Interim Exam 1 (Take home): October 10, 2017 (100 points)

Exam due: October 13, 2017

Note: Show all the details (including equations) of your calculations.

Problem 1 (40 points)

I. Ladle Metallurgy: Design (15 points)

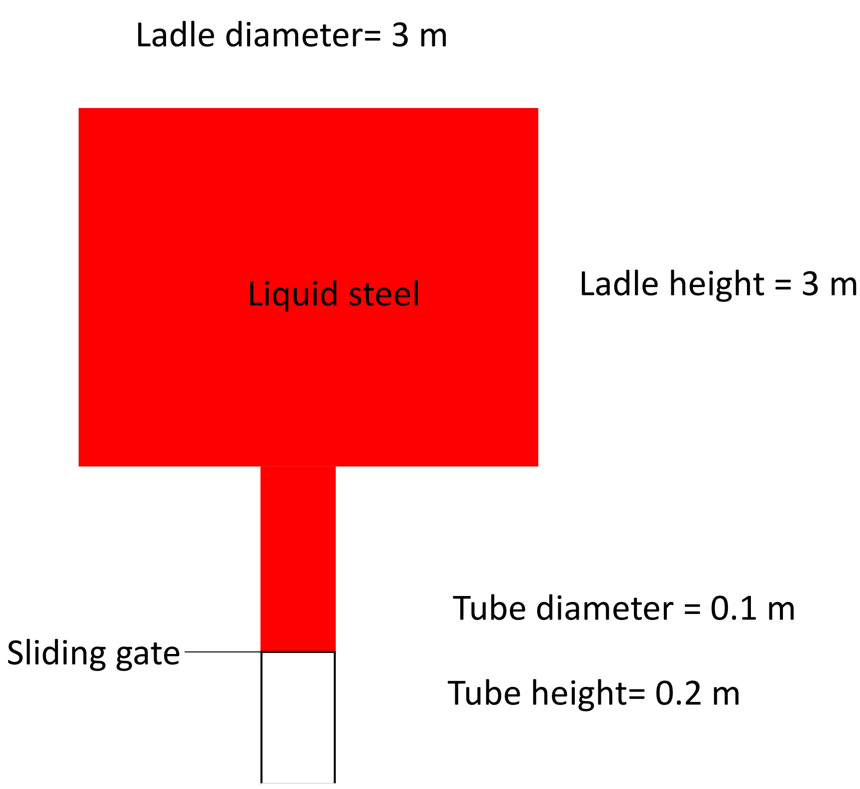

Figure 1. Ladle dimensions.

Data: The ladle dimensions are given in Fig.1. The molten steel density is $\rho = 7000\ kg/m^3$ and its dynamic viscosity is $\mu = 0.003\ kg/(s\cdot m)$.

(a) Calculate the velocity and mass flow rate through the tube in the ladle full of liquid steel (**4 points**)

(b) Estimate the velocity boundary layer thickness at the exit of the tube (**4 points**)

(c) Calculate the time to empty the ladle **(4 points)**

(d) How accurate is the methodology you used in part 2a? If not accurate does it overestimate or underestimate the flow rate? (**3 points**)

II. Ladle Metallurgy: Natural convection (15 points)

Natural convection plays a dominant role in fluid flow within the unstirred ladle (whether the gate is open or closed) because metal loses heat to the surroundings through the cooler ladle.

Data:

- Liquid steel thermal conductivity $k = 25$ W/(m K)
- Liquid steel heat capacity $c_p = 750$ J/(kg K)
- Liquid steel thermal expansion coefficient $\beta = 10^{-5}$ K^{-1}
- Temperature difference between steel bulk and ladle inner wall $\Delta T = 50K$

(e) Sketch the natural convection boundary layers and direction of flow in the ladle (**4 points**)

(f) Calculate the Grashof and Prandtl numbers. Is the flow likely to be laminar or turbulent? (**4 points**)

(g) Estimate the average heat transfer coefficient from the liquid metal to the ladle walls (**4 points**)

(h) The boundary layer thickness times circumference times average velocity total a flow rate comparable to that calculated in part 1a and 1b. What does this say about the temperature of the first metal drained from the ladle? It will it be hotter or colder than the average temperature? (**3 points**)

III. Ladle Metallurgy: Casting (10 points)

The mold shown in fig. 2 is filled up with the ladle shown in Fig. 2.

i) Calculate the casting filling time (cylinder with D=2m and H=2 m) assuming the casting is filled through the middle of the mold using a gating system (ceramic tubes of internal D=0.1 m), as sketched in Fig. 2 and the bottom pouring ladle shown in Fig. 1. Assume no flow resistance (no friction losses) through the gating system. (**10 points**).

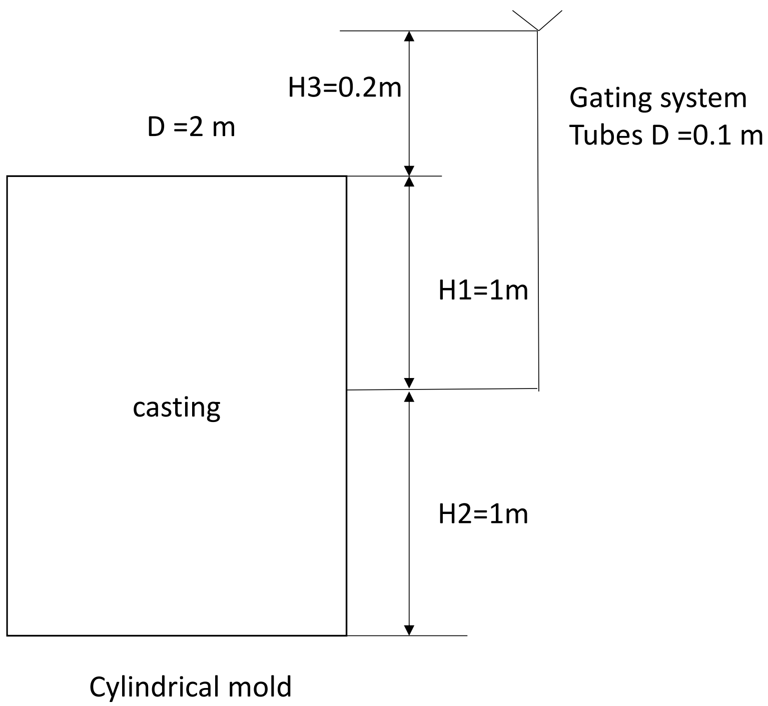

Figure 2. Casting dimensions and gating system.

Problem 2 (20 points)

Water flow rate and pressure in a smooth tube of 0.01 m diameter:

Data: The water density is $\rho = 1000$ kg/m^3 and its dynamic viscosity is $\mu = 0.001$ kg/(s·m).

(a) Briefly outline the steps required to calculate the pressure drop ΔP required to pump a Newtonian fluid through a horizontal tube at a given flow rate Q (assuming fully-developed axisymmetric flow, uniform density and viscosity, etc.) (**7 points**)

(b) Calculate the pressure drop per unit length $\Delta P/L$ required to pump water at flow rates of 10^{-6} m^3/s, 10^{-5} m^3/s, and 10^{-4} m^3/s. (**10 points**)

(c) Why is the results at Q = 10^{-4} m^3/s qualitatively different from the other two? (**3 points**)

Problem 3 (20 points)

A Ni alloy droplet of diameter D =100 microns is formed by atomization.
If the nucleation of the droplet occurs at 1000 K, what is the droplet cooling time from 1800K to 300 K (**12 points)**
What is the achieved cooling rate at T= 1000K (**8 points**)

Data: initial T of the droplet T_i = 1800K, c_p = 700 J/(kg K), ρ = 8900 kg/m^3
Latent heat of solidification, ΔH_f = 300,000 J/kg
Overall heat transfer coefficient, h = 1000 W/(m^2 K)

Problem 4 (20 points)

A laser beam is used as a moving point source to harden the surface of a thick piece of steel across the surface (no melting occurs).

To what depth is it possible to produce bainite with one pass if the critical cooling rate for the steel to produce bainite is 100 K/s at T=600K. The steel transformation temperature to austenite is T=1100K (**10 points**)

What is the achieved cooling rate at T=600K at the location where the peak temperature reached 1100K? (**10 points**)

Steel data: thermal diffusivity α = 7.2 10^{-6} m2/s; k =35 W/(m K), initial temperature = 300K
Laser data: power 2000 W; speed =0.5 m/s