Design of Cold and Hot Water Systems

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Design principles

- Common water supply systems
  - Cold water system
    - Potable/fresh water
    - Flushing (salt water in HK)
    - Cleansing water
    - Fire service
    - Swimming pool filtration
    - Irrigation (e.g. for landscape)
    - Fountain circulation
    - Air-conditioning water, etc.
  - Hot water system (e.g. in hotels & hospitals)

We will focus on these
Design principles

- Major tasks of water systems design:
  - 1. Assessment & estimation of demands
  - 2. Supply scheme & schematic
  - 3. Water storage requirements
  - 4. Piping layout
  - 5. Pipe sizing
  - 6. Pump system design

- The systems must comply with Water Authority (WSD) requirements
Design principles

• General principles for installing plumbing works (from *WSD Plumbing Installation Handbook*)
  • All water fittings and pipework shall comply with the relevant Waterworks Regulations
  • All plumbing works shall be carried out in accordance with the Hong Kong Waterworks Requirements
  • All plumbing works shall be carried out by a licensed plumber
  • System main pipes should preferably not be run through the individual premises

• Also, Building (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrine) Regulations
Design principles

- Plumbing proposal (vetted by WSD)
  - A block plan in a scale of 1:1000 showing the location and boundary of the development
  - The locations should be marked with datum level
  - A plan showing the alignment and size of the proposed connection pipes from the main to the development
  - A plan showing the proposed alignment and size of the internal underground water pipes to be laid in the development
  - Vertical plumbing line diagrams
Example of a plumbing system schematic (fresh & flushing water supplies)

(Source: http://www.arch.hku.hk/teaching/project/f-pl.htm)
Example of plumbing layout design

(Source: http://www.arch.hku.hk/teaching/project/f-pl.htm)
Design principles

• Plumbing proposal (cont’d)
  • A schedule containing the following items :-
    • (a) number of flats/units in each block of the building
    • (b) address of each premise needs individually metered water supply
    • (c) number of draw-off points and sanitary fittings in each unit
    • (d) estimated daily consumption for all trade purposes
  • Meters arranged in meter rooms & fittings at the meter positions
  • The relevant standards for the pipe materials to be used
  • Capacities of the water storage tanks e.g. roof storage tanks
Water demand

- **Water demand** depends on:
  - Type of building & its function
  - Number of occupants, permanent or transitional
  - Requirement for fire protection systems
  - Landscape & water features
- Typical appliances using the cold water
  - WC cistern, wash basin, bath, shower, sink
  - Washing machine, dishwasher
  - Urinal flushing cistern
Water demand

• Theoretical framework: **Probability Theory**
• Based on statistics & a binomial distribution

\[ P_m = \left( \frac{n!}{m!(n-m)!} \right) \times P^m (1 - P)^{n-m} \]

• \( P_m \) = probability of occurrence; \( n \) is the total number of fittings having the same probability and \( m \) is number of fitting in use at any one time

• Probability factor of a particular no. of draw off’s occurring at any one time is:

• \( P = \frac{t - \text{time of appliance filling}}{T - \text{time between successive usage of the appliance}} \)
Example:
If 100 appliances each take 30 sec to be filled, and are used at 1200 sec (20 min) frequency interval, then:

\[ P = \frac{t}{T} = \frac{30}{1200} = 0.025 \]

Using the graph, out of 100 appliances, only 7 would be in use at any one time.

Water demand

• **Simultaneous demand**
  • Most fittings are used only at irregular intervals
  • It is unlikely that all the appliances will be used simultaneously
  • No need to size pipework on continuous max.
• Key factors to consider:
  • Capacity of appliance (litres)
  • Draw-off flow rate (l/s)
  • Draw-off period, or time taken to fill appliance (sec)
  • Use frequency, time between each use (sec)
Water demand

- **Loading Unit (L.U.)**
  - A factor given to an appliance relating the flow rate at its terminal fitting to
    - Length of time in use
    - Frequency of use for a particular type
    - Use of building
  - Evaluate the ‘probable maximum’
  - Relates the flow rate to the probable usage
- Also, consider **design & minimum** flow rates
## Design flow rates and loading units

<table>
<thead>
<tr>
<th>Outlet fitting</th>
<th>Design flow rate (l/s)</th>
<th>Minimum flow rate (l/s)</th>
<th>Loading units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC flushing cistern single or dual flush (to fill in 2 min.)</td>
<td>0.13</td>
<td>0.05</td>
<td>2</td>
</tr>
<tr>
<td>WC trough cistern</td>
<td>0.15 per WC</td>
<td>0.10</td>
<td>2</td>
</tr>
<tr>
<td>Wash basin tap size ½-DN 15</td>
<td>0.15 per tap</td>
<td>0.10</td>
<td>1.5-3.0</td>
</tr>
<tr>
<td>Spray tap or spray mixer</td>
<td>0.05 per tap</td>
<td>0.30</td>
<td>---</td>
</tr>
<tr>
<td>Bidet</td>
<td>0.2 per tap</td>
<td>0.10</td>
<td>1</td>
</tr>
<tr>
<td>Bath tap, ¾-DN 20</td>
<td>0.30</td>
<td>0.20</td>
<td>10</td>
</tr>
<tr>
<td>Bath tap, 1-DN 25</td>
<td>0.60</td>
<td>0.40</td>
<td>22</td>
</tr>
<tr>
<td>Shower head (will vary with type of head)</td>
<td>0.2 hot or cold</td>
<td>0.10</td>
<td>3</td>
</tr>
<tr>
<td>Sink tap, ½-DN 15</td>
<td>0.20</td>
<td>0.10</td>
<td>3</td>
</tr>
<tr>
<td>Sink tap, ¾-DN 20</td>
<td>0.30</td>
<td>0.20</td>
<td>5</td>
</tr>
<tr>
<td>Washing machine size – DN 15</td>
<td>0.2 hot or cold</td>
<td>0.15</td>
<td>---</td>
</tr>
<tr>
<td>Dishwasher size – DN 15</td>
<td>0.15</td>
<td>0.10</td>
<td>3</td>
</tr>
<tr>
<td>Urinal flushing cistern</td>
<td>0.004 per position</td>
<td>0.002</td>
<td>---</td>
</tr>
</tbody>
</table>

Water demand

- Apply probability theory, with caution
  - Assume random usage with fittings (is this true?)
  - Determine max. frequencies of use
  - Estimate average water usage rates & time
- The theory is valid with large nos. of fittings
  - Often expect to be exceeded at 1% time only
  - Reliability and risk management (what is the consequence)
- Need to understand the context/circumstance
  - Is it similar to average/typical? (* adjust data if needed)
  - Any foreseeable special requirements?
Water demand

- Design flow considerations
  - A small increase in demand over design level will cause a slight reduction in pressure/flow (unlikely to be noticed by users)
- Exceptional cases, such as:
  - Cleaners’ sinks (depends on one’s behaviour)
  - Urinal flushing cisterns (constant small flow)
  - Team changing rooms at sport clubs (high demand)
  - Special events (ad hoc demand)
Water storage

- Purposes of *water storage*
  - Provide for an interruption of supply
  - Accommodate peak demand
  - Provide a pressure (head) for gravity supplies

- Design factors
  - Type and number of fittings
  - Frequency and pattern of use
  - Likelihood and frequency of breakdown of supply (often design for 12- or 24-hour reserve capacity)
<table>
<thead>
<tr>
<th>Type of building</th>
<th>Minimum cold water storage (litres)</th>
<th>Minimum hot water storage (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hostel</td>
<td>90 per bed space</td>
<td>32 per bed space</td>
</tr>
<tr>
<td>Hotel</td>
<td>200 per bed space</td>
<td>45 per bed space</td>
</tr>
<tr>
<td>Office premises:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- with canteen facilities</td>
<td>45 per employee</td>
<td>4.5 per employee</td>
</tr>
<tr>
<td>- without canteen facilities</td>
<td>40 per employee</td>
<td>4.0 per employee</td>
</tr>
<tr>
<td>Restaurant</td>
<td>7 per meal</td>
<td>3.5 per meal</td>
</tr>
<tr>
<td>Day school:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- nursery or primary</td>
<td>15 per pupil</td>
<td>4.5 per pupil</td>
</tr>
<tr>
<td>- secondary or technical</td>
<td>20 per pupil</td>
<td>5.0 per pupil</td>
</tr>
<tr>
<td>Boarding school</td>
<td>90 per pupil</td>
<td>23 per pupil</td>
</tr>
<tr>
<td>Children’s home or residential nursery</td>
<td>135 per bed space</td>
<td>25 per bed space</td>
</tr>
<tr>
<td>Nurses’ home</td>
<td>120 per bed space</td>
<td>45 per bed space</td>
</tr>
<tr>
<td>Nursing or convalescent home</td>
<td>135 per bed space</td>
<td>45 per bed space</td>
</tr>
</tbody>
</table>

Note: Minimum cold water storage shown includes that used to supply hot water outlets.

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Storage per occupant (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factories (no process)</td>
<td>10</td>
</tr>
<tr>
<td>Hospitals, per bed</td>
<td>135</td>
</tr>
<tr>
<td>Hospitals, per staff on duty</td>
<td>45</td>
</tr>
<tr>
<td>Hostels</td>
<td>90</td>
</tr>
<tr>
<td>Hotels</td>
<td>135</td>
</tr>
<tr>
<td>Houses and flats</td>
<td>135</td>
</tr>
<tr>
<td>Offices with canteens</td>
<td>45</td>
</tr>
<tr>
<td>Offices without canteens</td>
<td>35</td>
</tr>
<tr>
<td>Restaurant (* per meal)</td>
<td>7</td>
</tr>
<tr>
<td>Schools, boarding</td>
<td>90</td>
</tr>
<tr>
<td>Schools, day</td>
<td>30</td>
</tr>
</tbody>
</table>

(Source: www.engineeringtoolbox.com)
### Estimation of hot water consumption

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Consumption per occupant (litres/day)</th>
<th>Peak demand per occupant (litres/hr)</th>
<th>Storage per occupant (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factories (no process)</td>
<td>22 – 45</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Hospitals, general</td>
<td>160</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>Hospitals, mental</td>
<td>110</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>Hostels</td>
<td>90</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>Hotels</td>
<td>90 – 160</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>Houses and flats</td>
<td>90 – 160</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>Offices</td>
<td>22</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Schools, boarding</td>
<td>115</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Schools, day</td>
<td>15</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

(Source: www.engineeringtoolbox.com)
<table>
<thead>
<tr>
<th>Type of fixture</th>
<th>Flow rate (litres/min)</th>
<th>Minimum supply pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathtub faucet</td>
<td>19</td>
<td>55</td>
</tr>
<tr>
<td>Bidet</td>
<td>7.5</td>
<td>28</td>
</tr>
<tr>
<td>Laundry machine</td>
<td>15</td>
<td>55</td>
</tr>
<tr>
<td>Lavatory faucet, ordinary</td>
<td>7.5</td>
<td>55</td>
</tr>
<tr>
<td>Lavatory faucet, self closing</td>
<td>10</td>
<td>55</td>
</tr>
<tr>
<td>Shower head</td>
<td>19</td>
<td>55</td>
</tr>
<tr>
<td>Shower, temperature controlled</td>
<td>10</td>
<td>138</td>
</tr>
<tr>
<td>Sink 3/8&quot;, 1/2&quot;</td>
<td>17</td>
<td>55</td>
</tr>
<tr>
<td>Sink 3/4&quot;</td>
<td>23</td>
<td>55</td>
</tr>
<tr>
<td>Urinal flush valve</td>
<td>56</td>
<td>110</td>
</tr>
<tr>
<td>Water closet with flush valve</td>
<td>132</td>
<td>170</td>
</tr>
<tr>
<td>Water closet with gravity tank</td>
<td>10</td>
<td>55</td>
</tr>
</tbody>
</table>

(Source: www.engineeringtoolbox.com)
Fixtures, cold water storage, hot water consumption & flow rate

<table>
<thead>
<tr>
<th>Type of fixture</th>
<th>Cold water storage capacity (litres)</th>
<th>Hot water consumption (litre/hr)</th>
<th>Hot water flow rate (litre/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin (private)</td>
<td>90</td>
<td>14</td>
<td>0.08</td>
</tr>
<tr>
<td>Basin (public)</td>
<td>90</td>
<td>45</td>
<td>0.08</td>
</tr>
<tr>
<td>Bath</td>
<td>900</td>
<td>90 – 180</td>
<td>0.15</td>
</tr>
<tr>
<td>Garden water tap</td>
<td>180</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Shower</td>
<td>450 – 900</td>
<td>180</td>
<td>0.5 – 0.6</td>
</tr>
<tr>
<td>Sink</td>
<td>90</td>
<td>45 – 90</td>
<td>0.15</td>
</tr>
<tr>
<td>Urinal</td>
<td>180</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>WC</td>
<td>180</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

(Source: www.engineeringtoolbox.com)
Quantity of flushing water required

<table>
<thead>
<tr>
<th>User</th>
<th>Average demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic buildings</td>
<td>450 litres per number of required soil fitment per day</td>
</tr>
<tr>
<td>Offices, factories, department stores, shops, public buildings and other nondomestic buildings of a like nature</td>
<td>450 litres per number of required soil fitment per day</td>
</tr>
<tr>
<td>Restaurants</td>
<td>13.5 litres per seat per day</td>
</tr>
<tr>
<td>Cinemas</td>
<td>4.5 litres per seat per day</td>
</tr>
<tr>
<td>Schools</td>
<td>18 litres per head per day</td>
</tr>
<tr>
<td>Hotels and boarding houses</td>
<td>90 litres per room per day</td>
</tr>
</tbody>
</table>

(Source: Buildings Department HK, PNAP 17)
Water storage

- Minimum hot water storage capacities for dwelling (from BS6700)
  - 35-45 litre per occupant (unless the heat source provides a quick recovery rate)
  - 100 litres for systems heated by solid fuel boilers
  - 100 litres for systems heated by off-peak electricity
Water storage

- Recovery rate and hot water storage
  - Recovery period = time to heat up the stored water
  - Too high a storage volume: unnecessary costs
  - Inadequate storage: loads not met
  - Need to consider the following factors:
    - Pattern of use
    - Rate of heat input to the stored water
    - Recovery period for the hot water storage vessel
    - Any stratification of the stored water
### Typical heat input values

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Heat input (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric immersion heater</td>
<td>3</td>
</tr>
<tr>
<td>Gas-fired circulator</td>
<td>3</td>
</tr>
<tr>
<td>Small boiler and direct cylinder</td>
<td>6</td>
</tr>
<tr>
<td>Medium boiler and indirect cylinder</td>
<td>10</td>
</tr>
<tr>
<td>Directly gas-fired storage hot water heater (domestic type)</td>
<td>10</td>
</tr>
<tr>
<td>Large domestic boiler and indirect cylinder</td>
<td>15</td>
</tr>
</tbody>
</table>

**Effects of stratification**

(a) Bottom entry heater:
- More even temperature throughout cylinder

(b) Top entry heater:
- Hot at top
- Warm
- Cold at bottom

(c) Twin entry heater:
- Hot
- Warm
- Cold

Water storage

• Formula to calculate recovery period
  \[ M = \frac{V \cdot T}{(14.3 \cdot P)} \]
  - \( M \) = time to heat the water (min.)
  - \( V \) = volume of water heated (litres)
  - \( T \) = temperature rise (°C)
  - \( P \) = rate of heat input to the water (kW)
• It can be applied to any pattern of use
• It ignores heat losses from storage vessel
Example: A small dwelling with one bath. Maximum requirement: 1 bath (60 litre at 60ºC + 40 litre cold water) plus 10 litre hot water at 60ºC for kitchen use, followed by a second bath fill after 25 min. Thus, a draw-off of 70 litre at 60ºC is required, followed after 25 min by 100 litre at 40ºC, which may be achieved by mixing hot at 60ºC with cold at 10ºC.

Answer:
1) Assume good stratification (by heating w/ a top entry heater)
   With 3kW heat input, the time to heat the 60 litre for the second bath from 10ºC to 60ºC:
   \[ M = \frac{VT}{(14.3P)} = \frac{60 \times 50}{14.3 \times 3} = 70 \text{ min.} \]
   The second bath is required after 25 min., thus it has to be form storage. But in the 25 min. the volume of water heated to 60ºC is:
   \[ V = \frac{M(14.3)}{T} = \frac{25 \times 14.3 \times 3}{50} = 21 \text{ litre} \]
   Therefore, the minimum required storage capacity is:
   \[ 70 + 60 - 21 = 109 \text{ litre} \]
**Example: (Cont’d)**

2) **Assume good mixing of the stored water (by a primary coil in an indirect cylinder)**

After the first bath & kitchen use, the heat energy in the 70 litre replacement at 10ºC equals the heat energy of the water in the full cylinder. If $V$ is the min. size of the storage and $T$ is the water temperature in the cylinder after refilling:

$$(V - 70) \times 60 + (70 \times 10) = VT$$

$$T = (60V - 4200 + 700)/V \quad \text{or} \quad T = 60 - 3500/V$$

The second bath is required after 25 min. With 3 kW heat input:

$$25 = VT / (14.3 \times 3)$$

and temperature rise $T = (25 \times 14.3 \times 3)/V = 1072.5/V$

A temperature of at least 40ºC is required to run the second bath. Therefore the water temperature of the refilled cylinder after the first draw-off, plus the temperature rise after 25 min., must be at 40ºC, or:

$$(60 - 3500/V) + (1072.5V) = 40 \ (or \ more)$$

$$60 - 2427.5/V = 40$$

$$V = \underline{122 \ \text{litre}}$$

### Hot water storage vessel – minimum capacities

<table>
<thead>
<tr>
<th>Heat input for water (kW)</th>
<th>Dwelling with 1 bath</th>
<th>Dwelling with 2 baths*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With stratification litres</td>
<td>With mixing litres</td>
</tr>
<tr>
<td>3</td>
<td>109</td>
<td>122</td>
</tr>
<tr>
<td>6</td>
<td>88</td>
<td>88</td>
</tr>
<tr>
<td>10</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>15</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

Note: * Maximum requirement of 150 litre drawn off at 60ºC (2 baths plus 10 litre for kitchen use) followed by a further bath (100 litre at 40ºC) after 30 min.

Pipe sizing

- Correct pipe sizes will ensure adequate flow rates at appliances and avoid problems, e.g.
  - **Oversizing**
    - Additional & unnecessary installation costs
    - Delays in obtaining hot water at outlets
    - Increased heat losses from hot water pipes
  - **Undersizing**
    - Inadequate delivery from outlets
    - Some variation in temperature & pressure at outlets (e.g. showers and other mixers)
    - Some increase in noise levels
- For small, simple installations, pipes are often sized based on experience & convention
Available head (from cistern) = vertical distance in metres from water line in cistern to point under consideration

Available head (mains supply) = head at main minus height above main = 20 m – 4 m = 16 m head

1 m head = 9.81 kPa = 98.1 mbar

Pipe sizing

- Pipe sizing procedure
  - (a) Assume a pipe diameter
  - (b) Determine the flow rate:
    - 1) by using loading units
    - 2) for continuous flow
    - 3) obtain the design flow rate by adding 1) and 2)
  - (c) Determine the effective pipe length:
    - 4) work out the measured pipe length
    - 5) work out the equivalent pipe length for fittings
    - 6) work out the equivalent pipe length for draw-offs
    - 7) obtain the effective pipe length by adding 4), 5) & 6)
Pipe sizing

- Pipe sizing procedure (cont’d)
  - (d) Calculate the permissible loss of head:
    - 8) determine the available head
    - 9) determine the head loss per metre run through pipes
    - 10) determine the head loss through fittings
    - 11) calculate the permissible head loss
  - (e) Determine the pipe diameter:
    - 12) decide whether the assumed pipe size will give the design flow rate in 3) without exceeding the permissible head loss in 11)
- Usually, flow velocities shall be < 3 m/s
Example of use of loading units

12 wash basins × 1\(\frac{1}{2}\) = 18
10 WCs × 2 = 20
2 urinal bowls × = =
2 cleaners’ sinks × 3 = 6
Total loading units = 44

Required design flow (from graph) = 0.7 l/s

Example of measured & effective pipe lengths

Measured pipe length = 4.75 m
Equivalent pipe lengths:
- elbows \(2 \times 0.8 = 1.6\ m\)
- tee \(1 \times 1.0 = 1.0\ m\)
- stopvalve \(1 \times 7.0 = 7.0\ m\)
- taps \(2 \times 3.7 = 7.4\ m\)
- check valves \(2 \times 4.3 = 8.6\ m\)

Effective pipe length = \(30.35\ m\)

Note: There is no need to consider both branch pipes to taps.

<table>
<thead>
<tr>
<th>Bore of pipe (mm)</th>
<th>Elbow</th>
<th>Tee</th>
<th>Stopvalve</th>
<th>Check valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.5</td>
<td>0.6</td>
<td>4.0</td>
<td>2.5</td>
</tr>
<tr>
<td>20</td>
<td>0.8</td>
<td>1.0</td>
<td>7.0</td>
<td>4.3</td>
</tr>
<tr>
<td>25</td>
<td>1.0</td>
<td>1.5</td>
<td>10.0</td>
<td>5.6</td>
</tr>
<tr>
<td>32</td>
<td>1.4</td>
<td>2.0</td>
<td>13.0</td>
<td>6.0</td>
</tr>
<tr>
<td>40</td>
<td>1.7</td>
<td>2.5</td>
<td>16.0</td>
<td>7.9</td>
</tr>
<tr>
<td>50</td>
<td>2.3</td>
<td>3.5</td>
<td>22.0</td>
<td>11.5</td>
</tr>
<tr>
<td>65</td>
<td>3.0</td>
<td>4.5</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>73</td>
<td>3.4</td>
<td>5.8</td>
<td>34.0</td>
<td>---</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal size of tap</th>
<th>Flow rate (l/s)</th>
<th>Head loss (m)</th>
<th>Equiv. pipe length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1/2- DN 15</td>
<td>0.15</td>
<td>0.5</td>
<td>3.7</td>
</tr>
<tr>
<td>G1/2- DN 15</td>
<td>0.20</td>
<td>0.8</td>
<td>3.7</td>
</tr>
<tr>
<td>G3/4- DN 20</td>
<td>0.30</td>
<td>0.8</td>
<td>11.8</td>
</tr>
<tr>
<td>G1- DN 25</td>
<td>0.60</td>
<td>1.5</td>
<td>22.0</td>
</tr>
</tbody>
</table>

Permissible head loss = \( \frac{\text{available head (45 m)}}{\text{effective pipe length (30.55 m)}} \)

= 1.48 m/m run

**Example of permissible head loss**

Determination of pipe diameter

- **Loss of head:** 0.12 m/m run
- **Pipe size:** 20 mm
- **Flow velocity:** 1.4 m/s
- **Design flow rate:** 0.4 l/s

Lamont's smooth pipe formula S3:

\[
V = 0.552 \ d^{0.6936} \ j^{0.5848}
\]

Where:
- \( V \) is velocity (m/s)
- \( d \) is diameter (mm)
- \( j \) is hydraulic gradient

*Note: Figures shown are for cold water at 12°C. Hot water will show slightly more favourable head loss results.*

### Maximum recommended flow velocities

<table>
<thead>
<tr>
<th>Water temperature (°C)</th>
<th>Flow velocity (m/s)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pipes readily accessible</td>
<td>Pipes not readily accessible</td>
</tr>
<tr>
<td>10</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>50</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>70</td>
<td>2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>90</td>
<td>2.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Note: Flow velocities should be limited to reduce system noise.

Pipe sizing

• Pipe sizing & design using tabular methods
• Systematic way to design
• Can also be done using spreadsheet or computer

Table D.4  Example of pipe sizing calculations for cold water services

<table>
<thead>
<tr>
<th>Pipe reference</th>
<th>Flow rate</th>
<th>Pipe size</th>
<th>Velocity</th>
<th>Head loss</th>
<th>Drop + Rise</th>
<th>Available head (7 + 14)</th>
<th>Pipe length</th>
<th>Head loss</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Design</td>
<td>m</td>
<td>kPa/m</td>
<td>kPa</td>
<td>kPa</td>
<td>m</td>
<td>m</td>
<td>kPa</td>
</tr>
<tr>
<td>m</td>
<td>LU</td>
<td>l/s</td>
<td>DN</td>
<td>m/s</td>
<td>kPa</td>
<td>kPa</td>
<td>m</td>
<td>kPa</td>
<td>kPa</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
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<td>10</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>

Main service pipe – for this example the minimum head in main = 300 kPa (3 bar)

1 to 2      | 9 + list  | 0.6 + 0.3 | 28       | 1.7       | 1.4         | −50                      | 250         | 25        | 35       |
2 to 3      | 6 + list  | 0.4 + 0.2 | 22       | 2.0       | 2.5         | −30                      | 150         | 3         | 4.2      |
3 to 4      | 3 + list  | 0.2 + 0.1 | 15       | 2.2       | 5           | −30                      | 109         | 3         | 4.2      |
4 to 5      | 3 + list  | 0.2 + 0.1 | 15       | 2.2       | 5           | 0                       | 100         | 1         | 1.4      |
5 to 6      | 5         | 15        | 1.5      | 1.5       | 1.5         | 0.75                     | 0.6         | 0.6       | 0.6      |
5 to 7      | 6         | 15        | 1.5      | 1.5       | 1.5         | 0.75                     | 0.6         | 0.6       | 0.6      |

sink float valve (5 mm φ) | 5 | 1 | 63 | 67 | 30 | 37 | 58 | 37
Pipe sizing

- Pipe sizing for hot water systems
  - The same as cold water, except cold feed pipe must also be considered

- Useful formulae for pipes:
  - Thomas Box formula
    - See example
  - Relative discharging power
    - See example

\[
q = \sqrt{\frac{d^5 \times H}{25 \times L \times 10^5}}
\]

\[
N = \sqrt{\left(\frac{D}{d}\right)^5}
\]
**Example:** Determine the pipe size using **Thomas Box formula**.

\[ q = \sqrt[5]{\frac{d^5 \times H}{25 \times L \times 10^5}} \]

where

- \( d \) = pipe diameter (mm) 
- \( q \) = flow rate (l/s) 
- \( H \) = head or pressure (m) 
- \( L \) = effective length of pipe (actual length + allowance for bends, tees, etc.)

**Answer:** Using Thomas Box formula,

\[ d = \sqrt[5]{\frac{(1)^2 \times 25 \times 20 \times 10^5}{3}} = 27.83 \text{ mm} \]

Hence, the nearest commercial size is 32 mm bore steel or 35 mm outside diameter copper.

Example: Relative discharge of pipes

\[ N = \sqrt{\left( \frac{D}{d} \right)^5} \]

where \( N \) = number of short branch pipes
\( D \) = diameter of main pipe (mm)
\( d \) = diameter of short branch pipes (mm)

(a) The number of 32 mm short branch that can be served from 150 mm main.

**Answer:** \[ N = \sqrt{\left( \frac{150}{32} \right)^5} = 47 \]

(b) The size of water main required to supply 15 nos. 20 mm short branch pipes.

**Answer:** \[ D = d \times 5\sqrt{N^2} = 20 \times 5\sqrt{15^2} = 59 \]

Hence, the nearest commercial size is 65 mm.

Pipe materials

- Design & selection factors:
  - Effect on water quality
  - Cost, service life and maintenance needs
  - For metallic pipes, internal and external corrosion
  - Compatibility of materials
  - Ageing, fatigue and temperature effects, especially in plastics
  - Mechanical properties and durability
  - Vibration, stress or settlement
  - Internal water pressure
Pipe materials

- Commonly used pipe materials, such as:
  - Copper (BS EN 1057)
  - Galvanised iron (GI) with PVC-C lining (BS 1387)
  - PVC, unplasticized PVC, PB, PE, PE-X
  - Stainless steel (BS 4127)
  - Ductile iron (BS EN 545) (for pipe dia. > 80 mm)
  - Mild steel (for pipe dia. > 600 mm)
- * Plastic material generally will degrade on prolonged exposure to ultra-violet light
Copper pipe

Lined galvanized steel pipe

Polyethylene pipe

Rusty unlined galvanized steel pipe

## Common pipe materials in fresh water plumbing systems

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Cold Water</th>
<th>Hot Water</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>✓</td>
<td>✓</td>
<td>BS EN 1057</td>
</tr>
<tr>
<td>Ductile iron</td>
<td>✓</td>
<td>✓</td>
<td>BS EN 545</td>
</tr>
<tr>
<td>Galvanised iron (GI) with PVC-C lining</td>
<td>✓</td>
<td>✓</td>
<td>BS 1387</td>
</tr>
<tr>
<td>GI with PVC-U/PE lining</td>
<td>✓</td>
<td>X</td>
<td>BS 1387</td>
</tr>
<tr>
<td>Polybutylene (PB)*</td>
<td>✓</td>
<td>✓</td>
<td>BS 7291</td>
</tr>
<tr>
<td>Polyethylene (PE)*</td>
<td>✓</td>
<td>X</td>
<td>BS 6572 (below ground)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>X</td>
<td>BS 6730 (above ground)</td>
</tr>
<tr>
<td>Chlorinated polyvinyl chloride (PVC-C)</td>
<td>✓</td>
<td>✓</td>
<td>BS 7291</td>
</tr>
<tr>
<td>Unplasticized polyvinyl chloride (PVC-U)</td>
<td>✓</td>
<td>X</td>
<td>BS 3505 Class D or above</td>
</tr>
<tr>
<td>Crosslinked polyethylene (PE-X)</td>
<td>✓</td>
<td>✓</td>
<td>BS 7291</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>✓</td>
<td>✓</td>
<td>BS 4127</td>
</tr>
</tbody>
</table>

Pipe materials

- Classification of pipe materials
  - **Metallic**
    - Copper
    - Stainless steel
  - **Thermoplastics**
    - PVC-U, PVC-C
    - Polyethylene (PE)
    - Medium Density Polyethylene (MDPE)
    - High Density Polyethylene (HDPE)
    - Crosslinked Polyethylene (PEX)
Pipe materials

- Classification of pipe materials (cont’d)
  - Thermoplastics (cont’d)
    - Polybutylene (PB)
    - Acrylonitrile Butadiene Styrene (ABS)
  - Composite
    - Lined galvanised steel
    - Crosslinked Polyethylene/Aluminium/Crosslinked Polyethylene Composite Pressure Pipe (PEX-AL-PEX)
    - High Density Polyethylene/Aluminium/ High Density Polyethylene (HDPE-AL-HDPE)
Pipe materials

- **Copper pipes (BS EN 1057)**
  - **Advantages:**
    - High pressure capability
    - Good formability
    - Good corrosion resistance
    - High strength & durability to withstand external loading
    - Ease of jointing (compression & capillary joints)
    - Smooth surface: low resistance to water flow
    - Suitable for conveying hot water
  - **Disadvantages:**
    - Soft water can cause internal corrosion attack (give rise to ‘blue’ water)
Pipe materials

- **Stainless steel (BS 4127)**
  - **Advantages:**
    - High pressure capability
    - Good corrosion resistance
    - High strength & durability
    - Ease of jointing
    - Good resistance to accidental damage
    - Suitable for conveying hot water
  - **Disadvantage:**
    - More expensive than copper
Pipe materials

- **Lined galvanised steel**
  - PVC-U/PVC-C/Polyethylene or epoxy resin lined
  - **Advantages:**
    - Good resistance to internal corrosion & encrustation
    - Smooth surface: lower resistance to water flow
    - Can be used in vulnerable conditions e.g. exposure to direct sunlight & traffic loads
    - Readily compatible with existing commonly used unlined steel pipe
  - **Disadvantages:**
    - Heavy weight
    - Susceptible to impact damage (great care in handling)
    - Higher skills required for cutting, threading, jointing
Pipe materials

- **PVC-U (BS 3505 Class D)**
  - **Advantages:**
    - Good corrosion resistance
    - Light weight, low cost
    - Ease of jointing
    - Smooth surface: low resistance to water flow
    - Not a conductor of electricity (no galvanic/oxidative corrosion)
  - **Disadvantages:**
    - Brittle, susceptible to impact damage
    - Long drying time of solvent cement in jointing
    - Low abrasion resistance
    - Permeation/degradation by certain organic contaminants
    - UV degradation on prolonged exposure to sunlight
    - Not suitable for hot water supply
Pipe materials

- **PVC-C (BS 7291)**
  - **Advantages:**
    - Suitable for conveying hot water
    - Good corrosion resistance & chemical resistance
    - Light weight
    - Smooth surface: low resistance to water flow
    - Not a conductor of electricity (no galvanic/oxidative corrosion)
    - Can be connected to other materials easily
  - **Disadvantages:**
    - Brittle, susceptible to impact damage
    - Long drying time of solvent cement in jointing
    - Can be flammable
    - Reduction in strength & rigidity with increase of temperature
    - Permeation/degradation by certain organic contaminants
    - Can be attacked by detergents & oxidizing agents
    - UV degradation on prolonged exposure to sunlight
Pipe materials

- **MDPE (BS 7291)**
  - **Advantages:**
    - Good corrosion resistance
    - Good formability
    - Light weight
    - Fusion & mechanical joint available
    - Smooth surface: low resistance to water flow
    - Strong & tough
    - Flexible & durable, light & easy to handle
    - Good resistance to impact
  - **Disadvantages:**
    - Fusion jointing requires skilled installers & special equipment
    - Subject to creep
    - Strength decrease with time (at a very slow rate)
    - UV degradation on prolonged exposure to sunlight
    - Permeation/degradation by certain inorganic & organic contaminants
Pipe materials

- **Jointing of pipes**
  - Copper pipes
    - Capillary solder or brazed joints
    - Autogenous welding
    - Compression, push, press/crimp fittings
  - Steel pipes
    - Screwed joints, with pipe threads
    - Flange joints (screwed or welded flanges)
  - Stainless steel pipes
    - Compression, capillary, push, press/crimp fittings (but not joined by soft soldering)
Pipe materials

- **Jointing of pipes (cont’d)**
  - Unplasticized PVC pipes
    - Mechanical joints
    - Compression joints
    - Solvent cement welded joints
    - Flange joints
  - Polyethylene (PE) & polybutylene (PB) pipes
    - Mechanical joints (e.g. push-fit), thermal fusion
  - Acrylonitrile Butadiene Styrene (ABS) pipes
    - Similar to PVC-U pipes
Pump systems

• Centrifugal pumps are commonly used
  • Vertical and horizontal
  • Single & multiple stages
• Two types of systems:
  • Closed systems
    • Recirculation
  • Open systems
    • Open to atmosphere
Main characteristics of centrifugal & positive displacement pumps

<table>
<thead>
<tr>
<th>Centrifugal pumps</th>
<th>Positive displacement pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Capacity varies with head</td>
<td>- Capacity substantially independent of head</td>
</tr>
<tr>
<td>- Capacity proportional to pump speed</td>
<td>- Capacity proportional to speed</td>
</tr>
<tr>
<td>- Head proportional to the square of pump speed</td>
<td>- Self-priming</td>
</tr>
<tr>
<td>- Non self-priming</td>
<td>- Suitable for various liquids (reduced speeds usually necessary for high viscosity)</td>
</tr>
<tr>
<td>- Suitable for low-viscosity liquid</td>
<td></td>
</tr>
</tbody>
</table>
Pump pressure effects in an open system

\[ \text{Neutral point} \]

\[ \text{Suction lift } h \]

\[ \text{Negative pump pressure} \]

\[ \text{Positive pump pressure} \]

\[ h = 10.33 \text{ m} \]

\[ \text{atmospheric pressure} = 101,325 \text{ Pa} \]

\[ = h \times \text{density} \times 9.81 \]

Thus, \( h = 10.33 \text{ m} \)

Pump pressure effects in an open system
Pump systems

• Pump considerations
  • Practical suction lift is 5 m maximum
  • Also known as net positive suction head (NPSH)
• Pump location is important for both closed and open systems
  • **Open system**: not excessive to avoid cavitation
  • **Close system**: Influence water level of open vent pipe & the magnitude of antiflash margin (temp. difference between water & its saturation temp.)
  • ‘Self-priming’ to evacuate air from suction line
Pump systems

• Pump characteristics
  • Characteristics curves (e.g. from catalogue):
    • Total head
    • Power
    • efficiency
  • No-flow conditions (flow = zero)
    • Close valve pressure
    • Need to prevent over-heat

• Pump power \( (W) = \text{flow} \ (L/s) \times \text{pressure} \ (kPa) \)
Pump characteristics curves (centrifugal)
Characteristic curves for pump models

(Source: Fundamentals of Water System Design)
Selected pump pressure-capacity curve
(Source: Fundamentals of Water System Design)
Pump systems

- Pump characteristics (cont’d)
  - Pumps with steep characteristics
    - Change in pressure -> small change in flow rate
    - Useful where pipes tend to scale up
  - Pumps with flat characteristics
    - Change in flow -> small change in pressure
    - Useful where extensive hydraulic balancing is needed
What does this imply?

Flat versus steep pump curves

(Source: Fundamentals of Water System Design)
Pump systems

• Pump characteristics (cont’d)
  • Pumps with constant speed cannot respond to changes in load
    • Require a bypass to ensure constant flow
  • Variable speed pumps
    • Provides for savings in pumping costs during partial load
  • Pump materials to suit the environment, e.g. stainless steel pumps for salt water system
Other considerations

- Noise & vibration
  - Pipe noise
    - Pipe should not be fixed rigidly to lightweight panels
  - Flow noise
    - Keep velocities under control
  - Pump noise
    - Use rubber hose isolators, resilient inserts, acoustic filters
Other considerations

- **Water hammer**
  - Such as when a valve is closed rapidly
  - Pulsating type of noise by shock waves
- **Preventive measures:**
  - Prevent sudden closing of the valve
  - Absorb pressure peaks (e.g. by pneumatic vessels)
  - Increase the attenuation of pressure waves when transmitted through the pipework
  - Design the pipework to avoid long straight pipe runs
  - Restrict water velocities (e.g. to a maximum of 3 m/s)
Other considerations

- Back siphonage
  - Occur when water mains pressure reduce greatly
  - Contamination of water may happen
  - Contamination might also occur due to gravity & backpressure backflow
  - Anti-siphonage device and design precautions
Other considerations

- **Water economy & energy conservation**
  - **Economy of water**
    - A key factor in the design (to conserve water)
  - **Measures:**
    - Detect water leakage
    - Reduce water consumption
    - Reuse or recycle water

- **Energy conservation**
  - Insulation of hot water pipe, fittings & vessels
  - Use of fresh water for cooling tower make-up
Other considerations

- Water efficiency labelling scheme will be launched in HK soon
- Water saving devices
  - Low-flow showerheads
  - Taps with flow restrictors
  - Flow control valves
  - Washing machines & dish-washers with high water efficiency
  - Water plugs, self-closing taps, spray taps, aerators, etc.
Other considerations

- Water conservation (flushing water)
  - Low-water and pressure flushing cisterns
  - Dual-flush toilet cisterns
  - Urinal controls

- Water reuse and recycling
  - Rainwater reuse/recycling
  - Grey water recycling
Example: Rainwater recycling system for house

(Source: www.bsenotes.com)