CH402 Chemical Engineering Process Design

Class Notes L3

Pumps

BONUS OP

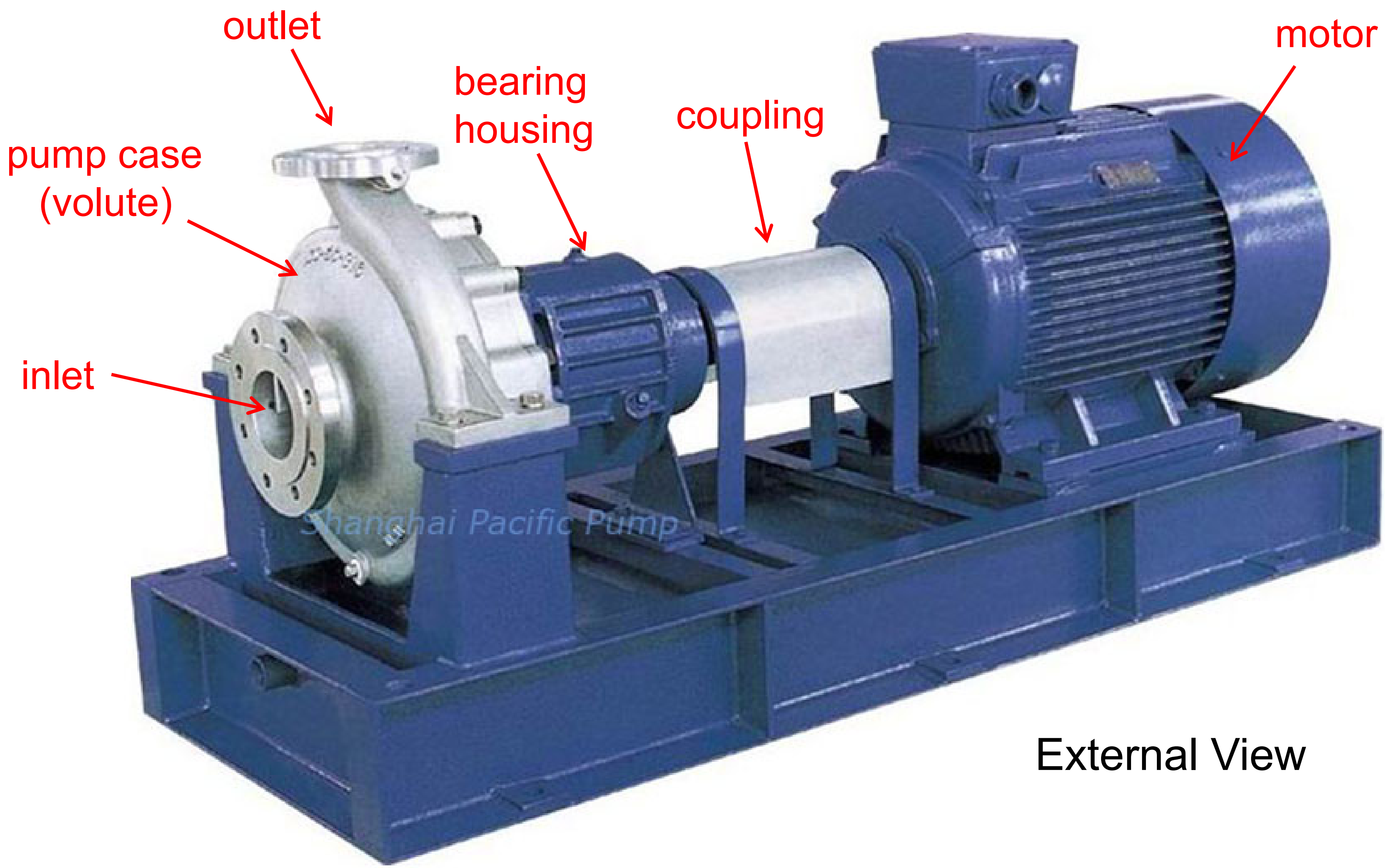
Chemical Engineering Plebe Open House

18 JAN 2023 1245 to ~1400
Bartlett Hall Room 150[1]

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

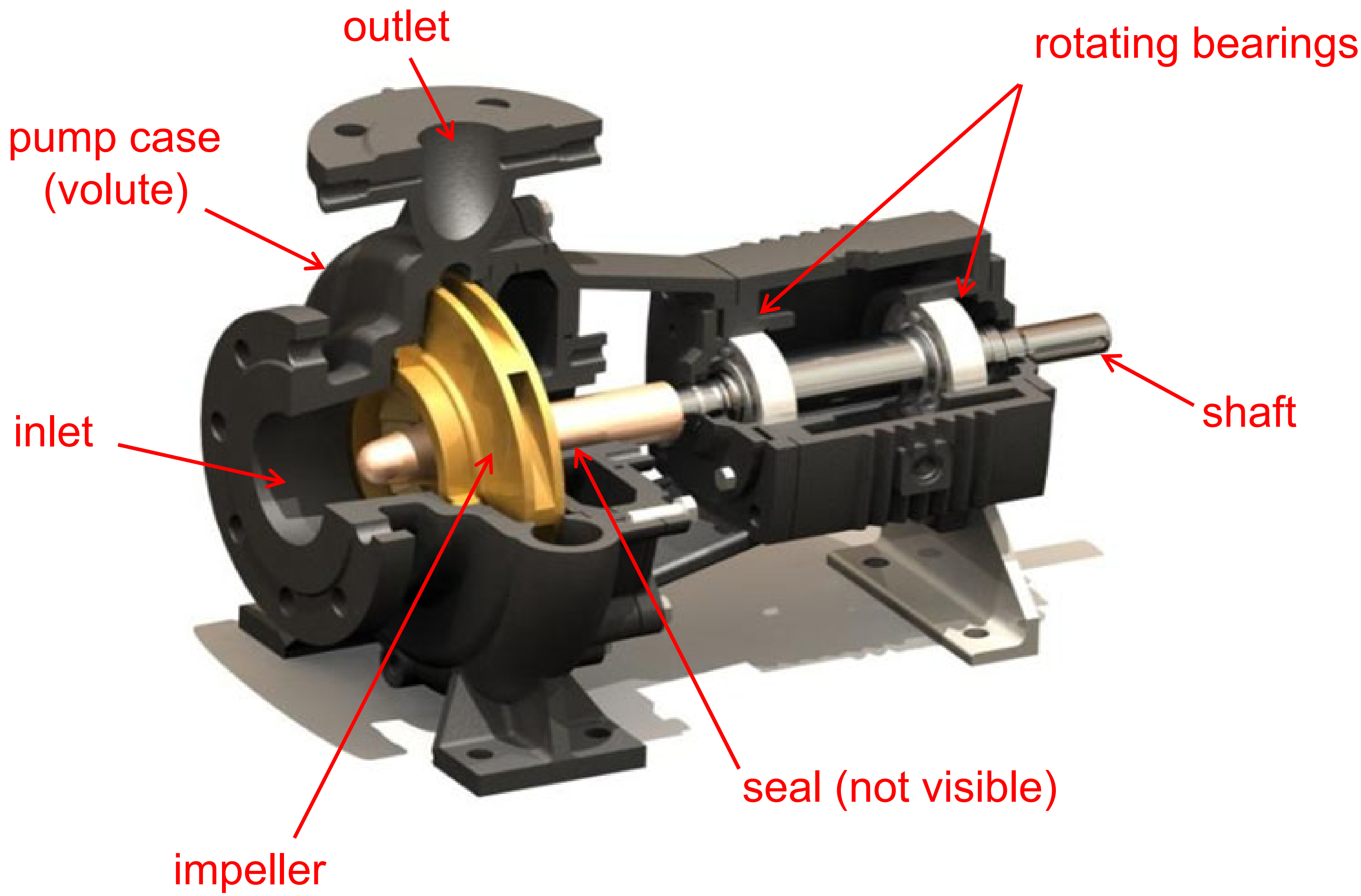
Notes:
1. If we are moved to a different location, we will still be somewhere near 150.
2. Sign in and out on the provided roster with time in and time out. Interact with prospective cadets. Stay active. Try not to congregate in friend clusters.

Pump Design Basics



External View

Pump Design Basics



Internal View

See Perry's Handbook, 1999 Edition, page 10-28, for more details

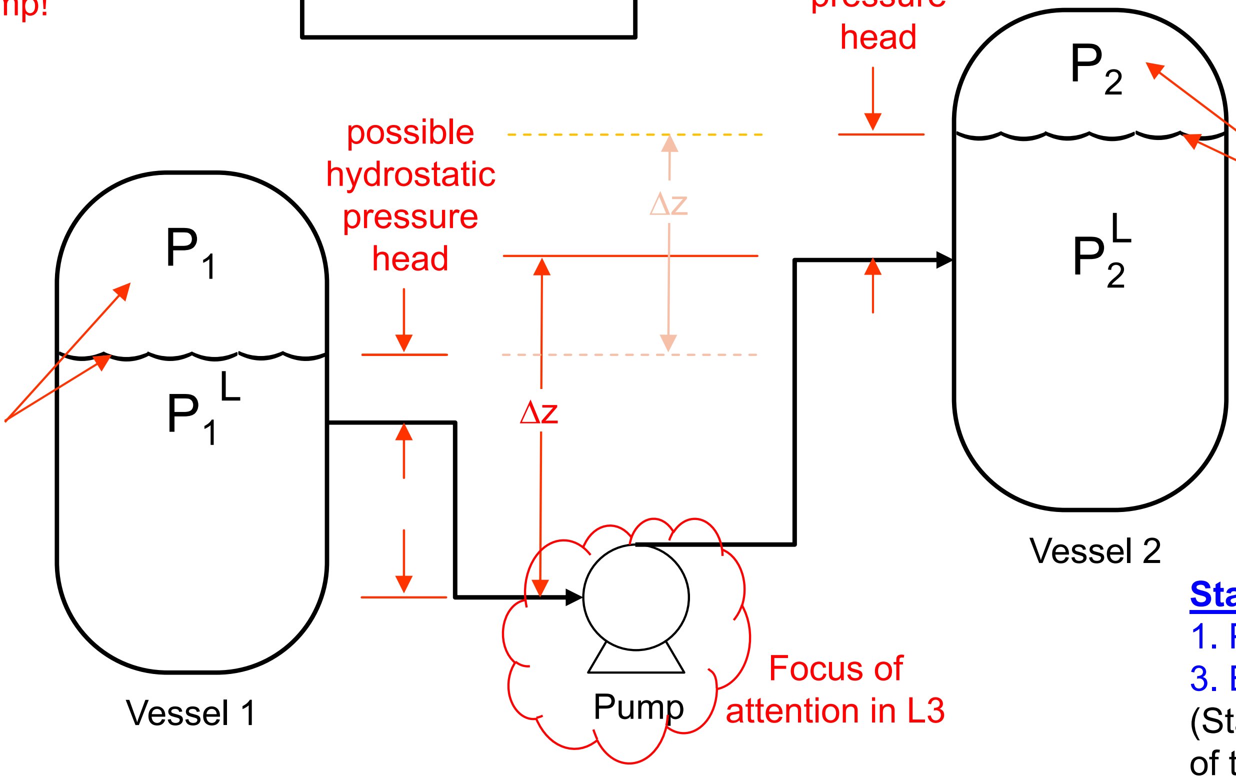
image from http://www.pumpi.com.mk/pscp_iso.html

Pump Overview (Purpose)

Important Slide for LAB 2

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

$$\mathbf{P_1^L < P_2^L}$$



- Pump power can be expressed power (W), pressure (Pa), or static pressure equivalent ("total head" or "meters of head")

$$W_o = \underset{1}{g\Delta z} + \underset{2}{\Delta\left(\frac{V^2}{2\alpha}\right)} + \underset{3}{\frac{\Delta p}{\rho}} + \underset{4}{\sum F}$$

- 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.

Static Head (1+3)

1. Potential energy
3. External pressures

(Static pump head is the sum of the potential energy and external pressure difference terms and does not depend on flow rate.)

Dynamic Head (2+4)

2. Frictional losses
4. Kinetic energy

Dynamic head is the sum of the kinetic energy and frictional loss terms and depends on the flow rate)

Important Slide for LAB 2

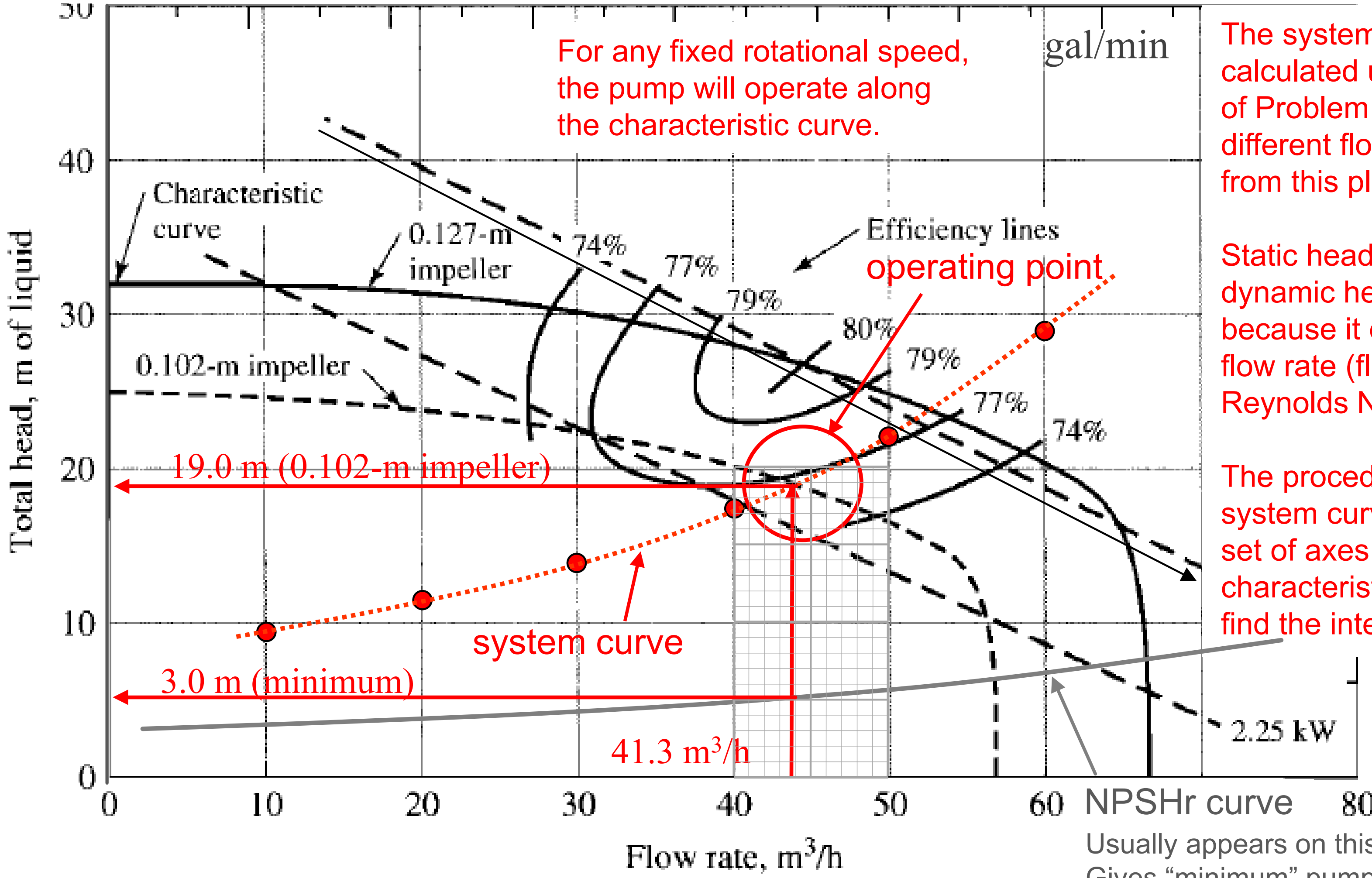
Pump Performance

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**.



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.

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};

In[6]:= (*modified Antoine eqn from CHEMCAD*)
        Psat[T_] = Exp[a + b/T + c*Log[T] + d*T^e];

In[7]:= x = {.5, .5};

In[8]:= P[T_] = Plus @@ (x*Psat[T]);

        P[293.] (*Pa*)

Out[9]= 1924.14
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$$\text{In[10]:= } Pa * \frac{\frac{N}{m^2}}{Pa} * \frac{\frac{kg*m}{s^2}}{N}$$

$$\text{Out[10]= } \frac{kg}{m\,s^2}$$

(*ΔP=ρ*g*h → h=ΔP/ρ*g*)

$$\text{In[11]:= } \frac{Pa * \frac{\frac{N}{m^2}}{Pa} * \frac{\frac{kg*m}{s^2}}{N}}{\frac{kg}{m^3} * \frac{m}{s^2}}$$

$$\text{Out[11]= } m$$

$$\text{In[12]:= } \frac{101325 - P[293.]}{868.1519 * 9.8}$$

$$\text{Out[12]= } 11.6834$$

“available” suction head
NPSHa

Design Procedure for Pumps

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

$$\frac{m}{s^2}\cdot m = \frac{m^2}{s^2} \qquad \frac{m^2}{s^2}\cdot\frac{kg}{s} = \frac{kg\cdot m^2}{s^3} = \text{Watts} \qquad w_0 = \frac{\Delta p}{\rho} = g\cdot H$$

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

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

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

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

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

In eq 12-20b, H in units of N/m²

Pascals

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

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

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 SET 2

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

COST MUST BE PURCHASED INSTALLED COST IN JANUARY 2024