

OM2025

Design for Fire Safety 1



Chapter 1

Introduction to Fire Safety & Principles of Hydraulics

Students are required to note-down additional points taught or discussed in the classroom

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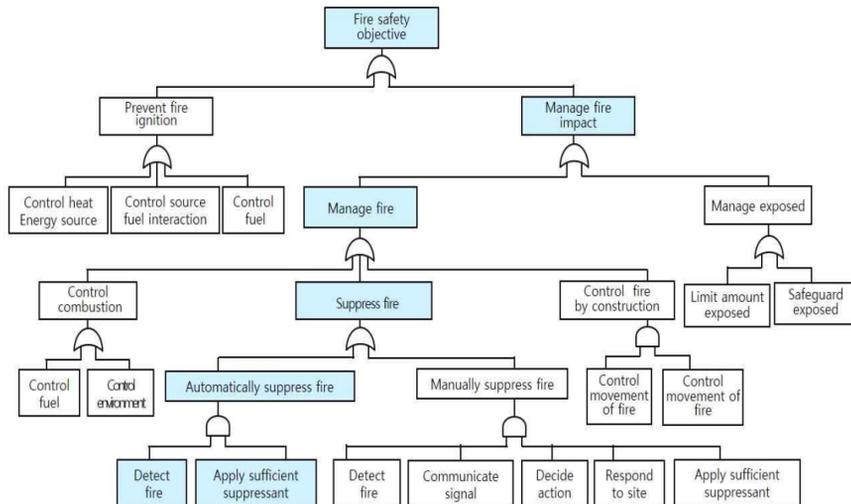
Fire safety objectives

- First thing the fire protection engineer may do when engaged in a development project is **to consult the relevant building codes and regulations** to seek guidance and to establish the legal requirements.
- A Fire Safety Strategy can be defined as a plan on how to use one or a combination of fire protection measures to achieve predetermined **fire safety objectives**.
- There could be one or more fire safety objectives in a project:
 - Life Safety
 - Property protection
 - Business and reputation protection
 - Environmental protection and sustainability

Source: ▼

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Fire safety objectives



NFPA 550 Guide to the Fire Safety Concept Tree

Source: ▼

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FIRE PROTECTION

Commonly two types of fire protection measures are widely adopted.

- **Active fire protection systems**

- **Passive fire protection systems**

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Active Fire Protection

- Active control refers to control of the fire by some action taken by a person or an automatic device.
- The best form of active fire protection is an water-based fire protection systems which use water over a local area where fire has taken place. AFP will extinguish most fires, and prevent growth of others.
- AFP controls of smoke spread which requires the operation of fans or other devices to remove smoke from certain areas or to pressurize stairwells.
- Occupants can prevent ignition or extinguish very small fires utilizing AFP.
- Fire-fighters can actively control or extinguish a fire.

Source: 0

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Passive fire protection

- Passive control refers to fire control by systems that are built into the structure or fabric of the building, not requiring operation by people or automatic controls.
- For pre-flashover fires, passive control includes selection of suitable materials for building contents and interior linings that do not support rapid flame spread in the growth period.
- In post-flashover fires, passive control is provided by structures and assemblies which have sufficient fire resistance to prevent both spread of fire and structural collapse.

Source: 0

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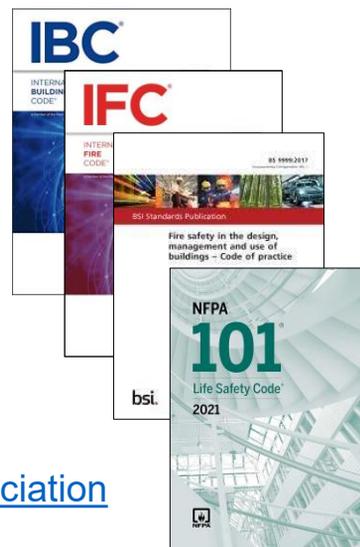
Examples ???

AFP	PFP

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Fire Safety Codes and Standards

- [International Building Code](#)
- [International Fire Code](#)
- [British Standards](#)
- [National Fire Protection Association](#)



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- DG of Civil Defence (Building Fire P & P requirements), 2002
- UAE Fire and Life Safety Code of practice, 2018
- Saudi Fire Protection Code and The Saudi building code, 2024
- Qatar Civil Defense Code, 2015



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TASK 1

Tabulate “*classification of occupancy*” as per NFPA standards, UK Building Regulations and BFPPR Document No. 77/2002.

- Submit your answers on or before **19/02/2026** on BlackBoard
- Your report should provide necessary citations and references.

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Introduction to Fire Hydraulics

- The term hydraulics refers to the study of the behaviour of water both when it is in motion or/and when it is at rest. In this chapter, we will be –
 - understanding the **behaviour of water** in relation to the operation of fire service equipment.
 - able to make **informed decisions** concerning the **supply** and **delivery** of water in the dynamic arena of the fireground.
 - able to make **effective arrangements** for the provision of water supplies at the pre-planning stage.

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The Properties of Water

- **Water is nearly incompressible.** This allows water to be moved to where it is needed. Pressure applied to one end of a hose moves the water to the other end of the hose where the fire is located. (Only at extreme pressures water can be compressed. Since these types of pressure are not used in firefighting, water can be considered incompressible.)
- **Water seeks its own level.** As water is poured into one side of a container, the surface will remain level. Figure shows that as water is poured into side A, the level in side B will reach the same height. This also means that water will flow downhill or into lower levels of a structure.

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- **Water has weight.** A litre of water has a mass of 1 kilogram (kg), and a cubic metre, which is for all practical purposes 1000 litres, therefore has a mass of 1000kg or 1 tonne.

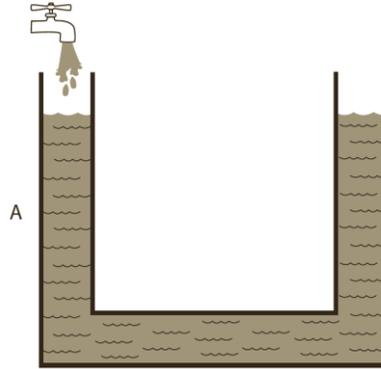


Figure: Water seeks its own level.

$$\text{weight} = m \cdot g \quad (N)$$

- where g is the acceleration due to gravity. The value of g varies very slightly over the surface of the earth but, to a close approximation, it is 9.81 metres per second per second (9.81 m/s^2), so the weight of 1 kilogram of water is:

$$1 \times 9.81 = 9.81 \text{ N}$$

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- A cubic metre of water therefore exerts a downward force of 9810 N (1000×9.81), or 9.81 kilonewtons (kN).

1 litre of water weighs 10 newtons
1 cubic metre of water weighs 10000 newtons

- Pure water has a freezing point of 0°C and a boiling point of 100°C , both at normal atmospheric pressure (1 bar approx.).

Source: ◉

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As good as water is as an extinguishing agent, it also has some disadvantages:

- Water **freezes**. As anyone who has fallen on ice knows, this can be dangerous. It can also prevent equipment from working properly.
- Water **conducts electricity**. This prevents its use for electrical fires, since the electricity can travel through the water to the nozzle operator.
- Water **reacts violently** with some chemicals. Magnesium, for example, burns at nearly explosive force.
- Water is **not viscous**. This means that water doesn't do well at smothering fires.

Source: ☹

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Principal characteristic of pressure

- In many applications in life, the terms pressure and force are used interchangeably. In hydraulics, there needs to be a distinction. Pressure has some meaning to nearly everyone.
- Pressure is defined as force per unit area. If force (F) is applied to the surface area (A) of a fluid in a perpendicular manner, then the pressure (P) may be defined as follows:

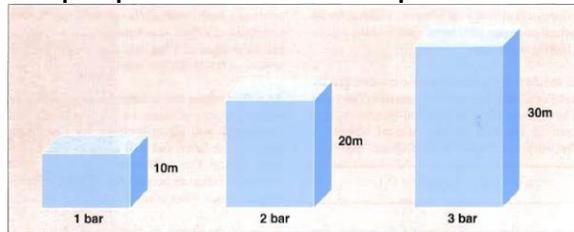
$$P = \frac{F}{A}$$

- The S.I. unit of pressure is the newton per square metre (N/m²) another name for which is the Pascal. The relationship between these units is:

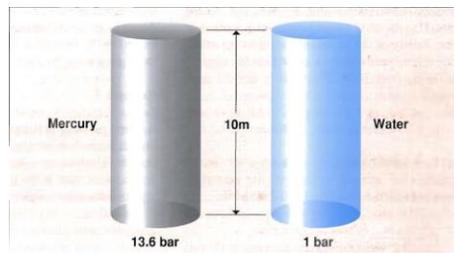
$$1 \text{ bar} = 100000 \text{ N/m}^2 \text{ or } 10^5 \text{ N/m}^2$$

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- Downward pressure of a fluid in an open vessel is proportional to its depth.



- The downward pressure of a fluid in an open vessel is proportional to the density of the fluid.



Source: ☺

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Relationship between Pressure and Head for Water

- The pressure of a liquid contained in an open vessel is proportional both to the depth of the liquid and to its density. The precise relationship for pressure is:

$$P = H\rho g$$

- where p is the pressure in newtons per square metre, H is the head (depth) of liquid in metres, ρ is the density of the liquid in kilograms per cubic metre (kg/m^3) and g is the acceleration due to gravity.
- For water:

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$$P = H \times 1000 \times 9.81 \frac{N}{m^2}$$

$$P = H \times 0.0981 \text{ bar}$$

- Transposing this formula to find Head, we have:

$$H = \frac{P}{0.0981} \text{ m}$$

Source: ◉

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Loss of Pressure due to Friction

- When water flows through a hose or pipe there is a gradual loss of pressure resulting from the need to overcome the frictional resistance which exists between the moving water stream and the internal surface of the hose or pipe.

Laws governing loss of pressure due to friction

1. P_r is directly proportional to the length (l) of hose through which the water flows.

$$P_r \propto l$$

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2. P_r is directly proportional to a quantity called the friction factor (t) for the hose (determined largely by the roughness of its inside surface).

$$P_r \propto f$$

Diameter of hose	Friction factor
38mm, 45mm, 64mm and 70mm	0.005
90mm with standard instantaneous couplings	0.007
90mm with full flow couplings	0.005
100mm and 125mm	0.004
150mm	0.003

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3. P_r is directly proportional to the square of the flowrate (L).

$$P_r \propto L^2$$

Thus, for example, if the flowrate through a line of hose is doubled, the pressure loss due to friction will be increased by a factor of four.

4. P_r is inversely proportional to the fifth power of the hose diameter (d).

$$P_r \propto \frac{1}{d^5}$$

Diameter is the most important single factor which affects friction loss. Because of the fifth power law, a modest change in hose diameter produces a dramatic change in friction loss.

Source: ◉

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The Friction Loss Formula

There are several formulae which may be used for the calculation of friction loss and the greater the required degree of accuracy required the more complex the formula becomes. For manual firefighting situations, where the highest accuracy is not required, the most useful relationship brings together the four proportionality statements given above and can be shown to be:

$$P_r = \frac{9000fLL^2}{d^5}$$

f is the **friction factor**, P_r the **pressure loss in bars**, I the **length of hose** in metres, L the **flowrate** in litres per minute and d the hose **diameter** in millimetres.

Source: ☹

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The Nozzle Discharge Formula

- This formula is obtained by substituting the expression for v given by the velocity of jets formula into the relationship for flowrate (L), in terms of pipe diameter (d) and velocity of flow (v):

$$L = \frac{vd^2}{21.2}$$

$$L = \frac{14.14\sqrt{P}d^2}{21.2}$$

- That the number of litres per minute (lpm) discharged, L , is given by:

$$L = \frac{2}{3}d^2\sqrt{P}$$

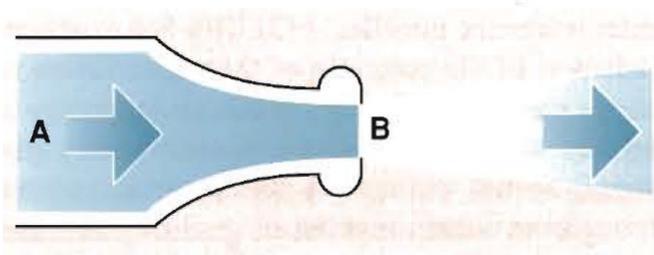
N.B. this formula cannot be applied to diffuser and jet/spray type nozzles because the water is not discharged through a simple circular section.

Source: ☹

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Reference only: Water flow through Nozzles

- As the water flows from point A to point B its velocity, and hence its kinetic energy, increase but only at the expense of the pressure which decreases from a few bar at point A to atmospheric at point B. There are no significant changes in the other types of energy.



Water flowing through a standard or type A nozzle.

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- The relationship between the **velocity of the jet**, v , and the **original pressure, P** , is:

$$\frac{v_1^2}{2} + \frac{p_1}{\rho} = \frac{v_2^2}{2} + \frac{p_2}{\rho}$$

- If the hose diameter is large to the nozzle diameter, then the velocity, v_1 be taken as zero. Also, the (gauge) pressure, p_2 of the water as it leaves the nozzle is zero.

$$\frac{p_1}{\rho} = \frac{v_2^2}{2}$$

$$\frac{100000 P}{1000} = \frac{v_2^2}{2} \quad (1 \text{ bar} = 100\,000 \text{ newtons per square metre})$$

$$v_2^2 = 200P$$

$$v = 14.14 \sqrt{P}$$

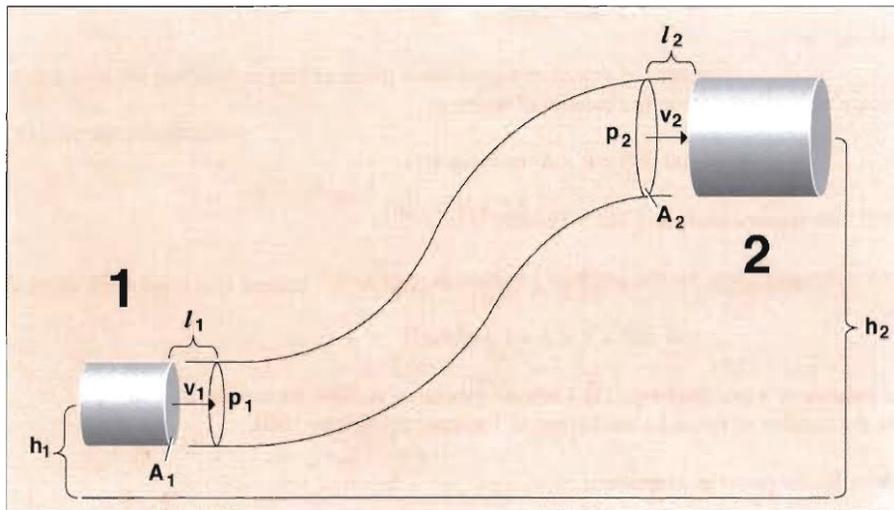
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Bernoulli's formula

- This is a relationship involving the pressure, velocity and height of a liquid flowing along a pipe of variable diameter at two different points in the pipe. Its derivation makes use of one of the fundamental principles of science; the Principle of the Conservation of Energy.
- Figure shows a liquid flowing along a pipe between two points indicated in the figure as position 1 and position 2. At position 1 the area of cross section is A_1 square metres, the pressure p_1 newtons per square metre, the velocity v_1 metres per second and the height above some arbitrary horizontal reference line (e.g. the ground) h_1 metres. At position 2 these values change to, respectively, A_2 , p_2 , v_2 , and h_2 .

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Bernoulli's equation is:

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

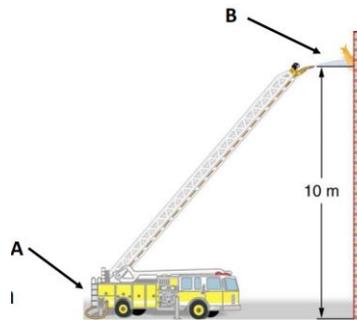
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- If we assume that the liquid is incompressible then the two volumes displaced, and consequently the two masses.

Pressure in the pipe is less than at ground level for **two reasons**:

1. Bernoulli's formula is set based on equal total pressure head in all locations within a system.
2. Bernoulli's formula ignores friction in the system and describes the total head as sum of all heads.



Example of the situation where Bernoulli's formula is used in firefighting

Source: ©

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Water Hammer

- This is a phenomenon with which most people will be familiar because it frequently occurs in domestic situations such as when the flow of water through a long run of metal pipe is stopped very quickly by the rapid closing of a tap. The consequent metallic 'clunk' which may be heard is the consequence of **'water hammer'**.
- Water hammer is represented as:

$$F = \frac{mv}{t}$$

- where m in kilogram, v in metres per second and t in seconds. The product $m \times v$ is known as the momentum of the moving object and the force (N), F , is therefore equal to the change of momentum per second.

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- There are a number of fireground situations where water hammer faced which include:
 1. **Shutting down a branch rapidly:** Even though fire service hose is flexible and therefore able to absorb much of the kinetic energy of the water, damage to couplings through too rapid shut-down of branches is possible and there is evidence that damage may also occur to pumps and collecting heads.
 2. **The rapid closure of the hydrant to tank valve or the hydrant valve itself:** This may cause the main on which the hydrant is situated to fracture. Damage is most likely to occur when the main is of small diameter with a consequent high velocity of flow.

Source: 

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Bibliography and Further reading

- HM fire service inspectorate (2001) Fire Service Manual Volume 1 Fire Service Technology, Equipment and Media Hydraulics, Pumps and Water Supplies, TSO, London.
- ▼ NFPA (2022) NFPA 550 Guide to the Fire Safety Concepts Tree, NFPA.
- △ LibreTexts physics (2023) Bernoulli's Equation:
https://phys.libretexts.org/Bookshelves/University_Physics/University_Physics_%28OpenStax%29/Book%3A_University_Physics_I_-_Mechanics_Sound_Oscillations_and_Waves_%28OpenStax%29/14%3A_Fluid_Mechanics/14.08%3A_Bernoullis_Equation

FURTHER READING:

- PAUL SPURGEON (2012) Fire Service Hydraulics and Pump Operations, PennWell Corporation.
- National Fire Protection Association (NFPA) (2008), Fire Protection Handbook, 20th Edition, Volume 1 & 2

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Revision Questions

1. Differentiate active fire protection systems and passive fire protection systems.
2. Outline disadvantages of water considering it as one of the most used fire extinguishing media.
3. Briefly describe the laws governing loss of pressure due to friction in water using appropriate formula.
4. Elaborate the relationship between water pressure and water head using appropriate formulae.
5. Explain Bernoulli's principle presenting relationship between the pressure, velocity and height of a liquid flowing through a pipe using a neat diagram and a hands-on example of firefighting.
6. Explain your understanding on "Water Hammer" presenting its formula and hands-on examples of firefighting.
7. Calculations:
 - Water head
 - Friction loss
 - Flow through nozzle

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Thank You!!!

Student's notes:

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