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Design Problem 2 – Hydraulics & Pump Characteristics

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Objective

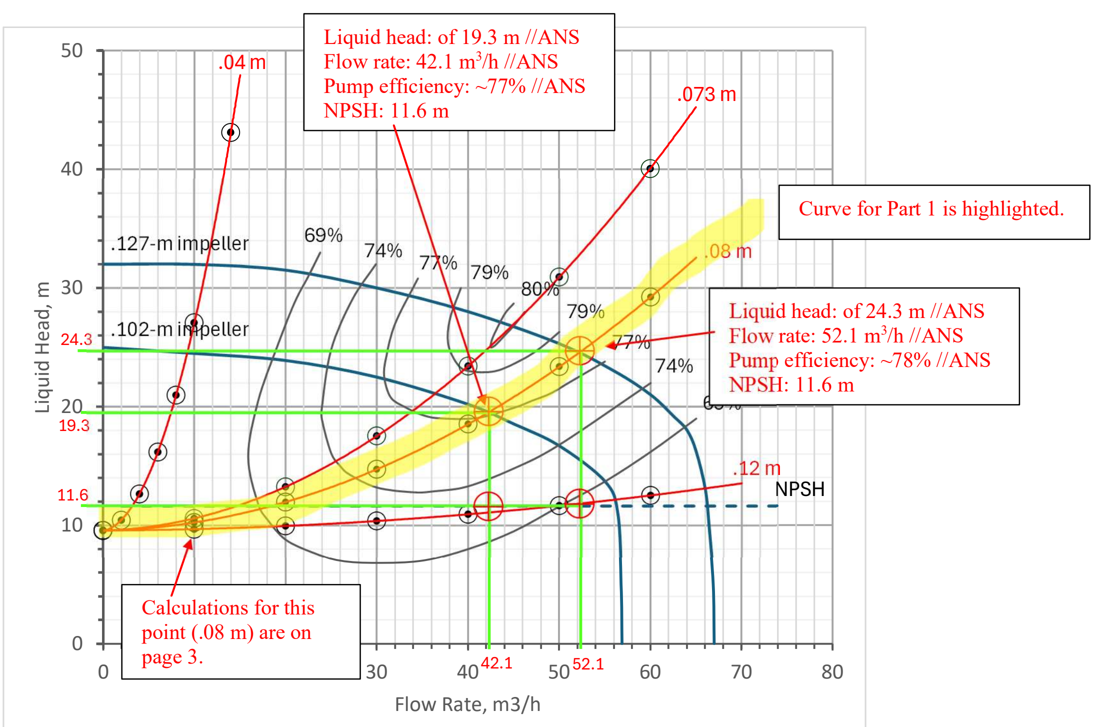
The objective is to determine the operating point for a pump-pipe system using the pump characteristic curve. This exercise accompanies the pump video by Jacques Chaurette.

Problem Statement

A process liquid is pumped from a storage tank to a distillation column using a centrifugal pump. The pump characteristic curve is shown below. The pipeline is 100 m long and is 80 mm-internal-diameter commercial carbon steel pipe. Miscellaneous losses from fittings and valves are equivalent to 600 pipe diameters. The storage tank operates at atmospheric pressure and the column at 1.7 bara. The lowest liquid level in the tank is 1.5 m above the pump inlet, and the feed to the column is 3 m above the pump inlet. The density of the fluid is 868 kg/m^3 and its viscosity is 0.631 mNs/m^2.

Part 1. Generate and plot the system curve for the system described above. The plot must be on the same axes as the characteristic curves. An Excel template is posted in CANVAS to assist with this. Use the plot to determine the operating point, pump efficiency, and NPSH for the 0.102-m and .127-m impellers, and complete the 0.08-m column in the table on page 2. A fillable pdf table form is posted in CANVAS.

Part 2. Optimize the system curve by changing the pipe diameter using the efficiency of the pump as an optimization metric. Use the diameters given in the table on page 2, then use your results to complete the table.



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Diameter	0.04 m	0.08 m	0.12 m	Opt: 0.073 m
0.102-m impeller				
Flow Rate, m^3/h	9.3	42.1	56.0	36.5 //ANS
Liquid head, m	24.5	19.3	12.0	21.0 //ANS
Efficiency, %	63	77	68	77 //ANS
NPSH, m	11.6	11.6	11.6	11.6 //ANS
0.127-m impeller				
Flow Rate, m^3/h	11.0	52.1	66.0	45 //ANS
Liquid head, m	32.0	24.3	13.0	26.5 //ANS
Efficiency, %	61	78	64	80 //ANS
NPSH, m	11.6	11.6	11.6	11.6 //ANS

Submission Requirements

1. A plot the required system curves on the same set of axes as the characteristic curves, with a minimum of six points for each curve and a "smooth" curve sketched through the points. You may use the Excel template in CANVAS to complete this requirement.

2. All four columns of the table completed. You may use the pdf template in CANVAS to complete this requirement.

3. A pdf of the plot, a pdf of the completed table, and a signed cover sheet, bundled into a single pdf.

4. Completed pdf and Excel documents submitted in Canvas.

Supporting Calculations *(Use space below. Append additional sheets as necessary)*

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Solution

Use Equation 12-12 on page 492 to calculate the static and dynamic head terms. Dynamic head terms are the flow-dependent terms and the static head terms remain constant with respect to flow. Static head includes elevation and pressure terms, and kinetic energy and frictional losses contribute to dynamic head. The static and dynamic heads are calculated below, with the sample calculation of dynamic head at one flow rate. The sample calculation is for 10 m^3/h.

Static head terms:

The static head is the same at all flow rates.

$$\text{Difference in elevation} = \Delta z = 3.0 - 1.5 = 1.5\text{m}$$

$$\text{Difference in pressure} = \Delta P = (1.7 - 1.01325)\times 10^5 = 0.7\times 10^5\,\tfrac{\text{N}}{\text{m}^2} = 0.7\times 10^5\,\tfrac{\text{kg}}{\text{m}\cdot\text{s}^2}$$

$$\Delta P \text{ as head of liquid} = (0.7\times 10^5\,\tfrac{\text{kg}}{\text{m}\cdot\text{s}^2}) / (868\,\tfrac{\text{kg}}{\text{m}^3}\times 9.8\,\tfrac{\text{m}}{\text{s}^2}) = 8.1\text{m}$$

$$\text{Total static head} = 1.5\,\text{m} + 8.1\,\text{m} = 9.6\text{m}$$

Dynamic head terms, for fluid flow rate of 10 m^3/h:

The dynamic head calculation is repeated for other flow rates to determine the points shown in the plot.

$$\text{cross-sectional area of pipe} = \frac{\pi}{4}(0.080\text{m})^2 = 5.03\times 10^{-3}\,\text{m}^2$$

$$\text{velocity} = \frac{\left(10\,\tfrac{\text{m}^3}{\text{h}}\right)\times\left(\tfrac{1\text{hr}}{3600\text{s}}\right)}{5.03\times 10^{-3}\,\text{m}^2} = 0.5526\ \text{m/s}$$

$$\text{Reynolds number} = \frac{.080\times .5526\times 868}{0.000631} = 68{,}675$$

$$\text{relative roughness} = 0.000046 / 0.080 = 0.000575$$

$$\text{friction factor} = 0.0055\ \text{(read from fig 12-1)}$$

$$\text{equivalent pipe length} = 100\text{m} + 600\times 0.080\text{m} = 148\text{m}$$

$$\text{frictional head from eq 12-7} = \frac{2\times .0055\times(.5526\,\tfrac{\text{m}}{\text{s}})^2\times 148\,\text{m}}{0.080\,\text{m}\times 9.8\,\tfrac{\text{m}}{\text{s}^2}} = 0.6\underline{3}7\,\text{m}$$

$$\text{kinetic energy term} = \frac{\tfrac{1}{2}(0.5526\,\tfrac{\text{m}}{\text{s}})^2}{9.8\,\tfrac{\text{m}}{\text{s}^2}} = 0.01\underline{5}6\,\text{m}$$

$$\text{total dynamic head} = 0.64\,\text{m} + 0.02\,\text{m} = 0.6\underline{5}3\,\text{m}$$

$$\text{total head} = 0.6\underline{5}3\,\text{m} + 9.\underline{6}\,\text{m} = 10.\underline{2}\,\text{m}$$

This last result is plotted as the second point in the plot.