

EXAM FTV1 – RUG
June 13, 2016

Maximum # points for each question are indicated
Total # points = 100

Question 1

Imagine a hydro-electrical power plant with in the base of the dam 20 (horizontal) cylindrical, pipes of 50 m length, a cross-sectional area of $3,14 \text{ m}^2$ and with a turbine located at the end of each of them (see figure). After passing the pipe and turbine the water has a free outflow in the lower lake B. The (total) volumetric flow is $125,6 \text{ m}^3/\text{s}$. The water levels between the lakes and the central axis of the pipe are as indicated. The turbines show ideal behavior, implying it operates like the opposite of an (ideal) pump.

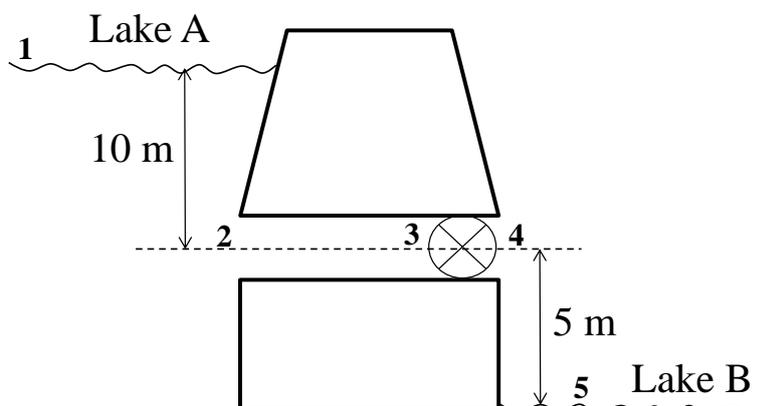
Possible reference points (1-5) are indicated, clearly indicate the ones you used for your calculation!

Assume steady-state conditions and ignore losses due to friction.

Density of water: $\rho=10^3 \text{ kg}\cdot\text{m}^{-3}$; Viscosity of water: $\eta=10^{-3} \text{ kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$, $g=10 \text{ m/s}^2$.

A) Calculate the total energy generated. 10

B) Assuming smooth pipes, show that the assumption that losses due to friction can be ignored is indeed justified. 10



Question 2

Objects moving through fluid experience a force from this fluid, the so-called drag force, measured in Newton with $1 \text{ N} = 1 \text{ kg.m.s}^{-2}$.

A researcher interested in the energy spent by whales for swimming aims to perform a study using a scale model, also operating in water. It is assumed that the drag force is a function of the velocity and diameter of the object and the density and viscosity of the fluid.

Density and viscosity of water is 10^3 kg.m^{-3} and $10^{-3} \text{ kg.m}^{-1}.\text{s}^{-1}$, respectively.

A) Find by dimensional analysis the two dimensionless numbers. **10**

B) Given the velocity of the prototype during the model study is 10x the (typical) velocity of the whale in real life, what should be the scale factor used? **10**

Question 3

Consider an (open) cylindrical tank, completely filled with 4500 liter water. The cross-sectional area of the tank is $4,5 \text{ m}^2$. At a certain moment the tank starts to leak due to a hole in the bottom. It takes 20 seconds before the tank is completely empty. Friction can be ignored.

Density of water: $\rho=10^3 \text{ kg.m}^{-3}$; $g=10 \text{ m.s}^{-2}$

A) Calculate the cross sectional area of the leaking hole. **10**

Suppose the tank would have had a second hole in its bottom with a cross-sectional area twice that of the first hole.

B) Still ignoring friction, how long would it have taken then to empty the tank? **10**

Question 4

Consider a rectangular aquarium with a volume of 3 m^3 containing cold-water fish that require the water temperature to be $10 \text{ }^\circ\text{C}$. With a (constant) room temperature of $22 \text{ }^\circ\text{C}$, the system needs a cooling element. The water is well stirred. Consider steady-state conditions.

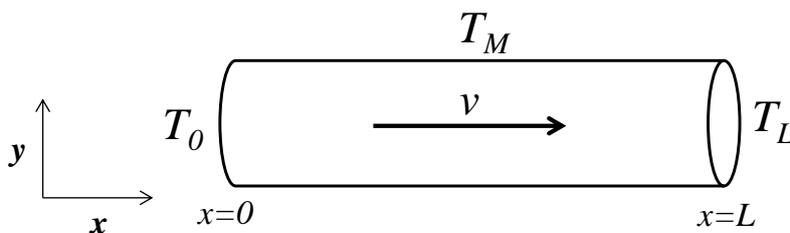
Water density (ρ) and specific heat capacity (c_p) are 10^3 kg.m^{-3} and $4.2.10^3 \text{ J.kg}^{-1}.\text{K}^{-1}$, respectively.

- A) Given a total average heat transfer coefficient (U) of $420 \text{ W/m}^2\text{K}$ and a total surface area for heat exchange of 6 m^2 , calculate the power of the cooling element. **5**
- B) Suppose I replace this aquarium by a larger one, i.e., length, width and height are all doubled. Given the same steady-state conditions but a heat transfer coefficient of just $300 \text{ W/m}^2\text{K}$ (because of the thicker glass!), what should now be the power of the cooling element? **10**
- C) Suppose (for the aquarium in A), the cooling element is turned off. How much time does it take for the water to warm up to $16 \text{ }^\circ\text{C}$? **10**

Question 5

Consider a water flow of velocity v through a horizontal, hollow, metal pipe of length L , cross-sectional area A and radius R . At $x=0$, the temperature of the water is T_0 and the metal pipe itself has a (constant) temperature of T_M , with $T_M > T_0$. Because of the high Re number, the water in the pipe is well-stirred, implying T is a function of x but not of y . The overall heat transfer coefficient from the pipe wall to the water is h .

- A) Assuming steady-state, derive an expression for the temperature profile along the length of the pipe. **15**



Final mark = total # points / 10