PVP 23

Code: 23ME6402

II B.Tech - II Semester – Honors Examinations – APRIL 2026

ADVANCED THERMODYNAMICS & COMBUSTION
(HONORS in MECHANICAL ENGINEERING)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	What is meant by thermodynamic equilibrium?	L1	CO1
1.b)	Define intensive and extensive properties with examples.	L1	CO1
1.c)	What is the significance of Maxwell relations?	L1	CO1
1.d)	Define specific heat at constant pressure.	L1	CO1
1.e)	State Amagat’s law of partial volumes.	L1	CO2
1.f)	Write the equation for entropy change in mixing of ideal gases.	L1	CO2
1.g)	Define reactant mixture in combustion.	L1	CO2
1.h)	Define adiabatic flame temperature.	L1	CO3
1.i)	What is ignition temperature?	L1	CO3
1.j)	What is meant by quenching of flame?	L1	CO3

PART – B

			BL	CO	Max. Marks
UNIT-I					
2	a)	Derive the entropy balance equation for a closed system.	L2	CO1	5 M
	b)	What amount of heat would be required to produce 4.4 kg of steam at a pressure of 6 bar and temperature of 250°C from water at 30°C ? Take specific heat for superheated steam as 2.2 kJ/kg K.	L3	CO1	5 M
OR					
3	a)	Explain the concept of exergy and irreversibility in thermodynamic systems.	L2	CO1	5 M
	b)	3 kg of water at 90°C is mixed with 5 kg of water at 30°C in an insulated container. Determine the entropy change during mixing.	L3	CO1	5 M
UNIT-II					
4	a)	Explain the significance and applications of the Clausius–Clapeyron equation.	L2	CO2	5 M
	b)	A gas at initial temperature 300 K expands from 8 bar to 2 bar. The Joule–Thomson coefficient is 0.3 K/bar. Determine the final temperature of the gas after throttling.	L3	CO2	5 M
OR					

5	a)	Explain the cooling and heating effect in Joule–Thomson expansion.	L2	CO2	5 M
	b)	A gas expands from 6 bar to 2 bar with a Joule–Thomson coefficient of –0.15 K/bar. Determine whether the gas heats or cools and calculate the temperature change.	L3	CO2	5 M
UNIT-III					
6	a)	Explain changes in entropy during gas mixing with equations.	L2	CO2	5 M
	b)	A gas mixture contains 3 kmol of nitrogen, 2 kmol of oxygen, and 1 kmol of carbon dioxide at a total pressure of 900 kPa. Determine: Mole fraction of each gas and Partial pressure of each gas.	L3	CO2	5 M
OR					
7	a)	Derive the relation for specific heat of a gas mixture.	L2	CO2	5 M
	b)	A container holds a mixture of 2 kmol of nitrogen and 1 kmol of oxygen at a total pressure of 600 kPa. Determine the partial pressure of each gas.	L3	CO2	5 M
UNIT-IV					
8	a)	Explain stoichiometric combustion and excess air combustion.	L2	CO3	5 M
	b)	A fuel burns in an adiabatic combustion chamber with stoichiometric air. If heat	L3	CO3	5 M

		of combustion = 45,000 kJ/kg and specific heat of products = 1.2 kJ/kg·K. Estimate the adiabatic flame temperature rise.			
OR					
9	a)	Explain the factors affecting adiabatic flame temperature.	L2	CO3	5 M
	b)	A fuel has the following composition by mass: Carbon = 80%, Hydrogen = 15%, Oxygen = 5%, Determine: Theoretical oxygen required, and Theoretical air required for combustion.	L3	CO3	5 M
UNIT-V					
10	a)	Explain the process of ignition in combustion systems.	L2	CO3	5 M
	b)	Explain the flammability limits of gaseous fuels.	L2	CO3	5 M
OR					
11	a)	Differentiate between premixed flames and diffusion flames.	L2	CO3	5 M
	b)	Explain the different types of flames with suitable examples.	L2	CO3	5 M

II. B.Tech II Semester Honors Examinations
April - 2026 PVP23.
Advanced Thermodynamics of combustion - 23ME
(Honors in Mechanical Engineering)
Scheme of valuation.

1.a. Definition — 2 marks
1.b any two points — 2 marks
1.c any two points — 2 marks
1.d definition — 2 marks
1.e defintion — 2 marks
1.f formula — 2 marks
1.g definition — 2 marks
1.h one point — 2 marks
1.i definition — 2 marks
1.j one point — 2 marks

2.a Derivation — 5 marks
2.b Given Data — 2 marks
solution — 3 marks } — 5 marks

3.a Explanation — 5 marks
3.b Given Data — 2 marks
solution — 3 marks } — 5 marks

4.a four points — 2 marks
formula — 1.5 marks
Three applications — 1.5 marks } — 5 marks

4.b Given Data — 2 marks
Solution — 3 marks } — 5 marks

5.a Explanation
cooling effect — 2.5 marks } — 5 marks
Heating effect — 2.5 marks }

5.b Given Data — 2 marks } — 5 marks
solution — 3 marks }

6.a. Explanation — 5 marks

6.b : Given Data — 2 marks } — 5 marks
solution — 3 marks }

7: a Derivation — 5 marks

7.b Given Data — 2 marks } — 5 marks
solution — 3 marks }

8.a Explanation — 5 marks

8.b Given Data — 2 marks } — 5 marks.
Solution — 3 marks }

9.a any five points — 5 marks

9.b solution — 5 marks

10.a any five points — 5 marks

10.b any four points — 5 marks

11.a any five points — 5 marks

11.b any six points — 5 marks

II B.Tech-II Semester- Honors Examinations-April, 2026

Advanced Thermodynamics& Combustion- 23ME6402- PVP 23

(Honors in Mechanical Engineering)

Scheme of Valuation

1.a) When the system is said to be in thermodynamic equilibrium then it must satisfy three conditions. Thermal equilibrium, Mechanical equilibrium and Chemical equilibrium.

1.b) Intensive properties are those properties whose values independent of mass/ size.

Examples: Density, thermal conductivity, Specific volume, etc.

Extensive properties are those properties whose values depend on mass/ size.

Examples: All types of energies.

1.c) (i) **Relate measurable and non-measurable properties**
They allow us to express difficult-to-measure quantities (like entropy change) in terms of easily measurable properties (like temperature, pressure, and volume).

(ii) **Reduce experimental effort**
Instead of measuring every property directly, Maxwell relations help calculate unknown properties using known data, saving time and resources.

(iii) **Provide internal consistency**
They ensure that thermodynamic equations are mathematically consistent, since they are derived from exact differentials of state functions.

(iv) **Useful in deriving other relations**
Many important thermodynamic equations (such as those involving enthalpy, internal energy, and Gibbs function) are derived using Maxwell relations.

(v) **Application in engineering and science**
They are widely used in fields like chemical engineering, mechanical engineering, and physical chemistry for analyzing systems involving heat, work, and energy transfer.

1.d) Specific heat at constant pressure is the amount of heat required to raise the temperature of unit mass of a substance by 1 °C (or 1 K) when the pressure is kept constant.

1.e) The total volume of a gas mixture is equal to the sum of the partial volumes of the individual gases, at the same temperature and pressure.

Mathematically

$$V=V_1+V_2+V_3+\cdots$$

1.f)

$$\Delta S_i=n_i R\ln\left(\frac{V}{V_i}\right)$$

$$\Delta S_i = n_i R \ln\left(\frac{1}{y_i}\right) = -n_i R \ln y_i$$

$$\Delta S_i = n_i R \ln\left(\frac{1}{y_i}\right) = -n_i R \ln y_i$$

1.g) A reactant mixture is the homogeneous or heterogeneous mixture of fuel and oxidizer (and possibly inert components) that undergoes a chemical reaction during combustion to form products like CO_2, H_2O, and other species.

1.h) It is the temperature attained by the combustion products when a fuel–oxidizer mixture burns completely under adiabatic conditions.

1.i) Ignition temperature is the minimum temperature at which a substance must be heated so that it starts burning spontaneously in the presence of oxygen and continues the combustion reaction without any external spark or flame.

1.j) It is the termination of a flame when heat losses (to surroundings, walls, or other surfaces) become greater than the heat generated by the combustion reaction.

2.a) Consider a closed system

No mass crosses the boundary. Only **heat** and **work** interactions are possible.

Entropy change of the system

Let the system entropy change from state 1 to state 2:

$$\Delta S = S_2 - S_1$$

Entropy transfer due to heat

If a small amount of heat $\delta Q$is transferred at boundary temperature T, the entropy transfer is:

$$\frac{\delta Q}{T}$$

For the entire process:

$$\int \frac{\delta Q}{T}$$

Include entropy generation

Due to irreversibilities (friction, mixing, heat transfer across finite temperature difference), entropy is generated inside the system:

$$S_{\text{gen}} \geq 0$$

Combine all terms

$$S_2 - S_1 = \int \frac{\delta Q}{T} + S_{\text{gen}}$$

entropy balance equation:

$$\boxed{\Delta S=\int\frac{\delta Q}{T}+S_{\text{gen}}}$$

Special cases:

- **Reversible process:** $S_{\text{gen}}=0$
- **Irreversible process:** $S_{\text{gen}}>0$
- **Isolated system:** $\Delta S=S_{\text{gen}}$

2. b) Given:

Mass $m=4.4$ kg

Initial temperature $T_1=30^\circ\ C$

Specific heat of water $c_w\approx4.18$ kJ/kgK

Specific heat of superheated steam $c_s=2.2$ kJ/kgK

Heat to raise water temperature to saturation

$$Q_1=mc_w(T_{sat}-T_1)$$
$$Q_1=4.4\times4.18\times(158.8-30)$$
$$Q_1=4.4\times4.18\times128.8\approx2368.7\text{ kJ}$$

Heat for phase change

$$Q_2=mh_{fg}=4.4\times2085\approx9174\text{ kJ}$$

Heat for superheating

$$Q_3=mc_s(T_{sup}-T_{sat})$$
$$Q_3=4.4\times2.2\times(250-158.8)$$
$$Q_3=4.4\times2.2\times91.2\approx883\text{ kJ}$$

Total heat required

$$Q=Q_1+Q_2+Q_3$$
$$Q=2368.7+9174+883\approx12425.7\text{ kJ}$$

3.a) Exergy is the maximum useful work that can be obtained from a system as it comes into equilibrium with its surroundings.

It Depends on both the **system state** and the **environment**

When the system reaches equilibrium with surroundings → **exergy becomes zero**

Example:

High-temperature steam has high exergy (can do work)

Low-temperature water has low exergy (less useful)

Irreversibility

Irreversibility refers to the **loss of useful work potential** due to real-world effects.

Definition:

It is the destruction of exergy caused by processes that are not perfectly reversible.

Causes of irreversibility:

- Friction
- Heat transfer across finite temperature difference
- Unrestrained expansion
- Mixing of different substances
- Chemical reactions

Relation between Exergy and Irreversibility

The two are directly connected:

$$\text{Exergy destruction} = T_0\, S_{\text{gen}}$$

where:

T_0= ambient temperature

S_{gen}= entropy generation

  - More entropy generation ⇒ more irreversibility ⇒ more exergy loss

3.b) Given Data

$T_1 = 90^\circ C$ $m = 3\,kg$

$T_2 = 30^\circ C$

Final temperature T_f

Energy balance (no heat loss):

$$m_1 c(T_1 - T_f) = m_2 c(T_f - T_2)$$

$$3(90 - Tf) = 5(Tf - 30)$$

$$270 - 3T_f = 5T_f - 150$$

$$420 = 8T_f \Rightarrow T_f = 52.5^\circ\ C$$

$$T1 = 363K,\ T2 = 303K,\ Tf = 325.5K$$

Entropy change formula

For each mass:

$$\Delta S = mc\ln\left(\frac{T_f}{T_i}\right)$$

Take $c = 4.18\ kJ/kgK$

Entropy change of hot water

$$\Delta S_1 = 3\times 4.18\times \ln\left(\frac{325.5}{363}\right)$$
$$\Delta S_1 \approx 12.54\times(-0.109)\approx -1.37\ \text{kJ/K}$$

Entropy change of cold water

$$\Delta S_2 = 5\times 4.18\times \ln\left(\frac{325.5}{303}\right)$$
$$\Delta S_2 \approx 20.9\times 0.0716 \approx 1.50\ \text{kJ/K}$$

Total entropy change

$$\Delta S_{total} = \Delta S_1 + \Delta S_2$$
$$\Delta S_{total} = -1.37 + 1.50 = 0.13\ \text{kJ/K}$$

4.a) Describes phase equilibrium

b) Predicts variation of saturation pressure with temperature

c) Links thermodynamic properties.

d) Basis for many thermodynamic calculations.

For liquid–vapor phase change (approximate form):

$$\frac{dP}{dT} = \frac{h_{fg}}{T(v_g - v_f)}$$

Simplified (ideal gas approximation):

$$\ln\quad P = -\frac{h_{fg}}{R}\frac{1}{T} + C$$

Applications

a) Determination of latent heat
b) Vapor pressure estimation
c) Refrigeration and air-conditioning
d) Meteorology
e) Chemical engineering processes
f) Power plants

4.b) **Given Data:**

Initial temperature $T_1 = 300\ K$

Initial pressure $P_1 = 8$ bar

Final pressure $P_2 = 2$ bar

Joule–Thomson coefficient $\mu_{JT}=0.3\ K/\text{bar}$

Calculate temperature change

$$\Delta T=0.3\times(2-8)=0.3\times(-6)=-1.8\ K$$

Final temperature

$$T_2=T_1+\Delta T=300-1.8=298.2\ K$$

Final Answer:

$$\boxed{T_2=298.2\ K}$$

5.a) When a gas expands from high pressure to low pressure during throttling:

- Its temperature may decrease (cooling) or
- Its temperature may increase (heating)
- This behavior depends on the nature of the gas and its initial temperature.

Joule–Thomson Coefficient

$$\mu_{JT}=\left(\frac{\partial T}{\partial P}\right)_H$$

- If $\mu_{JT}>0\rightarrow$ **Cooling effect**
- If $\mu_{JT}<0\rightarrow$ **Heating effect**

Cooling Effect

Occurs when gas temperature **decreases during expansion**

Happens when the gas is **below its inversion temperature**

Most real gases (like air, nitrogen, CO_2) show cooling at room temperature

Heating Effect

Occurs when gas temperature **increases during expansion**

Happens when the gas is **above its inversion temperature**

Gases like hydrogen and helium at room temperature may heat up.

Inversion Temperature

The temperature at which **no temperature change occurs**

At this point:

$$\mu_{JT}=0$$

Applications

Refrigeration and liquefaction of gases

Cryogenic systems

Air separation processes

Gas pipeline pressure regulation

5.b) Given:

Initial pressure $P_1=6$ bar

Final pressure $P_2=2$ bar

Joule–Thomson coefficient $\mu_{JT}=-0.15\ K/\text{bar}$

Temperature change

$$\Delta T=\mu_{JT}(P_2-P_1)$$
$$\Delta T=(-0.15)(2-6)=(-0.15)(-4)=+0.6\ K$$

Interpretation

$\Delta T=+0.6\ K\rightarrow$ Temperature **increases**

Therefore, the gas **heats up during expansion**

Final Answer:

Temperature change: $\boxed{+0.6\ K}$

Effect: $\boxed{\text{Heating}}$

The **Joule–Thomson coefficient** is **negative**, the gas lies **above its inversion temperature**, so it **warms upon throttling** instead of cooling.

6.a)

Entropy Change During Mixing of Gases

When two or more gases mix, the process is **irreversible**, and there is always an **increase in entropy** due to greater molecular disorder.

Mixing causes:

- Increase in randomness (disorder)
- No work interaction
- No heat transfer if insulated (ideal case)

Hence, entropy **always increases**

Entropy Change for Ideal Gas Mixing

For a mixture of ideal gases, the entropy change is given by:

$$\Delta S_{\text{mix}} = -R \sum n_i \ln x_i$$

where:

n_i= number of moles of component *i*

x_i= mole fraction of component *i*

R= universal gas constant

Alternative Form (per mole basis)

$$\Delta S_{\text{mix}} = -nR \sum x_i \ln x_i$$

For Two Gases

If two gases are mixed:

$$\Delta S_{\text{mix}} = -n_1 R \ln x_1 - n_2 R \ln x_2$$

so overall entropy change is **positive**

Valid for **ideal gases**

No change in internal energy (for ideal gases)

Entropy increase is due to **mixing only**, not heat transfer

Special Case

If gases are identical →

$$\Delta S_{\text{mix}} = 0$$

(No real mixing effect)

6.b) Given Data:

$n_1 = 3$ kmol

$n_2 = 2$ kmol

$n_3 = 1$ kmol

$P = 900$ kPa

Total number of moles

$n_{total} = 3+2+1 = 6$ kmol

Mole fractions

$$x_{N_2}=\frac{3}{6}=0.5$$
$$x_{O_2}=\frac{2}{6}=0.333$$
$$x_{CO_2}=\frac{1}{6}=0.167$$

Partial pressures

Using Dalton's law of partial pressures:

$$P_i=x_i \cdot P_{total}$$

Total pressure P=900 kPa

Nitrogen:

$$P_{N_2}=0.5\times900=450 \text{ kPa}$$

Oxygen:

$$P_{O_2}=0.333\times900\approx300 \text{ kPa}$$

Carbon dioxide:

$$P_{CO_2}=0.167\times900\approx150 \text{ kPa}$$

Total Pressure= 450+300+150=900kPa

7.a) Consider a gas mixture of several ideal gases. We derive expressions for specific heat at constant pressure and constant volume.

For an ideal gas mixture:

Each component behaves independently

Total energy = sum of energies of individual components

Specific Heat at Constant Volume C_v

Total internal energy of mixture:

$$U=\sum n_i u_i$$

Differentiating:

$$dU=\sum n_i C_{v,i}\, dT$$

For the mixture:

$$dU=nC_{v,m}\, dT$$

Equating:

$$nC_{v,m}=\sum n_i C_{v,i}$$

Divide by total moles n:

$$\boxed{C_{v,m}=\sum x_i C_{v,i}}$$

Specific Heat at Constant Pressure C_p

Total enthalpy:

$$H=\sum n_i h_i$$

Differentiating:

$$dH=\sum n_i C_{p,i}\, dT$$

For mixture:

$$dH=nC_{p,m}\, dT$$

Equating:

$$nC_{p,m}=\sum n_i C_{p,i}$$

Divide by total moles:

$$\boxed{C_{p,m}=\sum x_i C_{p,i}}$$

If expressed in terms of mass fraction y_i:

$$\boxed{c_{p,m}=\sum y_i c_{p,i}}, \boxed{c_{v,m}=\sum y_i c_{v,i}}$$

7.b) <u>Given Data</u>:

Mole fractions

$$x_{N_2}=\frac{2}{3}=0.667$$
$$x_{O_2}=\frac{1}{3}=0.333$$

Partial pressures

Using **Dalton's law of partial pressures**:

$$P_i=x_i \cdot\ P_{total}$$

Total pressure $P=600$ kPa

Nitrogen:

$$P_{N_2}=0.667\times 600\approx 400 \text{ kPa}$$

Oxygen:

$$P_{O_2}=0.333\times 600\approx 200 \text{ kPa}$$

8.a)

Stoichiometric Combustion

Stoichiometric combustion (also called theoretical combustion) occurs when a fuel is burned with exactly the amount of oxygen required for complete combustion, with no excess oxygen or unburnt fuel remaining.

Example:

For methane combustion:

$$CH_4+2O_2\rightarrow CO_2+2H_2O$$

2 moles of oxygen are exactly required per mole of methane → this is stoichiometric.

Air Requirement:

Since air contains about 21% oxygen, the actual air supplied is:

$$\text{Air}=\frac{O_2}{0.21}$$

Excess Air Combustion

Excess air combustion occurs when **more air than the stoichiometric requirement** is supplied.

Example:

$$CH_4+2O_2+\text{extra air}\rightarrow CO_2+2H_2O+\text{unused } O_2+N_2$$

Or

Comparison

Aspect	**Stoichiometric Combustion**	**Excess Air Combustion**
Air supplied	Exact required	More than required
Oxygen in products	None	Present
Combustion completeness	Ideal (theoretical)	Practically complete
Flame temperature	Maximum	Lower
Emissions	Can form CO if imperfect	Less CO, cleaner burn

8.b)

Given:

Heat of combustion, Q=45,000 kJ/kg

Specific heat of products, c_p=1.2 kJ/kgK

Assume initial temperature, T_i=300 K (standard unless specified)

Mass m=1 kg

$$45000=1\times1.2\times(T_f-300)$$

$$T_f-300=\frac{45{,}000}{1.2}=37500$$

$$T_f=37500+300=37800\text{ K}$$

$$T_f\approx 37{,}800\text{K}$$

9.a)

1. Air–Fuel Ratio

This is the most important factor.

Stoichiometric mixture → gives maximum flame temperature

Excess air → lowers temperature (extra air absorbs heat but doesn't react)

Fuel-rich mixture → incomplete combustion → lower temperature

2. Initial Temperature of Reactants

Higher initial temperature → higher flame temperature

Preheating air or fuel increases AFT significantly

3. Heat of Combustion of Fuel

Fuels with higher calorific value produce higher AFT

More energy released → more temperature rise

4. Dilution (Inert Gases)

Presence of inert gases like N_2, CO_2, H_2O lowers AFT

These gases absorb heat without contributing to combustion

5. Specific Heat of Products

Higher specific heat → lower temperature rise

Because more energy is required to raise temperature

6. Dissociation of Combustion Products

At high temperatures:

$CO_2 \rightarrow CO + O_2$

$H_2O \rightarrow H_2 + O_2$

7. Pressure of the System

Higher pressure → less dissociation → higher AFT

Lower pressure → more dissociation → lower temperature

8. Type of Fuel

Different fuels produce different products and heat release

Hydrogen → high AFT

Solid fuels → lower AFT due to impurities and incomplete combustion

9.b)

Oxygen required for each element

For Carbon:

$$C+O_2 \rightarrow CO_2$$

12 kg C requires 32 kg O_2

$$\Rightarrow 1 \text{ kg C needs } \frac{32}{12}=2.67 \text{ kg } O_2$$

For 0.80 kg C:

$$O_2=0.80\times 2.67=2.136 \text{ kg}$$

For Hydrogen:

$$H_2+\frac{1}{2}O_2 \rightarrow H_2O$$

2 kg H_2 requires 16 kg O_2

$$\Rightarrow 1 \text{ kg H needs 8 kg } O_2$$

For 0.15 kg H:

$$O_2=0.15\times8=1.20\text{ kg}$$

Subtract oxygen present in fuel

Fuel already contains 0.05 kg O, which reduces external oxygen needed:

$$\text{Effective } O_2=(2.136+1.20)-0.05$$

$$O_2=3.336-0.05=3.286\text{ kg}$$

Theoretical Oxygen Required:

$$\boxed{3.29\text{ kg O}_2\text{ per kg of fuel}}$$

Theoretical Air Required

Air contains **23% oxygen by mass**:

$$\text{Air required}=\frac{3.286}{0.23}$$

$$=14.29\text{ kg air}$$

10.a)

1. **Energy Supply / Preheating**
   Energy is supplied by a source such as:
   Electric spark
   Hot surface
   Compression (in engines)

The mixture temperature rises, but no visible combustion

2. **Chemical Initiation**

Fuel molecules start breaking down into active radicals (H, O, OH).

These radicals are highly reactive and initiate combustion reactions.

3. **Chain Reactions (Propagation & Branching)**

Reactions accelerate rapidly due to chain branching:

   - One reaction produces multiple radicals

Heat release increases sharply.

4. **Ignition Point**

   A critical point is reached where:

   Heat produced > heat lost

   Temperature rises rapidly → flame starts forming

5. **Self-Sustained Combustion**

   No external energy is needed anymore

   A stable flame front or reaction zone propagates through the mixture

10.b

Temperature

Increase in temperature → widens flammability limits

LFL decreases, UFL increases

Pressure

Higher pressure → increases UFL

Slight effect on LFL

Oxygen concentration

More oxygen → wider flammable range

Less oxygen → narrower range

Inert gases (CO_2, N_2, etc.)

Reduce flammability range by diluting mixture

Nature of fuel

Different fuels have different limits depending on chemical composition

11.a)

1. Mixing of Fuel and Air

Premixed flame
Fuel and air are mixed completely before ignition.
Example: Bunsen burner (with air holes open).

Diffusion flame
Fuel and air are not mixed before ignition; they mix during combustion by diffusion.
Example: Candle flame.

2. Combustion Zone

Premixed flame
Combustion occurs in a thin, well-defined flame front.

Diffusion flame
Combustion occurs over a broader region where fuel and oxygen meet.

3. Flame Appearance

Premixed flame
Usually blue and non-luminous (complete combustion).

Diffusion flame
Usually yellow/orange and luminous due to soot particles.

4. Rate of Combustion

Premixed flame
Faster and controlled by flame propagation speed.

Diffusion flame
Slower, controlled by rate of mixing (diffusion).

5. Temperature

Premixed flame
Generally higher and more uniform temperature.

Diffusion flame
Lower and non-uniform temperature distribution.

6. Efficiency

Premixed flame
More **efficient** (better fuel–air mixing → complete combustion).

Diffusion flame
Less efficient due to **incomplete mixing**.

7. Pollution

Premixed flame
Produces **less soot and smoke**.

Diffusion flame
Produces **more soot, smoke, and pollutants**.

8. Examples

Premixed flame
Gas stove (properly adjusted), Bunsen burner (air open), spark ignition engines.

Diffusion flame
Candle, kerosene lamp, diesel engine combustion.

11.b)

1. Based on Fuel–Air Mixing

(a) Premixed Flames

Fuel and air are mixed before ignition.

Features

Thin flame front

High flame speed

Blue, non-luminous (clean burning)

Examples

Bunsen burner (air holes open)

Domestic LPG stove (well-adjusted)

Spark ignition engines

(b) Diffusion Flames (Non-Premixed)

Fuel and air mix during combustion by diffusion.

Features

Broader flame zone

Slower burning (mixing-controlled)

Yellow/orange, luminous (soot present)

Examples

Candle flame

Kerosene lamp

Diesel engine combustion

2. Based on Flow Conditions

(a) Laminar Flames

Flame propagates in a smooth, orderly flow.

Features

Stable and well-defined

Occur at low velocities

Easy to analyze theoretically

Examples

Small Bunsen burner flame

Laboratory combustion experiments

(b) Turbulent Flames

Flame exists in a chaotic, fluctuating flow.

Features

Irregular shape

High mixing rate → faster combustion

Used in practical systems

Examples

Gas turbines

Industrial furnaces

Large boilers

3. Based on Flame Speed

(a) Deflagration

Subsonic flame propagation (slower than speed of sound).

Features

Driven by heat transfer and diffusion

Most common type of combustion

Examples

Gas stove flame

Petrol engine combustion

(b) Detonation

Supersonic combustion with shock waves.

Features

Extremely rapid energy release

High pressure and temperature rise

Examples

Explosives (e.g., TNT)

Accidental gas explosions

4. Based on Appearance (Luminosity)

(a) Luminous Flames

Bright yellow/orange

Contain glowing soot particles

Incomplete combustion

Examples

Candle flame

Oil lamps

(b) Non-Luminous Flames

Blue in color

Complete combustion

Cleaner and hotter

Examples

Bunsen burner (air open)

Gas stove flame

5. Based on Fuel Type

(a) Gaseous Fuel Flames

Clean combustion

Easy to control

Examples

LPG, methane burners

(b) Liquid Fuel Flames

Require atomization or vaporization

Examples

Kerosene lamps

Diesel engines

(c) Solid Fuel Flames

Involve pyrolysis before burning

Examples

Coal fire

Wood burning