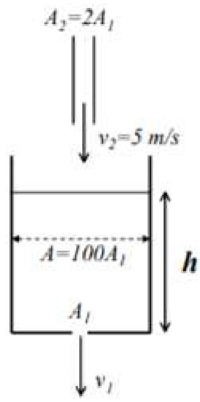
EXAM PHYSICAL TRANSPORT PHENOMENA – RUG
April, 2 - 2019

Maximum # points for each question are indicated

Question 1

Imagine a cylindrical open tank with cross-sectional area A filled with pure water. Because of a hole in the bottom with cross-sectional area A_1 water is flowing out with velocity v_1. Simultaneously, pure water is flowing in with velocity v_2 through a pipe above the tank with cross-sectional area A_2, with $A_2=2A_1$. Friction losses can be ignored and $A=100A_1$, implying $A \gg A_1$. Gravitational acceleration (g) is 10 m/s^2.



A) Calculate the steady-state water level height h in the tank, given v_2=5 m/s. **10**

While at steady-state ($dh/dt=0$), at $t=0$ compound c is added to the inflow stream with concentration c_{in}. The tank is well-stirred.

B) Give the concentration of c in the tank as function of time given c_{in}=10 mol/l. Check your answer by studying the initial and final concentration of c in the tank! **15**

Question 2

Objects moving through fluid experience a force from this fluid, the so-called drag force, measured in Newton with 1 N = 1 kg.m/s^2. A researcher interested in the swimming behavior and energy consumption of whales aims to perform a study using a scale model, also operating in water. As a start he assumes the drag force to be a function of the velocity of the object, the density of the fluid, the viscosity of the fluid and the diameter of the object.

Density and viscosity of water is 10^3 kg/m^3 and 10^{-3} kg/ms, respectively.

A) Apply dimensional analysis and find the two dimensionless groups. **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 a rectangular aquarium with a volume of 3 m^3 containing cold-water fish that require the water temperature to be 10 ^{0}C. With a (constant) room temperature (T_R) of 22 ^{0}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 J.kg^{-1}.K^{-1}, respectively.

A) Given a total average heat transfer coefficient (U) of 420 W/m^{2}K and a total surface area for heat exchange of 6 m^2, calculate the power of the cooling element. **5**

B) The aquarium is replaced with a larger one with length, width and height, all twice as large. Given the same steady-state conditions but a heat transfer coefficient of just 300 W/m^{2}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 ^{0}C? **15**

Question 4

One of the threats of accidents on sea is the free-coming oil that can have disastrous effects on the eco-system. Consider a layer of oil floating on the surface of the ocean. Due to diffusion, the oil penetrates into the water, over a period of 1 week to a depth of 75 cm. The concentration of oil at the oil-seawater interface (c_s) equals the (limit) solubility concentration of oil in seawater, 10 g/m^3. For the sake of simplicity the ocean can be considered of endless depth.

A) Calculate the (apparent) diffusion coefficient (D_A) of oil in seawater. **5**

B) Calculate the average oil concentration in the 75 cm seawater layer after 1 week. **10**

Suppose a similar accident with some chemical happens in a 3 m deep lake resulting in a layer of chemicals floating on the lake surface. Over a period of 1 week, this chemical penetrated to a depth of 2 m, resulting in an (average) concentration in the water of 11 g/m^3. The concentration of this chemical at the chemical-lake water interface (c_s) equals the (limit) solubility concentration of this chemical water, 20 g/m^3.

C) Calculate the (apparent) diffusion coefficient (D_A) of this chemical in water. **10**