CH402 Chemical Engineering Process Design

Class Notes L3

Pumps

BONUS OP

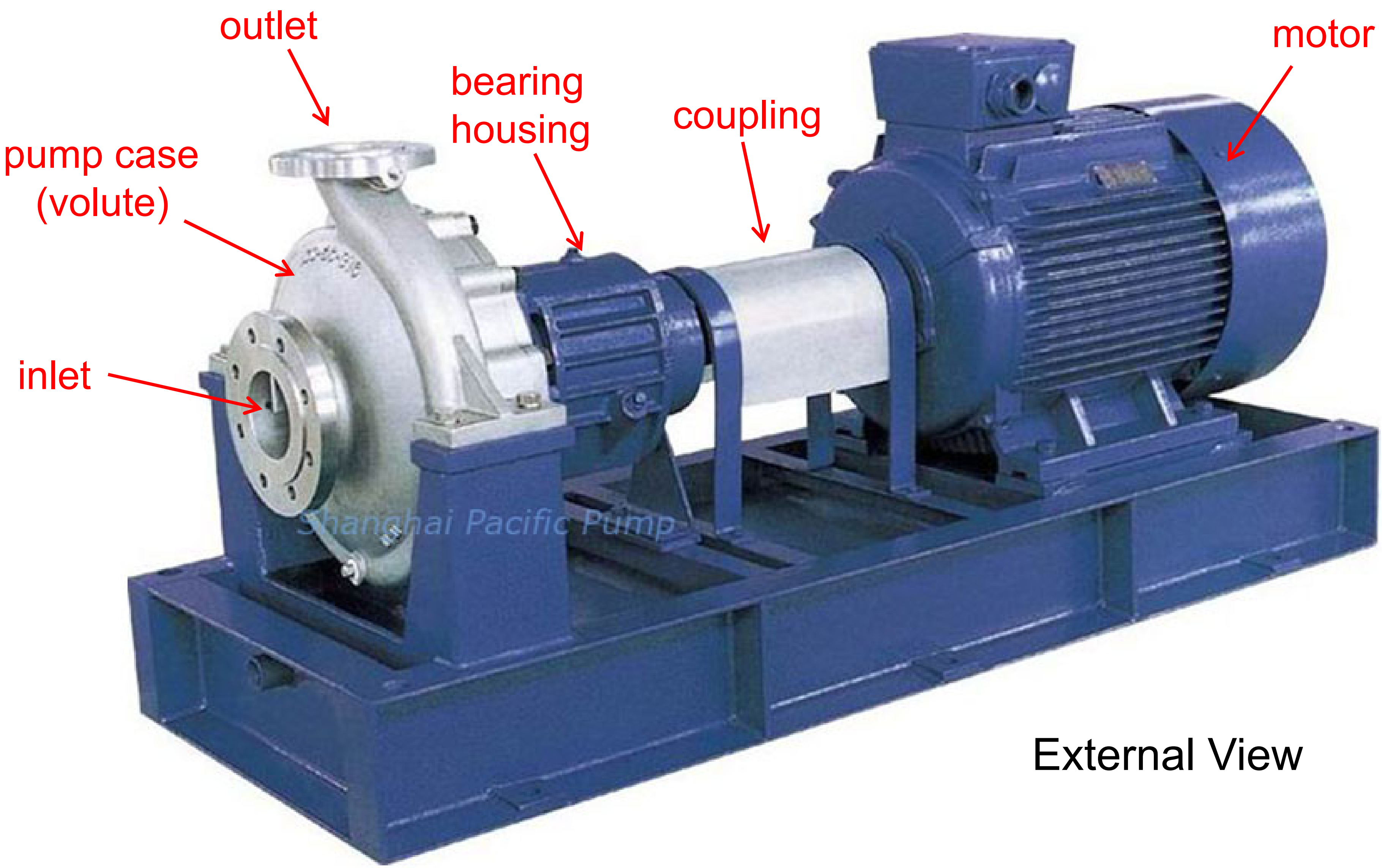
Chemical Engineering Plebe Open House

23 JAN 2025 1245 to ~1400
Bartlett Hall Room 150[1]

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

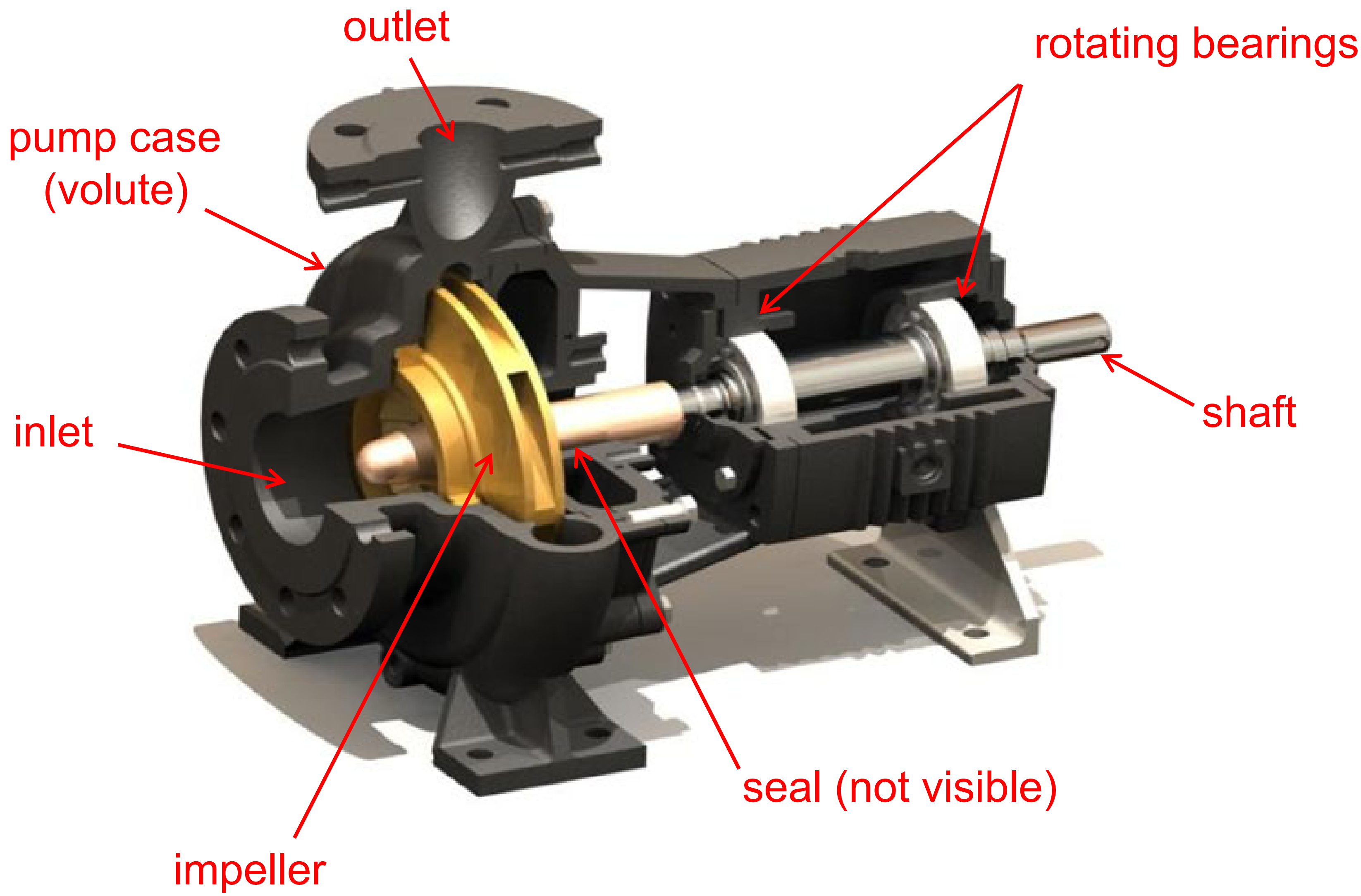
Notes:
1. If we are moved to a different location, we will still be somewhere near 150.
2. Sign in and out on the provided roster with time in and time out. Interact with prospective cadets. Stay active. Try not to congregate in friend clusters.

Pump Design Basics



External View

Pump Design Basics



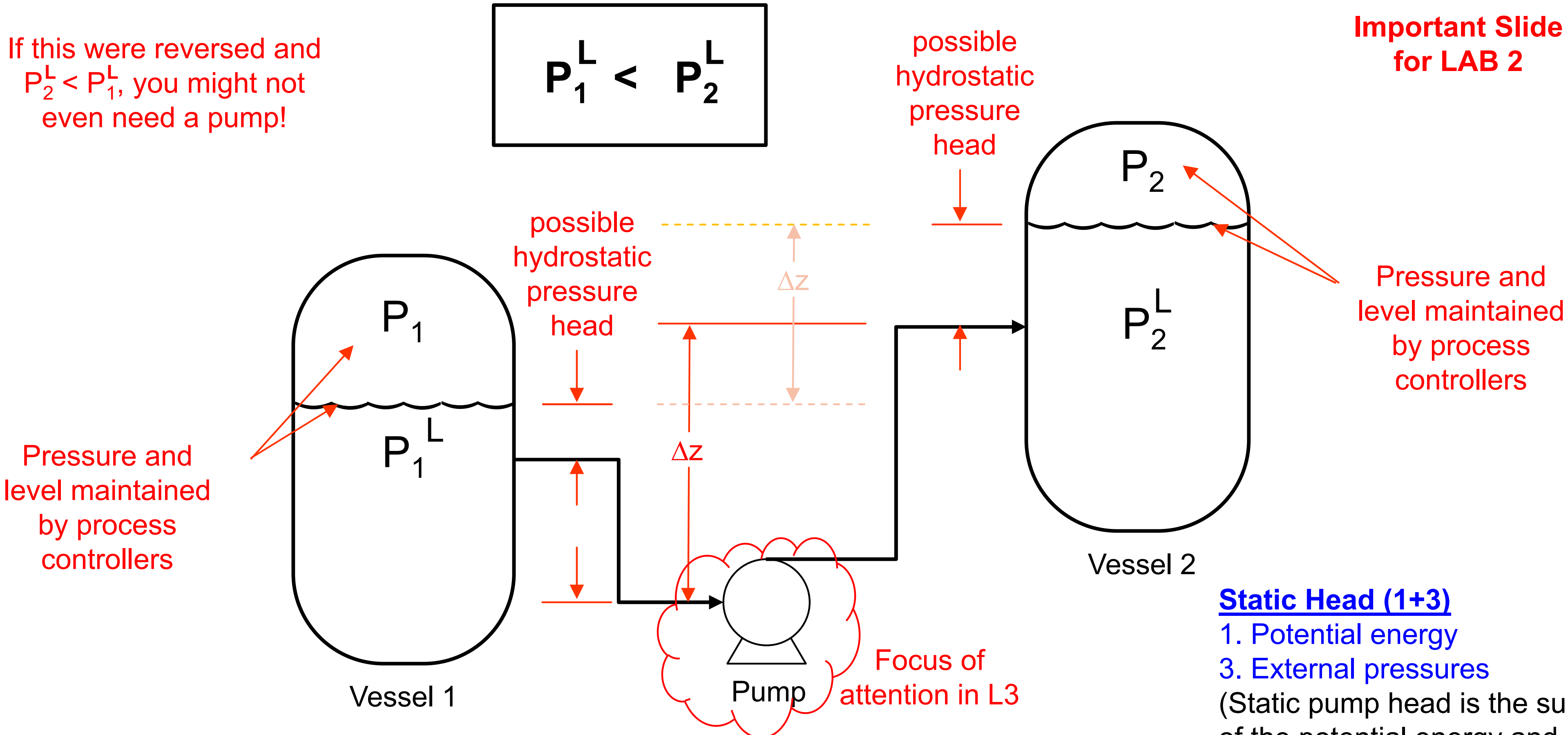
Internal View

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



- 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

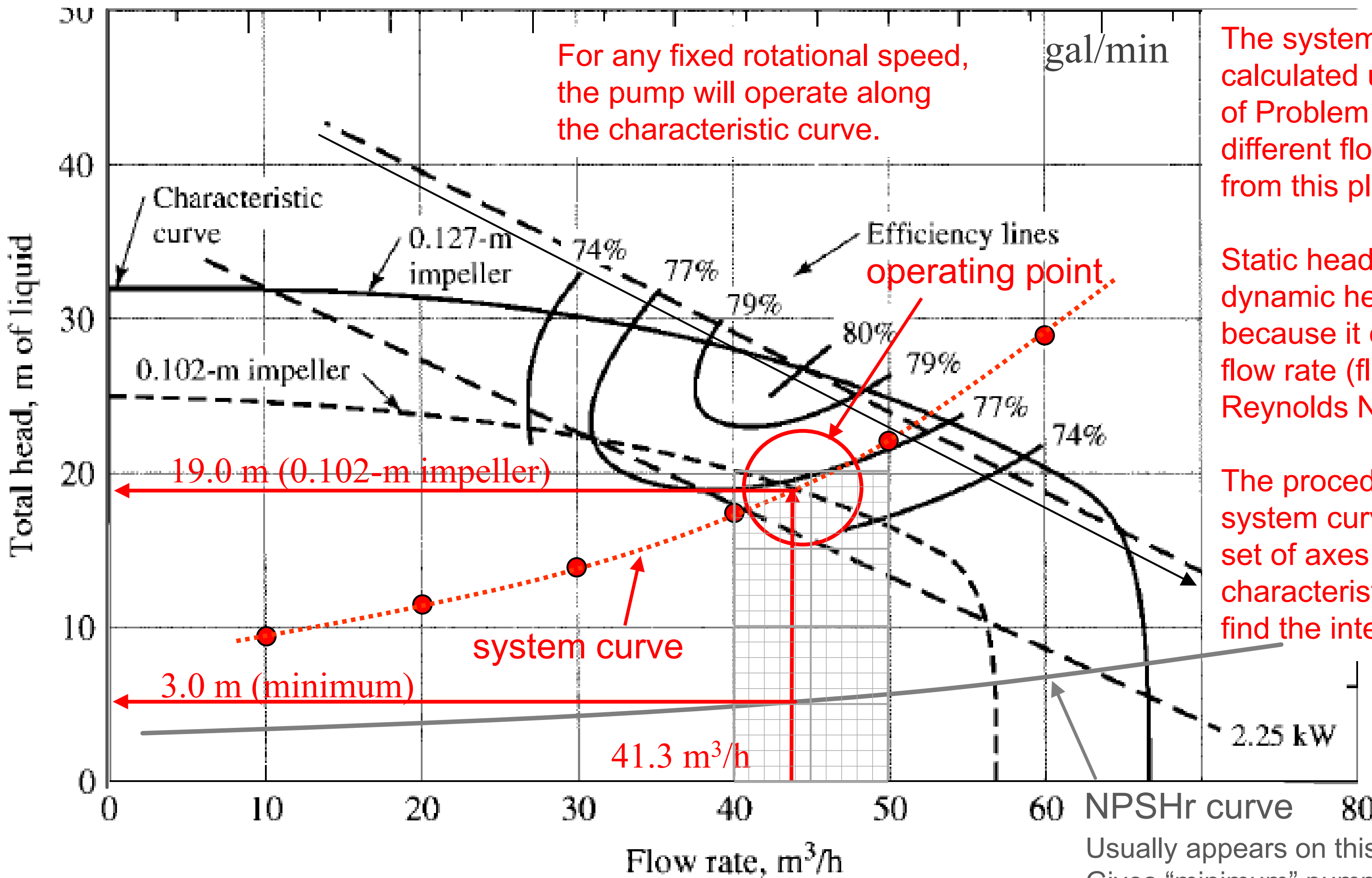
Pump Performance

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 (<u>N</u>et <u>P</u>ositive <u>S</u>uction <u>H</u>ead) 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
```

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

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

(*ΔP=ρ*g*h → h=ΔP/ρ*g*)

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

Out[11]= m

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

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

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

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

$$\underbrace{\frac{N\cdot m}{kg}}_{1N = 1\frac{kg\cdot m}{s^2}}\cdot\frac{m^3}{s}\cdot\frac{kg}{m^3} = \underbrace{\frac{kg\cdot m}{s^2}\cdot\frac{m}{kg}}\cdot\frac{m^3}{s}\cdot\frac{kg}{m^3} = \frac{kg\cdot m^2}{s^3} = \text{Watts}$$

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

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

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)

Questions

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 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 2025

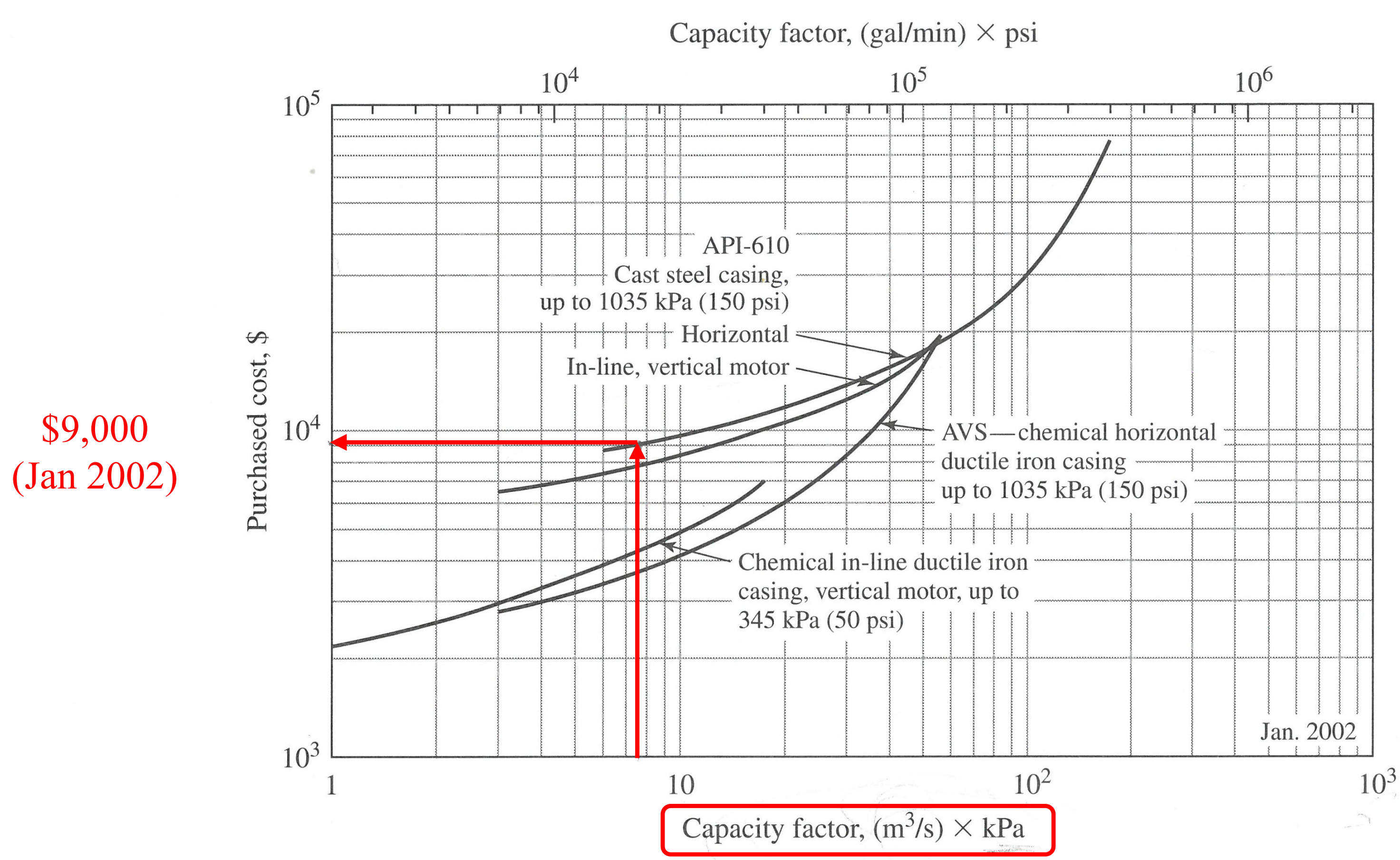

Figure 12-20
Purchased cost of centrifugal pumps. Price includes electric motor.

Supplemental

PS1 AAR

3/6 successful submissions for re-grade; 4 late;
2 cadets with CAC issues

Homework may be submitted in two ways. You may submit an electronic document or a printed document. Electronic submissions must be in pdf format in a single pdf document, contain a CAC-signed and CAC-initialed cover page, and be uploaded to SharePoint. Printed paper documents must include printouts of any Mathematica or Excel files used to solve the problem. Each version must be complete. You may not submit part of the document in print form and part electronic. IMPORTANT NOTE: Graded homework MUST be documented in a manner that is consistent with the Documentation of Academic Work (DAW). According to the DAW, a title page with your signature is also required for either type of submission. This includes all out-of-class assignments, including problem sets, capstone problems, IPRs, etc.

LATE HOMEWORK POLICY. Homework may be submitted late for a cut of 1 point per problem day (weekends and holidays included). Date and time of submission must appear on cover page on the late assignment, or it will not be accepted. Late assignments may not be submitted for a re-grade.

PS1 AAR

Electronic submissions:

- Due date time is 1600. Late cut applies even at 1601 hrs. Not in SIS.
- Must be compiled into a single pdf. In MMA, save as pdf. Then right-click the MMA pdf file and the cover page pdf file and then select “combine files in acrobat.”
- Must be CAC-signed; In Adobe Acrobat Pro DC, select “Tools,” then “Certificates,” then “Digitally Sign,” and follow the prompts.
- Must be on SharePoint. No exceptions, and no emails please.

Evidence of introspection:

- Indicate all answers – either double-underline with pencil or use other clear method such as typing (*//ANS*). Always clearly state units.
- Do not overuse “;” in MMA. Try to develop intuition by knowing the rough size of key values such as velocity, Reynolds number, and friction factor.
- Choose appropriate units for key answers – pressure in Pa, length in meters, viscosity in kg/ms, etc.

Pump Performance

Depends primarily on the "Characteristic Curves"

Very Important Slide!!
LAB 1B

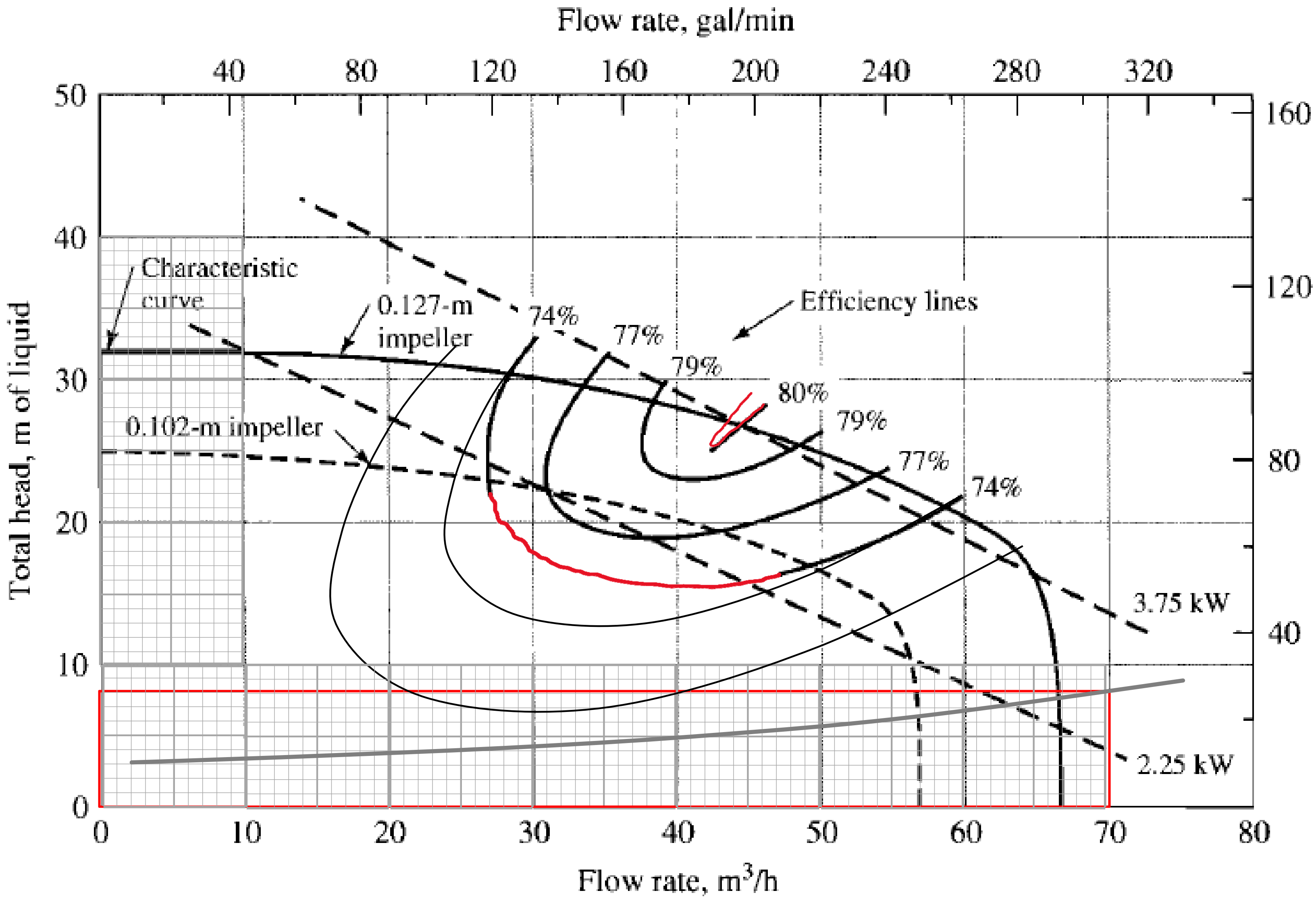

Figure 12-15
Characteristic curve of a centrifugal pump operating at a constant speed of 3450 r/min

Pump Performance

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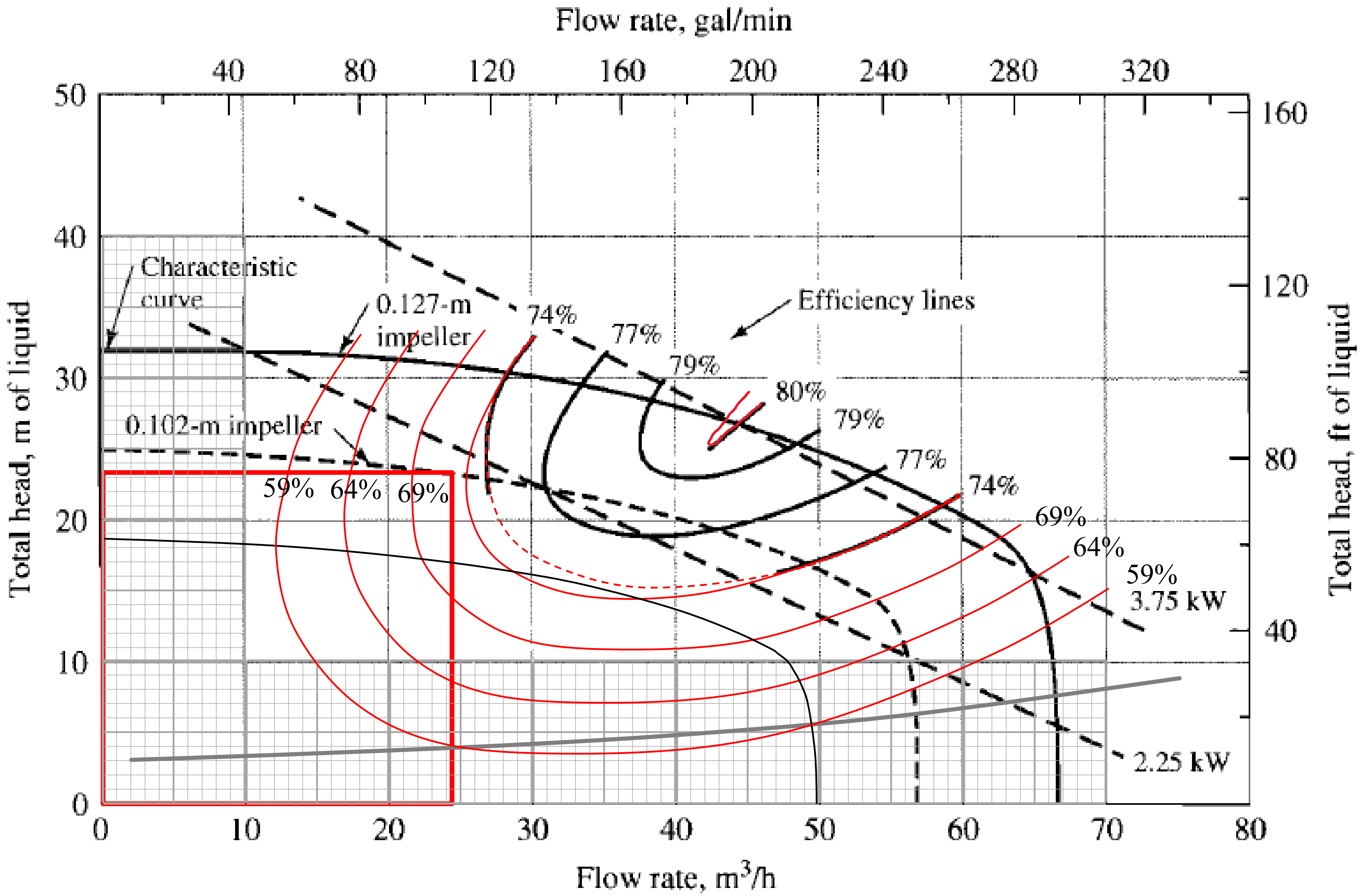
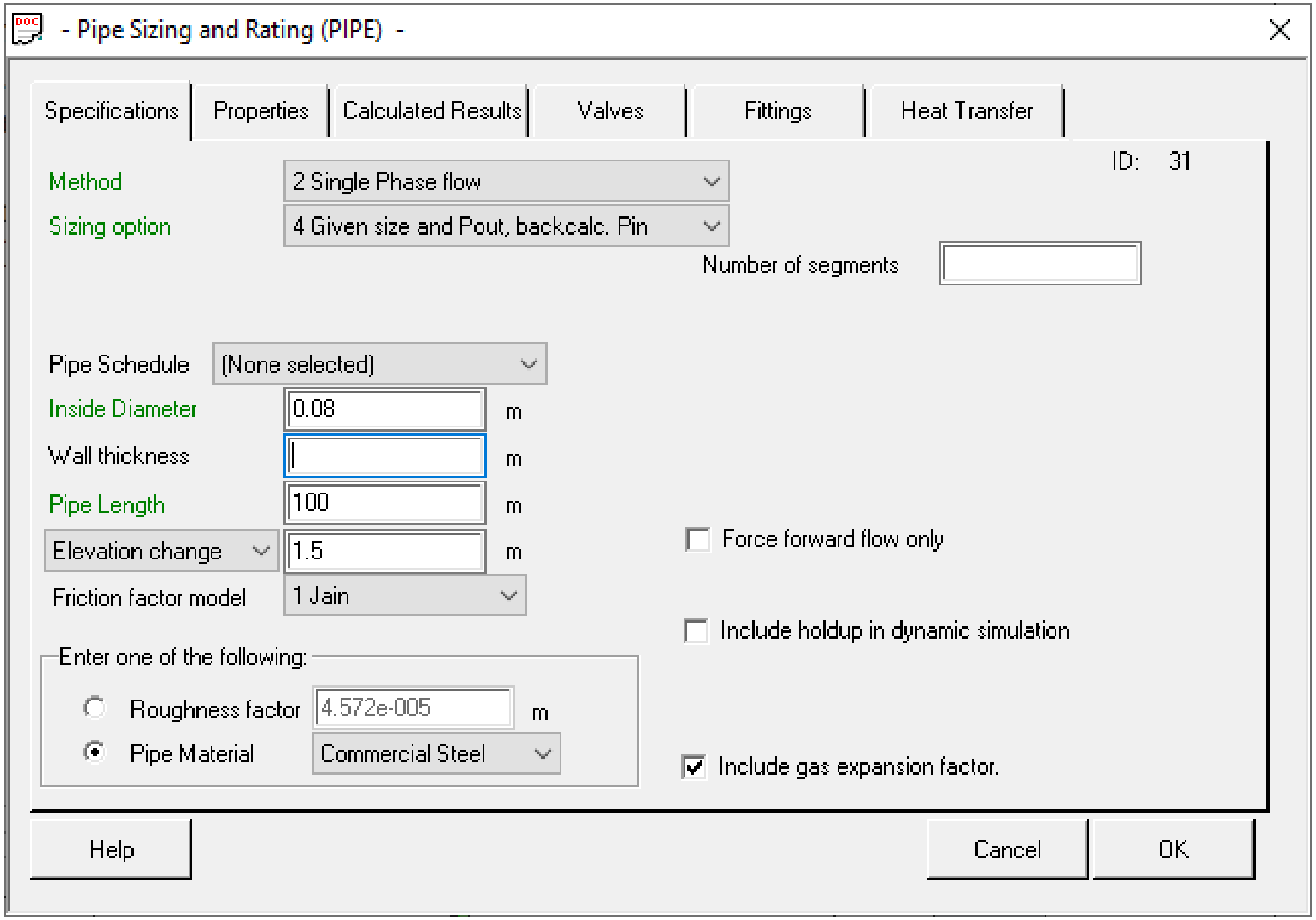


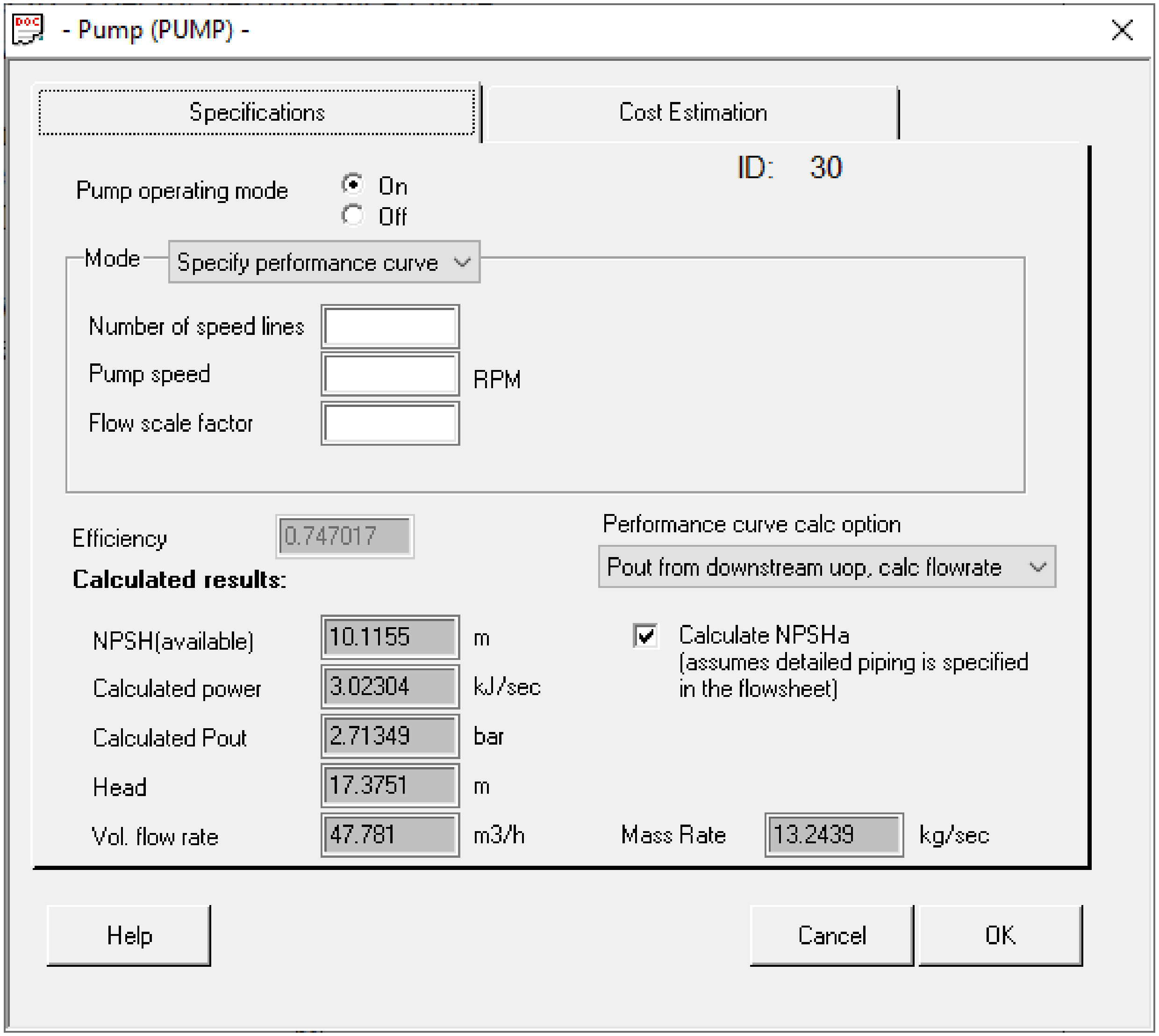
Figure 12-15
Characteristic curve of a centrifugal pump operating at a constant speed of 3450 r/min

Performance Curve

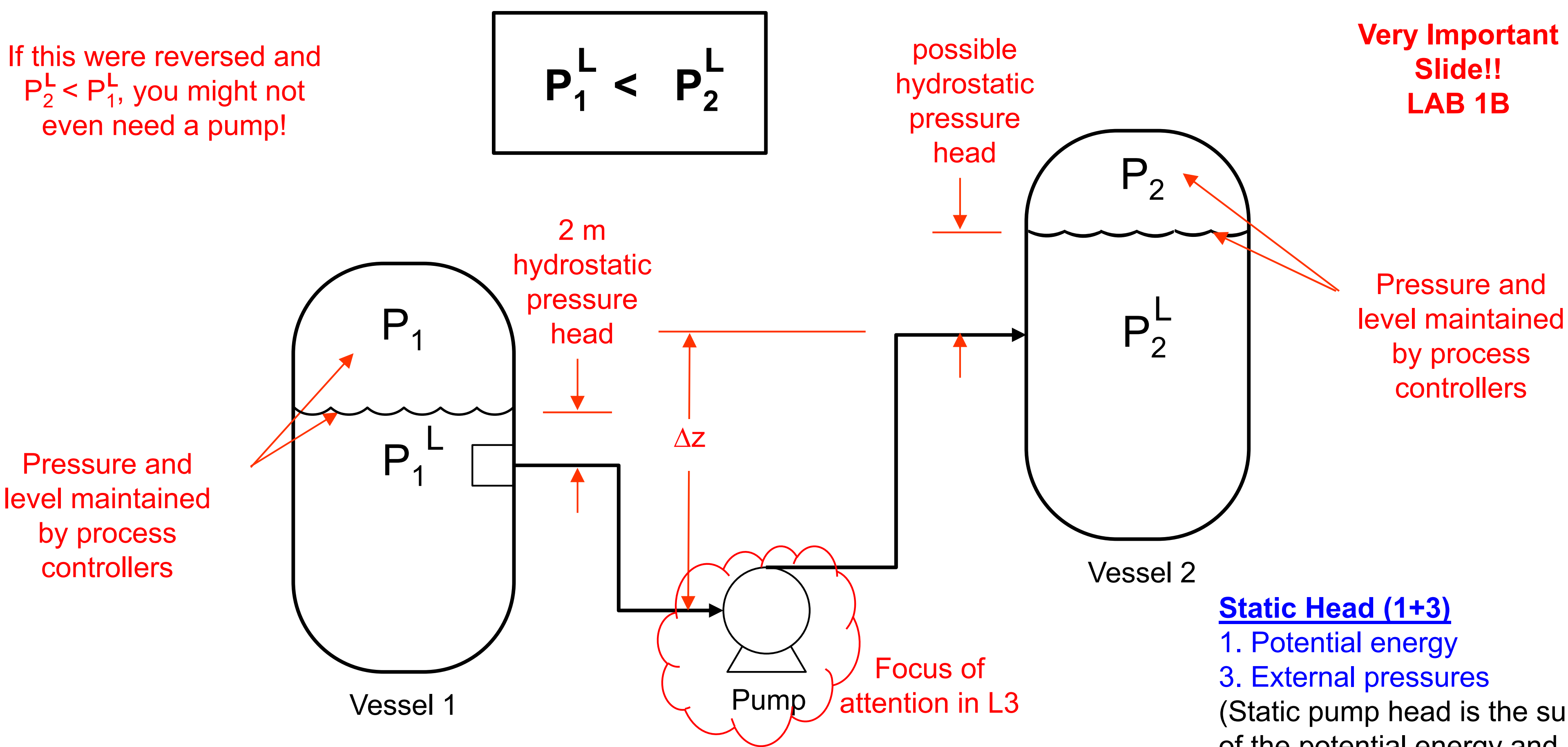
Cancel OK

	Flow (m3/h)	Efficiency	Head (m)
1	1e-005	0.4	25
2	10	0.55	24.8
3	20	0.67	23.8
4	30	0.76	22.5
5	40	0.78	20.1
6	45	0.76	18.5
7	50	0.73	16.3
8	55	.67	13.3
9	56	.64	11
10	56.6	.59	8
11	56.9	.4	.00001
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0


- Pipe Sizing and Rating (PIPE) -
Specifications
Properties
Calculated Results
Valves
Fittings
Heat Transfer
ID: 31
Method
2 Single Phase flow
Sizing option
4 Given size and Pout, backcalc. Pin
Number of segments
Pipe Schedule
(None selected)
Inside Diameter
0.08
m
Wall thickness
m
Pipe Length
100
m
Elevation change
1.5
m
Friction factor model
1 Jain
Force forward flow only
Include holdup in dynamic simulation
Enter one of the following:
Roughness factor
4.572e-005
m
Pipe Material
Commercial Steel
Include gas expansion factor.
Help
Cancel
OK


- Pump (PUMP) -
Specifications
Cost Estimation
ID: 30
Pump operating mode
On
Off
Mode
Specify performance curve
Number of speed lines
Pump speed
RPM
Flow scale factor
Efficiency
0.747017
Performance curve calc option
Pout from downstream uop, calc flowrate
Calculated results:
NPSH(available)
10.1155
m
Calculate NPSHa
(assumes detailed piping is specified
in the flowsheet)
Calculated power
3.02304
kJ/sec
Calculated Pout
2.71349
bar
Head
17.3751
m
Vol. flow rate
47.781
m3/h
Mass Rate
13.2439
kg/sec
Help
Cancel
OK

Pump Overview (Purpose)



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

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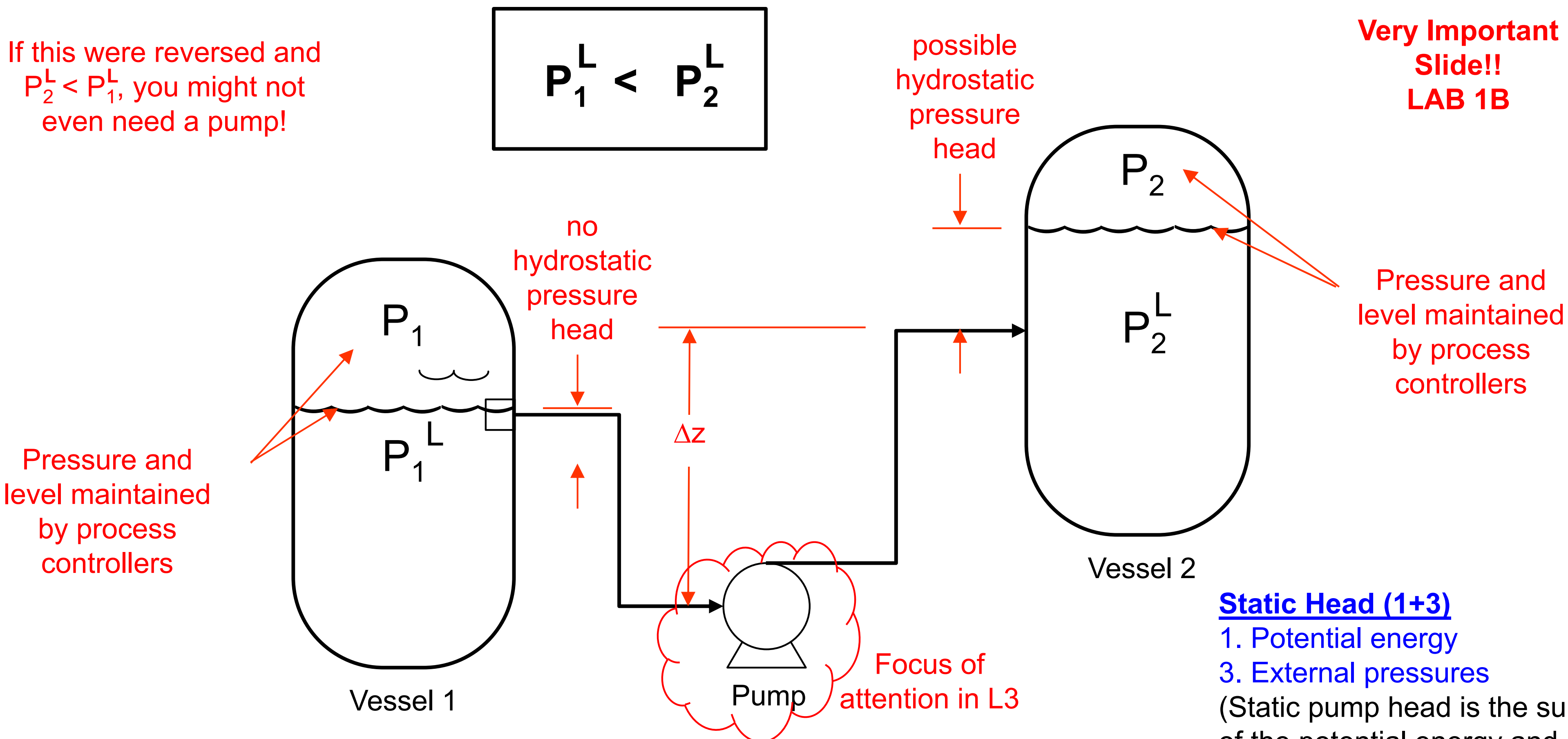
Pump Overview (Purpose)



Very Important Slide!!
LAB 1B

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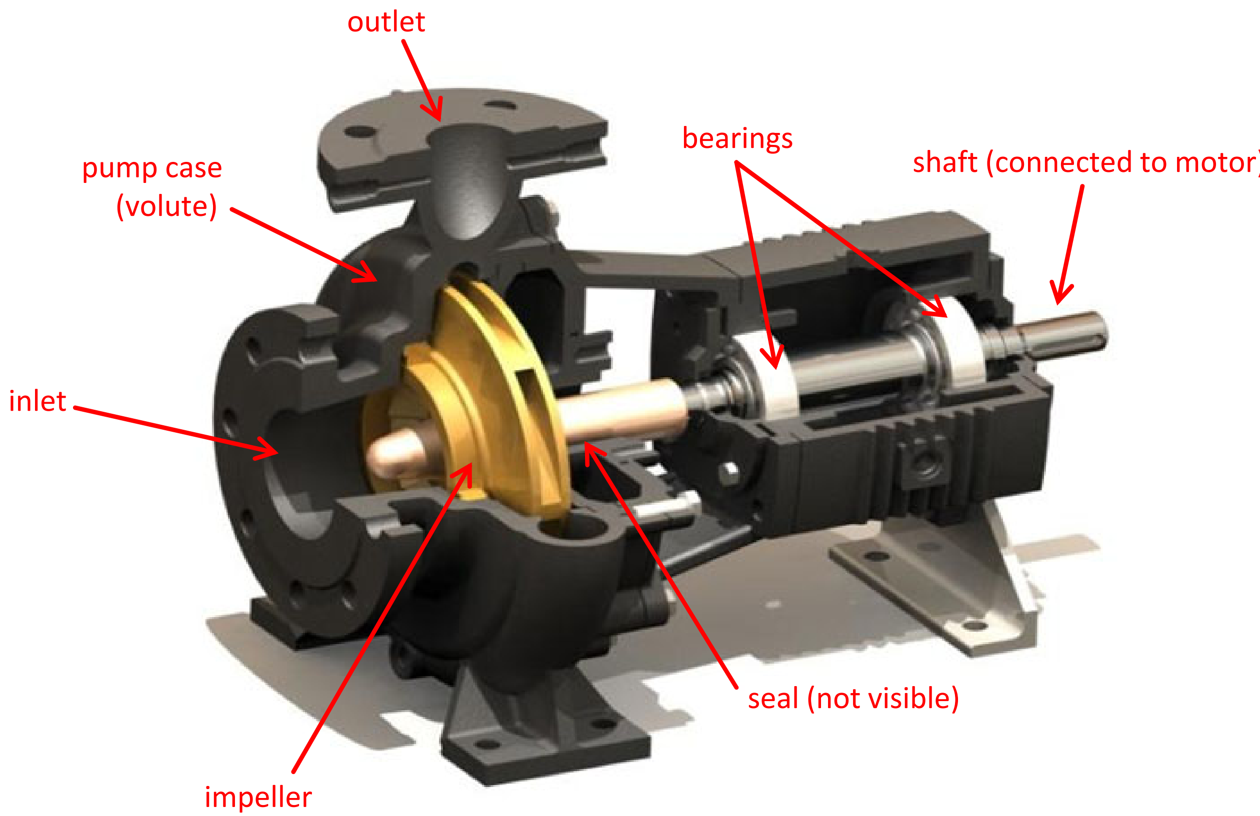
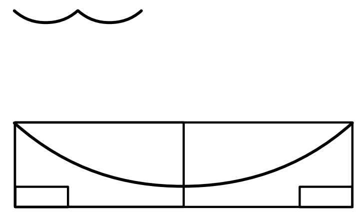

outlet
pump case
(volute)
bearings
shaft (connected to motor)
inlet
seal (not visible)
impeller



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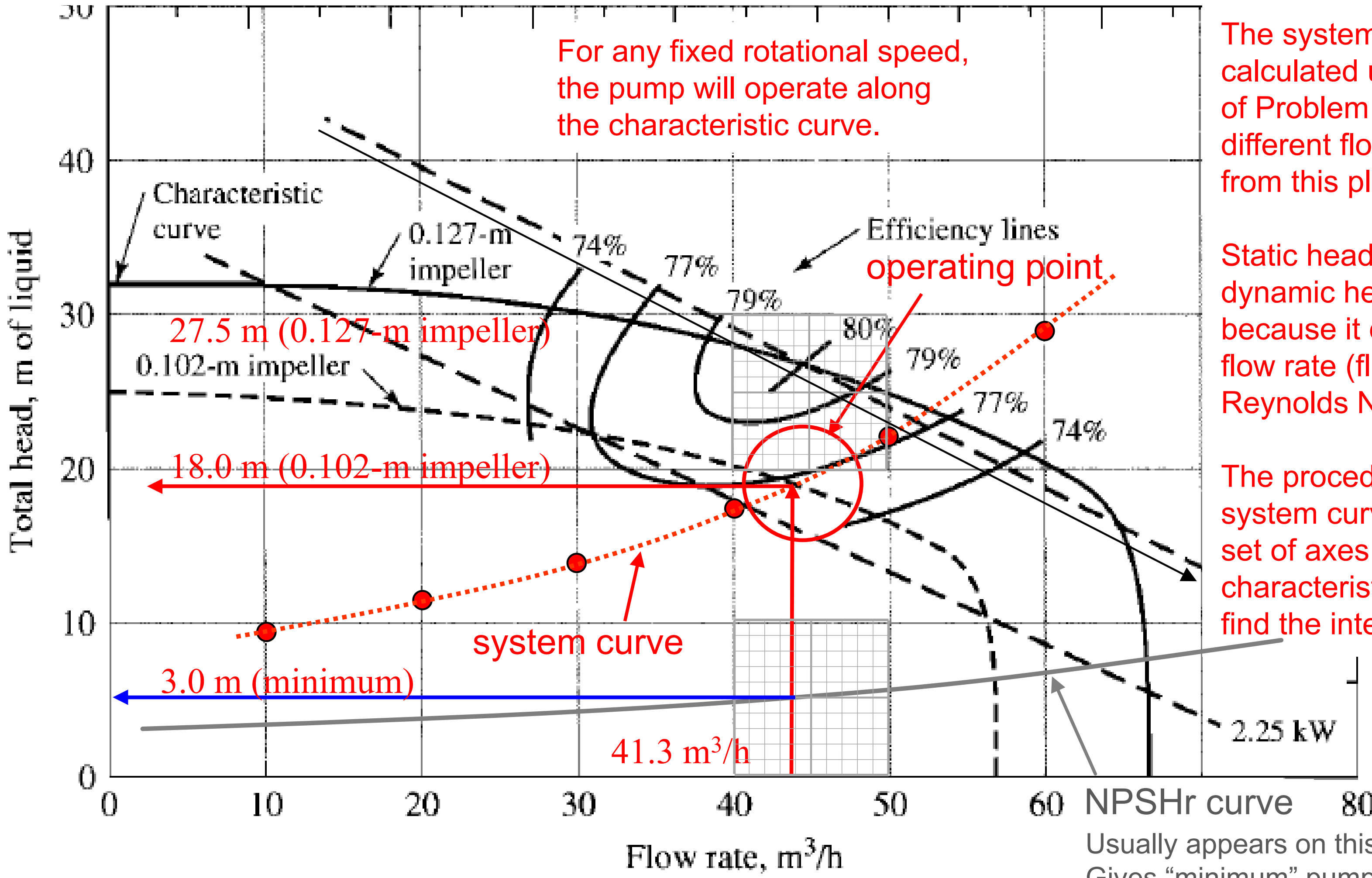

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Characteristic curve of a centrifugal pump operating at a constant speed of 3450 r/min

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