

## Exhaust Gas Temperatures

### SI engines

exhaust gas temp 400 – 600 °C average  
300 – 400 °C at idle and 900 °C at max power

when exhaust valve opens, in cylinder gas temperature is 200 – 300 °C more

### CI engines

200 – 500 °C average

cooling occurs due to larger expansion in Diesel engines

## Pollutant Formation

IC – engine exhaust gases contain oxides of nitrogen (NO and some amounts of NO<sub>2</sub> – collectively known as NO<sub>x</sub>), carbon monoxide (CO) and unburned hydrocarbons (HC).

Soot and PM in Diesel engines.

The amounts depend on engine design and operating conditions.

These pollutants are measured as concentrations;

CO, CO<sub>2</sub>, O<sub>2</sub> as vol. [%]

NO, NO<sub>2</sub>, NO<sub>x</sub> as [ppm] (parts per million)

HC as [ppm] or [ppm C]

eg 1 ppm propan, C<sub>3</sub>H<sub>8</sub>  
3 ppm C

## Control of Pollutant Emissions

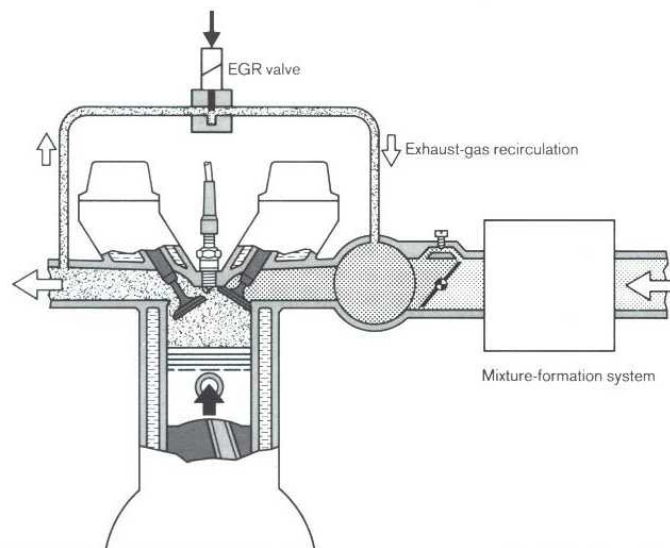
### Combustion related applications :

EGR (Exhaust gas recirculation)  
Water and alcohol injection

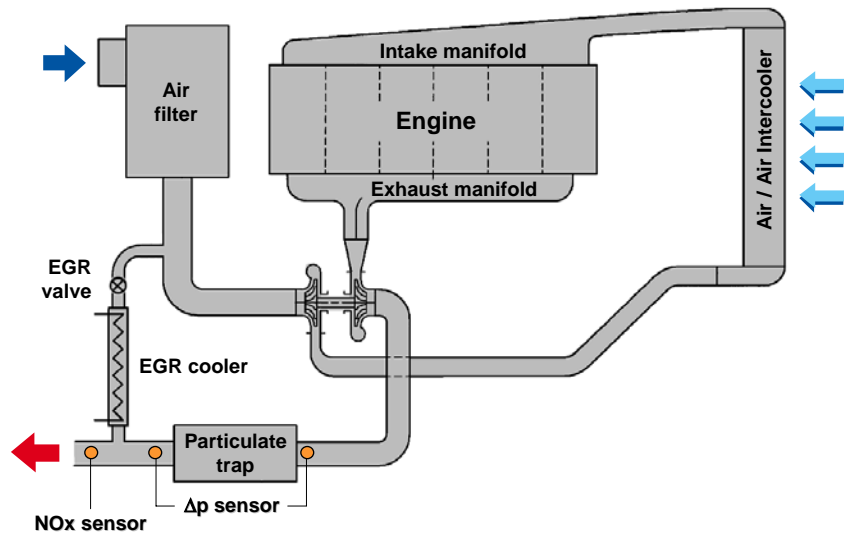
### Exhaust gas treatment :

Thermal reactors  
Catalytic converters  
Traps and filters

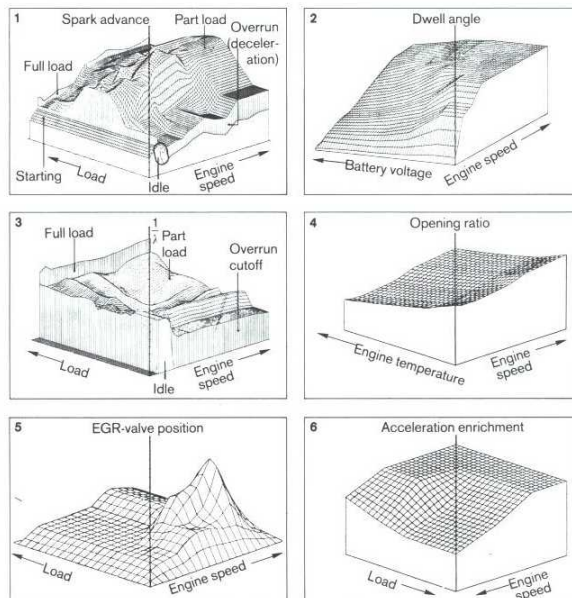
## EGR system



## Turbocharger with EGR system



## EGR control



## Exhaust Gas Treatment

### Thermal reactors

Require high temperatures,  
oxygen availability,  
sufficient time for reactions.

Used for oxidation of CO and HC

- Rich mixture + O<sub>2</sub> supplement : CO oxidation in exhaust system increases T, but fuel consumption also increases.
- Lean mixture + late ignition : high exhaust temperatures, but loss in power output

## Exhaust Gas Treatment

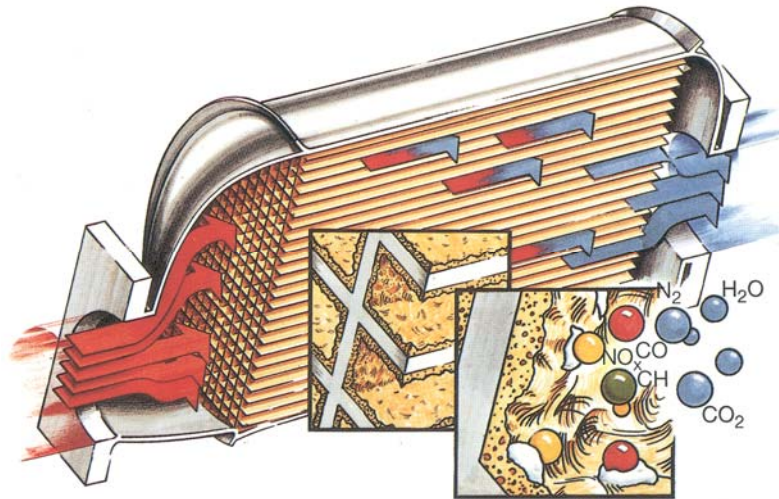
### Catalytic converters

Oxidizing catalysts for HC and CO

Reducing catalysts for NO<sub>x</sub>

Three-way catalysis for all three pollutants

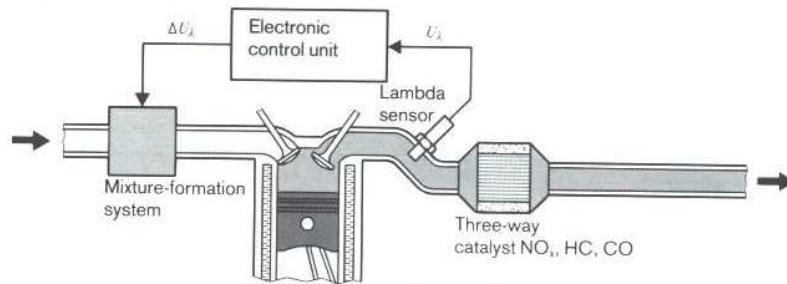
## Catalytic Converters



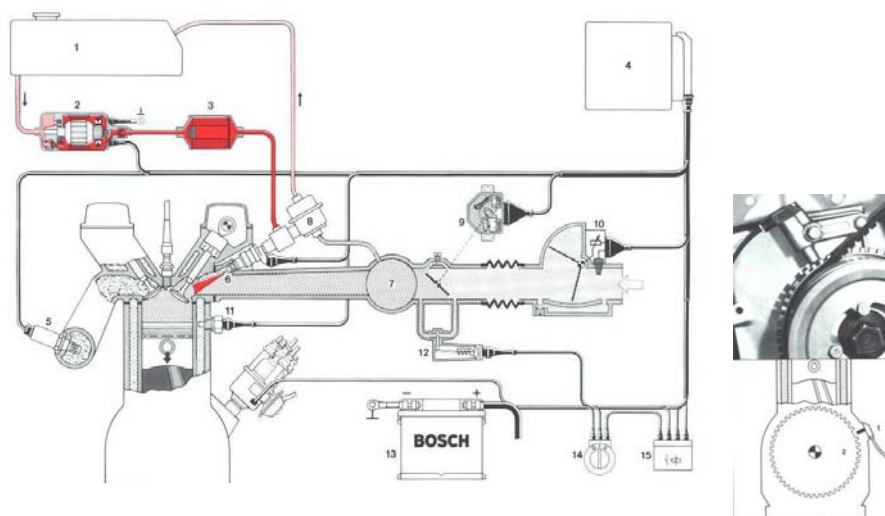
## Catalytic Converters



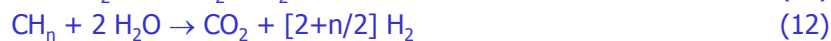
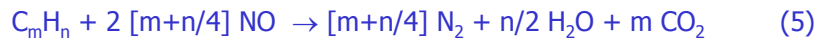
## Catalytic Converters



## Catalytic Converters



## Exhaust Gas Treatment



## Exhaust Gas Treatment



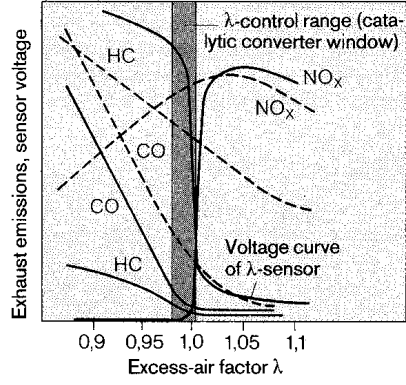
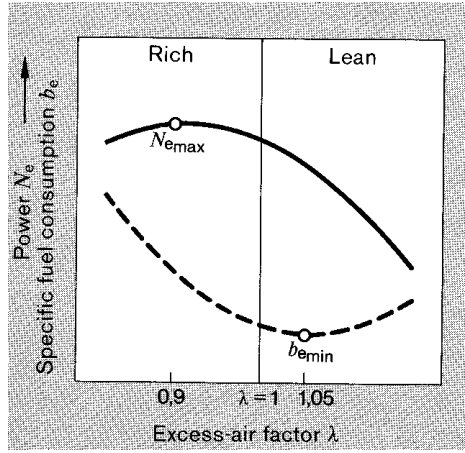
In lean mixtures reaction (2) is dominant – O<sub>2</sub> is present

CO is reduced by oxidation and insufficient CO for the relatively slow reaction(4).

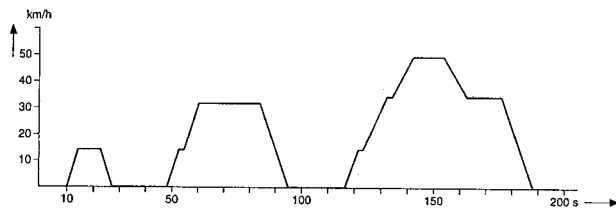


In rich mixtures reactions (11) and (12) have to be faster.

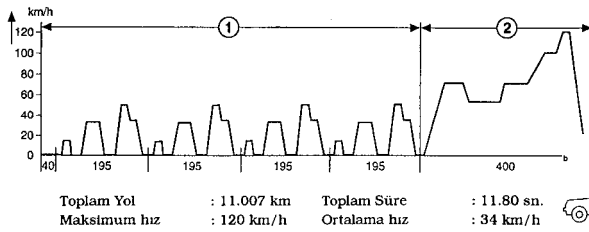
## Exhaust Gas Treatment



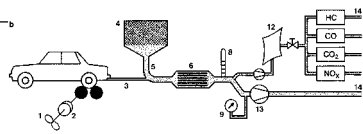
## Emission Regulations



Çevrim Tekrarı : 4 Bir Çevrim İçin Alınan Yol : 1.013 km  
 Toplam Süre : 820 s Ortalama Hız : 18.7 km / h  
 Bir Çevrim Süresi : 195 s Maximum Hız : 50 km / h  
 Toplam Test Yolu : 4.052 km



Toplam Yol : 11.007 km Toplam Süre : 11.80 sn.  
 Maksimum hız : 120 km/h Ortalama hız : 34 km/h





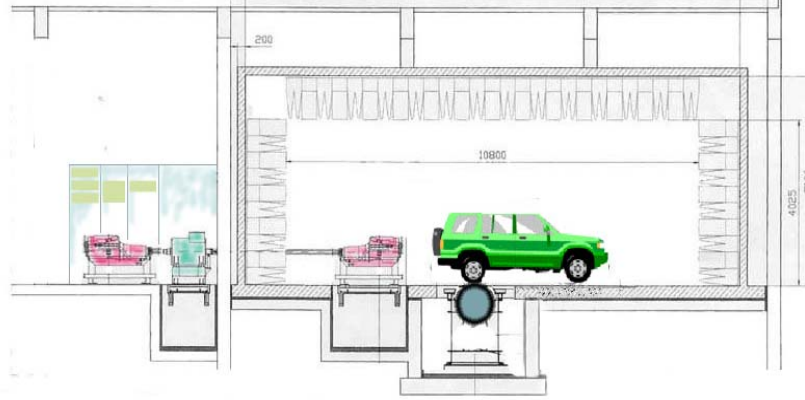
## Emission Regulations



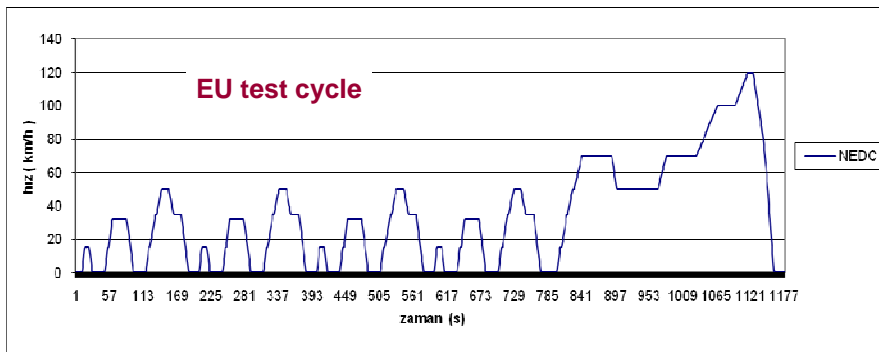
## Emission Regulations



## Emission Regulations



## Emission Regulations

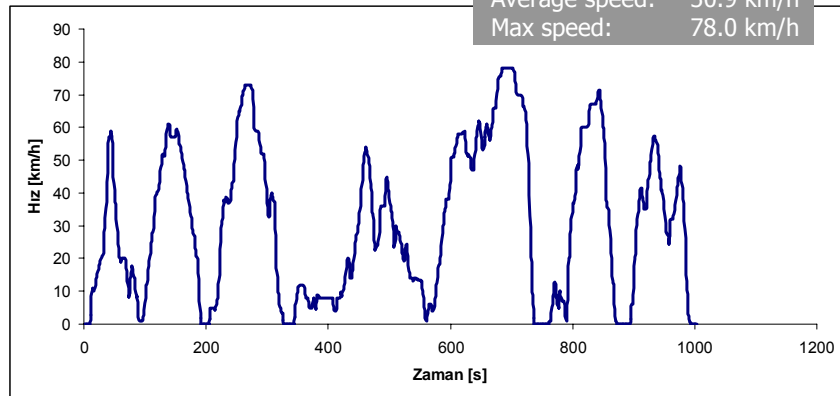


Çevrim Uzunluğu: 11,007 km  
Çevrim Süresi: 1180 s  
Ortalama Hız: 33,6 km/h  
Azami Hız: 120 km/h



## Istanbul Driving Cycle

Distance covered: 8.61 km  
Duration: 1003 s  
Average speed: 30.9 km/h  
Max speed: 78.0 km/h



## Emission Regulations



## Taşıt Parkı Dağılımı - Otomobiller

EKB(*)	2.098.206
R15.04	973.940
EURO1	114.889
EURO3	541.861
EURO4	153.192
<b>Toplam</b>	<b>3.882.088</b>

Türkiye geneli, Benzin-motorlu Otomobiller (2007)

(\*) Emisyon Kontrol donanımı Bulunmayan otomobiller, 1994 model yılı ve öncesi



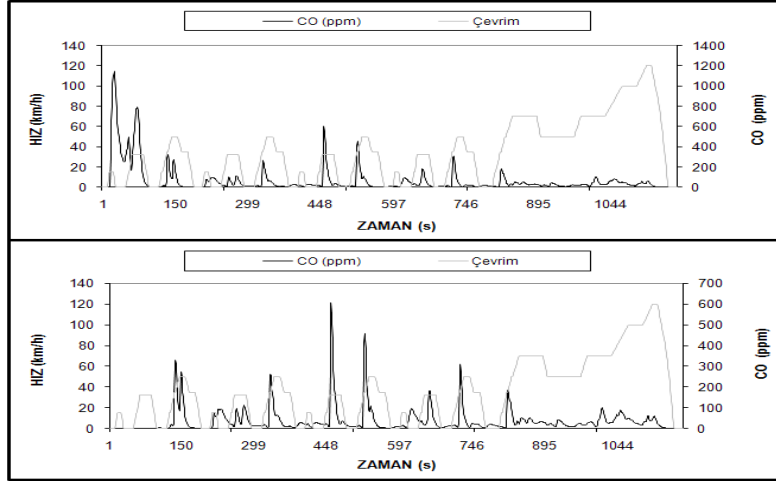
## Test Edilen Araçlar

EKB	10
R15.04	9
EURO1	3
EURO3	5
EURO4	3
<b>Toplam</b>	<b>30</b>

Test edilen Benzin-motorlu Otomobiller

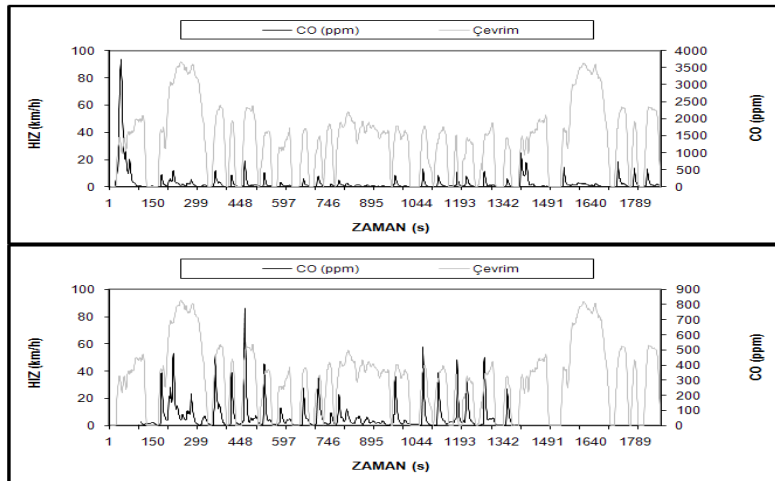


## CO Emisyonları



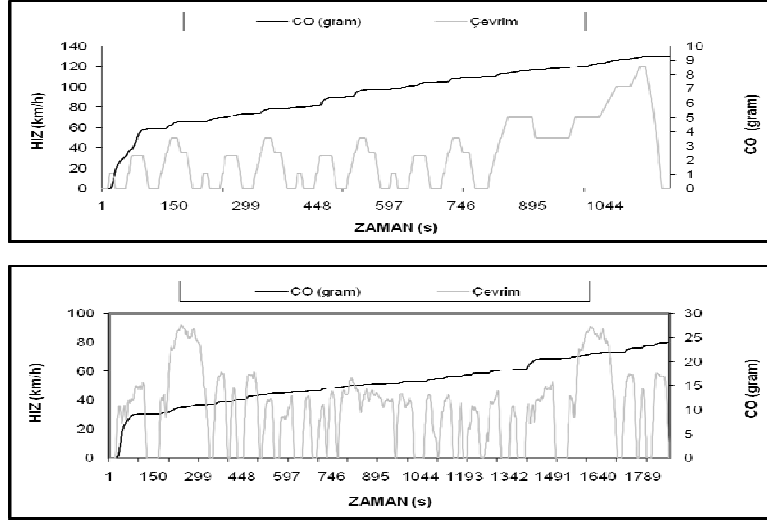
AB test çevrimi

## CO Emisyonları



ABD FTP 75 çevrimi

## Kümülatif CO Emisyonları



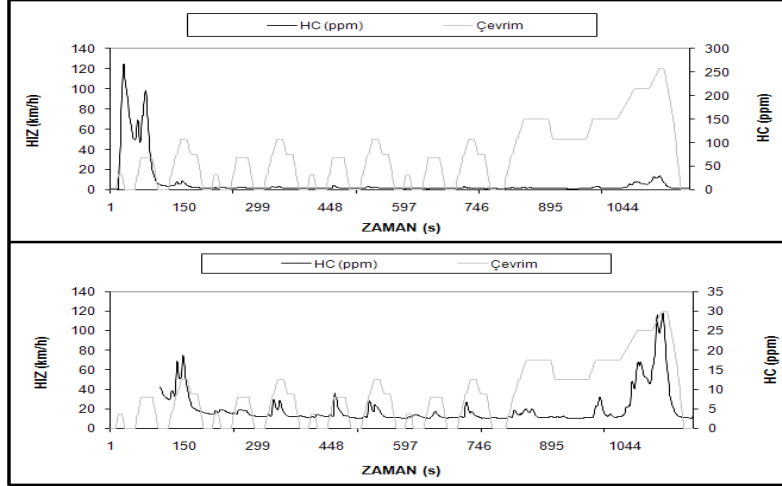
## CO Emisyonları

	FTP	AB	IDC (**)	IPCC
	CO [g-co/km]			
EKB(*)	16,50	17,77	<b>36,47</b>	46
R15.04	9,31	10,24	<b>13,91</b>	19
EURO1	2,36	3,39	<b>7,07</b>	2,9
EURO3	2,63	3,74	<b>5,88</b>	2,9
EURO4	0,43	0,52	<b>1,37</b>	-

(\*) Emisyon kontrol donanımı bulunmayan otomobiller, 1994 model yılı ve öncesi  
 (\*\*) İstanbul Driving Cycle (İstanbul Şehir Çevrimi)



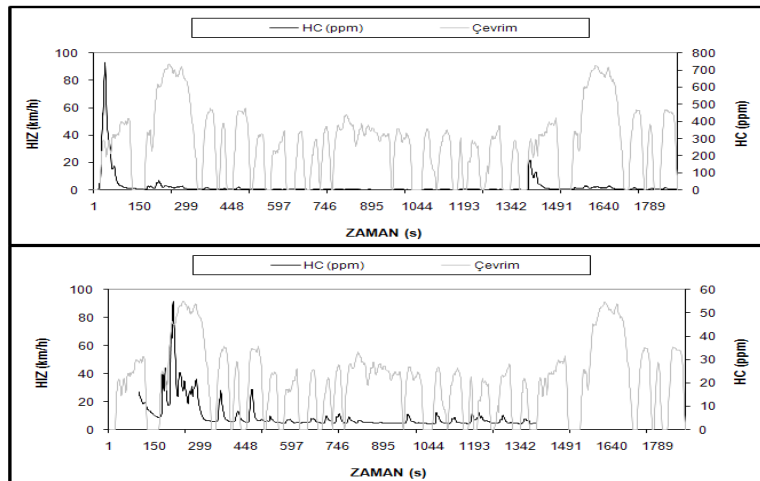
## HC Emisyonları



AB test çevrimi



## HC Emisyonları

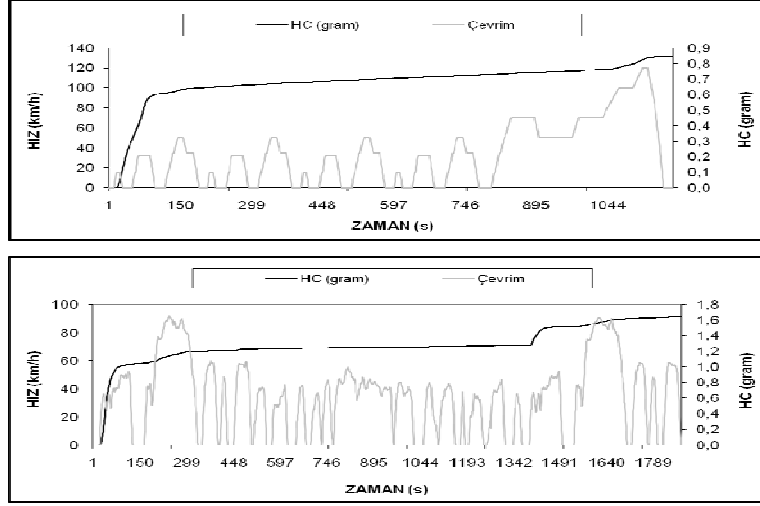


ABD FTP 75 çevrimi





## Kümülatif HC Emisyonları



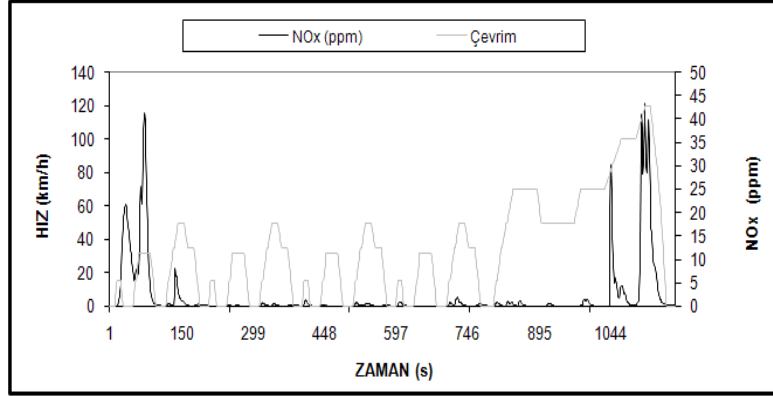
## HC Emisyonları

	FTP	AB	IDC (**)
	HC [g-HC/km]		
EKB(*)	2,99	2,19	<b>4,14</b>
R15.04	1,40	1,13	<b>1,53</b>
EURO1	0,60	0,65	<b>0,92</b>
EURO3	0,54	0,52	<b>0,72</b>
EURO4	0,05	0,05	<b>0,16</b>

(\*) Emisyon kontrol donanımı bulunmayan otomobiller, 1994 model yılı ve öncesi  
(\*\*) İstanbul Driving Cycle (İstanbul Şehir Çevrimi)



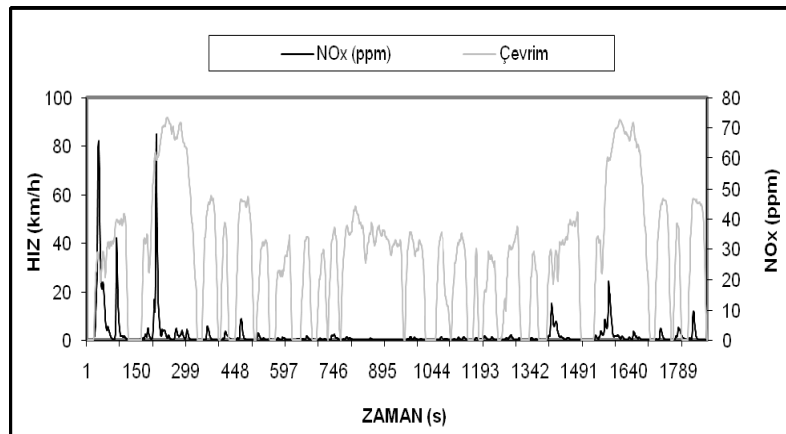
## NOx Emisyonları



AB test çevrimi



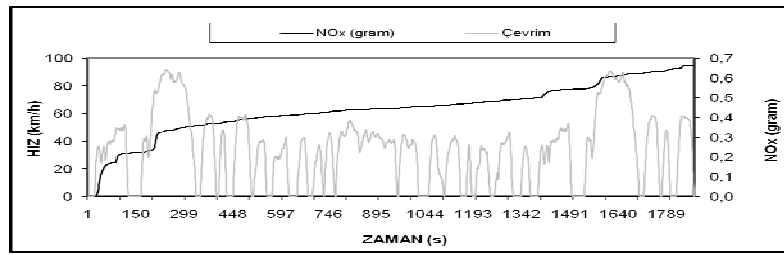
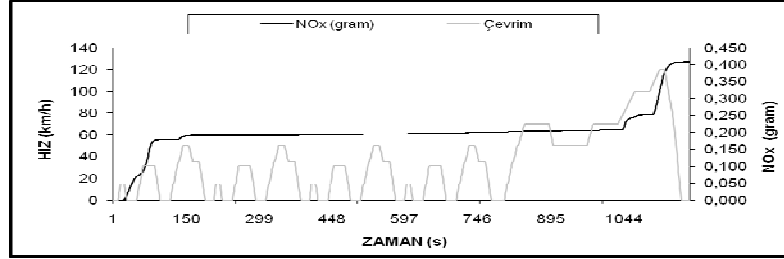
## NOx Emisyonları



ABD FTP 75 çevrimi



## Kümülatif NOx Emisyonları



## NOx Emisyonları

	FTP	AB	IDC (**)	IPCC
	NOx [g-nox/km]			
EKB(*)	1,15	<b>1,33</b>	<b>0,85</b>	2,2
R15.04	1,06	<b>1,16</b>	<b>1,02</b>	2,3
EURO1	0,59	<b>0,72</b>	<b>0,66</b>	0,5
EURO3	0,30	<b>0,40</b>	<b>0,37</b>	0,5
EURO4	0,03	0,05	<b>0,08</b>	

(\*) Emisyon kontrol donanımı bulunmayan otomobiller, 1994 model yılı ve öncesi  
(\*\*) İstanbul Driving Cycle (İstanbul Şehir Çevrimi)



## Yakıt Tüketimi ve Emisyonlar

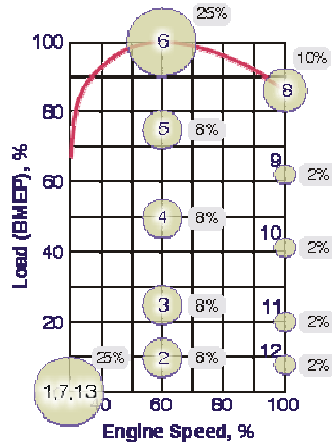
	FTP		AB		IDC (**)		IPCC
	CO2 [g/km]	Yakıt [l /100km]	CO2 [g/km]	Yakıt [l /100km]	CO2 [g/km]	Yakıt [l /100km]	CO2 [g/km]
EKB(*)	149,5	<b>7,9</b>	<b>169,1</b>	<b>8,6</b>	157,4	<b>9,6</b>	270
R15.04	139,2	<b>6,8</b>	<b>166,1</b>	<b>7,8</b>	165,9	<b>8,1</b>	200
EURO1	134,8	<b>6,0</b>	169,5	<b>7,5</b>	<b>170,2</b>	<b>7,8</b>	205
EURO3	133,3	<b>5,9</b>	155,4	<b>6,9</b>	<b>159,6</b>	<b>7,2</b>	205
EURO4	144,9	<b>6,2</b>	153,6	<b>6,5</b>	<b>164,7</b>	<b>7,1</b>	205

(\*) Emisyon kontrol donanımı bulunmayan otomobiller, 1994 model yılı ve öncesi

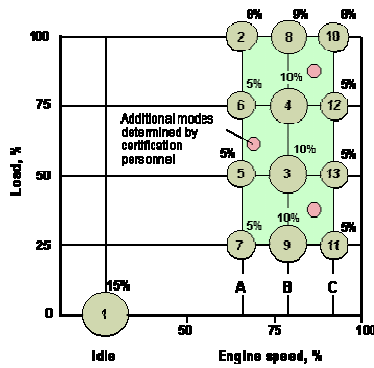
(\*\*) Istanbul Driving Cycle (Istanbul Şehir Çevrimi)



## R49 13 mode steady state Diesel test cycle



## ESC cycle - 13 mode steady state



Replaced R49 in 2000



The engine speeds are defined as follows:

The high speed  $n_{hi}$  is determined by calculating 70% of the declared maximum net power.

The highest engine speed where this power value occurs (i.e. above the rated speed) on the power curve is defined as  $n_{hi}$ .

The low speed  $n_{lo}$  is determined by calculating 50% of the declared maximum net power.

The lowest engine speed where this power value occurs (i.e. below the rated speed) on the power curve is defined as  $n_{lo}$ .

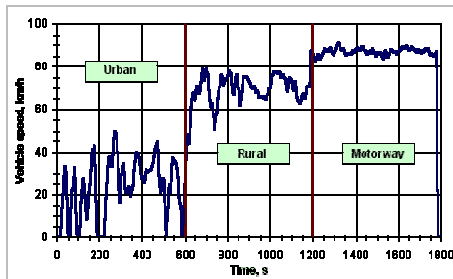
The engine speeds A, B, and C to be used during the test are then calculated from the following formulas:

$$A = n_{lo} + 0.25(n_{hi} - n_{lo})$$

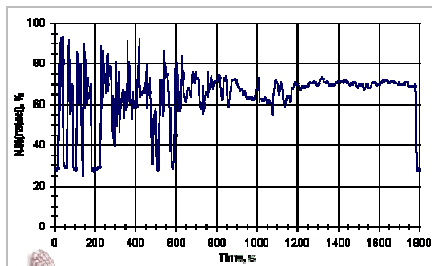
$$B = n_{lo} + 0.50(n_{hi} - n_{lo})$$

$$C = n_{lo} + 0.75(n_{hi} - n_{lo})$$

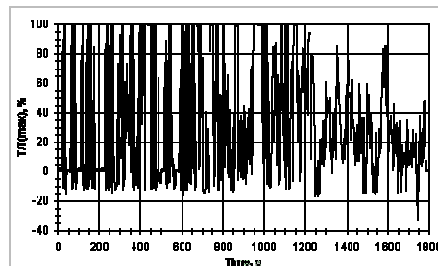
## ETC transient cycle



Vehicle speed – FIGE cycle



Engine speed



Engine torque



## Vehicle Categories

Category	Description
M	Motor vehicles with at least four wheels designed and constructed for the carriage of passengers.
M <sub>1</sub>	Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat
M <sub>2</sub>	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass ("technically permissible maximum laden mass") not exceeding 5 tons
M <sub>3</sub>	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tons
N	Motor vehicles with at least four wheels designed and constructed for the carriage of goods.
N <sub>1</sub>	Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tons
N <sub>2</sub>	Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 3.5 tons but not exceeding 12 tons
N <sub>3</sub>	Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 12 tons
O	Trailers (including semi-trailers)
G*	Off-Road Vehicles

\* Symbol G shall be combined with either symbol M or N. For example, a vehicle of category N<sub>1</sub> which is suited for off-road use shall be designated as N<sub>1</sub>G.



## Emission Standards

Tier	Date	CO	HC	HC+NOx	NOx	PM
<b>Compression Ignition (Diesel)</b>						
Euro 1 <sup>†</sup>	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08
Euro 2, DI	1996.01 <sup>a</sup>	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
Euro 5	2009.09 <sup>b</sup>	0.50	-	0.23	0.18	0.005 <sup>e</sup>
Euro 6	2014.09	0.50	-	0.17	0.08	0.005 <sup>e</sup>
<b>Positive Ignition (Gasoline)</b>						
Euro 1 <sup>†</sup>	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-
Euro 5	2009.09 <sup>b</sup>	1.0	0.10 <sup>c</sup>	-	0.06	0.005 <sup>d,e</sup>
Euro 6	2014.09	1.0	0.10 <sup>c</sup>	-	0.06	0.005 <sup>d,e</sup>

<sup>†</sup> At the Euro 1, 4 stages, passenger vehicles > 2,500 kg were type approved as Category N<sub>1</sub> vehicles  
<sup>†</sup> Values in brackets are conformity of production (COP) limits  
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)  
b - 2011.01 for all models  
c - and NWHC = 0.068 g/km  
d - applicable only to vehicles using DI engines  
e - 0.0045 g/km using the PMP measurement procedure



## Emission Standards

Category†	Tier	Date	CO	HC	HC+NOx	NOx	PM
<b>Compression Ignition (Diesel)</b>							
<b>N<sub>1</sub>, Class I</b> ≤1305 kg	Euro 1	1994.10	2.72	-	0.97	-	0.14
	Euro 2, IDI	1998.01	1.0	-	0.70	-	0.08
	Euro 2, DI	1998.01 <sup>a</sup>	1.0	-	0.90	-	0.10
	Euro 3	2000.01	0.64	-	0.56	0.50	0.05
	Euro 4	2005.01	0.50	-	0.30	0.25	0.025
	Euro 5	2009.09 <sup>b</sup>	0.50	-	0.23	0.18	0.005 <sup>e</sup>
<b>N<sub>1</sub>, Class II</b> 1305-1760 kg	Euro 6	2014.09	0.50	-	0.17	0.08	0.005 <sup>e</sup>
	Euro 1	1994.10	5.17	-	1.40	-	0.19
	Euro 2, IDI	1998.01	1.25	-	1.0	-	0.12
	Euro 2, DI	1998.01 <sup>a</sup>	1.25	-	1.30	-	0.14
	Euro 3	2001.01	0.80	-	0.72	0.65	0.07
	Euro 4	2006.01	0.63	-	0.39	0.33	0.04
<b>N<sub>1</sub>, Class III</b> >1760 kg	Euro 5	2010.09 <sup>c</sup>	0.63	-	0.295	0.235	0.005 <sup>e</sup>
	Euro 6	2015.09	0.63	-	0.195	0.105	0.005 <sup>e</sup>
	Euro 1	1994.10	6.90	-	1.70	-	0.25
	Euro 2, IDI	1998.01	1.5	-	1.20	-	0.17
	Euro 2, DI	1998.01 <sup>a</sup>	1.5	-	1.60	-	0.20
	Euro 3	2001.01	0.95	-	0.86	0.78	0.10
	Euro 4	2006.01	0.74	-	0.46	0.39	0.06
	Euro 5	2010.09 <sup>c</sup>	0.74	-	0.350	0.280	0.005 <sup>e</sup>
	Euro 6	2015.09	0.74	-	0.215	0.125	0.005 <sup>e</sup>

## Emission Standards

<b>Positive Ignition (Gasoline)</b>							
<b>N<sub>1</sub>, Class I</b> ≤1305 kg	Euro 1	1994.10	2.72	-	0.97	-	-
	Euro 2	1998.01	2.2	-	0.50	-	-
	Euro 3	2000.01	2.3	0.20	-	0.15	-
	Euro 4	2005.01	1.0	0.1	-	0.08	-
	Euro 5	2009.09 <sup>b</sup>	1.0	0.10 <sup>f</sup>	-	0.06	0.005 <sup>d,e</sup>
	Euro 6	2014.09	1.0	0.10 <sup>f</sup>	-	0.06	0.005 <sup>d,e</sup>
<b>N<sub>1</sub>, Class II</b> 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	-
	Euro 2	1998.01	4.0	-	0.65	-	-
	Euro 3	2001.01	4.17	0.25	-	0.18	-
	Euro 4	2006.01	1.81	0.13	-	0.10	-
	Euro 5	2010.09 <sup>c</sup>	1.81	0.13 <sup>g</sup>	-	0.075	0.005 <sup>d,e</sup>
	Euro 6	2015.09	1.81	0.13 <sup>g</sup>	-	0.075	0.005 <sup>d,e</sup>
<b>N<sub>1</sub>, Class III</b> >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	-
	Euro 2	1998.01	5.0	-	0.80	-	-
	Euro 3	2001.01	5.22	0.29	-	0.21	-
	Euro 4	2006.01	2.27	0.16	-	0.11	-
	Euro 5	2010.09 <sup>c</sup>	2.27	0.16 <sup>h</sup>	-	0.082	0.005 <sup>d,e</sup>
	Euro 6	2015.09	2.27	0.16 <sup>h</sup>	-	0.082	0.005 <sup>d,e</sup>
<b>N<sub>2</sub></b>	Euro 5	2010.09 <sup>c</sup>	2.27	0.16 <sup>h</sup>	-	0.082	0.005 <sup>d,e</sup>

