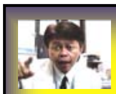

Thermodynamics Lecture Series

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First Law – Control Volume

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First Law - Quotes

Quote

"Education is not the piling on of learning, information, data, facts, skills, or abilities--that's training or instruction--but is rather a making visible what is hidden as a seed... To be educated, a person doesn't have to know much or be informed, but he or she does have to have been exposed vulnerably to the transformative events of an engaged human life... One of the greatest problems of our time is that many are schooled but few are educated."

Author:Thomas Moore
Source:he Education of the Heart by Thomas Moore

Introduction - Objectives

Objectives:

1. *State the conservation of mass principle.*
2. *State the meaning of steady-flow process and the implications on a system's properties.*
3. *Write the unit-mass basis and unit-time basis (or rate-form basis) energy balance for a general steady-flow process.*
4. *Write the unit-time basis (or rate-form basis) mass balance for a general steady-flow process.*

Introduction - Objectives

Objectives:

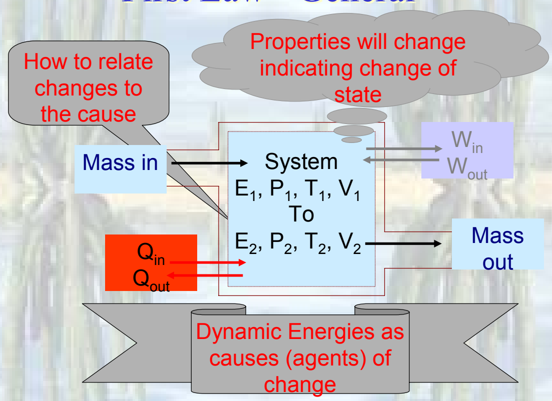
4. *State the assumptions for steady-flow devices such as nozzles, diffusers, turbines, compressors, throttle valves, heat exchangers and mixing chambers.*
5. *State the purpose for each of the steady-flow device noted above.*
6. *Write the unit-mass basis and unit-time basis (or rate-form basis) energy balance for each of the steady-flow devices noted above*

Introduction - Objectives

Objectives:

7. *Write the unit-time basis (or rate-form basis) mass balance for each of the steady-flow device.*
8. *Use the energy and mass balance to solve problems related to each of the steady-flow device.*

First Law - General



First Law – Energy Balance

Energy Entering a system	-	Energy Leaving a system	=	Change of system's energy

Energy Balance

Amount of **energy causing change** must be equal to amount of **energy change** of system

First Law – Energy Balance

Energy Entering a system	-	Energy Leaving a system	=	Change of system's energy

Energy Balance

$E_{in} - E_{out} = \Delta E_{sys}$, kJ or

$e_{in} - e_{out} = \Delta e_{sys}$, kJ/kg or

$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys}, kW$

First Law – Energy Balance

Energy Balance – General system

$Q_{in} - Q_{out} + W_{in} - W_{out} + E_{mass,in} - E_{mass,out}$
$= \Delta U + \Delta KE + \Delta PE$, kJ

$q_{in} - q_{out} + \omega_{in} - \omega_{out} + \theta_{in} - \theta_{out}$
$= \Delta u + \Delta ke + \Delta pe$, kJ/kg

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} + \dot{E}_{mass,in} - \dot{E}_{mass,out}$$
$$= \Delta \dot{U} + \Delta \dot{KE} + \Delta \dot{PE}, kW$$

First Law – Stationary Closed

Energy Balance – Stationary Closed system

$Q_{in} - Q_{out} + W_{in} - W_{out} + 0 - 0 = \Delta U + 0 + 0$, kJ

$q_{in} - q_{out} + \omega_{in} - \omega_{out} + 0 - 0 = \Delta u + 0 + 0$, kJ/kg

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} + 0 - 0 = \Delta \dot{U} + 0 + 0, \text{kW}$$

First Law – Mass Balance

Mass Entering a system	-	Mass Leaving a system	=	Change of system's mass

Mass Balance

$m_{in} - m_{out} = \Delta m_{sys}$, kg or

$\dot{m}_{in} - \dot{m}_{out} = \Delta \dot{m}_{sys}, kg/s$

First Law - Mass flow rates

Mass Balance – Mass & Volume Flow Rate

The volume of the cylinder is

$V = \ell A = m v, m^3$

The velocity of the mass is

$\vec{\upsilon} = \frac{\ell}{\Delta t}, m/s$

The volume flow rate is

$$\frac{V}{\Delta t} = \frac{\ell}{\Delta t} A = \frac{m}{\Delta t} v, \frac{\text{m}^3}{\text{s}}$$

$$\dot{V} = \dot{m} v = \vec{\upsilon} A, \frac{m^3}{s}$$

Then, mass flow rate is

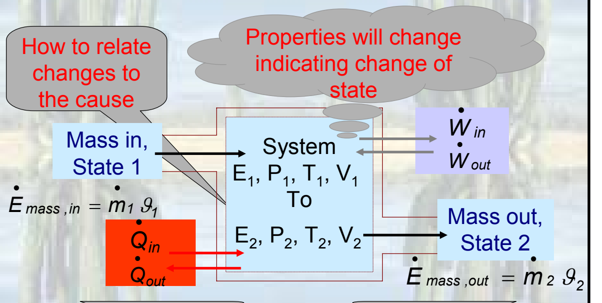
$$\dot{m} = \frac{\vec{\upsilon} A}{v}, \frac{kg}{s}$$

First Law – Steady - flow

Energy Balance – Control Volume Steady-Flow

Steady-flow is a flow where all properties within boundary of the system remains constant with time

First Law – single stream CV



Single Stream CV

First Law – Steady - flow

Energy Balance – Control Volume Steady-Flow

Steady-flow is a flow where all properties within boundary of the system remains constant with time

$\Delta E_{sys} = 0$, kJ; $\Delta e_{sys} = 0$, kJ/kg, $\Delta \dot{E}_{sys} = 0$, kJ/s

$\Delta V_{sys} = 0$, m^3; $\Delta m_{sys} = 0$ $\quad \Delta \dot{m}_{sys} = 0$, kg/s

First Law – Energy Balance CV

Mass & Energy Balance–Steady-Flow CV

Mass balance

$\Delta \dot{m}_{sys} = 0,\ So,\ \dot{m}_{in} = \dot{m}_{out}\ \ or\ \sum \dot{m}_{in} = \sum \dot{m}_{out}$, kg/s

Energy balance $\quad \Delta \dot{E}_{sys} = 0,\ \ So,\ \dot{E}_{in} = \dot{E}_{out}$ kJ/s

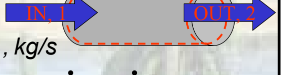
$$\dot{Q}_{in} + \dot{W}_{in} + \sum\left(\dot{m}\,\vartheta\right)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \sum\left(\dot{m}\,\vartheta\right)_{out}, kW$$

$$q + \omega + \sum \vartheta_{in} = q_{out} + \omega_{out} + \sum \vartheta_{out}, \text{kJ/kg}$$

First Law – Energy balance CV

Mass & Energy Balance–Steady-Flow: Single Stream

Mass balance



$\Delta \dot{m}_{sys} = 0.\ So,\ \dot{m}_{in} = \dot{m}_{out}$, kg/s

Energy balance $\quad \Delta \dot{E}_{sys} = 0.\ So,\ \dot{E}_{in} = \dot{E}_{out}$, kJ/s

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \left(\dot{m}\,\vartheta\right)_{out} - \left(\dot{m}\,\vartheta\right)_{in}, kW$$

$q_{in} - q_{out} + \omega_{in} - \omega_{out} = \theta_{out} - \theta_{in}$, kJ/kg

First Law - Single Stream

Mass & Energy Balance–Steady-Flow: Single Stream

Mass balance $\quad \dot{m}_1 = \dot{m}_2 = \dot{m}$, kg/s

Energy balance

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}\left(\vartheta_{out} - \vartheta_{in}\right), kW$$

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out}$$
$$= \dot{m}\left(h_2 + ke_2 + pe_2\right) - \dot{m}\left(h_1 + ke_1 + pe_1\right), kW$$
$$= \dot{m}\left(h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1\right),\ kW$$
$$= \dot{m}\left(\Delta h + \Delta ke + \Delta pe\right),\ kW$$

First Law Energy balance CV

Mass & Energy Balance–Steady-Flow: Single Stream

Mass balance: $\dot{m}_1 = \dot{m}_2 = \dot{m}, kg/s$

Energy balance:

$$q_{in} - q_{out} + \omega_{in} - \omega_{out} = \theta_{out} - \theta_{in}, \text{ kJ/kg}$$

$$= h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1, \text{ kJ/kg}$$

$$= \Delta h + \Delta ke + \Delta pe, \text{ kJ/kg}$$

First Law – Energy Balance CV

Mass & Energy Balance–Steady-Flow: Single Stream

Energy balance:

$$q_{in} - q_{out} + \omega_{in} - \omega_{out} = \Delta h + \Delta ke + \Delta pe, \text{ kJ/kg}$$

where

$$\Delta ke = ke_{final} - ke_{initial} = \frac{\upsilon_2^2 - \upsilon_1^2}{2000}, \frac{kJ}{kg}$$

and

$$\Delta pe = pe_{final} - pe_{initial} = \frac{g(y_2 - y_1)}{1000}, \frac{kJ}{kg}$$

First Law of – Ideal Gas

Mass & Energy Balance–Steady-Flow CV: Ideal Gases

Use Ideal Gas Equation of State for real gases that behave like ideal gases. Criteria:

$P_{gas} << P_{crit}$ and/or $T_{gas} >> T_{crit}$. $Pv = RT$

Where v is the specific volume, m^3/kg, R is gas constant, kJ/kg•K, T is absolute temperature in Kelvin

For known P and T, use to determine v, and hence the mass flow rate.

First Law of – Ideal Gas

Mass & Energy Balance–Steady-Flow CV: Ideal Gases

Use of property table for real gases that behave like ideal gases.

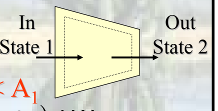
Knowing T, read value for h and vice-versa. If T or h not found, do interpolation

First Law - Nozzles

Nozzles

Purpose: Increase velocity Effect: Pressure drops

Mass balance $\dot{m}_1 = \dot{m}_2 = \dot{m}, kg/s$



Energy balance

$A_2 << A_1$

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(\vartheta_{out} - \vartheta_{in}), kW$$

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(\Delta h + \Delta ke + \Delta pe), \ kW$$

$$0 - 0 + 0 - 0 = \dot{m}(\Delta h + \Delta ke + 0), \ kW$$

First Law - Nozzles

Nozzles

Purpose: Increase velocity Effect: Pressure drops

Mass balance: $\dot{m}_1 = \dot{m}_2 \quad \frac{\upsilon_1 A_1}{v_1} = \frac{\upsilon_2 A_2}{v_2}$, kg/s

Energy balance: $0 - 0 + 0 - 0 = \dot{m}(\Delta h + \Delta ke + 0), \ kW$

$$0 = \Delta h + \Delta ke, \ kJ/kg \quad 0 = h_2 - h_1 + ke_2 - ke_1, \ kJ/kg$$

$$h_2 - h_1 = ke_1 - ke_2 = \frac{\upsilon_1^2 - \upsilon_2^2}{2000}, \ kJ/kg$$

First Law - Nozzles

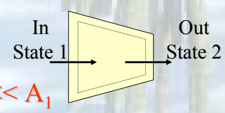
Nozzles

Purpose: Increase velocity   Effect: Pressure drops

Energy balance: $h_2 - h_1 = ke_1 - ke_2 = \frac{\vec{\upsilon}_1^{\,2} - \vec{\upsilon}_2^{\,2}}{2000}$, kJ/kg

Air: Use energy balance to find h_2 and use table A-17 (& interpolation technique) to determine T_2.

Air: Use table A-17 to find h_1 (& interpolation technique) for a given T_1.



$A_2 << A_1$

First Law - Diffusers

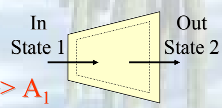
Diffusers

Purpose: Increase Pressure   Effect: Velocity drops

Energy balance: $h_2 - h_1 = ke_1 - ke_2 = \frac{\vec{\upsilon}_1^{\,2} - \vec{\upsilon}_2^{\,2}}{2000}$, kJ/kg

Air: Use energy balance to find h_2 and use table A-17 (& interpolation technique) to determine T_2.

Air: Use table A-17 to find h_1 (& interpolation technique) for a given T_1.



$A_2 >> A_1$

First Law - Turbines

Turbines

Purpose: Produce Work   Effect: Pressure Drops

Mass balance: $\dot{m}_1 = \dot{m}_2 \qquad \frac{\vec{\upsilon}_1 A_1}{v_1} = \frac{\vec{\upsilon}_2 A_2}{v_2}$, kg/s

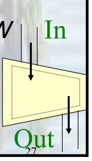
Energy balance:

$q_{in} - q_{out} + \omega_{in} - \omega_{out} = h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1$

$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(\Delta h + \Delta ke + \Delta pe)$, kW

$0 - 0 + 0 - \dot{W}_{out} = \dot{m}(h_2 - h_1 + 0 + 0)$, kW

$-\omega_{out} = h_2 - h_1$, kJ/kg $\omega_{out} = h_1 - h_2$, kJ/kg



First Law - Compressors

Compressors

Purpose: Increase Pressure   Sacrifice: Work supplied

Mass balance: $\dot{m}_1 = \dot{m}_2 \qquad \frac{\vec{\upsilon}_1 A_1}{v_1} = \frac{\vec{\upsilon}_2 A_2}{v_2}$, kg/s

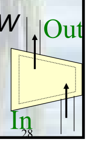
Energy balance:

$q_{in} - q_{out} + \omega_{in} - \omega_{out} = h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1$

$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(\Delta h + \Delta ke + \Delta pe)$, kW

$0 - 0 + 0 + \dot{W}_{in} = \dot{m}(h_2 - h_1 + 0 + 0)$, kW

$\omega_{in} = h_2 - h_1$, kJ/kg



First Law – Increase Pressure

Pressure Increasing Devices

Compressors: Increase Pressure of *gas* to high P

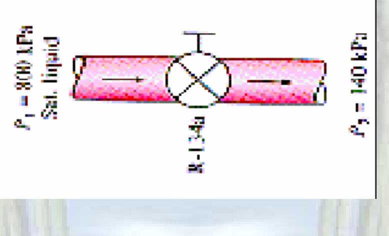
Fans: Increase Pressure of gas slightly to move air

Pumps: Increase Pressure of *liquid* to high P

Sacrifice: Work supplied

First Law - Throttle

Throttle



First Law - Throttle

Throttle

Purpose: Reduce Pressure Effect: Temp drops

Mass balance: $\dot{m}_1 = \dot{m}_2$ $\frac{\vec{\upsilon}_1 A_1}{v_1} = \frac{\vec{\upsilon}_2 A_2}{v_2}$, kg/s

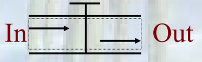
Energy balance:

$q_{in} - q_{out} + \omega_{in} - \omega_{out} = h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1$

$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(\Delta h + \Delta ke + \Delta pe),\ kW$

$0 - 0 + 0 - 0 = h_2 - h_1 + 0 + 0,\ kJ/kg$

$h_2 = h_1,\ kJ/kg$ isenthalpic process



First Law – Mixing Chamber

Mixing Chamber

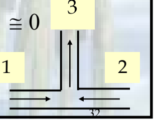
Purpose: Mixing Mass balance: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$, kg/s

Energy balance: $q_{net,in} - \omega_{net,out} = \theta_3 - \theta_1 - \theta_2$, kJ/kg

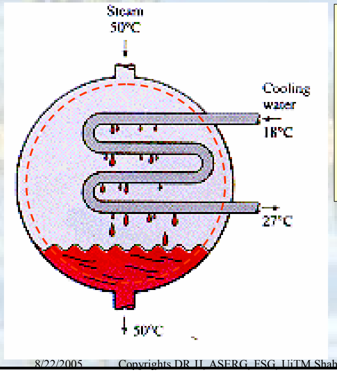
$$(\dot{m}_1 + \dot{m}_2)(h_3 + ke_3 + pe_3) = \dot{m}_2(h_2 + ke_2 + pe_2) + \dot{m}_1(h_1 + ke_1 + pe_1),\ \text{kW}$$

$$ke_3 - ke_2 = ke_1 - ke_3 \cong 0;\ pe_3 - pe_2 = pe_1 - pe_3 \cong 0$$

Then, $\dot{m}_2(h_3 - h_2) = \dot{m}_1(h_1 - h_3),\ \text{kW}$

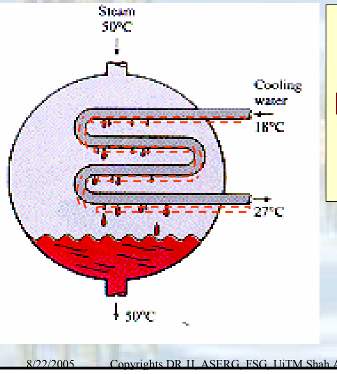


First Law – Heat Exchanger



Heat Exchanger Boundary has 2 inlets and 2 exits

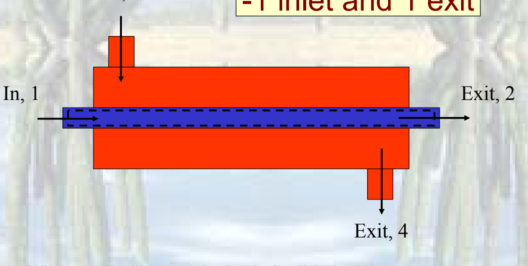
First Law – Heat Exchanger



Heat Exchanger Boundary has 1 inlet and 1 exit

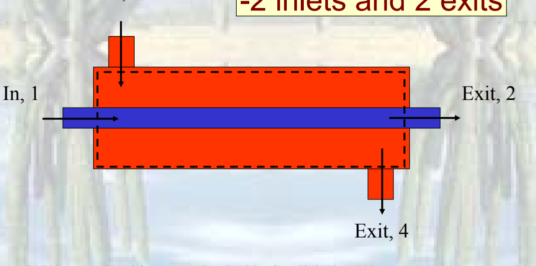
First Law of Thermodynamics

Heat Exchanger
-no mixing
-1 inlet and 1 exit



First Law of Thermodynamics

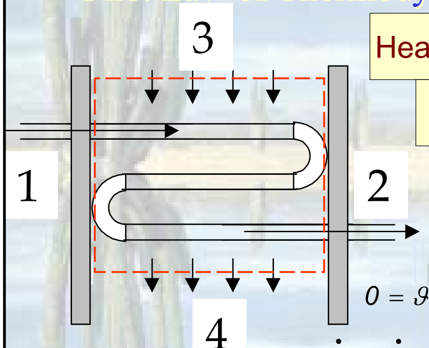
Heat Exchanger
-no mixing
-2 inlets and 2 exits



First Law of Thermodynamics

Heat Exchanger

Case 1



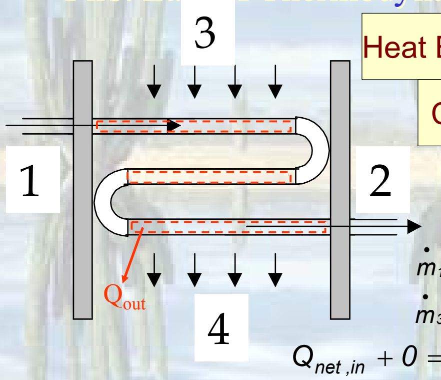
$0 = \vartheta_4 - \vartheta_3 + \vartheta_2 - \vartheta_1$

$\dot{m}_1 = \dot{m}_2,\ \dot{m}_3 = \dot{m}_4,\ kg/s$

First Law of Thermodynamics

Heat Exchanger

Case 2



$\dot{m}_1 = \dot{m}_2,\ kg/s$

$\dot{m}_3 = \dot{m}_4,\ kg/s$

$Q_{net,in} + 0 = \vartheta_2 - \vartheta_1$

First Law of Thermodynamics

Heat Exchanger

Purpose: Remove or add heat

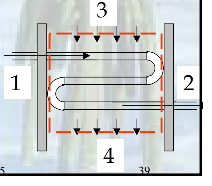
Energy balance: Case 1

$$0 - 0 + 0 - 0 = \dot{m}_4\left(h_4 + ke_4 + pe_4\right) - \dot{m}_3\left(h_3 + ke_3 + pe_3\right) + \dot{m}_2\left(h_2 + ke_2 + pe_2\right) - \dot{m}_1\left(h_1 + ke_1 + pe_1\right),\ \text{kW}$$

Mass balance: $\dot{m}_1 = \dot{m}_2,\ \dot{m}_3 = \dot{m}_4,\ kg/s$

$$\dot{m}_1\left(h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1\right) = \dot{m}_3\left(h_4 - h_3 + ke_4 - ke_3 + pe_4 - pe_3\right)$$

where $\Delta ke = \Delta pe \cong 0$



First Law of Thermodynamics

Heat Exchanger

Purpose: Remove or add heat

Mass balance:

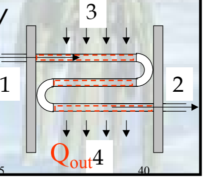
$\dot{m}_1 = \dot{m}_2,\ \dot{m}_3 = \dot{m}_4,\ kg/s$

Energy balance: Case 2

$$\dot{Q}_{in} - \dot{Q}_{out} + 0 - 0 = \dot{m}_2 h_2 - \dot{m}_1 h_1,\ kW$$

$$-\dot{Q}_{out} + 0 - 0 = \dot{m}_2\left(h_2 - h_1\right),\ kW$$

where $\left(h_2 - h_1\right) = \dfrac{\dot{m}_3\left(h_3 - h_4\right)}{\dot{m}_1}$



First Law of Thermodynamics

Heat Exchanger

Purpose: Remove or add heat

Mass balance:

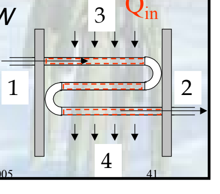
$\dot{m}_1 = \dot{m}_2,\ \dot{m}_3 = \dot{m}_4,\ kg/s$

Energy balance: Case 2

$$\dot{Q}_{in} - \dot{Q}_{out} + 0 - 0 = \dot{m}_2 h_2 - \dot{m}_1 h_1,\ kW$$

$$\dot{Q}_{in} - 0 + 0 - 0 = \dot{m}_2\left(h_2 - h_1\right),\ kW$$

where $\left(h_2 - h_1\right) = \dfrac{\dot{m}_3\left(h_3 - h_4\right)}{\dot{m}_1}$

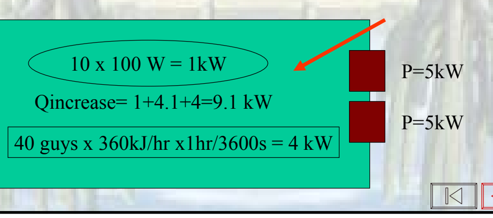


First Law of Thermodynamics

Example: Q7

40 studs. AC 5kW. Q_{person}=360 kJ/hr. 10 light bulbs, 100 W each. Q_{in} = 15,000 kJ/hr. Need to maintain room at 21°C. How many AC require?

Q_{in}=15,000 kJ/hr= 4.1 kW



First Law of Thermodynamics

Example: Q11

Radiator V=20 L, phase superheated vapor 300 kPa, 250°C. Closed system. Find Q_{out} when P=100 kPa, show on phase diagram.

Initial state: State 1

V = 20 L x 10^{-3} m^3 /L

10^{-3} L = 1cm^3 = $(10^{-2})^3$ = 10^{-6} m^3

P=300 kPa, 250°C, superheated vapor. u_1 = 2728.7 kJ/kg

ν = 0.7964 m^3/kg.

m=V/ ν =0.02m^3/0.7964m^3/kg

Final state: State 2

P=100 kPa, T?? Phase ??

ν= 0.7964 m^3/kg.

$\nu_f < \nu < \nu_g$, wet mix.

x = (ν- ν_f)/(ν_g - ν_f)=0.47

0 – q_{out} = Δu. Find quality x then use it to get $u_2=u_f+xu_{fg}$

First Law of Thermodynamics

Example: Q11

Radiator V=20 L, phase superheated vapor 300 kPa, 250 °C. Closed system. Find Q_{out} when P=100 kPa, show on phase diagram.

u_1 = 2728.7 kJ/kg

m=V/ ν =0.02m^3/0.7964m^3/kg

$u_2=u_f+xu_{fg}$ = 1399.049 kJ/kg

-q_{out} = $u_2 - u_1$ = -1329.7 kJ/kg

Q_{out} = m Δu =

Final state: State 2

P=100 kPa, T?? Phase ??

ν= 0.7964 m^3/kg.

$\nu_f < \nu < \nu_g$, wet mix.

x = (ν- ν_f)/(ν_g - ν_f)=0.47

0 – q_{out} = Δu. Find quality x then use it to get $u_2=u_f+xu_{fg}$

First Law of Thermodynamics

Concluding remarks - Quotes

"The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn."

Author: Alvin Toffler
Source: Lessons from the Art of Juggling; How to Achieve Your Full Potential in Business, Learning and Life by Michael Gelb and Tony Buzan