Effect of SI Engine Design and Operating Variables on Emissions

SI Engine Variables and Emissions

SI Engine Design and Operating Variables on missions

Any engine variable that affects oxygen availability during combustion would influence CO emissions. The factors which influence flame quenching, quench layer thickness and post flame oxidation control engine out HC emissions. The burned gas temperature-time history and oxygen concentration control NO formation and emission. Hence the engine variables that influence burned gas temperature and oxygen concentration would affect the NO emissions.

Principal design and operating variables affecting engine emissions are:

Design Variables:

Compression Ratio

Combustion chamber surface to volume ratio

Ignition timing

Valve timings and valve overlap

Air motion, swirl tumble etc

Charge stratification

Operating Variables:

Air-fuel Ratio

Charge dilution and exhaust gas recirculation (EGR)

Speed

Load

Coolant temperature

Transient engine operation: acceleration, deceleration etc.

The effect of some variables discussed below is typical in nature and variations in the trends with Specific engine design change is observed.

Compression Ratio:

The effect of compression ratio on engine emissions is shown on fig. below. The typical effect observed when the engine CR was reduced from 10:1 (CR used on high performance engines during pre-emission control period) to 8.5 and 7.0:1 are given on this figure.

Use of high CR results in;

(i) Higher burned gas temperature

(ii) Lower residual gas content

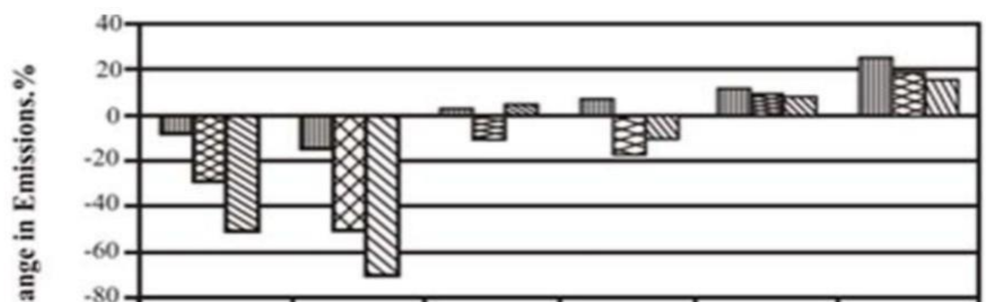
These lead to higher NO emissions on volume basis. However, as engine efficiency increases with increase in compression ratio, brake specific NO emissions decrease. High CR combustion chambers result in;

(i) High surface to volume ratio and

(ii) A proportionately higher crevice volume.

(iii) Lower exhaust gas temperatures

Thus the volume of flame quenching regions increases resulting in higher HC emissions. The problem is further enhanced as due to lower exhaust gas temperatures oxidation of the unburned HC is reduced during exhaust process. These factors result in an increase in HC emissions with increase in engine CR. At lower CR% fuel efficiency is also reduced thus increasing specific CO



	CR =8.5	CR =7.0	CR =8.5	CR =7.0	CR =8.5	CR =7.0
	HC Emissions		Nox Emissions		CO Emissions	
1500 rpm	-7	-14	2	-7	12	25
2000 rpm	-28	-50	-10	-17	9	18
2500 rpm	-50	-70	3	-10	8	16

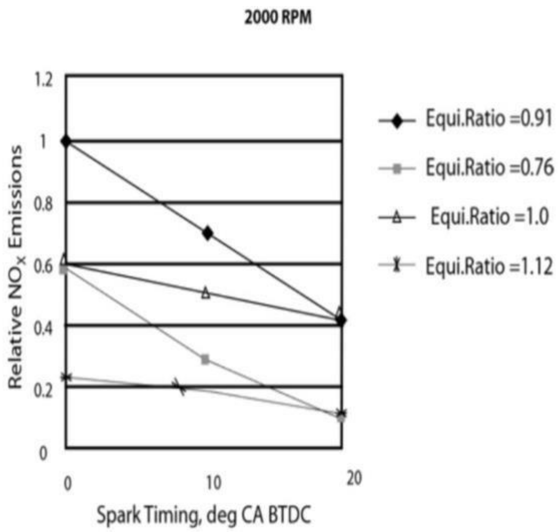
emissions.

Fig. Effect of reduction in compression ratio from 10:1 to 8.5:1 and 7.0:1 on SI engine emissions

Ignition Timings:

The effect of ignition timing on NO and HC emissions is shown on Fig below. When ignition occurs earlier in the cycle more heat is released before and around the top dead center. Thus, with advanced ignition timings higher peak cylinder pressures and temperatures result. As increase in combustion temperatures NO formation increases. Hence, higher NO emissions are obtained as the ignition timing is advanced.

As the ignition timing is retarded more burning takes place during expansion stroke resulting in lower peak combustion pressures and a lower of mass of charge is pushed into crevice volume. Also, at the retarded ignition timings exhaust gas temperature increases as the engine thermal efficiency is reduced. In the hotter exhaust gas with the retarded ignition timing higher oxidation rates of the HC and CO in the exhaust system are obtained. Due to these reasons, lower HC emissions are obtained with retarded ignition timings. The disadvantage of the retarded ignition timing is lower engine efficiency, lower power and a poorer fuel economy.



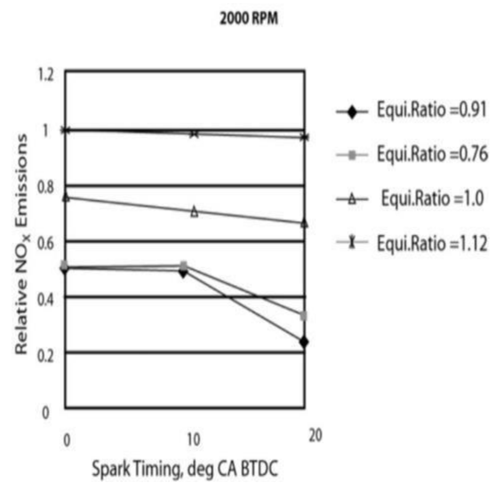


Fig. Effect of spark timing on NOx emissions

Fig. Effect of ignition timing on HC emissions

Air – Fuel Mixture:

Carbon monoxide results due to deficiency of oxygen during combustion and is reduced as the mixture is leaned. CO emissions are reduced to very low values as the mixture is leaned to phi= 0.90 – 0.95 i.e. air-fuel ratio is increased above the stoichiometric value by 5 to 10%. Further leaning of mixture shows very little additional reduction in the CO emissions. With increase in air fuel ratio, the initial concentration of hydrocarbons in the mixture is reduced and more oxygen is available for oxidation. Hydrocarbon emissions therefore, decrease with increase in air-fuel ratio until mixture becomes too lean when partial or complete engine misfire results which cause a sharp increase in HC emissions for phi < 0.8 engine may misfire more frequently thereby increasing HC emissions sharply. The highest burned gas temperatures are obtained for mixtures that are slightly (5 to 10 percent) richer than stoichiometric. On the other hand, there is little excess oxygen available under rich mixture conditions. As the mixture becomes lean, concentration of free oxygen increases but combustion temperature start decreasing. The interaction between these two parameters results in peak NO being obtained at about phi = 0.9 – 0.95.

Residual Gas and EGR;

Burned residual gases left from the previous cycle or part of the exhaust gas re-circulated back to engine act as charge diluents. The charge dilution by recirculation of part of the exhaust gas back to the engine is called exhaust gas recirculation (EGR). The combustion temperatures decrease due to charge dilution caused by the residual burned gases or EGR, the decrease in combustion temperatures is nearly proportional to the heat capacity of the diluents. The lower combustion temperatures resulting from the residual gas dilution/EGR reduces NO formation and emissions as shown in given fig.

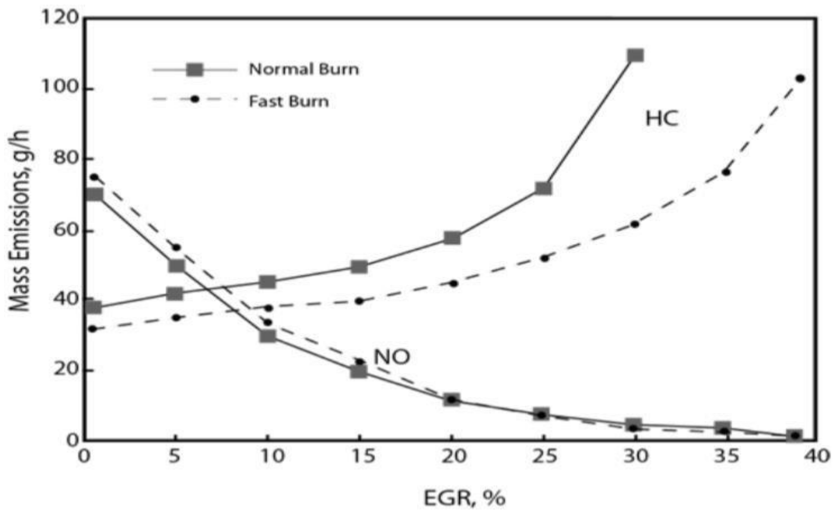


Fig. Effect of EGR on NO and HC emissions in normal burn and fast burn SI engines.

As the EGR is increased the combustion rates become more and more slow, and combustion becomes unstable. With increase in EGR cycle-to-cycle combustion variations increase and, more and more engine cycles having only partial combustion are observed. The frequency of partial burn cycles increases and these turn into misfired cycles at EGR rates of about more than 20%. In the partial burn and misfire cycles, combustion remains incomplete and results in high HC emissions. Moreover with EGR the burned gas temperatures are reduced and post-flame oxidation also reduces. Increase in HC becomes sharp as EGR increases beyond about 20 percent for a normal combustion engine. With EGR rates of 20 percent or higher Fast burn engines due to higher flame speeds have higher burned gas temperatures and tolerate higher EGR rates before the combustion becomes very unstable and loss in fuel efficiency becomes unacceptably high.

Fast burn rates are usually obtained by use of high air swirl and increasing turbulence in the charge through use of suitable designs of intake valve port and the combustion chamber.
The amount of charge dilution or EGR is usually limited to below 15% due to its adverse impact on engine performance causing power loss, high specific fuel consumption and high unburned fuel emissions**.**

Engine Speed;

Volumetric efficiency of the engine changes with speed, it being highest in the mid-speed range. At high engine speeds the volumetric efficiency generally decreases resulting in high residual gas dilution. Although heat transfer rates increase with increase in engine speed as a result of higher turbulence, but total amount of heat transfer is lower due to shorter cycle time. This gives higher gas temperatures at higher speeds. However, at high speeds a shorter time is available for NO formation kinetics. The net result is a moderate effect of speed on NO although this is specific to the engine design and operating conditions. Increase in exhaust gas temperatures at higher speeds enhances post flame oxidation of unburned hydrocarbons. A reduction of 20 to 50 percent in HC emissions has been observed with increase in speed from 1000 to 2000 rpm.

Cold Start and Warm-up Phase;

Engine cold start and warm-up phase contribute significantly to unburned hydrocarbons. One of the main sources of HC emissions during cold start and engine warm-up period is very rich fuel-air ratio needed for ignition and combustion for several seconds after engine start. During cold start, the engine has to be over-fuelled 5 to10 times the stoichiometric amount of gasoline. To obtain robust ignition on the first cycle on cold start, a fuel vapor- air equivalence ratio above lean threshold limit (f = 0.7-0.9) is required. This threshold is independent of the engine coolant temperature. The fuel-air equivalence ratio supplied to the engine during cold start is in the range, f = 4 to 7. For the first few engine cycles, a large fraction of inducted fuel is stored as liquid film in the intake port and cylinder as only the most volatile fractions evaporate when the engine is cold. The liquid fuel films do not participate in combustion and is emitted as unburned fuel emissions.

Coolant Temperature;

As the coolant temperature is increased, the contribution of piston ring zone crevice becomes lower due to decrease in gas density within this crevice. Secondly, the top piston-land side clearance is also reduced due to higher thermal expansion of the piston. A thinner oil film and reduced fuel vapour solubility would result in reduced absorption of fuel vapours in engine oil. Increased post-flame oxidation at high temperatures also contributes to reduction in HC emissions. Increase in coolant temperatures has been observed to reduce HC emissions by about 0.4 to 1.0 % per K increase in temperature. An increase in the coolant temperature from 20 to 90º C, roughly results in 25% lower HC emissions and hence, the need of a rapid engine warm up is obvious. For reduction of the cold start and warm up HC emissions, an important area of development is to improve the fuel injection and delivery to the cylinder with minimum wall wetting. Over-fuelling during cold start and warm-up is to be kept at a minimum, while still forming the combustible charge.

Summary

The effects of some of the important engine design and operating variables on emissions from SI engines are summarized in below Table.

Effect of SI Engine Design and Operating Variables on Exhaust Emissions
(Source: IC Engines - Combustion and Emissions by Pundir, 2010)

Variable Increased	HC	CO	NO_x
Fuel-air equivalence ratio			
Compression ratio	↑	-	↑
Surface/volume ratio	↑	-	↓
Bore/stroke ratio	↑	-	↓
Ignition timing advance	↑	-	↓
Port fuel injection	↑	↓	↓
Engine speed	↑	-	↑↓
Engine load	↑	-	↑
Coolant temperatures	↓	-	↑
Combustion chamber deposits	↓	-	↑
EGR	↓	-	↓
Intake swirl and turbulence	↓	-	↑

↑= increase; ↓ = decrease; ↑↓= uncertain; - = no effect

Evaporative emissions consist mainly of light **hydrocarbons** emitted by a vehicle as a result of fuel **evaporation** through vents open to the atmosphere. They are known to depend on three major factors: - vehicle and fuel system design; - ambient temperature and pressure; - gasoline volatility.

Emissions of many air pollutants have been shown to have variety of negative effects on public health and the natural environment.

A class of burned or partially burned fuel, hydrocarbons are toxins. Hydrocarbons are a major contributor to smog, which can be a major problem in urban areas. Prolonged exposure to hydrocarbons contributes to asthma, liver disease, lung disease, and cancer. Regulations governing hydrocarbons vary according to type of engine and jurisdiction; in some cases, "non-methane hydrocarbons" are regulated, while in other cases, "total hydrocarbons" are regulated. Technology for one application (to meet a non-methane hydrocarbon standard) may not be suitable for use in an application that has to meet a total hydrocarbon standard. Methane is not directly toxic, but is more difficult to break down in fuel vent lines and a charcoal canister is meant to collect and contain fuel vapors and route them either back to the fuel tank or, after the engine is started and warmed up, into the air intake to be burned in the engine

Emissions control

Engine efficiency has been steadily improved with improved engine design, more precise ignition timing and electronic ignition , more precise fuel metering , and computerized engine management .

Air injection

One of the first-developed exhaust emission control systems is secondary air injection. Originally, this system was used to inject air into the engine's exhaust ports to provide oxygen so unburned and partially burned hydrocarbons in the exhaust would finish burning. Air injection is now used to support the catalytic converter's oxidation reaction, and to reduce emissions when an engine is started from cold. After a cold start, an engine needs an air-fuel mixture richer than what it needs at operating temperature, and the catalytic converter does not function efficiently until it has reached its own operating temperature. The air injected upstream of the converter supports combustion in the exhaust head pipe , which speeds catalyst warmup and reduces the amount of unburned hydrocarbon emitted from the tailpipe.

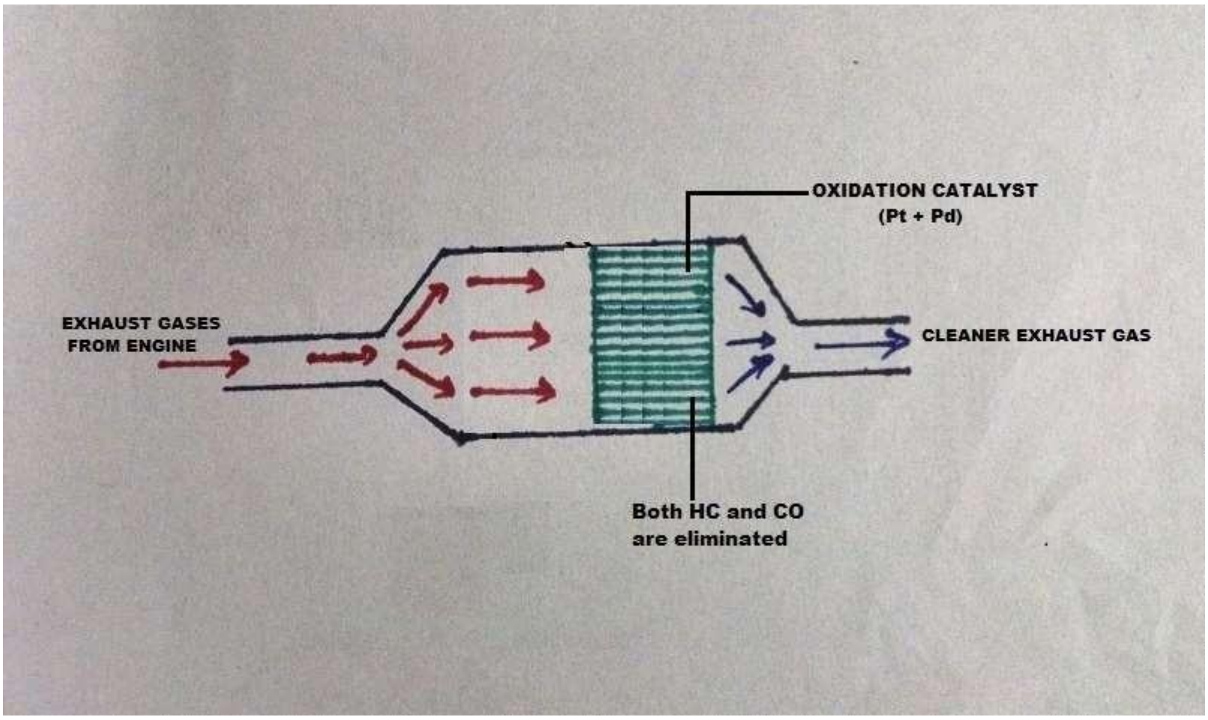
Exhaust gas recirculation

In the United States and Canada, many engines in 1973 and newer vehicles (1972 and newer in California) have a system that routes a metered amount of exhaust into the intake tract under particular operating conditions. Exhaust neither burns nor supports combustion, so it dilutes the air/fuel charge to reduce peak combustion chamber temperatures. This, in turn, reduces the formation of NO_x.

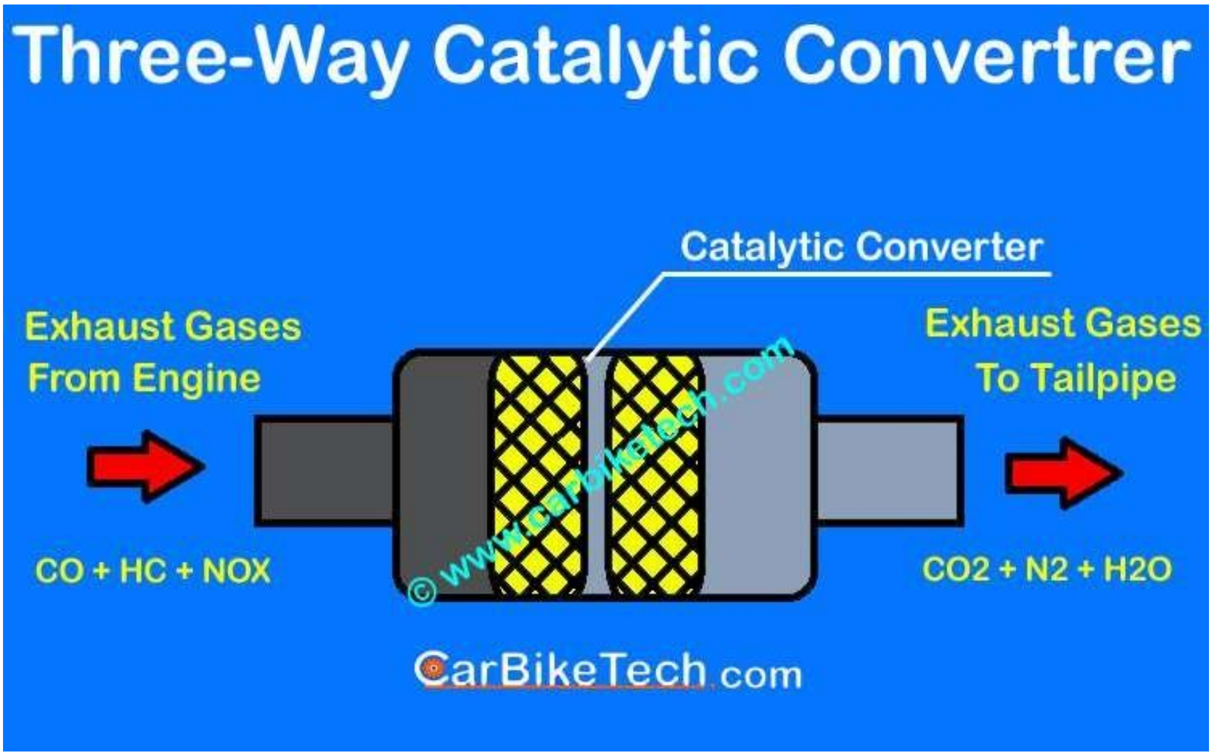
Catalytic converter

The catalytic converter is a device placed in the exhaust pipe, which converts hydrocarbons, carbon monoxide, and NO_x into less harmful gases by using a combination of platinum, palladium and rhodium as catalysts .

There are two types of catalytic converter, a two-way and a three-way converter. Two-way converters were common until the 1980s, when three-way converters replaced them on most automobile engines.



(Two Way Converter)



Evaporative emissions control

EVAP of a Peugeot 205.

Evaporative emissions are the result of gasoline vapors escaping from the vehicle's fuel system. Since 1971, all U.S. vehicles have had fully sealed fuel systems that do not vent directly to the atmosphere; mandates for systems of this type appeared contemporaneously in other jurisdictions. In a typical system, vapors from the fuel tank and carburetor bowl vent (on carbureted vehicles) are ducted to canisters containing activated carbon. The vapors are adsorbed within the canister, and during certain engine operational modes fresh air is drawn through the canister, pulling the vapor into the engine, where it burns.

Remote sensing emission testing

Some US states are also using a technology developed by Dr. Donald H. Stedman of the University of Denver, which uses infrared and ultraviolet light to detect emissions while vehicles pass by on public roads, thus eliminating the need for owners to go to a test center. Stedman's invisible light flash detection of exhaust gases is commonly used in metropolitan areas, is offered by the US-Swedish company OPUS Inspection and becoming more broadly known in Europe.

Use of emission test data

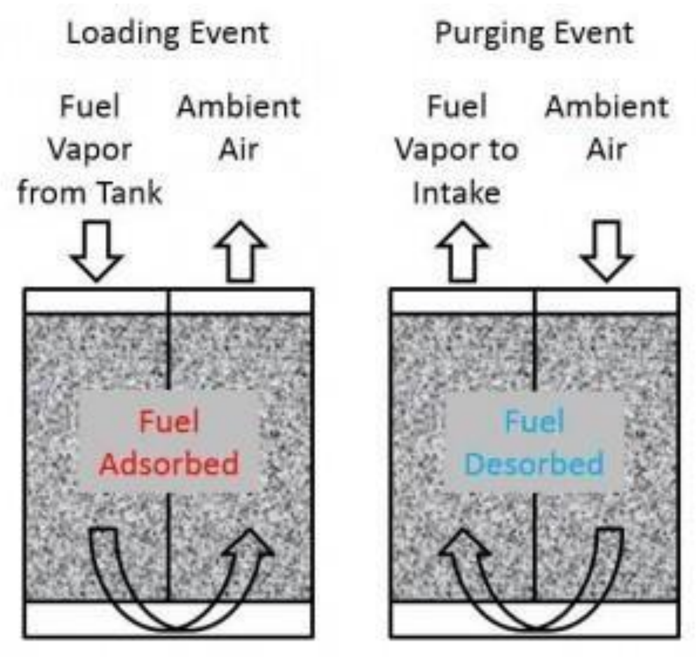
Emission test results from individual vehicles are in many cases compiled to evaluate the emissions performance of various classes of vehicles, the efficacy of the testing program and of various other emission-related regulations (such as changes to fuel formulations) and to model the effects of auto emissions on public health and the environment.

CONCLUSION :

The pollution can simply be reduced by making use of clean vehicle propulsion. The most popular mode include Hybrid electric vehicle and pure electric propulsion. China is by far the largest electric car market in the world. As of December 2019, China had the largest stock of highway legal plug-in passenger cars with 3.4 million units, 47% of the global fleet in use. Experiments are also being conducted with use of solar powered vehicles which are almost ready in the near future as the photovoltaics technology improves.

- Canisters for controlling evaporative emissions

An activated carbon canister is used to capture hydrocarbon vapor emissions from the fuel tank as part of an evaporative emission control system (EVAP). When the engine is running these stored hydrocarbons can be purged by opening a valve to the intake system and reversing the flow through the carbon canister allowing the engine to consume the hydrocarbon vapors by combustion. With LEV III evaporative emissions standards calling for zero evaporative emission losses by 2022, and with the increasing complexity of turbocharged GDI engines, there is increasing interest in optimizing the carbon canister size for hydrocarbon storage, and optimizing the hydrocarbon purge control strategy. For example when to purge during a drive cycle, where to purge (intake manifold under vacuum conditions or upstream of compressor during boosted conditions), and how a purge event affects engine performance and emissions.



The fuel we put in our cars contains more than 150 chemicals, including benzene, toluene and sometimes even lead. These ingredients can cause dizziness, breathing problems and headaches when they're inhaled. Inhaling large amounts of gasoline fumes can even cause death. On top of all that, evaporated gasoline is one of the leading causes of smog and air pollution.

For these reasons, carmakers are required to install systems on their vehicles that help mitigate gasoline evaporations. Environmental regulation in the United States began in earnest in the early 1970s, and as a result, cars have had evaporative emission control (EVAP) systems ever since. These systems are designed to store and dispose of fuel vapors before they can escape into the atmosphere.

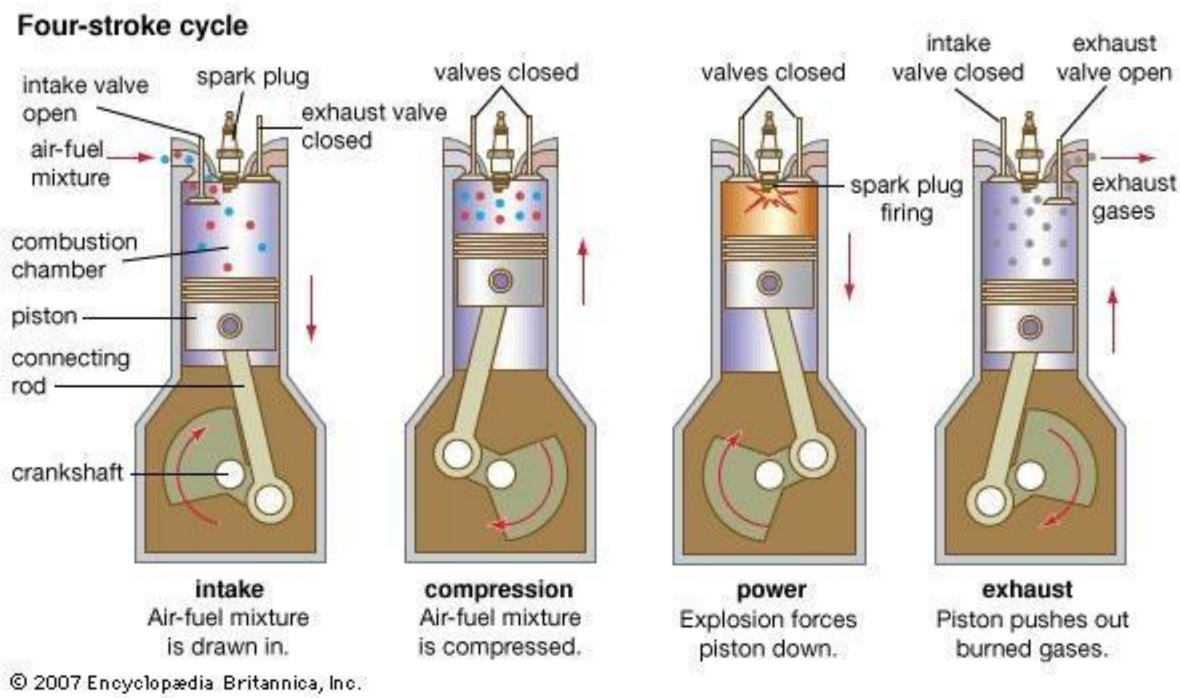
A typical system consists of a small canister full of charcoal, valves, hoses, vents in the fuel lines and a sealed fuel tank cap. When fuel evaporates inside the gas tank, the excess vapors are transferred to the charcoal canister. They're stored there until they can safely be transferred back to the engine to be burned with the normal air-fuel mixture.

When that's ready to happen, a valve creates a vacuum that draws the vapors into the engine. Fresh air is also drawn in through the vents and valves to mix with the vapors for better combustion. These systems can be controlled mechanically, or like on most on newer cars, through the engine's computer. The computer tells the valves when to purge the canister of vapors. This typically happens when the car is in motion, rather than at idle. It's just one example of some of the behind-the-scenes technology that you'll likely never see or feel.

As you may expect, things can go wrong with the EVAP system, too. If the canister fails to purge or does so under the wrong conditions, it can hamper the performance and emissions of your vehicle. When this happens, you may find that the entire system needs to be replaced.

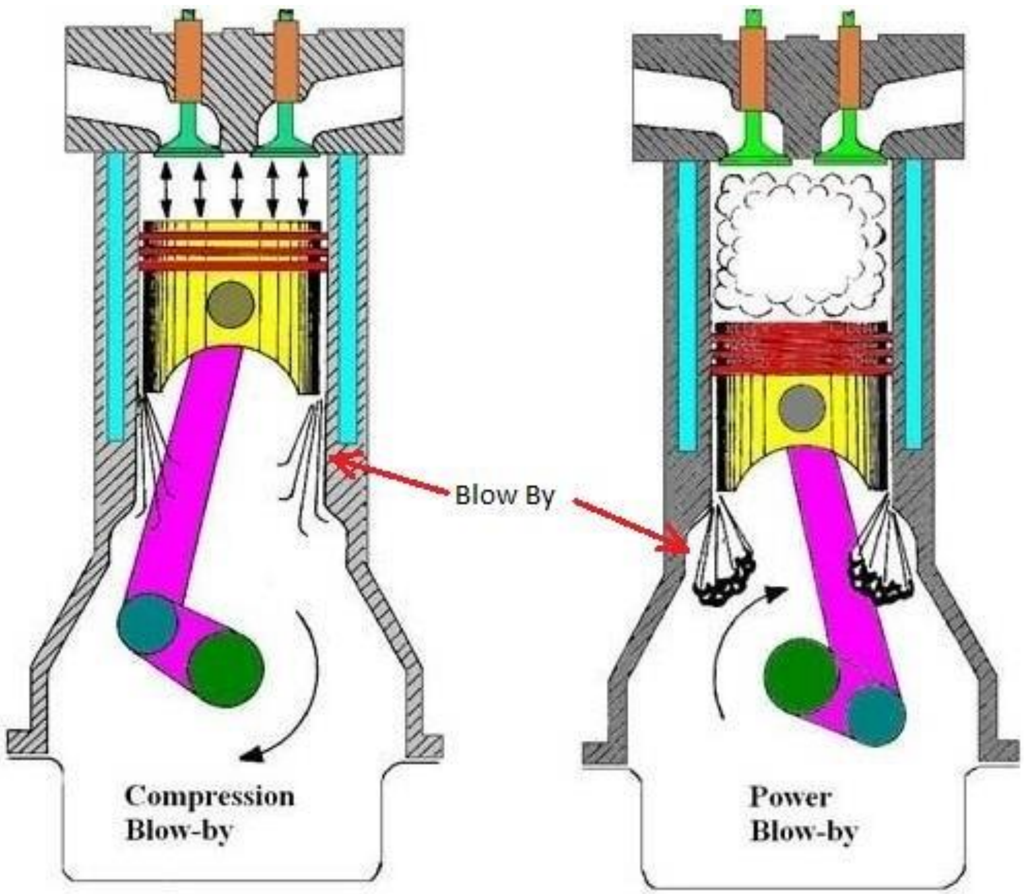
Emission control systems for gasoline engines: Blow by control closed PCV system design

Working of an Internal Combustion Engine



We know, that an internal compression engine comprises of pistons which are allowed to do translatory motion up and down inside the cylinder. Along with this, a mixture of air and gasoline is pumped through a system of tubes called the intake manifold through each cylinder's intake valve (or valves), where a spark from a spark plug causes the mixture to explode in the open space at the top of the cylinder called the combustion chamber. The pressure from this explosion drives the piston in the cylinder downward, where it causes the crankshaft to rotate. The rotation of the crankshaft not only pushes the piston back up into the cylinder so it can do all this again, but it also turns the gears within the car's transmission that eventually make the car move. Meanwhile, the rising piston pushes the air and gas left over from the explosion back out of the cylinder through an exhaust valve.

Blow by & its effects

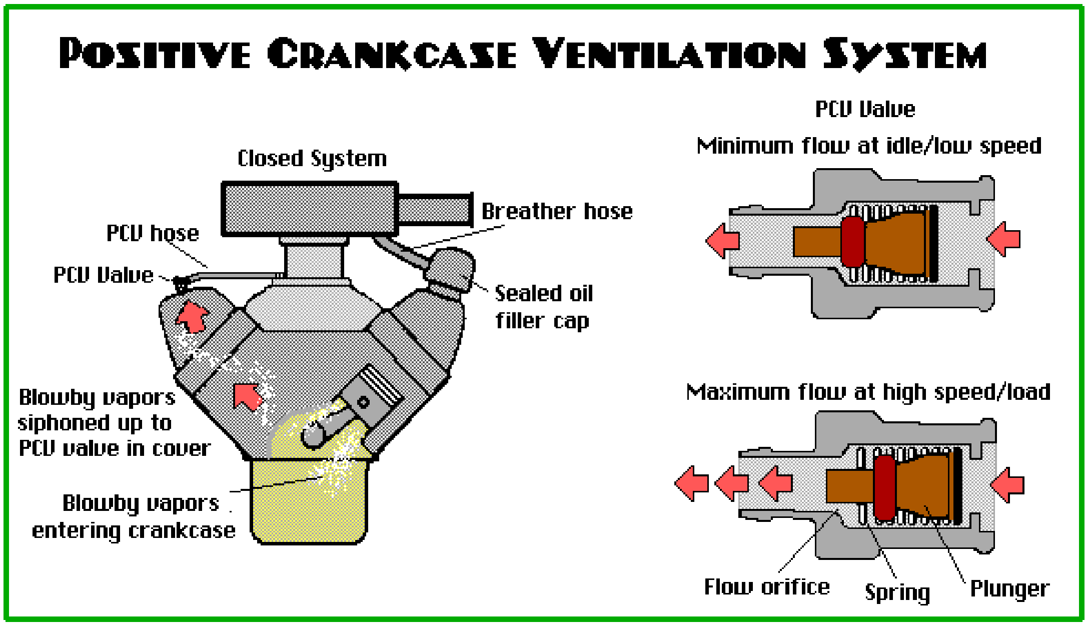


During the cycle, a certain amount of the air and gasoline mixture is pulled down by the piston and it slips through the piston rings into the crankcase, which is the protective cover that insulates the crankshaft. This escaping gas is called blow-by and it's unavoidable. It's also undesirable because the unburned gasoline in it can gunk up the system and produce problems in the crankcase.

It isn't always desirable to have these gases in the cylinders because they tend to be mostly air and can make the gas-air mixture in the cylinders a little too lean -- that is, too low on gasoline -- for effective combustion. So the blow-by gases should only be recycled when the car is traveling at slow speeds or idling.

Introduction of Positive Crankshaft Ventilation (PVC)

Until the early 1960s, these blow-by gases were removed simply by letting air circulate freely through the crankcase, wafting away the gases and venting them as emissions. Then, in the early 1960s, positive crankshaft ventilation (PCV) was invented.



Positive crankcase ventilation involves recycling these gases through a valve (called, appropriately, the PCV valve) to the intake manifold, where they're pumped back into the cylinders for another shot at combustion. When the engine is idling the air pressure in the intake manifold is lower than the air pressure in the crankcase, and it's this lower pressure (which sometimes approaches pure vacuum) that sucks the blow-by gases through the PCV valve and back into the intake. When the engine speeds up, the air pressure in the intake manifold increases and the suction slows down, reducing the amount of blow-by gas recycled to the cylinders. This is good, because the blow-by gases aren't needed when the engine speeds up. In fact, when the car is up to speed, the pressure in the intake manifold can actually become higher than the pressure in the crankcase, potentially forcing the blow-by gases back into the crankcase. Since the whole point of positive crankcase ventilation is to keep these gases out of the crankcase, the PCV valve is designed to close off when this happens and block the backflow of gases.