Student Code Number: _____

**Ph.D. Qualifying Exam**

**Thermodynamics**

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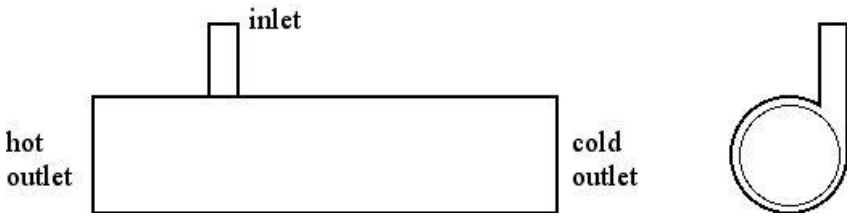
**Directions: Work all six problems. Problems are equally weighted. Students are allowed one book and five sheets of notes**

**Problem 1**

Consider a Ranque-Hilsch vortex tube. Compressed air enters tangentially at some point along the axis of the tube. The inlet conditions are 20 °C and 1 MPa. Cold air exits on one end of the tube at temperature $T_c$ and pressure of 0.1 MPa. Hot air exits on the other side at temperature $T_h$ and pressure of 0.1 MPa. Assume ideal gas behavior, constant specific heats, and that the walls of the tube are perfectly insulated.




a) Calculate the ratio of the cold to the hot mass flow rates if $T_h$=100 °C and $T_c$ = 0 °C.

b) Calculate the rate of entropy generation if the inlet mass flow rate is 0.1 kg/s.

**Problem 2**

One kilogram of saturated liquid water at 150 kPa is contained in a cylinder that is fitted with a freely moving piston. The water is heated to 300 °C in an isobaric process.

a. Calculate the initial volume in the cylinder.

b. Calculate the volume at the instant when the last water evaporates.

c. Calculate the total entropy change of the process if the water has been heated by heat transfer from the surroundings, which are at 350 °C.

**Problem 3**

Helium is expanded in a well-insulated nozzle in a steady-flow process. The helium is at 300 kPa and 450 K at the inlet of the nozzle and at 180 kPa at the exit of the nozzle. The velocity of the helium at the nozzle inlet is small compared with the exit velocity.

a. Calculate the maximum exit velocity that could be attained by the helium.

b. If the temperature of the helium is measured to be 373 K at the exit of the nozzle, calculate the actual exit velocity.

c. Calculate the total increase in entropy per unit mass of helium for the actual process and explain the source of the irreversibility.

**Problem 4**

An ideal diesel cycle has a compression ratio of 18 and a cutoff ratio of 1.2, where the cutoff ratio is the ratio of the cylinder volumes after and before the combustion process. Determine the maximum temperature of the air and the rate of heat addition to this cycle when it produces 250 kW of power and the state of the air at the beginning of the compression is 90 kPa and 20 °C. Use constant specific heats at room temperature.

**Problem 5**

One ton (1000 kg) of liquid water at 60 °C is brought into a well-insulated and well-sealed 4m x 6m x 7m room initially at 20 °C and 95 kPa. Assuming constant specific heats for both air and water at room temperature, determine the final equilibrium temperature in the room.

**Problem 6**

A refrigeration system is used to cool loaves of bread with an average mass of 400g from 30 °C to -10 °C at a rate of 1000 loaves per hour by refrigerated air at -30°C. Taking the average specific and latent heats of bread to be 2.93 kJ/kg °C and 109.3 kJ/kg respectively, determine (a) the rate of heat removal from the bread loaves in kJ/h; (b) the required volume flow rate of air, in $m^3$/h, if the temperature rise of air is not to exceed 8°C; and (c) the size of the compressor of the refrigeration system, in kW, for a COP of 1.2 for the refrigeration system.