ENGR10004

ENGINEERING SYSTEMS DESIGN 1

WORKSHOP 4

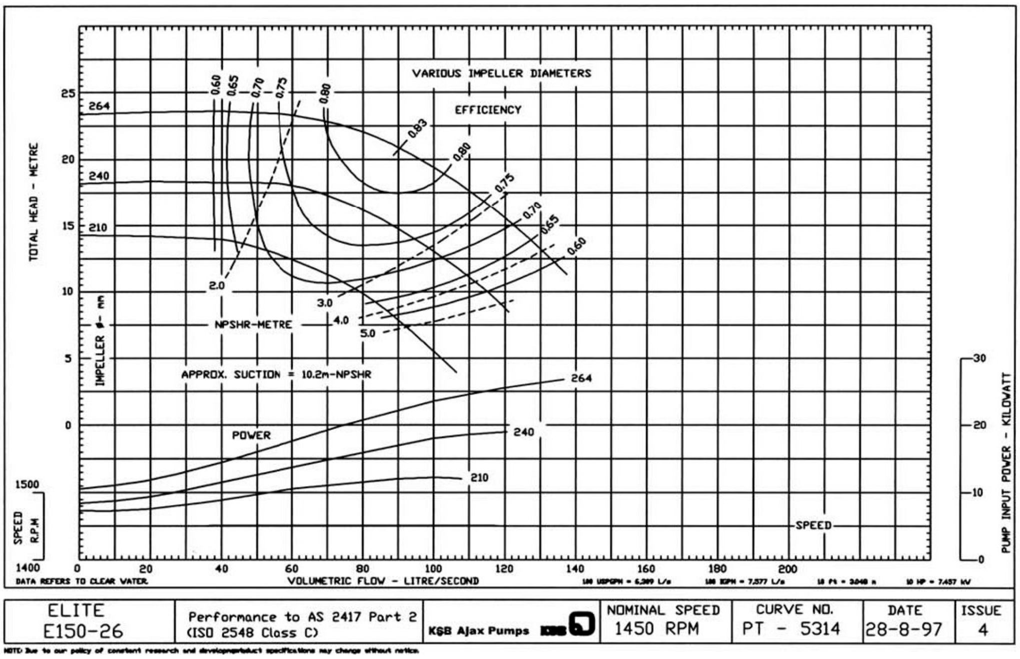
Fluid mechanics – pumps, system curves, system operating point

When necessary throughout these workshop questions, 0 °C = 273 K

Question 1

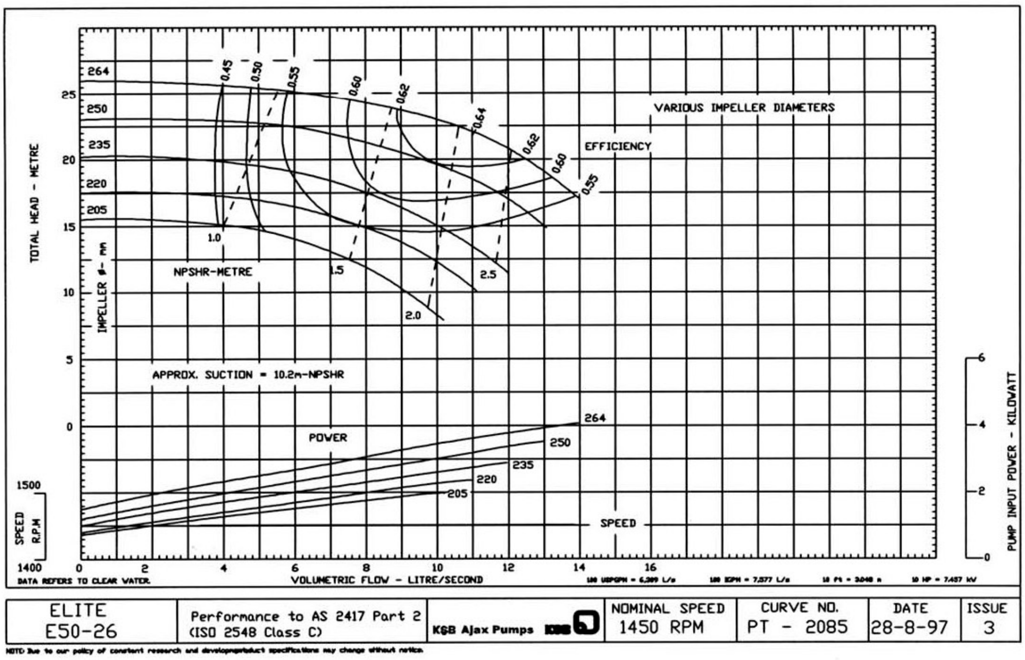
Based on the pump curve below, determine the following:

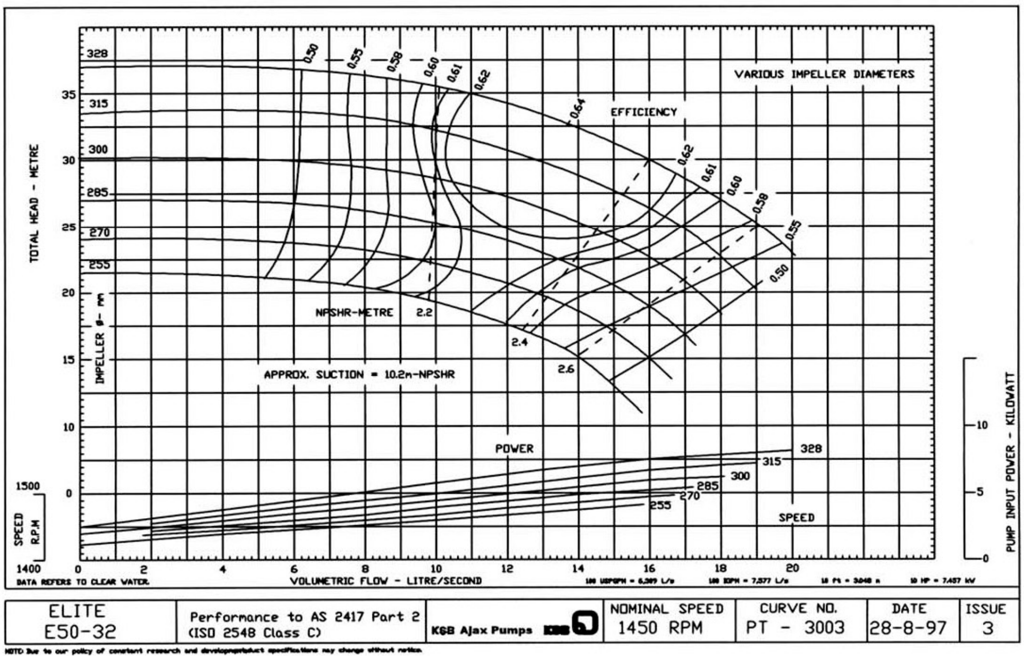
- The head obtained at 60 L/s with a 210 mm impeller
- The efficiency at 102 L/s with a 240 mm impeller
- The flow rate that could be obtained with a 264 mm impeller if 17.5 m of head were required
- The power consumed at 70 L/s with a 240 mm impeller
- The highest possible efficiency of this pump family
    - o The flow rate, impeller size required to achieve the maximum efficiency point
    - o The head developed at the maximum efficiency point



Question 2

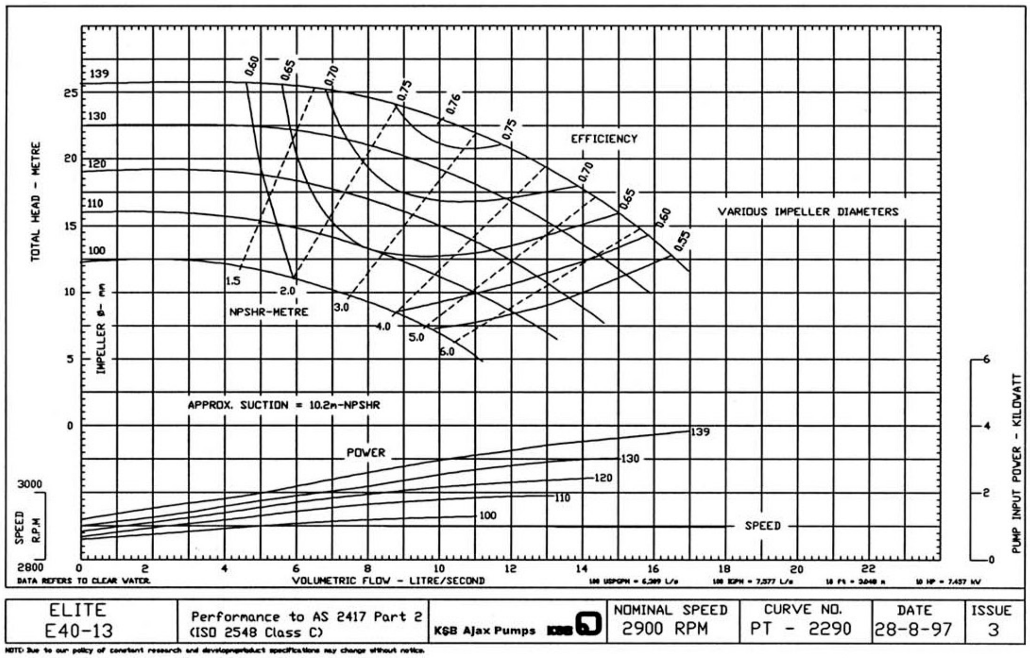
Given the option of the two pumps below – which one would you select if you needed to pump a flow rate of 15 L/s?





Question 3

Based on the pump curve below, if 15 m of head were required, which impeller size would you choose to maximise the flow rate to power consumption ratio?



Question 4

Based on the pump in question 3, if a 3 kW motor were available, which impeller size would you choose to maximise the head obtained?

What is the pump efficiency if operated under these conditions?

Question 5

Ethanol flows through the following system and enters a storage tank. It is being transported in 250 mm ID stainless steel piping.

- ½ open gate valve
- 47 m of pipe
- 45 ° elbow
- 16 m of pipe
- 90 ° elbow
- 15 m of vertical pipe (upwards flow)
- 90 ° elbow
- 1 m of pipe

Determine the total system head at flow rates between 0 and 200 L/s, in 10 L/s increments (write an m-file).

$\varepsilon_{SS} = 3.00 \cdot 10^{-7}$ m

$\varrho_{EtOH} = 789$ kg/m^3 $\mu_{EtOH} = 1.20 \cdot 10^{-3}$ Pa·s

Question 6

A pump with the following pump curve is going to be used to overcome the losses of the system described in question 5.

Flow [L/s]	**0**	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**
Head [m]	21.0	20.2	18.8	16.9	14.6	11.7	8.3	4.4	0

- Plot the above pump curve in Excel or MATLAB
- Plot the system curve from question 5 on the same axis

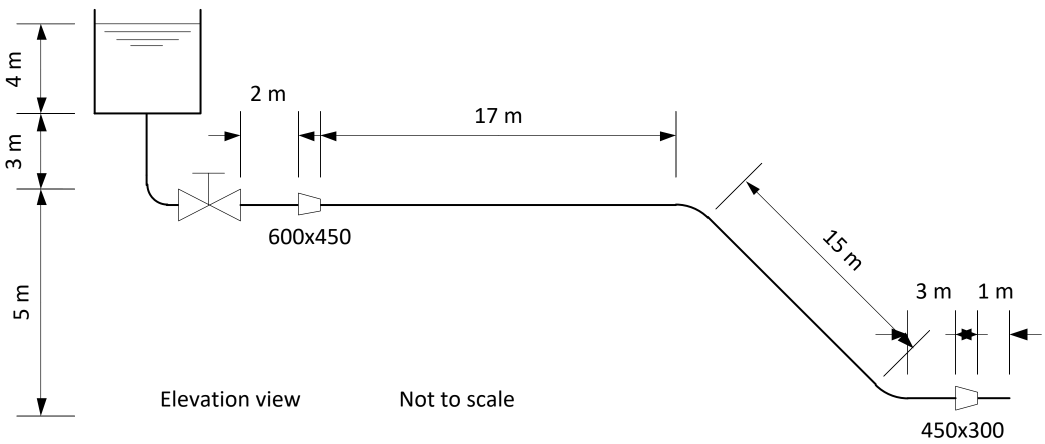
Based on these two plots, what is the operating point of the system?

Reminder: the system curve is the name given to the flow rate-head information for a fluid system.

Optional: determine the flow rate analytically by fitting the system curve and pump curve data with suitable equations, and solving for the flow rate.

Question 7

Determine the operating point of the following system if the pump with the specifications below will be used to overcome the losses. The gate valve is ¾ open, the piping is constructed from steel, and the physical properties of the fluid are below. The pump will be installed at the outlet of the tank.



Determine the system curve over a flow rate range of 0 to 1.50 m^3/s.

Pump curve data:

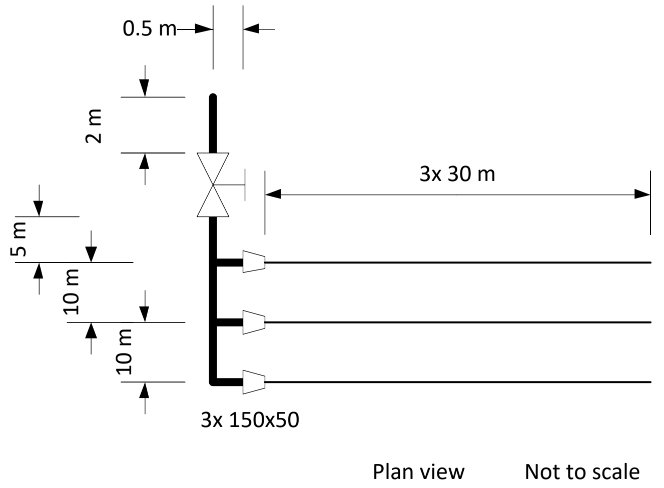
Flow [L/s]	**0**	**175**	**350**	**525**	**700**	**875**	**1050**	**1225**	**1400**	**1500**
Head [m]	25.0	24.7	23.6	21.9	19.6	16.5	12.8	8.33	3.22	0.00

Properties:

$\varepsilon_{Steel} = 45 \cdot 10^{-6}$ m $\qquad$ $\rho_{293K} = 998$ kg/m^3 $\qquad$ $\mu_{293K} = 1.0 \cdot 10^{-3}$ Pa·s

Question 8

Determine the operating point of the system shown below. For simplicity, assume that the total inlet flow rate is split equally to the 3 branches. The gate valve is fully open when running, and the system is constructed from PVC.



Determine the system curve over a flow rate range of 0 to 1200 L/min.

Pump curve data:

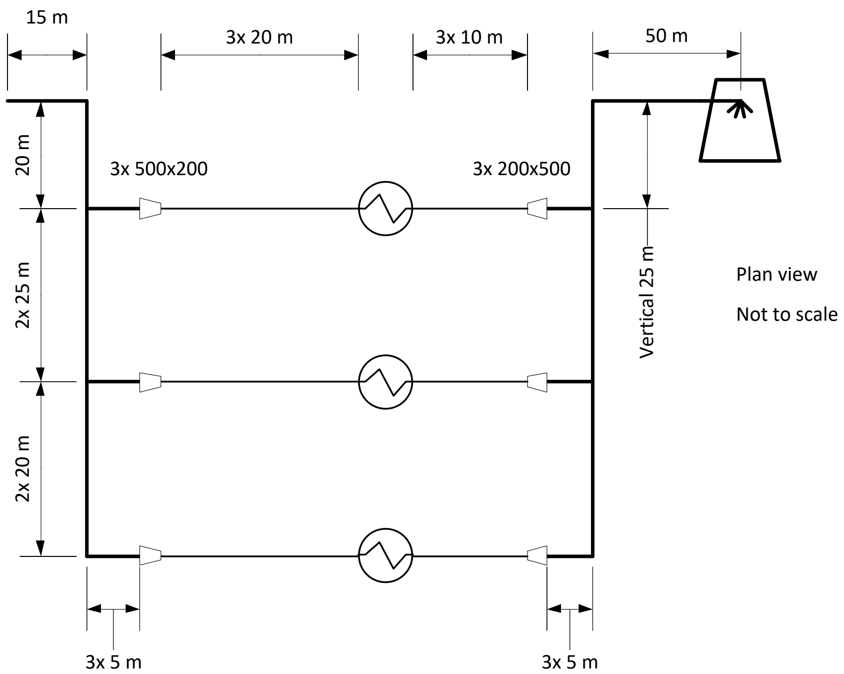
Flow [L/min]	**0**	**150**	**300**	**450**	**600**	**750**	**900**	**1050**	**1200**
Head [m]	20.0	20.4	20.0	18.8	16.7	13.8	10.0	5.42	0.00

Properties:

$\varepsilon_{PVC} = 3 \cdot 10^{-6}$ m $\qquad \rho_{293K} = 998$ kg/m^3 $\qquad \mu_{293K} = 1.0 \cdot 10^{-3}$ Pa·s

Question 9

Determine the operating point of the system below, the total inlet flow rate can be assumed to divide equally between the three branches. Cooling water enters the system at 20 °C and is used to cool other material in the heat exchangers. The water then returns to the cooling tower to be recycled. The system is constructed from steel, and you may ignore the change in fluid properties due to the change in temperature.



Determine the system curve over a flow rate range of 0 to 300 L/s.

Pump curve data:

Flow [L/s]	**0**	**40**	**80**	**120**	**160**	**200**	**240**	**280**	**320**
Head [m]	70.0	69.1	65.9	60.5	52.9	43.0	30.9	16.6	0.00

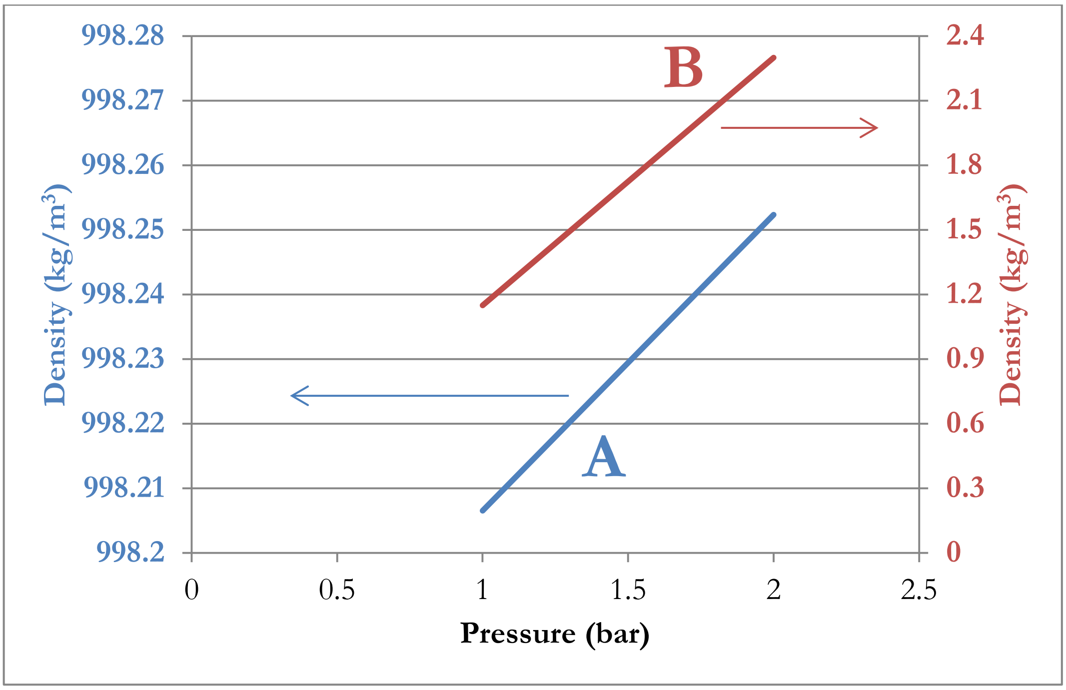
Properties:

$\varepsilon_{Steel} = 52 \cdot 10^{-6}$ m $\qquad \varrho_{293K} = 998$ kg/m^3 $\qquad \mu_{293K} = 1.0 \cdot 10^{-3}$ Pa·s

K value of heat exchanger = 2.5

Question 10 (optional)

The densities of two fluids are shown below as a function of pressure, at a constant temperature of 20 °C.



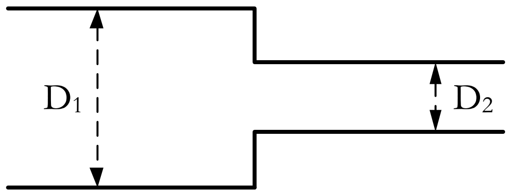
What is the main difference between fluid A and fluid B, and what impact would this have when using the Bernoulli equation to solve fluid flow problems?

K values for fittings

Fitting	K
45 ° elbow	0.35
90 ° elbow	0.75
180 ° bend	1.5
Tee – run through – branch blocked	0.4
Tee – all other flow patterns	1
Coupling	0.04
Union	0.04
Pipe exit	1
Pipe entrance	0.75
Gate valve – open	0.17
Gate valve – ¾ open	0.9
Gate valve – ½ open	4.5
Gate valve – ¼ open	24

K value functions for expanders and reducers

Reducers



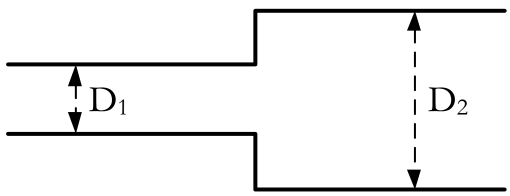
$Re_1 < 2500$

$$K = \left(1.2 + \frac{160}{\mathrm{Re}_1}\right)\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]$$

$Re_1 \geq 2500$

$$K = (0.6 + 0.48 f_1)\left(\frac{D_1}{D_2}\right)^2 \left[\left(\frac{D_1}{D_2}\right)^2 - 1\right]$$

Expanders



$Re_1 < 4000$

$$K = 2\left[1 - \left(\frac{D_1}{D_2}\right)^4\right]$$

$Re_1 \geq 4000$

$$K = (1 + 0.8 f_1)\left[1 - \left(\frac{D_1}{D_2}\right)^2\right]^2$$

Goudar-Sonnad correlations for f

Hydrocarbon Processing, 2008, 87 (8), page 79

$$a = \frac{2}{\ln(10)} \qquad b = \frac{\varepsilon/D}{3.7} \qquad d = \frac{\ln(10)}{5.02} \cdot \mathrm{Re}$$

$$s = b \cdot d + \ln(d) \qquad q = s^{\frac{s}{s+1}}$$

$$g = b \cdot d + \ln\left(\frac{d}{q}\right) \qquad z = \ln\left(\frac{q}{g}\right)$$

$$\delta_{LA} = \left(\frac{g}{g+1}\right) \cdot z$$

$$\delta_{CFA} = \delta_{LA} \cdot \left[1 + \frac{z/2}{(g+1)^2 + (z/3) \cdot (2g-1)}\right]$$

$$\frac{1}{\sqrt{f}} = \phi = a \cdot \left[\ln\left(\frac{d}{q}\right) + \delta_{CFA}\right]$$

$$f = \left(1/\phi\right)^2$$