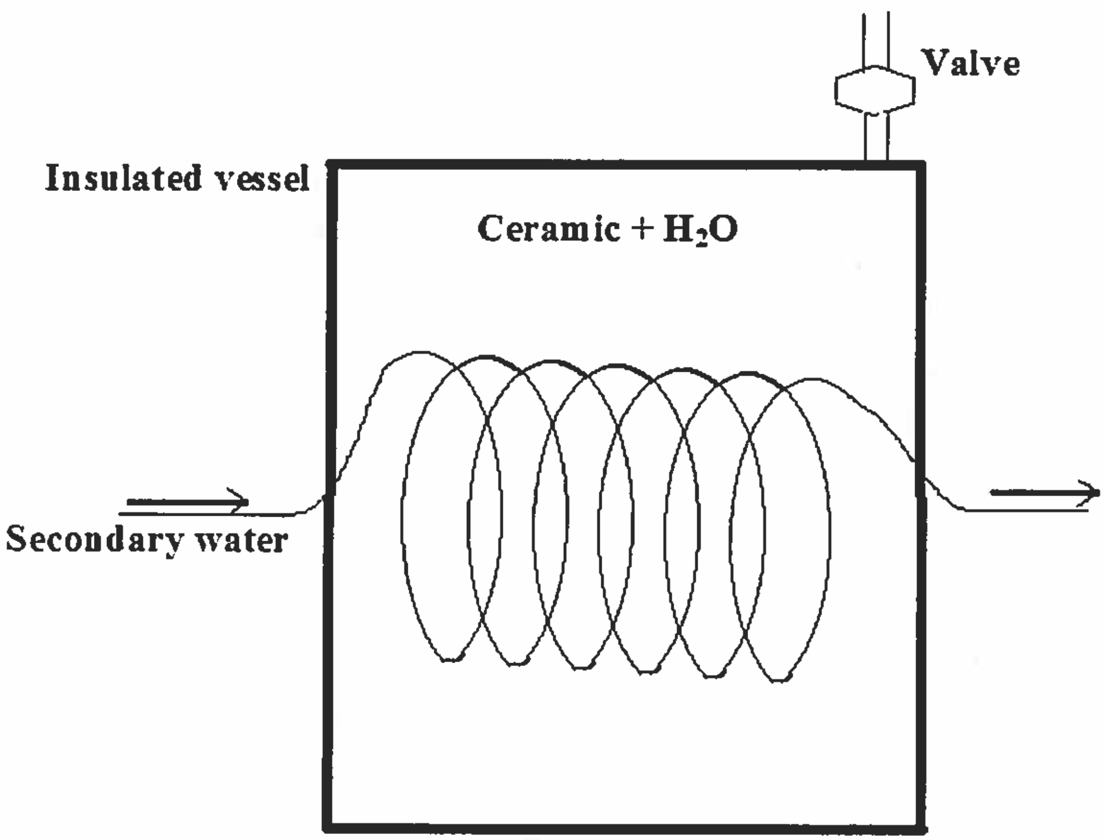
Problem 1

The insulated vessel shown in the figure is contains a porous ceramic structure that undergoes volumetric energy generation due to radioactive decay at the rate of 400 kW per meters cubed of ceramic. The vessel contains 10,000 kg of the ceramic substance, and the density of the ceramic substance is 11 g/cm^3. The total volume of the vessel is 3 m^3. The specific heat of the ceramic material is 300 J/kg.K. In normal, steady-state operation the vessel contains 300 kg of pure saturated water at a pressure of 5 bars pressure, while being cooled by a secondary water flowing inside a coil, as shown in the figure. The secondary water, which is under atmospheric pressure, enters the vessel at a temperature of 300 K, and leaves at 350 K. The vessel has a safety valve that opens when the vessel pressure reaches 50 bars.

a) Calculate the flow rate of secondary water, and the masses of vapor and liquid water in the vessel, under steady normal operation conditions.

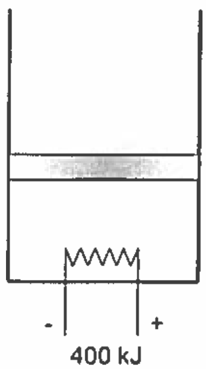
b) Now assume that the flow of the secondary water is abruptly stopped because of an accident. How long does it take until the safety valve opens?

For simplicity assume that the temperature difference between the ceramic and the surrounding fluid remains constant.



Problem 2

An uninsulated piston-cylinder device with a set of stops contains 10 kg of refrigerant R-134a. Initially, 8 kg of the refrigerant is in liquid form and the temperature is -8 °C. A small electric heater is immersed in the liquid and energized. The heater remains on until the volume of the cylinder is 400 liters. The electrical energy supplied to the heater during this period is 400 kJ. The surface temperature of the heating element is 34 °C and does not change during the process.



a) Determine the change in entropy of the R-134a during the process.
b) Determine the total entropy generation for the process.
c) Consider the R-134a as the system. State whether the process is internally reversible. Justify your answer.

Problem 3

A gas refrigeration system, schematically shown in the figure, is used to produce an overall refrigeration power of $Q_0=3000$ *kcal/hr* at $T_1= -140$ °C. The open system is outfitted with a regenerative heat exchanger between the fluid at compressor inlet and that at the turbine inlet (such a setup allows lower temperatures to be obtained even with less than excellent pressure ratios).

Air is extracted from the cold environment at temperature T_1 and pressure $P_1= 1$ *bar*. It is then heated at isobarically (constant pressure) up to temperature T_2, close to room temperature, in the regenerative heat exchanger. The heat exchanger is adiabatic externally and has an efficiency $r=0.9$ (the heat exchanger efficiency is the ratio between the actual increase in the temperature of the fluid to be heated and the maximum increase in temperature compatible with the temperature of the hot fluid at the inlet of the exchanger). Air is subsequently adiabatically compressed, with an isentropic efficiency of $\eta_{ic} = 0.8$, up to pressure $p_3= 4$ *bar*, before releasing heat to the environment by isobaric cooling to temperature $T_4= 30$ °C. Before expansion in the turbine up to $p_6=p_1$, it is further cooled (isobarically) in the regenerative heat exchanger. The expansion in the turbine is adiabatic with an isentropic efficiency of $\eta_{ie} = 0.85$.

If air is considered to be an ideal gas with temperature-independent specific heat constants, k=1.40 and M=28.97 kg/kmol,

1) draw the appropriate *T-s* diagram for the system;

2) determine the maximum and minimum temperatures of the cycle, T_3 and T_6;

3) determine the mass flow rate for the system, $\dot{m}$

4) calculate the net absorbed power, $|P|$;

5) calculate the coefficient of performance, β;

6) calculate the exergetic efficiency of the system using as reference room temperature $T_0=T_4$ (you can ignore the mechanical losses).

$\overline{R} = 8.314\ kJ/kmol.K$ 1kcal=4.187 kJ