

Module 4: Vehicle Emission Standards and Measurement

Lecture17:Emission Standards

The Lecture Contains:

- EMISSION STANDARDS
- Light Duty Vehicles
- Heavy Duty Engines
- Motorcycle Emission Standards

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EMISSION STANDARDS

The vehicle emission standards were implemented for the first time in 1965 when control of crankcase hydrocarbon emissions from gasoline passenger cars was required as per the law. Use of positive crankcase ventilation (PCV) system on the gasoline passenger cars became necessary to prevent emission of hydrocarbon rich crankcase blow by gases into atmosphere. At the same time, the exhaust gas emission standards for new cars were also established in the state of California and in 1968, US enacted legislation to implement nationwide vehicle emission regulations. In Europe , vehicle emission standards were implemented beginning from the year 1970. Over the years, the emission standards have become more and more stringent and have driven the development of advanced engine designs and emission control technology. Now, nearly all the countries all over the world have enforced vehicle emission regulations of varying severity following largely either the US or the European regulations. The emission limits that are in force in the US and Europe and the trends thereof over the years are discussed below.

Light Duty Vehicles

US Standards

The US emission standards for passenger cars are given in Table 4.1 since the limits were set for the first time under the Clean Air Act of 1968. The standards set for 1975 were rather stringent such that the oxidation catalytic converters were required on most cars. Amendments to Clean Air Act in 1977 resulted in the standards that required in 1980/1981 reduction of 90% in HC and CO, and 75% in NO_x . The 1980-81 standards resulted in widespread use of 3-way catalyst technology.

During 1990s, the 1977 amendments were found inadequate as 9 US cities had higher ozone levels and 41 cities higher CO levels than the air quality standards. The 1990 Clean Air Act Amendments (CAAA) followed resulting in further tightening of the emission standards besides other measures like introduction of better quality fuels such as the reformulated gasoline. The new emission regulations known as Tier 1 were implemented from 1994 and Tier 2 standards from 2004 through to 2009. It is seen that the current production vehicles emit less than 1% of emissions of pre-control era vehicles.

In the mean time California introduced a new set of emission regulations (Table 4.2) and called the vehicles meeting these regulations by the name of different grades of low emission vehicles (LEV) such as TLEV (Transitional), LEV, ULEV (Ultra), SULEV (Super Ultra) and PZEV (Partial zero emission vehicles).

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Table 4.1

US Federal Emission Standards for Passenger Cars, g/mile

Year	NMOG/ NMHC	CO	NO _x	PM (1)	HCHO(2)	Evap. g/test
US Federal						
Pre-control (1966)	15 (3)	90	6.2			6.0
1975	1.5 (3)	15	3.1			2.0 (4)
1981	0.41 (3)	3.4	1.0			2.0 (5)
Tier1 ⁽⁶⁾ , 1994						(7)
Gasoline	0.25(0.31)	3.4 (4.2)	0.4 (0.6)	-		
Diesel	0.25(0.31)	3.4 (4.2)	1.0 (1.25)	0.08 (0.10)		
Tier2 ⁽⁸⁾ , 2004 - 2009	0.125	1.7	0.2	0.02	0.018	(7)

NMHC/NMOG = Non-methane hydrocarbons or organic gases

(1) For diesel vehicles only (2) for alcohol fueled vehicles only (3) Total hydrocarbons (4) Carbon canister trap method (5) SHED (Sealed Housing Evaporative Determination) technique, the 6.0 g/test limit represents about 70 % less than 2.0 g/test by carbon trap method (6) values in parentheses for full useful life equal to 100,000 miles, (7) new limits (8) To be phased in between 2004-2009,limits for all types of light duty vehicles GVW<8500 lbs at the end of full useful life 120,000 miles. Eight different emission categories called 'bins' in the given range to which vehicles can be certified and average NO_x of the total fleet of a manufacturer not more than 0.07 g/mile.

Table 4.2

California Emission Standards for Passenger Cars, g/mile (1)

Year	NMOG/ NMHC	CO	NO _x	PM (1)	HCHO (2)	Evap. g/test
TLEV, 1996	0.125 (0.156)	3.4 (4.2)	0.4 (0.6)	(0.08)	0.015 (0.018)	2.0
LEV, 2000	0.075 (0.090)	3.4 (4.2)	0.2 (0.3)	(0.08)	0.015 (0.018)	2.0
ULEV, 2001	0.04 (0.055)	1.7 (2.1)	0.2(0.3)	(0.04)	0.015 (0.018)	2.0
LEV 2, 2004	0.075(0.090)	3.4 (4.2)	0.05 (0.07)	(0.01)	0.015 (0.018)	2.0
ULEV2,2004	0.040(0.055)	1.7(2.1)	0.05(0.07)	(0.01)	0.008 (0.011)	2.0
SULEV2, 2004	(0.010)	(1.0)	(0.02)	(0.01)	(0.004)	2.0
PZEV (2)	0.010	1.0	0.02	0.01	0.004	

(1) Limits in parentheses at the end of durability run for 100,000 miles and from the year 2004 at 120,000 miles. (2) Partial zero emission vehicles (PZEV) limits are for 150,000 miles durability.

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European Standards

European emission standards for the light duty vehicles are given in the Table 4.3. Before 1992 i.e. prior to Euro 1 standards, emission limits were based on ECE-15 cycle and varied with vehicle reference weight, the higher emissions were permitted for the heavier passenger cars. From 1992 however, the same limits for all the passenger cars irrespective of vehicle weight as in the US were introduced. EU standards up to Euro 3 stage require durability demonstration for 80,000 km or 5 years, whichever occurs first. In lieu of actual durability test, the manufacturers may use the following deterioration factors:

- Gasoline cars: 1.2 for CO, HC and NO_x
- Diesel cars: 1.1 for CO, NO_x and HC+ NO_x, 1.2 for PM

Euro 5 stage requires durability of 160,000 km or 5 years, whichever occurs first. The emission standards for the light duty trucks and medium duty vehicles also, have been laid down and can be found in the European regulations.

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Table 4.3
European Emission Standards for
Passenger Cars, g/km

Description	Vehicle Type	CO	HC	NO _x	HC+NO _x	PM
1992 – Euro 1	All	2.72	-	-	0.97	0.14 ⁽¹⁾
		(3.16)			(1.13)	(0.18) ⁽²⁾
1996 – Euro 2	Gasoline	2.2	-	-	0.50	-
	Diesel IDI	1.0	-	-	0.70	0.08
	Diesel DI	1.0	-	-	0.90	0.10
2000 - Euro 3 ⁽³⁾	Gasoline	2.3	0.20	0.15	-	-
	Diesel	0.64	-	0.50	0.56	0.05
	Gasoline	1.00	0.10	0.08	-	-
2005 – Euro 4	Gasoline	1.00	0.10	0.08	-	-
	Diesel	0.50	-	0.25	0.30	0.025
2009 - Euro 5	Gasoline	1.0	0.10 ⁽⁴⁾	0.06	-	0.005 ^(5,6)
	Diesel	0.50	-	0.18	0.23	0.005 ⁽⁶⁾
2014 – Euro 6	Gasoline	1.0	0.10 ⁽⁴⁾	0.06	-	0.005 ^(5,6)
	0.50	-	0.08	0.17	0.17	0.005 ⁽⁶⁾

- (1) PM limits apply only to diesel cars.
- (2) Values in parentheses are conformity of production (COP) limits. From Euro 2 standards type approval and COP limits are the same
- (3) 40s idle phase preceding test eliminated
- (4) 0.068 g/km NMHC (non-methane hydrocarbons)
- (5) applicable only to lean burn gasoline direct injection engines
- (6) Likely to be reduced to 0.003 with new measurement method .

Since 1991/1992 when the European vehicles needed catalytic exhaust aftertreatment to meet the regulations drastic reductions in emission limits have been enforced. Relative emissions limits since 1990 (pre-Euro1) to Euro 4 limits are shown on Fig 4.8. The Euro 4 limits were only about 5 to 15 % of the pre 1990 limits. Beyond Euro 4 standards, drastic reductions in diesel NO_x and PM emissions are required. The diesel passenger car NO_x would be reduced to just 1/3 rd and PM to 1/5 th of Euro 4 limits.

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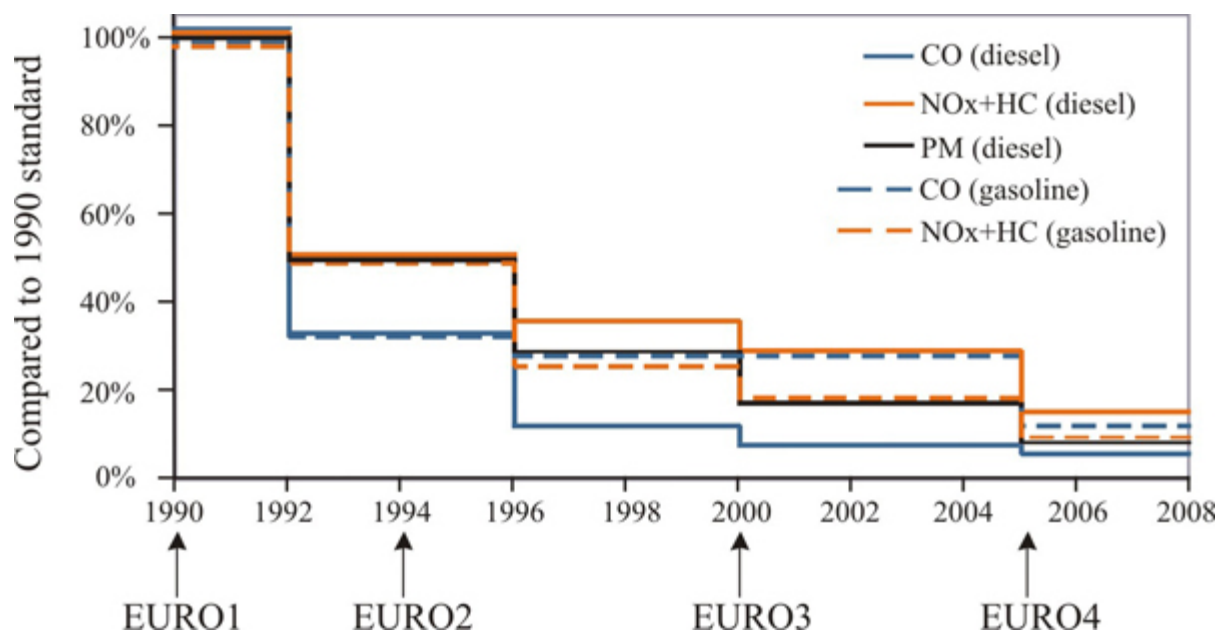


Figure 4.8 Evolution of EU emission standards (light duty)

Heavy Duty Engines

Most heavy-duty vehicles are powered by the diesel engines. Hence, the heavy duty engine emission regulations have been directed more towards reduction in NO_x and PM emissions.

US Standards

The US emission standards for the engines of heavy-duty vehicles (GVW >3855 kg) are given in Table 4.4. The emission limits applicable from the model year 2007 specify a drastic reduction over the year 2004 standards. The PM standards will be fully effective from the year 2007. The NO_x and NMHC standards are to be phased-in for the diesel engines between 2007 and 2010.

Emission durability is to be demonstrated over the useful life of the vehicles that varies from 8 years or 176,000 km for light heavy-duty engine vehicles (>8,860 kg <15000 GVW) to 8 years or 465,300 km for heavy heavy-duty vehicles (> 15000 kg GVW). To make the year 2007 standards effective, diesel fuel sulphur is to be reduced to 15 ppm maximum down from the earlier limit of 500 ppm.

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Table 4.4

US Federal Heavy Duty Engine Emission Standards, g/bhp-h, (US HD-Transient cycle)

Year	CO	HC	NMHC + NO _x	NO _x	PM
1988	15.5	1.3	-	10.7	0.60
1990	15.5	1.3	-	6.0	0.60
1991	15.5	1.3	-	5.0	0.25 (0.25)
1994	15.5	1.3	-	5.0	0.10 (0.07)
1996	15.5	1.3	-	5.0	0.10 (0.05) ⁽¹⁾
1998	15.5	1.3	-	4.0	0.10 (0.05) ⁽¹⁾
2004 ⁽²⁾					
Option 1	15.5	-	2.4	-	0.10 (0.05)
Option 2	15.5	0.5 ⁽³⁾	2.5	-	0.10 (0.05)
2007	15.5	0.14 ⁽³⁾	-	0.2	0.01

Note: values in parentheses apply to urban buses

- (1) PM standard in use is 0.07 g/hp.h
- (2) Engine manufacturers may use either of the two options.
- (3) NMHC limits apply.

European Standards

The European regulations for new production heavy-duty diesel engines since Euro 1 stage are given in Tables 4.5 and 4.6. These standards apply to both heavy-duty highway vehicles as well as to urban buses. The test cycle was changed with the implementation of Euro 3 standards in the year 2000. To meet the Euro 4 standards and beyond, diesel engines need some form of aftertreatment devices such as oxidation catalysts, particulate filters, de-NO_x catalysts etc. From Euro 3 regulations, heavy-duty engines operating on gaseous fuels are tested also on ETC in addition to ESC cycle. However, for compliance with Euro 4 or later standards, all heavy-duty engines are to meet ESC, ELR and ETC test limits. Evolution of European emission regulations for heavy duty vehicles is shown on Fig. 4.9.

Table 4.5
European Heavy Duty Diesel (CI) Engine Emission Standards –
g/kWh (smoke in m⁻¹) [2-4]

	Date & Category	Test cycle	CO	HC	NO _x	PM	Smoke
Euro1	1992 <85 kW	ECE R-49	4.5	1.1	8.0	0.61	
	1992 >85 kW		4.5	1.1	8.0	0.36	
Euro 2	Oct. 1996		4.0	1.1	7.0	0.25	
	Oct. 1998		4.0	1.1	7.0	0.15	
Euro 3	Oct. 2000	ESC & ELR	2.1	0.66	5.0	0.10	0.8
						0.13*	
Euro 4	Oct 2005	ESC& ELR	1.5	0.46	3.5	0.02	0.5
Euro 5	Oct. 2008		1.5	0.46	2.0	0.02	0.5
Euro 6	Jan. 2013	ESC	1.5	0.13	0.4	0.01	-

*For engines of less than 0.75 litre /cylinder swept volume and rated speed of more than 3000 rpm.

Table 4.6
Emission Standards for CI and SI
Engines, ETC Test, g/kWh

	Date & Category	Test cycle	CO	NMHC	CH 4 ⁽¹⁾	NO _x	PM ⁽²⁾
Euro3	Oct. 2000	ETC	5.45	0.78	1.6	5.0	0.16 0.21 ⁽³⁾
Euro 4	Oct. 2005		4.0	0.55	1.1	1.1	0.03
Euro 5	Oct. 2008		4.0	0.55	1.1	2.0	0.03
Euro 6	Jan. 2013		4.0	0.16 (4)	0.5	0.4	0.01 (5)

(1) for natural gas engines only; (2) not applicable for gas fuelled engines for approval to Euro 3 and Euro 4 standards; (3) for engines of less than 0.75 litre/cylinder swept volume and rated speed above 3000 rpm; .(4) THC (total hydrocarbons) limits apply for diesel; (5) particle number limit may apply to prevent ultra fine particles from flow through (or partial flow) filters.

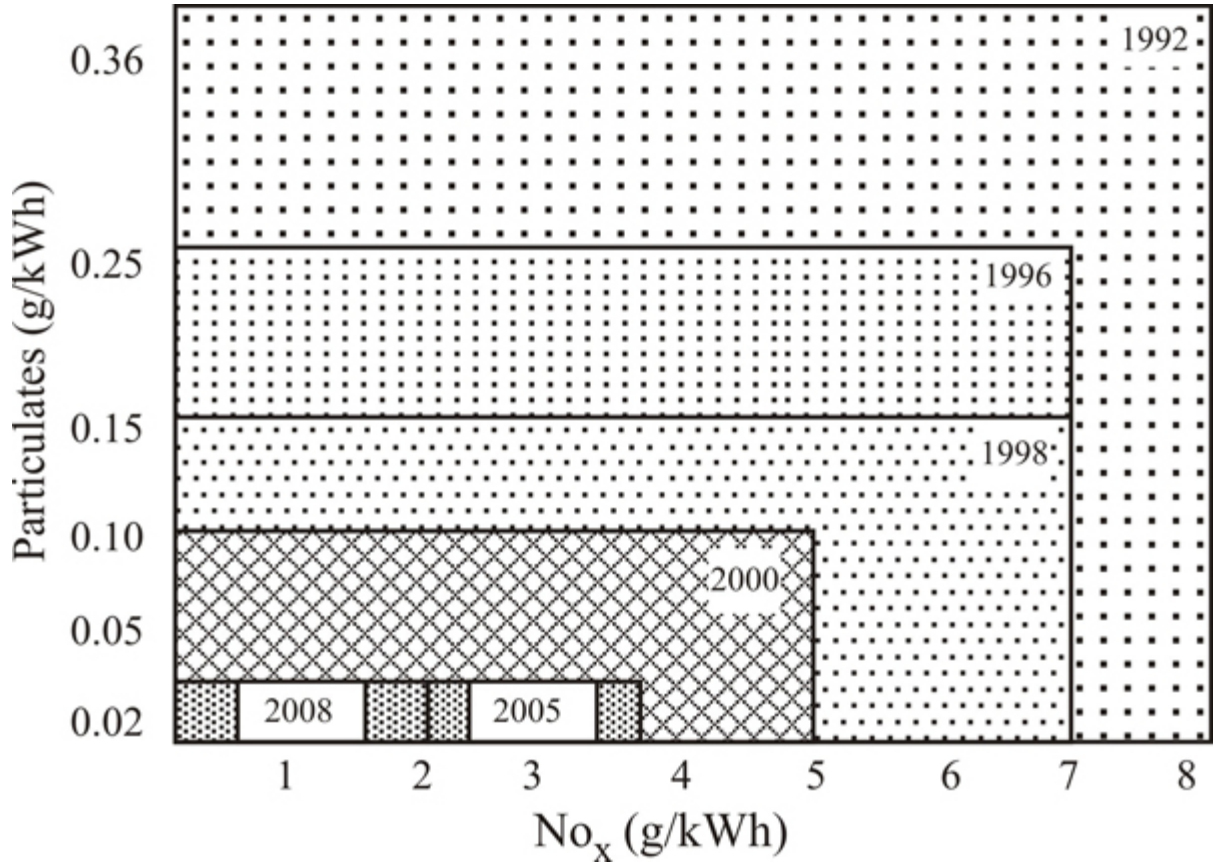


Figure 4.9 Evolution of European Heavy duty
Emission Standards



Emission Standards in India

India has adopted the European emission limits on a slightly modified driving cycle for the light duty vehicles. The overall emission limits and test procedures for the heavy duty vehicles however are the same as those in Europe . In India , the emission limits are being enforced by a time lag of around 5 years as shown in Table 4.7.

Table 4.7
Indian Emission Regulations
(light duty emission standards with a modified EUDC - maximum speed limited to 90 km/h)

Year of Implementation	Level of European Emission Standards
2000	E uro 2: four metro-cities ⁽¹⁾
	Euro 1: rest of the country
2003	Euro 2: seven more cities ⁽²⁾
2005	Euro 3: thirteen cities
	Euro 2: rest of the country
2010	Euro 4: thirteen cities
	Euro 3: rest of the country

(1) Delhi , Mumbai, Kolkatta, Chennai

(2) Banglore, Hyderabad , Ahmedabad, Pune, Surat , Kanpur , Agra ; added from the year 2005- Sholapur and Lucknow

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Motorcycle Emission Standards

Asian countries have a very large population of motorcycles and mopeds and these vehicles are estimated to contribute very heavily to urban air pollution. Taiwan and India have lead enforcement of stringent emission limits for two wheelers. Although the USA and Europe have implemented emission regulations for the two wheelers many decades back, but the number of these vehicles not being very large the standards were not tightened for a long time. However, now in these countries too very stringent limits are being enforced. Motorcycle emission standards in some countries are given in Table 4.8. Presently, most countries follow different test procedures. However, as discussed earlier, a world motorcycle test cycle has been developed and in future most countries are expected to use WMTC.

Table 4.8
Worldwide Motorcycle Emission Standards

Country/Year/ Type of Motorcycle	Test Cycle		Emission Limits, g/km			Durability,Kms
		CO	HC	NO _x	HC+NO _x	
USA						
1980	FTP-75	12.0	5.0	-	-	-
2006 < 279 CC		12.0	1.0	-	-	12,000-30,000
> 280 CC		12.0	-	-	1.4	6,000 -18,000
2010 < 279 CC		12.0	1.0	-	-	
> 280 CC		12.0	-	-	0.8	
Europe						
2003 < 50CC	ECE 47	1.0	-	-	1.2	-
> 50< 150CC	ECE 40	5.5	1.2	0.3	-	-
> 150 CC		5.5	1.0	0.3	-	-
2006 > 50< 150CC	ECE 40 (1)	2.0	0.8	0.15	-	-
> 150 CC	ECE15 +EUDC	2.0	0.3	0.15	-	-
2007< 130 km/h	WMTC	2.62	0.75	0.15	-	30,000
>130 km/h max. Speed	(optional)	2.62	0.33	0.22	-	30,000
India , 2000	IDC (cold)	2.0			2.0	-
2005 (2)	IDC	1.5			1.5	30,000

	(cold)					
2010 (2)	IDC (cold)	1.0			1.0	30,000

- (1) Warm-up period before emission measurement of ECE 15 cycle eliminated.
- (2) For catalyst equipped motorcycles an emission deterioration factor of 1.2 applies.