

**BPT-201 (semester II)**

**Topic: Joule-Thomson effect**

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# *Joule-Thomson effect-Part 1*

# Background

- The *adiabatic* expansion of a gas may be carried out in different ways and the change in temperature experienced by the gas during expansion depends
  - not only on the initial and final pressure,
  - but also on how the expansion is carried out.
- The process can be reversible or free expansion
- In reversible expansion process the gas remains in thermodynamic equilibrium at all times, it is called an *isentropic* expansion. Here the gas does positive work during the expansion, and its temperature decreases.
- In a free expansion, the gas does no work and absorbs no heat, so the internal energy is conserved. In such kind of expanded ideal gas temperature will remain constant whereas the temperature of a real gas decreases subject to the initial temperature at which the process started

## Joule–Thomson effect or Joule–Kelvin effect or Kelvin–Joule effect

- As we know the real gas never follows the ideal gas behavior.
- The **Joule–Thomson effect** (or **Joule–Kelvin effect** or **Kelvin–Joule effect**) how a *real* gas or liquid's temperature changes when it is forced through valve or porous plug in an adiabatic process
- The procedure is called a *throttling process* or *Joule–Thomson process*.
- It has been observed that at room temperature, many gases (except hydrogen, helium, neon) cool upon expansion by the Joule–Thomson process .
- hydrogen, helium and neon indicated heating effects at room temperature instead of cooling. The cooling effect was observed only at lower temperatures. It has been observed that most liquids will also show heating effect in the Joule–Thomson throttling process.

# Where do we use throttling process

- *The most common use of the gas-cooling throttling process is in refrigeration processes such as air conditioners, heat pumps, and liquefiers.*
- *Whereas the warming effect from Joule-Thomson throttling process is used to find internally leaking valves as these will produce heat which can be easily detected by thermocouple or thermal-imaging camera.*

- During an adiabatic expansion temperature of a fluid is controlled by two factors
  - i) a change in internal energy or
  - ii) the conversion between potential and kinetic internal energy and total internal energy remains constant.
- The internal energy is the sum of thermal kinetic energy and thermal potential energy
- Since the temperature is the measure of thermal kinetic energy and hence temperature indicates the thermal kinetic energy of the system.

- It indicates that when the kinetic energy is converted in potential energy then although the total internal energy remains constant the temperature of the system decreases.
- This conversion of kinetic energy in potential energy takes place during free expansion and results in a decrease in temperature.
- If work is done on or by the fluid as it expands, then the total internal energy changes.
- This is what happens in a Joule-Thomson expansion and can produce larger heating or cooling than observed in a free expansion.

- In a Joule-Thomson expansion the enthalpy remains constant. The enthalpy,  $H$ , is defined as
- $H = U + PV$
- where  $U$  is internal energy,  $P$  is pressure, and  $V$  is volume.
- Under the conditions of a Joule-Thomson expansion, the change in  $PV$  represents the work done by the gas/fluid.
- If  $PV$  increases, with constant  $H$ , then  $U$  must decrease as a result of the gas/fluid doing work on its surroundings.
- This produces a decrease in temperature and results in a positive Joule-Thomson coefficient.
- Conversely, a decrease in  $PV$  means that work is done on the gas/fluid and the internal energy increases.



- If the increase in kinetic energy exceeds the increase in potential energy, there will be an increase in the temperature of the fluid and the Joule-Thomson coefficient will be negative.
- For an ideal gas,  $PV$  does not change during a Joule-Thomson expansion.
- As a result, there is no change in internal energy;
- since there is also no change in thermal potential energy, there can be no change in thermal kinetic energy and, therefore, no change in temperature.
- In real gases,  $PV$  does change

# compressibility factor or the compression factor or the gas deviation factor Z:

- It is the ratio of the value of  $PV$  of a real gas to the value expected for an ideal gas at the same temperature.
- This, is a correction factor which describes the deviation of a real gas from ideal gas behavior. It is simply defined as the ratio of the molar volume of a gas to the molar volume of an ideal gas at the same temperature and pressure.
- It is a useful thermodynamic property for modifying the ideal gas law to account for the real gas behavior.
- The deviation from ideal behavior is found to be more significant when the a gas is closer to a phase change, or at lower temperature or the larger pressure.
- Compressibility factor values are usually obtained by calculation from equations of state (EOS), such as the virial equation which take compound-specific empirical constants as input.
- For a gas that is a mixture of two or more pure gases, the gas composition must be known before compressibility can be calculated.

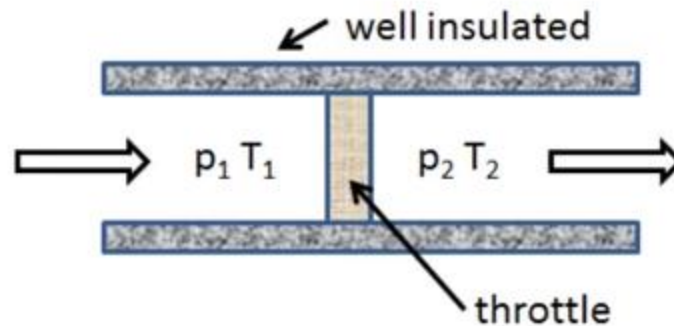
- For a gaseous system, at low temperature  $Z$  is typically less than unity
- At high temperature  $Z$  has value greater than unity
- Where as at low pressure, the value of  $Z$  always moves towards unity as a gas expands.
- Thus at low temperature,  $Z$  and  $PV$  will increase as the gas expands, resulting in a positive Joule-Thomson coefficient.
- At high temperature,  $Z$  and  $PV$  decrease as the gas expands; if the decrease is large enough, the Joule-Thomson coefficient will be negative.
- For liquids, and for supercritical fluids under high pressure,  $PV$  increases as pressure increases.
- This is due to molecules are already very close, so that the volume can barely decrease due to higher pressure. Under such conditions, the Joule-Thomson coefficient is negative.

# Proof that the specific enthalpy remains constant

- To ignore the effect of mass in thermodynamics "specific quantities" i.e. 'quantity per unit mass' (kg) are used.
- They are denoted by lower-case characters.
- $h$  = specific enthalpy
- $u$  = specific internal energy
- and  $v$  = specific volume
- In a Joule–Thomson process the specific enthalpy  $h$  remains constant.
- To prove this, the first step is to compute the net work done when a mass  $m$  of the gas moves through the plug.

# JT expansion experiment

- The experiment has two chambers separated by throttling pores system which is made of glass wool etc.



- Chambers wall are made of insulating materials so the experiment can be carried out in adiabatic manner

- Using the specific quantity we define the quantities
- volume of  $V_1 = m v_1$  in the region at pressure  $P_1$  (region 1)
- volume  $V_2 = m v_2$  in the region at pressure  $P_2$  (region 2).
- Then in region 1, the "flow work" done on the amount of gas by the rest of the gas is:  $W_1 = m P_1 v_1$ .
- In region 2, the work done by the amount of gas on the rest of the gas is:  $W_2 = m P_2 v_2$ .
- So, the total work done on the mass  $m$  of gas is
- $W = m P_1 v_1 - m P_2 v_2$

- The change in internal energy minus the total work done on the amount of gas is, by the first law of thermodynamics, the total heat supplied to the amount of gas.
- $U-W=Q$
- In the Joule-Thomson process, the gas is insulated, so no heat is absorbed. This means that
- $(mu_2 - mu_1) - (mP_1v_1 - mP_2v_2) = 0$
- $mP_1v_1 + mu_1 = mu_2 + mP_2v_2$
- $P_1v_1 + u_1 = P_2v_2 + u_2$

- where  $u_1$  and  $u_2$  denote the specific internal energies of the gas in regions 1 and 2, respectively.
- Using the definition of the specific enthalpy  $h = u + Pv$ , the above equation implies that ..... $h_1=h_2$
- where  $h_1$  and  $h_2$  denote the specific enthalpies of the amount of gas in regions 1 and 2, respectively.
- One should remember that ENTHALPY is not constant during the process BUT it is constant in the process.



# Derivation of the Joule-Thomson coefficient

- The joule- Thomson process can be defined using three quantities  $T$ ,  $P$  and  $H$
- Using the cyclic rule we can write

$$\left(\frac{\partial T}{\partial P}\right)_H \left(\frac{\partial H}{\partial T}\right)_P \left(\frac{\partial P}{\partial H}\right)_T = -1.$$

- Each of the three partial derivatives in this expression has a specific meaning.

$$C_p = \left(\frac{\partial H}{\partial T}\right)_P \quad \mu_T = \left(\frac{\partial H}{\partial P}\right)_T \quad \mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H$$

- Where  $C_p$  is **heat capacity** at constant pressure,  $\mu_{JT}$  is **joule Thomson coefficient** and  $\mu_T$  is **isothermal joule Thomson**

- Hence the cyclic rule gives us  $\mu_{JT} = -\frac{\mu_T}{C_p}$ .
- Isothermal joule Thomson coefficient is much easier to measure and hence above equation becomes important
- Let us start from a fundamental thermodynamic equation
- $dH = TdS + VdP$
- Now "dividing through" by  $dP$ , while holding temperature constant, yields  $\left(\frac{\partial H}{\partial P}\right)_T = T\left(\frac{\partial S}{\partial P}\right)_T + V$

And using  $\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P = -V\alpha$  We get  $\mu_T = -TV\alpha + V$ .

- Hence using these equation we get

$$\mu_{JT} \equiv \left( \frac{\partial T}{\partial P} \right)_H = \frac{V}{C_p} (\alpha T - 1).$$

## **Relevant site for the topic**

- [https://swayam.gov.in/nd1\\_noc19\\_me57/preview](https://swayam.gov.in/nd1_noc19_me57/preview)
- [https://www.youtube.com/watch?v=jQepo3O4IN8&feature=emb\\_rel\\_pause](https://www.youtube.com/watch?v=jQepo3O4IN8&feature=emb_rel_pause)
- <https://www.youtube.com/watch?v=X9h0Ifn6jmk>
- <https://www.youtube.com/watch?v=rUB-hpek0NE>
- <https://www.youtube.com/watch?v=Th-LQz5bBJA>
- <https://www.youtube.com/watch?v=Vz5MYK1TT4I>
- [https://www.youtube.com/watch?v=5Bmmp5PyK\\_I](https://www.youtube.com/watch?v=5Bmmp5PyK_I)
- <https://www.youtube.com/watch?v=pTnNGhIfDRM>
- <https://www.youtube.com/watch?v=nxuZNZuHHg0>
- [https://www.youtube.com/watch?v=v\\_Osf5gy8OY](https://www.youtube.com/watch?v=v_Osf5gy8OY)
- <https://www.youtube.com/watch?v=dzoQ3VEi7YI>
- <https://www.youtube.com/watch?v=LDXLOCTeJQE>