CONTROL OF AIR POLLUTANT EMISSIONS FROM AUTOMOBILES

See section 7.B.3, page 436

TABLE 10-1 Federal Vehicle Emission Standards

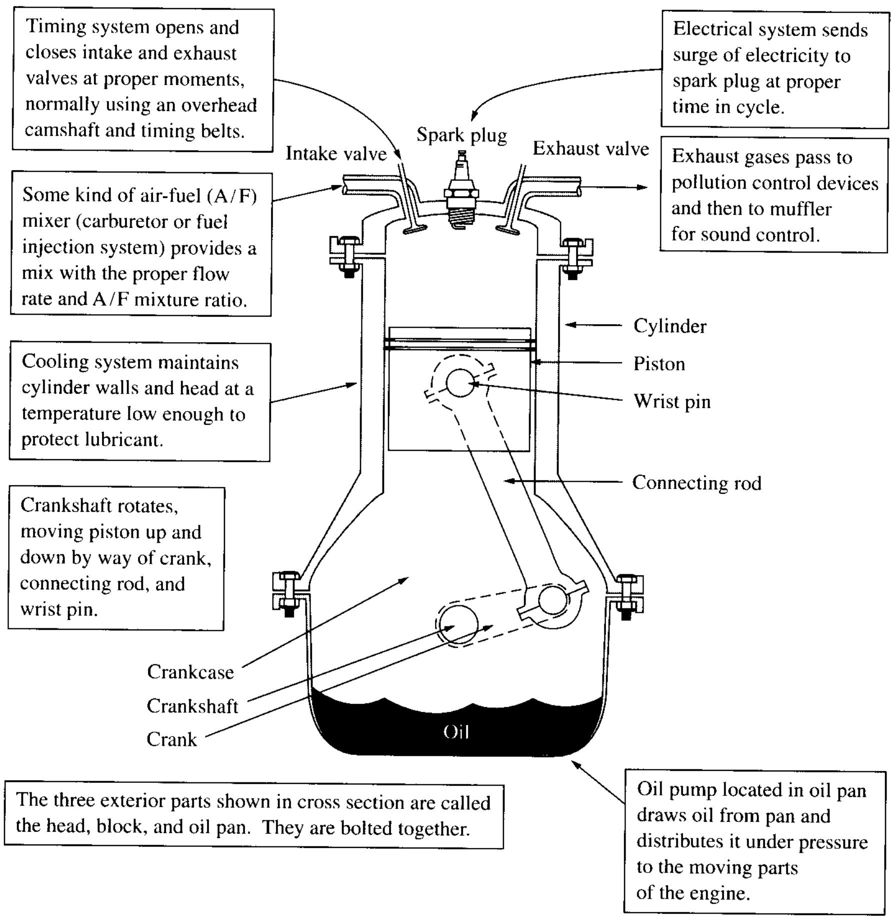
	Light Duty vehicles (auto)				*Light Light-Duty Trucks*			
	HC	CO	NO_x	PM	HC	CO	NO_x	PM
Year	(g/mi)	(g/mi)	(g/mi)	(g/mi)	(g/mi)	(g/mi)	(g/mi)	(g/mi)
1968	3.2	33						
1971*	4.6	47	4.0					
1974	3.4	39	3.0					
1977	1.5	15	2.0					
1978	1.5	15	2.0		2.0	20	3.1	
1979	1.5	15	2.0		1.7	18	2.3	
1980	0.41	7.0	2.0		1.7	18	2.3	
1981	0.41	3.4	1.0		1.7	18	2.3	
1982	0.41	3.4	1.0	0.6^{a}	1.7	18	2.3	
1985	0.41	3.4	1.0	0.6^{a}	0.8	10	2.3	1.6^{a}
1987	0.41	3.4	1.0	0.2^{a}	0.8	10	2.3	$2.6^{a,b}$ $0.50^{a,c}$
1988	0.41	3.4	1.0	0.2^{a}	0.8	10	1.2^{b} 1.7^{c} 2.3^{d}	$0.26^{a,b}$ $0.45^{a,c}$
1990	0.41	3.4	1.0	0.2^{a}	0.8	10	1.2^{b} 1.7^{c}	$0.26^{a,b}$ $0.45^{a,c}$
1991	0.41	3.4	1.0	0.2^{a}	0.8	10	1.2^{b} 1.7^{c}	$0.26^{a,b}$ $0.13^{a,c}$
	Tier 1 Intermediate Useful Life Standards (g/mi)							
1994	$0.41^{a,c}$ $0.25^{a,e,f}$ $0.041^{g,i}$ $0.25^{g,h}$	3.4	$0.4^{e,g}$ 1.0^{a}	0.08	$0.25^{a,b,e,f}$ $0.25^{b,g,h}$ $0.32^{a,c,e,f}$ $0.32^{c,g,h}$	3.4^{b} 4.4^{c}	$0.4^{b,e,g}$ $0.7^{c,e,g}$ $1.0^{a,b}$	0.08
	Tier 1 Full Life Standards (g/mi)							
1994	$0.31^{a,e,f}$ $0.31^{g,h}$	4.2 4.2	$0.6^{e,g}$ 1.25^{a}	0.10	$0.8^{a,b,c,e}$ $0.8^{g,i}$ $0.31^{a,b,e,f}$ $0.31^{b,g,h}$ $0.40^{a,c,e,f}$ $0.40^{c,g,h}$	4.2^{b} 5.5^{c}	$0.6^{b,e,g}$ 0.97^{c} $1.25^{a,b}$	0.10

[a]Diesel [b]LVW ≤ 3750 lbs [c]LVW ≥ 3751 lbs [d]LVW ≥ 6001 lbs
[e]Gasoline [f]Non-methane Hydrocarbons [g]Methanol
[h]Org. Mat. Non-methane HC Equivalent [i]Org. Mat. HC *Test method changed in 1971

From your text, uncontrolled emissions are as follows:
HC: several thousand ppm or about 10.6 g/mile (tailpipe emissions); 97.6% reduction
CO: several percent, or about 84 g/mile; 96% reduction
NOx: 900 ppm or about 4.1 g/mile; 90.2% reduction

Reduction is achieved by reducing outlet flow as well as by reducing concentrations: $E = Q\,C$
Outlet flow, Q, is reduced by improving fuel economy (less gas burned)
Concentration, C, is reduced by use of control equipment

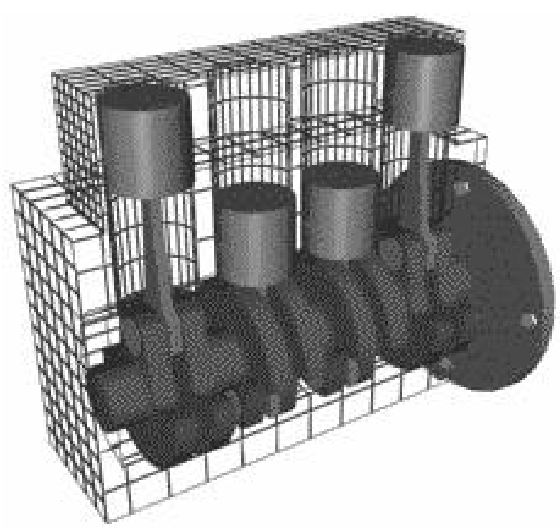
Operation of a 4-Stroke Engine

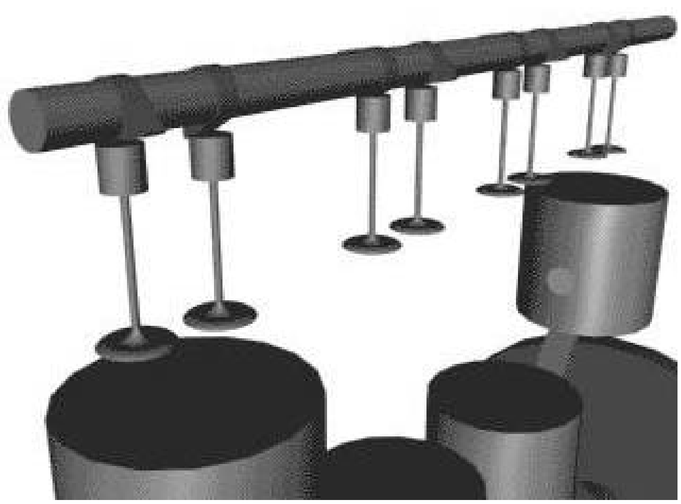


See Figure 7.B.10
(figure at left)

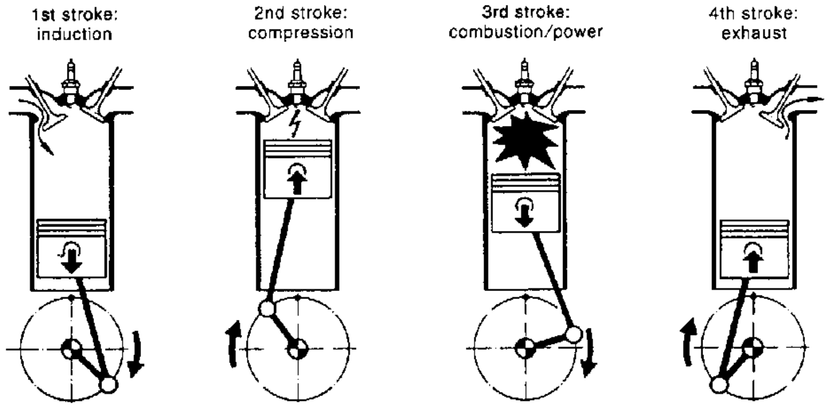
4-cylinder engine
(left bottom)

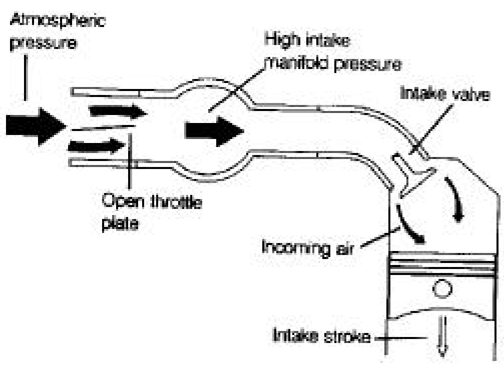
valves open due to operation of camshaft, driven by belt from crankshaft
(right bottom)



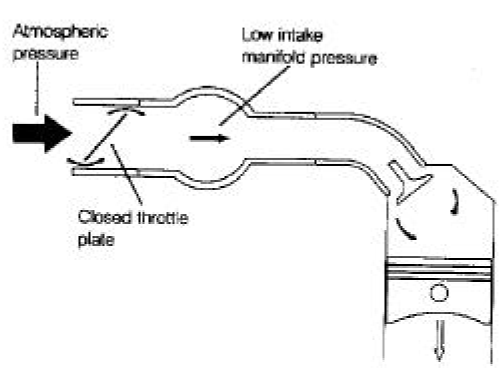


Operation of a Four-Stroke Engine - see http://www.howstuffworks.com/engine1.htm

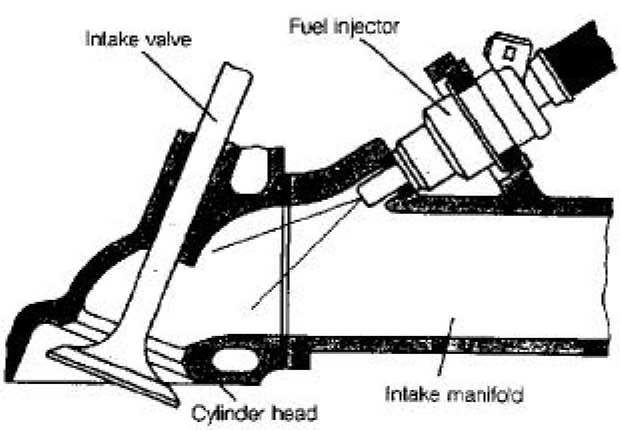




At full throttle, nearly unrestricted atmospheric pressure raises manifold pressure. Large pressure differential between manifold and cylinders increases air flow.



With the throttle closed, atmospheric pressure has little effect on manifold pressure. Low pressure differential between manifold and cylinders results in little air flow.



Port injection delivers fuel to the manifold at the intake port

Multi-Port Fuel Injection System

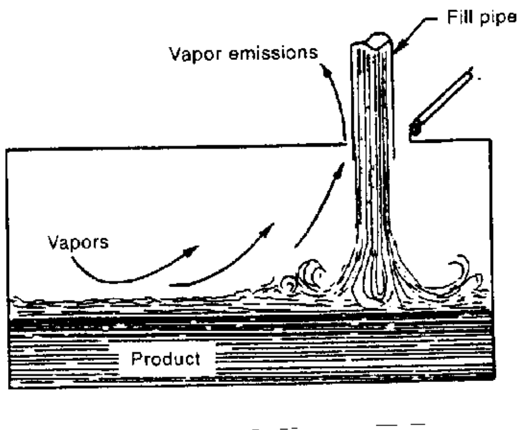
Air flow is controlled by throttle position, which is controlled by accelerator pedal (figures above). Air flow is measured by a sensor and the data fed to a computer.

Fuel flow is controlled by fuel injectors, which inject gasoline into intake manifold ahead of intake valve (figure at left). The amount of fuel delivered is controlled by a computer that matches fuel flow required to the amount of air flow entering the engine. (Details on computer operation given later)

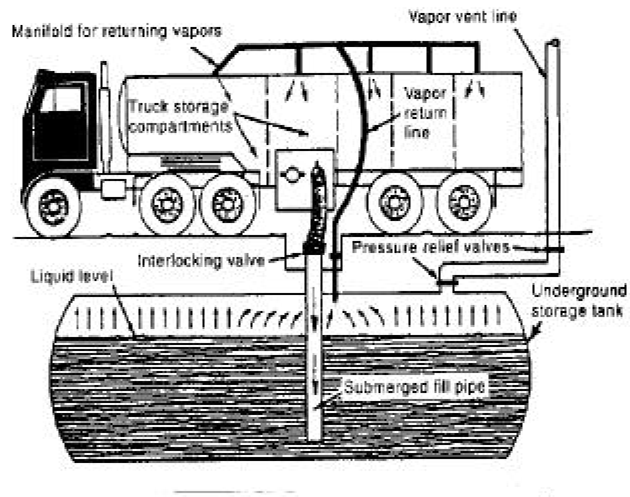
AUTO EMISSION SOURCES:

Evaporative emissions: HC,
Blowby – crankcase ventilation: HC
Exhaust emissions: HC, CO, NO_x

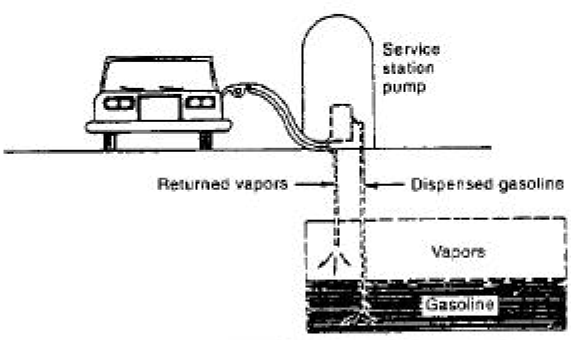
Evaporative: controlled by vapor return or combustion



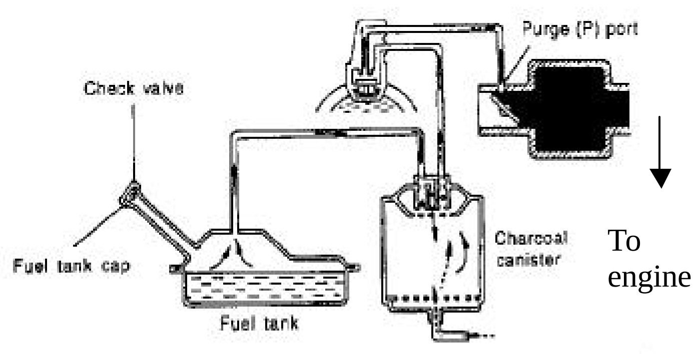
Gas entering tank displaces HC vapors



As gasoline goes from truck to tank, vapors go from tank to truck in closed system.

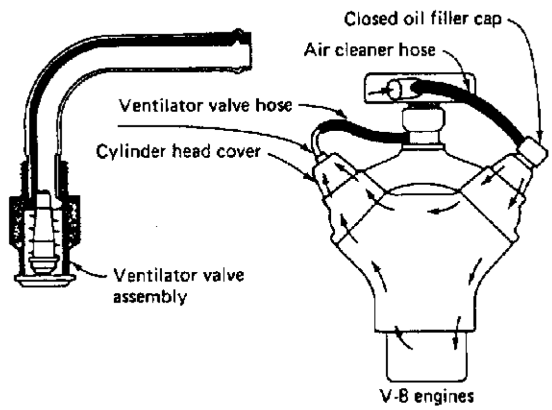


In some locations, liquid and vapor return systems are required for gas stations



Vapor control system in car. Vapor pressure of gasoline is about half an atmosphere on a warm day.

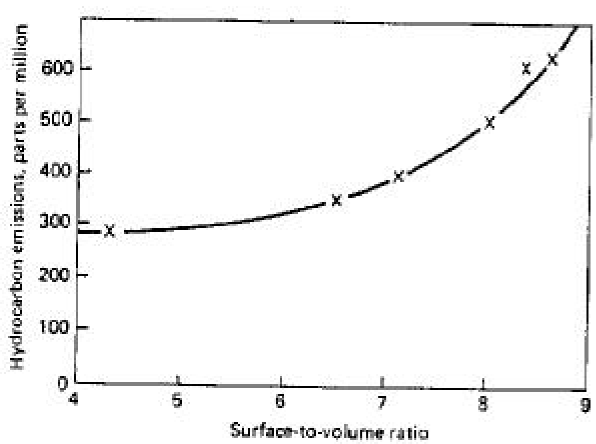
Blowby: controlled by crankcase ventilation



Exhaust: emissions controlled by:

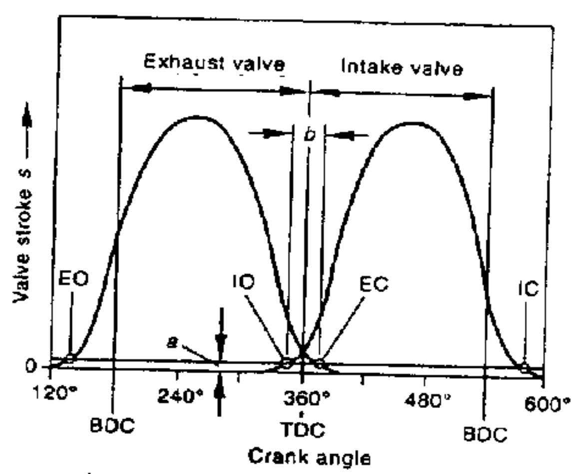
1. Engine design:
2. Engine management system
3. Exhaust gas control system

1. Engine Design (details):



Design of Combustion Chamber – Combustion quenching due to high specific surface and presence of edges in combustion chamber

Exhaust stroke Intake stroke



TDC top dead center – piston fully up
BDC bottom dead center – piston fully down

s distance valve opens
b valve overlap – both valves open same time
EO exhaust valve opens
EC exhaust valve closes
IO intake valve opens
IC intake valve closes

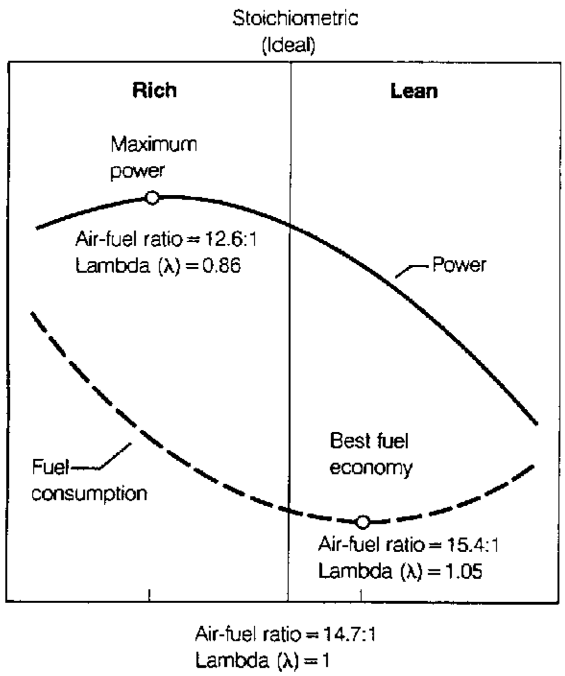
Valve Profile – Valve overlap and profile affects emissions and driveability

2. Engine Management System (details)

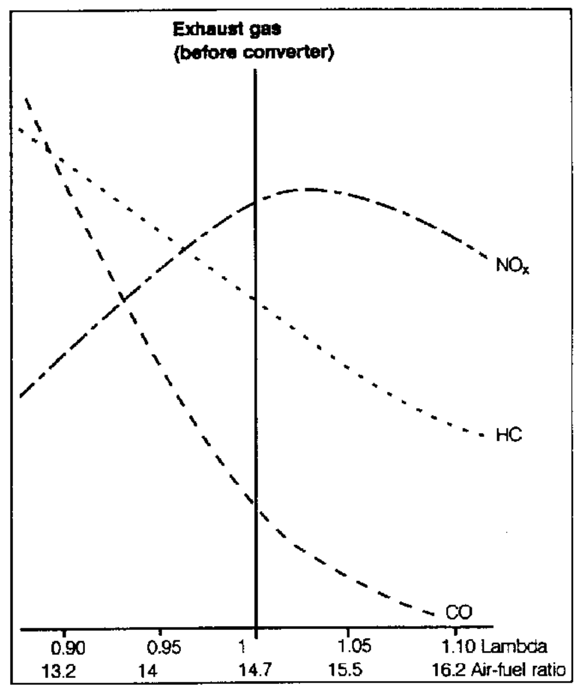
The engine management computer gets input on air flow, engine speed, temperature, and then controls:

the amount of fuel injected (injector pulse duration)
the time when spark occurs (ignition timing)

The figures below show the effects of air/fuel ratio on power and performance



Effect of air/fuel ratio on power and economy



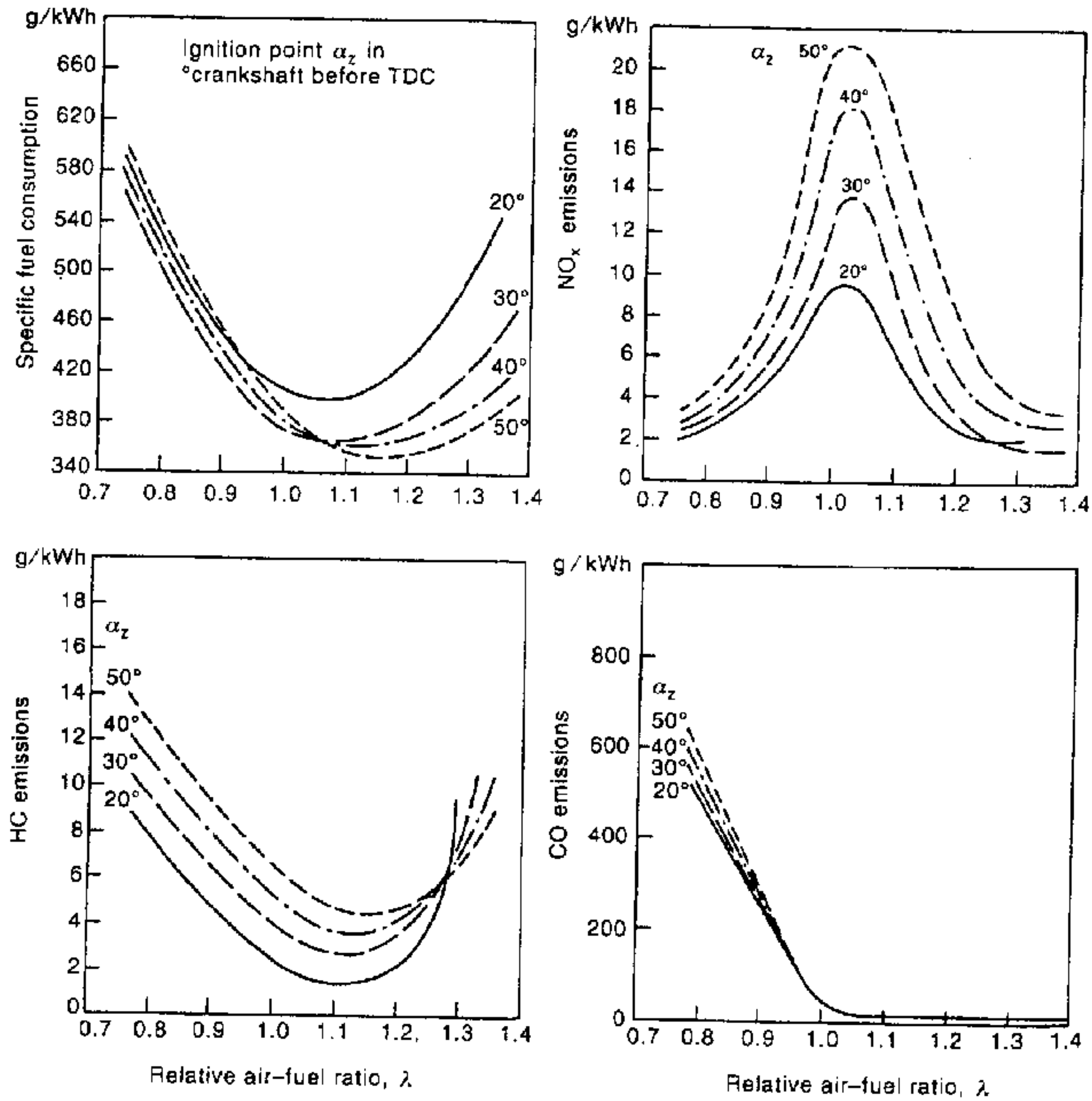
Effect of air/fuel ratio on exhaust gas composition

Your book uses $1/\phi$ instead of λ to describe stoichiometry of combustion. $\lambda = 1/\phi$ See eqn 7.B.9

These are two-dimensional plots. The third dimension is how much fuel and are present. More fuel and air give more power.

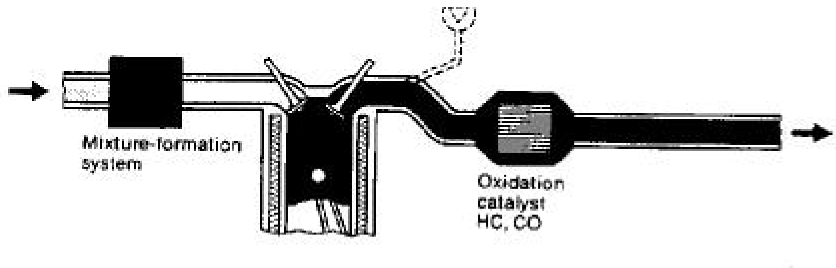
2. Engine Management System (cont'd)

Effect of timing and air-fuel ratio on engine emissions and on fuel consumption. Note: the figures below are similar to the ones on the previous page, but give additional detail regarding the effect of ignition timing. Again, these are two-dimensional plots. Other dimensions are the amount of fuel and air present (engine load), the engine speed, and temperature of the air and temperature of the engine.



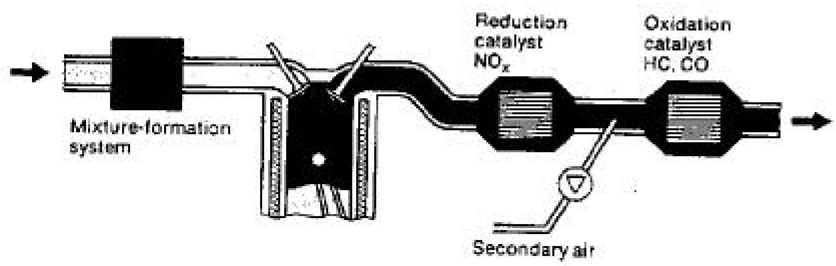
3. Exhaust Gas Control System

Catalytic converters can be used in the exhaust pipe to reduce NO_x to N_2 and O_2, and to oxidize HC and CO to CO_2 and H_2O.



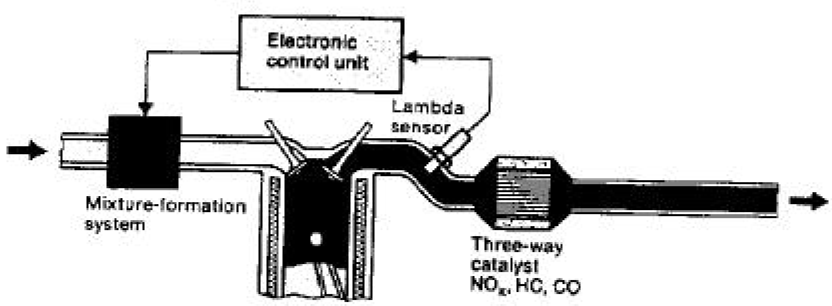
1970s – oxidation catalyst for HC and CO. No NOx control

(b) Dual-bed catalyst.



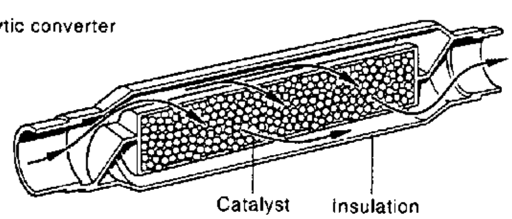
1980s – reduction catalyst for NOx followed by air injection and oxidation catalyst for HC and CO

(c) Single-bed three-way catalyst.

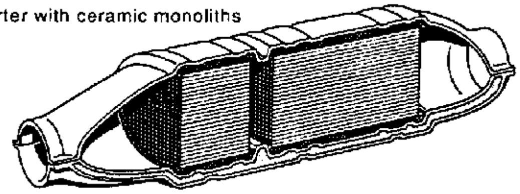


1990s – three-way catalyst with oxygen sensor and feedback control of fuel injection to maintain stoichiometry

(a) Pellet-type catalytic converter



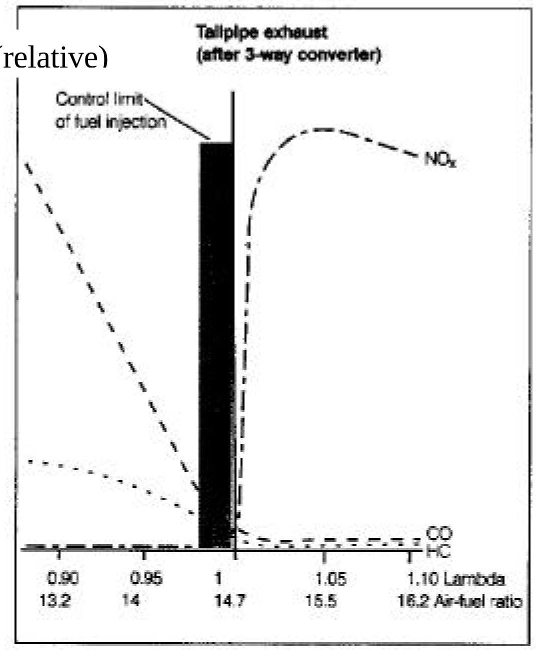
(b) Catalytic converter with ceramic monoliths



Catalysts

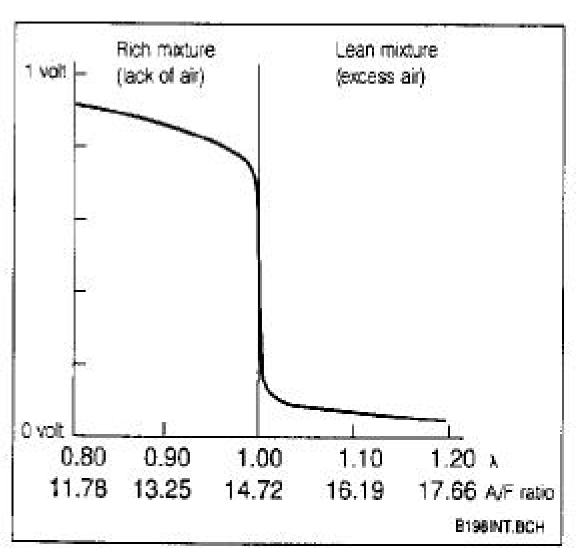
Operation of 3-way catalysts

Emissions (relative)

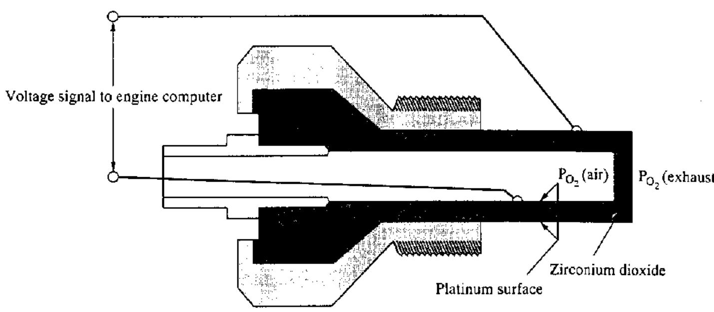


The 3-way catalyst reduces emissions of all three pollutants effectively, but only if the air/fuel ratio is stoichiometric. The figure at the left shows how emissions vary with stoichiometry following a 3-way catalyst

The voltage output from the oxygen sensor is very sensitive to the presence of oxygen in exhaust gases. If oxygen is present, voltage drops sharply.



Oxygen sensor output vs. air/fuel ratio



Schematic drawing of lambda sensor (oxygen sensor) used to detect whether oxygen is present in exhaust

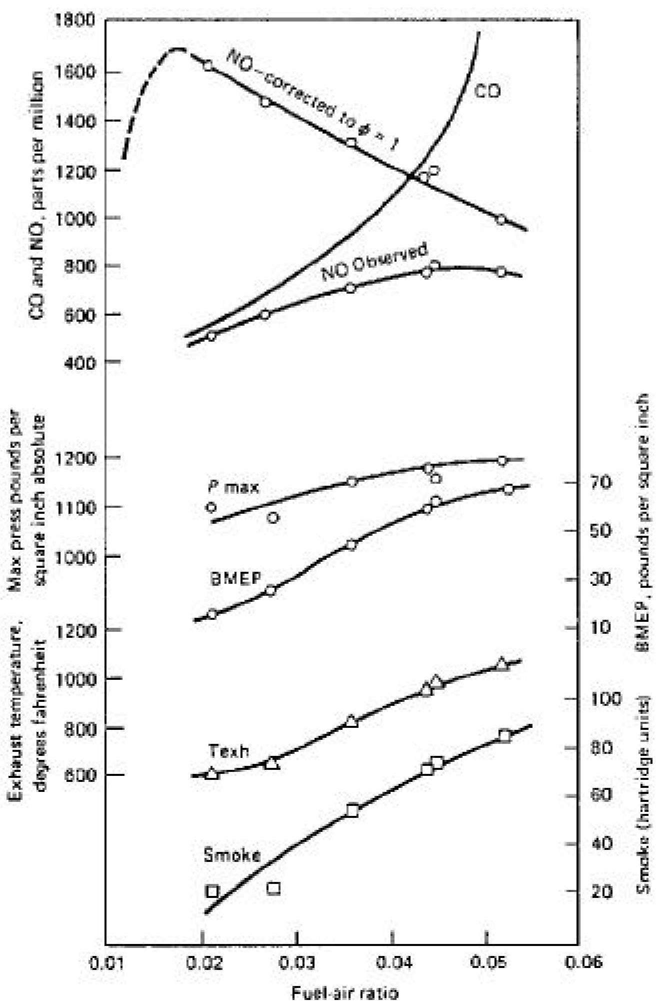
The closed end of the zirconium dioxide cylinder in the drawing above projects into the exhaust manifold, whereas its open end is in air. The difference in oxygen content between the exhaust and the atmosphere generates a voltage difference across the platinum electrodes plated on the surface of the zirconium oxide.

Diesel Engine Emissions

No control on air entering engine
Power regulated by amount of fuel injected;
air/fuel ratios of 100/1 to 15/1
Very high compression ratios
No spark plugs; ignition due to heat of compression

TABLE 10-5 Automobile Diesel Exhaust Emissions

Car	Displacement (in.^{3})	Mileage (mi/gal)	*Exhaust Emissions (g/mi)* HC	CO	NO_x
Mercedes 240D	134	25.9	0.18	1.30	1.01
Mercedes 300D	183	23.8	0.16	0.85	1.72
Peugot	83	35.9	1.11	1.70	0.67
Perkins	247	25.7	0.72	2.86	1.48
Cutlass Diesel		26.9	0.47	2.00	0.70
VW Rabbit Diesel	89.7	52.2	0.37	0.79	0.87



HC emissions depend on fuel injection equipment and combustion chamber design

CO increases as more fuel is provided

NO_x increases as more fuel is provided and temperatures increase

Smoke is related to more fuel (higher load) and poor fuel-air mixing. Can be reduced by good design (swirl) and good maintenance of fuel injectors.