



Internal Combustion Engines

Lecture-14

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European Diesel Emission Standard

Tier	Date	CO	THC	NMHC	NOx	HC+NOx	PM	P [# /km]
Diesel								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)	-
Euro 2	January 1996	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.50	0.56	0.05	-
Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025	-
Euro 5a	September 2009	0.50	-	-	0.180	0.230	0.005	-
Euro 5b	September 2011	0.50	-	-	0.180	0.230	0.005	6×10 ¹¹
Euro 6	September 2014	0.50	-	-	0.080	0.170	0.005	6×10 ¹¹

* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N₁-I

** Applies only to vehicles with direct injection engines

*** 6×10¹²/km within first three years from Euro 6 effective dates

† Values in parentheses are conformity of production (COP) limits



European Petrol Emission Standard

Tier	Date	CO	THC	NMHC	NOx	HC+NOx	PM	P [# /km]
Petrol (Gasoline)								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	January 1996	2.2	-	-	-	0.5	-	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-	-
Euro 5	September 2009	1.0	0.10	0.068	0.060	-	0.005**	-
Euro 6	September 2014	1.0	0.10	0.068	0.060	-	0.005**	6×10 ¹¹ ***

* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N₁-I

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† Values in parentheses are conformity of production (COP) limits



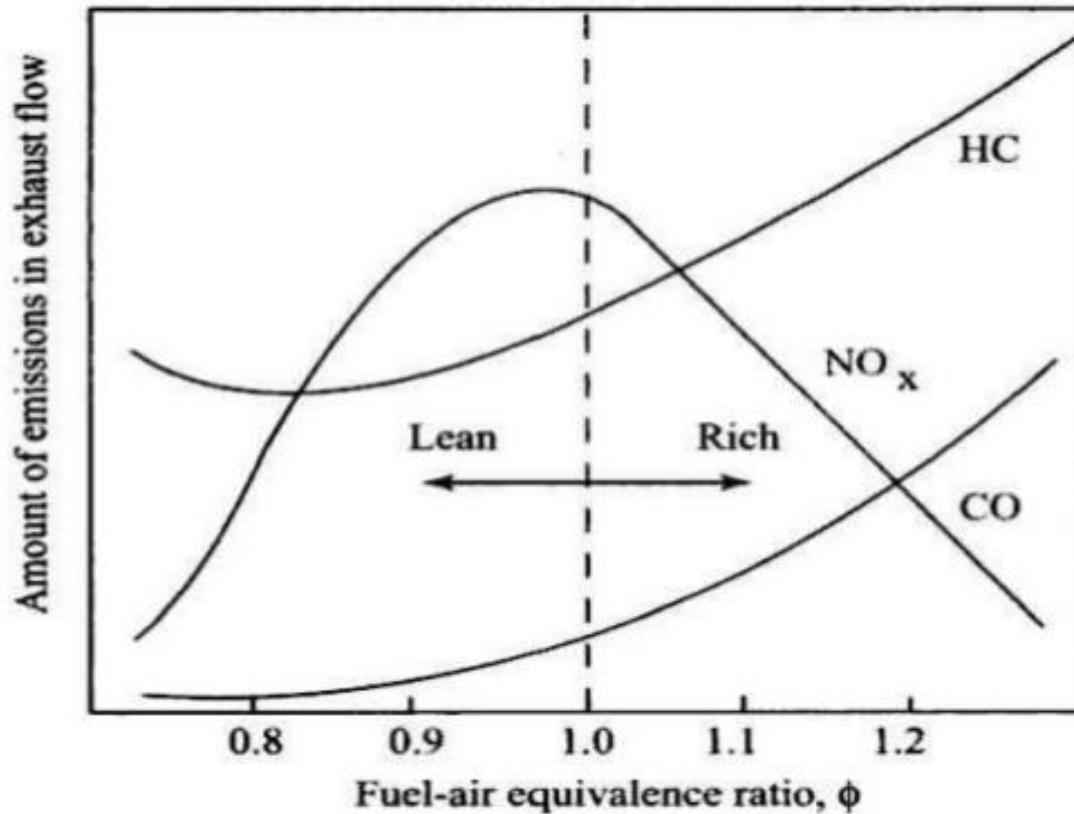
Indian Emission Standard

Standard	Reference	YEAR	Region
India 2000	Euro 1	2000	Nationwide
Bharat Stage II	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003.04	NCR*, 13 Cities†
		2005.04	Nationwide
Bharat Stage III	Euro 3	2005.04	NCR*, 13 Cities†
		2010.04	Nationwide
Bharat Stage IV	Euro 4	2010.04	NCR*, 13 Cities†
Bharat Stage V	Euro 5	(to be skipped)	
Bharat Stage VI	Euro 6	2020.04 (proposed) ^[11]	Entire country

* National Capital Region (Delhi)

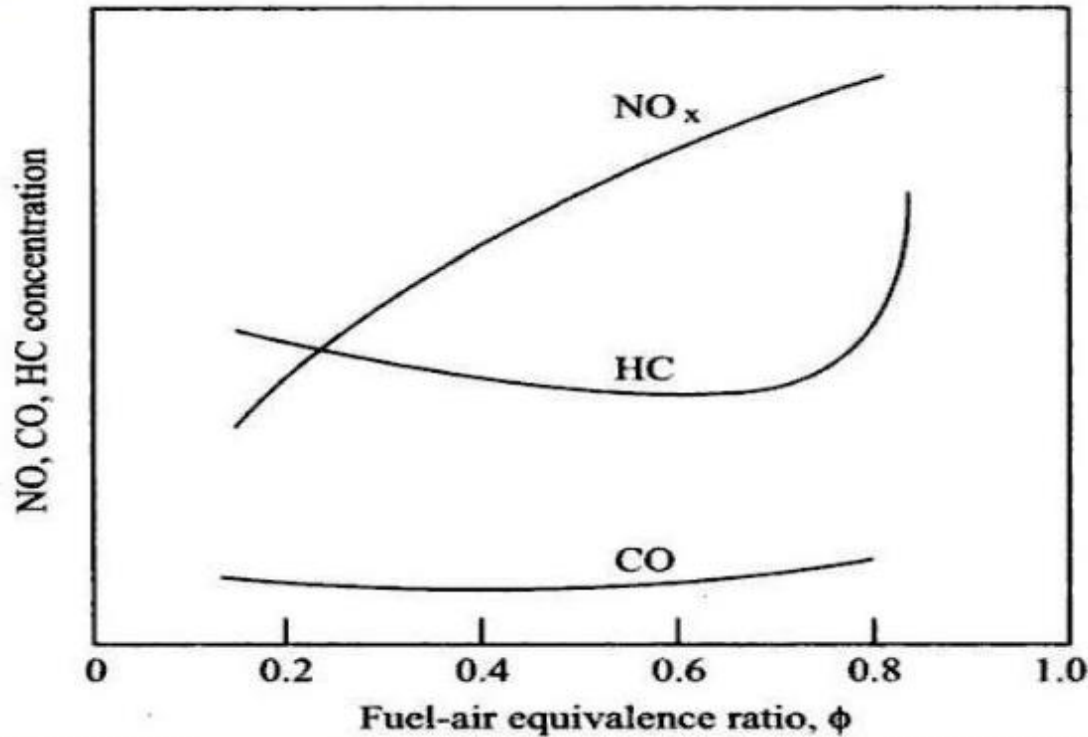
† Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Sholapur, Jamshedpur and Agra

SI Engine Emission



- CO, Hydrocarbon and NO_x are the main pollutant from SI engine
- Oxides of sulphur are there. Sulphur is present in fuel.
- There are other pollutants also – but in a negligible quantities

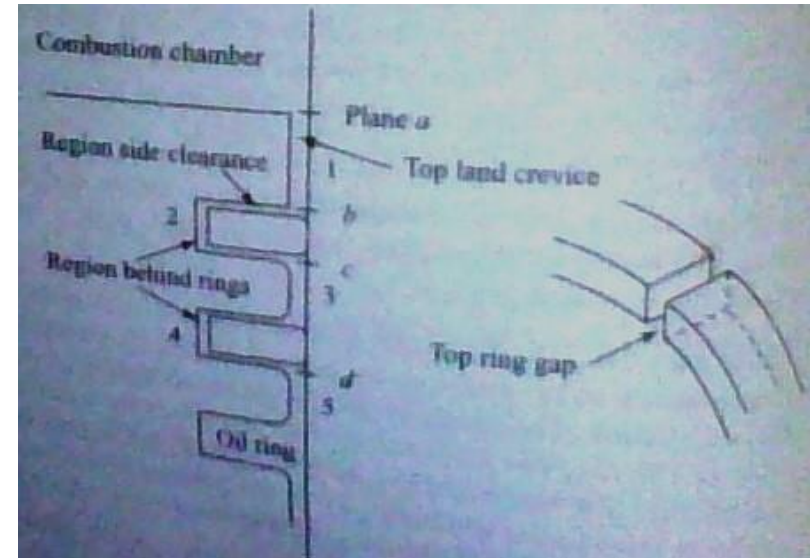
CI Engine Emission



- CO, Hydrocarbon and NO_x are the main pollutant from SI engine
- **There are particulates in the exhaust**
- Oxides of sulphur are there. Sulphur is present in fuel.
- There are other pollutants also – but in a negligible quantities

Hydrocarbon Emission

- **Incomplete combustion**
 - Improper mixing
 - Flame quenching
- **Crevice volume and flow in crevice**
- **Leakage past the exhaust valve**
- **Valve overlap**
- **Deposit on walls**
- **Oil on combustion chamber walls**





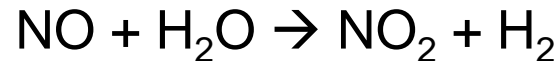
Carbon Monoxide Emission

- Generated due to incomplete combustion
- Present in fuel rich combustion zone
- Energy loss is associated with CO generation
$$2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2 + \text{heat}$$
- Low in CI engine exhaust



NOx Emission

- There are mainly NO, small amount of NO₂ and trace of other oxides together called NOx
- Possible major reactions are



- Dissociation occurs at 2500-3000K



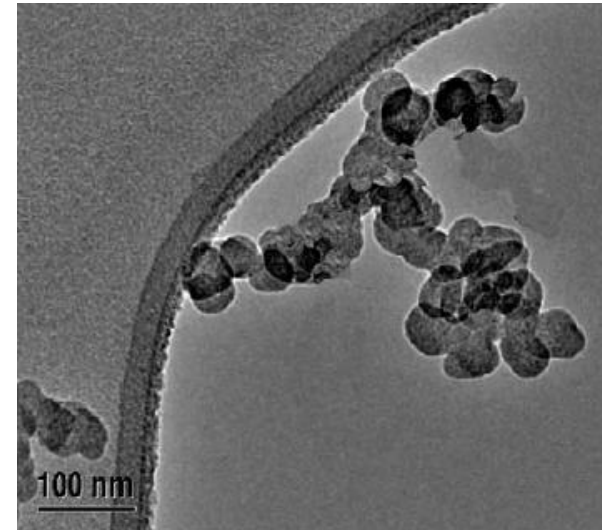
- Photochemical smog formation from NOx



Internal Combustion Engines

Particulate (Soot) Emission

- Soot is amorphous carbon particles
- Generated at rich combustion area
- The formation mechanism of soot particles is quite complex and not yet completely understood. Four broad steps have been identified
 - Precursor formation
 - polycyclic aromatic hydrocarbons (PAH)
 - 1200K – 1800K
 - Particle inception
 - Growth and agglomeration
 - Oxidation



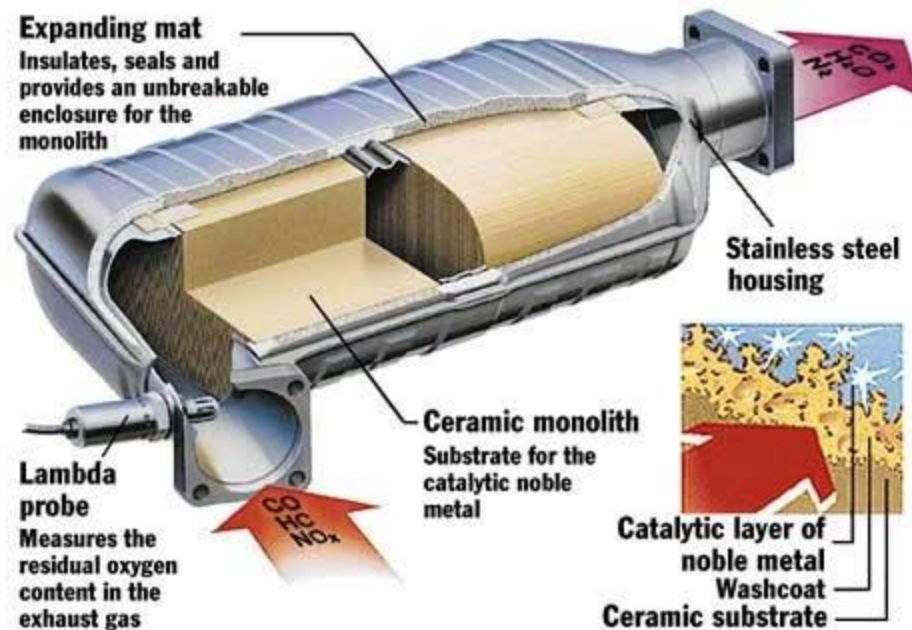


Thermal Converter

- At 600°C and 50 millisecond residence time, the following reactions occur
 - $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$
 - $\text{C}_x\text{H}_y + (x + 0.25y)\text{O}_2 \rightarrow x\text{CO}_2 + y\text{H}_2\text{O}$
- For efficient operation temperature should be above 700°C
- This causes energy loss in cylinders

Catalytic Converter

- The oxidation occurs at 250-300°C in presence of platinum or palladium
- Rhodium promotes the reduction reactions of Nox
 - $\text{NO} + \text{CO} \rightarrow 0.5 \text{N}_2 + \text{CO}_2$





Thank You