**Thermodynamics**

## Caution: Students please read before starting

(1) You should be provided with a set of thermodynamics properties tables for use during this exam.

(2) The exam consists of three (3) problems on three (3) separate pages. Check NOW to verify that your exam is complete.

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If you are missing the properties tables or any of the three (3) exam pages stop work NOW and advise your proctor immediately.

**Problem 1**

Consider the well-insulated piston-cylinder apparatus given in Figure 1. Initially the cylinder contains 2 kg of $H_2O$ as a saturated liquid at $T_1$ = 120 °C. At $t$ = 0, a stream of superheated steam at $p_{inlet}$=10 bar and $T_{inlet}$=320 °C is introduced from the bottom of the cylinder at a mass flowrate of $\dot{m}_{inlet}$ = 0.1 kg/s. The piston is held in place by gravity but is free to move up and down the cylinder unimpeded by friction. A stopper at the top of the cylinder prevents piston from leaving the cylinder.

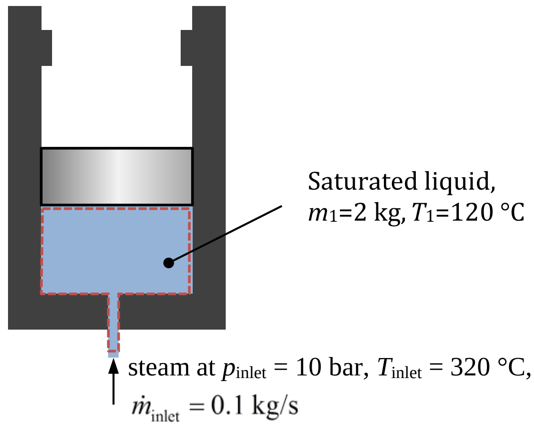


Figure 1.

a) If $t$ = 30 s is required to raise the piston to the stoppers, determine the quality of the steam in the cylinder and work done. Start with a list of all assumptions.

b) The stopper breaks after an <u>additional</u> 40 s due to the upward force from the piston, identify and compute the two independent properties required to fix the pressure immediately before the stopper breaks.

**Problem 2**

Consider a device that uses air to cool water vapor. Air enters this device at $P_1$=0.3 MPa and $T_1$=20 °C with a flow rate of $\dot{m}_1$=100 kg/min. Superheated water vapor enters the device through another inlet at $T_2$=200 °C and $P_2$=0.3 MPa. Saturated water vapor leaves the device at a pressure of 0.3 MPa, while air leaves the device through a separate exit at a pressure of 0.3 MPa and at the same exit temperature as that of the saturated water vapor. The device is rigid and well insulated and the fluid streams do not mix. Additionally, air can be treated as an ideal gas with a constant specific heat: $c_{p,air}$=1.0 kJ/kg-K.

(a) What is the mass flow rate of superheated steam entering the device in kg/min?

(b) What is the rate of entropy production in kW/K?

(c) Can this device ever operate reversibly (i.e., without irreversibilities)? Said another way, if this device were to operate with no entropy production, what would be the mass flow rate of the water and the temperature of the exiting air?

(d) Alternatively, if saturated vapor at the same pressure enters the device and exits as saturated liquid, derive an expression for the rate of entropy production per mass flow rate of air in terms of the air temperature, the saturation temperature, and the air specific heat only.

**Problem 3**

The vapor compression and throttling refrigeration cycle shown in the figure uses R-134a as the working fluid. The evaporator's pressure is 1 bar and the condenser's pressure is 16 bar. The fluid is saturated vapor at the exit from the evaporator, and it is saturated liquid at the inlet to the throttling valve. Frictional, kinetic energy, and potential energy effects can be neglected. The compressor operates isentropically. You are asked to evaluate using a regenerative counter-flow heat exchanger in the cycle where the temperature at the inlet to the compressor would be equal to the temperature at the inlet of the throttling valve if this heat exchanger is used.

a) With the heat exchanger absent (i.e., state 6 = state 1, and state 2 = state 3), sketch the cycle on a T-s diagram, and calculate the coefficient of performance (defined as the heat removal rate in the evaporator divided by the compressor power).
b) Repeat Part (a), but now with the heat exchanger present.