ME 200 Spring 2003
Exam 2
Tuesday March 11

You may use one only the basic equation sheet and your book of tables when working this exam. You may not use any additional notes, books, technical papers, etc. You may not add anything to either the basic equation sheet or your book of tables.

Name: ____________________________________________

THERMO NUMBER: ______

CIRCLE YOUR DIVISION

Div. 1 (830)  Prof. Sojka
Div. 2 (1030) Prof. Chen
Div. 3 (1230) Prof. Hawks
Div. 4 (130)  Prof. Baek

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Average 53
1. [40 points]
A pair of rigid uninsulated tanks are connected by a pipe and valve as shown in the figure below. The left tank, whose volume is 1.0 m³, is initially filled with steam at a pressure of 100 kPa and a temperature of 120°C. The right tank, whose volume is 0.5 m³, is initially evacuated. The valve isolating the tanks from each other is opened and the steam flows until it reaches equilibrium. The pressure at equilibrium is 50 kPa.

Given: steam with \( p_1 = 100 \text{ kPa} \), \( T_1 = 120 \text{ C} \), \( \forall_1 = 1.0 \text{ m}^3 \); \( p_2 = 50 \text{ kPa} \), \( \forall_2 = 0.5 \text{ m}^3 \)

Find: a) [20 points] The quality at equilibrium; b) [20 points] The heat transfer required during this process. Report your answer in kJ.

\[ \text{Find: } \text{Quality at equilibrium, } \]

\[ \text{Equations: } \Delta Q = \Delta U + \Delta KE + \Delta PE \]
\[ \gamma = (1-x) \gamma_b + x \gamma_{vap} = \gamma_b + x \gamma_{vap} \]

\[ \text{System: Initially just left side} \]
\[ \text{In total both tanks} \]

\[ \text{Assume: No leaks, } \Delta KE = \Delta PE = 0, \quad Q \neq 0, \quad W = 0 \]

\[ \text{Analysis: From A-4 at 1.0 bar, 120°C} \]
\[ V = 1.793 \text{ m}^3 \]
\[ m = \frac{V}{\gamma_b} = \frac{1.0 \text{ m}^3}{1.793 \text{ m}^3/\text{kg}} = 0.5577 \text{ kg} \]
\[ V_2 = \frac{V}{m} = \frac{1.5 \text{ m}^3}{0.5577} = 2.6896 \text{ m}^3/\text{kg} \]

From A-3 at 0.5 bar
\[ \gamma_b = 3.24 \text{ m}^3/\text{kg} \]
\[ \gamma_f = 1.0 \times 10^{-3} \text{ m}^3/\text{kg} \]

\[ x = \frac{V - V_f}{V_b - V_f} = \frac{2.6896 - 1.0 \times 10^{-3}}{3.240 - 1.0 \times 10^{-3}} = 0.830 \]
Law rewrite = \[ Q = \Delta U \]

\[ Q = (u_f - u_i) \cdot m \]

\[ u_i \text{ from A-4 at 1 bar, 120}^\circ \text{C} \]
\[ u_i = 2537.3 \text{ kJ/kg} \]

\[ u_f \text{ from A-3 at 0.5 bar, x = 0.830} \]
\[ u_g = 2483.9 \text{ kJ/kg} \]
\[ u_f = 340.44 \text{ kJ/kg} \]

\[ u_f = (1 - 0.83) \cdot 340.44 + 0.83 \cdot (2483.9) \]

\[ u_f = 2119.5118 \text{ kJ/kg} \]

\[ Q = (2119.5118 - 2537.3) \frac{\text{kJ}}{\text{kg}} \cdot 0.5577 \text{kg} \]

\[ Q = -233.00 \text{ kJ} \]
2. [25 points]
Saturated vapor Ammonia at 100 kPa enters the nozzle shown below with a velocity of 25 m/s. It exits at a pressure of 100 kPa and a quality of 0.9. The nozzle has an inlet diameter of 10 cm and an exit diameter of 3 cm.

Given: NH₃ with \( v_1 = 25 \) m/s, \( p_1 = 100 \) kPa, sat. vapor, \( D_1 = 10 \) cm; \( p_2 = 100 \) kPa, \( x_2 = 0.9, D_2 = 3 \) cm.
Determine if the change in Ammonia kinetic energy can be ignored when analyzing this device.
Support your answer with a quantitative Thermodynamic analysis.

\[
\begin{align*}
\text{1st Law:} & \quad Q = m \left( h_1 - h_2 + \frac{v_1^2}{2} - \frac{v_2^2}{2} \right)
\end{align*}
\]

Find: Is change in KE can be ignored

System: CT of nozzle of NH₃

Equations:
- \( \frac{dE}{dt} = \sum Q_{\text{in}} - \sum Q_{\text{out}} + \sum \dot{m} (h + \frac{v_i^2}{2} + gz) - \sum \dot{m} (h + \frac{v_o^2}{2} + gz) \)
- \( \frac{dm}{dt} = \sum \dot{m} \)
- \( \dot{m} = \frac{VA}{\rho} \), \( \rho \psi = \dot{m}RT \)

Assume: SSSSE, 1-D flow, \( \partial PE = 0 \), \( W = 0 \), one inlet, one outlet, no leaks

Analysis:
From A-14 at 1.0 bar
- \( T = -33.6^\circ C \)
- \( h_2 = 19.64 \text{ kJ/kg} \)
- \( h_1 = 1395.27 \text{ kJ/kg} \)

\[
\dot{m} = \frac{VA}{\rho} = A_i \pi (0.05)^2 = 0.067854 \text{ m}^2
\]
From A-14 at 1 bar, sat. vapor
- \( v_1 = 1178.81 \text{ m/s} \)
- \( v_2 = 25 \text{ m/s} \)

\[
\dot{m} = \frac{25 \text{ m}^3}{1.1381 \text{ m}^3/\text{kg}} = 0.1725 \text{ kg/s}
\]
\[ v_2 = \sqrt{\frac{1725 \text{ bar}}{2 \times 7.0686 \times 10^{-4}} \times 2.49,9915 \text{ g/s}} \]

\[ h_1 = 1398.41 \text{ kJ/kg} \]

\[ h_2 = 1261.387 \text{ kJ/kg} \]

\[ \dot{Q}_{\text{cv}} = \dot{m}\left( h_1 - h_2 + \frac{V_1^2 - V_2^2}{2} \right) \]

\[ = \frac{1725 \text{ kg}}{s} \times \left( 1398.41 \frac{\text{kJ}}{\text{kg}} - 1261.387 \frac{\text{kJ}}{\text{kg}} \right) + \left( 1 - 1.3382 \times \frac{250^2}{2} \right) \frac{\text{m}^2}{\text{s}^2} \]

\[ = 23,636 \frac{\text{kJ}}{\text{s}} - 513905 \frac{\text{kJ}}{\text{s}} \]

\[ = 18,245 \text{ kW} \]

You cannot ignore KE because it makes up about 1/4 of total energy transfer.
3. [35 points]
An insulated pump draws in 0.001 m$^3$/sec of water at 25 C and an inlet pressure of 1 bar through a 5-cm diameter insulated line. It sends that water through a 2-cm diameter insulated line to a reservoir 100 m above the inlet where the exit pressure is 8 bars. The process is isothermal.

Given: 0.001 m$^3$/sec water, T$_1$=25 C, p$_1$=1 bar, D$_1$=5 cm; T$_2$=25 C, p$_2$=8 bar, D$_2$=2 cm, z$_2$ = 100 m.

Find the power required by the pump to move the water. Report your answer in kW.

\[
\begin{align*}
\text{Given:} & & \text{T}_2 &= 25^\circ \text{C} \\
& & \text{z} &= 100 \text{ m} \\
\text{FIND:} & & \text{Power required by pump in kW} \\
\text{ASSUME:} & & \text{1-D flow, SSSF, } Q=0, \text{ one inlet, one outlet, no leaks, incompressible fluid} \\
\text{Equations:} & & \frac{dE}{dt} \text{cv} &= \dot{Q} - W + \Sigma \dot{m} \left( h + \frac{u^2}{2} + gz \right) - \Sigma \dot{m} \left( h + \frac{u^2}{2} + gz \right) \\
& & \frac{dm}{dt} \text{cv} &= \Sigma \dot{m} \text{ in} - \Sigma \dot{m} \text{ out} \\
& & \dot{m} &= \rho A \frac{V}{V} \\
\text{SYSTEM:} & & \text{pipe and pump}
\end{align*}
\]
Analysis:

From 1-atm, water at 25°, 1bar

\[ h_{\text{CL}} = h_{\text{SL}}(T, P_{\text{sat}}) \]

\[ h_1 = \left[ 104.89 \right] \left( \frac{\text{kg}}{\text{m}^3} \right) = h_{\text{CL}} \]

\[ \dot{W} = \dot{m} \left( h + \frac{v_1^2}{2} + gz \right) - \dot{m} \text{out} \left( h + \frac{v_2^2}{2} + gz \right) \]

\[ \dot{V} = \frac{\dot{V}_A}{V} \]

\[ V = 10629 \times 10^{-3} \text{ m}^3/\text{kg} \]

\[ A = \pi (0.025)^2 = 0.001963 \text{ m}^2 \]

\[ V_A = \frac{\dot{V}_A}{V} \]

\[ V_1 = \frac{\dot{V}_A}{A} = \frac{0.001 \text{ m}^3/\text{s}}{0.001963 \text{ m}^2} = 5.109 \text{ m/s} \]

\[ \dot{m} = \frac{\dot{V}}{V} = \frac{0.001 \text{ m}^3/\text{s}}{0.0027 \times 10^{-3} \text{ m}^3/\text{s}} \]

\[ \dot{V}_L = \frac{\dot{m} V}{A_2} \]

\[ A_2 = \pi (0.01)^2 = 3.1416 \times 10^{-4} \text{ m}^2 \]

\[ V_2 = \frac{\left( \frac{0.001 \text{ m}^3/\text{s}}{3.1416 \times 10^{-4} \text{ m}^3} \right)}{2} = 3.183 \text{ m/s} \]

\[ \dot{W} = \dot{m} \left( \left( \frac{v_1^2}{2} - \frac{v_2^2}{2} \right) + (g_2 - g_2) \right) \]

\[ \dot{W} = 0.9971 \left( \frac{5.094^2}{2} - \frac{3.183^2}{2} \right) + (9.81(0) - 9.81(100 \text{ m})) \]

\[ \dot{W} = 0.9971 \left( 7.9084 \frac{\text{m}^2}{\text{s}^2} - 981 \frac{\text{m}^2}{\text{s}^2} \right) \]

\[ \dot{W} = 0.9971 \frac{\text{kg}}{\text{s}} \left( -973.0916 \frac{\text{m}^2}{\text{s}^2} \right) \]

\[ \dot{W} = -970.3 \text{ kW} \times \text{gun ignored} \]

\[ \dot{W} = -1168 \text{ kW} \]

\[ \text{Correct} \]

\[ 28 \frac{1}{2} \text{ kwh} \]