Exercise 02 – Fans and Pumps

1. What are the important design considerations for chilled water systems? Briefly explain the principles for analysis of pipe network in a water distribution system.

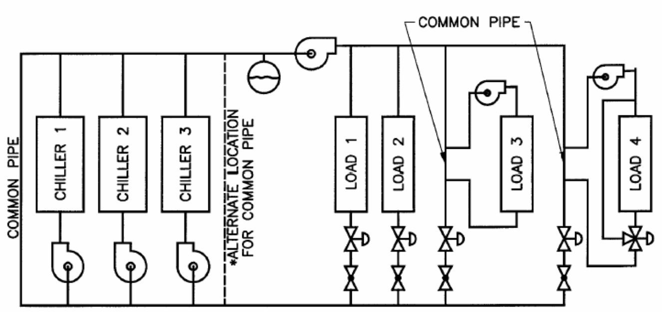
Answer (outline):

The important design considerations for chilled water systems are:
- Design water temperature and flow rate
- Piping layout
- Pump selection and speed control
- Terminal unit selection
- Pressure distribution and system balancing
- Thermal expansion & joints
- Accessories (e.g. safety relief valves, air separator/vent, strainers, thermal insulation and condensate drains)

The principles for analysis of pipe network in a water distribution system is summarised below:
- Set up equations for fluid mechanics
  1) Conservation of mass (continuity principle)
  2) Work-energy principle (Darcy-Weisbach or Hazen-Williams)
  3) Fluid friction & energy dissipation
- Describe the hydraulic system accurately and efficiently
  - Define an appropriate pipe system
  - Decide what features are important & to retain
  - Determine which demands should be specified
  - Analysis for a range of system demands
  - For large systems, require some "skeletonization"
    - Not all pipes or nodes are included in the analysis, some may be lumped
- Solve these simultaneous equations effectively
  - For example, equations for steady flow in networks include:
    - Q-equations (pipe charges are the unknowns)
    - H-equations (heads are the unknowns)
    - ΔQ-equations (corrective discharges are the unknowns)

2. Draw a diagram to show typical design of a variable flow chilled water system with plant-building loop. Explain the pump affinity laws that can be used to evaluate pump performance and characteristics. What precaution shall be taken to minimise the risk of cavitation at the pump impeller?

Answer (outline):



Pump affinity laws are given below:

Function	Speed change	Impeller diameter change
Flow	$Q_2 = Q_1 \, (N_2/N_1)$	$Q_2 = Q_1 \, (D_2/D_1)$
Pressure	$p_2 = p_1 \, (N_2/N_1)^2$	$p_2 = p_1 \, (D_2/D_1)^2$
Power	$P_2 = P_1 \, (N_2/N_1)^3$	$P_2 = P_1 \, (D_2/D_1)^3$

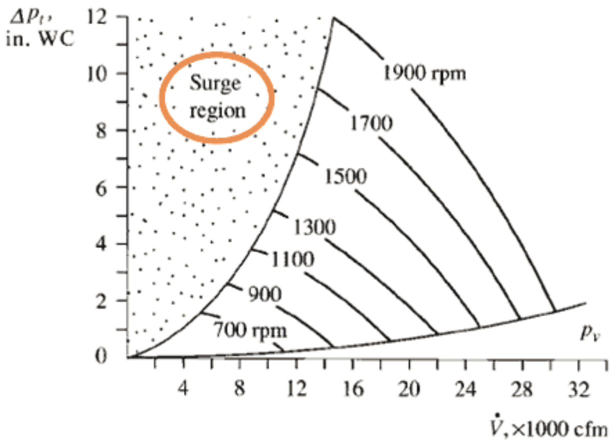
Precaution taken to minimise the risk of cavitation at the pump impeller:
- Check the Net Positive Suction (NPS) available and required
- Ensure NPS available > NPS required

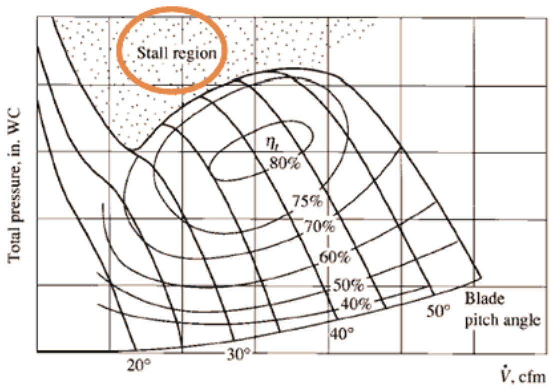
3. Briefly describe the <u>five</u> common methods for fan modulation and capacity control. With the help of suitable diagrams, explain the likely unstable regions for centrifugal and axial fans.

<u>Answer (outline):</u>

Five common methods for fan modulation and capacity control are:
- Damper (vary the opening of the air flow passage): simple but waste energy
- Inlet vanes (opening & angle of inlet vanes): low cost; less efficient than following types
- Inlet cone (peripheral area of fan impeller); inexpensive; for backward curved centrifugal fan
- Blade pitch (blade angle of axial fan)
- Fan speed (using adjustable frequency drives): most energy-efficient; but usually cost more

Unstable operating regions for centrifugal and axial fans:
- Fan surge (in centrifugal fan)
  - Occurs when air volume flow is not sufficient to sustain the static pressure difference between discharge & suction
- Fan stall (in axial fans)
  - When smooth air flow suddenly breaks & pressure difference across the blades decreases

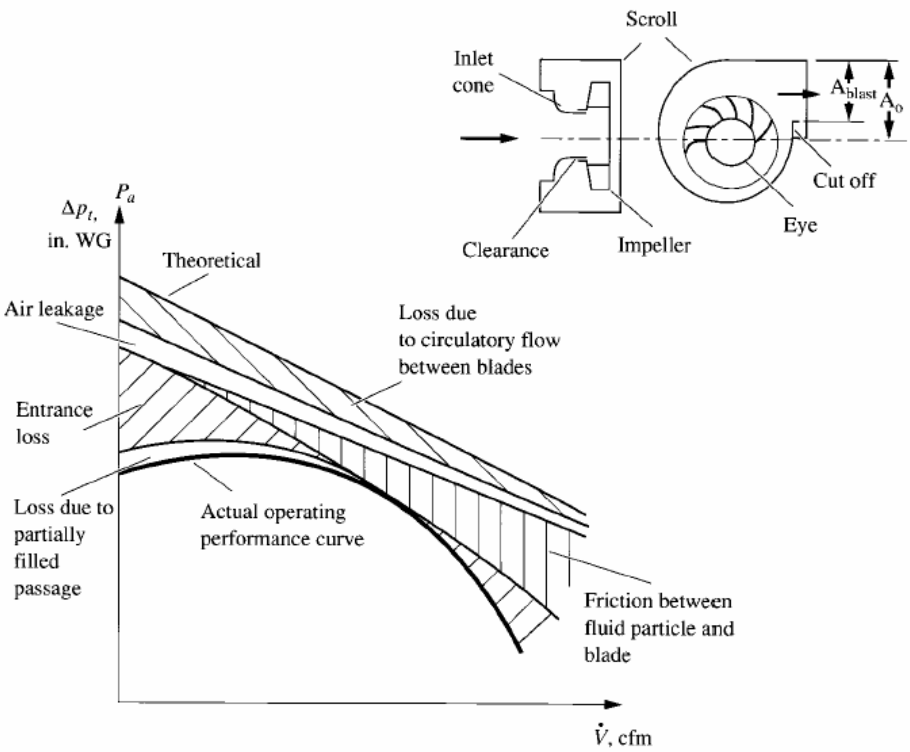




4. Briefly explain the <u>five</u> major issues causing energy losses to a centrifugal fan. Draw a simple diagram of fan pressure against flow rate to show how the actual fan performance curve is obtained by deducting the energy losses from the theoretical line.

Answer (outline):

Major issues causing energy losses to a centrifugal fan:
- Circulatory flow between the blades
- Air leakage at the inlet
- Friction between fluid particles and the blade
- Energy loss at the entrance
- Partially filled passage



5. Using the Darcy-Weisbach equation and other related formulae, calculate the frictional loss for 2 m long of an air duct with $D = 0.2$ m, surface roughness $\varepsilon = 0.003$ m, mean air velocity inside the air duct $v = 5$ m/s. Assume air density $\rho = 1.2$ kg/m^3, absolute viscosity $\mu = 0.00002$ Pa•s and gravitational constant $g = 9.81$ m/s^2. The frictional factor may be determined using the following empirical equation.

Answer (outline):

The Reynolds number (Re_D) = (1.2 kg/m^3 x 5 m/s x 0.2 m) / 0.00002 Pa.s = 60000

The friction factor (f) = 0.25 / {log[0.003/(3.7x 0.2) + 5.74/(0.9 x 60000)]}^{2} = 0.044

Using the Darcey-Weisbach equation, the frictional pressure loss for 2 m air duct is:

$$\Delta p_f = f\left(\frac{L}{D}\right)\left(\frac{\rho v^2}{2}\right) = 0.044 \times (2 / 0.2) \times (1.2 \times (5)^2/2) = 6.6 \text{ Pa}$$