MEBS6008 Environmental Services II

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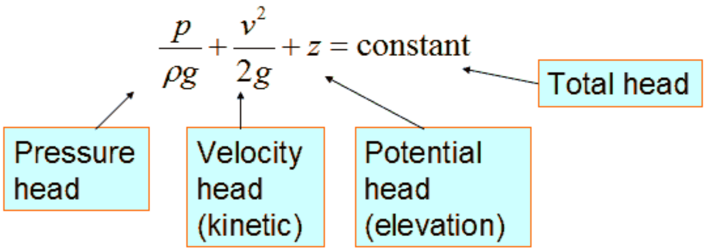
Self-evaluation Exercises

1. Briefly describe the terms in the generalised Bernoulli equation and their physical meanings in fluid dynamics.

Answer (outline):

Bernoulli equation is a useful basic tool for fluid flow analysis. It can be written in a few different forms and the most common one is shown below, with the physical meaning of each item indicated.

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$$



Assume α = kinetic energy factor and heat absorbed is neglected, the generalised Bernoulli equation can be developed to determine the change in energy between two stations.

$$\left(\frac{p}{\rho g} + \alpha\frac{V^2}{2g} + z\right)_1 + H_M = \left(\frac{p}{\rho g} + \alpha\frac{V^2}{2g} + z\right)_2 + H_L$$

2. Suggest two methods to control flow separation in air diffusers and three ways to avoid cavitation.

Answer (outline):

Two methods to control flow separation in air diffusers:

- Use splitters to divide the diffuser into smaller divisions
- Bleed some low-velocity fluid near the wall

Three ways to avoid cavitation: (any three of them)

- Operate the device at high enough pressure
- Change the flow
- Device is built to withstand the cavitation effects
- Design surface contours to delay the advent of cavitation

3. 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 ε = 0.003 m, mean air velocity inside the air duct v = 5 m/s. Assume air density ρ = 1.2 kg/m^3, absolute viscosity μ = 0.00002 Pa•s and gravitational constant g = 9.81 m/s^2. The frictional factor may be determined using the following empirical equation.

$$f = \frac{0.25}{\left\{\log\left[\frac{\varepsilon}{3.7D} + \frac{5.74}{0.9\,\mathrm{Re}_D}\right]\right\}^2}$$

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:

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

4. 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:

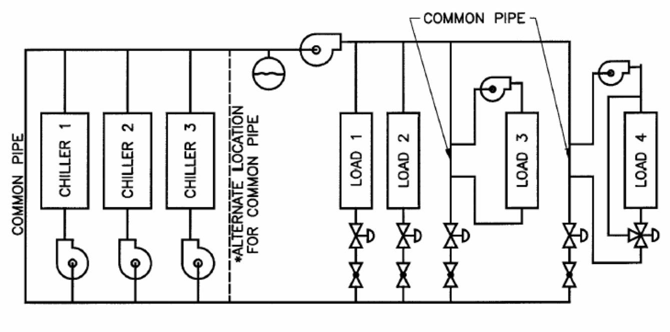
- Design water temperature and flow rate
- Piping layout
- Pump selection and speed control
- Terminal unit selection
- Pressure distribution and system balancing
- Thermal expansion & joints
- Accessories (e.g. safety relief valves, air separator/vent, strainers, thermal insulation and condensate drains)

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)

5. 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

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

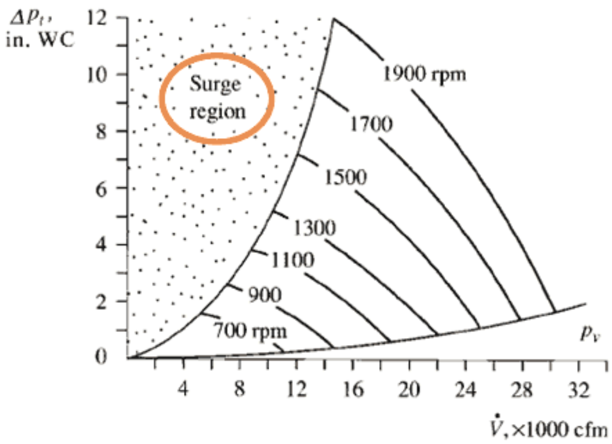
Answer (outline):

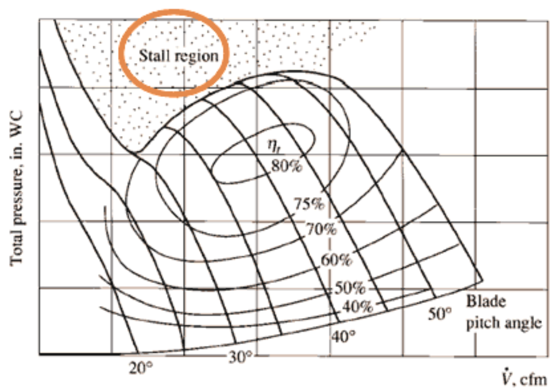
Five common methods for fan modulation and capacity control are:

- 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





7. Briefly explain the following terms for space air diffusion.

   (a) Age of air
   (b) Air change effectiveness
   (c) Air diffusion performance index
   (d) Characteristic length

Answer (outline):

(a) Age of air

- Time period that outdoor ventilation air has been in a space
- Evaluated using tracer gas method
- The "youngest" air = freshest air

(b) Air change effectiveness

- Air system's ability to deliver ventilation air; determine how well outdoor air is diffused to various locations
- $\varepsilon_N = \tau_N / \theta_{age,\,N}$
  - τ_N : nominal time constant (min. or hr.) = supply volume flow rate / space volume
  - For proper air distribution system, $\varepsilon_N \approx 1$

(c) Air diffusion performance index

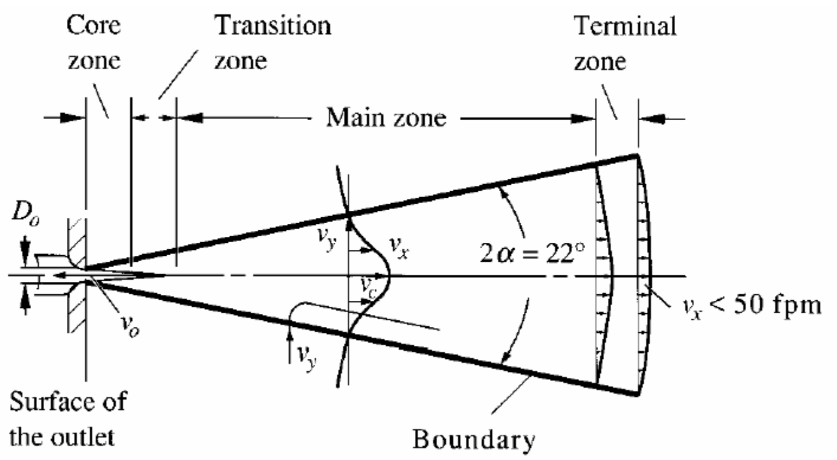
- Developed by ASHRAE
- ADPI = (N_θ x 100) / N
  - θ: effective draft temperature
  - N_θ: number of points measured in occupied zone in which -1.7 °C < θ <1.1 °C
  - N : total number of points measured in occupied zone
- Higher the ADPI, higher % of occupants who feel comfortable
- ADPI is useful for cooling mode operation

(d) Characteristic length

- Horizontal distance from outlet to the nearest vertical opposite wall, or to the midplane between 2 outlets in the direction, OR the distance to the closest intersection of air jets

8. Draw a diagram to show the four zones of a free, isothermal, axial air jet. What are the typical terminal air velocities used for design of space air jet?

Answer (outline):



Typical terminal air velocities are 0.25, 0.5 and 0.75 m/s.

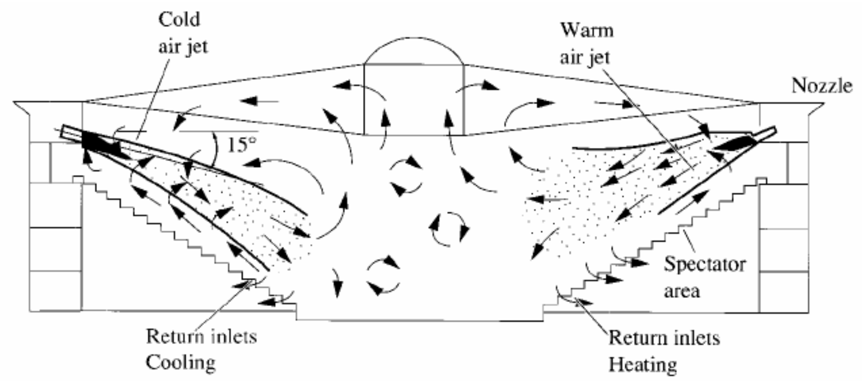
9. Briefly explain the characteristics of stratified mixing flow that can be found in a large indoor sport stadium. What type of supply air outlet can be used in such a situation?

Answer (outline):

Stratified mixing flow in a large indoor sport stadium is shown below and the characteristics include:

- Cooling loads in lower zone is offset by supply air
- Convective heat transfer from hot roof is blocked or reduced

- Although supply airflow rate & temp. affect the throw & drop of the air jet, the induced recirculating airflow patterns in upper & lower zones remain the same
- Height of supply air jet determines upper boundary of the lower zone
- Location of return inlets influences cooling load only when they are located in the upper zone



Suitable supply air outlet in such a situation are high-speed air nozzles and grilles.

10. What are the advantages and disadvantages of using underfloor air distribution in office buildings? Draw a diagram to show the stratified displacement flow in a typical room.

Answer (outline):

Advantages of underfloor air distribution in office buildings
- Integrated well with raised floor plenum
- Can be very flexible for future changes/relocations
- Suitable for computer rooms and related high-load-density areas
- Conditioned air is supplied directly to occupants
- Stagnant air can be reduced (if ceiling return)
- Upward flow lifts some unneutralised heat
- It can utilise thermal mass of access floor & slab to reduce peak demands

Disadvantages
- Higher initial costs
- Need for raised floor system & floor diffusers

Stratified displacement flow in a typical room: