2-2-1 [NX] A 20 kg block of solid cools down by transferring heat at a rate of 1 kW to the surroundings. Determine the rate of change of (a) stored energy and (b) internal energy of the block.

SOLUTION

(a) For this closed system:

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}; \quad \Rightarrow \frac{dE}{dt} = (-1) - 0; \quad \Rightarrow \frac{dE}{dt} = -1 \text{ kW}$$

(b) $$\frac{dU}{dt} = \frac{d(E - \text{KE} - \text{PE})}{dt}; \quad \Rightarrow \frac{dU}{dt} = \frac{dE}{dt} - \cancel{\frac{d(\text{KE})}{dt}}^{0} - \cancel{\frac{d(\text{PE})}{dt}}^{0};$$

$$\Rightarrow \frac{dU}{dt} = -1 \text{ kW}$$

2-2-2 [KE] A rigid chamber contains 100 kg of water at 500 kPa, 100^{o}C. A paddle wheel stirs the water at 1000 rpm with a torque of 100 N-m. while an internal electrical resistance heater heats the water, consuming 10 amps of current at 110 Volts. Because of thin insulation, the chamber loses heat to the surroundings at 27^{o}C at a rate of 1.2 kW. Determine the rate at which the stored energy of the system changes.

SOLUTION

For this closed system:

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}; \qquad \Rightarrow \frac{dE}{dt} = \left(-\dot{Q}_{\text{loss}}\right) - \left(-\dot{W}_{\text{in,sh}} - \dot{W}_{\text{in,el}}\right);$$

$$\Rightarrow \frac{dE}{dt} = \dot{W}_{\text{in,sh}} + \dot{W}_{\text{in,el}} - \dot{Q}_{\text{loss}};$$

$$\Rightarrow \frac{dE}{dt} = 2\pi NT + \frac{VI}{1000} - \dot{Q}_{\text{loss}}; \qquad \Rightarrow \frac{dE}{dt} = 2\pi\left(\frac{1000}{60}\right)\left(\frac{100}{1000}\right) + \frac{(110)(10)}{1000} - 1.2;$$

$$\Rightarrow \frac{dE}{dt} = 10.372 \text{ kW}$$

2-2-3 [NC] A closed system interacts with its surroundings and the following data are supplied: W_{sh} = -10 kW, W_{el} = 5 kW, Q = -5 kW. (a) If there are no other interactions, determine dE/dt. (b) Is this system necessarily steady (yes: 1; no: 0)?

SOLUTION

(a) $\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}$;

$$\Rightarrow \frac{dE}{dt} = (-5) - (-10+5); \qquad \Rightarrow \frac{dE}{dt} = 0$$

(b) For a system, $\frac{dE}{dt} = 0$. The reverse, however, is not necessarily true. Therefore, the system is not necessarily steady (no: 0).

2-2-4 [QY] An electric bulb consumes 500 W of electricity. After it is turned on, the bulb becomes warmer and starts losing heat to the surroundings at a rate of 5*t* (*t* in seconds) watts until the heat loss equals the electric power input. (a) Plot the change in stored energy of the bulb with time. (b) How long does it take for the bulb to reach steady state?

SOLUTION

(a) $\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}; \qquad \Rightarrow \frac{dE}{dt} = \left(-\frac{5t}{1000}\right) - \left(-\frac{500}{1000}\right); \quad [\text{kW}]$

$$\Rightarrow \frac{dE}{dt} = 0.5 - \frac{t}{200};$$

$$\Rightarrow dE = 0.5dt - \frac{t}{200}dt; \quad [\text{kW}]$$

Integrating,

$$\Rightarrow E = c + 0.5t - \frac{t^2}{400};$$

If $E = E(0)$ at $t = 0$, $c = E(0)$, then

$$E(t) = E(0) + 0.5t - \frac{t^2}{400};$$

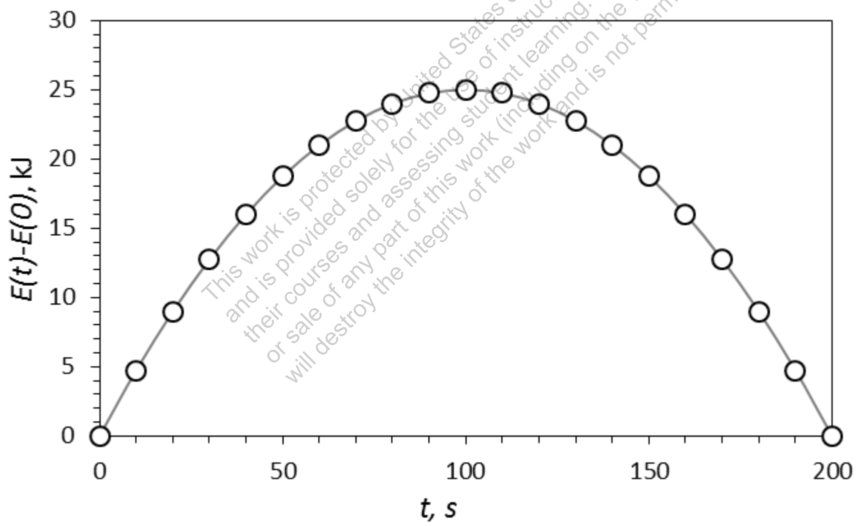


Fig. 1 Plot showing how the stored energy of the system changes with time, reaching steady state after 200 s.

(b) At $t = 200$ s, $\frac{dE}{dt} = 0$. The system (most likely) reaches its steady state at that time.

2-2-5 [NV] Suppose the specific internal energy in kJ/kg of the solid in problem 2-2-1 [NX] is related to its temperature through $u = 0.5T$, where T is the temperature of the solid in Kelvin, determine the rate of change of temperature of the solid. Assume the density of the solid to be 2700 kg/m^3.

SOLUTION

$$\frac{dU}{dt} = -1 \text{ kW};$$

$$\frac{dU}{dt} = \frac{d(mu)}{dt}; \quad \Rightarrow \frac{dU}{dt} = m\frac{du}{dt}; \quad \Rightarrow \frac{dU}{dt} = m\frac{d(0.5T)}{dt}; \quad \Rightarrow \frac{dU}{dt} = (0.5)m\frac{dT}{dt};$$

$$\Rightarrow \frac{dT}{dt} = \frac{1}{(0.5)m}\frac{dU}{dt}; \quad \Rightarrow \frac{dT}{dt} = \frac{1}{(0.5)(20)}(-1); \quad \Rightarrow \frac{dT}{dt} = -0.1\ \frac{\text{K}}{\text{s}}$$

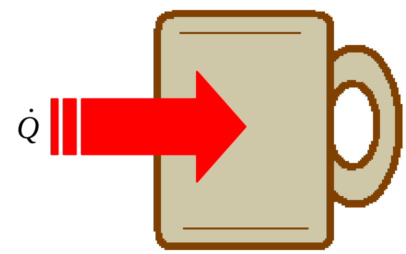
2-2-6 [NQ] A cup of coffee is heated in a microwave oven. If the mass of coffee (modeled as liquid water) is 0.2 kg and the rate of heat transfer is 0.1 kW, (a) determine the rate of change of internal energy (u). (b) Assuming the density of coffee to be 1000 kg/m^3 and the specific internal energy in kJ/kg to be related to temperature through $u = 4.2T$, where T is in Kelvin, determine how long it takes for the temperature of the coffee to increase by 20°C.

SOLUTION

Since there is no movement of this system

(a) $$\frac{d\cancel{E}^{U}}{dt} = \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0};$$

$$\Rightarrow \frac{dE}{dt} = \frac{dU}{dt} = 0.1 \text{ kW}$$



(b) $$\frac{d\cancel{E}^{U}}{dt} = \cancel{\dot{J}_{\text{net}}}^{0} + \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0}; \quad \Rightarrow \frac{d(mu)}{dt} = \dot{Q}; \quad \Rightarrow \frac{du}{dt} = \frac{\dot{Q}}{m};$$

$$\Rightarrow \dot{u} = \frac{\dot{Q}}{m}; \quad \Rightarrow 4.2\dot{T} = \frac{\dot{Q}}{m}; \quad \Rightarrow 4.2\frac{\Delta T}{\Delta t} = \frac{\dot{Q}}{m};$$

$$\frac{dU}{dt} = 0.1 \text{ kW};$$

$$\frac{dU}{dt} = \frac{d(mu)}{dt}; \quad \Rightarrow \frac{dU}{dt} = m\frac{du}{dt}; \quad \Rightarrow \frac{dU}{dt} = m\frac{d(4.2T)}{dt}; \quad \Rightarrow \frac{dU}{dt} = (4.2)m\frac{dT}{dt};$$

$$\Rightarrow \frac{dT}{dt} = \frac{1}{(4.2)m}\frac{dU}{dt}; \quad \Rightarrow \frac{dT}{dt} = \frac{1}{(4.2)(0.2)}(0.1); \quad \Rightarrow \frac{dT}{dt} = \frac{1}{8.4}; \quad \left[\frac{\text{K}}{\text{s}}\right]$$

Therefore,

$$\Delta T = \frac{\Delta t}{8.4}; \quad [\text{K}]$$

$$\Rightarrow \Delta t = (20)(8.4); \quad \Rightarrow \Delta t = 168 \text{ s}$$

2-2-7 [NT] At a given instant a closed system is loosing 0.1 kW of heat to the outside atmosphere. A battery inside the system keeps it warm by powering a 0.1 kW internal heating lamp. A shaft transfers 0.1 kW of work into the system at the same time. Determine:

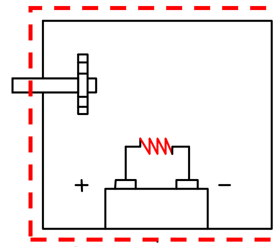
(a) the rate of external work transfer (include sign),

(b) the rate of heat transfer (include sign), and

(c) dE/dt of the system.

SOLUTION

Since the internal battery does not cross the boundary, shaft work and heat loss are the only energy transfers. Using appropriate signs (WinHip),



(a) $\dot{W}_{\text{ext}} = \dot{W}_{\text{sh}}; \quad \Rightarrow \dot{W}_{\text{ext}} = -0.1 \text{ kW}$

(b) $\dot{Q} = -0.1 \text{ kW}$

(c) $\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}; \quad \Rightarrow \frac{dE}{dt} = (-0.1) - (-0.1); \quad \Rightarrow \frac{dE}{dt} = 0 \text{ kW}$

2-2-8 [TR] A semi-truck of mass 20,000 lb accelerates from 0 to 75 m/h (1 m/h = 0.447 m/s) in 10 seconds. (a) What is the change in kinetic energy of the truck in 10 seconds? (b) If PE and *U* of the truck can be assumed constant, what is the average value of *dE/dt* of the truck in kW during this period? (c) If 30% of the heat released from the combustion of diesel (heating value of diesel is 40 MJ/kg) is converted to kinetic energy, determine the average rate of fuel consumption in kg/s.

SOLUTION

(a) $V_f = (75)(0.447); \qquad \Rightarrow V_f = 33.5\ \frac{\text{m}}{\text{s}};$

$$m = \frac{20{,}000}{2.2}; \qquad \Rightarrow m = 9072\ \text{kg};$$

$$\Delta\text{KE} = \frac{m\left(V_f^{\,2} - V_b^{\,2}\right)}{2000}; \qquad \Rightarrow \Delta\text{KE} = \frac{(9072)\left(33.5^2\right)}{2000}; \qquad \Rightarrow \Delta\text{KE} = 5098\ \text{kJ}$$

(b) $\frac{dE}{dt} = \frac{d(U + \text{KE} + \text{PE})}{dt}; \qquad \Rightarrow \frac{dE}{dt} = \cancel{\frac{dU}{dt}}^{0} + \frac{d(\text{KE})}{dt} + \cancel{\frac{d(\text{PE})}{dt}}^{0}; \qquad \Rightarrow \frac{dE}{dt} = \frac{d(\text{KE})}{dt};$

$$\Rightarrow \left(\frac{dE}{dt}\right)_{\text{avg}} = \left(\frac{d(\text{KE})}{dt}\right)_{\text{avg}}; \qquad \Rightarrow \left(\frac{dE}{dt}\right)_{\text{avg}} = \frac{\Delta\text{KE}}{\Delta t};$$

$$\Rightarrow \left(\frac{dE}{dt}\right)_{\text{avg}} = \frac{5098}{10}; \qquad \Rightarrow \left(\frac{dE}{dt}\right)_{\text{avg}} = 509.8\ \text{kW}$$

(c) Assuming the net heat transfer due to fuel burning goes entirely into increasing the KE of the truck,

$$\left(\frac{dE}{dt}\right)_{\text{avg}} = \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0}; \qquad \Rightarrow \left(\frac{dE}{dt}\right)_{\text{avg}} = \dot{Q}_{\text{in}} - \dot{Q}_{\text{out}};$$

$$\dot{Q}_{\text{in}} = \frac{1}{0.3}\frac{d(\text{KE})}{dt}; \qquad [\text{kW}]$$

$$\Rightarrow \dot{m}_F = \frac{\dot{Q}_{\text{in}}}{\text{Heating value}}; \qquad \Rightarrow \dot{m}_F = \frac{1}{0.3}\frac{d(\text{KE})}{dt}\frac{1}{40000};$$

$$\Rightarrow \dot{m}_F = \frac{509.8}{(0.3)(40000)}; \qquad \Rightarrow \dot{m}_F = 0.0425\ \frac{\text{kg}}{\text{s}}$$

TEST Solution:

Use the SL system state TESTcalc. Instructions and TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

2-2-9 [NY] An insulated tank contains 50 kg of water, which is stirred by a paddle wheel at 300 rpm while transmitting a torque of 0.1 kN-m. At the same time, an electric resistance heater inside the tank operates at 110 V, drawing a current of 2 A. Determine the rate of heat transfer after the system achieves steady state.

SOLUTION

$$\dot{W}_{\text{sh,in}} = 2\pi\dot{n}T; \quad \Rightarrow \dot{W}_{\text{sh,in}} = 2\pi(300/60)0.1; \quad \Rightarrow \dot{W}_{\text{sh,in}} = 3.1416 \text{ kW};$$

$$\dot{W}_{\text{el,in}} = \frac{VI}{1000}; \quad \Rightarrow \dot{W}_{\text{el,in}} = -\frac{(110)(2)}{1000}; \quad \Rightarrow \dot{W}_{\text{el,in}} = 0.220 \text{ kW};$$

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{Q} = \dot{W}_{\text{ext}}; \quad \Rightarrow \dot{Q} = \left(-\dot{W}_{\text{sh,in}}\right) + \left(-\dot{W}_{\text{el,in}}\right);$$

$$\dot{Q} = -3.1416 - 0.22; \quad \Rightarrow \dot{Q} = -3.3616 \text{ kW}$$

2-2-10 [NF] A drill rotates at 4000 rpm while transmitting a torque of 0.012 kN-m. Determine the rate of change of stored energy of the block initially.

SOLUTION

$$\frac{dE}{dt} = \cancel{\dot{Q}}^{0} - \dot{W}_{\text{ext}}; \quad \Rightarrow \frac{dE}{dt} = -\dot{W}_{\text{ext}}; \quad \Rightarrow \frac{dE}{dt} = -\left(-\dot{W}_{\text{sh,in}}\right);$$

$$\Rightarrow \frac{dE}{dt} = 2\pi \frac{4000}{60}(0.012); \quad \Rightarrow \frac{dE}{dt} = 5 \text{ kW}$$

2-2-11 [ND] A 20 kg slab of aluminum is raised by a rope and pulley, arranged vertically, at a constant speed of 10 m/min. At the same time the block absorbs solar radiation at a rate of 0.2 kW. Determine the rate of change of (a) potential energy (PE), (b) internal energy (U), and (c) stored energy (E).

SOLUTION

(a) $\frac{d}{dt}(\mathrm{PE}) = \frac{d}{dt}\left(\frac{mgz}{1000}\right); \quad \Rightarrow \frac{d}{dt}(\mathrm{PE}) = \frac{mg}{1000}\frac{dz}{dt}; \quad \Rightarrow \frac{d}{dt}(\mathrm{PE}) = \frac{(20)(9.81)}{1000}\left(\frac{10}{60}\right);$

$$\Rightarrow \frac{d}{dt}(\mathrm{PE}) = 0.0327 \text{ kW}$$

(b) $\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$

$$\Rightarrow \frac{dU}{dt} + \cancel{\frac{d}{dt}(\mathrm{KE})}^{0} + \frac{d}{dt}(\mathrm{PE}) = \dot{Q}_{\text{rad}} - \left(-\dot{W}_{\text{pull}}\right);$$

$$\Rightarrow \frac{dU}{dt} + \frac{d}{dt}(\mathrm{PE}) = \dot{Q}_{\text{rad}} - (-FV);$$

$$\Rightarrow \frac{dU}{dt} + \frac{d}{dt}(\mathrm{PE}) = \dot{Q}_{\text{rad}} + FV;$$

$$\Rightarrow \frac{dU}{dt} + \frac{d}{dt}(\mathrm{PE}) = \dot{Q}_{\text{rad}} + \frac{mg}{1000}V;$$

$$\Rightarrow \frac{dU}{dt} + 0.0327 = 0.2 + 0.0327;$$

$$\Rightarrow \frac{dU}{dt} = 0.2 \text{ kW}$$

(c) $\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}; \quad \Rightarrow \frac{dE}{dt} = \dot{Q}_{\text{rad}} + FV; \quad \Rightarrow \frac{dE}{dt} = 0.2 + 0.0327; \quad \Rightarrow \frac{dE}{dt} = 0.2327 \text{ kW}$

2-2-12 [NM] An external force F is applied to a rigid body of mass m. If its internal and potential energy remain unchanged, show that an energy balance on the body reproduces Newton's law of motion.

SOLUTION

We assume that there is no heat transfer.

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}}$$

$$\Rightarrow \cancel{\frac{dU}{dt}}^{0} + \frac{d}{dt}(\text{KE}) + \frac{d}{dt}(\text{PE}) = \cancel{\dot{Q}}^{0} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{d}{dt}(\text{KE}) + \cancel{\frac{d}{dt}(\text{PE})}^{0} = -\dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{d}{dt}(\text{KE}) = -(-FV);$$

$$\Rightarrow \frac{d}{dt}\left(\frac{mV^2}{2000}\right) = FV;$$

$$\Rightarrow \frac{m}{2000}\frac{dV^2}{dt} = FV;$$

$$\Rightarrow \frac{m}{2000}\frac{dV^2}{dV}\frac{dV}{dt} = FV;$$

$$\Rightarrow \frac{m}{2000}(2V)a = FV;$$

$$\Rightarrow \frac{ma}{1000} = F \qquad [\text{kN}]$$

$$\Rightarrow F = ma \qquad [\text{N}]$$

2-2-13 [NJ] An insulated block with a mass of 100 kg is acted upon by a horizontal force of 0.02 kN. Balanced by frictional forces, the body moves at a constant velocity of 2 m/s. Determine (a) the rate of change of stored energy in the system and (b) power transferred by the external force. (c) How do you account for the work performed by the external force?

SOLUTION

(a) $\frac{dE}{dt} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \dot{Q} - \dot{W}_{\text{ext}};$

For an insulated system with no mass transfer, the energy equation becomes

$$\frac{dE}{dt} = -\dot{W}_{\text{ext}}; \quad \Rightarrow \frac{dE}{dt} = -\left(-\dot{W}_{\text{in}} + \dot{W}_{\text{out,friction}}\right); \quad \Rightarrow \frac{dE}{dt} = \dot{W}_{\text{in}} - \dot{W}_{\text{out,friction}};$$

However, because the frictional force is equal to the applied force (to keep the body form accelerating) $\dot{W}_{\text{in}} = \dot{W}_{\text{out,friction}};$

Therefore,

$$\frac{dE}{dt} = \dot{W}_{\text{in}} - \dot{W}_{\text{out,friction}}; \quad \Rightarrow \frac{dE}{dt} = 0$$

(b) $\dot{W}_{\text{in}} = FV; \quad \Rightarrow \dot{W}_{\text{in}} = (0.02)(2); \quad \Rightarrow \dot{W}_{\text{in}} = 40 \text{ W}$

(c) The work done by the external force is transferred out of the system through frictional work. The frictional work is transferred to internal energy raising the temperature of the resisting material at the interface.

2-2-14 [NW] Do an energy analysis of a pendulum bob to show that the sum of its kinetic and potential energies remain constant. Assume internal energy to remain constant, neglect viscous friction and heat transfer. What-if Scenario: Discuss how the energy equation would be affected if viscous friction is not negligible.

SOLUTION

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \cancel{\frac{dU}{dt}}^{0} + \frac{d}{dt}(\text{KE}) + \frac{d}{dt}(\text{PE}) = \cancel{\dot{Q}}^{0} - \cancel{\dot{W}_{\text{ext}}}^{0};$$

$$\Rightarrow \frac{d}{dt}(\text{KE+PE}) = 0;$$

$$\Rightarrow \text{KE+PE} = \text{constant}$$

What-if Scenario:
Work done to overcome viscous friction would be a transfer of work from the pendulum to the surroundings, that is, $\dot{W}_{\text{ext}}$ must be negative.
Therefore, the sum of KE and PE would decrease over time

2-2-15 [ER] A rigid insulated tank contains 2 kg of a gas at 300 K and 100 kPa. A 1 kW internal heater is turned on. (a) Determine the rate of change of total stored energy (dE/dt). (b) If the internal energy of the gas is related to the temperature by u = 1.1T (kJ/kg), where T is in Kelvin, determine the rate of temperature increase.

SOLUTION

(a) With no mass or heat transfer

$$\frac{dE}{dt} = -\dot{W}_{ext}; \quad \Rightarrow \frac{dE}{dt} = -\left(-\dot{W}_{\text{el,in}}\right); \quad \Rightarrow \frac{dE}{dt} = -\left(-1\text{ kW}\right); \quad \Rightarrow \frac{dE}{dt} = 1\text{ kW}$$

(b) With no change in KE or PE

$$\frac{dE}{dt} = \frac{dU}{dt} = 1\text{ kW};$$

$$\Rightarrow \frac{dU}{dt} = \frac{d\left(mu\right)}{dt}; \quad \Rightarrow \frac{dU}{dt} = m\frac{du}{dt}; \quad \Rightarrow \frac{dU}{dt} = m\frac{d\left(1.1T\right)}{dt}; \quad \Rightarrow \frac{dU}{dt} = \left(1.1\right)m\frac{dT}{dt};$$

$$\Rightarrow \frac{dT}{dt} = \frac{1}{\left(1.1\right)m}\frac{dU}{dt}; \quad \Rightarrow \frac{dT}{dt} = \frac{1}{\left(1.1\right)\left(2\right)}\left(1\right); \quad \Rightarrow \frac{dT}{dt} = 0.455\ \frac{\text{K}}{\text{s}}$$

2-2-16 [EO] A 10 m^3 rigid tank contains air at 200 kPa and 150^{o}C. A 1 kW internal heater is turned on. Determine the rate of change of (a) stored energy (b) temperature and (c) pressure of air in the tank. Use the IG system state daemon. (Hint: Evaluate state-2 with stored energy incremented by the amount added in a small time interval, say, 0.1 s)

TEST Solution:

Let us evaluate two neighboring states, State-1 for the initial state and State-2 after a small interval, say 0.1 s.

Launch the IG system-state TESTcalc. Select air and evaluate State-1 from the given information. From State-2, m2=m1, Vol2=Vol1 (rigid tank). The energy equation for this closed system provides the missing property u2=u1+0.1/m1.

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{dU}{dt} + \cancelto{0}{\frac{d}{dt}(\text{KE})} + \cancelto{0}{\frac{d}{dt}(\text{PE})} = \cancelto{0}{\dot{Q}} - \left(-\dot{W}_{\text{el,in}}\right); \; [\text{kW}]$$

$$\Rightarrow dU = \dot{W}_{\text{el,in}} dt; \; [\text{kJ}]$$

$$\Rightarrow m du = \dot{W}_{\text{el,in}} dt;$$

$$\Rightarrow m \Delta u = \dot{W}_{\text{el,in}} \Delta t;$$

$$\Rightarrow u_2 - u_1 = \frac{\dot{W}_{\text{el,in}} \Delta t}{m}; \; \left[\frac{\text{kJ}}{\text{kg}}\right]$$

$$\Rightarrow u_2 = u_1 + \frac{\dot{W}_{\text{el,in}} \Delta t}{m};$$

$$\Rightarrow u_2 = u_1 + \frac{0.1}{m_1};$$

(a) In the I/O panel, evaluate =m1*(e2-e1)/0.1 = 1 kW

(b) In the I/O panel, evaluate =m1*(T2-T1)/0.1 = $0.0824 \ \frac{\text{K}}{\text{s}}$

(c) In the I/O panel, evaluate =m1*(p2-p1)/0.1 = $0.0389 \ \frac{\text{kPa}}{\text{s}}$

2-2-17 [EB] A 10 m^3 rigid tank contains steam with a quality of 0.5 at 200 kPa. A 1 MW internal heater is turned on. Determine the rate of change of (a) stored energy, (b) temperature and (c) pressure of steam in the tank. Use the PC system state daemon. (Hint: Evaluate state-2 with stored energy incremented by the amount added in a small time interval, say, 0.1 s)

TEST Solution:

Let us evaluate two neighboring states, State-1 for the initial state and State-2 after a small interval, say 0.1 s.

Launch the PC system-state TESTcalc. Select H2O and evaluate State-1 from the given information. From State-2, m2=m1, Vol2=Vol1 (rigid tank). The energy equation for this closed system provides the missing property u2=u1+0.1*1000/m1.

$$\frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{dU}{dt} + \cancel{\frac{d}{dt}(\text{KE})}^{0} + \cancel{\frac{d}{dt}(\text{PE})}^{0} = \cancel{\dot{Q}}^{0} - \left(-\dot{W}_{\text{el,in}}\right); \ [\text{kW}]$$

$$\Rightarrow dU = \dot{W}_{\text{el,in}} dt; \ [\text{kJ}]$$

$$\Rightarrow m du = \dot{W}_{\text{el,in}} dt;$$

$$\Rightarrow m \Delta u = \dot{W}_{\text{el,in}} \Delta t;$$

$$\Rightarrow u_2 - u_1 = \frac{\dot{W}_{\text{el,in}} \Delta t}{m}; \ \left[\frac{\text{kJ}}{\text{kg}}\right]$$

$$\Rightarrow u_2 = u_1 + \frac{\dot{W}_{\text{el,in}} \Delta t}{m} = u_1 + \frac{0.1}{m_1};$$

(a) In the I/O panel, evaluate =m1*(e2-e1)/0.1 = 1000 kW

(b) In the I/O panel, evaluate =m1*(T2-T1)/0.1 = 1.1 $\frac{\text{K}}{\text{s}}$

(c) In the I/O panel, evaluate =m1*(p2-p1)/0.1 = 5.16 $\frac{\text{kPa}}{\text{s}}$

2-2-18 [ES] A piston-cylinder device containing air at 200 kPa loses heat at a rate of 0.5 kW to the surrounding atmosphere. At a given instant, the piston which has a cross-sectional area of 0.01 m^2 moves down with a velocity of 1 cm/s. Determine the rate of change of stored energy in the gas.

SOLUTION

$$\frac{dE}{dt} = \underbrace{\sum \dot{m}_i j_i}_{0} - \underbrace{\sum \dot{m}_e j_e}_{0} + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - \left(-\dot{W}_{\text{B,in}}\right);$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} + p_i \frac{d\mathcal{V}}{dt};$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} + p_i A \frac{dx}{dt};$$

$$\Rightarrow \frac{dE}{dt} = -0.5 + (200)(0.01)(0.01);$$

$$\Rightarrow \frac{dE}{dt} = -0.48 \text{ kW}$$

2-2-19 [EA] A piston-cylinder device contains a gas, which is heated at a rate of 0.5 kW from an external source. At a given instant the piston, which has an area of 10 cm^2 moves up with a velocity of 1 cm/s. (a) Determine the rate of change of stored energy (dE/dt) in the gas. Assume atmospheric pressure to be 101 kPa and the piston to be weightless. Also, neglect friction. (b) What-if Scenario: How would the answer change if the piston were locked in its original position with a pin.

SOLUTION

(a) Since the piston is weightless, $p_i = p_0 = 101$ kPa

$$\frac{dE}{dt} = \underbrace{\sum \dot{m}_i j_i}_{0} - \underbrace{\sum \dot{m}_e j_e}_{0} + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{B}};$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - p_o \frac{d\Psi}{dt};$$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - p_0 A \frac{dx}{dt};$$

$$\Rightarrow \frac{dE}{dt} = 0.5 - (101)(0.001)(0.01);$$

$$\Rightarrow \frac{dE}{dt} = 0.499 \text{ kW}$$

(b) If the piston were locked in its initial position, then there would be no boundary work done by the system.

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - \underbrace{\dot{W}_{\text{B}}}_{0};$$

$$\Rightarrow \frac{dE}{dt} = 0.5 - 0;$$

$$\Rightarrow \frac{dE}{dt} = 0.5 \text{ kW}$$

2-2-20 [EH] A gas trapped in a piston-cylinder device is heated (as shown in figure of problem 2-2-19 [EA]) from an initial temperature of 300 K. The initial load on the massless piston of area 0.2 m^2 is such that the initial pressure of the gas is 200 kPa. When the temperature of the gas reaches 600 K, the piston velocity is measured as 0.5 m/s and dE/dt is measured as 30 kW. At that instant, determine

(a) the rate of external work transfer,

(b)the rate of heat transfer, and

(c) the load (in kg) on the piston at that instant. Assume the ambient atmospheric pressure to be 100 kPa.

SOLUTION

(a) $\dot{W}_{\text{ext}} = \dot{W}_{\text{B}}; \quad \Rightarrow \dot{W}_{\text{ext}} = pA\dfrac{dx}{dt}; \quad \Rightarrow \dot{W}_{\text{ext}} = (200)(0.2)(0.5); \quad \Rightarrow \dot{W}_{\text{ext}} = 20 \text{ kW}$

(b) $\dfrac{dE}{dt} = \underbrace{\sum \dot{m}_i j_i}_{0} - \underbrace{\sum \dot{m}_e j_e}_{0} + \dot{Q} - \dot{W}_{\text{ext}};$

$$\Rightarrow \frac{dE}{dt} = \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{Q} = \frac{dE}{dt} + \dot{W}_{\text{ext}}; \quad \Rightarrow \dot{Q} = 30 + 20; \quad \Rightarrow \dot{Q} = 50 \text{ kW}$$

(c) Force balance

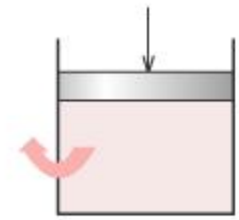
$$p_i A_p = p_o A_p + \frac{mg}{1000}; \quad [\text{kPa}]$$

$$\Rightarrow m = \frac{(1000)A_p\left(p_i - p_o\right)}{g}; \quad \Rightarrow m = \frac{0.2(200-100)(1000)}{9.81}; \quad \Rightarrow m = 2038.74 \text{ kg}$$

2-2-21 [EN] A piston-cylinder device is used to compress a gas by pushing the piston with an external force. During the compression process, heat is transferred out of the gas in such a manner that the stored energy in the gas remains unchanged. Also, the pressure is found to be inversely proportional to the volume of the gas. (a) Determine an expression for the heat transfer rate in terms of the instantaneous volume and the rate of change of pressure of the gas. (b) At a given instant, when the gas occupies a volume of 0.1 m3, the rate of change of pressure is found to be 1 kPa/s. Determine the rate of heat transfer.

SOLUTION

(a) $$\underbrace{\frac{dE}{dt}}_{0} = \underbrace{\sum \dot{m}_i j_i}_{0} - \underbrace{\sum \dot{m}_e j_e}_{0} + \dot{Q} - \dot{W}_{\text{ext}};$$



$$\Rightarrow \dot{Q} = \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{Q} = \dot{W}_{\text{B}};$$

$$\Rightarrow \dot{Q} = p_i \frac{dV}{dt};$$

Given $p_i \propto \frac{1}{V}$; $\quad \Rightarrow p_i V = \text{c};$

$$\Rightarrow \dot{Q} = p_i \frac{dV}{dt}; \qquad \Rightarrow \dot{Q} = p_i \frac{dV}{dt} + V\frac{dP_i}{dt} - V\frac{dP_i}{dt};$$

$$\Rightarrow \dot{Q} = \underbrace{\frac{d}{dt}\left(p_i V\right)}_{0 \text{ because } p_i V \text{ is constant}} - V\frac{dP_i}{dt};$$

$$\Rightarrow \dot{Q} = -V\frac{dp_i}{dt}$$

(b) $\dot{Q} = -V\frac{dp_i}{dt}$; $\quad \Rightarrow \dot{Q} = -(0.1)(1)$; $\quad \Rightarrow \dot{Q} = -0.1 \text{ kW}$

2-2-22 [EE] A fluid flows steadily through a long insulated pipeline. Perform a mass and energy analysis to show that the flow energy *j* remains unchanged between the inlet and exit. What-if Scenario: How would this conclusion be modified if kinetic and potential energy changes were negligible?

SOLUTION

(a) At steady state, the mass balance equation is simplified as

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

With no external work or heat transfer,

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

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

$$\Rightarrow j_i = j_e$$

(b) With no negligible changes in kinetic or potential energy, the energy equation can be further simplified as:

$$j_i = j_e;$$

$$\Rightarrow h_i + \text{ke}_i + \text{pe}_i = h_e + \text{ke}_e + \text{pe}_e;$$

$$\Rightarrow h_i = h_e + \cancel{\Delta(\text{ke})}^{0} + \cancel{\Delta(\text{pe})}^{0};$$

$$\Rightarrow h_i = h_e$$

2-2-23 [EI] Water enters a constant-diameter, insulated, horizontal pipe at 500 kPa. Due to the presence of viscous friction the pressure drops to 400 kPa at the exit. At steady state, determine the changes in (a) specific kinetic energy (ke) and (b) specific internal energy (u) between the inlet and the exit. Assume water density to be 1000 kg/m^3. Use the SL flow state daemon to verify the answer.

SOLUTION

(a) At steady state

$$\dot{m}_i = \dot{m}_e = \dot{m};$$
$$\Rightarrow \rho A V_i = \rho A V_e;$$
$$\Rightarrow V_i = V_e;$$
$$\Delta \text{ke} = \text{ke}_e - \text{ke}_i; \qquad \Rightarrow \Delta \text{ke} = \frac{V_e^2}{2000} - \frac{V_i^2}{2000}; \qquad \Rightarrow \Delta \text{ke} = 0$$

(b) With no external work or heat transfer,

$$\underbrace{\frac{dE}{dt}}_{0} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e \underbrace{+\dot{Q} - \dot{W}_{\text{ext}}}_{0};$$
$$\Rightarrow \cancel{\dot{m}} j_i = \cancel{\dot{m}} j_e; \qquad \Rightarrow j_i = j_e;$$
$$\Rightarrow h_i + \text{ke}_i + \text{pe}_i = h_e + \text{ke}_e + \text{pe}_e;$$
$$\Rightarrow (u_i + p_i v) + \cancel{ke_i} + \cancel{pe_i} = (u_e + p_e v) + \cancel{ke_e} + \cancel{pe_e};$$
$$\Rightarrow (u_i + p_i v) = (u_e + p_e v);$$
$$\Rightarrow u_e - u_i = p_i v - p_e v;$$
$$\Rightarrow \Delta u = p_i v - p_e v;$$
$$\Rightarrow \Delta u = (500)\left(\frac{1}{1000}\right) - (400)\left(\frac{1}{1000}\right); \qquad \Rightarrow \Delta u = 0.1 \ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the SL flow state TESTCalc. Evaluate the inlet state, State-1, assigning an arbitrary temperature, area, and mass flow rate. For the exit, State-2, use mdot2=mdot1, A2=A1, j2=j1 and p2 = 400 kPa. The velocities in the two states must be set as unknown and calculated as part of the states. Verify the answer by evaluating the expression = u2-u1 in the I/O panel. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-24 [EL] Water flows steadily through a variable diameter insulated pipe. At the inlet, the velocity is 20 m/s and at the exit, the flow area is half of the inlet area. If the internal energy of water remains constant, determine the change in pressure between the inlet and exit. Assume water density to be 1000 kg/m^3.

SOLUTION

At steady state

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

$$\Rightarrow \rho A V_i = \rho\left(\frac{1}{2}A\right)V_e; \qquad \Rightarrow V_i = \frac{1}{2}V_e; \qquad \Rightarrow V_e = 40\ \frac{\text{m}}{\text{s}};$$

At steady state, and with no external work or heat transfer,

$$\underbrace{\frac{dE}{dt}}_{0} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e \underbrace{+\dot{Q} - \dot{W}}_{0};$$

$$\Rightarrow \cancel{\dot{m}} j_i = \cancel{\dot{m}} j_e; \qquad \Rightarrow j_i = j_e;$$

$$\Rightarrow (u_i + p_i v) + ke_i + pe_i = (u_e + p_e v) + ke_e + pe_e;$$

With no change in potential energy,

$$\Rightarrow (u_i + p_i v) + ke_i = (u_e + p_e v) + ke_e;$$

With no change in internal energy,

$$\Rightarrow p_i v + \frac{V_i^2}{2000} = + p_e v + \frac{V_e^2}{2000}; \qquad \Rightarrow p_e - p_i = \frac{\left(\frac{V_i^2}{2000} - \frac{V_e^2}{2000}\right)}{v};$$

$$\Rightarrow \Delta p = \frac{\left(\frac{(20)^2}{2000} - \frac{(40)^2}{2000}\right)}{\left(\frac{1}{1000}\right)}; \Rightarrow \Delta p = -600\ \text{kPa}$$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state, State-1, from the given conditions and assigning an arbitrary temperature and area. For the exit, State-2, use mdot2=mdot1, A2=A1, j2=j1 and u2 = u1. The velocity at State-2 must be set as unknown to be calculated. Verify the answer by evaluating the expression = p2-p1 in the I/O panel. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-25 [EG] Oil enters a long insulated pipe at 200 kPa and 20 m/s. It exits at 175 kPa. Assuming steady flow, determine the changes in the following properties between the inlet and exit (a) *j*, (b) ke and (c) *h*. Assume oil density to be constant.

SOLUTION

(a) At steady state with no heat (insulated pipe) or external work transfer, the energy equation simplifies to:

$$\frac{dE}{dt} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \dot{Q} - \dot{W};$$

$$0 = \dot{m}_i j_i - \dot{m}_e j_e + 0 - 0;$$

$$\Rightarrow \dot{m} j_i = \dot{m} j_e;$$

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

(b) $\dot{m}_i = \dot{m}_e;$

$$\Rightarrow \rho A V_i = \rho A V_e;$$

$$\Rightarrow V_i = V_e;$$

$$\Delta \text{ke} = \text{ke}_e - \text{ke}_i; \qquad \Rightarrow \Delta \text{ke} = \frac{V_e^2}{2000} - \frac{V_i^2}{2000}; \qquad \Rightarrow \Delta \text{ke} = 0$$

(c) $\Delta j = (\Delta h + \Delta ke + \Delta pe); \qquad \Rightarrow 0 = (\Delta h + 0 + 0);$

$$\Delta h = 0$$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state, State-1, from the given conditions and assigning an arbitrary temperature and area. For the exit, State-2, use mdot2=mdot1, A2=A1, j2=j1 and p2 = 175 kPa. Note that while enthalpy remains unchanged the temperature (and internal energy) increases slightly. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-26 [EZ] Nitrogen gas flows steadily through a pipe of diameter 10 cm. The inlet conditions are as follows: pressure 400 kPa, temperature 300 K and velocity 20 m/s. At the exit the pressure is 350 kPa (due to frictional losses). If the flow rate of mass and flow energy remain constant, determine (a) the exit temperature and (b) exit velocity. Use the IG (ideal gas) flow state daemon. (c) What-if Scenario: What would the exit temperature be if kinetic energy were neglected?

TEST Solution:

Launch the IG flow-state TESTCalc. Evaluate the inlet state, State-1, from the given conditions. For the exit, State-2, use mdot2=mdot1, A2=A1, j2=j1 and the given pressure. For State-3 (what-if scenario), use h3=h1 instead of j3=j1. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

(a) T2 = 299.9 K

(b) Vel2 = $22.85\ \dfrac{\text{m}}{\text{s}}$

(c) T3 = 300 K

2-2-27 [EK] A 5 cm diameter pipe discharges water into the open atmosphere at a rate of 20 kg/s at an elevation of 20 m. The temperature of water is 25°C and the atmospheric pressure is 100 kPa. Determine (a) $\dot{J}$, (b) $\dot{E}$, (c) $\dot{KE}$, (d) $\dot{H}$ and (e) $\dot{W}_F$. (f) How important is the flow work transfer compared to kinetic and potential energy carried by the mass? Use the SL flow state daemon.

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the exit state from the given conditions. Calculate the desired quantities in the I/O panel. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

(a) mdot1*j1 = -317319.5 kW

(b) mdot1*el = -317321.5 kW

(c) mdot1*(Vel1*Vel1)/2000 = 1.0437 kW

(d) mdot1*h1 = -317324.47 kW

(e) p1*A1*Vel1 = 2.0 kW

The negative values for the energy transport terms are due to the way zero energy is defined in TEST. Just like potential energy can be negative, energy can be negative in a relative scale.

2-2-28 [EP] Water enters a pipe at 90 kPa, 25°C and a velocity of 10 m/s. At the exit the pressure is 500 kPa and velocity is 12 m/s while the temperature remains unchanged. If the volume flow rate is 10 m^3/min both at the inlet and exit, determine the difference of flow rate of energy (*J*) between the exit and inlet. What-if Scenario: What would the answer if the exit velocity were 15 m/s instead?

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet and exit states from the given conditions. Calculate the desired quantities in the I/O panel. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

(a) mdot2*(j2-j1) = 72 kW

(b) mdot2*(j2-j1) = 78.7 kW

The negative values for the energy transport terms are due to the way zero energy is defined in TEST. Just like potential energy can be negative, energy can be negative in a relative scale.

2-2-29 [EU] Water at 1000 kPa, 25°C enters a 1-m-diameter horizontal pipe with a steady velocity of 10 m/s. At the exit the pressure drops to 950 kPa due to viscous resistance. Assuming steady-state flow, determine the rate of heat transfer ($\dot{Q}$) necessary to maintain a constant specific internal energy (u).

SOLUTION

At steady state, the mass balance equation is simplified as

$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\Rightarrow \dot{m}_i = \dot{m}_e = \dot{m}; \qquad \Rightarrow \rho A V_i = \rho A V_e;$$

$$\Rightarrow V_i = V_e;$$

$$\Rightarrow \dot{m} = (1000)\left(\frac{\pi(1)^2}{4}\right)(10); \qquad \Rightarrow \dot{m} = 7854\ \frac{\text{kg}}{\text{s}};$$

$$\frac{dE}{dt} = \sum \dot{m} j_i - \sum \dot{m} j_e + \dot{Q} - \dot{W}_{\text{ext}};$$

With no external work, no change in ke or pe, at steady state,

$$\Rightarrow \dot{Q} = \dot{m}\left(j_e - j_i\right);$$

$$\Rightarrow \dot{Q} = \dot{m}\left[\left(u_e + p_e v + \text{ke}_e + \text{pe}_e\right) - \left(u_i + p_i v + \text{ke}_i + \text{pe}_i\right)\right];$$

$$\Rightarrow \dot{Q} = \dot{m}\left[\left(u_e - u_i\right) + p_e v - p_i v\right];$$

Since $u_e - u_i = \Delta u = 0$,

$$\Rightarrow \dot{Q} = \dot{m} v\left(p_e - p_i\right);$$

$$\Rightarrow \dot{Q} = (7854)\left(\frac{1}{1000}\right)(950 - 1000); \qquad \Rightarrow \dot{Q} = -392.7\ \text{kW}$$

TEST Solution:

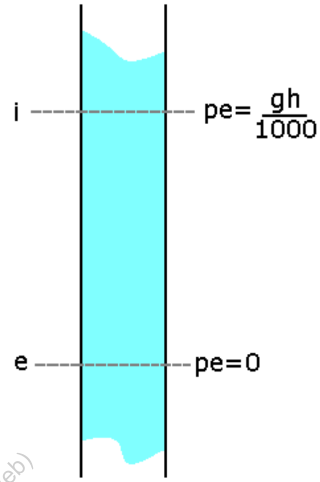
Launch the SL flow-state TESTCalc. Evaluate the inlet and exit states from the given conditions. Calculate =mdot1*(j2-j1) in the I/O panel to verify the manual result. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-30 [EX] An incompressible fluid (constant density) flows steadily downward along a constant-diameter, insulated vertical pipe. Assuming internal energy remains constant, show that the pressure variation is hydrostatic.

SOLUTION
SOLUTION

$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e; \qquad \Rightarrow \dot{m}_i = \dot{m}_e = \dot{m};$$

$$\Rightarrow \rho A V_i = \rho A V_e; \qquad \Rightarrow V_i = V_e; \qquad \Rightarrow \Delta \text{ke} = 0;$$



Steady state with no external work or heat transfer,

$$\underset{0}{\frac{dE}{dt}} = \sum \dot{m} j_i - \sum \dot{m} j_e \underbrace{+ \dot{Q} - \dot{W}}_{0}; \quad [\text{kW}]$$

$$\Rightarrow \cancel{\dot{m}} j_i = \cancel{\dot{m}} j_e;$$

$$\Rightarrow j_i = j_e; \quad \left[\frac{\text{kJ}}{\text{kg}} \right]$$

$$\Rightarrow u_i + p_i v + \text{pe}_i = u_e + p_e v + \text{pe}_e;$$

$$\Rightarrow (p_e - p_i) v = \cancel{(u_i - u_e)}^{0} + (\text{pe}_i - \text{pe}_e);$$

$$\Rightarrow (p_e - p_i) v = \frac{g(z_i - z_e)}{1000};$$

$$\Rightarrow (p_e - p_i) = \frac{\rho g (z_i - z_e)}{1000}; \quad [\text{kPa}]$$

The pressure variation is hydrostatic even in the presence of the flow. Note that the answer is independent of the direction of the flow.

TEST Solution:
Launch the SL flow-state TESTCalc. Evaluate an inlet state with arbitrary properties, say, 1000 kPa, 25 deg-C, 20 m/s, 50 m, and 0.1 m^2. At the exit, mdot1=mdot2, j2=j1, A2=A1. Let us assume z2=25 m. In the I/O panel, calculate the hydrostatic pressure difference 9.81*(z1-z2)*rho1/1000. It is exactly equal to p2-p1. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-31 [EC] An incompressible fluid (constant density) flows steadily through a converging nozzle. (a) Show that the specific flow energy remains constant if the nozzle is adiabatic. (b) Assuming internal energy remains constant and neglecting the inlet kinetic energy, obtain an expression for the exit velocity in terms of pressures at the inlet and exit and the fluid density. (c) For an inlet pressure of 300 kPa and exit pressure of 100 kPa, determine the exit velocity for a water nozzle.

SOLUTION

(a) $\underbrace{\frac{dE}{dt}}_{0} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \underbrace{\dot{Q}}_{0,\,Adiabadic} - \underbrace{\dot{W}_{\text{ext}}}_{0};$

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

At steady state, $\dot{m}_i = \dot{m}_e = \dot{m},$

$$\Rightarrow \cancel{\dot{m}} j_i = \cancel{\dot{m}} j_e;$$

$$\Rightarrow j_i = j_e$$

(b) With no changes in pe, constant v, and by negligible ke_i

$$\Rightarrow j_i = j_e; \qquad \Rightarrow h_i + \text{ke}_i = h_e + \text{ke}_e;$$

$$\Rightarrow u_i + p_i v = u_e + p_e v + \text{ke}_e;$$

$$\Rightarrow p_i v = (u_e - u_i) + p_e v + \frac{(V_e)^2}{2000};$$

Since $u_e - u_i = \Delta u = 0,$

$$\Rightarrow V_e = \sqrt{(2000)v(p_i - p_e)}$$

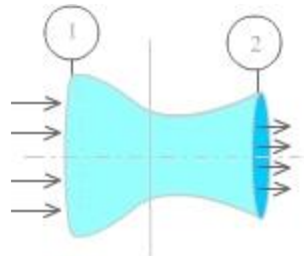
(c) $V_e = \sqrt{(2000)v(p_i - p_e)}; \quad \Rightarrow V_e = \sqrt{(2000)\left(\frac{1}{1000}\right)(300-100)}; \qquad \Rightarrow V_e = 20 \ \frac{\text{m}}{\text{s}}$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state for water for the given pressure and arbitrarily assumed mdot1, T1, and a very small Vel1 (say 0.1 m/s). At the exit, set u2 = u1, mdot2=mdot1, j2=j1, A2=A1. To see the effect of inlet ke on exit velocity, change Vel1 and click the Super-Calculate button. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-32 [EV] Water flows steadily through an insulated nozzle. The following data is supplied: Inlet: p = 200 kPa, V = 10 m/s, z = 2 m; Exit: p = 100 kPa, z = 0. (a) Determine the exit velocity. Assume density of water to be 1000 kg/m^3. Also assume the internal energy remains constant. What-if Scenario: What would the exit velocity be if (b) change in potential energy or (c) inlet kinetic energy were neglected in the analysis?

SOLUTION



(a) $$\underset{0}{\frac{dE}{dt}} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \underset{0,\,Adiabadic}{\dot{Q}} - \underset{0}{\dot{W}_{\text{ext}}};$$

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

At steady state, $\dot{m}_i = \dot{m}_e = \dot{m}$,

$$\Rightarrow \cancel{\dot{m}} j_i = \cancel{\dot{m}} j_e; \qquad \Rightarrow j_i = j_e;$$

$$\Rightarrow h_i + \text{ke}_i + \text{pe}_i = h_e + \text{ke}_e + \text{pe}_e;$$

$$\Rightarrow (u_i + p_i v) + \text{ke}_i + \text{pe}_i = (u_e + p_i v) + \text{ke}_e + \text{pe}_e;$$

Since $u_e - u_i = \Delta u = 0$,

$$\Rightarrow \text{ke}_e = \frac{(V_e)^2}{2000} = p_i v + \text{ke}_i + \text{pe}_i - p_i v - \text{pe}_e;$$

$$\Rightarrow V_e = \sqrt{(2000)(p_i v + \text{ke}_i + \text{pe}_i - p_i v - \text{pe}_e)};$$

$$\Rightarrow V_e = \sqrt{(2000)\left(\frac{200}{1000} + \frac{(10)^2}{2000} + \frac{(9.81)(2)}{1000} - \frac{100}{1000} - \frac{(9.81)(0)}{1000}\right)}; \qquad \Rightarrow V_e = 18.42\ \frac{\text{m}}{\text{s}}$$

(b) $$V_e = \sqrt{(2000)\left(p_i v + \text{ke}_i - \underset{0}{\Delta\text{pe}} - p_i v\right)}; \qquad \Rightarrow v_e = \sqrt{(2000)(p_i v + \text{ke}_i - p_i v)};$$

$$\Rightarrow v_e = \sqrt{(2000)\left(\frac{200}{1000} + \frac{(10)^2}{2000} - \frac{100}{1000}\right)}; \qquad \Rightarrow v_e = 17.32\ \frac{\text{m}}{\text{s}}$$

(c) $$v_e = \sqrt{(2000)\left(p_i v + \underset{0}{\text{ke}_i} + pe_i - p_i v - \text{pe}_e\right)};$$

$$\Rightarrow v_e = \sqrt{(2000)\left(\frac{200}{1000} + \frac{(9.81)(2)}{1000} - \frac{100}{1000} - \frac{(9.81)(0)}{1000}\right)};$$

$$\Rightarrow v_e = 15.47\ \frac{\text{m}}{\text{s}}$$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state for water for the given pressure and arbitrarily assumed mdot1 and T1. At the exit, set u2 = u1, mdot2=mdot1, j2=j1, A2=A1. To see the effect of inlet ke on exit pe, change Vel1 or z1 to a small value and click the Super-Calculate button. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-33 [BNW] Water flowing steadily through a 2 cm diameter pipe at 30 m/s goes through an expansion joint to flow through a 4 cm diameter pipe. Assuming the internal energy remains constant, determine (a) the change in pressure as the water goes through the transition. (b) Also determine the displacement of a mercury column in mm for this change in pressure. Assume water density to be 997 kg/m^3.

SOLUTION

(a) $A_i = \pi \dfrac{(0.02)^2}{4}; \qquad \Rightarrow A_i = 0.000314 \text{ m}^2;$

$$A_e = \pi \frac{(0.02)^2}{4}; \qquad \Rightarrow A_e = 0.001257 \text{ m}^2;$$

At steady state $\dot{m}_i = \dot{m}_e;$

$$\Rightarrow \rho A_i V_i = \rho A_e V_e;$$

$$\Rightarrow V_e = \frac{\rho A_i}{\rho A_e} V_i; \qquad \Rightarrow V_e = \frac{A_i}{A_e} V_i; \qquad \Rightarrow V_e = \frac{0.000314}{0.001257}(30); \qquad \Rightarrow V_e = 7.5 \ \frac{\text{m}}{\text{s}};$$

At steady state, and with no external work or heat transfer,

$$\underbrace{\frac{dE}{dt}}_{0} = \sum \dot{m} j_i - \sum \dot{m} j_e \underbrace{+\dot{Q} - \dot{W}}_{0};$$

$$\Rightarrow \cancel{\dot{m}} j_i = \cancel{\dot{m}} j_e; \qquad \Rightarrow j_i = j_e; \qquad \Rightarrow h_i + \text{ke}_i + \text{pe}_i = h_e + \text{ke}_e + \text{pe}_e;$$

With $\Delta u = 0$ and $\Delta \text{pe} = 0$, the specific flow energy balance equation becomes

$$\Rightarrow p_i v + \text{ke}_i = p_e v + \text{ke}_e;$$

$$\Rightarrow p_e - p_i = \frac{(\text{ke}_i - \text{ke}_e)}{v};$$

$$\Rightarrow \Delta p = \rho \left(\frac{(V_i)^2}{2000} - \frac{(V_e)^2}{2000} \right);$$

$$\Rightarrow \Delta p = (997) \left(\frac{(30)^2}{2000} - \frac{(7.5)^2}{2000} \right); \qquad \Rightarrow \Delta p = 420.61 \text{ kPa}$$

(b) Using $1 \text{ kPa} \approx 7.5 \text{ mmHg}$

$$\Delta p_{\text{mmHg}} = (420.61 \text{ kPa}) \left(7.5 \frac{\text{mmHg}}{\text{kPa}} \right); \qquad \Rightarrow \Delta p_{\text{mmHg}} = 3154.58 \text{ mmHg}$$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state for water for the given velocity and flow area and arbitrarily assumed p1 and T1 (100 kPa and 25 °C). At the exit, set u2 = u1, mdot2=mdot1, j2=j1, and known area. The increase in pressure can be calculated in the I/O panel from =p2-p1. Verify that the answer is independent of the inlet pressure or temperature. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-34 [ET] An adiabatic work producing device works at steady state with the working fluid entering through a single inlet and leaving through a single exit. Derive an expression for the work output in terms of the flow properties at the inlet and exit. What-if Scenario: How would the expression for work simplify if changes in ke and pe were neglected?

SOLUTION

(a) The energy balance equation is given as

$$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \underbrace{\dot{Q}}_{0,\text{Adiabadic}} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}_i j_i - \dot{m}_e j_e;$$

At steady state, $\dot{m}_i = \dot{m}_e = \dot{m},$

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(u_i + p_i v + pe_i + ke_i\right) - \left(u_e + p_e v + pe_e + ke_e\right)\right]$$

(b) What-if Scenario: With no changes in *ke* or *pe*,

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i + \text{ke}_i + \text{pe}_i\right) - \left(h_e + \text{ke}_e + \text{pe}_e\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i - h_e\right) - \Delta\text{ke} - \Delta\text{pe}\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_i - h_e\right)$$

2-2-35 [EY] A pump is a device that raises the pressure of a liquid at the expense of external work. (a) Determine the pumping power necessary to raise the pressure of liquid water from 10 kPa to 2000 kPa at a flow rate of 1000 L/min. Assume density of water to be 1000 kg/m3 and neglect changes in specific internal, kinetic and potential energies. (b) What-if Scenario: What would the pumping power be if pe were not negligible and z_1 = -10, z_2 = 0?

SOLUTION

(a) At steady state, $\dot{m}_i = \dot{m}_e = \dot{m}$,

$$\dot{m} = \left(1000\ \frac{\text{L}}{\text{min}}\right)\left(0.001\ \frac{\text{m}^3}{\text{L}}\right)\left(1000\ \frac{\text{kg}}{\text{m}^3}\right)\left(\frac{1}{60}\ \frac{\text{min}}{\text{s}}\right); \qquad \Rightarrow \dot{m} = 16.\overline{6}\ \frac{\text{kg}}{\text{s}};$$

$$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m}j_i - \sum \dot{m}j_e + \underbrace{\dot{Q}}_{0} - \dot{W}_{\text{ext}};$$

The energy equation becomes

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

By neglecting changes in ke and pe,

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_i - h_e\right); \qquad \Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(u_i + p_i v\right) - \left(u_e + p_e v\right)\right];$$

By neglecting changes in specific internal energy

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}v\left(p_i - p_e\right); \qquad \Rightarrow \dot{W}_{\text{ext}} = \frac{\dot{m}}{\rho}\left(p_i - p_e\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \frac{16.\overline{6}}{1000}\left(10 - 2000\right); \qquad \Rightarrow \dot{W}_{\text{ext}} = -33.17\ \text{kW};$$

The negative sign implies that the work is transferred into the system. The pumping power is the magnitude of that work transfer: $\dot{W}_{\text{P}} = -\dot{W}_{\text{ext}} = 33.17\ \text{kW}$.

(b) By including the changes in pe, the expression for work becomes

$$\dot{W}_{\text{ext}} = \dot{m}\left[\left(p_i v + \frac{gz_i}{1000}\right) - \left(p_e v + \frac{gz_e}{1000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = \left(16.\overline{6}\right)\left[\left(\frac{10}{1000} + \frac{(9.81)(-10)}{1000}\right) - \left(\frac{2000}{1000} + \frac{(9.81)(0)}{1000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = -34.8\ \text{kW};$$

$$\Rightarrow \dot{W}_{\text{pump}} = 34.8\ \text{kW}$$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state for water for the given volume flow rate, pressure and an arbitrarily assumed T1 (25 deg-C). At the exit, set p2, u2 = u1, mdot2=mdot1, and let Vel2 and z2 be at their default zero values. Calculate the pumping power in the I/O panel from = mdot1*(j2-j1). For the second part, change z2, calculate State-2 again, and evaluate the pumping power in the I/O panel. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-36 [EF] An adiabatic pump working at steady state raises the pressure of water from 100 kPa to 1 MPa, while the specific internal energy (u) remains constant. If the exit is 10 m above the inlet and the flow rate of water is 100 kg/s, (a) determine the pumping power. Neglect any change in kinetic energy (ke). Assume density of water to be 997 kg/m^3. (b) What-if Scenario: What would the pumping power be if any change in potential energy (pe) were also neglected?

SOLUTION

(a) At steady state, $\dot{m}_i = \dot{m}_e = \dot{m} = 100 \ \frac{\text{kg}}{\text{s}}$;

$$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m} j_i - \sum \dot{m} j_e + \underbrace{\dot{Q}}_{0} - \dot{W}_{\text{ext}};$$

The energy equation becomes

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}(j_i - j_e); \qquad \Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[(u_i + p_i v + ke_i + pe_i) - (u_e + p_e v + ke_e + pe_e)\right];$$

By neglecting changes in ke,

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[(u_i + p_i v + \text{pe}_i) - (u_e + p_e v + \text{pe}_e)\right]; \qquad \Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[(p_i v + \text{pe}_i) - (p_e v + \text{pe}_e)\right];$$

By choosing to reference pe from state e,

$$\Rightarrow \dot{W}_{\text{ext}} = (100)\left[\left(\frac{100}{997} + \frac{(9.81)(0)}{1000}\right) - \left(\frac{1000}{997} + \frac{(9.81)(10)}{1000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = -100.1 \text{ kW}; \text{ (WinHip: negative means work is going in)}$$

$$\Rightarrow \dot{W}_{\text{P}} = -\dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{P}} = 100.1 \text{ kW} \text{ (Pumping power is positive with an obvious direction of work transfer)}$$

(b) By neglecting changes in pe, the expression for $\dot{W}_{ext}$ becomes

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m} v (p_i - p_e); \qquad \Rightarrow \dot{W}_{\text{ext}} = \frac{\dot{m}}{\rho}(p_i - p_e);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \frac{100}{997}(100 - 1000); \qquad \Rightarrow \dot{W}_{\text{P}} = -\dot{W}_{\text{ext}}; \qquad \Rightarrow \dot{W}_{\text{P}} = 90.3 \text{ kW}$$

TEST Solution:

Launch the SL flow-state TESTCalc. Evaluate the inlet state for water for the given volume flow rate, pressure and an arbitrarily assumed T1 (25 deg-C). At the exit, set p2, z2, u2 = u1, mdot2=mdot1, and let Vel2 be at its default zero value. Calculate the pumping power in the I/O panel from = mdot1*(j2-j1). For the second part, change z2, calculate State-2 again, and evaluate the pumping power in the I/O panel. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-37 [ED] Steam flows steadily through a single-flow device with a flow rate of 10 kg/s. It enters with an enthalpy of 3698 kJ/kg and a velocity of 30 m/s. At the exit, the corresponding values are 3368 kJ/kg and 20 m/s respectively. If the rate of heat loss from the device is measured as 100 kW, (a) determine the rate of work transfer. Neglect any change in potential energy. (b) What-if Scenario: What would the rate of work transfer be if the change in kinetic energy were also neglected?

SOLUTION

(a) At steady state, $\dot{m}_i = \dot{m}_e = \dot{m} = 10 \ \frac{\text{kg}}{\text{s}};$

$$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m} j_i - \sum \dot{m} j_e + \dot{Q} - \dot{W}_{\text{ext}};$$

The energy equation becomes

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(j_i - j_e\right) + \dot{Q};$$

With no change in potential energy

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i + \text{ke}_i\right) - \left(h_e + \text{ke}_e\right)\right] + \dot{Q};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i + \frac{(V_i)^2}{2000}\right) - \left(h_e + \frac{(V_e)^2}{2000}\right)\right] + \dot{Q};$$

$$\Rightarrow \dot{W}_{\text{ext}} = (10)\left[\left(3698 + \frac{(30)^2}{2000}\right) - \left(3368 + \frac{(20)^2}{2000}\right)\right] - 100;$$

$$\Rightarrow \dot{W}_{\text{ext}} = 3202.5 \text{ kW}$$

(b) With no change in kinetic energy, the expression for $\dot{W}_{\text{ext}}$ becomes

$$\dot{W}_{\text{ext}} = \dot{m}\left(h_i - h_e\right) + \dot{Q};$$

$$\Rightarrow \dot{W}_{\text{ext}} = (10)(3698 - 3368) + 100; \qquad \Rightarrow \dot{W}_{\text{ext}} = 3200 \text{ kW}$$

TEST Solution:

Launch the PC flow-state TESTCalc. Evaluate the inlet and exit states, State-1 and State-2, from the given conditions. In the I/O panel, calculate the external work transfer as =mdot1*(j2-j1) - 100. The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-38 [EM] Steam enters an adiabatic turbine with a mass flow rate of 5 kg/s at 3 MPa, 600°C and 80 m/s. It exits the turbine at 40°C, 30 m/s and a quality of 0.9. Assuming steady-state operation, determine the shaft power produced by the turbine. Use the PC flow- state daemon to evaluate enthalpies at the inlet and exit.

SOLUTION

(a) At steady state, $\dot{m}_i = \dot{m}_e = \dot{m} = 5\ \dfrac{\text{kg}}{\text{s}}$;

$$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m}j_i - \sum \dot{m}j_e + \cancel{\dot{Q}}^{0} - \dot{W}_{\text{ext}};$$

The energy equation becomes

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

Neglecting any change in potential energy

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i + \text{ke}_i\right) - \left(h_e + \text{ke}_e\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i + \frac{(V_i)^2}{2000}\right) - \left(h_e + \frac{(V_e)^2}{2000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = (5)\left[\left(3682 + \frac{(80)^2}{2000}\right) - \left(2334 + \frac{(30)^2}{2000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = 6757\ \text{kW}$$

(b) With no change in kinetic energy, the expression for $\dot{W}_{\text{ext}}$ becomes

$$\dot{W}_{\text{ext}} = \dot{m}\left(h_i - h_e\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = (10)(3682 - 2334); \qquad \Rightarrow \dot{W}_{\text{ext}} = 6743.5\ \text{kW}$$

TEST Solution:

Launch the PC flow-state TESTCalc. Evaluate the inlet and exit states, State-1 and State-2, from the given conditions. In the I/O panel, calculate the external work transfer as =mdot1*(j2-j1). When ke is negligible, the external work is =mdot1*(h2-h1). The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

2-2-39 [EJ] A gas enters an adiabatic work consuming device at 300 K, 20 m/s, and leaves at 500 K, 40 m/s. (a) If the mass flow rate is 5 kg/s, determine the rate of work transfer. Neglect change in potential energy and assume the specific enthalpy of the gas to be related to its temperature in K through h = 1.005T. (b) What-if Scenario: By what percent would the answer change if the change in kinetic energy were also neglected?

SOLUTION

(a) At steady state, $\dot{m}_i = \dot{m}_e = \dot{m} = 5 \ \dfrac{\text{kg}}{\text{s}}$;

$$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m}j_i - \sum \dot{m}j_e + \underbrace{\dot{Q}}_{0,\text{ Adiabatic}} - \dot{W}_{\text{ext}};$$

The energy equation becomes

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

With no change in potential energy

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(h_i + \text{ke}_i\right) - \left(h_e + \text{ke}_e\right)\right];$$

Given: $h = 1.005T$;

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[\left(1.005T_i + \frac{(V_i)^2}{2000}\right) - \left(1.005T_e + \frac{(V_e)^2}{2000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = (5)\left[\left(1.005(300) + \frac{(20)^2}{2000}\right) - \left(1.005(500) + \frac{(40)^2}{2000}\right)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = -1008 \text{ kW}$$

(b) With change in kinetic energy neglected,

$$\dot{W}_{\text{ext}} = \dot{m}\left(h_i - h_e\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(1.005T_i - 1.005T_e\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = (5)\left(1.005(300) - 1.005(500)\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = -1005 \text{ kW};$$

The percent change is given as:

$$\Rightarrow \frac{(-1008) - (-1005)}{-1008}(100) = 0.3\ \%$$

TEST Solution:

In the PG model (Chapter 3) enthalpy change is proportional to temperature change and the constant of proportionality is called c_p. Launch the PG flow-state TESTCalc and select 'Custom'. Evaluate the inlet and exit states, State-1 and State-2, from the given conditions and using c_p = 1.005 for each state. In the I/O panel, calculate the external work transfer as =mdot1*(j2-j1). When ke is negligible, the external work is

=mdot1*(h2-h1). The TEST-code for this problem can be found in the TEST-pro website at www.thermofliuds.net.

xxx2-2-40 [EW] A refrigerant is compressed by an adiabatic compressor operating at steady state to raise the pressure from 200 kPa to 750 kPa. The following data are supplied for the inlet and exit ports. Inlet: $v = 0.0835$ m^3/kg, $h = 182.1$ kJ/kg, $V = 30$ m/s; Exit: $v = 0.0244$ m^3/kg, $h = 205.4$ kJ/kg, $V = 40$ m/s. If the volume flow rate at the inlet is 3000 L/min, determine (a) the mass flow rate, (b) the volume flow rate at the exit and (c) the compressor power. (d) What-if Scenario: What would the power consumption be if the change in kinetic energy were neglected?

SOLUTION

(a) $$\dot{V} = \left(3000\ \frac{\text{L}}{\text{min}}\right)\left(\frac{1}{1000}\ \frac{\text{m}^3}{\text{L}}\right)\left(\frac{1}{60}\ \frac{\text{min}}{\text{s}}\right); \qquad \Rightarrow \dot{V} = 0.05\ \frac{\text{m}^3}{\text{s}};$$

$$\dot{m}_i = \frac{\dot{V}_i}{v_i}; \qquad \Rightarrow \dot{m}_i = \frac{0.05}{0.0835}; \qquad \Rightarrow \dot{m}_i = 0.598\ \frac{\text{kg}}{\text{s}}$$

(b) At steady state

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

$$\dot{V}_e = \dot{m} v_e; \qquad \Rightarrow \dot{V}_e = (0.598)(0.0244); \qquad \Rightarrow \dot{V}_e = 0.0146\ \frac{\text{m}^3}{\text{s}};$$

$$\Rightarrow \dot{V}_e = 876\ \frac{\text{L}}{\text{min}}$$

(c) $$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m}_i j_i - \sum \dot{m}_e j_e + \underbrace{\dot{Q}}_{0,\text{ Adiabatic}} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}(j_i - j_e);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left[(h_i + \text{ke}_i) - (h_e + \text{ke}_e)\right];$$

$$\Rightarrow \dot{W}_{\text{ext}} = (0.598)\left[\left(182.1 + \frac{(30)^2}{2000}\right) - \left(205.4 + \frac{(40)^2}{2000}\right)\right]; \qquad \Rightarrow \dot{W}_{\text{ext}} = -14.2\ \text{kW};$$

While the external work transfer is negative, indicating work going in (WinHip), the compressor power automatically implies energy consumption and a sign is not necessary.

$$\Rightarrow \dot{W}_{\text{C}} = -\dot{W}_{\text{ext}} = 14.2\ \text{kW}$$

(d) With no change in ke, the external work can be calculated as

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}(h_i - h_e);$$

$$\Rightarrow \dot{W}_{\text{ext}} = (0.598)(182.1 - 205.4); \qquad \Rightarrow \dot{W}_{\text{ext}} = -14\ \text{kW}$$

$$\Rightarrow \dot{W}_{\text{C}} = -\dot{W}_{\text{ext}} = 14\ \text{kW}$$

TEST Solution:

Because the identity of the fluid is not known, a TEST solution is not possible.

2-2-41 [IR] Two flows of equal mass flow rate, one at state-1 and another at state-2 enter an adiabatic mixing chamber and leave through a single port at state-3. Obtain an expression for the velocity and specific enthalpy at the exit. Assume negligible changes in ke and pe.

SOLUTION

At steady state

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

(a) Where $\dot{m}_1 + \dot{m}_2 = \dot{m}_i$ and $\dot{m}_3 = \dot{m}_e$;

$$\Rightarrow \dot{m}_3 = \rho A_3 v_3 = 2\dot{m};$$

$$\Rightarrow v_3 = \frac{2\dot{m}}{\rho A_3}$$

(b) $$\underbrace{\frac{dE}{dt}}_{0,\text{Steady State}} = \sum \dot{m} j_i - \sum \dot{m} j_e + \underbrace{\dot{Q}}_{0,\text{ Adiabatic}} - \underbrace{\dot{W}_{\text{ext}}}_{0};$$

The energy equation becomes

$$\Rightarrow \dot{m}_3 j_3 = \dot{m}_1 j_1 + \dot{m}_2 j_2;$$

Since $\dot{m}_1 = \dot{m}_2$

$$\Rightarrow \dot{m} j_3 = \frac{\dot{m}}{2} j_1 + \frac{\dot{m}}{2} j_2;$$

$$\Rightarrow j_3 = (0.5)(j_1 + j_2);$$

With no changes in *ke* or *pe*

$$\Rightarrow h_3 = (0.5)(h_1 + h_2)$$

2-2-42 [IO] Air at 500 kPa, 30°C from a supply line is used to fill an adiabatic tank. At a particular moment during the filling process, the tank contains 0.2 kg of air at 200 kPa and 50°C. If the mass flow rate is 0.1 kg/s, and the specific enthalpy of air at the inlet is 297.2 kJ/kg, determine (a) the rate of flow energy into the tank, (b) the rate of increase of internal energy in the tank and (c) the rate of increase of specific internal energy if the specific internal energy in the tank is 224.5 kJ/kg at that instant. Assume the tank to be uniform at all times and neglect kinetic and potential energies.

SOLUTION

(a) Neglecting the ke and pe:

$$\dot{J}_i = \dot{m}_i j_i; \qquad \Rightarrow \dot{J}_i = \dot{m}_i h_i; \qquad \Rightarrow \dot{J}_i = (0.1)(297.2); \qquad \Rightarrow \dot{J}_i = 29.72 \text{ kW}$$

(b) The energy equation is given as:

$$\frac{dE}{dt} = \sum \dot{m}_i j_i - \underbrace{\sum \dot{m}_e j_e}_{0} + \underbrace{\dot{Q}}_{0,\text{ Adiabatic}} - \underbrace{\dot{W}_{\text{ext}}}_{0};$$

$$\Rightarrow \frac{dE}{dt} = \dot{m}_i j_i; \qquad \Rightarrow \frac{dE}{dt} = \dot{m}_i h_i; \qquad \Rightarrow \frac{dE}{dt} = (0.1)(297.2); \qquad \Rightarrow \frac{dE}{dt} = 29.72 \text{ kW};$$

$$\Rightarrow \frac{d(U + \text{KE} + \text{PE})}{dt} = 29.72 \text{ kW};$$

$$\Rightarrow \frac{dU}{dt} = 29.72 \text{ kW}$$

(c) $\frac{dU}{dt} = 29.72 \text{ kW};$

$$\Rightarrow \frac{d(mu)}{dt} = 29.72 \text{ kW};$$

$$\Rightarrow m\frac{du}{dt} + u\frac{dm}{dt} = 29.72 \text{ kW};$$

$$\Rightarrow m\frac{du}{dt} = 29.72 - (224.5)(0.1); \qquad \Rightarrow m\frac{du}{dt} = 7.27 \text{ kW};$$

$$\Rightarrow \frac{du}{dt} = \frac{7.27}{0.2}; \qquad \Rightarrow \frac{du}{dt} = 36.35 \frac{\text{kW}}{\text{kg}}$$

2-2-43 [IB] An insulated tank is being filled with a gas through a single inlet. At a given instant, the mass flow rate is measured as 0.5 kg/s and the enthalpy h as 400 kJ/kg. Negleting ke and pe, determine the rate of increase of stored energy in the system at that instant.

SOLUTION

The energy equation is given as:

$$\frac{dE}{dt} = \sum \dot{m}_i j_i - \underbrace{\sum \dot{m}_e j_e}_{0} + \underbrace{\dot{Q}}_{0,\text{ Adiabatic}} - \underbrace{\dot{W}_{\text{ext}}}_{0};$$

$$\Rightarrow \frac{dE}{dt} = \dot{m}_i j_i; \qquad \Rightarrow \frac{dE}{dt} = \dot{m}_i h_i; \qquad \Rightarrow \frac{dE}{dt} = (0.5)(400); \qquad \Rightarrow \frac{dE}{dt} = 200 \text{ kW}$$

2-2-44 [IS] Saturated steam at 200 kPa, which has a specific enthalpy (h) of 2707 kJ/kg is expelled from a pressure cooker at a rate of 0.1 kg/s. Determine the rate of heat transfer necessary to maintain a constant stored energy E in the cooker. Assume that there is sufficient liquid water in the cooker at all time to generate the saturated steam. Neglect kinetic and potential energy of the steam.

SOLUTION

The energy equation is given as:

$$\underset{0}{\frac{dE}{dt}} = \underbrace{\sum \dot{m}_i j_i}_{0} - \sum \dot{m}_e j_e + \dot{Q} - \underset{0}{\dot{W}_{\text{ext}}};$$

$$\Rightarrow \dot{Q} = \dot{m}_e j_e;$$

With no changes in ke or pe:

$$\Rightarrow \dot{Q} = \dot{m}_e h_e; \qquad \Rightarrow \dot{Q} = (0.1)(2707);$$

$$\Rightarrow \dot{Q} = 270.7 \text{ kW}$$

The positive sign indicates that heat must be added.