

Basics of Mechanical Engineering-3

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Week 03

Lecture 11: Tutorial 1 (Introduction to Thermodynamics)

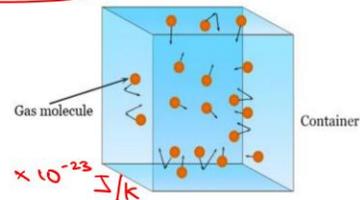
Welcome to week 3 of the course Basics of Mechanical Engineering. We are discussing thermodynamics and fluid mechanics in this course. Professor Ramkumar has covered in the first two weeks an introduction to thermodynamics, and we have also discussed in detail the basic laws of thermodynamics. This is a tutorial session that I will take on the introduction to thermodynamics, where I will discuss some problem statements based on the relationships you have learned in weeks one and two. I am Dr. Amandeep Singh Oberoi from IIT Kanpur.

Kinetic Interpretation of Temperature



- The kinetic energy arises from the motion of particles: vibration in solids, sliding in liquids, and free motion in gases.
- The average kinetic energy per particle is directly proportional to the absolute temperature T.
- This relation is given by:

$$KE_{avg} = \frac{3}{2} kT$$



where k is the Boltzmann constant.

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

- The lowest theoretical temperature, absolute zero (0 K), corresponds to zero kinetic energy, where molecular motion would theoretically cease.

Just to recall the concept of the kinetic interpretation of temperature, this is the relation that we have. The kinetic energy arises from the motion of particles, vibration in solids, sliding in liquids, and free motion in gases. The average kinetic energy per particle is

directly proportional to the absolute temperature. We have temperature here. It is directly proportional here.

And the relation is given by $KE_{avg} = \frac{3}{2} kT$ where k is the Boltzmann constant, and this value of k is 1.38×10^{-23} joules per Kelvin. The lowest theoretical temperature, absolute zero, which is 0 Kelvin, corresponds to zero kinetic energy, where molecular motion would theoretically cease. This is just a recall of the concept.

Kinetic Interpretation of Temperature



Problem Statement: What is the average kinetic energy of a molecule in air at room temperature (25°C)?

Solution:

$$T = 25^\circ\text{C}$$

Conversion into Kelvin scale:

$$= 25 + 273$$
$$= 298 \text{ K}$$

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

$$KE_{avg} = \frac{3}{2} kT$$

$$= \frac{3}{2} \times 1.38 \times 10^{-23} \times 298$$

$$= 6.1686 \times 10^{-21} \text{ J}$$



Let me directly come to a problem statement. It is a very simple problem statement where it is mentioned that the average kinetic energy of a molecule in air at room temperature, 25 degrees, is to be determined.

Conversion into Kelvin Scale:

$$25 + 273 = 298 \text{ K}$$

$$KE_{avg} = \frac{3}{2} kT$$

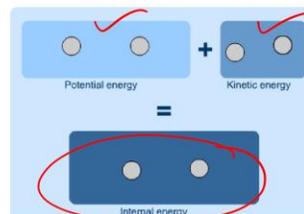
$$= \frac{3}{2} \times 1.38 \times 10^{-23} \times 298$$

$$= 6.1686 \times 10^{-21} \text{ J}$$

This is the very first problem statement of the course and I have kept it the most simple.

Internal Energy

- It refers to the energy contained within the system.
- The energy represents the overall energy of the system and may include many forms of energy such as:
 - ✓ potential energy,
 - ✓ kinetic energy, etc.
- In a chemical reaction, we know about energy transformations and basic thermodynamics provides us with information regarding energy change associated with the particles of the system.

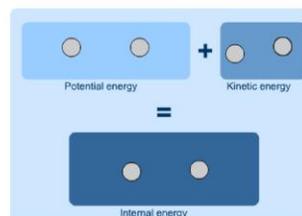


Now, let us see or recall the concept of Internal Energy. Internal energy refers to the energy contained within the system. The energy represents the overall energy of the system. In the overall energy, we have potential energy and kinetic energy both. So, we have potential energy that is stored. We have kinetic energy based upon the movement. Total internal energy for the two particles is shown here.

In a chemical reaction, we know about energy transformation, and basic thermodynamics provides us with information regarding energy changes associated with particles of the system. This energy change is the change in internal energy.

Internal Energy

- It is the total energy within the substance.
- It is the sum of many types of energies like vibrational energy, translational energy etc.
- Its absolute value cannot be determined but experimentally change in internal energy (ΔU) can be determined by $\Delta U = U_2 - U_1$



It is the total energy within the substance. It is the sum of many types of energies, like vibrational energy, translational energy, etc. The absolute value cannot be determined, but experimentally, we can find the change in internal energy, that is, $\Delta U = U_2 - U_1$.

Internal Energy



Factors Affecting the Internal Energy

- (a) Work is done on or by the system or matter enters or leaves the system.
- (b) Heat passes into or out of the system.

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

$$\Delta U = Q - W$$

Change in internal energy

Heat added to the system

Work done by the system



Image Source: <https://medium.com/illumination/the-first-law-of-thermodynamics-2cf43aad9039> 6

Also, this change in internal energy is the difference between heat added to the system and work done by the system. Work is done on or by the system, or matter enters or leaves the system. Heat passes into or out of the system. So, the change in internal energy of the system equals heat added to the system minus the work done by the system.

Internal Energy



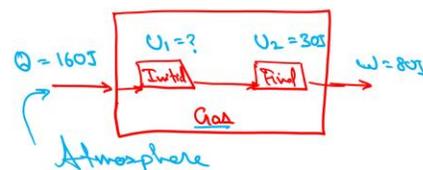
Problem Statement: A gas absorbs 160 J of heat from its surroundings and does 80 J of work on its surroundings. If the final internal energy is 30 J then what is the initial internal energy of the gas?

Solution:

$$\begin{aligned}
 Q &= 160 \text{ J} \\
 W &= 80 \text{ J} \\
 U_2 &= 30 \text{ J} \\
 \Delta U &= Q - W \\
 &= 160 - 80 \\
 &= 80 \text{ J}
 \end{aligned}$$

$$\begin{aligned}
 \Delta U &= U_2 - U_1 \\
 80 &= 30 - U_1
 \end{aligned}$$

$$U_1 = -50 \text{ J}$$



7

Using these relations, let us now try to solve a problem statement where it says: gas absorbs 160 joules of heat from its surroundings and does 80 joules of work. This means 160 joules here is Q . 80 joules of work is done. If the final internal energy is 30 joules, then what is the initial internal energy of the gas?

Now, out of U_2 and U_1 , if I try to make a small illustration for this, let us see it this way: we have a gas here, and we have initial and final internal energies. And in this system, we have heat coming in and work being done by the system. I could say it enters here, it goes, and then it goes out. So here, this is U_1 , the initial internal energy, which is to be determined. We know U_2 is 30 joules. We know work done is 80 joules. We know the gas absorbs 160 joules of heat from the surroundings.

So, that is Q , which is the heat entering the system, at 160 joules. So, this is gas, and outside here we have the atmosphere from where this energy enters. Now, let us find the initial internal energy. We know U_2 here is given as 30 joules, which is the final energy.

$$dU = Q - W$$

$$= 160 - 80$$

$$= 80 \text{ J}$$

$$dU = U_2 - U_1$$

$$80 = 30 - U_1$$

$$U_1 = -50 \text{ J}$$

So, there could be some problem statements like this in the activity questions.

There could be some problem statements in the exams or maybe in the quizzes. So, it's a very simple problem statement, just trying to relate to the system.

Temperature Scales Conversion



- Around the world, various fields and regions utilize different temperature scales for measurement.
- To ensure consistency and enable accurate conversions, it's essential to understand the relationships between these scales.
- Below, you will find information on the four primary temperature scales used globally, along with the formulas that define their connections to one another.

$$\frac{F-32}{180} = \frac{C}{100} = \frac{K-273}{100} = \frac{R}{80}$$

Where;

F = Temperature in Fahrenheit Scale

C = Temperature in Celsius Scale

K = Temperature in Kelvin Scale

R = Temperature in Réaumur Scale



8

Temperature Scales Conversion



Problem Statement: Convert 113°F to Kelvin.

Solution:

Temp in Fahrenheit, $F = 113^{\circ}\text{F}$

$$\frac{F-32}{180} = \frac{K-273}{100}$$

$$K = \frac{100(F-32)}{180} + 273$$

$$K = \frac{100(113-32)}{180} + 273$$

$$K = 318^{\circ}\text{K}$$



9

Next, I will move to the topic: Revision of the Temperature Scales Conversion. This is also a very commonly used transformation system, and it is very important to learn. Around the world, various fields and regions utilize different temperature scales for measurement.

This is all discussed. Only these scales: $(F-32)/180$, the difference $C/100$, $(K-273)/100$, $R/80$ for the Fahrenheit, Celsius, Kelvin, and Riemann scale. These relationships are already discussed.

Let me come to a problem statement. Convert 113°F to Kelvin. We have been given temperature in Fahrenheit. That is $F = 113$ degrees Fahrenheit.

$$(F - 32)/180 = (K-273)/100$$

$$K = \frac{100(F-32)}{180} + 273$$

$$K = \frac{100(113-32)}{180} + 273$$

$$K = 318 \text{ K}$$

There could be problems where we need to convert Fahrenheit to Celsius or maybe Fahrenheit to Riemann scales. Commonly used scales are generally Fahrenheit, Celsius, and Kelvin.

First Law of Thermodynamics

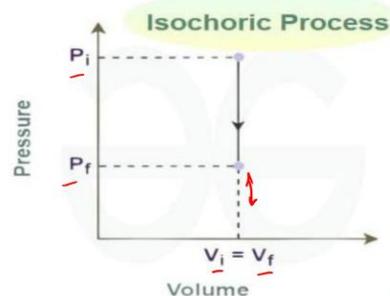


Isochoric Process (Constant Volume)

Definition: An isochoric process is one in which the **volume remains constant** throughout the process.

Key Characteristics:

- Any heat added or removed changes the internal energy and pressure.
- No work is done since the volume doesn't change.



Examples:

- Heating of gas in a sealed, rigid container.
- Combustion of fuel in an engine cylinder before the piston moves.
- Pressure increase in a pressure cooker before the safety valve operates.



Now, let me come to the laws of thermodynamics. The First Law of Thermodynamics involves an isochoric process. There is an isobaric process. Many processes were discussed in week 2. To discuss the isochoric process, it is a constant-volume process. An isochoric process is one in which the volume remains constant throughout.

Three characteristics are: any heat added or removed changes the internal energy and pressure, but the volume remains constant. No work is done since the volume doesn't change. Examples include heating gas in a sealed or rigid container. The volume of the rigid container remains the same, like your LPG gas cylinders at home. Combustion of fuel in an engine cylinder before the piston moves.

Those are metallic parts. The volume is 100% fixed. There is no change. Pressure increases in a pressure cooker before the safety valve operates. These are examples of an isochoric process where the volume remains the same. That is, V_{initial} is equal to V_{final} .

First Law of Thermodynamics



Process	Q	W = ∫PdV	P-V-T Relation
Reversible ✓ Constant Volume	$Q = \Delta U$ $= \dot{m}c_v(T_2 - T_1)$	W = 0 ✓	$P_1/T_1 = P_2/T_2$

Where

\dot{m} - Mass flow rate, kg/s

c_v - Specific heat at constant volume, J/kgK

T_1, T_2 - Temperatures at inlet and outlet, K

P_1, P_2 - Pressure at inlet and outlet, Pa



However, the pressure varies. Now, isochoric means a constant volume process. For a reversible constant volume process,

$$Q = \Delta U = \dot{m}c_v(T_2 - T_1)$$

Where

\dot{m} - Mass flow rate, kg/s

C_v - Specific heat at constant volume, J/kgK

T_1, T_2 - Temperatures at inlet and outlet, K

P_1, P_2 - Pressure at inlet and outlet, Pa

First Law of Thermodynamics

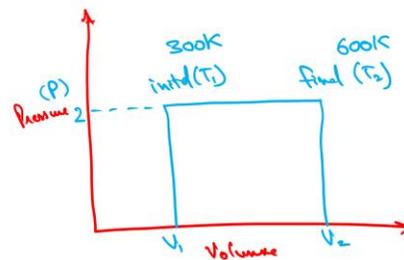


Problem Statement: Air enters a steady-flow system at a pressure of 2 bar and a temperature of 300 K. It is heated at constant pressure until its temperature reaches 600 K. The mass flow rate is 2 kg/s. Assume air behaves as an ideal gas with $R=0.287$ kJ/kgK and $C_p=1.005$ kJ/kgK. Calculate:

- 1) The rate of heat transfer to the air.
- 2) The rate of work done by the system.
- 3) The ratio of final to initial volume.

Solution:

$$\begin{aligned} P &= 2 \text{ bar} \\ T_1 &= 300 \text{ K} \\ T_2 &= 600 \text{ K} \\ \dot{m} &= 2 \text{ kg/s} \end{aligned}$$



16

First Law of Thermodynamics



Solution:

$$\begin{aligned} T_2 &=? \\ P_1/T_1 &= P_2/T_2 \\ 1/290 &= 2/T_2 \\ T_2 &= 290 \times 2 = 580 \text{ K} \end{aligned}$$

$$\begin{aligned} Q &= \dot{m} C_v (T_2 - T_1) \\ &= 1.3 \times 0.718 \times (580 - 290) \\ &= 1.3 \times 0.718 \times 290 \\ &= 541.87 \text{ kW} \quad (\text{Heat rejected for isochoric process}) \\ &\quad (\text{Constant Volume}) \end{aligned}$$



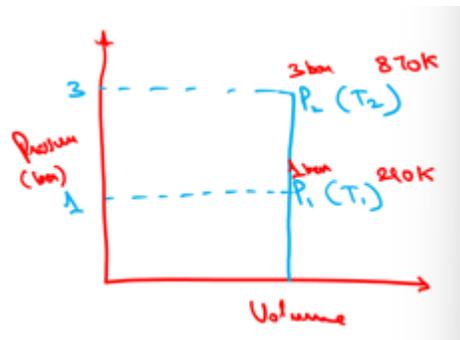
Using these relations, let us try to solve a problem. A steady flow system is operating with air as the working fluid. The air undergoes a reversible process at constant volume, that is, we are talking about isochoric. The mass flow rate through the system is 1.3 kg per second. At the inlet, the air has a pressure of 1 bar and a temperature of 290 Kelvin. At the outlet, the pressure is 3 bar. Assuming air behaves as an ideal gas with a constant specific heat at constant volume, that is, C_v is given as 0.718 kJ/kgK. Determine the rate of heat transfer.

The rate of heat transfer is to be determined. That is, heat exerted for this process in kilowatts. Here, as you saw in the figure on the previous slide, we have constant volume. This is volume here.

On the x-axis and the y-axis, we have pressure. Pressure is in bar. It has been given here: \dot{m} , which is the mass flow rate. It is in kilograms per second as 1.3 kg per second. P_1 is the pressure at 1 bar at the inlet, and the temperature here is 290 Kelvin.

P_2 is 3 bar, and C_v is also given as 0.718 kilojoules per kg Kelvin. The volume is constant. There is an initial pressure of 1 bar. There is a final pressure of 3 bar. So, this is the P_1 and P_2 level, and here correspondingly we have T_1 here and T_2 here.

Now, first, calculate T_2 so that we can calculate the heat exerted. The heat exerted would be calculated using this relation Q , and we need $\dot{m} C_v (T_2 - T_1)$. Here, T_2 is missing.



$$P_1/T_1 = P_2/T_2$$

$$1/290 = 3/T_2$$

$$T_2 = 290 \times 3 = 870 \text{ K}$$

$$Q = m \cdot C_v (T_2 - T_1)$$

$$= 1.3 \times 0.718 \times (870 - 290)$$

$$= 1.3 \times 0.718 \times 580$$

$$= 541.37 \text{ kW}$$

That is, the heat exerted for the isochoric process, which is at constant volume.

First Law of Thermodynamics



Isobaric Process (Constant Pressure)

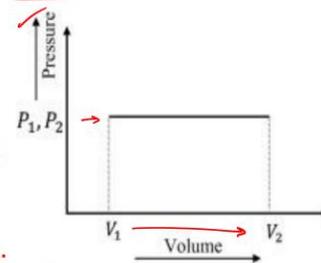
Definition: An isobaric process is one in which the pressure remains constant throughout the process.

Key Characteristics:

- Volume and temperature may change.
- Common in systems with movable boundaries, like pistons.

Examples:

- Boiling water in an open container at atmospheric pressure.
- Heating air in a piston-cylinder assembly with a freely moving piston.
- Steam generation in boilers operating at constant pressure.



Now, the other process that was discussed is isobaric, where we have constant pressure. An isobaric process is one in which the pressure remains constant throughout the process. Here, we have pressure versus volume. You see here, the volume varies from V_1 to V_2 , but the pressure remains constant. Key characteristics are volume and temperature may change, combining systems with movable boundaries like pistons. Earlier, I talked about the LPG cylinder, which is a closed system. Now, the piston and cylinder system is moving. The cylinder is closing and opening, so the volume is changing here. Some of

the other examples given are: boiling water in an open container at atmospheric pressure, heating in a piston-cylinder assembly with a freely moving piston, and steam generation in boilers operating at constant pressure, where the volume is changing.



First Law of Thermodynamics

Process	Q	W = ∫PdV	P-V-T Relation
Reversible ✓ Constant Pressure	$Q = H$ $= \dot{m}C_p(T_2 - T_1)$	$W = P(V_2 - V_1)$ $= \dot{m}R(T_2 - T_1)$	$V_1/T_1 = V_2/T_2$

Where

\dot{m} - Mass flow rate, kg/s

C_p - Specific heat at constant pressure, J/kgK

T_1, T_2 - Temperatures at inlet and outlet, K

P_1, P_2 - Pressure at inlet and outlet, Pa



When we saw the reversible constant pressure relationship,

Process	Q	W = ∫PdV	P-V-T Relation
Reversible ✓ Constant Pressure	$Q = H$ $= \dot{m}C_p(T_2 - T_1)$	$W = P(V_2 - V_1)$ $= \dot{m}R(T_2 - T_1)$	$V_1/T_1 = V_2/T_2$

Where

\dot{m} - Mass flow rate, kg/s

C_p - Specific heat at constant pressure, J/kgK

T_1, T_2 - Temperatures at inlet and outlet, K

P_1, P_2 - Pressure at inlet and outlet, Pa

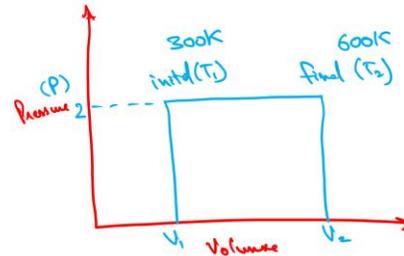
First Law of Thermodynamics

Problem Statement: Air enters a steady-flow system at a pressure of 2 bar and a temperature of 300 K. It is heated at constant pressure until its temperature reaches 600 K. The mass flow rate is 2 kg/s. Assume air behaves as an ideal gas with $R=0.287$ kJ/kgK and $C_p=1.005$ kJ/kgK. Calculate:

- 1) The rate of heat transfer to the air.
- 2) The rate of work done by the system.
- 3) The ratio of final to initial volume.

Solution:

$$\begin{aligned}
 P &= 2 \text{ bar} \\
 T_1 &= 300 \text{ K} \\
 T_2 &= 600 \text{ K} \\
 \dot{m} &= 2 \text{ kg/s}
 \end{aligned}$$



First Law of Thermodynamics

Solution:

$$\begin{aligned}
 1) \text{ Rate of heat transfer} \\
 \dot{Q} = \dot{H} &= \dot{m} C_p (T_2 - T_1) \\
 &= 2 \times 1.005 (600 - 300) \\
 &= 603 \text{ kW/hr}
 \end{aligned}$$

$$\begin{aligned}
 2) \text{ Rate of work done} \\
 \dot{W} &= \dot{m} R (T_2 - T_1) \\
 &= 2 \times 0.287 (600 - 300) \\
 &= 172.2 \text{ kW/hr}
 \end{aligned}$$

$$3) V_2/V_1 = ?$$

In P-V-T relation

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad (\text{Isobaric process})$$

$$\frac{V_2}{V_1} = \frac{T_2}{T_1} = \frac{600}{300} = 2$$

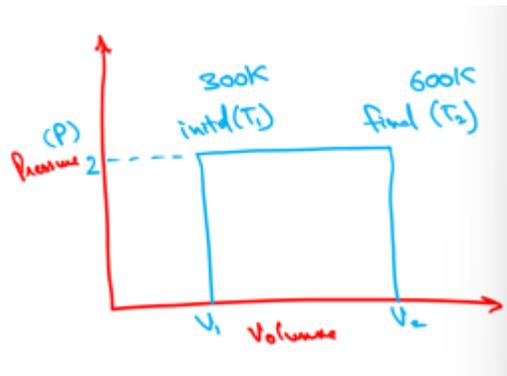
$$\boxed{V_2/V_1 = 2}$$

Let us see a statement and try to find the solution to the questions given here. Air enters a steady flow system at a pressure of 2 bar and a temperature of 300 Kelvin. It is heated at constant pressure until its temperature reaches 600 Kelvin. Now, here, I will again draw a figure. They say air enters the system at the pressure of 2 bar. The pressure here given is 2 bar. And, they say the temperature here is $T_1 = 300$ Kelvin.

This is a constant pressure system. Heat is heated at a constant pressure until the temperature reaches 600 Kelvin. That is the $T_2 = 600$ Kelvin. But, this is at a constant

pressure. So, if I draw this relation, pressure versus volume, here the pressure remains constant but the volume varies. So, this is pressure. We call it as pressure P, that is 2 bar P1 or P2, whatever you call it, it is 2 bar. I need to call it at P, only P1 is not required.

And, final volume and initial and final temperature as well. We have T1 here and T2 here. Temperature one is 300 kelvin, temperature two is 600 kelvin, volume V1 and V2. The mass flow rate is 2 kg/s. That means $\dot{m} = 2 \text{ kg/s}$. Assume, air behaves an ideal gas with $R = 0.287 \text{ kJ/kgK}$ and C_p that is the specific heat at constant pressure is equal to 1.005 kJ/kgK .



1) Rate of heat transfer

$$Q = \dot{m} C_p (T_2 - T_1)$$

$$= 2 \times 1.005 (600 - 300)$$

$$= 603 \text{ kW/hr}$$

2) Rate of work done:

$$W = \dot{m} R (T_2 - T_1)$$

$$= 2 \times 0.287 (600 - 300)$$

$$= 172.2 \text{ kW/hr}$$

3) $V_2/V_1 = ?$

In PVT relation

$$V_1/T_1 = V_2/T_2 \quad (\text{Isobaric process})$$

$$V_2/V_1 = T_2/T_1$$

$$= 600/3 = 2$$

$$= V_2/V_1 = 2$$

Hence, all solved.



First Law of Thermodynamics

Polytropic process

Polytropic is a thermodynamic process that obeys the relation;

$$PV^n = C$$

Here, P is the Pressure

V is the Volume

n is the Polytropic Index

C is the Constant

The polytropic index will take any value between 0 and ∞ , depending on the process.



18

One more topic I will cover in the first law of thermodynamics is the polytropic process. A polytropic process is a thermodynamic process that obeys the relation $PV^n = C$, where P is pressure, V is volume, n is the polytropic index, and C is a constant. The polytropic index can take any value between 0 and infinity, depending on the process under discussion.



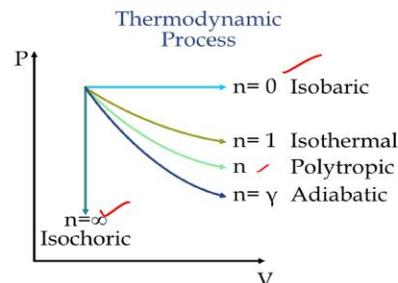
First Law of Thermodynamics

Work done in polytropic process:

$$W = \frac{(P_2 V_2 - P_1 V_1)}{(1-n)}$$

where $PV^n = \text{constant}$

- The exponent n defines the type of process (e.g., n=0 is isobaric, n=1 is isothermal).



Work done in a polytropic process is also discussed, that is,

$$W = \frac{(P_2 V_2 - P_1 V_1)}{(1-n)}$$

where $PV^n = \text{constant}$

The exponent n defines the type of process, that is, $n=0$ is isobaric, $n=1$ is isothermal. So, in thermodynamic processes, $n=0$ is for a complete isobaric process.

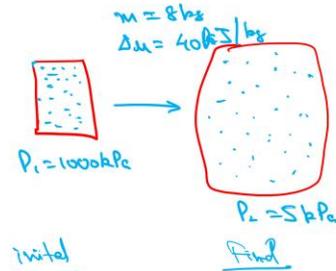
That is, pressure is constant. n is equal to 1 is an isothermal process. In between, we have a polytropic process. And, an isochoric process is when the volume is constant. That is, n is equal to infinity.

First Law of Thermodynamics



Problem Statement: A mass of 8 kg gas expands within a flexible container so that the PV relationship is of the form $PV^{1.2} = \text{constant}$. The initial pressure is 1000 kPa and the initial volume is 1 m^3 . The final pressure is 5 kPa. If specific internal energy of the gas decreases by 40 kJ/kg, find the heat transfer.

$n = 1.2$
 $P_1 = 1000 \text{ kPa}$
 $V_1 = 1 \text{ m}^3$
 $P_2 = 5 \text{ kPa}$
 $\Delta u = 40 \text{ kJ/kg}$ (decreased, i.e. negative)
 $m = 8 \text{ kg}$



First Law of Thermodynamics



Solution:

$$\Delta U = m \cdot \Delta u = 8(-40) = -320 \text{ kJ}$$

$$PV^n = \text{constant} \quad (\text{polytropic process})$$

$$\Delta U = Q - W$$

$$Q = \Delta U + W$$

$$W = \frac{P_2 V_2 - P_1 V_1}{1-n}$$

$$P_1 V_1^n = P_2 V_2^n$$

$$\left(\frac{V_2}{V_1}\right)^n = \frac{P_1}{P_2}$$

$$V_2 = \left(\frac{P_1}{P_2}\right)^{1/n} V_1$$

$$V_2 = \left(\frac{1000}{5}\right)^{1/1.2} \times 1 = 82.4 \text{ m}^3$$

$$W = \frac{5 \times 82.4 - 1000 \times 1}{1-1.2} = 2940 \text{ kJ}$$

$$Q = \Delta U + W$$

$$Q = -320 + 2940$$

$$Q = 2620 \text{ kJ}$$

Answer



Now, let us see this problem. It says: a mass of 8 kg gas expands within a flexible container so that the PV relationship is of the form $PV^{1.2} = \text{constant}$. The value of n is 1.2 here. The initial pressure is 1000 kilopascal. Initial pressure, that is $P_1 = 1000$ kilopascal, and the initial volume is 1 meter cube, that is v_1 is equal to 1 m^3 . The final pressure is 5 kilopascal.

And, the specific internal energy of the gas is decreased by 40 kJ/kg. That is, we have to find dU and $du = 40 \text{ kJ/kg}$. They say; it is a flexible container, the keyword. If there is a container that carries some mass, this finally would be a bigger container, would just make it something like this, where the pressure is drastically reduced.

So here, suppose in a container, we have some mass of the gas. So here, suppose in a container, we have some gas. For the gas, I will just draw dots. This is expanded here. Initial pressure is given as $P_1 = 1000 \text{ kPa}$.

Final pressure $P_2 = 5 \text{ kPa}$. From initial to final, it goes with mass as 8 kg, that is given, and change in specific internal energy as 40 kilojoules per kg. So, this is initial and this is final. So, I can put here as mass is also given 8 kg. So, all the given values are put here.

Let me try to find what it has asked.

$$dU = m \cdot du$$

$$8 \cdot (-40) = -320 \text{ kJ}$$

$$\text{Now, } P_1 V_1^n = P_2 V_2^n$$

$$(V_2/V_1)^n = P_1/P_2$$

$$V_2 = (P_1/P_2)^{1/n} V_1$$

$$V_2 = (1000/5)^{1/1.2} \times 1 = 82.4 \text{ m}^3$$

$$\text{Now, } W = \frac{P_2 V_2 - P_1 V_1}{1-n}$$

$$W = \frac{5 \times 82.4 - 1000 \times 1}{1-1.2}$$

$$\text{So, } dU = Q - W$$

$$Q = dU + W$$

$$Q = -320 + 2940 = 2620 \text{ kJ (Ans.)}$$

So, these were a few simple and slightly calculative problem statements on the first law of thermodynamics. I will discuss heat engines and heat pumps in the second part of the tutorial session, which is based upon the week 1 and week 2 lectures, in the coming lecture. Thank you.