

Thermodynamics
Professor Anand T N C
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Lecture No 27
Ideal gas - Part 1

(Refer Slide Time 0:14)

- Problem solving methodology
 - (i) Are there one or more systems/control volumes?
 - (ii) Identify work/heat flow/ forces
 - (iii) What do we know about initial state?
 - (iv) What is the TD model: Property relation: Ideal gas? Steam?
 - (v) What do we know about process? Something constant? Process relation?
 - (vi) What do we know about final state?
 - (vii) Does sketching on a p-v (etc) diagram help?
 - (viii) Use conservation of energy, mass etc.
 - (ix) Is trial and error necessary?



Figure 1.

While solving problems, we are going to use a particular methodology which is listed in Fig. 1.

1. We are going to find out whether there are one or more systems or control volumes or whether we can deal with the substance considering it to be a system or a control volume.
2. We will then identify energy transfers across the boundary in the form of either work or in the form of heat. For this, we may also need to find out all the forces acting on the system so that we can find out work interactions.
3. We will need to list out what we know about the initial state before the process happens, e.g., properties of the system such as pressure, temperature, volume, etc.
4. This step asks about the thermodynamic model (TD model) to be implemented, for example, a property relation for an ideal gas.

In this lecture, we are going to discuss in detail what the 4th step of the problem solving methodology is all about. After that, we will go through the methodology again.

(Refer Slide Time 1:48)

- What is an ideal gas?



What is an ideal gas which many of us have heard about or studied at some point in school?

(Refer Slide Time 1:57)

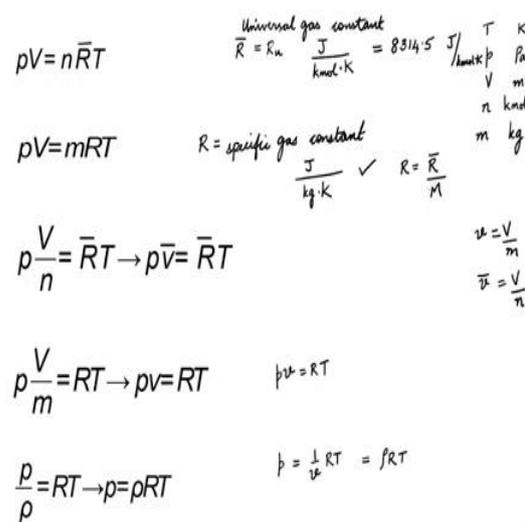
- Any gas can be treated as an ideal gas if its molecules exert negligible attractive (van der Waal) forces on each other
- Assumption is valid if molecules are separated wide apart
 - $v \rightarrow \infty$ and $p \rightarrow 0$
 - Follows Boyle's law ✓ $p \propto \frac{1}{v}$
 - Follows Charles' law ✓ $v \propto T$
 - $pV/T = \text{constant}$ ✓



Any gas can be treated as an ideal gas, if its molecules exert negligible attractive forces on each other. So, the molecules of an ideal gas do not affect each other. This assumption is valid if the molecules are separated and they are sufficiently far apart, which means the volume as well as specific volume of this gas must be very large. For an ideal gas, specific volume $v \rightarrow \infty$ and its pressure $p \rightarrow 0$.

Ideal gas follows the Boyle's law which is stated as follows: pressure of the gas into volume of the gas is constant if its temperature is constant. Mathematically, $pV = \text{constant}$ at constant temperature (isothermal process). Ideal gas also follows Charles' law which is stated as follows: volume of the gas is directly proportional to its temperature at constant pressure. Mathematically, $v \propto T$ at constant pressure (specific volume v is used in both the expression as we are dealing with the system here). Putting these two laws together, we get $\frac{pV}{T} = \text{constant}$. Ideal gas follows the above relation.

(Refer Slide Time 3:47)



$pV = n\bar{R}T$
 $\bar{R} = R_u = \frac{\text{J}}{\text{kmol} \cdot \text{K}} = 8314.5 \frac{\text{J}}{\text{kmol} \cdot \text{K}}$
 $R = \text{specific gas constant} = \frac{\text{J}}{\text{kg} \cdot \text{K}}$
 $R = \frac{\bar{R}}{M}$
 $p\frac{V}{n} = \bar{R}T \rightarrow p\bar{v} = \bar{R}T$
 $p\frac{V}{m} = RT \rightarrow p v = RT$
 $\frac{p}{\rho} = RT \rightarrow p = \rho RT$

Units:
 T K
 p Pa
 V m³
 n kmol
 m kg
 $v = \frac{V}{m}$
 $\bar{v} = \frac{V}{n}$



For an ideal gas, $pV = n\bar{R}T$, where p is the pressure in pascal, V is volume in m³, n is the number of moles in kmol (kilomole), \bar{R} (R_u) is the universal gas constant in J/kmol·K, and T is the temperature in kelvin. $R_u = \bar{R} = 8314.5 \text{ J/kmol} \cdot \text{K}$. The expression $pV = n\bar{R}T$ can be used when the quantity of gas is given in moles or kilomoles. However, we do not use this expression often. The expression which is used more commonly is $pV = mRT$, where m is the mass of the gas in kg and R is the specific gas constant in J/kg·K. The specific gas constant is different from the universal gas constant. The value of the universal gas constant is the same irrespective of the gas under consideration which is $8314.5 \text{ J/kmol} \cdot \text{K}$ for all the gases. However, this is not true for the specific gas constant. It changes as the gas changes.

Dividing by n throughout the expression $pV = n\bar{R}T$, we get $p\bar{v} = \bar{R}T$, where $\bar{v} \left(= \frac{V}{n} \right)$ is the molar specific volume. Dividing by m throughout the expression $pV = mRT$, we get

$pv = RT$, where v is the specific volume. Since $v = \frac{1}{\rho}$, $p = \rho RT$, where ρ is density of the gas.

Specific gas constant is obtained from the universal gas constant by dividing the universal gas constant by the molecular weight of the gas under consideration. For example, the specific

gas constant for nitrogen is $\frac{8314.5 \frac{J}{kmol \cdot K}}{28 \frac{kg}{kmol}} = 297 \frac{J}{kg \cdot K}$.