

CHAPTER 1

Motivation and Scope

Over the years, regulations on automobile exhaust emission have steadily increased in both their severity and the number of pollutants that fall under regulated jurisdiction. To date, most industrialized countries have regulations on the amount of allowable exhaust emissions. The amount of regulation varies from county to country. The US enacted its first federal standard for automobile emissions under the Clean Air Act in 1966. It applied to 1968 model vehicles. However, California had enacted state regulations in 1959 to limit crankcase emissions, CO, and HC. Federal and California legislation have drastically cut the amount of allowable gaseous pollutants since the first legislation was passed. This steady downward move in legislation towards little to no emissions, ULEV (Ultra Low Emissions Vehicle) and ZEV (Zero Emissions Vehicle), as proposed by California, has been the driving force behind industry advances in the design and control of the spark ignition (SI) automobile engine.

For SI engines burning hydrocarbon fuels, the products of combustion under regulation are carbon monoxide (CO), nitrogen compounds (NO_x), and unburned hydrocarbon fuel (HC). The production of CO, HC, and NO_x, are of particular interest for their undesirable effects on the surroundings. Environmental studies over the years have linked the production of the fore mentioned gasses to detrimental changes in the environment.

Carbon monoxide is a odorless, tasteless, highly toxic gas. It is formed in its largest quantity during incomplete combustion of fuel rich mixtures. CO is fatal at concentrations above 1000 ppm. However, due to its ability to attach to blood hemoglobin 240 times easier than oxygen, it can intoxicate a person at much lower levels causing nausea, dizziness, and headaches by depriving the body of oxygen. Fortunately it has a high level of atmospheric reactivity and does not accumulate excessively with time. Carbon Dioxide is the final product formed when the carbon based fuels are oxidized. Although CO₂ it is not toxic like CO, it is believed to be in part the cause behind global

warming through the greenhouse effect. Nitrogen compounds (NO_x) in the exhaust of gasoline SI engines are formed mostly through the oxidation of atmospheric (molecular) nitrogen. NO is the largest fraction of the NO_x division. Atmospheric NO production increases with temperature. Production peaks around stoichiometric A/F conditions falling off on the rich and lean side. Some fuels contain significant amounts of nitrogen and can serve as an additional source, but gasoline usually does not contain significant amounts of nitrogen. Nitrogen Compounds along with ground level ozone and smog are associated with the formation of nitric acid and acid rain.

There are several methods and driving cycles used to test automobile emissions throughout the world. The general test cycle used throughout the United States is known as the FTP-72 and FTP-75. FTP stands for Federal Test Procedure. There are other specialized test cycles for heavy duty vehicles and dense urban traffic such as New York and California and highway situations. The FTP-72 and FTP-75 cycles are shown below in Figure 1.1.

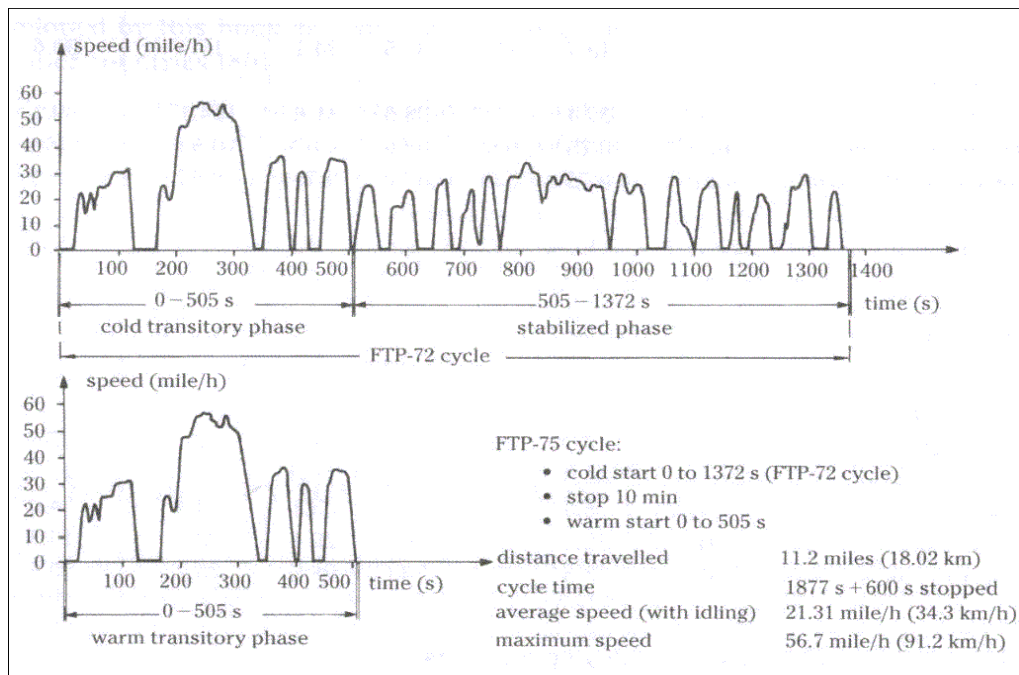


Figure 1.1 - Federal Test Procedure Emission Test 72 and 75

The FTP-72 cycle has two phases with the first being 505 seconds and the second lasting 867 seconds. Before starting the first phase, cold transitory stage, the vehicle soaks overnight at around 20° C. After the first phase the engine is turned off for 10 minutes and restarted for phase 2, the stabilized phase. The FTP -75 cycle adds another 10 minute stop and then a third phase, warm transitory phase. This third phase is identical to the first phase of the FTP-72 but the engine is started warm. The FTP -72 cycle is designed to model an urban drive. With speeds varying from 0 to 91.2 km/h, it covers 12.07 km having an average speed of 31.5 km/h (34.1 km/h for FTP-75)[1].

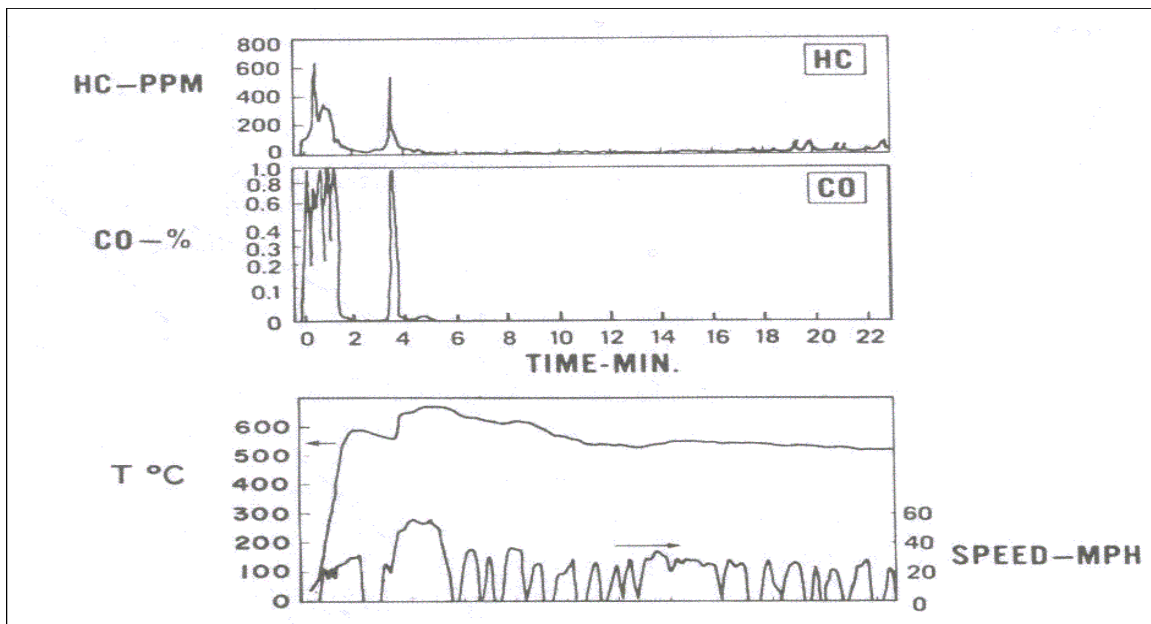


Figure 1.2 - Emissions Trace Over FTP-72 Test

During testing anywhere from 70%- 90% of the total HC and CO emissions occur during the first 2 minutes of operation [2]. Figure 1.2 shows a typical emissions trace during the federal test. This disproportional balance in emissions production has forced automobile makers to concentrate on engine operation under cold starts. By failing to control cold start emission alone, a car can fail to meet government specifications. In a study on the length of trips made by cars in the US show that about 62% of the trips are of 5 miles or less and account for 31% of the total fuel consumption. [3]. Short trip frequency is higher in the US than in most European countries due to less developed

public transportation. During these trips the fuel economy may only reach 60-70% of the fully warmed fuel economy[2]. The decreased fuel economy can be related to increased CO, HC , an CO₂ emissions in most cases.

Several factors lead to hydrocarbon emissions. All are linked to inability of the engine under these conditions to completely oxidize all of the fuel provided. When an engine is fully warmed the main mechanisms that contribute to unburned fuel in the exhaust are quench layer, crevices in combustion chamber, oil absorption, deposits, and exhaust valve leakage [4]. Quench layers are areas close to cooled engine walls that the flame front can not propagate through. Crevices in the combustion chamber work to increases HC emissions similar to quench areas. The small crevices in the combustion chamber also extinguish the flame leaving fuel unburned in the crevice volume. An example of a crevice volume would be the area between the top ring, the cylinder wall, and the top of piston. Lubricating oil on the cylinder wall contributes to HC emission by absorbing a small fraction of the fuel before the flame has a chance to reach it. Then the fuel is released during the blow down phase partially oxidized or unoxidized and into the exhaust . Deposits in the chamber act similar to the oil by absorbing fuel and preventing its burning.

While the fore mentioned sources of HC emissions all contribute during cold start conditions, their overall contributions are a small percentage. The main sources of HC emissions during cold start are created by poor fuel vaporization and a cold catalytic system. During cold start, parts in contact with fuel air mixture are cold and can not supply the heat needed to vaporize sufficient quantities of liquid fuel. To compensate for decreased vaporization, increased amounts of liquid fuel is supplied. Air/fuel ratios can go as low as 1:1 in very cold climates. A study done by GM [5] on cold start fuel requirements revealed that the amount of vapor needed to start over a -30°C to 20°C. range was almost constant while the fuel/air equivalence ratio, ϕ , for liquid gasoline supplied to create the vapor ranged from as high as 5.6 at -29°C to 1.1 at 21°C. A graph showing the percent of gasoline vaporized by volume versus temperature clarifies GM's findings (Appendix A).

The injection of the fuel at several times the of stoichiometric proportions wets the intake port and cylinder wall. In the first few cycles the vapor formed is not sufficient to support flame propagation. Most of the vapor and some of the liquid fuel is flushed out of the cylinder. Over the successive cycles the liquid film layer in the ports and on the cylinder wall is increased until a sufficient amount of vapor can be formed to sustain combustion. Depending on the condition the first firing may or may not be proceeded by another. If it is not followed, then the film layer will repeat its growth in similar fashion as with events leading up to the first firing. The cycle to cycle variation in the vapor and film layer development causes the engine to miss on some cycles during cold start. After combustion takes place, some of the hot products flow back into the ports increasing vaporization of fuel. Within the combustion chamber, the walls are still cold. Quenching of the already overly rich mixture is increased leading to increased fuel escaping oxidation [6]. With the tailpipe HC emissions standards decreasing, stable repeatable combustion during cold conditions is increasing in importance.

The connections between the fuel, liquid film layer and cold start HC emission are complex. The complex interactions involve many factors ranging from droplet size and injection timing to air temperature and speed. Plus, they have to be accounted for in very transient conditions making understanding even more complicated. Large efforts are being made to better understand the process and develop better control strategies. As more is learned on the processes involved, emission will continue to decrease.

Curing the cold start HC emissions problem has developed into two basic approaches. The first approach is to eliminate the causes of cold start HC emissions at the engine. The second is to eliminate the HC produced by the engine before the exit the tailpipe. Efforts to reduce cold start HC production encompass strategies from better mixture preparation and control to better combustion chamber designs. To provide more uniformly mixed air and fuel, engineers have experimented with new fuel injector designs that increase the vaporization of fuel droplets. Some of the designs are air assisted where air under high pressure is injected into the fuel spray to promote dispersion [7,8]. The results vary from design to design. Preheating engine components, from the intake to the

whole engine, have been under study for several years. The idea was introduced to aid carbureted engines. The use of dual fuels has also been studied.

Development of methods to eliminate HC emission produced by the engine before they exit the tail pipe has focused on better catalyst and catalyst operation. Catalytic systems are over 90% (two-way catalyst) efficient at oxidizing unburned HC's at operating temperature. The problem with catalyst is that the catalyst takes a finite amount time to reach operating temperature. The typical time required to reach light-off temperature is about 2 minutes. Light-off temperature is the temperature at which the catalyst efficiency is 50%. Catalyst operating temperatures, which are higher than their light-off temperatures, are usually in excess of 300°C. Up until this temperature, catalytic systems have limited to no effect. The poor conversion efficiency during the first 2 minutes period compounds the problem created by the need for a rich fuel/air mixture and the poor quality of combustion in the cold engine. When the engine is at its worst so is the catalyst system [9]. By decreasing the amount of time needed to reach operating temperatures several studies have shown that significant reductions in cold start HC emission can be accomplished. Methods to decrease the warm up time vary from electric heating to heat storage to ignition retardation [10,11] Another approach at solving the light-off time problem is the HC trap. The theory behind the HC trap is to catch and hold all the HC emission until the catalyst reaches operating temperature. When the catalyst reaches operating temperature, the trap releases caught HC's into the catalyst for complete oxidation. The HC trap exhaust systems are more complicated but the systems have been able to reduce cold start HC emissions by up to 70% [12,13]. HC traps have shown the most promise. But 70% reductions will only pass EPA standards for a while. Continuing progress towards zero emissions is paramount.

The approach taken in this study was to attempt the reduction of the initial production of HC emissions through increasing the efficiency of the combustion process. This experiment studied the effect of increased ignition energy on the levels of unburned hydrocarbons emitted during cold start conditions. The idea that increased ignition energy levels promote increased engine performance has been around for years. There have been several studies that used various forms of ignition systems at varying levels of

ignition energy. The studies covered a wide variety of ignitors as well as energy delivery system. The energy delivery system was of interest in this experiment so a conventional spark plug was used. The description of the supplemental ignition system used in the experiment can be found in Section 2.3.3.

Under ideal operating conditions in a warmed engine, a stoichiometric mixture requires about 0.2 mJ of energy to ignite by means of spark. However, a automobile engine rarely operates under ideal conditions. The amount of energy needed to ignite the mixture increases for rich and lean mixture as well light and heavy loading conditions. If sufficient energy is not supplied misfires occur. To ensure the absence of misfires most automotive ignition system are designed to deliver 60-120 mJ to insure ignition independent of operating condition [14]. However, most ignition systems are not designed to increase the rich and lean operating range of a particular engine or optimize a particular engine's performance.

Anderson[15] showed that with the use of increased ignition energy and different delivery methods significant gains in engine performance could be obtained. His work and other similar research [16] illustrated how increased burn rates and extended lean operating conditions are achieved with increased ignition energy. The research also demonstrated the ability to increase the thermal efficiency with increased cylinder pressures and decreased specific fuel consumption over tested operating conditions.

High energy ignition (HEI) systems produce larger plasma arcs over standard ignition systems. The duration of the arc is often extended also. The duration depends on the type of delivery system [15]. The increased arc size increases the entertainment of fresh fuel and creates larger initial flame kernels. The HEI system's larger initial flame kernel increases the burn rate. The increased burn rate allows less time between spark and peak cylinder pressure for disturbances to hinder the combustion process. This is very important when operating around the lean limit to avoid misfires and enhance combustion stability.

Most of the studies involving ignition systems have been done at fully warmed operating conditions. In the fully warmed condition cycle to cycle variations in mixture are small unless operating on a lean mixture. In cold conditions however, the cycle to cycle

variations in mixture quality are more drastic. The variations result from the unpredictable development of vapors from liquid fuel injected into the engine is cold. This variation often shows up as rough engine operation for the consumer and high emissions concentrations for the EPA. HEI systems have demonstrated the ability to extend the rich and lean operating range of an engine. The ability to consistently ignite in conditions when cycle to cycle variation in the mixture are high, makes it a viable approach to reduce cold start emissions. HEI systems reduce misfires and promote complete combustion resulting in decreased emission.

The focus of this experiment was to study the effects of increased ignition energy on cold start hydrocarbon emissions. Because of the relationships existing between the various components in the exhaust, the effects of the increased energy on cold start CO, CO₂, and NO_x, were also investigated. The increased ignition energy was added to the energy level of the stock system. The additional levels were 0.387 joules and 1.187 joules above the stock ignition system output. At each energy level the number of cycles required until the first successful fire was recorded.