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Exercises – Series 3

Exercise 1: Centrifugal pump

We want to install a centrifugal pump to drive water at a nominal flowrate $Q_n = 0.2\ m^3/s$, between 2 large tanks located at 218 m and 320 m above sea level. The pump is located $4\ m$ above the lower tank free surface. The diameter of the pipe is $D = 0.5\ m$ and its total length is $L_{tot} = L_1 + L_2 = 20 + 6800 = 6820\ m$. The flow is assumed steady and incompressible. The fluid density is $\rho = 998\ kg/m^3$, its dynamic viscosity is $\mu = 10^{-3}\ Pa.s$ and the atmospheric pressure is $p_{atm} = 10^5\ Pa$.
The hydraulic system is schematized in
Figure *1*.

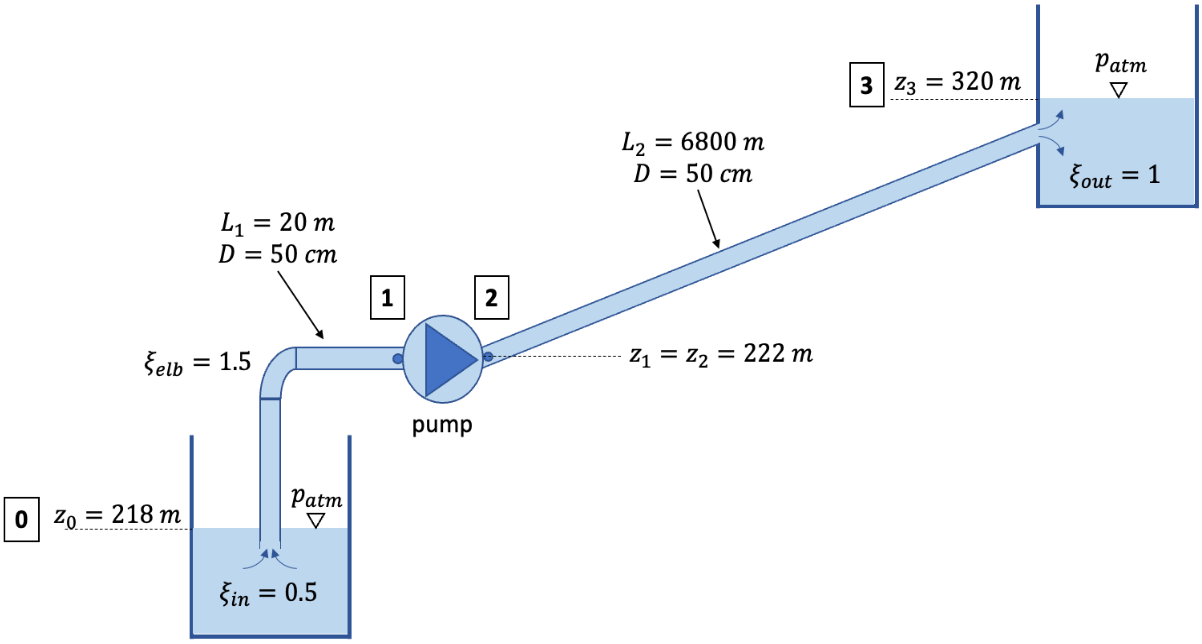

Figure 1: Hydraulic system.

The manufacturer proposes a centrifugal pump, whose characteristics are provided in Figure 2, in terms of Head, Efficiency and $NPSH_{3\%}$ as functions of the flowrate.

Note: $NPSH_{3\%}$ is the Net Positive Suction Head corresponding to 3% drop of the efficiency, due to cavitation.

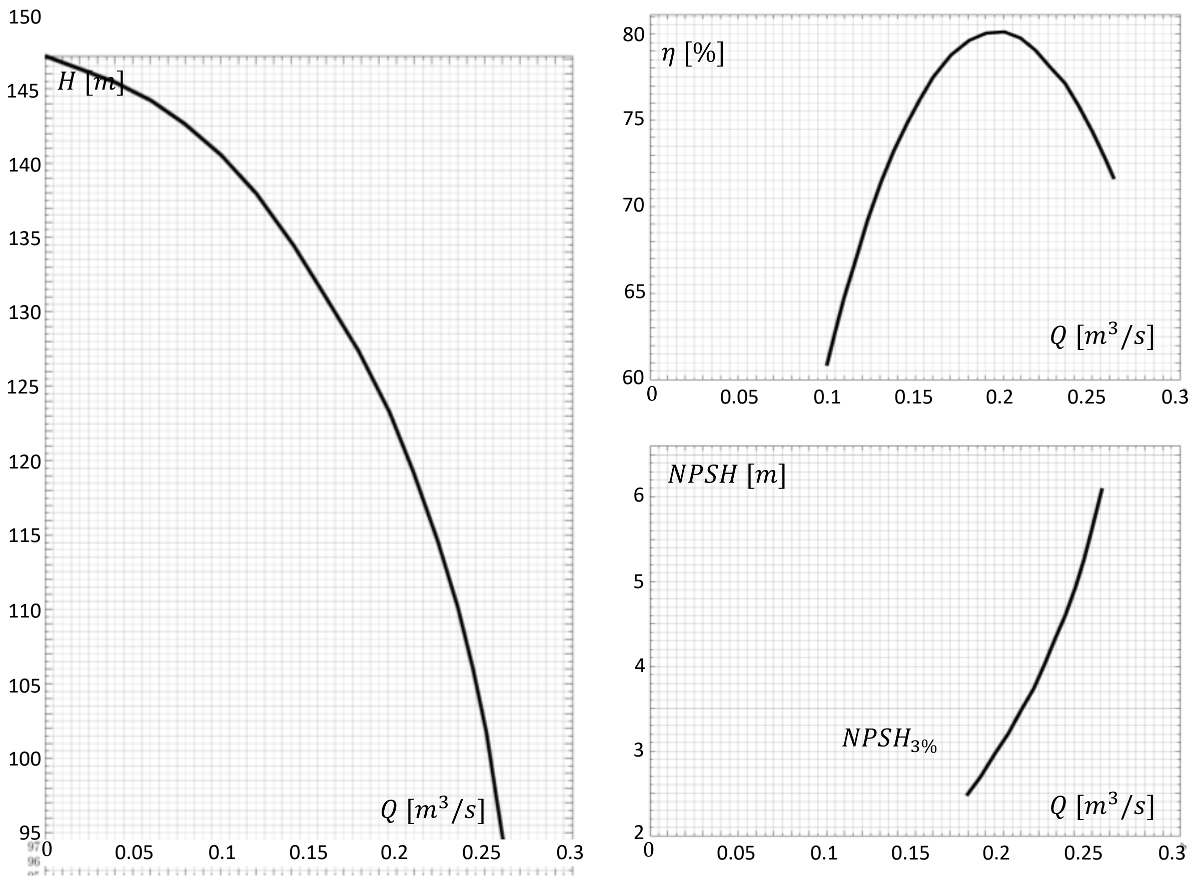

Figure 2: Centrifugal pump characteristics. Head, efficiency, $NPSH_{3\%}$.

Table 1 Centrifugal pump characteristics. Head, efficiency, $NPSH_{3\%}$.

$Q[m^3/s]$	$H\ [m]$	η [%]	$NPSH_{3\%}\ [m]$
0.00	150.2000		
0.02	149.3249		
0.04	148.4165		
0.06	147.2235		
0.08	145.5868		
0.10	143.5593	60.8160	
0.12	140.9826	68.1603	
0.14	137.7130	73.6645	
0.16	133.9341	77.4537	
0.18	129.9891	79.5653	2.4963
0.20	125.0644	80.1032	3.1190
0.22	118.7382	78.8231	3.8705
0.24	110.6621	76.2637	4.8895
0.26	97.8858	72.2213	6.4473

1. Compute the Reynolds number for the pipe flow at nominal conditions. Is this flow laminar or turbulent?

2. Use the Moody diagram to determine the regular head loss coefficient f for the pipe, assuming a relative pipe roughness of 0.001.

3. Determine the characteristic curve of the system under the form $H(Q) = A + BQ^2$ (where A and B are two constants) and draw its evolution on the head diagram.

   Use the major (regular) head loss coefficient in 2) and minor (singular) head loss coefficients given in Figure 1 ($K_{L,in}$ for the inlet, $K_{L,elb}$ for the elbow and $K_{L,out}$ for the outlet).

4. What are the effective operating conditions of the pump: Q_{op} and H_{op}?

5. What is the mechanical power P_m required to drive the pump at the effective operating point?

6. Express the available net positive suction head $\left(NPSH_A = \left(\frac{p_1}{\gamma} + \frac{V_1^2}{2g}\right) - \frac{p_v}{\gamma}\right)$ under the form $NPSH_A(Q) = C - FQ^2$ (where C and F are two constants), considering the head loss between the lower tank free surface and the pump inlet. Draw its evolution on the $NPSH_{3\%}$ diagram.

   At standard temperature the vapor pressure of water $p_v = 2300\ Pa$.

7. Evaluate the cavitation performance of the proposed pump.

Exercise 2: Cavitation on a hydrofoil

We consider an inviscid water flow around a symmetrical Naca 0009 hydrofoil with a $c = 10\ cm$ chord length. The upstream velocity is $V_\infty = 24\ m/s$ and upstream pressure $p_\infty = 1\ \text{atm}$ (101325 Pa). The incidence angle is $\alpha = 1°$. At ambient temperature, the vapor pressure is $p_v = 2300$ Pa and the density of water is 998 kg/m^3. The gravitational acceleration is $g = 9.81\ m/s^2$.

1. Use JavaFoil to compute and draw the evolution of the pressure coefficient on pressure and suction sides of the hydrofoil.

2. Show that cavitation develops on the suction side, using non-dimensional numbers.

3. Give an estimation of the cavity length L_{cavity}.

4. How would the cavity length evolve if the velocity is increased to 50 m/s while the incidence angle and cavitation number are kept constant? Does it increase? decrease? or remains unchanged? N.B. Without the help of JavaFoil.
   How can we keep the cavitation number constant if the velocity is increased?

5. We consider a sailing boat, which uses a lifting foil with a Naca 0009 section. The lifting foil is located 1 m below the free surface and its incidence angle is 1°.

   a. Give the maximum speed the boat can reach without cavitation occurrence.

   b. How this maximum velocity evolves if the immersion of the lifting foil is 10m?

   c. Is it possible to set the incidence angle so that the boat can reach 80 knots without cavitation occurrence (1 m immersion)?