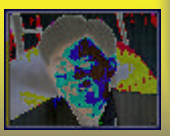
Thermodynamics Lecture Series

Assoc. Prof. Dr. J.J.

Dynamic Energy Transfer – Heat, Work and Mass



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CHAPTER 2

Pure substance

Properties of Pure Substances- A Review

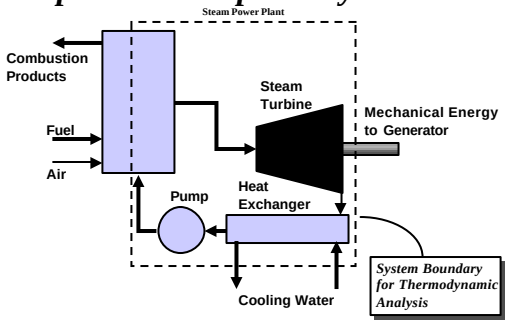
Quotes

"Good judgment comes from experience. Experience comes from bad judgment"

- Anonymous

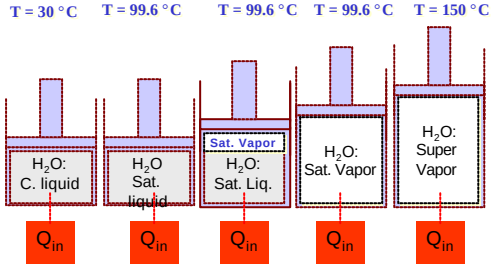
"The roots of education are bitter, but the fruit is sweet." -Aristotle

Example: A steam power cycle.



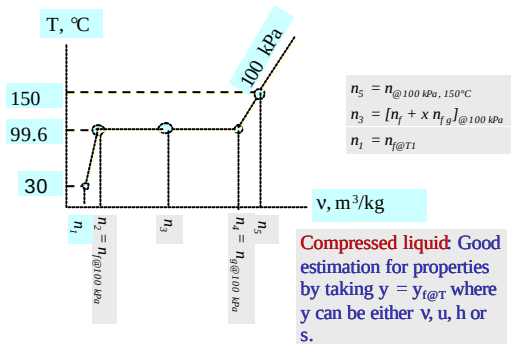
Phase Change of Water

P = 100 kPa	P = 100 kPa	P = 100 kPa	P = 100 kPa	P = 100 kPa
T = 30 °C	T = 99.6 °C	T = 99.6 °C	T = 99.6 °C	T = 150 °C



Water interacts with thermal energy

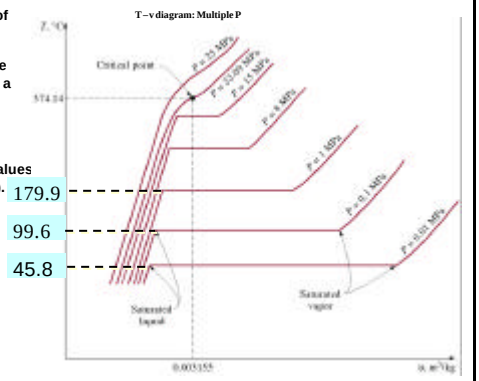
Phase Change of Water



Compressed liquid: Good estimation for properties by taking $y = y_{f@T}$ where y can be either ν, u, h or s.

FIGURE 2-16

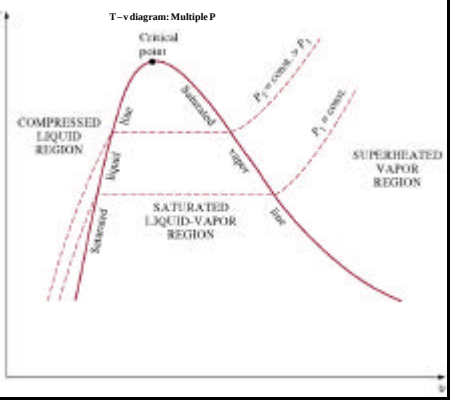
T-v diagram of constant-pressure phase-change processes of a pure substance at various pressures (numerical values are for water).



2-2

FIGURE 2-18

T-v diagram of a pure substance.

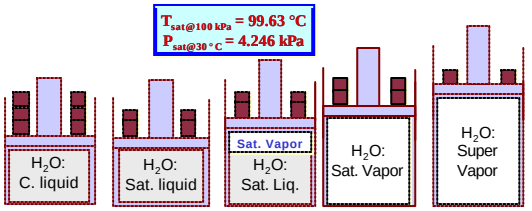


2-3

Phase Change of Water - Pressure Change

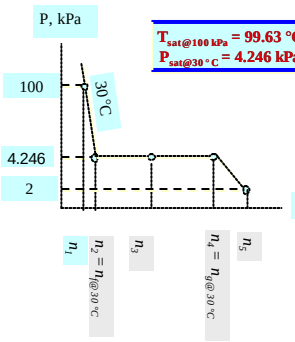
T = 30 °C	T = 30 °C	T = 30 °C	T = 30 °C	T = 30 °C
P = 100 kPa	P = 4.246 kPa	P = 4.246 kPa	P = 4.246 kPa	P = 2 kPa

$T_{sat@100\ kPa} = 99.63\ °C$
$P_{sat@30\ °C} = 4.246\ kPa$



Water when pressure is reduced

Phase Change of Water- Pressure Change

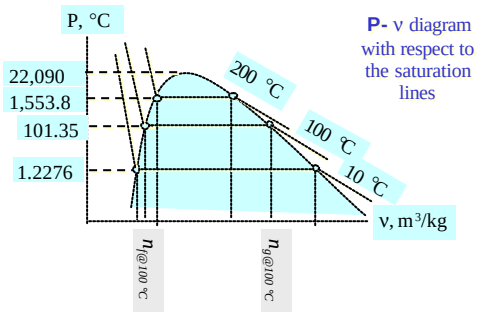


$T_{sat@100\ kPa} = 99.63\ °C$
$P_{sat@30\ °C} = 4.246\ kPa$

$n_1 = n_{f@30\,°C}$
$n_2 = n_{f@30\,°C}$
$n_3 = [n_f + x\,n_{fg}]_{@30\,°C}$
$n_4 = n_{g@30\,°C}$
$n_5 = n_{@2kPa,\ 30\,°C}$

Compressed liquid: Good estimation for properties by taking $y \cong y_{f@T}$ where y can be either v, u, h or s.

Phase Change of Water



P- v diagram with respect to the saturation lines

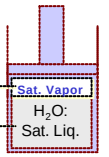
Saturated Liquid-Vapor Mixture

Given the pressure, P, then
$T = T_{sat}$, $y_f < y < y_g$

Vapor Phase:, V_g, m_g, n_g, u_g, h_g

Liquid Phase:, V_f, m_f, n_f, u_f, h_f

Mixture:, V, m, n, u, h, x



Mixture's quality $x = \frac{m_g}{m_t}$

$$m n_{avg} = m_f n_f + m_g n_g = (m_t - m_g) n_f + m_g n_g$$

Divide by total mass, m_t

$$n_{avg} = \left(1 - \frac{m_g}{m_t}\right) n_f + x n_g = n_f + x n_g - x n_f = n_f + x n_{fg}$$

where $n_{fg} = n_g - n_f$

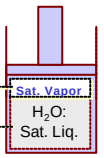
Saturated Liquid-Vapor Mixture

Given the pressure, P, then $T = T_{sat}$, $y_f < y < y_g$

Vapor Phase:, V_g, m_g, n_g, u_g, h_g

Liquid Phase:, V_f, m_f, n_f, u_f, h_f

Mixture:, V, m, n, u, h, x



Mixture's quality $x = \frac{m_g}{m_t}$

$n = n_f + x n_{fg}$ where $n_{fg} = n_g - n_f$

$y = y_f + x y_{fg}$ where $y_{fg} = y_g - y_f$ y can be n, u, h

If x is known or has been determined, use above relations to find other properties. If either n, u, h are known, use it to find quality, x.

CHAPTER 3

Energy Transfer by Heat, Work, and Mass

Goal: Identify forms of energy interactions and ways of representing it in thermodynamics processes

Objectives:

1. *Identify the types of dynamic energies interacting with a system.*
2. *Distinguish the difference and relate between heat transfer and thermal energy.*
3. *Write the different symbols and the conventions used to represent heat transfer.*
4. *Differentiate between heat transfer and work done.*

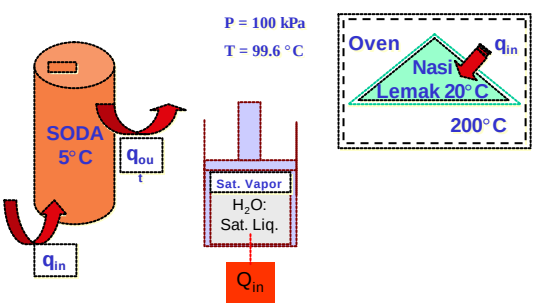
Objectives:

5. *Write the symbols and convention used for work done.*
6. *Obtain a mathematical relation representing mechanical work done for any system.*
7. *Obtain the amount of work done from a P – V or P - n graph.*
8. *Write down the relationship between mass and volume flow rate.*

Objectives:

9. *Obtain a mathematical relation representing mass flow rate in terms of the mass velocities and the system's inlet or exit area.*
10. *Write the specific energy carried by a flowing mass.*
11. *Use all mathematical relations and graphing skills to solve problems involving interaction energies.*

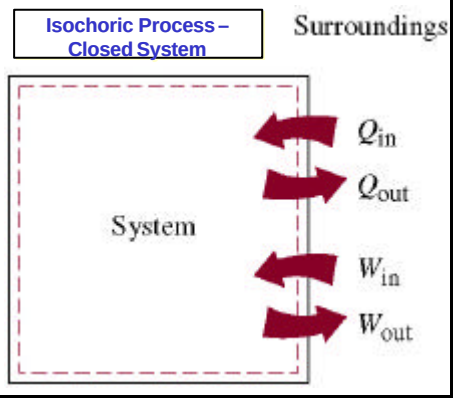
Energy Transfer -Heat Transfer



3-1

FIGURE 3-9
Specifying the directions of heat and work.

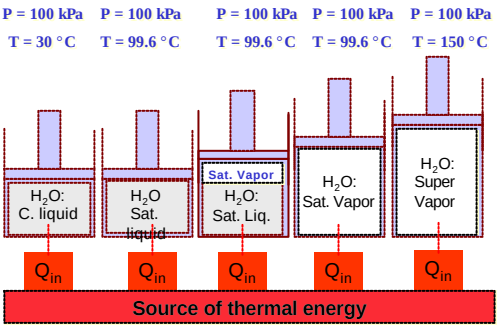
Isochoric Process – Closed System



3-1

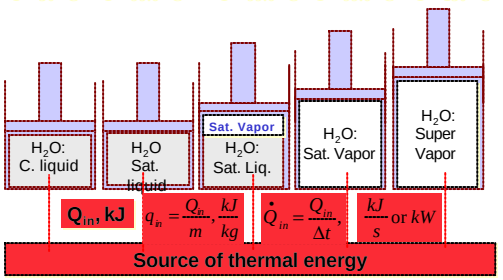
Isobaric Process – Closed System

System expands, volume increases



Isobaric Process – Closed System

System expands, volume increases



Symbols and Convention – Heat transfer

Total heat entering, Q_{in} = 100 kJ, m = 5 kg

Specific heat $q_{in} = \frac{Q_{in}}{m} = \frac{100\,kJ}{5\,kg} = 20\,\frac{kJ}{kg}$

Rate of heat transfer if heat is allowed to interact for 50 seconds

$$\dot{Q}_{in} = \frac{Q_{out}}{\Delta t} = \frac{100\,kJ}{50\,s} = 2\,\frac{kJ}{s} = 2\,kW$$

Symbols and Convention – Heat transfer

Total heat leaving, Q_{out} = 20 kJ, m = 5 kg

Specific heat $q_{out} = \frac{Q_{out}}{m} = \frac{20\,kJ}{5\,kg} = 4\,\frac{kJ}{kg}$

Rate of heat transfer if heat is allowed to interact for 50 seconds

$$\dot{Q}_{out} = \frac{Q_{out}}{\Delta t} = \frac{20\,kJ}{50\,s} = 0.4\,\frac{kJ}{s} = 0.4\,kW$$

Symbols and Convention – Heat transfer

Net heat transfer

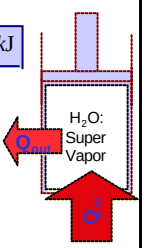
$$Q = Q_{net,in} = Q_{in} - Q_{out} = 80\,kJ - 20\,kJ = 60\,kJ$$

Net specific heat transfer

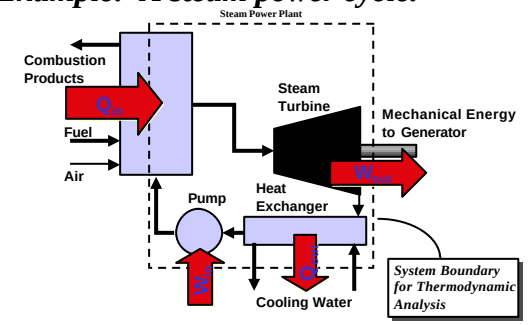
$$q = q_{net,in} = \frac{Q_{net,in}}{m} = \frac{60\,kJ}{5\,kg} = 12\,\frac{kJ}{kg}$$

Net rate of heat transfer if heat is allowed to interact for 50 seconds

$$\dot{Q} = \dot{Q}_{net,in} = \frac{Q_{in} - Q_{out}}{\Delta t} = \frac{60\,kJ}{50\,s} = 1.2\,\frac{kJ}{s} = 1.2\,kW$$



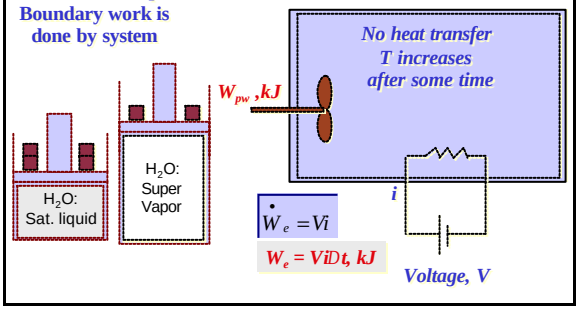
Example: A steam power cycle.



Energy Transfer – Work Done

Mechanical work:
Piston moves up
Boundary work is done by system

Electrical work is done on system



$\dot{W}_e = Vi$

$W_e = ViDt$, kJ

Symbols and conventions for Work – Isothermal

System expands, volume increases-boundary work is done

T = 30 °C	T = 30 °C	T = 30 °C	T = 30 °C	T = 30 °C
P = 100 kPa	P = 4.246 kPa	P = 4.246 kPa	P = 4.246 kPa	P = 2 kPa

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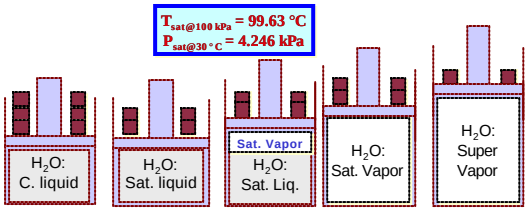
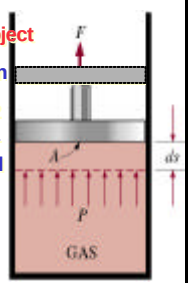


Water when pressure is reduced – **no thermal energy or heat**

Boundary Work, $W_{b,out}$

Work done involves force moving an object in the direction of movement

FIGURE 3-19
A gas does a differential amount of work dW_b as it forces the piston to move by a differential amount ds.



Final, n
2
1
Initial

$dW_b = F \bullet ds$

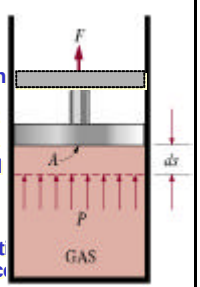
Total work done by system to expand from initial to state

$$W_b = \sum_i^f dW_b = dW_{b,1} + dW_{b,2} + \ldots + dW_{b,n}$$

$$W_b = \sum_i^f dW_b = F_1 \bullet ds_1 + F_2 \bullet ds_2 + \ldots + F_n \bullet ds_n$$

Boundary Work, $W_{b,out}$

FIGURE 3-19
A gas does a differential amount of work dW_b as it forces the piston to move by a differential amount ds.



Final, n
2
1
Initial

As ds approaches zero

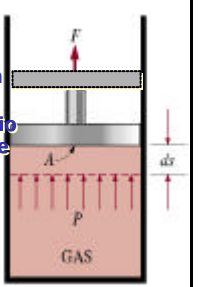
$$W_b = \int_i^f dW_b = \int_i^f F \bullet ds$$

Pressure exerted on a surface is the rat
of force applied w.r.t. the area of surfac

$$P = \frac{F}{A},\ kPa$$

Boundary Work, $W_{b,out}$

FIGURE 3-19
A gas does a differential amount of work dW_b as it forces the piston to move by a differential amount ds.



Final, n
2
1
Initial

Pressure exerted on a surface is the ratio of force applied w.r.t. the area of surface

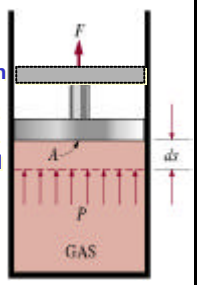
Then $F = PA$

So $$W_b = \int_i^f F \bullet ds = \int_i^f PA \bullet ds$$

But $A \bullet ds = dV$ Hence $$W_b = \int_i^f dW_b = \int_i^f PdV$$

Boundary Work, $W_{b,out}$

FIGURE 3-19
A gas does a differential amount of work dW_b as it forces the piston to move by a differential amount ds.



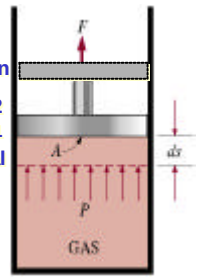
When the pressure is kept constant, Isobaric process,

Then $W_b = P\int_i^f dV = P(V_f - V_i)$

Or $W_b = P\int_i^f dV = P_f V_f - P_i V_i$ where $P_f = P_i = const = P$

Specific Boundary Work, $w_{b,out}$

FIGURE 3-19
A gas does a differential amount of work dW_b as it forces the piston to move by a differential amount ds.



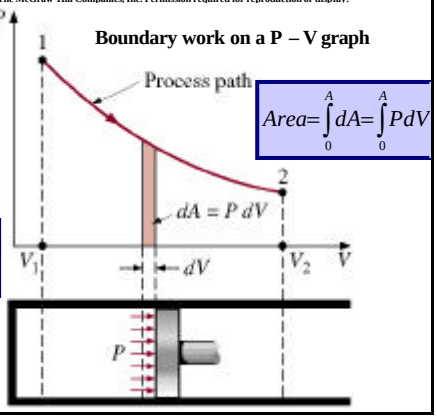
When the pressure is kept constant, Isobaric process,

Then $w_b = P\int_i^f dn = P(n_f - n_i), \frac{kJ}{kg}$

Or $w_b = P\int_i^f dn = P_f n_f - P_i n_i, \frac{kJ}{kg}$ where $P_f = P_i = const = P$

FIGURE 3-20
The area under the process curve on a *P-V* diagram represents the boundary work.

Boundary work on a P – V graph



$Area = \int_0^A dA = \int_0^A PdV$

$W_b = \int_i^f F \bullet ds$

$W_b = \int_i^f PA \bullet ds$

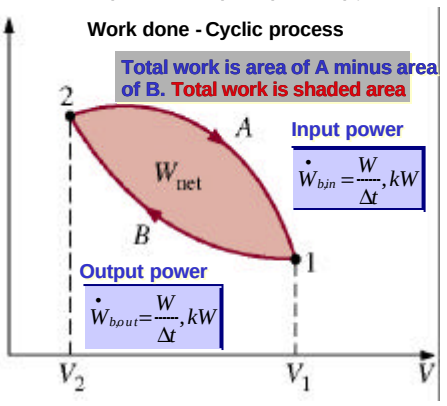
$W_b = \int_i^f PdV$

3-3

FIGURE 3-22
The net work done during a cycle is the difference between the work done by the system and the work done on the system.

Work done - Cyclic process

Total work is area of A minus area of B. Total work is shaded area



Input power

$\dot{W}_{b,in} = \frac{W}{\Delta t}, kW$

Output power

$\dot{W}_{b,out} = \frac{W}{\Delta t}, kW$

$w_b = \int_i^f Pdn$

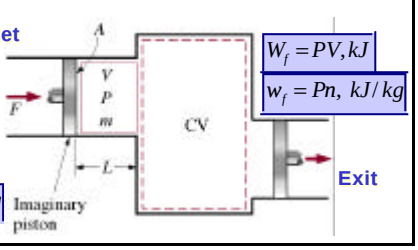
$W_b = \int_i^f PdV$

3-4

Work done – Flow work

Flow work is energy required to overcome resistance at the Boundary both while entering and leaving the system

FIGURE 3-48
Schematic for flow work.



$W_f = PV, kJ$

$w_f = Pn, \ kJ/kg$

$W_f = PV, kJ$

$w_f = Pn, \ kJ/kg$

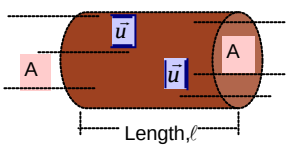
3-5

Energy Transfer – Mass Conservation

Consider mass flowing through cylinder of length and area

Mass must be conserved in any process.

$\sum m_{in} - \sum m_{out} = \Delta m_{sys}, kg$ or $\sum \dot{m}_{in} - \sum \dot{m}_{out} = \Delta \dot{m}_{sys}, \frac{kg}{s}$



For steady flow $\Delta \dot{m}_{sys} = 0$

Exit

Then $\sum \dot{m}_{in} = \sum \dot{m}_{out}$

Energy Transfer – Energy of Moving Mass

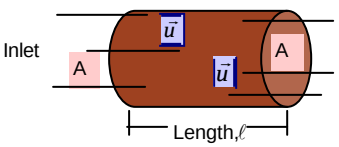
Consider mass flowing through cylinder of length ℓ and area A

Let the mass flow through for time interval of Δt, such as 10 seconds

Let the mass flow with a velocity $\vec{u}$

Since volume is $V = mn$

Then volume flow rate is $\frac{V}{\Delta t} = \frac{mn}{\Delta t}$



or $\dot{V} = mn, \frac{m^3}{s}$

Then mass Flow rate $\dot{m} = \frac{\dot{V}}{n}, \frac{kg}{s}$

Energy Transfer – Energy of Moving Mass

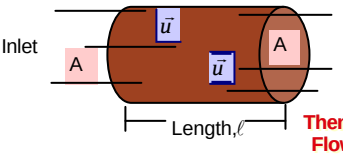
Consider mass flowing through cylinder of length ℓ and area A

Let the mass flow through for time interval of Δt, such as 10 seconds

Let the mass flow with a velocity $\vec{u}$

Since volume $V = \ell A = mn$

Then volume flow rate is $\frac{V}{\Delta t} = \frac{lA}{\Delta t} = \frac{mn}{\Delta t}$ or



$\dot{V} = \vec{u}A = mn, \frac{m^3}{s}$

Then mass Flow rate $\dot{m} = \frac{\dot{V}}{n} = \frac{\vec{u}A}{n}, \frac{kg}{s}$

Energy Transfer – Energy of Moving Mass

Kinetic energy, ke $ke = \frac{\vec{?}^2}{2000}, \frac{kJ}{kg}$

Potential energy, pe $pe = \frac{gh}{2000}, \frac{kJ}{kg}$

Internal energy, u $u, \frac{kJ}{kg}$

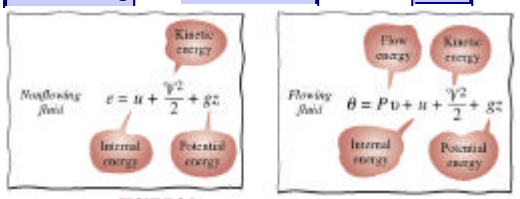


FIGURE 3-51
The total energy consists of three parts for a nonflowing fluid and four parts for a flowing fluid.

Gas Mixtures – Ideal Gases

➢ **Equation of State** - P-v-T behaviour

$PV = mRT$

Hence, can also write $PV = NR_uT$

where

N is no of kilomoles, kmol,

M is molar mass in kg/kmole and

R_u is universal gas constant; $R_u = MR$.

R_u = 8.314 kJ/kmol.K