# AMME2262 – SEMESTER 2

*Engineering thermodynamics is the science of energy that applies to the design and analysis of energy conversion systems*

Energy can be:

- Thermal or internal energy (stored in molecular forces)
- Chemical energy in molecular bonds (combustion)
- Kinetic energy (motion)
- Potential energy (elevation)
- Nuclear, magnetic and electric energy
- Sum of all energies = total energy E of the system

## Important Terms:

| | |
|---|---|
| **Pressure (Pa, $Nm^{-2}$)** | • *Absolute pressure*: measured relative to absolute zero pressure (**used mostly**)<br>• *Gage/Vacuum pressure*: measured relative to atmospheric pressure<br>$P_{abs} = P_{atm} \pm P_{gage}$ $P_{vac} = P_{atm} - P_{abs}$ $P_{gage} = P_{abs} - P_{atm}$ |
| **Temperature (K)** | • Use Kelvin Scale for units<br>$T(K) = T(^\circ C) + 273.15$<br>• Engineering thermodynamics deals with temperatures in the range of 200K-3000K |
| **Force (N)** | • F=ma, or where a=g (gravity) F=mg<br>• kgf, relative to local gravity |
| **Pascal's law:** | • The pressure applied to a confined fluid increases the pressure throughout by the same amount<br>$P_1 = P_2 \rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2} \rightarrow \frac{F_2}{F_1} = \frac{A_2}{A_1}$ |

## Density and specific gravity

| Density ($kgm^{-3}$) | Specific Volume ($m^3kg^{-1}$) |
|---|---|
| $\rho = \frac{m}{V}\left(kg/m^3\right)$ | $v = \frac{V}{m} = \frac{1}{\rho}\left(m^3/kg\right)$ |
| **Specific Weight ($Nm^{-3}$)** | **Specific Gravity** |
| $\gamma_s = \rho g$ | $SG = \frac{\rho}{\rho_{H_2O}}$ |

## Determining Type of System

<table>
<tr><th><u>Closed System</u></th><th><u>Open System</u></th></tr>
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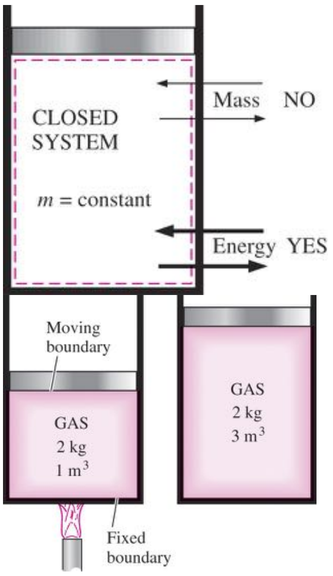
- no mass transfer across boundaries
- Energy transfer across boundaries

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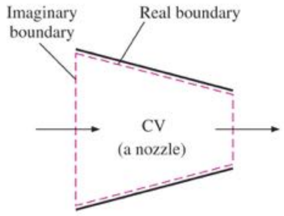
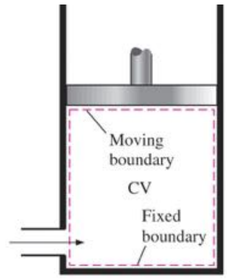
- mass transfer across boundaries




(*a*) A control volume with real and imaginary boundaries




(*b*) A control volume with fixed and moving boundaries

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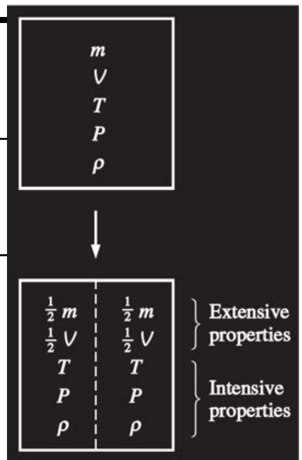
***<u>Assumption:</u>*** *Substances are treated as a* ***continuum*** *because of the very large number of molecules even in an extremely small volume (no need to consider on atomic level)*

## Properties of Systems:

| | |
|---|---|
| **Intensive Property** | *Independent* of System Size<br>• Temperature-T (K), Pressure-P (Pa), Density- $\rho$ (kg/m$^3$) |
| **Extensive Property** | *Dependent* of System Size<br>• Mass - m (kg), Volume - V (m$^3$), Energy - E (J) |
| **Specific Properties** | Extensive Properties per unit mass that become intensive properties<br>• mass-m (kg)<br>• *V/m=*, specific volume (m3/kg)<br>• *U/m=u*, specific internal energy (kJ/kg)<br>• *E/m=e*, specific energy (kJ/kg) |




## Units (metric system)

All equations must be dimensionally homogeneous

## Equilibrium

- System in thermodynamic equilibrium if it is in thermal, mechanical, phase and chemical equilibrium.
- Properties of system do not change over entire system

## Temperature and the Zeroth law of thermodynamics

- Zeroth law states that two bodies are in thermal equilibrium if both have the same temperature reading even without being in contact
- Heat moves from hot to cold objects

## Equations Of State (The Ideal Gas Equation)

Ideal Gas Equation relates pressure, temperature and specific volume of a substance. The assumptions made for it to hold true include:

- The gas is composed of a large amount of small molecules
- The gas molecules are elastic (KE is conserved)
- The size and total volume of the molecules is small relative to the volume
- Thermal motions of the gas are random

**Note:** real gases can be approximated by an ideal gas at "low" densities: "low" pressures and "high" temperatures

| Substance | *R*, kJ/kg.K |
|---|---|
| Air | 0.2870 |
| Helium | 2.0769 |
| Argon | 0.2081 |
| Nitrogen | 0.2968 |

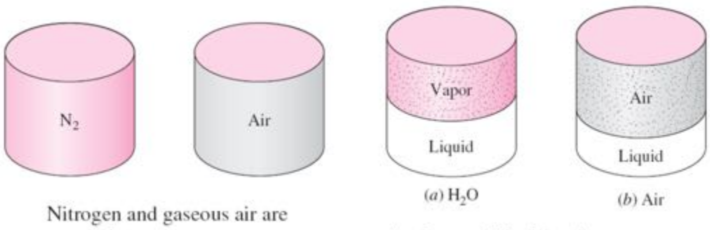
## State Postulate

**State postulate:** The number of properties required to fix the state of a system

- The state of a **simple* compressible system** (i.*e. A system that involves no electrical, magnetic, gravitational, motion, and surface tension effects*) is completely specified by **2 independent, intensive properties**
- The state of the nitrogen here is fixed by two independent, intensive properties


## Pure Substances

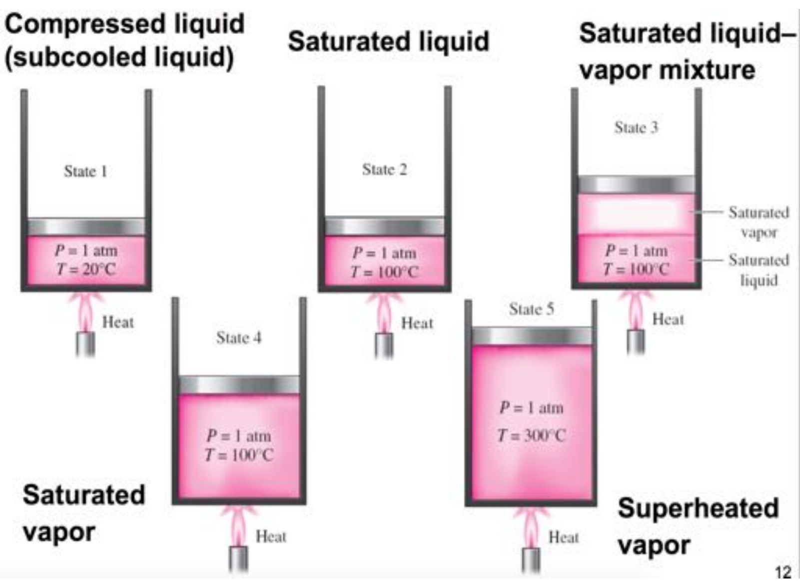
- A substance that has a fixed chemical composition throughout.
- Air is a pure substance at atmospheric pressure and temperature, despite being a mixture of several gases

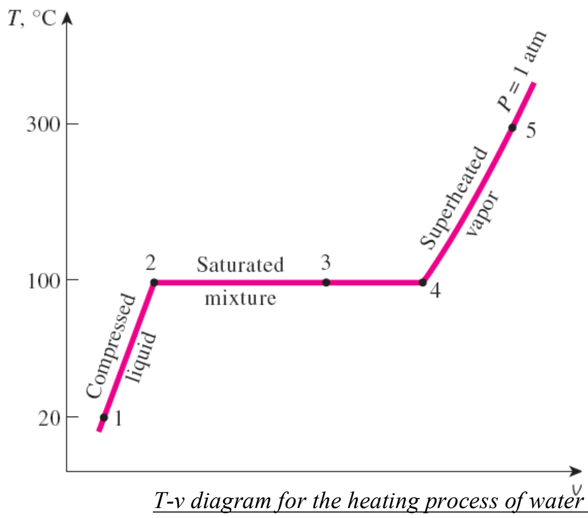



Nitrogen and gaseous air are pure substances.

A mixture of liquid and gaseous water is a pure substance, but a mixture of liquid and gaseous air is not.

| Phase Change | Description |
|---|---|
| 1. **Compressed liquid (subcooled liquid)**: | A substance that it is ***not about*** *to vaporize* (i.e. liquid phase) |
| 2. **Saturated liquid**: | Exists as liquid that is ***about to*** *vaporize.* |
| 3. **Saturated liquid–vapor mixture**: | The state at which the *liquid and vapor phases coexist* in equilibrium |
| 4. **Saturated vapor**: | A vapor that is ***about to*** *condense* |
| **5. Superheated Vapour** | A vapor that is ***not about*** *to condense* (i.e., not a saturated vapor) |





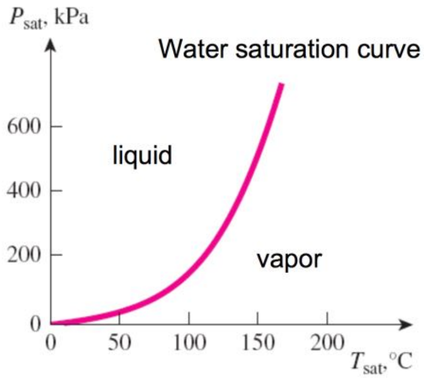

*T-v diagram for the heating process of water at constant pressure*

- **Reversing** the process 5 --> 1 following the same path releases the **same amount of heat** as was added in the forward process

The temperature at which water starts boiling depends on the pressure; therefore, **if the pressure is fixed, so is the boiling temperature.**

**Saturation temperature $T_{sat}$**: The temperature at which a pure substance changes phase at a given pressure.

**Saturation pressure $P_{sat}$**: The pressure at which a pure substance changes phase at a given temperature.




*The liquid–vapor saturation curve of a pure substance (water) – water boils at 100°C at 1 atm pressure*

Saturation (boiling) pressure of water at various temperatures

| Temperature, $T$, °C | Saturation pressure, $P_{sat}$, kPa |
|---|---|
| −10 | 0.26 |
| −5 | 0.40 |
| 0 | 0.61 |
| 5 | 0.87 |
| 10 | 1.23 |
| 15 | 1.71 |
| 20 | 2.34 |
| 25 | 3.17 |
| 30 | 4.25 |
| 40 | 7.39 |
| 50 | 12.35 |
| 100 | 101.4 |
| 150 | 476.2 |
| 200 | 1555 |
| 250 | 3976 |
| 300 | 8588 |

Variation of the standard atmospheric pressure and the boiling (saturation) temperature of water with altitude

| Elevation m | Atmospheric pressure, kPa | Boiling temperature, °C |
|---|---|---|
| 0 | 101.33 | 100.0 |
| 1,000 | 89.55 | 96.5 |
| 2,000 | 79.50 | 93.3 |
| 5,000 | 54.05 | 83.3 |
| 10,000 | 26.50 | 66.3 |
| 20,000 | 5.53 | 34.7 |

| **At a given temperature if:** | **At a given pressure if:** |
|---|---|
| • Pressure < liquid-vapor saturation pressure = vapor<br>• Pressure > liquid-vapor saturation pressure = liquid | • Temp. < liquid-vapor saturation temp. = liquid<br>• Temp. > liquid-vapor saturation temp. = vapour |

## Latenet Heat

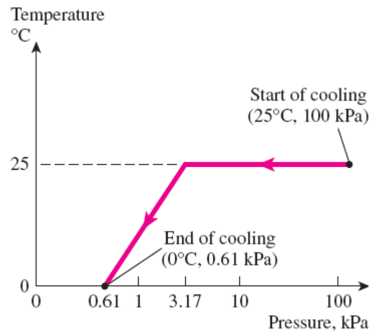
| | |
|---|---|
| **Latent heat**: | amount of energy absorbed or **released during a phase- change process** |
| **Latent heat of fusion:** | amount of energy absorbed during **melting** (*equal to energy released during freezing*) |
| **Latent heat of** | amount of energy absorbed during **vaporization** (*equal to energy released* |

| vaporization: | during condensation) |
|---|---|

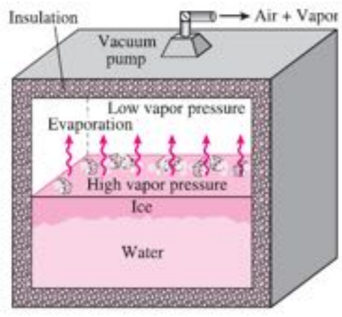
*Magnitudes of the latent heats dependent on temp. or pressure at which the phase change occurs.

e.g. At 1 atm pressure, the latent heat of fusion of water = 333.7 kJ/kg and the latent heat of vaporization = 2256.5 kJ/kg.

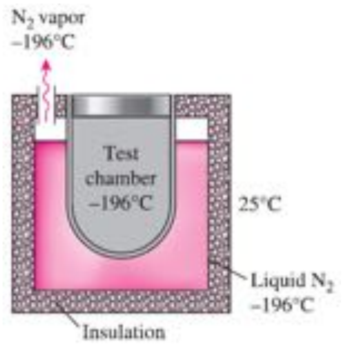
## Consequences of $T_{sat}$ and $P_{sat}$ Dependence



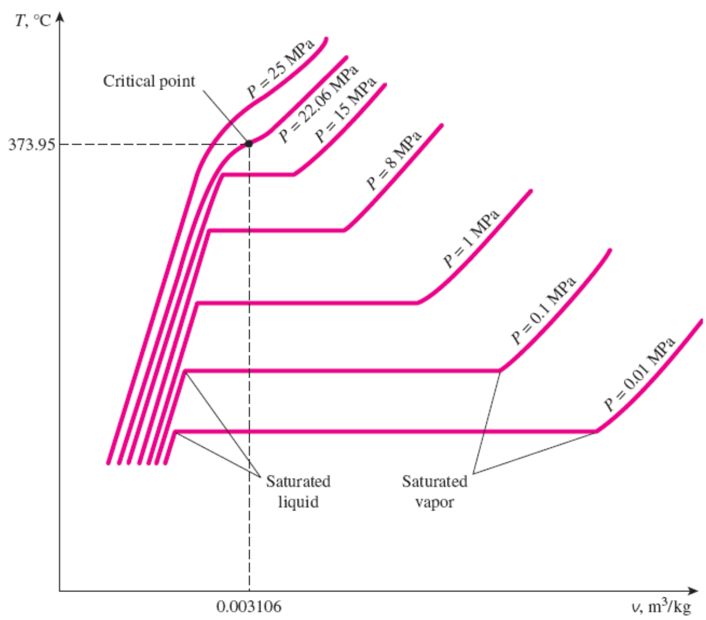

*The variation of the temperature of fruits and vegetables with pressure during vacuum cooling from 25°C to 0°C*




*Ice made by evacuating air space in water tank*




*The temperature of liquid nitrogen exposed to the atmosphere remains constant at -196°C and thus maintains the test chamber at -196°C*




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