Internal Combustion Engines – MAK 493E

EXHAUST PROCESS and EMISSIONS

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Internal Combustion Engines – MAK 493E

Exhaust Process in Engines and Emissions

- Introduction
- Exhaust process phases
- Gas flow rate and temperature variation
- Exhaust emissions

Introduction

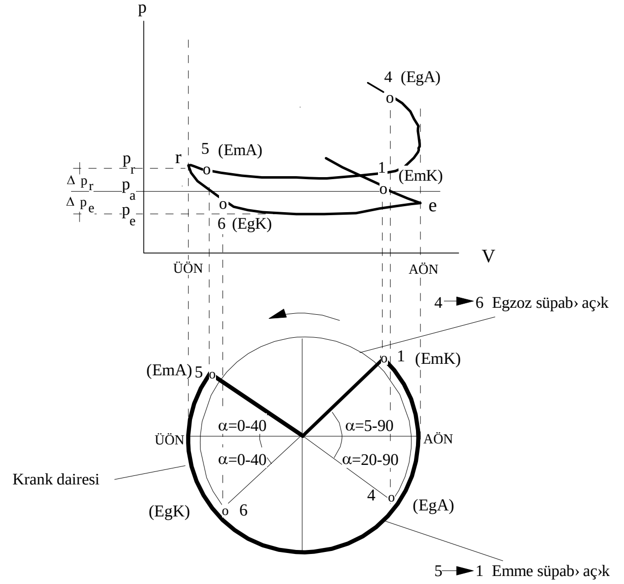
After combustion is completed and resulting high pressure gases have been used to transfer work to crankshaft during expansion stroke, these gases are removed from the cylinder in two steps :

exhaust blowdown which is followed by exhaust stroke

valve overlap

The resulting flow in the exhaust pipe is a non-steady state pulsating flow.

Introduction



Introduction

Blowdown phase

when exhaust valve opens towards the end of power stroke (60 – 40° BBDC) cylinder pressure is about 0.4 – 0.5 MPa and temperature up to 1000 K, while pressure in exhaust system is one atm.

pressure difference causes rapid flow of exhaust gases from cylinder – blowdown phase.

flow at first is choked and outflow will be sonic

With increasing engine speed, crank angle duration of blowdown phase increases

Introduction

Displacement phase (exhaust stroke)

mass flow is controled by piston movement from BDC to TDC
pressure is slightly above atm pressure

closing of the valve starts at or close to TDC and the total closing is at 8 – 50 ° ATDC

Valve overlap

intake valve starts to open 10 – 25 ° BTDC
valve overlap 15 – 50 ° CA

there can be reverse flow into cylinder :

- inc residual gases, which is worst at low speeds and idle
- short circuit of intake air/fuel mixture – inc pollution

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 NO2 – collectively known as NOx), 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_2, O_2 as vol. [%]

NO, NO_2, NO_x as [ppm] (parts per million)

HC as [ppm] or [ppm C]

eg 1 ppm propan, C_3H_8

3 ppm C

Control of Pollutant Emissions

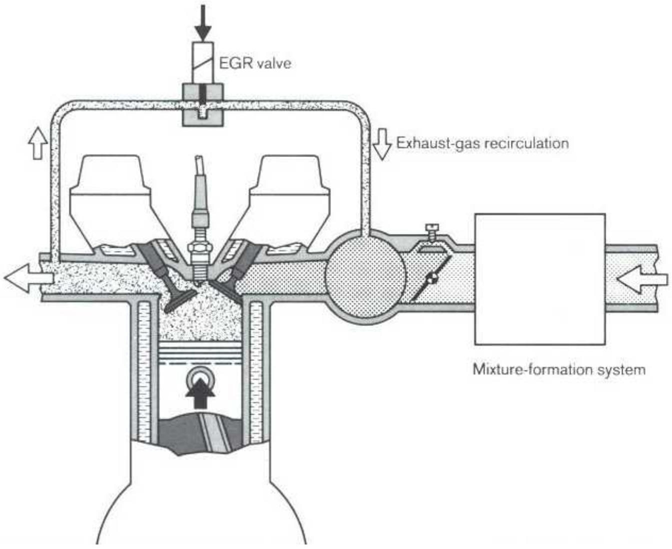
Combustion related applications :

EGR (Exhaust gas recirculation)
Water and alcohol injection

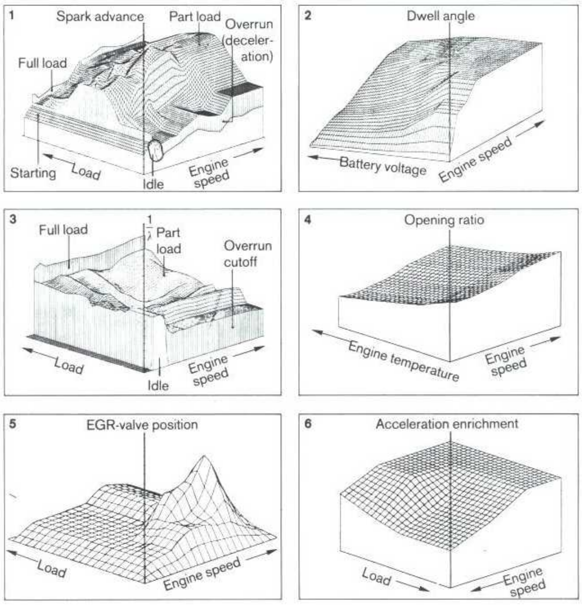
Exhaust gas treatment :

Thermal reactors
Catalytic converters
Traps and filters

EGR system



EGR control



Exhaust Gas Treatment

Thermal reactors

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

Used for oxidation of CO and HC

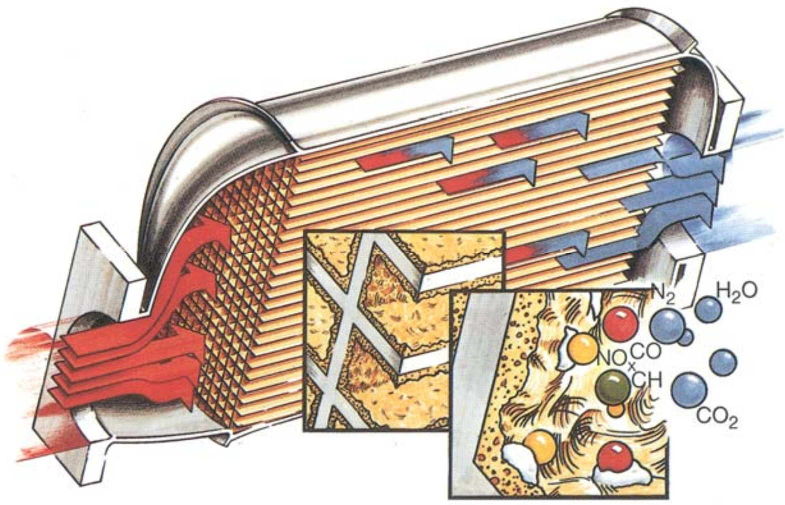
- Rich mixture + O2 supplement : CO oxidation in exhaust system increases T, but fuel consumption also increases.
- Lean mixture + late ignition : high exhaust temperatures, but loss in power output

Exhaust Gas Treatment

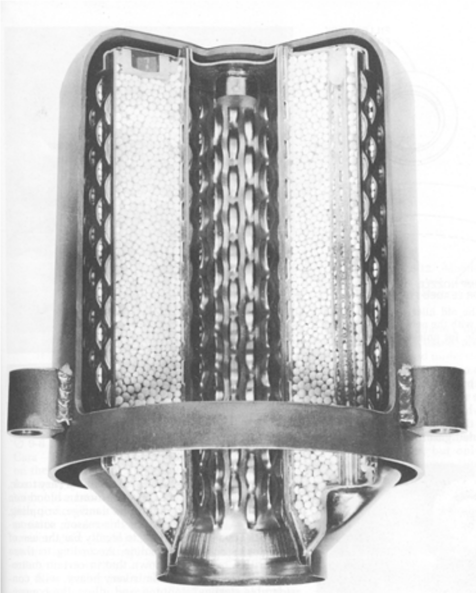
Catalytic converters

- Oxidizing catalysts for HC and CO
- Reducing catalysts for NOx
- Three-way catalysys for all three pollutants

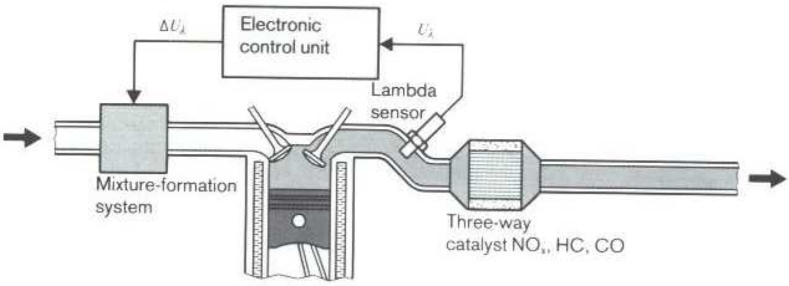
Catalytic Converters



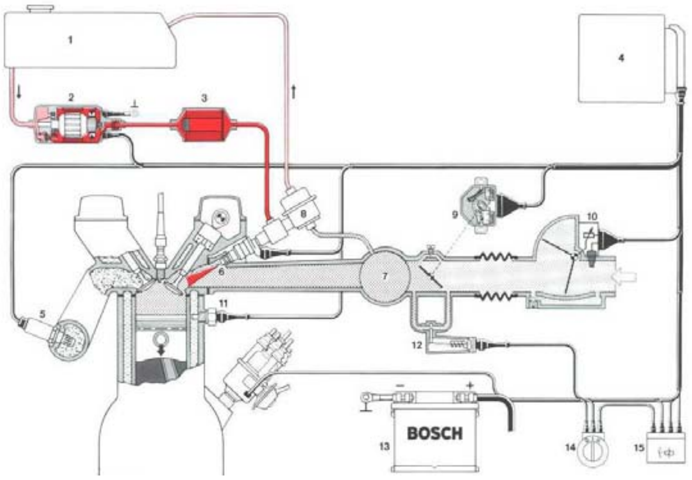
Catalytic Converters

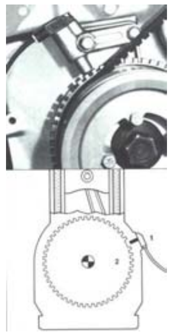


Catalytic Converters



Catalytic Converters





Exhaust Gas Treatment

$C_mH_n + [m+n/4]\, O_2 \rightarrow m\, CO_2 + n/2\, H_2O$ (1)

$CO + ½\, O_2 \rightarrow CO_2$ (2)

$H_2 + ½\, O_2 \rightarrow H_2O$ (3)

$CO + NO \rightarrow ½\, N_2 + CO_2$ (4)

$C_mH_n + 2\, [m+n/4]\, NO \rightarrow [m+n/4]\, N_2 + n/2\, H_2O + m\, CO_2$ (5)

$H_2 + NO \rightarrow ½\, N_2 + H_2O$ (6)

$SO_2 + ½\, O_2 \rightarrow SO_3$ (7)

$5/2\, H_2 + NO \rightarrow NH_3 + H_2O$ (8)

$SO_2 + 3\, H_2 \rightarrow H_2S + 2\, H_2O$ (9)

$NH_3 + CH_4 \rightarrow HCN + 3\, H_2$ (10)

$CO + H_2O \rightarrow CO_2 + H_2$ (11)

$CH_n + 2\, H_2O \rightarrow CO_2 + [2+n/2]\, H_2$ (12)

Exhaust Gas Treatment

$CO + ½ O_2 \rightarrow CO_2$ (2)

$CO + NO \rightarrow ½ N_2 + CO_2$ (4)

In lean mixtures reaction (2) is dominant – O2 is present

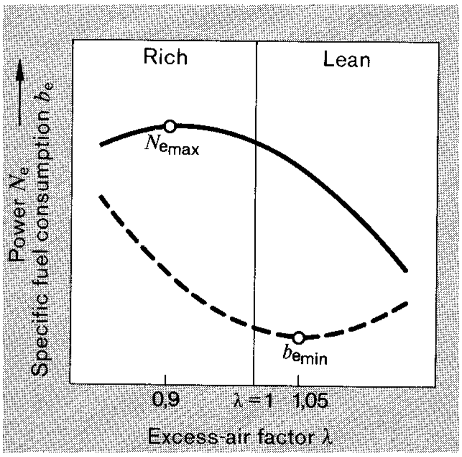
CO is reduced by oxidation and insufficient CO for the relatively slow reaction(4).

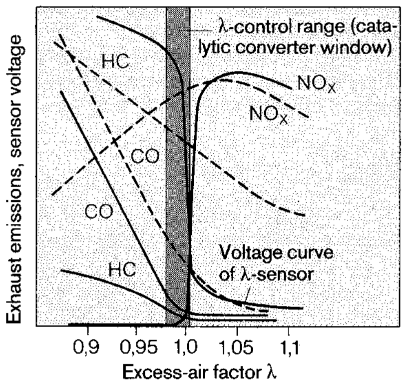
$CO + H_2O \rightarrow CO_2 + H_2$ (11)

$CH_n + 2 H_2O \rightarrow CO_2 + [2+n/2] H_2$ (12)

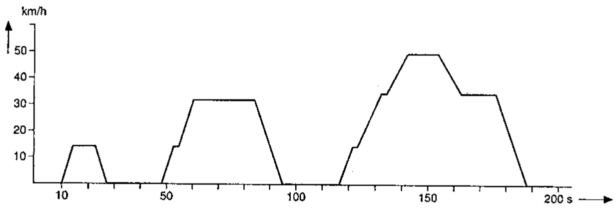
In rich mixtures reactions (11) and (12) have to be faster.

Exhaust Gas Treatment

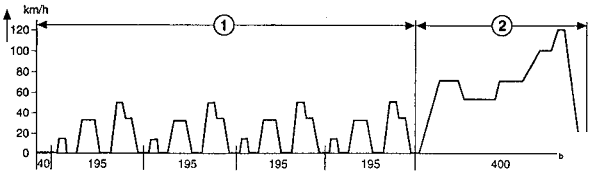




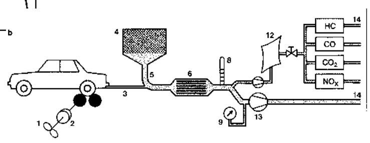
Emission Regulations – Road Simulations



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 – Exhaust Gas Emissions

Emission Regulations – Chasis Dynamometers

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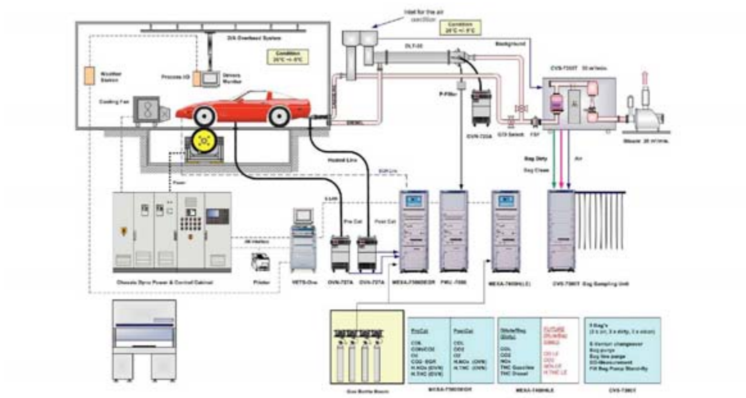
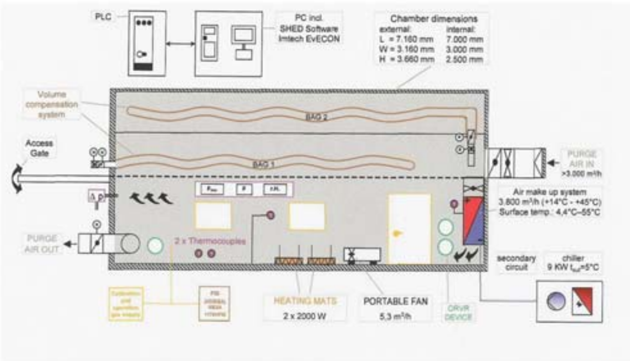
Emission Regulations – Exhaust Gas Emissions



HORIBA Exhaust Gas Analysis System

Emission Regulations – SHED Test



Evaporative Emission Test Chamber