tentamen ta3220: Fluid flow, heat and mass transfer
9.00-12.00 uur, 26 januari 2004, TA Gebouw

There are 3 questions in two pages, with a total mark of 60. Please read and understand each question well, before you prepare the answers.

Question 1 - Gas-liquid flow *(20 marks)*

Air and water are flowing simultaneously through a long, straight, smooth horizontal pipe with an inner diameter of 6.00 cm. The flow-rates of air and water are 85.0 and 0.100 m^3/h, respectively. The flow circumstances are such, that the water is only present near the wall in the sense that the lower part of this wall is wet, while the upper part is dry. The wetted fraction of the wall, θ, has already been calculated: it is 0.23.

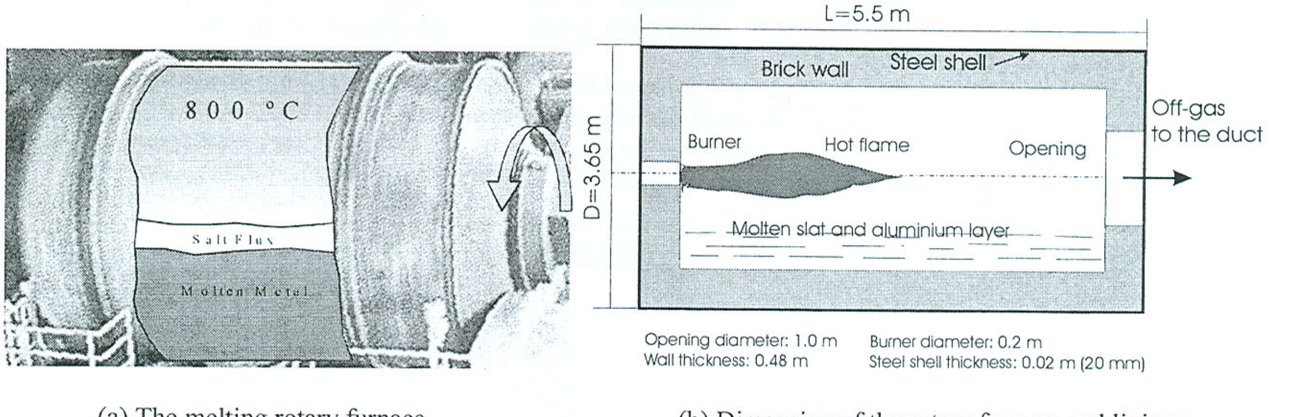
Questions:

(1) Calculate the water fraction, ε_L, using the equation given in the article by Hart, Hamersma and Fortuin (HHF) (keep in mind that the order of magnitude of this fraction will be a few per cent).
(2) Calculate the two-phase pressure drop (in Pa), for a pipe length of 100 m, using the HHF method.
(3) Calculate also the pressure drop (in Pa), for a pipe length of 100 m, in case only air would have been present.

Further data:
Densities (in kg/m^3): 2.50 (air) and 1000 (water).
Dynamic viscosities (in Pa.s): 0.0000190 (air) and 0.00100 (water).
Constants a, b, c, d: use the values given in the HHF article.

Question 2 - Heat loss from a metallurgical furnace *(20 marks)*

In secondary aluminium production, rotary furnaces are used to melt and refine aluminium scraps. Heat loss through furnace walls may account for significant part of the total energy requirement, and should be minimised to reduce the energy consumption. Heat loss through furnace walls can be estimated in a number of ways, depending on the known information. In this question, you are required to apply different methods in calculation of heat loss for this furnace (the cylindrical reactor). The dimensions of the furnace are given in **Figure 1** below. The furnace has two layers: inner brick layer of 48 cm thick, and outer steel shell of 2 cm thick. The thermal conductivity for the brick is 0.69 W/m·K, and for steel shell is 43 W/m·K. Please ignore the corner effect (temperature gradient) near the two ends of the furnace, and assume that the surface temperature of the cylindrical part is the same for the whole surface.



(a) The melting rotary furnace. (b) Dimension of the rotary furnace and linings

Figure 1: Furnace dimension and lining information

Questions:

Estimate the heat loss from the side wall (cylindrical part), under the following known conditions (*see Page 2*):

(1) If the outer and inner surface temperatures are measured as: $T_{in,w}$=750°C, $T_{out,w}$=100°C, calculate the heat loss from the cylindrical side wall. Further question: what is the heat loss if the brick is worn to the half of the original thickness (% of the original case)?

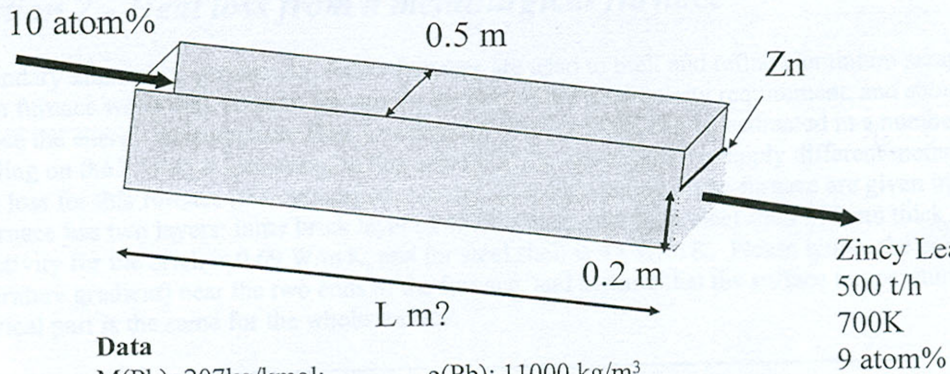
(2) Only the outer surface temperature is known and measured at 100°C, and inner surface temperature is unknown (normally difficult to measure). The outer surface emissivity is estimated as 0.8. The environment air temperature is at 20°C. Please estimate the total heat loss by both radiation and free convection from the cylindrical wall.

(3) The hot gas temperature is known at 1000°C, and the ambient air temperature is 20°C. The estimated effective convective heat transfer coefficients on the hot and cold sides are 250 and 20 W/m²K, which include already the contribution of thermal radiation. Please calculate the total heat loss from the outer surface of the cylindrical part of the furnace.

Question 3: The launder of Imperial Smelting Furnace *(20 marks)*

It is your task to design the lead launder of an Imperial Smelting Furnace (ISF). To this end you determined in the laboratory the data presented in Table 1, giving the change of zinc concentration at 700K in a laboratory scale batch reactor with a 1 m² cross sectional surface area and a volume of 0.1 m³.

Knowing from thermodynamics that the equilibrium zinc concentration is 8 atom% in zincy lead at 700K, please calculate the length of the launder for the given dimensions of the launder below (assume plug flow behaviour and base calculations on a temperature of 700K).



Data

M(Pb)=207kg/kmol; ρ(Pb): 11000 kg/m³
M(Zn)=65.38kg/kmol; ρ(Zn): 6900 kg/m³

Figure 2: Data for a lead launder after an Imperial Smelting Furnace for the separation of zinc from lead by cooling the lead from around 800K at the inlet to 700K

Table 1: Change of the concentration (kg/m³) of Zn in zincy lead in a laboratory batch reactor measured at 700K

Time (min)	kg Zn in lead/m³
0.00	400.00
1.00	371.72
2.00	350.78
3.00	335.26
4.00	323.76
5.00	315.24
6.00	308.93
7.00	304.26
8.00	300.80
9.00	298.23
10.00	296.33

$\frac{dC_{ZN}}{dt}$

700K batch reactor