CH402 Chemical Engineering Process Design

Class Notes L3

Pumps

BONUS OP

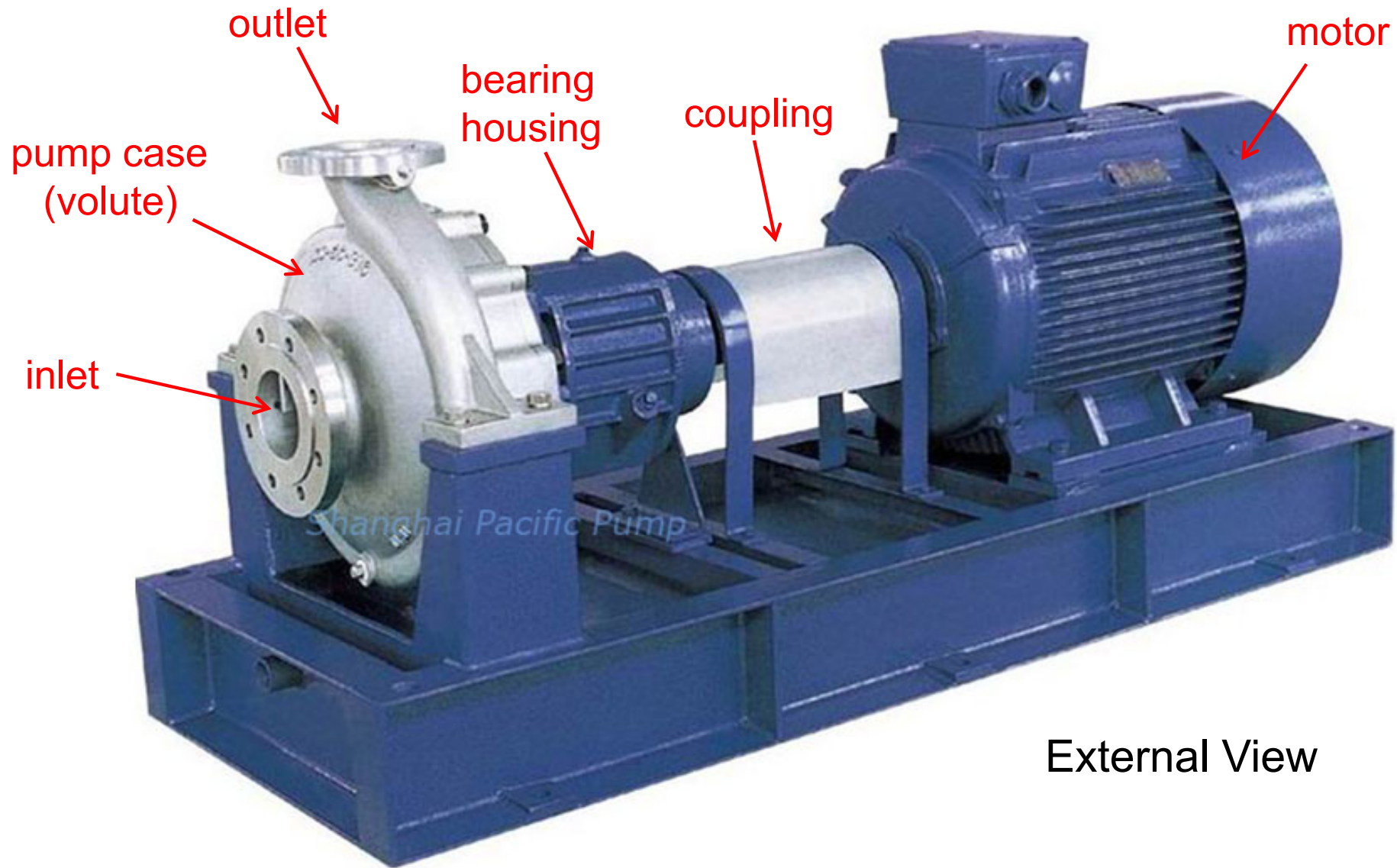## Chemical Engineering Plebe Open House

DATE and TIME TBD
Bartlett Hall Room 150[1]

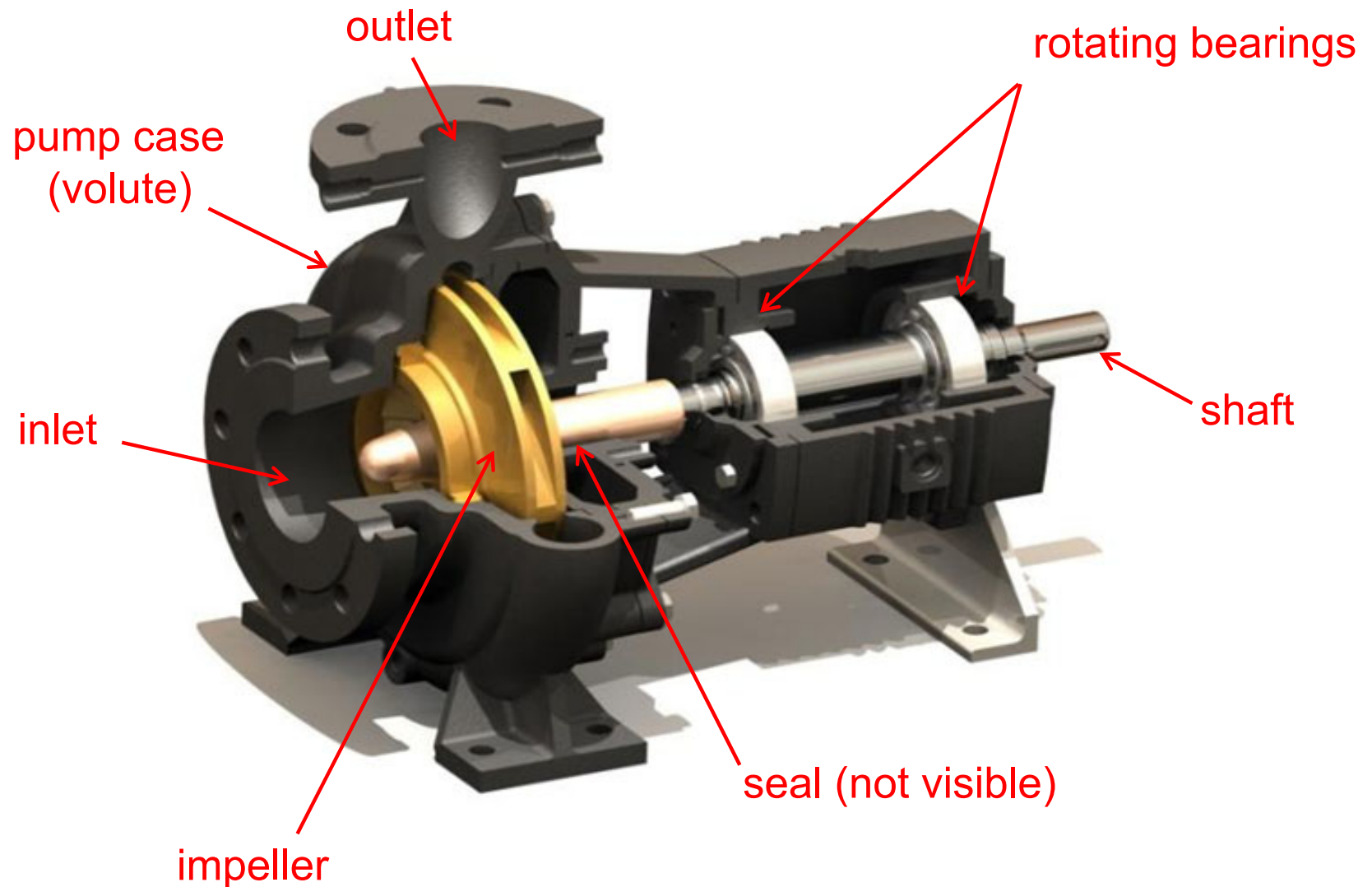30 minutes = 5 points[2]
Max 1.5 hours (15 points)

Notes:
1. If we are moved to a different location, we will still be somewhere near 150.
2. Sign in and out on the provided roster with time in and time out. Interact with prospective cadets. Stay active. Try not to congregate in friend clusters.

Pump Design Basics

outlet

bearing housing

coupling

motor

pump case (volute)

inlet

External View

Pump Design Basics

outlet

rotating bearings

pump case
(volute)

shaft

inlet

seal (not visible)
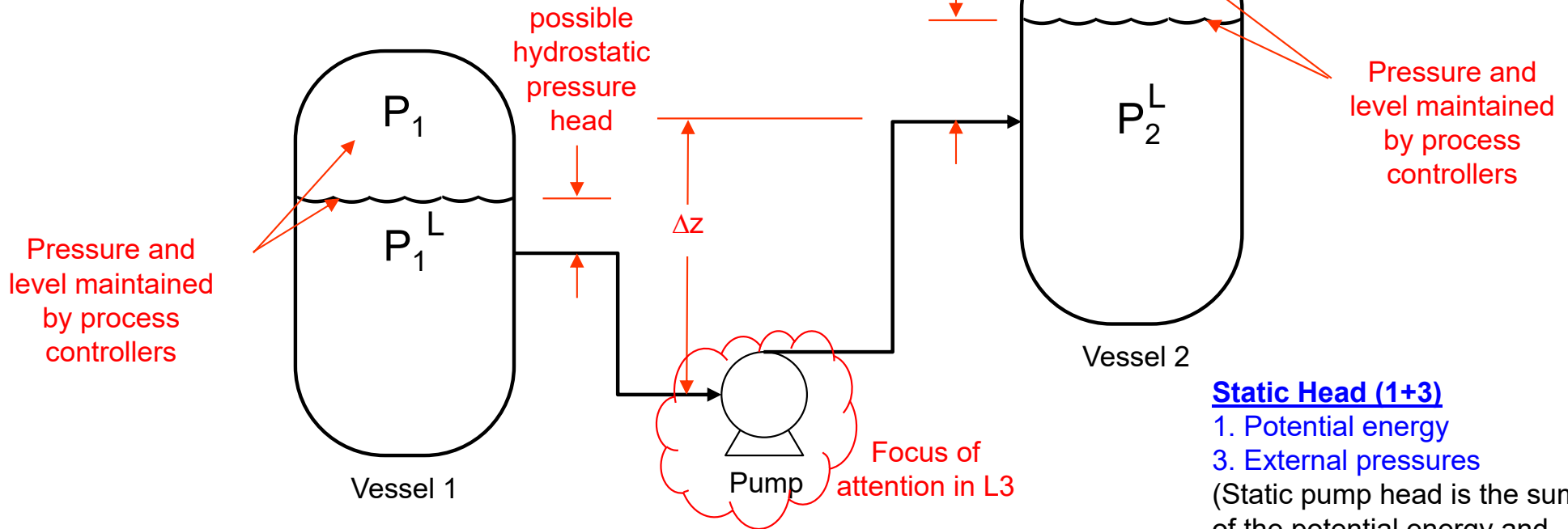
impeller

Internal View

Pump Overview (Purpose)

If this were reversed and $P_2^L < P_1^L$, you might not even need a pump!

$$P_1^L < P_2^L$$

possible hydrostatic pressure head

Important Slide for LAB 2

P_2

Pressure and level maintained by process controllers

possible hydrostatic pressure head

P_1

Δz

P_1^L

P_2

P_2^L

Pressure and level maintained by process controllers

Vessel 1

Vessel 2

Pump

Focus of attention in L3

<u>Static Head (1+3)</u>
1. Potential energy
3. External pressures
(Static pump head is the sum of the potential energy and external pressure difference terms and <u>does not depend on flow rate</u>.)

$$W_o = g\Delta z \;+\; \Delta\left(\frac{V^2}{2\alpha}\right) + \frac{\Delta p}{\rho} + \sum F$$

① ② ③ ④

- Pump power must be sufficient to overcome changes in elevation, kinetic energy changes, external pressure difference, and frictional losses.

- Pump cost depends on pump power and pump flow rate, then materials & design details.

<u>Dynamic Head (2+4)</u>
2. Frictional losses
4. Kinetic energy
Dynamic head is the sum of the kinetic energy and frictional loss terms and <u>depends on the flow rate</u>)

Pump Performance
Depends primarily on the "Characteristic Curves"

The characteristic curve is determined by the manufacturer and is a plot of pump head versus flow rate.

Pump head is a combination of input power and friction, internal leakage and recirculation losses.

The "System Curve" is determined by the piping system designer and is the **sum of the static and dynamic heads**.
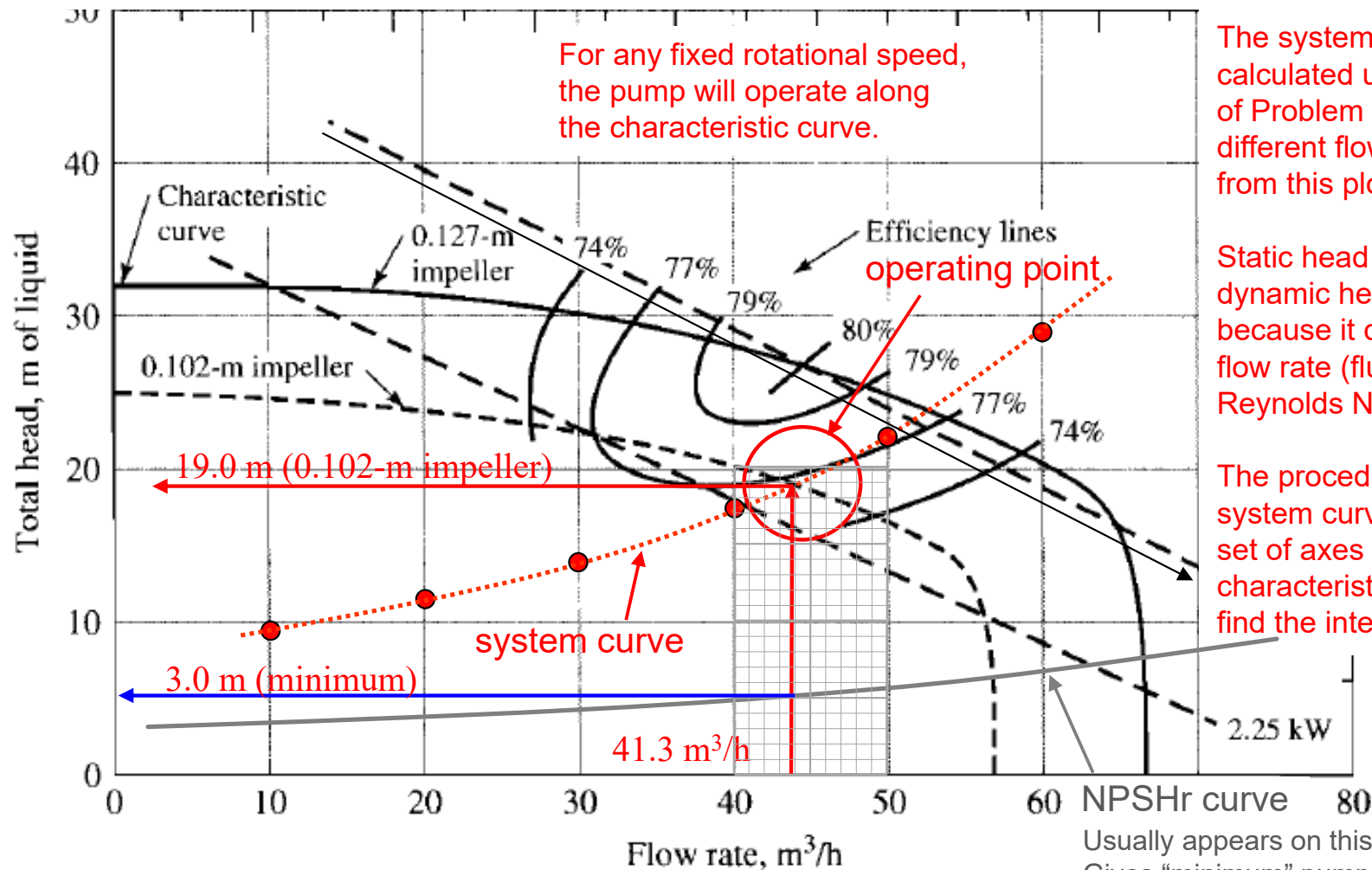
For any fixed rotational speed, the pump will operate along the characteristic curve.

The system curve is calculated using the methods of Problem 12-1 but using different flow rates selected from this plot.

Static head is constant and dynamic head varies because it depends on the flow rate (fluid velocity and Reynolds Number)

The procedure is to plot the system curve on the same set of axes as the characteristic curve and then find the intersection.

operating point

19.0 m (0.102-m impeller)

system curve

3.0 m (minimum)

41.3 m³/h

Characteristic curve

0.127-m impeller

0.102-m impeller

74%   77%
79%
80%
79%
77%
74%

Efficiency lines

2.25 kW

NPSHr curve

Usually appears on this plot
Gives "minimum" pump head
Sometimes uses a separate scale.
Calculated in CHEMCAD

Figure 12-15

Characteristic curve of a centrifugal pump operating at a constant speed of 3450 r/min

NPSH (Net Positive Suction Head) is the "available" pressure present in the liquid at the entrance to the pump.

NPSHa Example Calculation

Conditions taken from feed stream in DP2

50/50 mol% mixture of toluene and ethylbenzene

T = 20 deg C (293 K)
P = 101325 Pa

In[1]:= a = {76.945, 89.063};

b = {-6729.8, -7733.7};

c = {-8.179, -9.917};

d = {5.3017 * 10^{-6}, 5.986 * 10^{-6}};

e = {2, 2};

(*modified Antoine eqn from CHEMCAD*)

$$Psat[T\_] = Exp\left[a + \frac{b}{T} + c * Log[T] + d * T^e\right];$$

In[8]:= x = {.5, .5};

In[9]:= P[T_] = Plus @@ (x * Psat[T]);

In[19]:= P[293.]

Out[19]= 1924.136307

In[13]:= $$Pa * \frac{\frac{N}{m^2}}{Pa} * \frac{\frac{kg*m}{s^2}}{N}$$

Out[13]= $$\frac{kg}{m\, s^2}$$

(*ρ*g*h*)

In[15]:= $$\frac{Pa * \frac{\frac{N}{m^2}}{Pa} * \frac{\frac{kg*m}{s^2}}{N}}{\frac{kg}{m^3} * \frac{m}{s^2}}$$

Out[15]= m

In[20]:= $$\frac{101\,325 - P[293.]}{868.1519 * 9.8}$$

Out[20]= 11.68337623

"available" suction head
NPSHa

<u>Design Procedure for Pumps</u>

Mechanical Energy Balance – Equation 12-12 – Excel, Mathematica, CAD, By-hand

(same as we used in problem set 1)

Total pressure developed by pump

Total pressure expressed in meters of liquid

$$\frac{m}{s^2} \cdot m = \frac{m^2}{s^2}$$

$$\frac{m^2}{s^2} \cdot \frac{kg}{s} = \frac{kg \cdot m^2}{s^3} = Watts$$

$$w_0 = \frac{\Delta p}{\rho} = g \cdot H$$ specific work; from eq 12-12

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pump work equations on page 515

in eq 12-20a, H in units of Nm/kg

$$\frac{N \cdot m}{kg} = \frac{kg \cdot m}{s^2} \cdot \frac{m}{kg} = \frac{m^2}{s^2}$$

$$w_0 = \frac{H \cdot \dot{m}_v \cdot \rho}{10^3}$$

$$\frac{N \cdot m}{kg} \cdot \frac{m^3}{s} \cdot \frac{kg}{m^3} = \frac{kg \cdot m}{s^2} \cdot \frac{m}{kg} \cdot \frac{m^3}{s} \cdot \frac{kg}{m^3} = \frac{kg \cdot m^2}{s^3} = Watts$$

$$1N = 1\frac{kg \cdot m}{s^2}$$

In eq 12-20b, H in units of N/m²

Pascals

$$w_0 = \frac{H \cdot \dot{m}_v}{10^3}$$

$$\frac{N}{m^2} \cdot \frac{m^3}{s} = \frac{N \cdot m}{s} = \frac{J}{s} = Watts$$

Cavitation

$$NPSH = \frac{1}{g} \cdot \left(\frac{p_{reference} - p_{vapor}}{\rho} - h_f \right) - Z_{ref}$$

Frictional losses

Typically 2-5 m for small pumps
And up to 15 m for large pumps
See McCabe, et al, page 204

Efficiency

$$\eta = \frac{w_0}{w}$$

Use Fig. 12-17, page 516

Cost

Use Figs 12-19 through 12-24, pages 517-520; PTW website; CHEMCAD

Pump Video Links - Watch

multistage
(1st two minutes)

centrifugal
explained

pump internals

cavitation
sound

simple piston

pump curve
(Jacques Chaurette, #2)

cavitation

cavitation
explained

centrifugal force
(fantastic demo)

Homework

Problem 12-6

A preliminary estimate of the total cost for a completely installed pumping system is required for a certain design project. In this system, 15.75 kg/s of cooling water at 15.5 °C is to be provided using 305-m pipeline. It has been estimated that the theoretical power requirements for the pump will be 7.5 kW. Using the following data, estimate the total cost of the pumping system:

Material of construction – carbon steel   Insulation (85% magnesia) – 0.038 m
Number of fittings (equivalent to tees) – 40   Pump – centrifugal
Number of valves (gate) – 4   Motor – AC, enclosed, 3-phase, 1800 r/min

COST MUST BE PURCHASED INSTALLED COST IN
JANUARY 2024

Questions