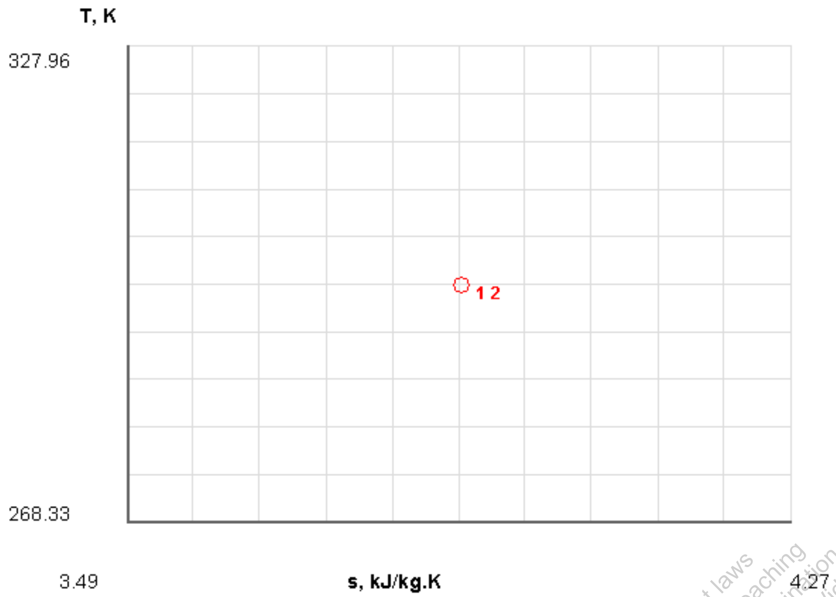
***3-2-1** [TP] Determine the changes in (a) specific enthalpy (Δh) and (b) specific entropy (Δs) if the pressure of liquid water is increased from 100 kPa to 1 MPa at a constant temperature of 25°C. Use the SL model for water.

SOLUTION



Using the SL model for water:

$c_v = c_p = c;$

(a) The change in specific enthalpy can be calculated as

$$\Delta h = h_2 - h_1; \quad \Rightarrow \Delta h = \underbrace{c\left(T_2 - T_1\right)}_{0,\ \text{constant } T} + v\left(p_2 - p_1\right);$$

$$\Rightarrow \Delta h = v\left(p_2 - p_1\right); \quad \Rightarrow \Delta h = \frac{1}{997}\left(1000 - 100\right); \quad \Rightarrow \Delta h = 0.903\ \frac{\text{kJ}}{\text{kg}}$$

(b) The change in specific entropy can be calculated as

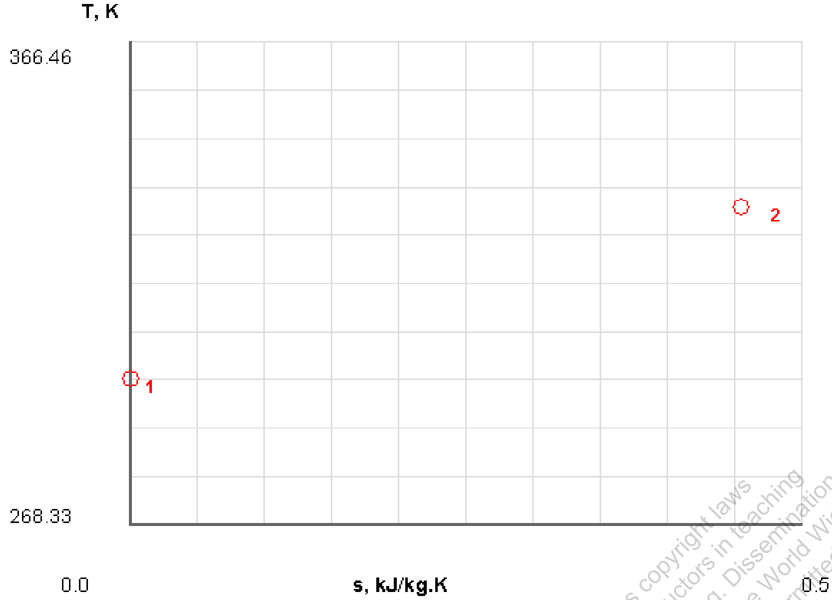
$$\Delta s = s_2 - s_1; \quad \Rightarrow \Delta s = c\ln\left(\cancelto{1}{\frac{T_2}{T_1}}\right); \quad \Rightarrow \Delta s = c\ln\left(1\right); \quad \Rightarrow \Delta s = c\left(0\right); \quad \Rightarrow \Delta s = 0$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-2** [TU] A cup of coffee of volume 0.3 L is heated from a temperature of 25°C to 60°C at a pressure of 100 kPa. Determine the change in the (a) internal energy (ΔU), (b) enthalpy (ΔH) and (c) entropy (ΔS). Assume the density (ρ) and specific heat of coffee to be 1100 kg/m^3 and 4.1 kJ/kg-K respectively. Employ the SL model. (d) What-if Scenario: How would the answers change if the heating were done inside a chamber pressurized at 1 MPa? (1:increase; -1:decrease; 0:remain same)

SOLUTION



Using the SL material model

(a) The change in internal energy of the coffee can be found as

$$\Delta U = U_2 - U_1; \quad \Rightarrow \Delta U = mc(T_2 - T_1); \quad \Rightarrow \Delta U = \rho \forall c(T_2 - T_1);$$

$$\Rightarrow \Delta U = 1100\left(\frac{0.3}{1000}\right)(4.1)(60-25); \quad \Rightarrow \Delta U = 47.36 \text{ kJ}$$

(b) Change in enthalpy

$$\Delta H = \Delta U + v\cancel{\Delta p}^{0}; \quad \Rightarrow \Delta H = \Delta U; \quad \Rightarrow \Delta H = 47.36 \text{ kJ}$$

(c) Change in entropy

$$\Delta S = S_2 - S_1; \quad \Rightarrow \Delta S = \rho \forall c \ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S = 1100\left(\frac{0.3}{1000}\right)(4.1)\ln\left(\frac{273+60}{273+25}\right);$$

$$\Rightarrow \Delta S = 0.15 \ \frac{\text{kJ}}{\text{K}}$$

(d) At 1 MPa:

$$\Delta U = 47.36 \text{ kJ};$$
$$\Delta H = 47.36 \text{ kJ};$$
$$\Delta S = 0.15 \ \frac{\text{kJ}}{\text{K}};$$

Therefore the answers remain the same.

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-2-3 [TX] A block of solid with a mass of 10 kg is heated from 25^{o}C to 200^{o}C. If the change in the specific internal energy (Δu) is found to be 67.55 kJ/kg, identify the material (aluminum: 1; copper: 2; iron: 3; wood: 4; sand: 5).

SOLUTION

This material can be identified by its specific heat capacity, which can be found in the definition of change in specific internal energy.

$$\Delta u = c_{\text{Material}}\left(T_2 - T_1\right);$$

$$\Rightarrow c_{\text{Material}} = \frac{\Delta u}{T_2 - T_1}; \qquad \Rightarrow c_{\text{Material}} = \frac{67.55}{200 - 25}; \qquad \Rightarrow c_{\text{Material}} = 0.386 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Using Table-A

$$c_{\text{Material}} \cong c_{\text{Copper}} = 0.386 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

This material is concluded to be copper: 2.

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-2-4 [TC] A system contains an unknown solid of unknown mass, which is heated from 300 K to 900 K at 100 kPa. The change in internal energy (*ΔU*) of the system is measured as 61.02 MJ. Using the SL model, determine the change in entropy (*ΔS*) of the system.

SOLUTION

$c_v = c_p = c;$

$$\Delta U = mc\left(T_2 - T_1\right); \quad \Rightarrow 61.02 = mc\left(900 - 300\right); \quad \Rightarrow mc = 101.7\,\frac{\text{kJ}}{\text{K}}$$

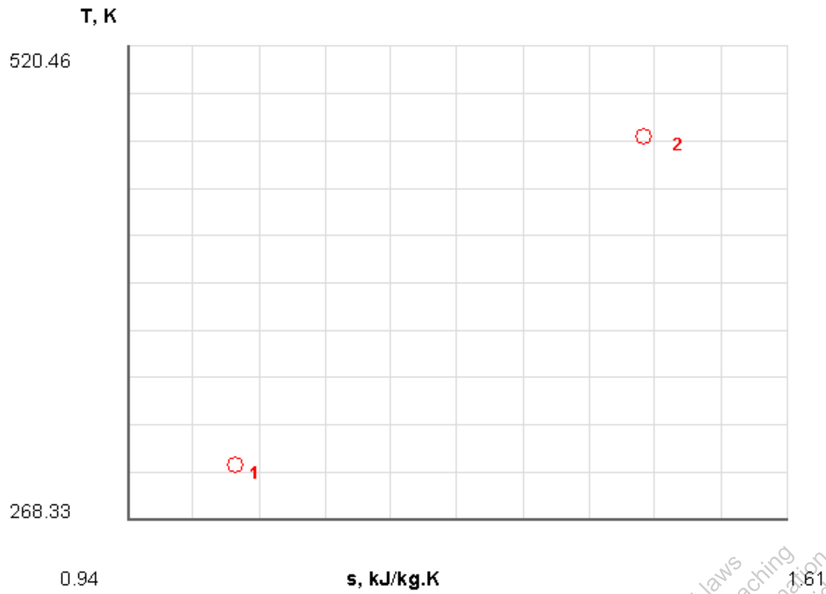
$$\Delta S = mc\ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S = \left(101.7\right)\ln\left(\frac{900}{300}\right); \quad \Rightarrow \Delta S = 111.73\,\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

*3-2-5 [TV] A block of aluminum with a mass of 10 kg is heated from 25°C to 200°C. Determine (a) the total change in internal energy (ΔU) and (b) entropy (ΔS) of the block. (c) What-if Scenario: What would the change in entropy be if the block were made of copper instead?

SOLUTION



Using Table-A

$$c_{AL} = 0.902 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in internal energy can now be calculated as

$$\Delta U_{AL} = U_2 - U_1; \quad \Rightarrow \Delta U_{AL} = mc_{AL}(T_2 - T_1);$$

$$\Rightarrow \Delta U_{AL} = 10(0.902)(200-25); \quad \Rightarrow \Delta U_{AL} = 1578.5 \text{ kJ}$$

(b) The change in entropy can be calculated as

$$\Delta S_{AL} = S_2 - S_1; \quad \Rightarrow \Delta S_{AL} = mc_{AL} \ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S_{AL} = 10(0.902)\ln\left(\frac{273+200}{273+25}\right);$$

$$\Rightarrow \Delta S_{AL} = 4.17 \ \frac{\text{kJ}}{\text{K}}$$

(c) If the block was made of copper

$$c_{Copper} = 0.386 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\Delta S_{Copper} = S_2 - S_1; \quad \Rightarrow \Delta S_{Copper} = mc_{AL} \ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S_{Copper} = 10(0.386)\ln\left(\frac{273+200}{273+25}\right);$$

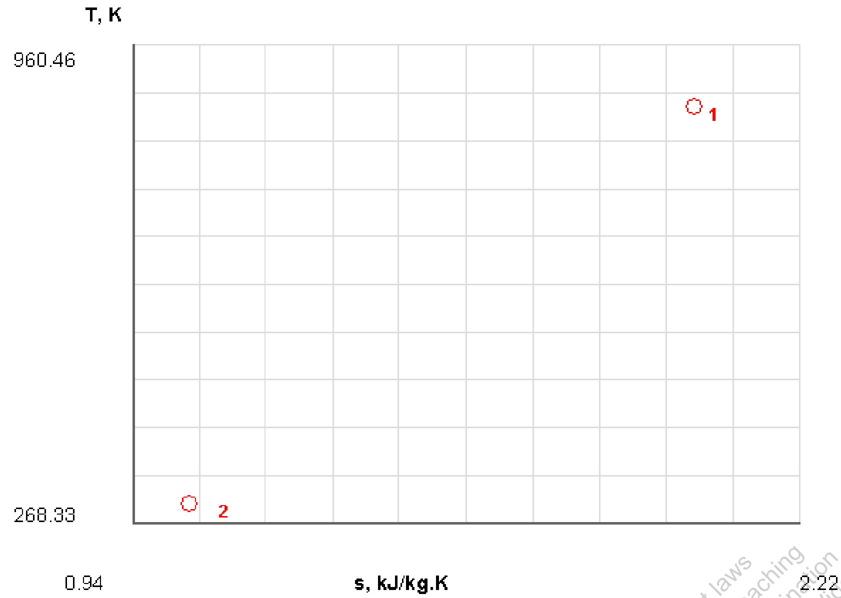
$$\Rightarrow \Delta S_{Copper} = 1.783 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-6** [TQ] A 2 kg block of aluminum at 600°C is dropped into a cooling tank. If the final temperature (T_2) at equilibrium is 25°C, determine (a) the change in internal energy (ΔU) and (b) the change in entropy (ΔS) of the block as the system. Use the SL model for aluminum (c_v = 0.902 kJ/kg-K).

SOLUTION



(a) The change in internal energy

$$\Delta U = U_2 - U_1; \quad \Rightarrow \Delta U = mc_v\left(T_2 - T_1\right);$$

$$\Rightarrow \Delta U = 2(0.902)(25-600); \quad \Rightarrow \Delta U = -1037.3 \text{ kJ}$$

(b) The change in entropy

$$\Delta S_{\text{AL}} = S_2 - S_1; \quad \Rightarrow \Delta S = mc_v \ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S = 2(0.902)\ln\left(\frac{273.15+25}{273.15+600}\right);$$

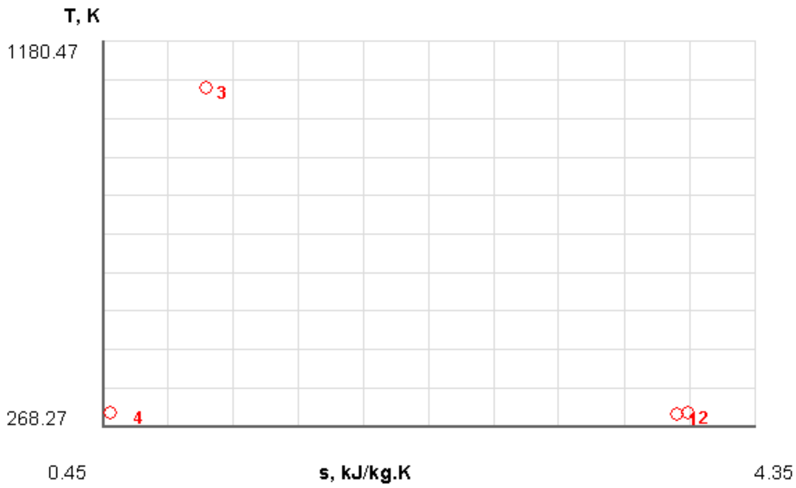
$$\Rightarrow \Delta S = -1.938 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-2-7 [TT] A 3 kg block of iron at 800°C is dropped into 50 kg of water in an insulated cooling tank. If the final temperature (T_2) at equilibrium is 29.9°C, determine (a) the change in internal energy (ΔU) and (b) the change in entropy (ΔS) of the block and water as the system. Use the SL model for iron (c_v = 0.45 kJ/kg-K) and water (c_v = 4.184 kJ/kg-K).

SOLUTION



(a) The change in internal energy

$$\Delta U = 0 \quad \text{(insulated system)}$$

(b) The change in entropy

$$\Delta S = \Delta S_{H_2O} + \Delta S_{Fe}; \quad \Rightarrow \Delta S = mc_{v,H_2O} \ln\left(\frac{T_{2,H_2O}}{T_{1,H_2O}}\right) + mc_{v,Fe} \ln\left(\frac{T_{2,Fe}}{T_{1,Fe}}\right);$$

$$\Rightarrow \Delta S = 50(4.184)\ln\left(\frac{273.15+29.9}{273.15+25}\right) + 3(0.45)\ln\left(\frac{273.15+29.9}{273.15+800}\right); \quad \Rightarrow \Delta S = 1.703 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL/SL non-uniform non-mixing closed system TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-8** [TF] The heat transfer necessary to raise the temperature of a constant-volume closed system is given by $Q = \Delta U$. Using the SL model, compare the heat necessary to raise the temperature by 10°C for such a system of 1 kg and composed of (a) liquid water, (b) liquid ethanol and (c) crude oil.

SOLUTION

The specific heat capacities for the materials are listed as

$$c_{\text{liquid water}} = 4.184 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_{\text{liquid ethanol}} = 2.456 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_{\text{crude oil}} = 2.0 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The necessary heat transfer can be calculated for the liquid water as

$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{liquid water}}\Delta T; \quad \Rightarrow Q = 1(4.184)(10); \quad \Rightarrow Q = 41.8 \text{ kJ}$$

(b) For the liquid ethanol

$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{liquid ethanol}}\Delta T; \quad \Rightarrow Q = 1(2.456)(10); \quad \Rightarrow Q = 24.56 \text{ kJ}$$

(c) For the crude oil

$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{crude oil}}\Delta T; \quad \Rightarrow Q = 1(2.0)(10); \quad \Rightarrow Q = 20 \text{ kJ}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-9** [TD] Repeat the above problem (3-2-8 [TF]) for the following solids as the working substance: (a) Gold, (b) Iron, (c) Sand and (d) Granite.

SOLUTION

The specific heat capacities for these materials are listed as

$$c_{\text{gold}} = 0.129 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_{\text{iron}} = 0.45 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_{\text{sand}} = 0.8 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_{\text{granite}} = 1.017 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The necessary heat transfer can be calculated for the gold as

$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{gold}}\Delta T; \quad \Rightarrow Q = 1(0.129)(10); \quad \Rightarrow Q = 1.29 \text{ kJ}$$

(b) For the iron

$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{iron}}\Delta T; \quad \Rightarrow Q = 1(0.45)(10); \quad \Rightarrow Q = 4.5 \text{ kJ}$$

(c) For the sand

$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{sand}}\Delta T; \quad \Rightarrow Q = 1(0.8)(10); \quad \Rightarrow Q = 8 \text{ kJ}$$

(d) For the granite

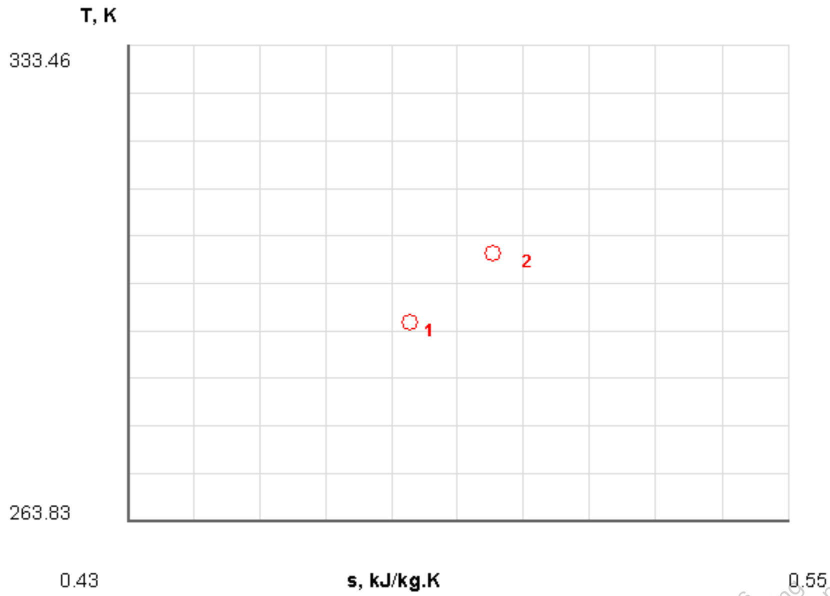
$$Q = \Delta U; \quad \Rightarrow Q = mc_{\text{granite}}\Delta T; \quad \Rightarrow Q = 1(1.017)(10); \quad \Rightarrow Q = 10.17 \text{ kJ}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-10** [TY] A block of iron of volume 1 m^3 undergoes the following change of state. State-1: p_1 = 100 kPa, T_1 = 20°C, V_1 = 0, z_1 = 0; State-2: p_2 = 500 kPa, T_2 = 30°C, V_2 = 30 m/s, z_2 = 100 m. Determine (a) ΔE, (b) ΔU, (c) ΔH and (d) ΔS.

SOLUTION



Using Table-A

$$\rho_{\text{iron}} = 7840 \ \frac{\text{kg}}{\text{m}^3};$$

$$c_{\text{iron}} = 0.45 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in stored energy of this system is described as

$$\Delta E = m\Delta j;$$

$$\Rightarrow \Delta E = m\left(\Delta h + \Delta\text{ke} + \Delta\text{pe}\right);$$

$$\Rightarrow \Delta E = \rho\mathcal{V}(\underbrace{\underbrace{\Delta u}_{\text{internal energy}} + v\Delta p}_{\text{enthalpy}} + \Delta\text{ke} + \Delta\text{pe});$$

$$\Rightarrow \Delta E = 46500 \text{ kJ}$$

(b) The change in internal energy can be calculated as

$$\Delta U = \rho\mathcal{V}\left\lfloor c\left(T_2 - T_1\right)\right\rfloor; \quad \Rightarrow \Delta U = 7840(1)\left\lfloor 0.45(30-20)\right\rfloor; \quad \Rightarrow \Delta U = 35280 \text{ kJ}$$

(c) The change in enthalpy can be calculated as

$$\Delta H = \Delta U + mv\left(p_2 - p_1\right); \quad \Rightarrow \ \Delta H = 35280 + (7840)\left(\frac{500-100}{7840}\right); \quad \Rightarrow \ \Delta H = 35680 \text{ kJ}$$

(d) The change in entropy can be calculated as

$$\Delta S = mc\ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S = \rho\mathcal{V}c\ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S = 7840(1)(0.45)\ln\left(\frac{273+30}{273+20}\right);$$

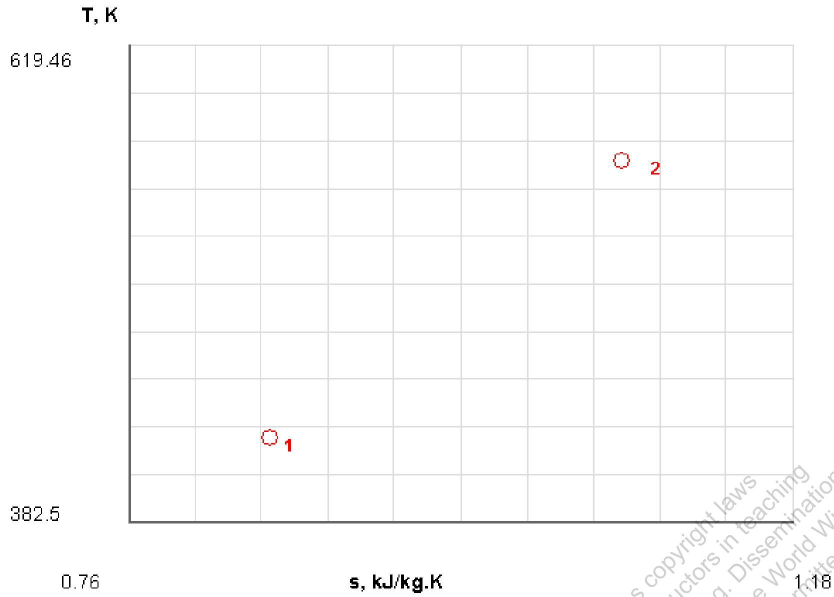
$$\Rightarrow \Delta S = 118.4 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-11** [TW] A thermal storage is made of a granite rock bed of 10 m^3 which is heated to 425 K using solar energy. A heat engine receives heat from the bed and rejects the waste heat to the ambient surroundings at 290 K. During the process, the rock bed cools down and as it reaches 290 K, the engine stops working. The heat transfer from the rock is given as $Q_H = \Delta E$. Determine (a) the magnitude of the heat transfer (Q_H) and the maximum thermal efficiency (η_{th}) at (b) the beginning and (c) the end of the process.

SOLUTION



Using Table-A

$$\rho_{\text{granite}} = 2700 \ \frac{\text{kg}}{\text{m}^3};$$

$$c_{\text{granite}} = 1.017 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

The energy balance into of this system during the heat addition process can be written as

$$\Rightarrow \Delta E = m\left(\Delta u + v\cancel{\Delta p}^{0} + \cancel{\Delta ke}^{0} + \cancel{\Delta pe}^{0}\right); \qquad \Rightarrow \Delta E = \rho\cancel{V}\left[c\left(T_2 - T_1\right)\right];$$

(a) The heat transfer into (and out of) the block can be calculated as

$$Q_H = \Delta E; \qquad \Rightarrow Q_H = \rho\cancel{V}\left\lfloor c\left(T_2 - T_1\right)\right\rfloor; \qquad \Rightarrow Q_H = 2700(10)\left\lfloor 1.017(425-290)\right\rfloor;$$

$$\Rightarrow Q_H = 370.7 \text{ MJ}$$

(b) The maximum thermal efficiency can be found by modeling this heat engine as a Carnot heat engine.
At the beginning:

$$\eta_{\text{Carnot}} = 1 - \frac{T_C}{T_H}; \qquad \Rightarrow \eta_{\text{Carnot}} = 1 - \frac{290}{425}; \qquad \Rightarrow \eta_{\text{Carnot}} = 0.3176; \qquad \Rightarrow \eta_{\text{Carnot}} = 31.76\%$$

(c) At the end:

$$\eta_{\text{Carnot}} = 1 - \frac{T_C}{T_H}; \quad \text{and} \quad \cancel{T_H}^{T_C},$$

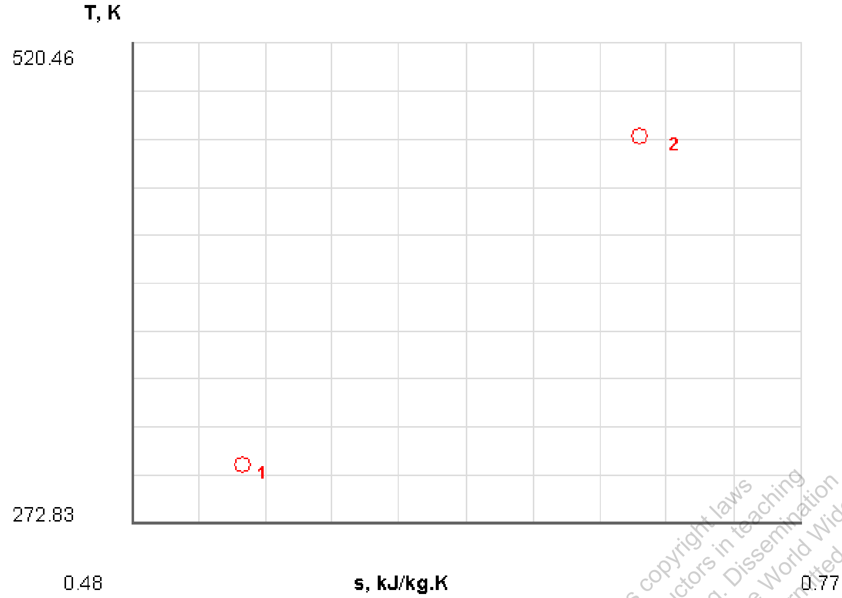
$$\Rightarrow \eta_{\text{Carnot}} = 1 - \frac{T_{\text{C}}}{T_{\text{C}}}; \qquad \Rightarrow \eta_{\text{Carnot}} = 1 - 1; \qquad \Rightarrow \eta_{\text{Carnot}} = 0\%$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

*3-2-12 [TM] A copper block of mass 5 kg, initially at equilibrium with the surroundings at 30°C and 100 kPa, is placed in a pressurized chamber with a pressure of 20 MPa and a temperature of 200°C. Determine (a) the change in the internal energy (ΔU), (b) enthalpy (ΔH) and (c) entropy (ΔS) of the block after it comes to a new equilibrium. (d) What-if Scenario: What would the change in internal energy be if the block were made of silver?

SOLUTION



Using Table-A

$$\rho_{\text{copper}} = 8900 \ \frac{\text{kg}}{\text{m}^3};$$

$$c_{\text{copper}} = 0.386 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in internal energy can be calculated as

$$\Delta U = m(u_2 - u_1); \quad \Rightarrow \Delta U = mc(T_2 - T_1); \quad \Rightarrow \Delta U = 5(0.386)(200 - 30);$$

$$\Rightarrow \Delta U = 328.1 \text{ kJ}$$

(b) The change in enthalpy can be calculated as

$$\Delta H = \Delta U + v\Delta p; \quad \Rightarrow \Delta H = \Delta U + \frac{p_2 - p_1}{\rho}; \quad \Rightarrow \Delta H = 329.28 + \frac{20000 - 100}{8900};$$

$$\Rightarrow \Delta H = 339.28 \text{ kJ}$$

(c) The change in entropy can be calculated as

$$\Delta S = mc\ln\left(\frac{T_2}{T_1}\right); \quad \Rightarrow \Delta S = 5(0.386)\ln\left(\frac{273+200}{273+30}\right); \quad \Rightarrow \Delta S = 0.86 \ \frac{\text{kJ}}{\text{K}}$$

(d) Using Table-A for silver

$$c_{\text{silver}} = 0.235 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

The change in internal energy can be calculated as

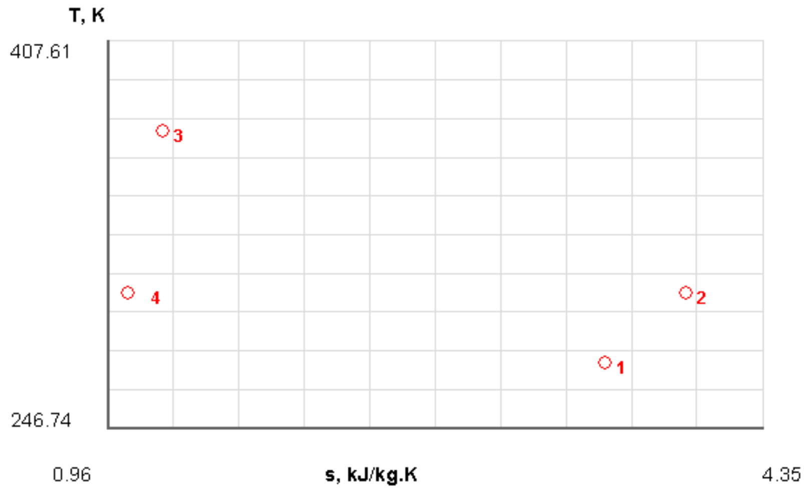
$$\Delta U = mc(T_2 - T_1); \quad \Rightarrow \Delta U = 5(0.235)(200 - 30); \quad \Rightarrow \Delta U = 199.75 \text{ kJ}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-13** [TJ] A 20 kg block of aluminum at 97.4°C is dropped into a tank containing 10 kg of water at 1°C. If the final temperature after equilibrium is 30°C, determine (a) ΔU and (b) ΔS for the combined system of aluminum and water after the process is complete.

SOLUTION



Using Table-A

$$c_{\text{water}} = 4.18 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_{\text{aluminum}} = 0.902 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in internal energy of this system can be calculated as

$$\Delta U_{\text{System}} = \Delta U_{\text{water}} + \Delta U_{\text{Al}};$$

$$\Rightarrow \Delta U_{\text{System}} = m_{\text{water}} c_{\text{water}} \left(T_f - T_i\right) + m_{\text{Al}} c_{\text{Al}} \left(T_f - T_i\right);$$

$$\Rightarrow \Delta U_{\text{System}} = 10(4.18)(30-1) + 20(0.902)(30-97.4); \qquad \Rightarrow \Delta U_{\text{System}} = -2.54 \text{ kJ}$$

(b) The change in entropy of this system

$$\Delta S_{\text{System}} = \Delta S_{\text{water}} + \Delta S_{\text{Al}};$$

$$\Rightarrow \Delta S_{\text{System}} = m_{\text{water}} c_{\text{water}} \ln\left(\frac{T_f}{T_i}\right) + m_{\text{Al}} c_{\text{Al}} \ln\left(\frac{T_f}{T_i}\right);$$

$$\Rightarrow \Delta S_{\text{System}} = 10(4.18)\ln\left(\frac{273+30}{273+1}\right) + 20(0.902)\ln\left(\frac{273+30}{273+97.4}\right);$$

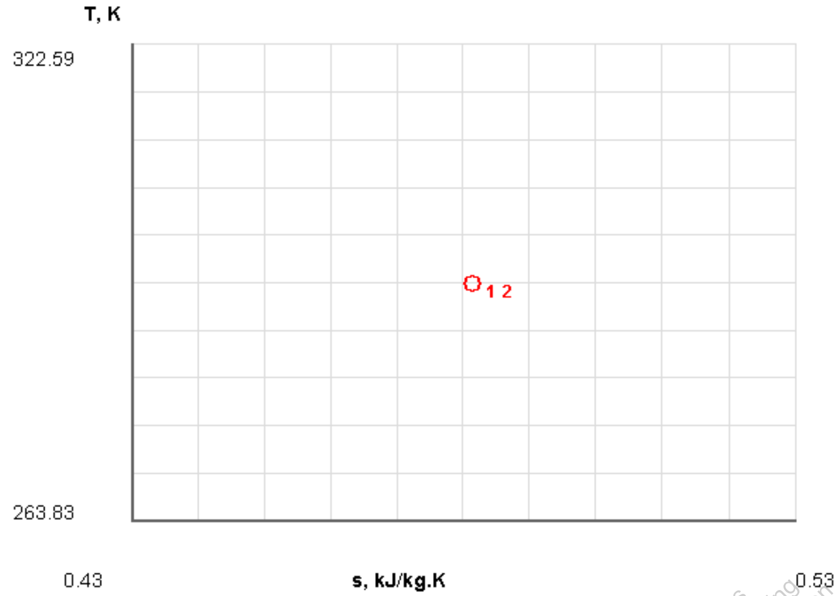
$$\Rightarrow \Delta S_{\text{System}} = 0.593 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL/SL multicomponent non-mixing closed system TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

*3-2-14 [YR] A 20-kg block of iron (specific heat 0.45 kJ/kg-K) is heated by conduction at a rate of 1 kW. Assuming the block to be uniform at all time, determine the rate of change of temperature (dT/dt).

SOLUTION



Given the following properties:

$m = 20$ kg;

$\dot{Q} = 1\text{ kW} = 1\dfrac{\text{kJ}}{\text{s}}$;

$c = 0.45\dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$;

Heat can be expressed as

$$Q\ [\text{kW}] = c\left|\frac{\text{kJ}}{\cancel{\text{kg}}\cdot\cancel{\text{K}}}\right| m\left[\cancel{\text{kg}}\right] T\left[\cancel{\text{K}}\right]; \quad \Rightarrow Q = cmT\ [\text{kJ}];$$

$$\Rightarrow T = \frac{Q}{cm};$$

The derivative of this equation will yield the rate of change of temperature

$$\frac{dT}{dt} = \frac{\dot{Q}}{cm};$$

$$\frac{dT}{dt} = \frac{1}{0.45(20)}; \quad \Rightarrow \frac{dT}{dt} = 0.111\ \frac{\text{K}}{\text{s}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-2-15 [YO] A copper bullet of mass 0.1 kg, traveling at 400 m/s, hits a copper block of mass 2 kg at rest and becomes embedded. The combined system moves with a velocity of 19.05 m/s in accordance with the conservation of momentum principle. Both the bullet and copper block are at 25°C initially. Assuming the stored energy of the combined system to remain constant during the collision, determine (a) the rise in temperature (ΔT) and (b) entropy (ΔS) change of the combined system. Assume the system to achieve a uniform temperature quickly after the collision and neglect any change in potential energy.

SOLUTION

Using Table-A

$$c_{cu} = 0.386 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) Given that the stored energy of this bullet-block system remains constant

$$\Delta E_{\text{system}} = 0;$$

$$\Rightarrow 0 = \underbrace{\Delta E_{\text{P}}}_{\text{projectile}} + \underbrace{\Delta E_{\text{B}}}_{\text{block}};$$

$$\Rightarrow 0 = m_{\text{P}}\left(\Delta u_{\text{P}} + \Delta ke_{\text{P}} + \cancel{\Delta pe_{\text{P}}}^{0}\right) + m_{\text{B}}\left(\Delta u_{\text{B}} + \Delta ke_{\text{B}} + \cancel{\Delta pe_{\text{B}}}^{0}\right);$$

$$\Rightarrow 0 = m_{\text{P}}\left(c_{cu}\Delta T + \frac{\text{V}_{\text{f,P}}^2 - \text{V}_{\text{i,P}}^2}{2000}\right) + m_{\text{B}}\left(c_{cu}\Delta T + \frac{\text{V}_{\text{f,B}}^2 - \text{V}_{\text{i,B}}^2}{2000}\right);$$

$$\Rightarrow \Delta T = -\frac{m_{\text{P}}\left(\text{V}_{\text{f,P}}^2 - \text{V}_{\text{i,P}}^2\right) + m_{\text{B}}\left(\text{V}_{\text{f,B}}^2 - \text{V}_{\text{i,B}}^2\right)}{2000\left(m_{\text{P}} + m_{\text{B}}\right)c_{cu}};$$

$$\Rightarrow \Delta T = -\frac{0.1\left(19.05^2 - 400^2\right) + 2\left(19.05^2 - 0^2\right)}{2000\left(0.1 + 2\right)\left(0.386\right)};$$

$$\Rightarrow \Delta T = 9.399^\circ\text{C}$$

(b) The entropy change of this system can be calculated as

$$\Delta S_{\text{System}} = \Delta S_{\text{P}} + \Delta S_{\text{B}};$$

$$\Rightarrow \Delta S_{\text{System}} = m_{\text{P}}c_{cu}\ln\left(\frac{T_f}{T_i}\right) + m_{\text{B}}c_{cu}\ln\left(\frac{T_f}{T_i}\right);$$

$$\Rightarrow \Delta S_{\text{System}} = \left(m_{\text{P}} + m_{\text{B}}\right)c_{cu}\ln\left(\frac{T_f}{T_i}\right);$$

$$\Rightarrow \Delta S_{\text{System}} = \left(0.1 + 0.2\right)\left(0.386\right)\ln\left(\frac{273 + 25 + 9.399}{273 + 25}\right);$$

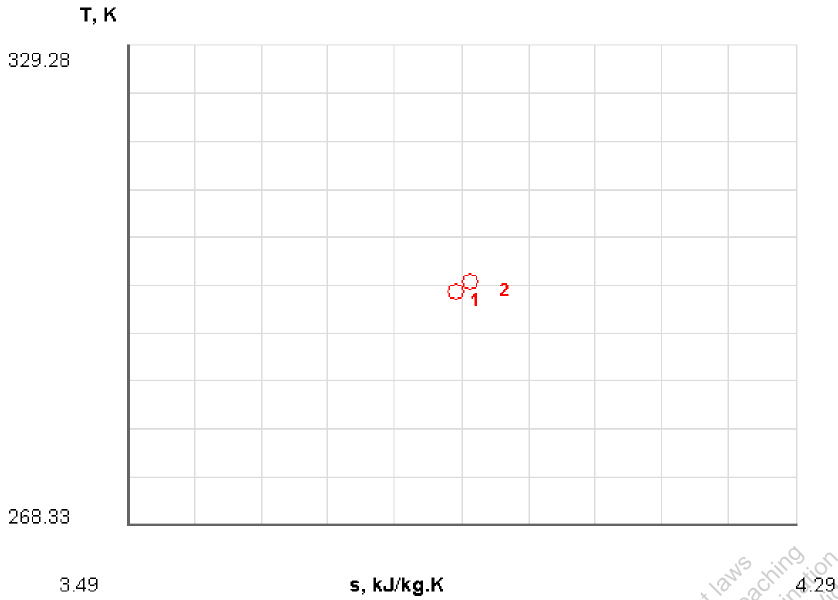
$$\Rightarrow \Delta S_{\text{System}} = 0.0252 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

*3-2-16 [YB] A cup of coffee cools down by transferring heat to the surroundings at a rate of 1 kW. If the mass of the coffee is 0.2 kg and coffee can be modeled as water, determine the rate of change of temperature (dT/dt) of coffee.

SOLUTION



Given the following properties

$m = 0.2$ kg;

$\dot{Q} = -1 \text{ kW} = -1 \dfrac{\text{kJ}}{\text{s}}$; (Heat lost is negative according to WINHIP sign convention)

$c = 4.18 \dfrac{\text{kJ}}{\text{kg} \cdot \text{K}}$;

Heat can be expressed as

$$Q\,[\text{kW}] = c\left[\frac{\text{kJ}}{\cancel{\text{kg}} \cdot \cancel{\text{K}}}\right] m\left[\cancel{\text{kg}}\right] T\left[\cancel{\text{K}}\right]; \qquad \Rightarrow Q = cmT\ [\text{kJ}];$$

$$\Rightarrow T = \frac{Q}{cm};$$

The derivative of this equation will yield the rate of change of temperature

$$\frac{dT}{dt} = \frac{\dot{Q}}{cm};$$

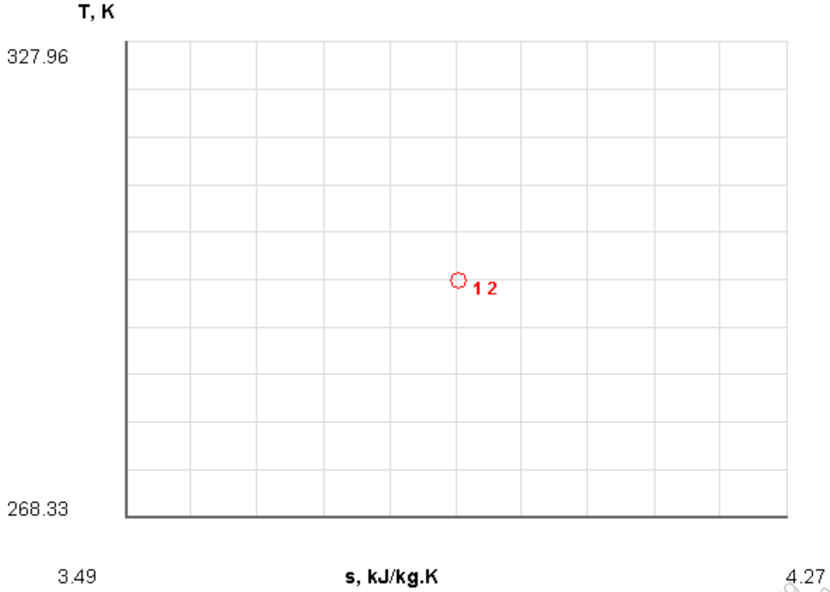
$$\frac{dT}{dt} = \frac{-1}{4.18(0.2)}; \qquad \Rightarrow \frac{dT}{dt} = -1.2\frac{\text{K}}{\text{s}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-17** [YS] A pump raises the pressure of liquid water from 50 kPa to 5000 kPa in an isentropic manner. Determine (a) the change in temperature (ΔT) and (b) specific enthalpy (Δh) between the inlet and exit.

SOLUTION



Using Table-A

$$\rho_{\text{water}} = 997 \ \frac{\text{kg}}{\text{m}^3};$$

$$c_{\text{water}} = 4.18 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) As an isentropic process

$$\Delta s = 0; \qquad \Rightarrow \Delta s = c_{\text{water}} \ln\left(\frac{T_f}{T_i}\right);$$

$$\Rightarrow \frac{T_f}{T_i} = 0;$$

$$\Rightarrow T_f = T_i;$$

$$\Rightarrow \Delta T = 0 \text{ K}$$

(b) The enthalpy change is calculated as

$$\Delta H = \Delta u + v\Delta p; \qquad \Rightarrow \Delta H = c_{\text{water}} \cancel{\Delta T}^{0} + \frac{p_2 - p_1}{\rho}; \qquad \Rightarrow \Delta H = 0 + \frac{5000 - 50}{997};$$

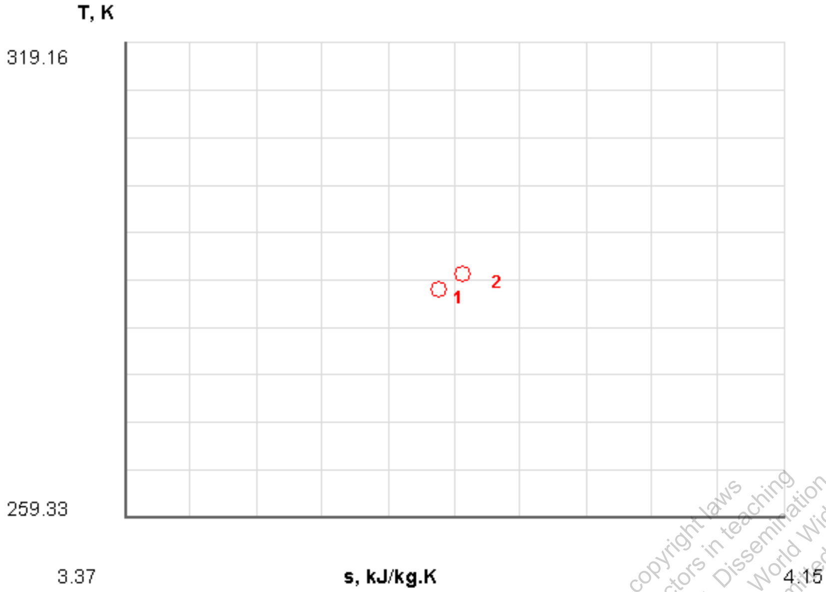
$$\Rightarrow \Delta H = 4.965 \ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-18** [YA] Water flows through an adiabatic pumping system at a steady flow rate (m) of 5 kg/s. The conditions at the inlet are p_1 = 90 kPa, T_1 = 15°C and z_1 = 0 m; and the conditions at the exit are p_2 = 500 kPa, T_2 = 17°C and z_2 = 200 m. (a) Simplify the energy equation to derive an expression for the pumping power. (b) Use the SL model to evaluate the pumping power (W_{net}). Neglect any change in kinetic energy. What-if Scenario: (c) What would the pumping power be if the exit temperature were 18°C?

SOLUTION



Using Table-A

$$\rho_{\text{water}} = 997 \ \frac{\text{kg}}{\text{m}^3};$$

$$c_{\text{water}} = 4.18 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

(a) The energy balance equation is given as

$$\cancel{\frac{dE}{dt}}^{0,\text{ Steady}} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \cancel{\dot{Q}}^{0,\text{ Adibadic}} - \dot{W}_{\text{net}};$$

$$\Rightarrow \dot{W}_{\text{net}} = \dot{m}_i \left(j_i - j_e \right)$$

(b) Pumping Power

$$\Rightarrow \dot{W}_{\text{net}} = \dot{m}_i \left(j_i - j_e \right);$$

$$\Rightarrow \dot{W}_{\text{net}} = \dot{m} \left(\Delta u + v\Delta p + \cancel{\Delta ke}^{0,\text{ neg}} + \Delta pe \right);$$

$$\Rightarrow \dot{W}_{\text{net}} = \dot{m} \left(c_{\text{water}} \left(T_f - T_i \right) + v \left(p_f - p_i \right) + \frac{g \left(z_f - z_i \right)}{1000} \right);$$

$$\Rightarrow \dot{W}_{\text{net}} = 5 \left(4.18(17-15) + \frac{500-90}{997} + \frac{9.81(200-0)}{1000} \right);$$

$$\Rightarrow \dot{W}_{\text{net}} = 53.67 \text{ kW}$$

(c) If the exit temp was 18°C

$$\Rightarrow \dot{W}_{\text{net}} = 5\left(4.18(18-15) + \frac{500-90}{997} + \frac{9.81(200-0)}{1000}\right)$$

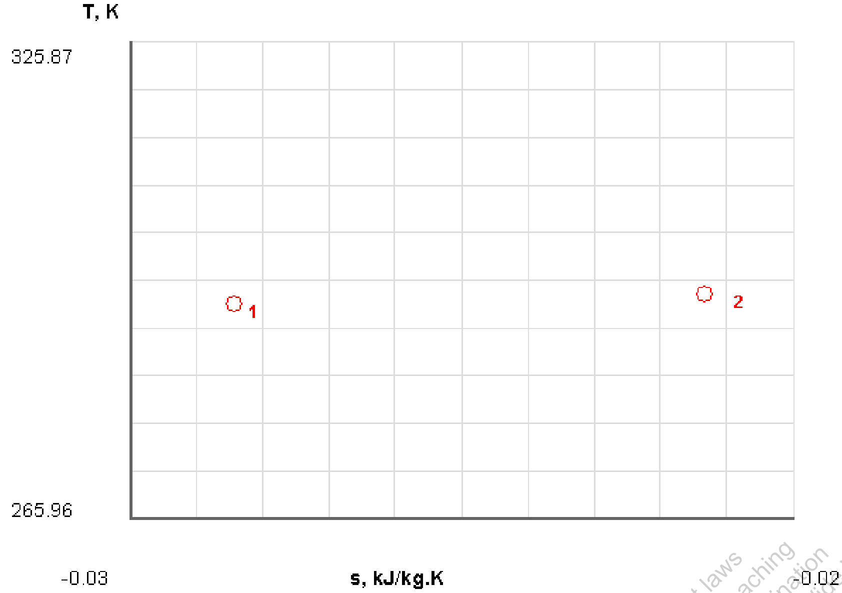
$$\Rightarrow \dot{W}_{\text{net}} = 74.57 \text{ kW}$$

TEST Solution:

Launch the SL open steady state single flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-19** [YE] Oil (c_v = 1.8 kJ/kg-K, ρ = 910 kg/m^3) flows steadily through a long insulated constant-diameter pipe at a volume flow rate of 10 m^3/min. The conditions at the inlet are p = 3000 kPa, T = 20°C, V = 20 m/s and z = 100 m. The conditions at the exit are p = 2000 kPa and z = 0 m. (a) Evaluate the velocity (V) at the exit. (b) Determine the exit temperature (T_2).

SOLUTION



(a) Using the mass balance equation

$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e; \quad \Rightarrow \cancel{\frac{dm}{dt}}^{0,\text{ Steady}} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\Rightarrow \dot{m}_i = \dot{m}_e;$$

$$\Rightarrow \rho \mathrm{A}_i \mathrm{v}_i = \rho \mathrm{A}_e \mathrm{v}_e;$$

$$\Rightarrow \mathrm{v}_e = \cancel{\frac{\rho \mathrm{A}_i}{\rho \mathrm{A}_e}}^{1} \mathrm{v}_i; \quad \Rightarrow \mathrm{v}_e = \mathrm{v}_i; \quad \Rightarrow \mathrm{v}_e = 20\,\frac{\mathrm{m}}{\mathrm{s}}$$

(b) The flow energy can be analyzed the energy balance equation.

$$\cancel{\frac{dE}{dt}}^{0,\text{ Steady}} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \cancel{\dot{Q}}^{0,\text{ Adibadic}} - \cancel{\dot{W}_{\text{net}}}^{0};$$

$$\dot{m}_i j_i = \dot{m}_e j_e;$$

$$\Rightarrow \dot{m}_i = \dot{m}_e;$$

$$\Rightarrow j_i = j_e;$$

This relationship can be used to solve for the exit temperature.

$$\Rightarrow 0 = j_e - j_i; \quad \Rightarrow 0 = \Delta j;$$

$$\Rightarrow 0 = \Delta h + \cancel{\Delta ke}^{0} + \Delta pe;$$

$$\Rightarrow 0 = c_v\left(T_2 - T_1\right) + v\left(p_2 - p_1\right) + \frac{g\left(z_2 - z_1\right)}{1000};$$

$$\Rightarrow T_2 = -\frac{\left[\dfrac{\left(p_2 - p_1\right)}{\rho} + \dfrac{g\left(z_2 - z_1\right)}{1000}\right]}{c_v} + T_1;$$

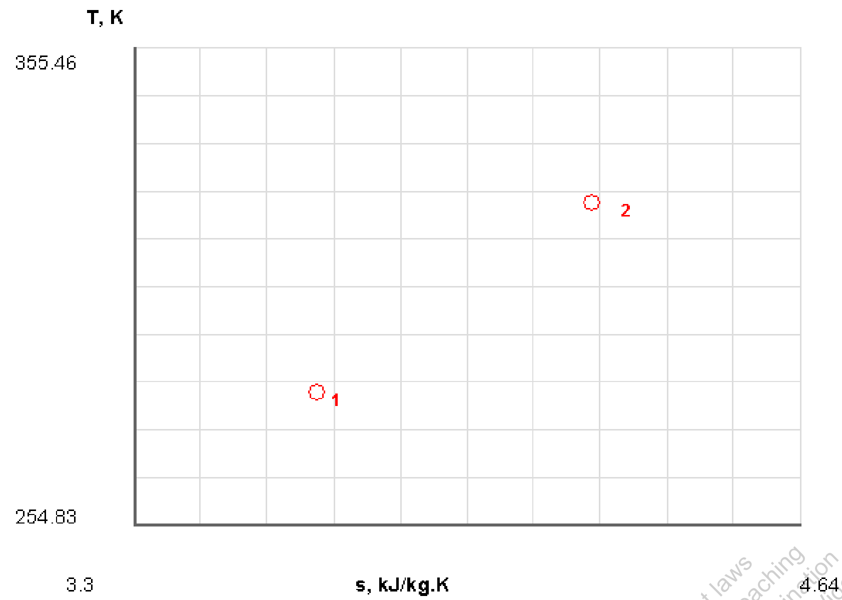
$$\Rightarrow T_2 = -\frac{\left[\frac{2000-3000}{910} + \frac{9.81(0-100)}{1000}\right]}{1.8} + 20; \qquad \Rightarrow T_2 = 21.16^{\circ}\mathrm{C}$$

TEST Solution:

Launch the SL single-flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

***3-2-20** [YH] Water flows steadily through a device at a flow rate of 20 kg/s. At the inlet, the conditions are 200 kPa and 10^{o}C. At the exit, the conditions are 2000 kPa and 50^{o}C. (a) Determine the difference between the entropy (S) transported by the flow at the exit and at the inlet. (b) What are the possible reasons behind the increase in entropy transport?

SOLUTION



Using the property tables for water

$$@\ 200\ \text{kPa},\ 10^\circ\text{C} \quad h_i = -62.661\ \frac{\text{kJ}}{\text{kg}};$$

$$@\ 2000\ \text{kPa},\ 50^\circ\text{C} \quad h_i = 106.337\ \frac{\text{kJ}}{\text{kg}};$$

(a) The difference between the entropy transported by the flow at the exit and at the inlet can be expressed as

$$\Delta\dot{S} = \dot{m}\left(s_e - s_i\right) = \dot{m}\left(c_v \ln\frac{T_e}{T_i}\right) = (20)\left(4.\ln\frac{50+273}{10+273}\right) = 11.1; \Delta\dot{S} = 20\left(\frac{106.337}{323} - \frac{-62.66}{283}\right) = 11.1\ \frac{\text{kW}}{\text{K}}$$

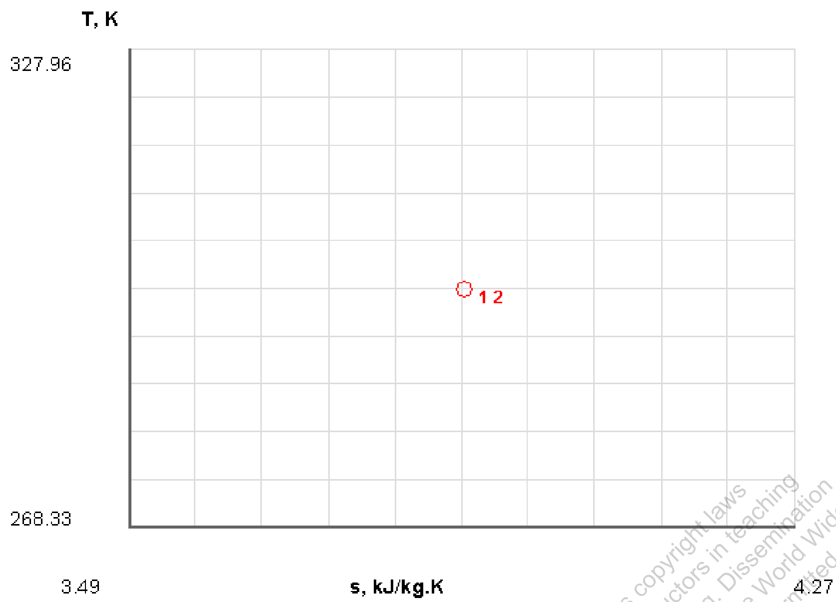
(b) One possibility is that the pipe in not insulated and allows for some heat addition. Other contributing factors include viscous friction and other irreversibilities.

TEST Solution:

Launch the SL open steady state single flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-2-21 [YN] In an isentropic nozzle, operating at steady state, the specific flow energy (j) and specific entropy (s) remain constant along the flow. The following properties are known at the inlet and exit ports of an isentropic nozzle discharging water at a steady rate of 2 kg/s. Inlet: p_1 = 300 kPa, A_1 = 4 cm^2; Exit: p_2 = 100 kPa. Determine (a) the exit velocity (V_2) and (b) the exit area. Use the SL model for liquid water. (c) What-if Scenario: What would the exit velocity be if the inlet kinetic energy were neglected?

SOLUTION



Since the entropy of this flow remains constant, this flow can be considered an isentropic process where

$$\Delta s = 0; \qquad \Rightarrow \Delta s = c_{\text{water}} \ln\left(\frac{T_f}{T_i}\right);$$

$$\Rightarrow \frac{T_f}{T_i} = 0; \qquad \Rightarrow T_f = T_i; \qquad \Rightarrow \Delta T = 0;$$

At steady state

$$\dot{m}_i = \dot{m}_e = \dot{m};$$

$$\Rightarrow \dot{m} = \rho \mathrm{A}_i \mathrm{v}_i;$$

$$\Rightarrow \mathrm{v}_i = \frac{\dot{m}}{\rho \mathrm{A}_i}; \qquad \Rightarrow \mathrm{v}_i = \frac{2}{997\left(\frac{4}{100^2}\right)}; \qquad \Rightarrow \mathrm{v}_i = 5.015\ \frac{\mathrm{m}}{\mathrm{s}};$$

(a) Since the specific flow energy remains constant

$$\Rightarrow 0 = j_e - j_i; \qquad \Rightarrow 0 = \Delta j;$$

$$\Rightarrow 0 = c\cancelto{0}{\Delta T} + v\Delta p + \Delta ke + \cancelto{0,\text{ neg}}{\Delta pe};$$

$$\Rightarrow 0 = \frac{p_e - p_i}{\rho} + \frac{\mathrm{v}_e^2 - \mathrm{v}_i^2}{2000};$$

$$\Rightarrow \mathrm{v}_e = \sqrt{\frac{2000(p_e - p_i)}{\rho} + \mathrm{v}_i^2} = \sqrt{\frac{2000(300-100)}{997} + 5.015}; \qquad \Rightarrow \mathrm{v}_e = 20.65\ \frac{\mathrm{m}}{\mathrm{s}}$$

(b) $\dot{m} = \rho A_e v_e;$

$$\Rightarrow A_e = \frac{\dot{m}}{\rho v_e}; \quad \Rightarrow A_e = \frac{2}{997(20.65)}; \quad \Rightarrow A_e = 9.72\times10^{-5}; \quad \Rightarrow A_e = 97.2 \text{ mm}^2$$

(c) By neglecting kinetic energy at the inlet

$$\Rightarrow v_e = \sqrt{\frac{2000(p_e - p_i)}{\rho} + \cancel{V_i^2}^{\,0}}; \quad \Rightarrow v_e = \sqrt{\frac{2000(300-100)}{997} + 0}; \quad \Rightarrow v_e = 20.03 \ \frac{\text{m}}{\text{s}}$$

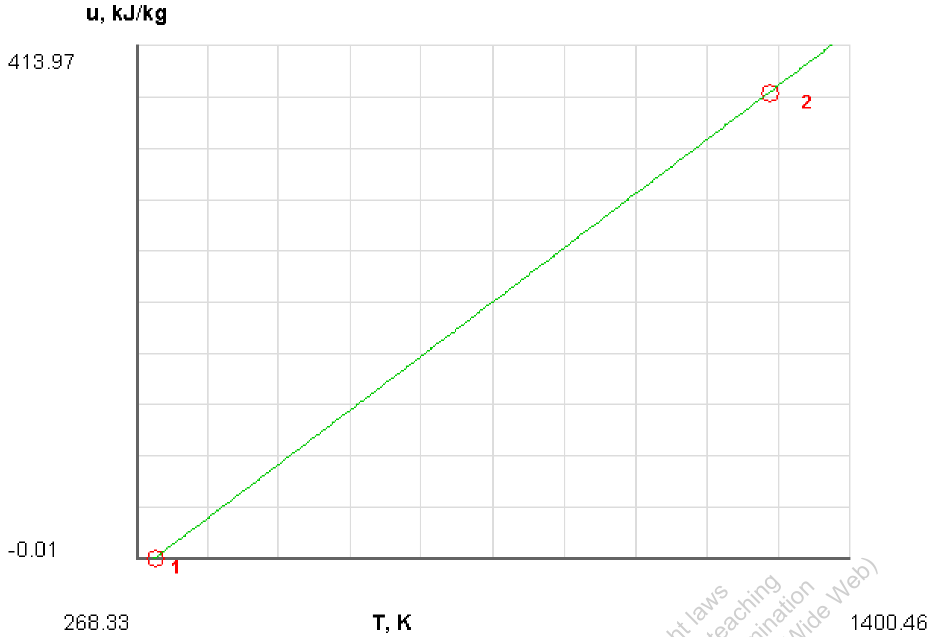
TEST Solution:

Launch the SL open steady state single flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

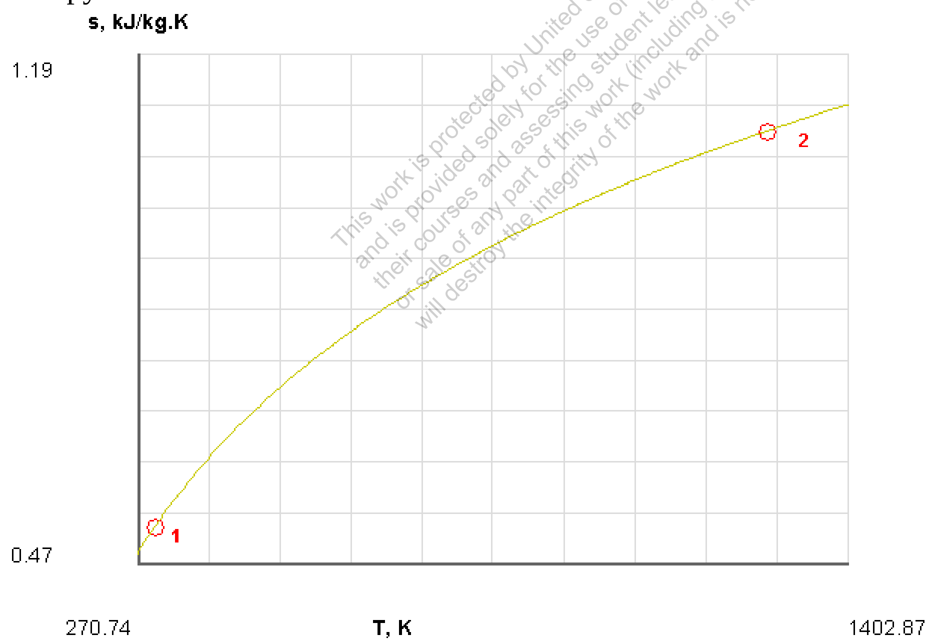
***3-2-22** [YI] For copper, plot how the internal energy (*U*), and entropy (*S*), vary with *T* within the range 25^{o}C - 1000^{o}C. Use the SL system state daemon.

SOLUTION

Internal Energy



Entropy



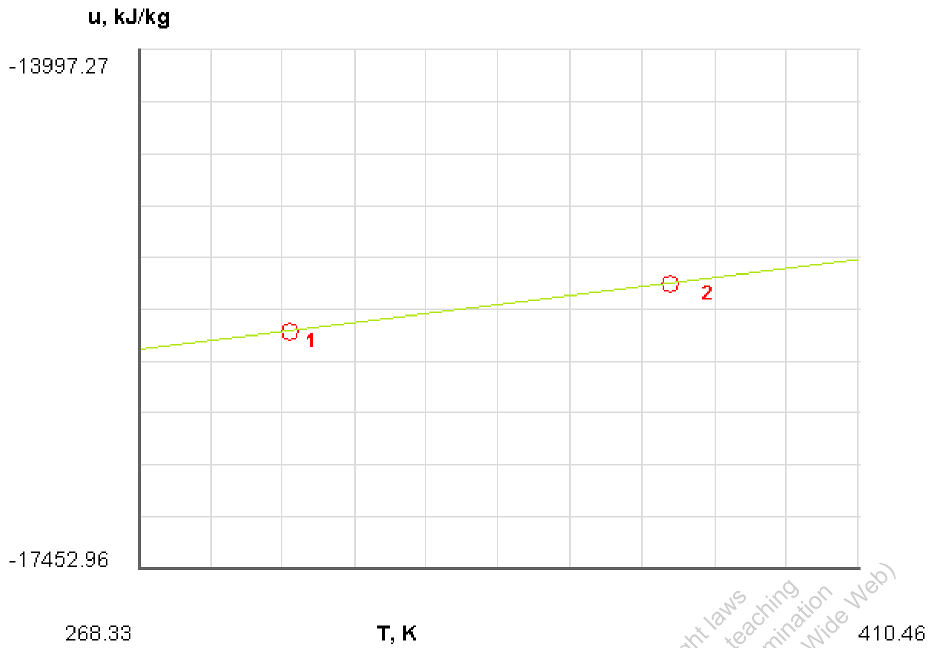
TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

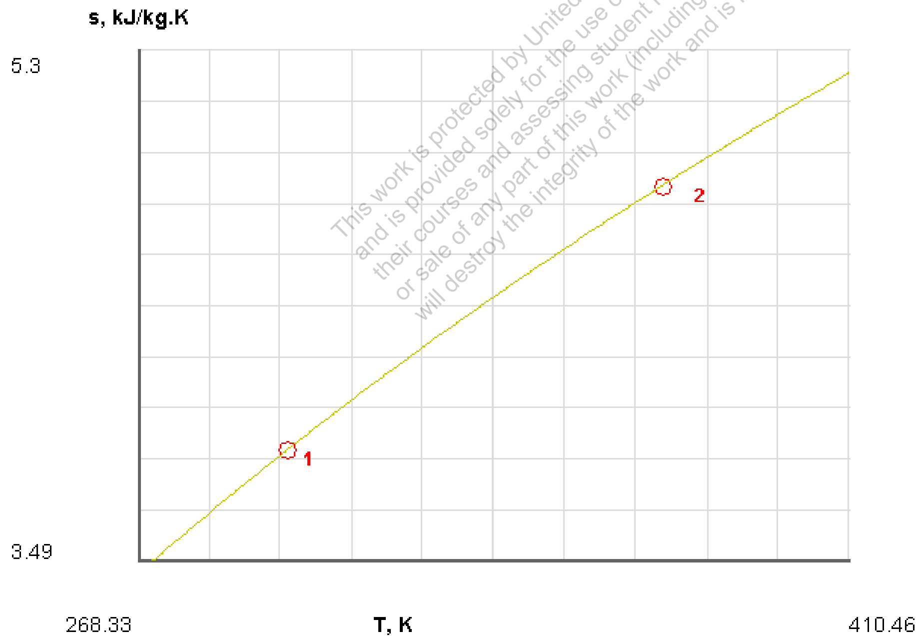
***3-2-23** [YG] For liquid water, plot how the internal energy (U), and entropy (S), vary with T within the range 25°C - 100°C. Use the SL system state daemon.

SOLUTION

Internal Energy



Entropy



TEST Solution:

Launch the SL system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

TEST Solution (3*ManSol Note2: can be added here):

***Daemon Path:: States>System>SL-Model;

```
***TEST Code::    States       {
           State-1:  Custom;
           Given:       { T1= 25.0 deg-C;   Vel1= 0.0 m/s;   z1= 0.0 m;   m1= 10.0 kg;   }

           State-2:  Custom;
           Given:       { T2= 200.0 deg-C;   Vel2= 0.0 m/s;   z2= 0.0 m;   m2= "m1" kg;   }
          }
```