	Ready-mixed concrete
BS 1972	-	Polythene pipe (Type 32) for cold water services
BS 1984	-	Gravel aggregates for surface treatment (including surface drssings) on roads
BS 2494	-	Materials for eiastomeric joint rings for pipework and pipelines
BS 2499	-	Hot applied joint sealants for concrete pavements
BS 2569	-	Sprayed metal coatings
BS 2571	-	Flexible PVC compounds
BS 2871	-	Copper and copper alloys. Tubes
BS 3083	-	Hot-dip galvanised corrugated steel sheets for general purposes
BS 3148	-	Tests for water for making concrete
BS 3416	-	Black bitumen coating solutions for cold application
BS 3505	-	Unplasticised PVC pipe for cold water services
BS 3656	-	Asbestos-cement pipes, joints and fittings for sewerage and drainage
BS 3690	-	Bitumen for road purposes
BS 3871	-	Miniature and moulded case circuit-breakers

BS 4017	-	Capacitors for use in tubular fluorescent, high pressure mercury and low pressure sodium vapour lamp circuits
BS 4027	-	Sulphate-resisting Portland cement
BS 4102	-	Steel wire for fences
BS 4232	-	Surface finish of blast-cleaned steel for painting
BS 4254	-	Two-part polysulphide-based sealants for the building industry
BS 4293	-	Current-operated earth-leakage circuit-breakers
BS 4346	-	Joints and fittings with unplasticised PVC pressure pipes
BS 4360	-	Weldable structural steels
BS 4449	-	Hot rolled steel bars for the reinforcement of concrete
BS 4461	-	Cold worked steel bars for the reinforcement of concrete
BS 4466	-	Bending dimensions and scheduling of bars for the reinforcement of concrete
BS 4483	-	Steel fabric for the reinforcement of concrete
BS 4504	-	Flanges and bolting for pipes, valves and fittings. Metric series
BS 4550	-	Methods of testing cement
BS 4568	-	Steel conduits and fittings with metric threads of ISO form for electrical installations
BS 4622	-	Grey iron pipes and fittings
BS 4752	-	Part 1 Circuit-breakers of rated voltage up to and including 1000 V a.c. and 1200 V d.c.
BS 4772	-	Ductile iron pipes and fittings
BS 4848	-	Hot-rolled structural steel sections
BS 4887	-	Mortar plasticisers
BS 4921	-	Sherardized coatings on iron and steel articles
BS 4999	-	General requirements for rotating electrical machines
BS 5000	-	Rotating electrical machines of particular types or for particular applications

BS 5150	-	Cast iron wedge and double disk gate valves for general purposes
BS 5153	-	Cast iron check valves for general purposes
BS 5155	-	Butterfly valves
BS 5257	-	Horizontal end-suction centrifugal pumps
BS 5262	-	Code of Practice for external rendered finishes
BS 5292	-	Jointing materials and compounds for installations using water, low pressure steam or gases
BS 5316	-	Acceptance tests for centrifugal, mixed flow and axial pumps
BS 5328	-	Methods for specifying concrete, including ready-mixed concrete
BS 5337	-	Code of practice for the structural use of concrete for retaining aqueous liquids
BS 5390	-	Code of practice for stone masonry
BS 5480	-	GRP pipes and fittings for use for water supply or sewerage
BS 5481	-	Unplasticised PVC pipe and fittings for gravity sewers
BS 5492	-	Code of practice for internal plastering
BS 5493	-	Code of practice for protective coating of iron and steel structures against corrosion
BS 5728	-	Measurements of flow of cold potable water in closed conduits
BS 5821	-	Method of rating sound insulation in buildings and of building elements
BS 5834	-	Surface boxes and guards for underground stop-valves for gas and waterworks purposes
BS 5970	-	Code of practice for thermal insulation of pipework and equipment (in the temperature range of -100°C to +870°C)
BS 6004	-	PVC-insulated cables (non-armoured) for electric power and lighting
BS 6007	-	Rubber-insulated cables for electric power and lighting

BS 6068 - Water quality
BS 6150 - Code of practice for painting of buildings
BS 6262 - Code of practice for glazing for buildings
BS 6316 - Code of practice for test pumping water wells
BS 6346 - PVC-insulated cables for electricity supply
BS 6500 - Insulated flexible cords and cables

Code of Practice

CP 110 - The structural use of concrete
CP 112 - The structural use of timber
CP 121 - Walling
CP 152 - Glazing and fixing of glass for buildings
CP 231 - Painting of buildings
CP 310 - Water supply
CP 312 - Plastics pipework (thermoplastics material)
CP 2010 - Pipelines

9.1.2. British Water Research Association (UK)

TIR 130 - Technical Inquiry Report

9.1.3 A.W.W.A. Standards

a. Source
A 100 - water wells

b. Treatment.
B 100 - filtration
B 200 - softening
B 300 - disinfection
B 300-80 - hypochlorites
B 301-81 - liquidchlorine
B 400 - coagulation
B 500 - scale and corrosion control
B 600 - taste and odor control
B 700 - prophylaxis

c. Distribution.

C 100	-	cast iron pipe, fittings
C 104	-	cement mortar lining
C 105	-	Polyethylene encasement for d.i. piping for water and other liquids
C 111	-	Rubber gasket joints for d.i. and grey iron pressure pipe and fittings
C 200	-	steel pipe
C 203	-	Coal tar enamel protective coatings for steel water pip
C 210	-	Epoxy coating systems for the interior and exterior of steel water pipelines
C 300	-	concrete pipe
C 400	-	asbestos-cement pipe
C 500	-	valves and hydrants
C 600	-	pipe laying
C 700	-	meters
C 800	-	service line
C 900	-	plastic pipe

d. Storage.

D 100 - welded steel tanks

e. Pumping.

E 101-77 - vertical turbine pumps, lineshaft and submersible types.

9.1.4 Swedish Standards Institution

SIS 05 59 00 - Pictorial surface preparation standards for painting steel surfaces

9.1.5 International Standards

ISO 7	-	Pipe threads where pressure tight joints are made on the treads
ISO 160	-	Asbestos-cement pressure pipes and joints
ISO 2531	-	Ductile iron pipes, fittings and accessories for pressure pipelines

ISO 2785 - Guide to selection of asbestos-cement pipes subject to external loads with or without internal pressure

9.2 Preparation of Tender Documents

Detailed instructions and specifications for the construction of a water supply project are given in the Tender Documents. These documents are prepared by the Consultant after having completed the preliminary designs, approved by the Ministry.
The Tender Documents shall contain sufficient details and information for complete understanding of the project at the Tendering stage.

The Tender Documents usually consist of three parts:

- General/administrative part and Technical Specifications.
  - Instructions to Tenderers
  - Conditions of Contract
  - Technical Specifications

- Part to be filled out by Tenderer:
  - Bill of quantities
  - Form of Tender
  - Technical data sheets

- Tender Drawings, including Standard Drawings

General/adminstrative part and Technical Specifications

The Instructions to Tenderer shall describe how the Tenderer shall submit his Tender, the contents of the tender package, submission of tender bonds, data and information required.
The Conditions of Contract shall be the Standard Conditions of Contract as given in the Third Edition (July 1981) of the Standard Documents for Building and Civil Engineering Works, prepared by the Directorate General of Finance, Muscat. No amendments, additions or modifications to these Conditions are allowed, only explanations and clarifications to clauses may be added.
Any amendments necessary shall be included in the Technical Specifications

The Technical Specifications shall comprise all general and technical requirements, scope of works , specifications, methods of measurement of works, applicable standards etc.

Part te be filled out by Tenderer

The tenderer shall fill out:
- the Bill of Quantities
- the Form of Tender and its Appendix
- the Technical Data Sheets

The completed documents from part of the Tender Package to be submitted by the Tenderer.

Tender Drawings and Standard Drawings

The Tender Drawings shall, as a minimum comprise the following drawings.
- Distribution network key map
- Pipeline route and profiles
- Reservoir/pumpingstation site
- General lay-out pumpingroom
- Well pumping facilities
- Service reservoirs
- Office, housing facilities
- Flow diagram
- Electrical single line diagram
- Typical details/standard drawings for:
    - valve chambers
    - anchor blocks
    - reinforcement details
    - well construction
    - door- and window schedules

Where items are paid on unit rate basis, full detailed drawings shall be provided.

9.3 Conversion tables

Length

cm	Inches	Feet	m
1	0.394	0.033	0.01
2.54	1	0.083	0.0254
30.48	12	1	0.3048
100	39.37	3.281	1

Area

cm^2	m^2	ft^2	m^2
1	0.155	0.001	1×10^{-4}
6.45	1	0.0069	6.45×10^{-4}
929	144	1	0.093
10^4	1550	10.764	1

Volume

in^3	l	U.S. gallon	Imp. gallon	ft^3
1	0.0164	0.0043	0.00360	0.58×10^{-3}
61	1	0.264	0.220	0.0353
231	3.785	1	0.834	0.1337
277.46	5.546	1.20	1	0.1605
1728	28.32	7.48	6.23	1

Flow rate

Gal/min (U.S.)	Gal/min (Imp.)	l/s	m^3/h	m^3/d	mgd (U.S.)	mgd (Imp.)
1	0.833	0.063	0.227	5.45		
1.20	1	0.076	0.273	6.55		
15.85	13.198	1	3.600	86.40		
4.40	3.667	0.278	1	24		
183.46	152.765	11.574	41.667	1000		
694.44	579.72	43.811	157.726	3785	1	
834.06	694.445	52.615	189.415	4546	1.200	1

Velocity

m/h	ft/min	cm/sec	ft/sec
1	0.055	0.0278	0.91×10^{-3}
18.3	1	0.508	0.0167
36	1.97	1	0.033
1098	60	30.48	1

Hardness units

The genuine definition of the hardness of water is the sum of the Ca^{2+}-ions plus the Mg^{2+}-ions. Following hardness units are used throughout the world.

	French degree (°F)	German degree (°D)	US° + UK°	Meq /l	mmol/l
1 French degree (°F)	1.00	0.56	10.0	0.20	0.10
1 German degree (°D)	1.78	1.00	17.8	0.36	0.18
1 ppm $CaCO_3$=1°US=1°UK	0.10	0.056	1.0	0.02	0.01
1 meq/l	5.0	2.8	50.0	1.00	0.50
1 mmol/l	10.0	5.6	100.0	2.0	1.00

1 ppm = 1 part per million = 1 milligram per litre = 1 mg/l

1 ppb = 1 part per billion = 1 microgram per liter = 1 g/l

	mmol/l	meq/l	mg/l	°D
Ca^{++}	1	2	40	5,6
Mg^{++}	1	2	24,3	5,6
HCO_3^-	1	1	61	2,8
CO_3^-	1	2	60	5,6
CO_2	1	2	44	-

Hardness classification of waters:		
mg/l $CaCO_3$	°D	Description
0-50	0-2.8	soft
50-100	2.8-5.6	moderately soft
100-150	5.6-8.4	slightly hard
150-200	8.4-11.2	moderately hard
200-300	11.2-16.8	hard
300	16.8	very hard

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- Water utility management practices.
- Water meters; selection, installation, testing and maintenance
- A training course in water distribution
- Simplified procedures for water examination
- Guidelines for the selection of laboratory instruments
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A.W.W.A. Water Supply operations; training course series:

- introduction to water sources and transmission
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