Chapter 4.

Exhaust Emissions.

How and Why Exhaust Emissions became so Important.

The emissions business is driven largely by the California Air Resources Board (CARB – sometimes shortened to ARB) and the Environmental Protection Agency (EPA) in the USA, both coming to prominence after motor vehicle exhaust pollution had been positively identified in the late 1960s as a significant cause of serious photochemical smog problems in the Los Angeles basin and Tokyo bay. The situation in both places was made particularly acute by local geographic and climatic features which were not replicated in many other locations, conspiring to prevent pollutants in rising air from dispersing easily. Nevertheless it cannot be disputed that exhaust pollution could make most city centres very unpleasant at certain times of the day. Even in the open country there is no pleasure at all in finding oneself driving behind an ill-maintained smoky old banger. Yet to think about exhaust emissions only as being something unpleasant is to miss the main point. Almost any combustion process inevitably produces a whole host of chemical compounds of varying degrees of toxicity, whether the subject is a forest fire or a motor car driving past. We cannot do much about the former but we have learnt that we can do quite a lot to reduce the impact of the latter.

Densities of Various Gases (lbs/cu ft).

Water vapour	**0.048**
Combustion gases	**0.069**
Air	**0.075**
Nitric oxide	**0.078**
Carbon monoxide	**0.078**
Carbon dioxide	**0.123**
Ozone	**0.125**
Benzene	**0.206**
Toluene	**0.243**

The products of combustion have an average density about 10-15% less than air (see table), mainly due to the water vapour content, and being also heated will tend to rise as a mass in the atmosphere.

The pollutants that were identified as the main culprits were: the various oxides of nitrogen (NO, NO_2, N_2O, known collectively as NOx) produced by high temperatures and pressures, numerous hydrocarbon compounds (HC) resulting from inefficient combustion, and carbon monoxide (CO) resulting from excess fuel and inefficient combustion.

The photochemical smog that produced the impetus to do something about vehicle emissions was created by a combination of NOx and HC emissions, mainly from vehicle exhausts, rising until bright sunlight promoted various reactions to produce ozone and a host of highly reactive compounds. These would then sink back to ground level to become a serious threat to the wellbeing of people, livestock, and even plants, if exposed to them in any quantity.

Ozone is an important constituent gas in the upper atmosphere but is an oxidizing agent that can be most unpleasant at ground level, even attacking building structures. The irritant and corrosive effects of ozone are relatively simple to understand but the myriad organic compounds can have all sorts of effects ranging from benign through irritants to carcinogens. Peroxyacyl nitrates (PANs) are another unpleasant group of compounds that only occur as a consequence of photochemical smog so are classed as secondary pollutants. They can cause irritation and damage to eyes, lung tissues and vegetation even at very low levels of a few parts per billion.

The incidence of respiratory problems causing deaths and hospitalization has been strongly linked to high levels of this type of atmospheric pollution. The human body is surprisingly tolerant of many pollutants in modest doses, evolution having provided some very effective defence mechanisms, but at increasing levels of exposure the natural resistance eventually becomes overwhelmed and of course it is the elderly and the infirm who tend to be the most vulnerable.

Whilst it is true that the NOx/HC based photochemical smog is mostly concentrated in particular areas it does also carry some distance on the wind, remaining reactive enough to cause trouble in less likely places. Of course, wind would disrupt the stable situation in which photochemical smog is created so the conditions in which it can become a significant long distance problem are probably relatively uncommon. The most effective way of dealing with photochemical smog is to reduce the emissions of NOx and HC that are the prime cause.

NOx and Exhaust Gas Recirculation.

NOx generation is very dependent on combustion temperatures but only a relatively modest temperature reduction is required for quite a profound effect. One method of achieving this is to dilute the incoming charge with inert gases such as CO_2, nitrogen or even water vapour, all of which are present in exhaust gas. Exhaust Gas Recirculation (EGR), the technique of feeding a proportion of spent exhaust gas back into the incoming charge, is very effective at reducing NOx, by a two-way mechanism. Firstly, it has the effect of reducing the peak combustion temperatures and secondly, it slows combustion so more of the process takes place after the peak pressure point which is therefore reduced in magnitude. Retarding the ignition timing has a similar effect which is why it is often used as another NOx palliative.

The proportion of EGR in the incoming charge is important and the gains fall off beyond about 15% but by that point economy and drivability will be starting to deteriorate. In the early days of emission control before three-way catalysts, EGR was heavily relied on and the emissions from the richer mixtures it then demanded were usually resolved by an air pump and oxidizing catalyst. In those days when mixture quality was often rather indifferent, any fuel caught in a pocket of exhaust gas would be unable to burn properly so richer fueling would be required to ensure the remainder of the charge would be combustible. The same phenomenon tended to magnify cycle to cycle combustion pressure variations so drivability would also suffer.

High turbulence of the charge was found to increase tolerance of EGR and reduce the rich fueling requirement so in the early 1970s nearly every manufacturer in the world was experimenting with stratified charge and high swirl combustion systems. Honda’s famous CVCC engine was a notable example of this sort of approach (Fig. 4.1).

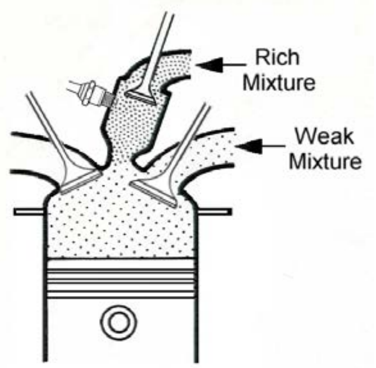

Fig. 4.1 Honda CVCC stratified charge system.

EGR was usually administered by a valve operated either by vacuum (Fig. 4.2) or solenoid. Vacuum operation from a throttle edge port was very popular because the valve could then be easily arranged to only open in part throttle operation which is when the test conditions require it. The proportion of EGR was usually governed by a control orifice but because the pressure difference between the exhaust system and the inlet manifold was variable, EGR was never very accurately controlled by this method.

The tendency to suffer deposit fouling was another a problem that had to be overcome but in the mid-1970s EGR valves were virtually standard equipment on any cars intended for the US and Japanese markets. When Jaguar’s V12 went from carburetors to electronic fuel injection in 1975, solenoid operated EGR valves were used, discharging into the throttle assembly. This had the unexpected result of transmitting exhaust noise which then became audible from the air intakes, resolved by relocation of the tapping points from the exhaust down-pipes.

Vacuum operated EGR valves were simple and reliable so continued to be used in combination with an electronically controlled valve to modulate the vacuum signal to provide much more refined control of the process.

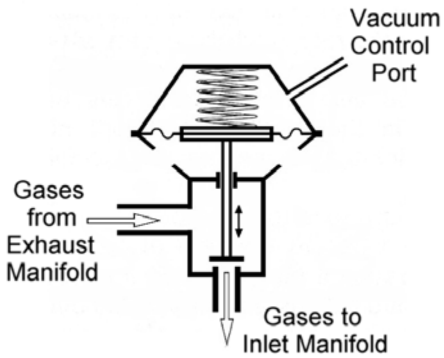

Fig. 4.2 Typical vacuum operated EGR valve.

Although EGR is effective, the reduced peak pressure requires that the throttle will have to be opened further to maintain the same level of torque from the engine, an action which will itself tend to increase NOx. Emissions engineers therefore have to carefully juggle conflicting requirements.

The operation of modern EGR systems is integrated into the engine management strategy often via a stepper type of control valve and with feedback from a temperature sensor in the EGR tract. A built-in position feedback sensor on the valve enables the control unit to determine if deposit fouling is restricting flow but deposits can also occur in the induction tract, requiring extra cleaning agents in the fuel. These more sophisticated EGR valves dispense with the vacuum method and position the valve via an electronic servo.

When EGR is properly administered at part load the manifold pressure will become higher so pumping losses will be reduced and also the ignition timing might be advanced slightly as an alternative to the need for more throttle opening, so there can be a small net gain in fuel efficiency, unlike in the early days when EGR earned a bad reputation.

EGR can also be provided by increasing valve overlap at the speed and loads when it is required, sometimes known as ‘internal EGR’, which is one reason why variable valve event (VVT) systems described in Chapter 10 have become so popular. This avoids all the problems of deposit build up in external pipes and control valves although in critical situations normal EGR may have to be used as well, often because it provides a means of accurately controlling the total EGR proportions.

There is some merit in cooling the exhaust gases, if at all possible, before they are introduced to the incoming charge which removes any increased threat of detonation so permits use of a higher compression ratio and the potential benefits that can bring.

HC Emissions.

It is well established that emitted HC (hydrocarbon) compounds can be harmful on their own without any association with photochemical smog. The HC content in exhaust gases will have been raised to a highly reactive state by their passage through the engine so can be more unpleasant than simple evaporative fumes from gasoline. It is therefore fortunate that all modern engines generate a low level of HC raw emissions in normal urban use, typically no more than around than 150 ppm (0.015%), which a three-way catalyst will reduce to virtually zero. At full throttle with power enrichment and no feedback the figure may well approach 300 ppm and the catalyst will be out of its operating regime so its effect will be limited, however this condition is outside the realm of most emission testing and legislation.

One of the most hazardous of the HC compounds is benzene, which has proven links with myeloid leukemia as well as genetic and other disorders in embryos. The maximum content in modern gasoline fuels is limited to 1% in many countries, and hardly any will survive through the combustion process, however it can reappear as a trace product of combustion from similar HC compounds such as toluene. Benzene is likely to be released from tank vapours when refueling but to put some perspective on the real risk to health, a cigarette smoker who never goes near a filling station will receive much more exposure to benzene than any driver.

Carbon Monoxide (CO) Emissions.

CO is another exhaust pollutant that can cause additional difficulties for those with respiratory and cardiovascular problems. It is perhaps the easiest combustion by-product to control because in the presence of spare oxygen it will burn off to form CO_2. Full throttle raw emissions of CO with rich fueling are likely to be in the range of 2 - 5%, but in cruise the raw level with Lambda feedback should be very low, no more than about 0.1%.

Carbon Dioxide (CO_2) Emissions.

Although CO_2 was not originally regarded as a pollutant it soon became necessary to include it in the analysis of emissions in order to calculate the total carbon mass balance of the exhaust gases and thereby determine the exact fuel consumption during an emission test procedure. CO_2 and water are the products of perfect combustion of a hydrocarbon fuel and the former was regarded as a relatively innocuous gas, essential for the process of photosynthesis in plant life. Only when the issue of Anthropological (i.e. man-made) Global Warming rose to prominence did it begin to be considered as something to be controlled and the EPA were directed by a Supreme Court ruling in 2007 to classify it as a pollutant which fell foul of the Clean Air Act. It seems to be a bizarre piece of logic to declare that a gas that is expired in the breath of virtually all animal life and which is essential to most plant life is a pollutant to be rigidly controlled.

The writer makes no claim to be an expert on the subject of climate but has made an effort to develop some sort of understanding of what it is all about. Human activity probably does have some influence but how significant that influence is, compared to numerous other factors, is a matter for conjecture – starting with uncertainty about how well we understand the subject. One of the originators of global warming alarmism, James Lovelock, recently admitted that he now thinks he might have been wrong and that even now we still don't really know enough about it to make a proper judgement.

A succession of very cold winters in recent years and the failure of temperatures to follow computer generated predictions, increased skepticism and instigated a change of alarmist emphasis from 'Global Warming' to the more flexible 'Climate Change' or even 'Climate Disruption' with claims that extreme weather events like hurricanes would become more common. When Hurricane Sandy hit the US east coast in 2012 it was touted as an example of what could be expected yet statistically Sandy was not at all remarkable and in recent times hurricane activity has actually been less than in most of the preceding decades.

Be that as it may, because CO_2 mass emissions are largely a function of rate of fuel consumption, improving fuel efficiency will reduce CO_2. It is ironic that the use of three-way catalysts and Lambda feedback in pursuit of lower emissions, as described in Chapter 3, actually forces engines to operate in the regime where they generate the maximum possible amount of CO_2, as well as consuming more fuel than is really necessary.

The Clean Air Act and the EPA.

It doesn't seem to be widely known that the California Air Resources Board (CARB) actually came into existence about two years before the EPA, as a result of which it has always had a priority over relevant policies in that state. The CARB had itself resulted from concerns relating to pollution around Los Angeles dating back to the late 1940s.

21 pages follow.