**ORDRE DES INGÉNIEURS DU QUÉBEC**
**may 2019**

**Open book examination**
**Calculators: only authorized models**
**Duration: 3 hours**
**14-BR-A2 Thermal engineering**

## Question 1 : (20 points)

An iceberg has an approximate cubical shape (side=400 m). There is no wind and the iceberg is not moving through the water.

The density of the salt water is 1027 kg/m$^3$ and the density of the ice is 937 kg/m$^3$. The temperature of both the ambient air and the ocean water are 4 degrees C. What are the rates of melting (in kg/sec) of both the submerged and the emerged parts of the iceberg? Use the hypothesis that the water side heat transfer coefficient is 150 W/m$^2$-K and the air side coefficient is 15. The melting energy for ice can be estimated as 334 kJ/kg.

**Properties of sea water: viscosity 0.01002 g/cm-sec, thermal conductivity 0.57 W/m-K, specific heat 4474 J/kg-K.**

## Question 2 (20 points):

The temperature read by a thermocouple in a black[1] enclosure is 800 K. The heat transfer coefficient between the fluid and the thermocouple is h=30 W/m$^2$-K and the thermocouple is not protected from radiation. What is the temperature of the fluid if the walls of the black enclosure are maintained at 300 K?

**1- black enclosure for radiation**

**Question 3 (25 points):**

A thermocouple is located at the center of a small polymer sphere ( density 1200 kg/m$^3$ , thermal conductivity 0.21 W/m-K, heat capacity 1250 J/kg-K, radius 3 mm) .

The sphere is initially at an equilibrium temperature of 0 degrees C. It is suddenly immersed in a hot fluid (100 degrees C) with a very high heat transfer coefficient. After how many seconds will the thermocouple show an increase in temperature?

**Question 4 (30 points):**

A pipeline transports 13000 barrels/h of oil at 55 degrees C, the temperature of the outside air is -10 degrees C. The wall thickness is 1 cm and the internal diameter is 1.2 m. The wall thermal conductivity is 25 W/m-K) and is insulated with a 8 cm (k=0.1 W/m-K) layer. The heat capacity of the oil is 2300 J/kg-K with a density of 890 kg/m$^3$ and a thermal conductivity of 0.2 W/m-K and a 0.1 Pa-s viscosity. The external heat transfer coefficient is approximately 7 W/m$^2$-K.

a) **10 points** Estimate the internal heat transfer coefficient.

b) **10 points** Estimate the overall heat loss in W/m.

c) **10 points** Using a differential energy balance, estimate the length of the pipeline where the temperature of the oil will have dropped to 35 degrees C.