4 THERMODYNAMICS & ENERGY BALANCE

Lecture Note
Principles of Food Engineering (ITP 330)

Dosen :
Prof. Dr. Purwiyatno Hariyadi, MSc

Dept of Food Science & Technology
Faculty of Agricultural Technology
Bogor Agricultural University
BOGOR

2002

THERMODYNAMICS AND ENERGY BALANCE

- Learning Objectives
  - Understand the conceptual basis of the Law of Thermodynamics
  - Understand the fundamental energy balance concepts
  - Be able to list and discuss important terms related to energy transfer
  - Be able to list and discuss energy balance applications in food processing and handling operations
  - Be able to conceptually describe how energy balance determinations or calculations are obtained

Pur Hariyadi/TPG/Fateta/IPB

WHAT IS THERMODYNAMICS?

Thermodynamics is the branch of science which studies the transformation of energy from one form to another

Thermodynamics - Science which is concerned with changes in the forms or location of energy and may be thought in terms of "energy dynamics"

Thermodynamics of process :

............> looks at the energy transformations which occur as a result of process

- How much heat is evolved during a process?
- What determines the spontaneous process?
- What determines the extent of process?

Pur Hariyadi/TPG/Fateta/IPB

DESCRIPTION OF THE SYSTEM.........1

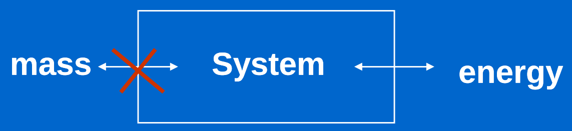
- Composed of a finite portion of matter and is defined in terms of the boundaries which enclose it
- Boundaries may be real or imaginary
- Region surrounding boundaries may be referred to as its environment
- May consider a plant or any portion thereof as a boundary

Surrounding=environment

Pur Hariyadi/TPG/Fateta/IPB

DESCRIPTION OF THE SYSTEM.........2

- Two (common) types of systems are:
  - open system
  - closed system



- Open system
  - boundaries permit the crossing of matter
  - energy may cross the boundaries of the open system with the flow of mass or separately
- Closed System
  - boundaries do not permit the crossing of matter
  - energy may cross the boundaries of closed systems

Pur Hariyadi/TPG/Fateta/IPB

DESCRIPTION OF THE SYSTEM.........3

Steady state conditions:

> mass of the system remains unchanged
> rate of flow leaving system is constant and equal to that entering the system

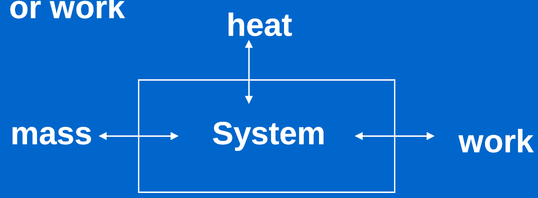
Transient (unsteady) state conditions:

> mass of the system may remain unchanged
> heat of the system changes with time

Pur Hariyadi/TPG/Fateta/IPB

DESCRIPTION OF THE SYSTEM 4

- Energy which crosses the boundary is classified as either heat or work



- Heat is the form of energy that is transferred from the environment external to the system by way of diffusion due to a temperature gradient.
- Positive sign - refers to heat entering system
- Negative sign - heat leaving system

Pur Hariyadi/TPG/Fateta/IPB

PROPERTIES OF THE SYSTEM 1

- Property - Observable, measurable, or calculable characteristic of a substance which depends only upon the state of the substance
- State of a given system is its condition or its position with respect to other systems
- Equation of state - relationship between
  - > pressure,
  - > specific volume, and
  - > temperature

Pur Hariyadi/TPG/Fateta/IPB

PROPERTIES OF THE SYSTEM 2

- Equation of state of a perfect/ideal gas (Boyle, Charles, Guy-Lussac) :

  PV = nRT; where:

  P = absolute pressure, kPa/m^2
  V = volume, m^3
  n = number of molecules, kgmole
  R = universal gas constant [=]????
  T = absolute temperature, ^oK

- Standard Condition?
  At 273^{o}K, 760 mm Hg (101.325 kPa),
  1 gmole occupy 22,4 L
  1 kgmole occupy 22.4 m^3

Pur Hariyadi/TPG/Fateta/IPB

PROPERTIES OF THE SYSTEM 3

- R = 0.08206 lit(atm)/(gmole.^{o}K)
  = 8315 Nm/kgmole.^{o}K
  = 1545 ft(lbf)/(lbmole.^{o}R

- Typical properties of a system for a given state are :
  > pressure,
  > volume,
  > temperature,
  > velocity, and
  > the elevation of the system.

Pur Hariyadi/TPG/Fateta/IPB

PROPERTIES OF THE SYSTEM 4

- Van der Waal's Equation of state :

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

where:

P = absolute pressure
n = number of molecule
T = absolute temp.
V = volume, m^3
R = gas constant
a, b = constant

Gas	a Pa(m^3/kgmole)^2	b m^3/kgmole
Air	1.348 10^5	0.0366
Ammonia	4.246 10^5	0.0373
CO2	3.648 10^5	0.0428
Water vapor	5.553 10^5	0.0306

Pur Hariyadi/TPG/Fateta/IPB

PURE SUBSTANCES...... 1

- Pure substance is a single substance which retains an unvarying molecular structure
- Examples include:
  > pure oxygen
  > ammonia
  > dry air (in the gaseous state) - largely composed of oxygen and nitrogen with fixed percentages of each

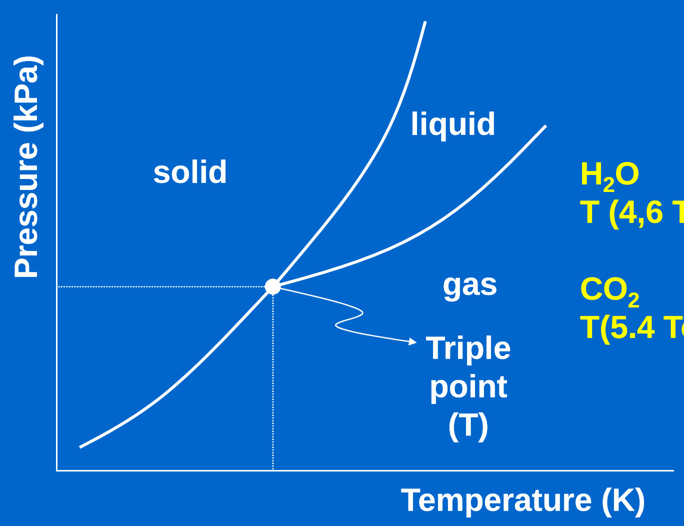
Pur Hariyadi/TPG/Fateta/IPB

PURE SUBSTANCES...... 2

- A pure substance may exist in any of three phases including solid, liquid, or gas = f (P, V, T)
  - **Melting** - change of phase from solid to liquid
  - **Vaporization** - change of phase from liquid to gas
  - **Condensation** - change of phase from vapor to liquid
  - **Sublimation** - substance passing from the solid directly to a gaseous phase (dry ice)

Pur Hariyadi/TPG/Fateta/IPB

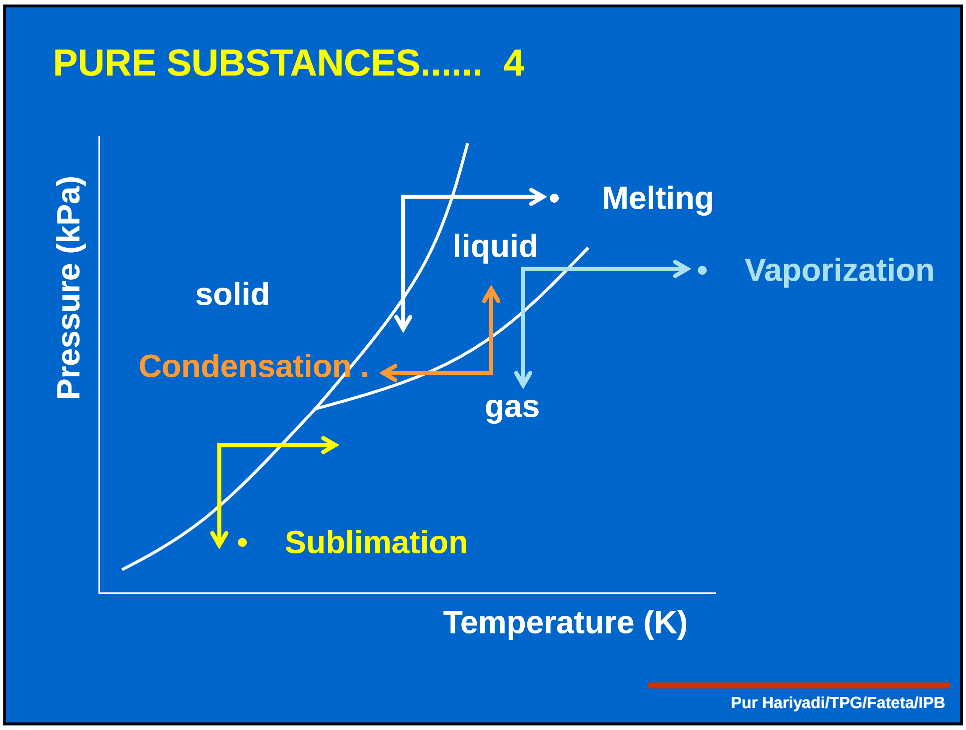
PURE SUBSTANCES...... 3

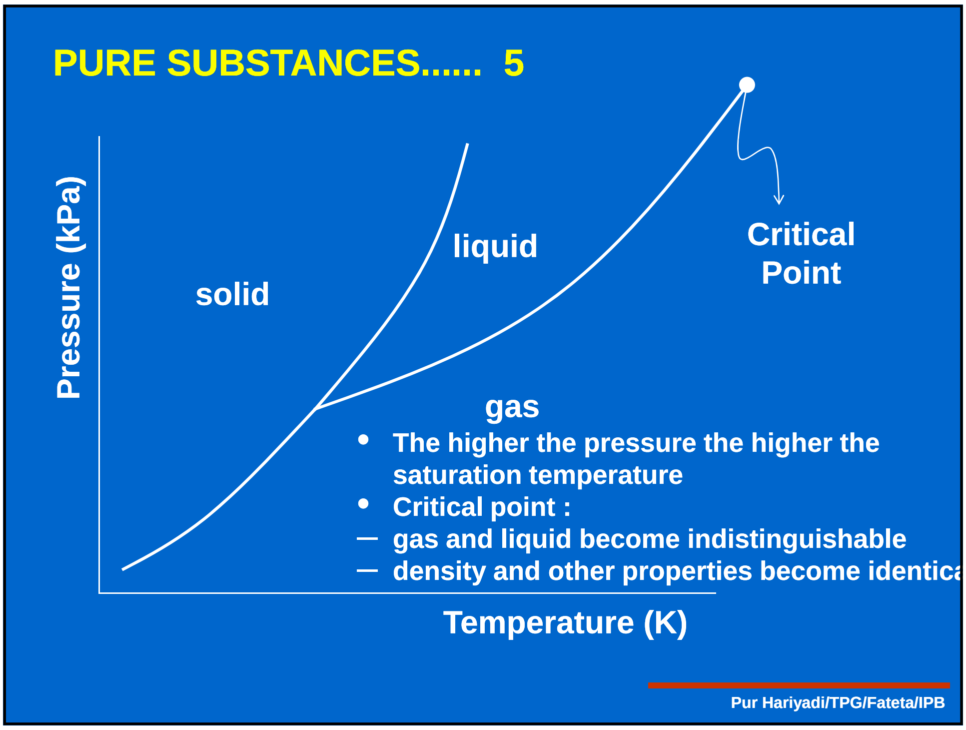


H_2O
T (4,6 Torr, 0.01°C)

CO_2
T(5.4 Torr, - 57°C)

Pur Hariyadi/TPG/Fateta/IPB


PURE SUBSTANCES...... 4
Pressure (kPa)
Melting
liquid
Vaporization
solid
Condensation
gas
Sublimation
Temperature (K)
Pur Hariyadi/TPG/Fateta/IPB


PURE SUBSTANCES...... 5
Pressure (kPa)
liquid
Critical Point
solid
gas
• The higher the pressure the higher the saturation temperature
• Critical point :
– gas and liquid become indistinguishable
– density and other properties become identica
Temperature (K)
Pur Hariyadi/TPG/Fateta/IPB

PURE SUBSTANCES...... 6

Gas or Vapor?

.........> = identical !!!

Vapor :

- gas which exists below its critical temperature
- condensable by compresion at constant T

Gas :

- non condensable gas
- gas above the critical point

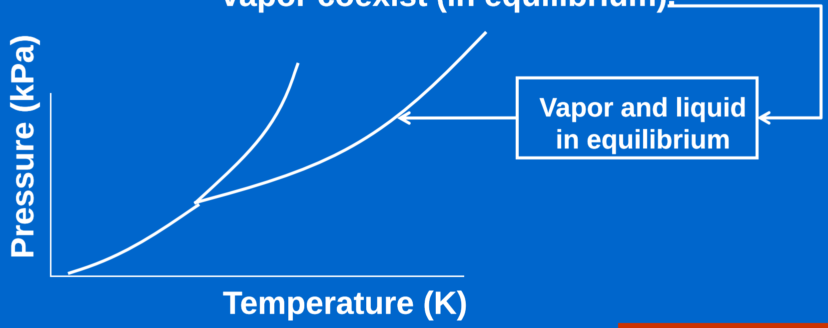
Pur Hariyadi/TPG/Fateta/IPB

PURE SUBSTANCES ...... Vapor Pressure ...... Vapor-liquid Equlibrium

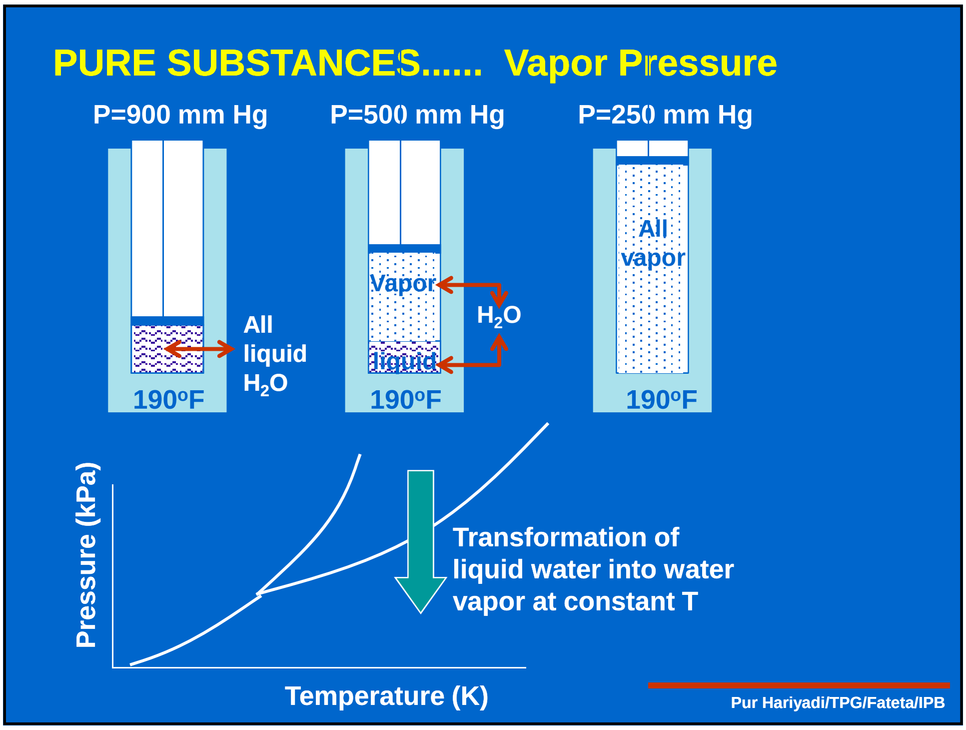
Vaporization and condensation at constant T and P are equilibrium process

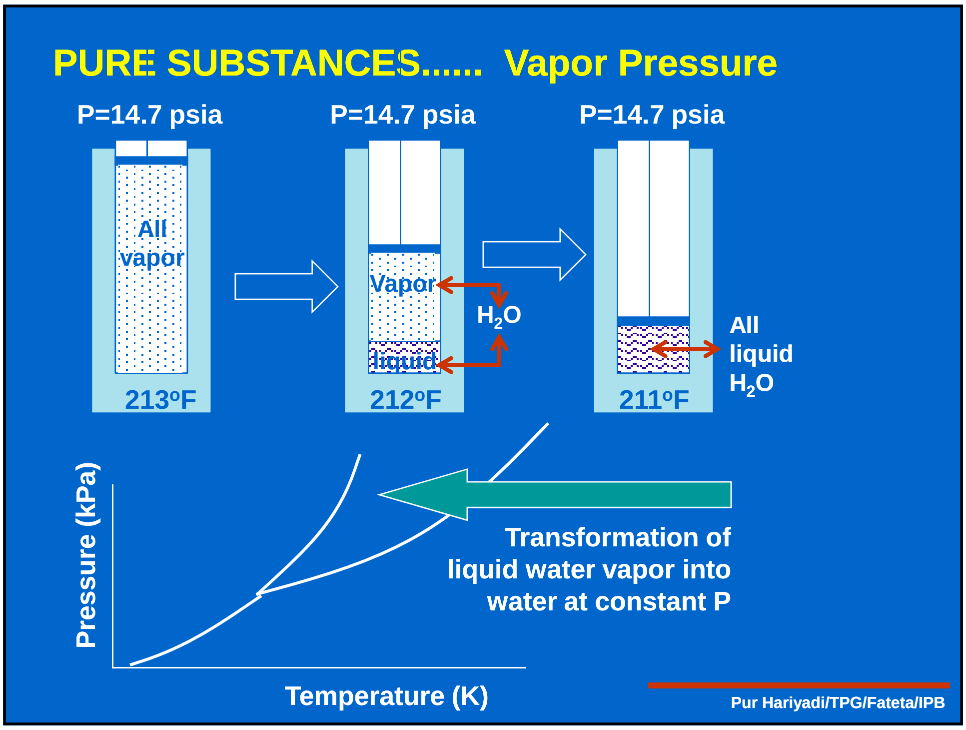
- equilibrium pressure = vapor pressure
- at a given T :

.... > there is only one P at which liquid and vapor coexist (in equilibrium).



Pur Hariyadi/TPG/Fateta/IPB


PURE SUBSTANCES...... Vapor Pressure
P=900 mm Hg
P=500 mm Hg
P=250 mm Hg
All liquid H2O
Vapor
H2O
liquid
All vapor
190°F
190°F
190°F
Pressure (kPa)
Transformation of liquid water into water vapor at constant T
Temperature (K)
Pur Hariyadi/TPG/Fateta/IPB


PURE SUBSTANCES...... Vapor Pressure
P=14.7 psia
P=14.7 psia
P=14.7 psia
All vapor
Vapor
H2O
liquid
All liquid H2O
213°F
212°F
211°F
Pressure (kPa)
Transformation of liquid water vapor into water at constant P
Temperature (K)
Pur Hariyadi/TPG/Fateta/IPB

Internal Energy, E

- System may be losing and gaining energy
- Total energy of the system?. ··········> internal energy, E.
- Internal energy : total energy of system
  (the sum of all the system's energy).
- Chemical, nuclear, heat, gravitational, etc
- It is impossible to measure the total internal energy of our system ··········> intrinsic property
- So why define a quantity which we cannot measure?
- We can measure changes in the internal energy.
- Thermodynamics is all about changes in energy :
- The change in internal energy of a system a very useful experimental quantity.

Pur Hariyadi/TPG/Fateta/IPB

Change of Internal Energy, E

E may change in 3 different ways :

- heat passes into or out of the system;
- work is done on or by the system;
- mass enters or leaves the system.

Again :

- Closed system :
  no transfer of mass is possible :
  E may only change due to heat and work.
- Isolated system :
  heat, work and mass transfer are all impossible
  no change in E
- Open system :
  E may change due to transfer of heat, mass and work between system and surroundings.

Pur Hariyadi/TPG/Fateta/IPB

Closed system

If δQ and δW are the increments of heat and work energy crossing the system's boundaries :

$$dE = \delta Q - \delta W$$

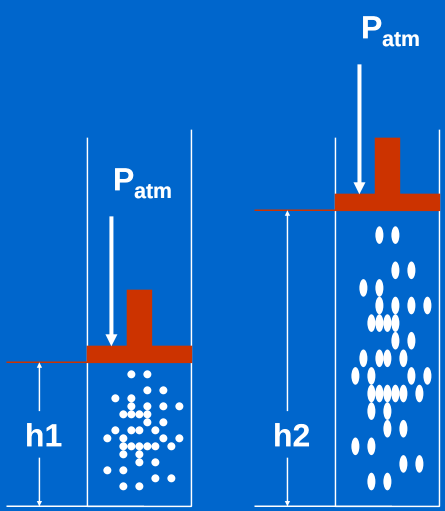
or

$$\Delta E = Q - W$$

- The First Law of Thermodynamics = law of conservation of energy

Pur Hariyadi/TPG/Fateta/IPB

ISOTHERMAL EXPANSION OF AN IDEAL GAS AGAINST A FIXED ESTERNAL PRESSURE



Work ??

= force x distance

= pressure x area x distance

= P_{atm} x A x (h2-h1)

=$P_{atm}\Delta V$

Pur Hariyadi/TPG/Fateta/IPB

ISOTHERMAL EXPANSION OF AN IDEAL GAS AGAINST A FIXED ESTERNAL PRESSURE

Remember!

- Positive sign - heat entering system
  - work done on the system (compression)
- Negative sign - heat leaving system
  - work done by the system (expansion)

$W = - P_{atm} . \Delta V$

- If ··········> P [=] Pa
  ··········> V [=] m^3

then
··········> W [=] J

Pur Hariyadi/TPG/Fateta/IPB

Enthalpy (H)

- Another intrinsic thermodynamic variable

$H = E + PV$

or, in differential form :
$dH = dE + PdV + VdP$

$PdV = \delta W$ ··········> $dH = dE + \delta W + VdP$
$\delta W + dE = \delta Q$ ··········> $dH = \delta Q + VdP$

for constant pressure process (dP=0)
$dH = \delta Q$ or $\Delta H = Q$

- Specific heat at constant P (C_p) ··········> $C_p = \left.\frac{dQ}{dT}\right|_p$

Enthalpy $\equiv$ Heat content <····· ··········> $\Delta H = Q = \int C_p dT$

Pur Hariyadi/TPG/Fateta/IPB

Enthalpy (H)

- Enthalpy $\equiv$ Heat content ………> $\Delta H = Q = \int C_p dT$
  ………> $\Delta H = mC_{p.av}(T_2 - T_1)$
- ΔH : positive ……> heat is absorbed (*endothermic*)
- ΔH : negative ……> heat is envolved (*exothermic*)
- Back to Ineternal energy : $dE = \delta Q - \delta W$
- Constant Volume process :
  $\delta W = 0$ ………> $dE = \delta Q$
  $\Delta E = Q$
- Specific heat at constant V (C_v) ………> $C_V = \left.\frac{dQ}{dT}\right|_V$

………> $\Delta E = C_V dT$

Pur Hariyadi/TPG/Fateta/IPB

Relationship between C_p and C_v

$dE = dQ - PdV$

teking the derivative with resoect to T :

$$\frac{dE}{dT} = \left.\frac{dQ}{dT}\right|_P - P\frac{dV}{dT}$$

$\frac{dE}{dT} \rightarrow C_V$; $\left.\frac{dQ}{dT}\right|_P \rightarrow C_p$; $P\frac{dV}{dT} \rightarrow R$

1 mole of Ideal gas
PV = RT
at constant pressure :
(dV/dT) = R/P

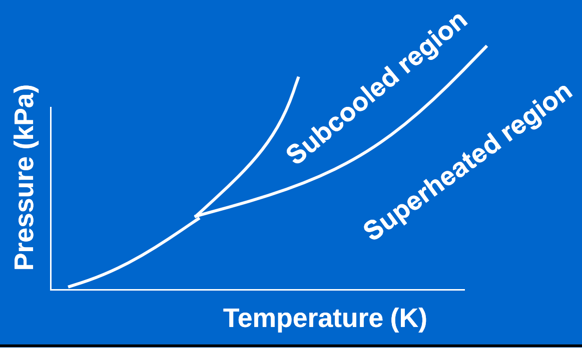
$C_V = C_P - R$ ………> $C_P/C_V = \gamma$
………> $C_P/R = \gamma/(\gamma-1)$

Pur Hariyadi/TPG/Fateta/IPB

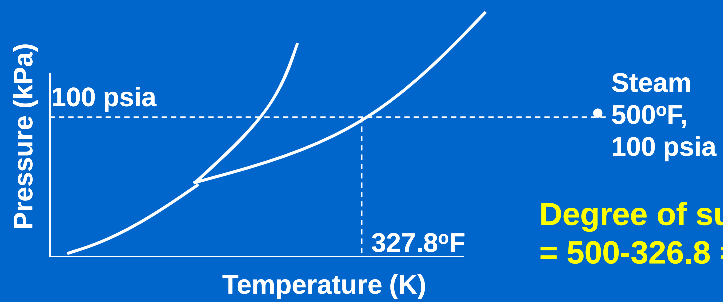
STEAM TABLE

Gas ready to start to condense : saturated gas
·············> dew point
Liquid ready to start to vaporize : saturated liquid
·············> bubble/boiling point

Mixture of liquid and vapor at equilibrium (called a wet gas)
·············> both liquid and vapor are saturated



STEAM TABLE ………. Degree of superheat ..and.. Steam quality



Degree of superheat
= 500-326.8 = 172.2ºF

Wet vapor :
consists of saturated vapor + saturated liquid

Steam quality
= weight fraction of vapor

SAT- STEAM TABLE .... Appendix A3 (Toledo, p. 572-3)

Temp (^OF)	Absolute presure lb/in^2	Spec. Vol (ft^3/lb)			Ethalpy (BTU/lb)		
		Sat. liquid v_f	Evap. v_{fg}	Sat. vapor v_g	Sat. liquid h_f	Evap. h_{fg}	Sat. vapor h_g
32	0.08859	0.016022	3304.7	3304.7	-.0179	1075.5	1075.5
.							
.							
.							
.							
80	0.5068	0.016072	633.3	633.3	48.037	1048.4	1096.4
.							
.							
.							
.							
212	14.696	0.016719	26.782	26.799	180.17	970.3	1150.5

SAT-STEAM TABLE .... Appendix A4 (Toledo, p. 574-5)

Temp (^OC)	Absolute presure kPa	Ethalpy (MJ/kg)		
		Sat. liquid h_f	Evap. h_{fg}	Sat. vapor h_g
0	0.6108	-0.00004	2.5016	2.5016
.				
.				
.				
.				
100	101.3250	0.41908	2.25692	2.67996
.				
.				
.				
.				
120	198.5414	0.50372	2.20225	2.70607

SAT-STEAM TABLE .... Example (1)

At 290°F and 57.752 psia the specific volume of a wet steam mixture is 4.05 ft³/lb. What is the quality of the steam?

Look at the Table (A.3)
v_f = 0.017360 ft³/lb
v_g = 7.4641 ft³/lb
basis : 1 lb of wet steam mixture
let x = vapor weight fraction
............> (1-x) = liquid weight fraction

$$\frac{0.017360\,ft^3}{1\,lb\,liquid}\left[(1-x)\,lb\,liquid\right]+\frac{7.4641\,ft^3}{1\,lb\,vapor}\left[x\,lb\,vapor\right]=4.05\,ft^3$$

$$0.017360-0.07360x+7.4641x=4.05$$

$$X=.....?$$

Gas Mixture

$P_t = P_a + P_b + P_c \ldots P_n$ ....> Dalton's Law of Partial Pressures

P_t = total presure

P_a, P_b, P_c and P_n = partial pressure

$n_i = f(P_i)$ ....> $P_i\, V = n_i RT$

$V_t = V_a + V_b + V_c \ldots V_n$ ....> Amagat's Law of Partial Volumes

P_t = total volume

P_a, P_b, P_c and P_n = partial volume

$n_i = f(V_i)$ ....> $P\, V_i = n_i RT$

Gas Mixture/Sat-steam table ...example (Toledo, p. 119)

Head space of can at 20°C. Pressure : 10 in Hg vacuum.
Atmospheric pressure = 30 in Hg. Volume head space = 16.4 cm^3
Calculate the quantity of air in head space!

Head space consists of air and water vapor.
$P_t = P_{air} + P_{water}$
P_t = 10 in Hg vacuum
= $P_{bar} - P_{gage}$
= (30 - 10)= 20 in Hg (3386.38 Pa/in Hg) = 67,728 Pa

P_{water} = ?
From Steam Table (appendix A4) :
at 20°C, vapor pressure of water = P_{water} = 2336.6 Pa

$P_{air} = P_t - P_{water}$
P_{air} = 67,728 - 2336.6 = 65,392.4 Pa

Gas Mixture/Sat-team table ...example (Toledo, p. 119)

Head space of can at 20°C. Pressure : 10 in Hg vacuum.
Atmospheric pressure = 30 in Hg. Volume head space = 16.4 cm^3
Calculate the quantity of air in head space!

$n_{air} = (P_{air}V)/RT$

use SI unit
T = 20 + 273 = 293 K
P_{air} = 65,392.4 Pa
V = 16.4 cm^3 = 16.4 $cm^3(10^{-6})m^3/cm^3$ = 2 x 10^{-5} m^3
R = 8315 Nm/kgmole.K

$$n_{air} = \frac{P_{air}V}{RT} = \frac{(63,392.4 \frac{N}{m^2})(1.64 \times 10^{-5} m^3)}{(8315 \frac{Nm}{kgmoles\ .K})(293\ K)}$$

$$n_{air} = 4.40 \times 10^{-7}\ kgmoles$$

Pur Hariyadi/TPG/Fateta/IPB

Gas Mixture/Sat-steam table ...example (Toledo, p. 128)

Sealing condition for canning process :

Temperature : 80°C; P atmospheric = 758 mmHg
Calculate the vacuum (mm Hg) inside the can when the content cool down to 20°C.

Answer :

Assume the headspace consists of air and H_2O vapor.
Appendix A.4.
Vapor pressure of H_2O at 80°C = 47.3601 kPa = 47.360.1 Pa
Vapor pressure of H_2O at 20°C = 2.3366 kPa = 2,336.6 Pa

$P_t = P_{air} + P_{H2O}$
$P_{air} = P_t - P_{H2O}$

Condition 1 : T = 80°C and P_t = 758 mm Hg= 101,064 Pa.
P_{air} = (101,064 - 46,360.1) Pa

$$n_{air} = \left[\frac{PV}{RT}\right]_1 = \frac{(101{,}064 - 47{,}360.1)\text{Pa} \times V\ \text{m}^3}{8315 \frac{\text{Nm}}{\text{kgmole.K}} (273 + 80)\ \text{K}} = 0.018296V \ \text{kgmole}$$

Gas Mixture/Sat-steam table ...example (Toledo, p. 128)

Sealing condition for canning process :

Temperature : 80°C; P atmospheric = 758 mmHg
Calculate the vacuum (mm Hg) inside the can when the content cool down to 20°C.

Answer :

Condition 2 : T = 20°C and P_t = ?.
n_{air} = 0.018296V kgmole

$$n_{air} = \left[\frac{PV}{RT}\right]_1 = \frac{P \times V}{8315 \frac{\text{Nm}}{\text{kgmole.K}} (273 + 20)\ \text{K}} = 0.018296V\ \text{kgmole}$$

$4.1014\ 10^{-7} PV = 0.018296V$
$4.1014\ 10^{-7} P = 0.018296$
P = 44,575 Pa absolute
P = 332 mm Hg absolute
Vacuum = 758 - 332 = 426 mm Hg

SUPERHEATED STEAM TABLE... Appendix A.2 (Toledo, p. 571)

Superheated steam : steam (water vapor) at T higher than boiling point.

Temp (°F)	Abs. Pressure (psi) 1 psi Ts=101.74°F v	h	5 psi Ts=162.24°F v	h
200	392.5	1150.2	78.14	1148.6
250	422.4	1172.9	84.21	1171.7
300	452.3	1195.7	90.24	1194.8
.				
.				
.				
600	631.1	1336.1	126.15	1335.9

Ts : saturation Temp at deignated pressure
v : spec volume (ft^3/lb)
h : enthalpy (BTU/lb)

Sat-steam table ...example (Toledo, p. 148)

How much heat is required to convert 1 lb H2O (70°F) to steam at 14.696 psia (250°F)

- steam at 14.696 psia ....> boiling point=212°F (Sat. steam Table)
  ....> at 250°F > 212°F : superheated!
- heat required = h_g (250°F, 14.696 psia) - h_f (70°F)
  = 1168 BTU/lb - 38.05 BTU/lb
  = 1130.75 BTU/lb

How much heat would be given off by cooling superheated steam at 14.696 psia (500°F) to 250°F at the same pressure?

- basis 1 lb of steam
- heat given off = h_g (14.696 psia, 500°F) - h_g (14.696 psia, 250°F)
  = 1287.4 - 1168.8
  = 118.6 BTU/lb
- superheated steam is not very efficeient heating medium!

HUKUM THERMODINAMIKA I :

………………> Konservasi Energi
………………> Kesetimbangan Energi

$Energi_{masuk} = Energi_{keluar} + Akumulasi$

Kondisi *Steady State* = tidak terjadi akumulasi :

………> $Energi_{masuk} = Energi_{keluar}$

ENERGI

………> PANAS= uap, air, padatan, dll
………> MEKANIK
………> ELEKTRIK
………> ELEKTROMAGNETIK
………> HIDROLIK
………> DLL

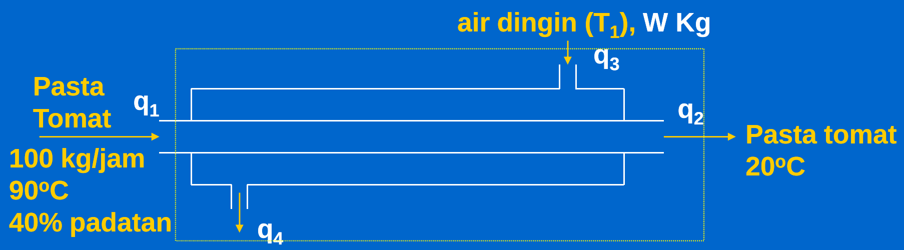
Steps in Energy Balance Preparation
= Steps in Mass Balance Preparation

- Draw a sketch or diagram describing process
  - Identify information available
- Identify boundaries of system with dotted lines
  - Identify all input (inflows) and output (outflows)
- Use symbols or letters to identify unknown items/quantities
- Write energy balance equation :
  - choose appropriate basis of calculation
  - do total and/or component energy balance
- Solve resulting algebraic equation(s)

Pur Hariyadi/TPG/Fateta/IPB

KESETIMBANGAN PANAS……………contoh 1

Hitung air yang diperlukan untuk mensuplai alat pindah panas yang digunakan untuk mendinginkan pasta tomat (100 kg/jam) dari 90ºC ke 20ºC. Pasta tomat: 40% padatan.
Naiknya suhu air pendingin ≤= 10ºC



Air "hangat"

T_2 ($T_2 > T_1$; $T_2 - T_1$ ≤= 10ºC)
$T_2 = T_1$ + 10ºC

KESETIMBANGAN PANAS……………contoh 1

Misal:

T_1 = 20ºC ← T_{ref} : 20ºC
T_2 = 30ºC

Cp. air = 4187 $\frac{J}{Kg.K}$

Cp. Pasta tomat = 3349 M + 837.36 ← Formula Siebel
= 3349(0.6) + 837.36 = 2846.76 J/Kg.K

Kandungan panas masuk:

$$q_1 = 100\ Kg\left(2846.76\ \frac{J}{Kg.K}\right)(90-20)^{o}K = 19.927\ MJ$$

Kandungan panas keluar:

$$q_2 = 100\ Kg\left(2846.76\ \frac{J}{Kg.K}\right)(20-20)^{o}K = 0$$

Pur Hariyadi/TPG/Fateta/IPB

KESETIMBANGAN PANAS..............contoh 1

Air masuk, W kg

$$q_3 = Wkg \left(4187 \frac{J}{Kg.K}\right)(20 - 20)\,^{o}K = 0$$

$$q_4 = Wkg \left(4187 \frac{J}{Kg.K}\right)(30 - 20)\,^{o}K = 41{,}870\,(w)\,J$$

Kesetimbangan Panas

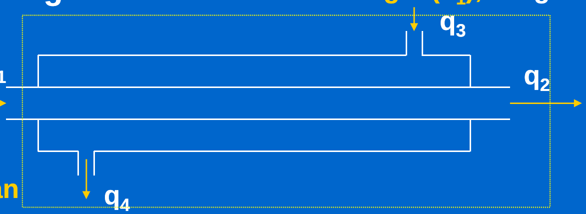
air dingin (T_1), WKg

Pasta Tomat

100 kg/jam

90°C

40% padatan



Pasta tomat 20°C

Air "hangat"

T_2 ($T_2 > T_1$; $T_2 - T_1 \leq= 10^oC$)

$T_2 = T_1 + 10^oC$

$$q_1 + q_3 = q_2 + q_4$$

KESETIMBANGAN PANAS..............contoh 1

$q_1 + q_3 = q_2 + q_4$

$q_2 = q_4$

19.927 MJ = q_4

19.927 103^3 J = 41,870 (w) J

w = 475.9 Kg

Atau: Σ Panas yang hilang dari pasta tomat =
Σ Panas yang diserap oleh air pendingin

$$100\ kg \left(2846.76 \frac{J}{Kg.K}\right)(90 - 20)K = W \left(4187 \frac{J}{Kg.K}\right)(T_1 + 10 - T_1)\,^oK$$

100 (2846.76) (70) = 41,870 W

W = 475.9 Kg

KESETIMBANGAN PANAS…………..contoh 2

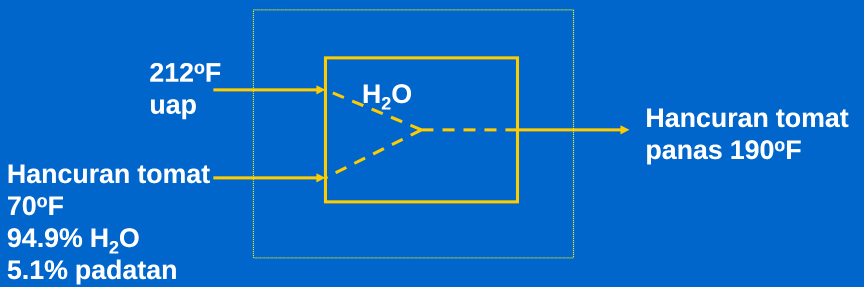
Pemblansiran hancuran tomat dengan uap

1. Hancuran tomat: 94.9% H_2O
   5.1% padatan
   70°F
2. Uap yang digunakan: uap jenuh pada 1 atm (212°F)
3. Kondensat uap akan mengencerkan hancuran tomat dan suhu hancuran tomat keluar = 190°F
4. $C_{padatan\ tomat} = 0.5 \frac{BTU}{lb.^{o}F}$

Hitung:

Konsentrasi total padatan hancuran tomat yang dihasilkan

KESETIMBANGAN PANAS…………..contoh 2



Basis: 100 lb

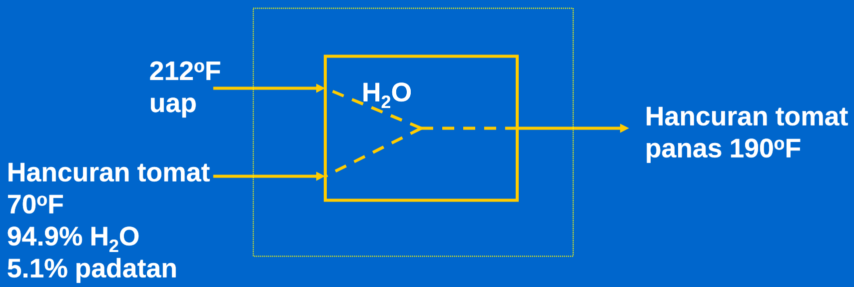
<u>Hancuran tomat masuk</u>

94.9 lb air, 70°F → $h_1 = 38.052\ ^{BTU}/_{lb}$ (daftar uap)

5.1 lb padatan, 70°F $h_2 = C_p(T - T_o) = 0.5\ (70 - 0) = 35\ ^{BTU}/_{lb}$

↑ $T_0 = T_{ref} = 0^oF$

KESETIMBANGAN PANAS..............contoh 2



Uap masuk

X lb, h_3 = 1150.5 BTU/lb (Tabel Uap)

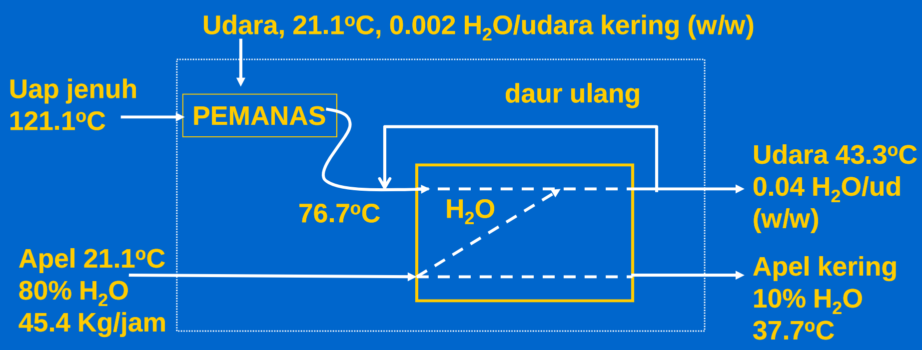
Produk

(94.9 + x) lb air, 190°F → h_4 = 158 BTU/lb (Tabel Uap)

5.1 lb padatan, 190°F $h_5 = C_p$ (190 - 0) = 85 BTU/lb

Total keseimbangan entalpi: $h_1 + h_2 + h_3 = h_4 + h_5$

KESETIMBANGAN PANAS..............contoh 3



Notasi: q_1 : entalpi air dalam udara masuk (uap pada 121.1°C)
q_2 : entalpi udara kering pada 21.1°C
q_3 : entalpi air dalam apel masuk (air pada 21.1°C)
q_4 : entalpi padatan dalam buah apel masuk pada 21.1°C
q : masukan panas
q_5 : entalpi air dalam udara keluar (uap pada 43.3°C)
q_6 : entalpi udara kering keluar (43.3°C)
q_7 : entalpi air pada apel keluar (37.7°C)
q_8 : entalpi padatan dalam apel keluar (37.7°C)

KESETIMBANGAN PANAS……………contoh 3

Kesetimbangan Entalpi :

$q + q_1 + q_2 + q_3 + q_4 = q_5 + q_6 + q_7 + q_8$

Kesetimbangan massa untuk padatan apel :

(0.2) (45.4) = x (0.9) x= berat apel kering

x = 10.09 Kg/hr

Kesetimbangan air:

Air hilang dari apel = air diterima oleh udara pengering

45.4 - 10.09 = 35.51 Kg/jam

Per kilogram udara kering → (0.04 - 0.002) = 0.038 $\frac{\text{Kg air}}{\text{Kg udara kering}}$

Mis. W = massa udara yang kering (Kg)

∴ Total air yang diterima = 0.038 (w) kg

35.31 = 0.038 w

w = 929.21 Kg udara kering/jam

KESETIMBANGAN PANAS……………contoh 3

q_1 = entalpi air dalam udara masuk (uap pada 21.1°C)

Tabel uap → h_q = 2.54017 MJ/kg (interpolasi)

$$q_1 = (929.21\,\text{kg ud. kering})\left(0.002\,\frac{\text{Kg air}}{\text{Kg. ud. kering}}\right)\left(2.54017\,\frac{\text{mJ}}{\text{Kg}}\right)$$

$$q_1 = 4.7207\,\frac{\text{mJ}}{\text{Kg}}$$

q_2 = entalpi udara kering pada 21.1°C

$q_2 = m.C_p.dT - m.C_p.(T_2 - T_{ref})$

Dari tabel 25°C: C_{pm} = 1008 J/Kg.K

50°C: C_{pm} = 1007 J/Kg.K

Asumsi: C_{pm} pada 21.1°C = 1008 J/Kg.K

$$q_2 = (929.21\,\text{kg ud. kering})\left(1008\,\frac{\text{J}}{\text{Kg.K}}\right)(21.1 - 0)\,\text{K}$$

q_2 = 19.7632

KESETIMBANGAN PANAS...............contoh 3

q_3 = entalpi air dalam apel masuk (air pada 21.1°C)

Tabel uap → h_f = 0.08999 MJ/kg (interpolasi)

q_3 = 45.4 (0.8) (0.08999) = 3.2684 mJ

q_4 = entalpi padat dalam apel (21.1°C)

q_4 = (45.4) (0.2) (837.36) (21.1 - 0) = 0.16043 mJ

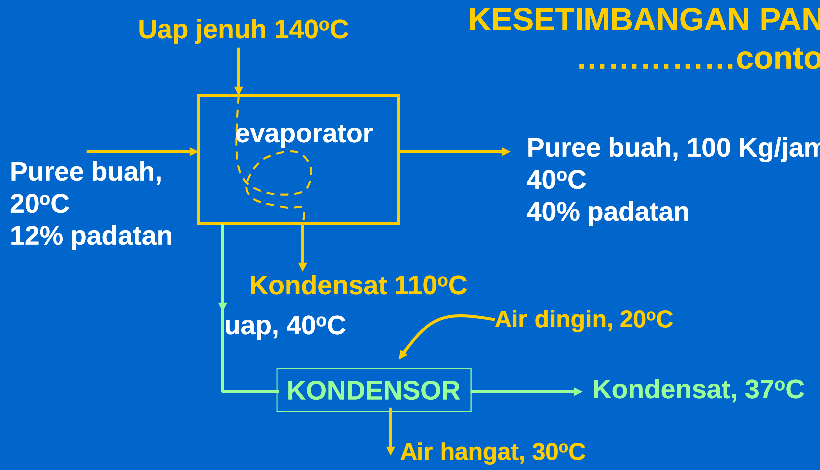
C_p padatan = 837.36 $\frac{J}{Kg.K}$

q_5 = entalpi air dalam udara kering (43.3°C)

q_5 = (929.21 kg ud. Kering) (0.04 $\frac{Kg\ air}{Kg\ ud.\ kering}$) ($h_g$ pada 43.3°C)

Tabel uap
h_g = 2.5802 mJ/Kg

KESETIMBANGAN PANAS ....contoh 4



a. hitung laju aliran masing-masing produk (kondensat).
b. hitung konsumsi uap (uap jenuh yangdipakai, 140°C, akan berkondensasi pada 110°C)
   $C_{total\ padatan}$ = 2.10 kJ/Kg.K
   C_{air} = 4.19 kJ/Kg.K
C. pada kondensor: hitung laju aliran air dingin (gunakan Tabel Uap

TERIMAKASIH

SELAMAT BELAJAR