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# Biofuels Ethanol and Methanol in OTTO Engines

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Additional information is available at the end of the chapter

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## 1. Introduction

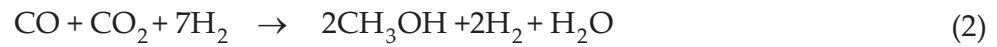
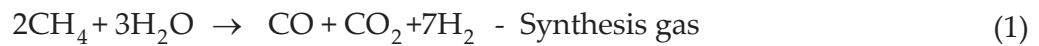
Today, humanity faces many environmental problems, one of which is atmospheric pollution that leads to greenhouse effect, ozone formation and to many health problems to human beings. Also, many countries around the world face the problem of energy shortage. At the same time we must not forget the need for clean air, clean fuel and biodegradable, renewable materials. Hazardous pollutants that lead to atmospheric pollution have many sources and automobile's exhaust emission is one of these. Petroleum-based products that have been used as fuels produce dangerous gas emissions. In order to decrease environmental impacts, scientists and many governments turned their attention to renewable fuels as alternatives to conventional fossil fuels and as oxygenates [1]. The beginning of the 21st century finds humans more familiar with the concept of sustainable development. We must prevent the degradation of our environment focusing in more friendly technologies. This need lead scientists to the use of other energy sources that can be used with the same efficiency but won't have damaging effect to the environment. The increased vehicle number that usually uses petroleum-based fuels results to dangerous emissions production such as carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), hydrocarbons (HC), nitrogen oxides (NO<sub>x</sub>) and others. These emissions besides the fact that lead to environmental degradation they also constitute a threat for human health. People's concern about the risks associated with hazardous pollutants results to an increased demand for renewable fuels as alternatives to fossil fuels [1,2]. Ethanol and methanol are alcohols that can be used as fuels instead of gasoline in automobile engines. For better understanding of the use of these two alcohols we must examine them separately. Fuel ethanol is an alternative fuel that is produced from biologically renewable resources that it can also be used as an octane enhancer and as oxygenate. Ethanol (ethyl alcohol, grain alcohol, ETOH) is a clear, colorless liquid alcohol with characteristic odor and as alcohol is a group of chemical compounds whose molecules contain a hydroxyl group, -OH, bonded to a carbon atom. Is produced with the process of fermentation of grains such as wheat, barley, corn, wood, or

sugar cane. In the United States ethanol is made by the fermentation of corn [1-3]. By the reaction of fermentation simple sugars change into ethanol and carbon dioxide with the presence of zymase, an enzyme from yeast. Ethanol can also be made from cellulose that is obtained from agricultural residue and waste paper [1]. It is a high-octane fuel with high oxygen content (35% oxygen by weight) and when blended properly in gasoline produces a cleaner and more complete combustion. Ethanol is used as an automotive fuel either by itself or in blends with gasoline, such as mixtures of 10% ethanol and 90% gasoline, or 85% ethanol and 15% gasoline [3-6]. Many countries around the world use ethanol as fuel. For example, in Brazil ethanol is produced using as raw material sugarcane and many vehicles use ethanol as fuel. Also in Canada and in Sweden ethanol is highly promoted as fuel because of the many environmental benefits that ethanol has. When gasoline is used as fuel hydrocarbons (HC) escape to the atmosphere. Many hydrocarbons are toxic and some, such as benzene, can cause cancer to humans. If ethanol is used as fuel hydrocarbons are not being produced because ethanol is an alcohol that does not produce HC when is burned. The reaction of hydrocarbons and nitrogen oxides that are produced from the gasoline burning, in the presence of sunlight leads to the formation of photochemical smog. The use of ethanol as fuel can contribute to the decrease of photochemical smog since it does not produce hydrocarbons [5-8]. Vehicles that burn petroleum fuels produce carbon monoxide (CO) because these fuels do not contain oxygen in their molecular structure. Carbon monoxide is a toxic gas that is formed by incomplete combustion. When ethanol, which contains oxygen, is mixed with gasoline the combustion of the engine is more complete and the result is CO reduction [9-11].

Using renewable fuels, such as ethanol, there is also a reduction of carbon dioxide (CO<sub>2</sub>) in the atmosphere. Carbon dioxide is non-toxic but contributes to the greenhouse effect. Because of the fact that plants absorb carbon dioxide and give off oxygen, that balances the amount of CO<sub>2</sub> that is formed during combustion absorbed by plants used to produce ethanol. That is why the use of ethanol will partially offset the greenhouse effect that is formed by carbon dioxide emissions of burning gasoline [11-13]. Ethanol, as an octane enhancer, can substitute benzene and other benzene-like compounds, which are powerful liver carcinogens, and reduce their emissions to the atmosphere. Besides the environmental benefits, production and use of ethanol, which is a renewable fuel, increases economic activity, creates job openings, stabilizes prices and can increase farm income. That is why ethanol as an automotive fuel has many advantages.

Methanol (CH<sub>3</sub>OH) is an alcohol that is produced from natural gas, biomass, coal and also municipal solid wastes and sewage. It is quite corrosive and poisonous and has lower volatility compared to gasoline, which means that is not instantly flammable. Usually methanol is used as a gasoline-blending compound, but it can be used directly as an automobile fuel with some modifications of the automobile engine.

Although there are many feedstocks that are being used for the production of methanol, natural gas is more economic. Methanol is produced from natural gas with a technology of steam reforming. By this method natural gas is transformed to a synthesis gas that is fed to a reactor vessel to produce methanol and water at the presence of a catalyst. The reactions (equation 1,2) that represent methanol production are the following [4]:

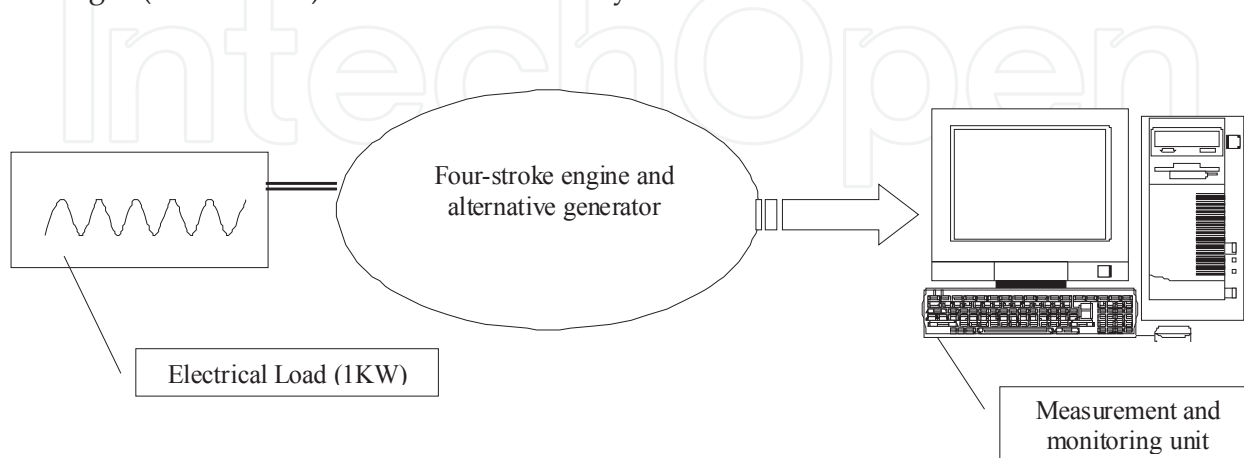


The main advantage of methanol as fuel is that it is produced from resources that can be found globally, while a large percentage of petroleum is located in Middle East. Furthermore, the materials needed for methanol production such as natural gas or biomass are renewable. This means that methanol can also be cheaper and more economically attractive than gasoline. When fossil fuels are used in automobiles produce exhaust emissions of hydrocarbons, carbon dioxide and other gases that contribute to the greenhouse effect. Methanol can give lower HC and CO emissions and besides that the vehicles that use methanol emit minimum particulate matter compared to gasoline, which usually has damaging effect to humans. In addition, methanol has high-octane content that promotes better the process of combustion. Another advantage of methanol is that if it does ignite can cause less severe fires to the vehicle because it is less flammable than gasoline [4]. Some disadvantages that methanol has are the lower energy content compared to gasoline, the fact that it is not volatile enough for easy cold starting and can damage plastic and rubber fuel system components. The vehicle that uses methanol for fuel must have a large storage tank because pure methanol burns faster than gasoline, and corrosion resistant, materials must be used for the storage equipment [14-16]. Renewable fuels such as ethanol and methanol will probably replace petroleum-based fuels in the near future because petroleum reserves are not sufficient enough to last many years. Also, the severe environmental problems around the world will eventually lead to the use of more environmentally friendly technologies. The question that is examined in this chapter is how the mixtures of gasoline-ethanol and gasoline-methanol behave in a four-stroke engine from the aspect of emissions and fuel consumption.

## 2. Experimental part

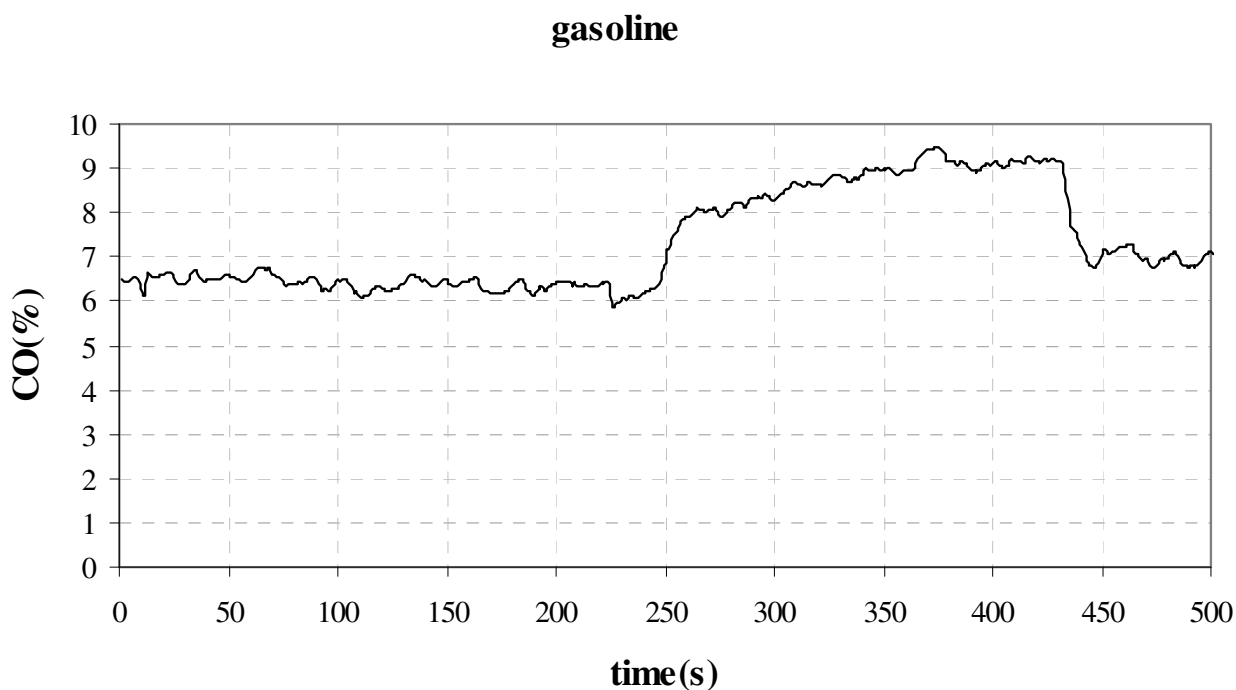
The experimental measurements were carried out on a four-stroke, air-cooled engine. This is a one-cylinder engine with 123cm<sup>3</sup> displacement that is connected with a phase single alternative generator (230V/50Hz) with maximum electrical load approximately 1KW (picture 1). The engine according to the manufacturer uses as fuel gasoline. The engine functioned without load and under full load conditions (1KW) using different fuel mixtures: gasoline, gasoline-10%ethanol, gasoline-20%ethanol, gasoline-30%ethanol, gasoline-40%ethanol, gasoline-50%ethanol, gasoline-60%ethanol, gasoline-70%ethanol, gasoline-80%ethanol, gasoline-90%ethanol and 100% ethanol, gasoline-10% methanol, gasoline-20%methanol, gasoline-30%methanol, gasoline-40%methanol, gasoline-50%methanol, gasoline-60%methanol, gasoline-70%methanol. During the tests, exhaust gases measurements, were also monitored for every fuel mixture and for every load conditions. Also, during the function of the engine the consumption was recorded for every fuel. There was lack of engine regulation concern-

ing the stable air/fuel ratio. For this purpose, data Acquisition card was used with the terminal wiring board with on-board Cold Junction The data acquisition card was installed at a PC. This particular measuring system and software completed a scanning cycle per channel every 0.1 second approximately. This measuring speed was considered adequate for the purpose of the experiment and the sampling capabilities of the chemical sensors. For the exhaust gas (CO and HC) measurements a analyzer was used.

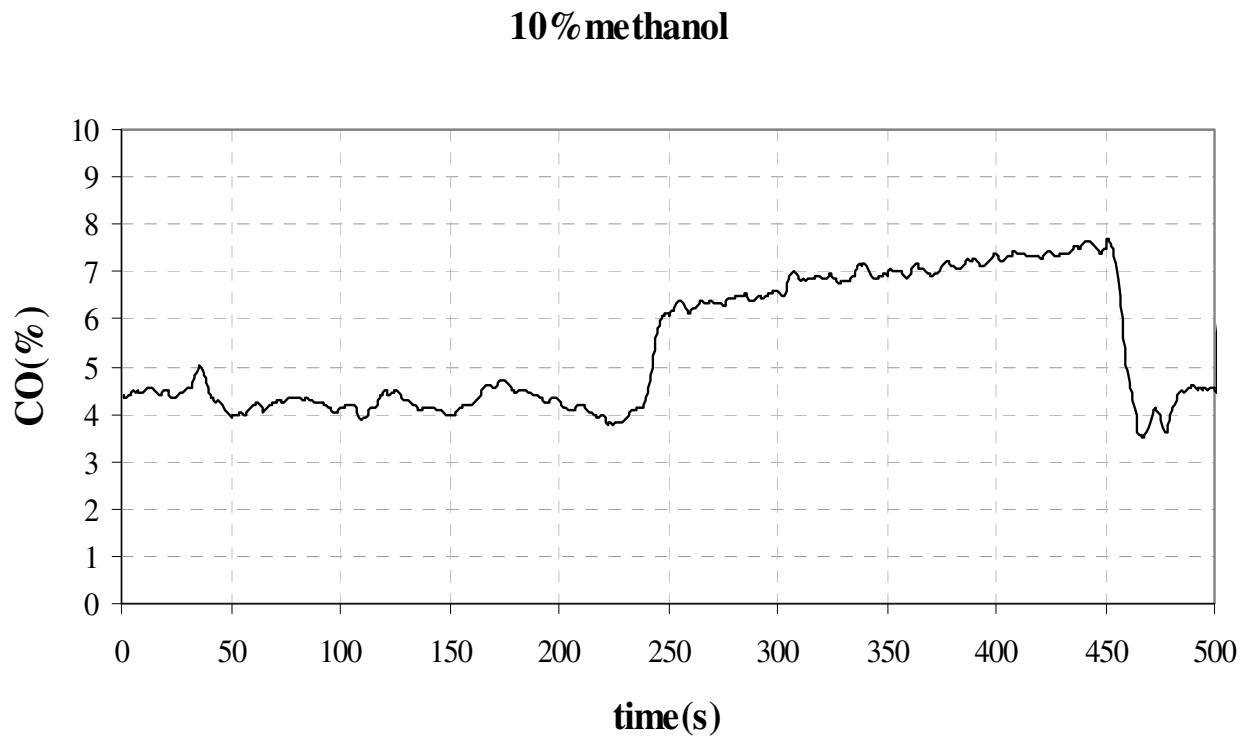


**Figure 1.** The illustration of the experimental unit

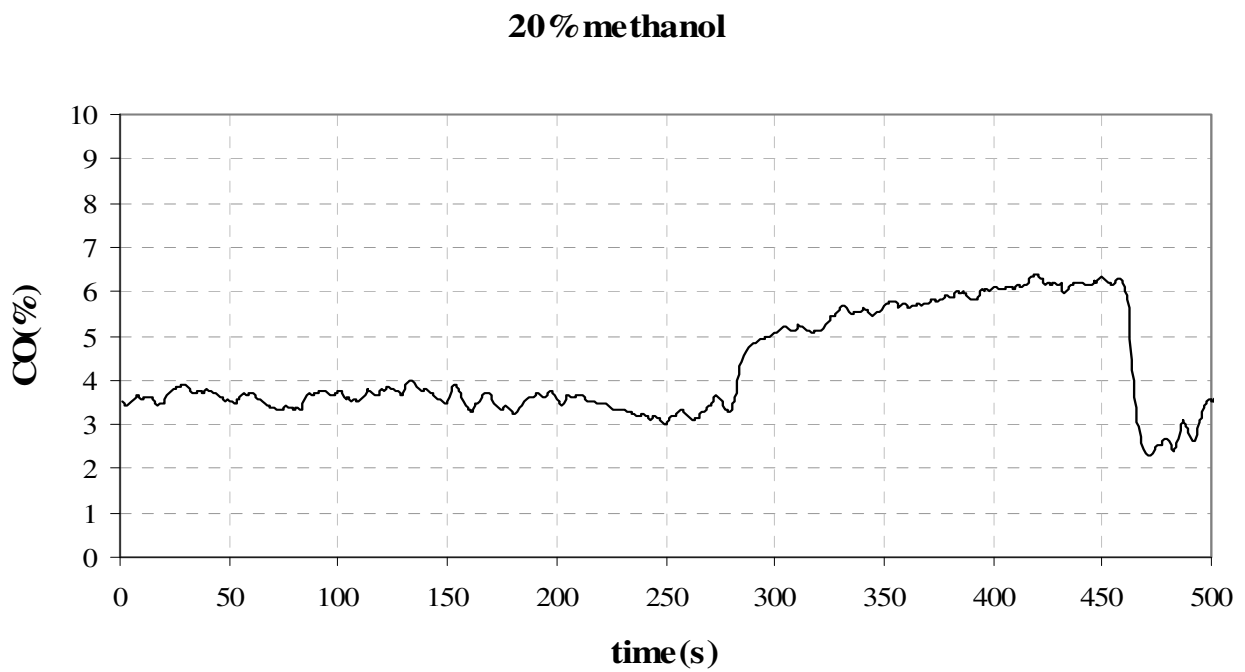
The figures of CO and HC emissions, for every fuel and for every load conditions, are represented below [4-7]:



**Figure 2.** The CO variation when gasoline is used as fuel



**Figure 3.** The CO variation when mixture of gasoline-10%methanol is used as fuel



**Figure 4.** The CO variation when mixture of gasoline-20%methanol is used as fuel

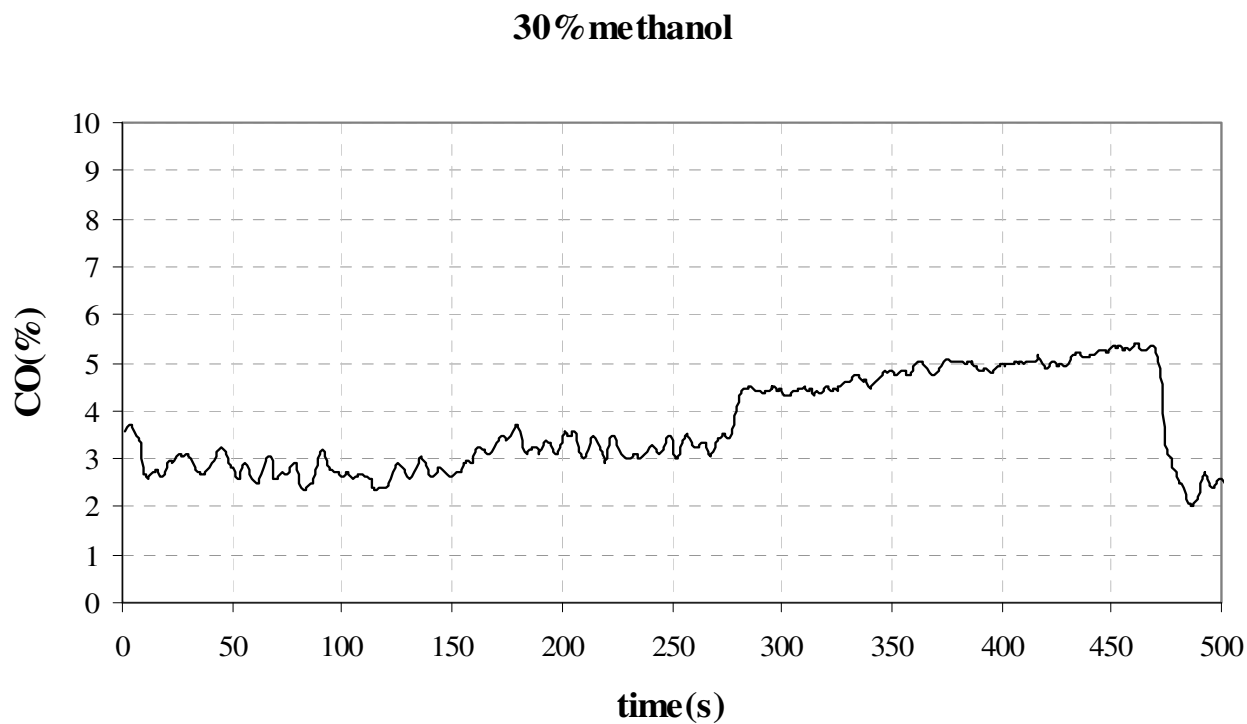


Figure 5. The CO variation when mixture of gasoline-30%methanol is used as fuel

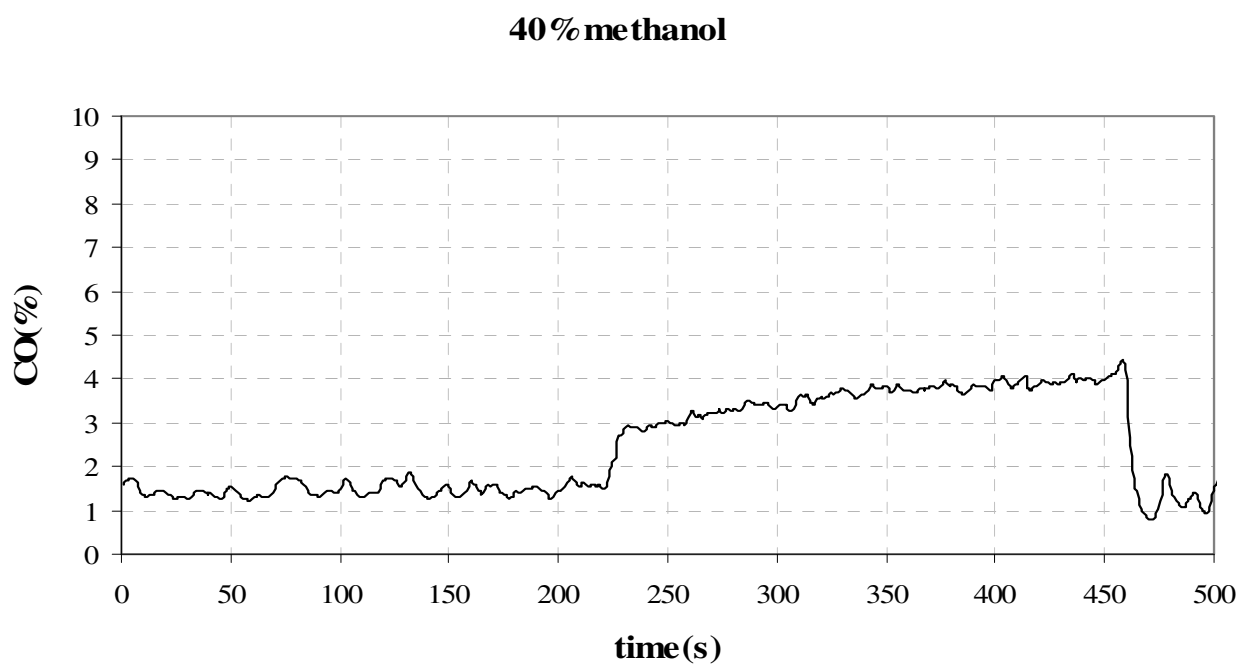
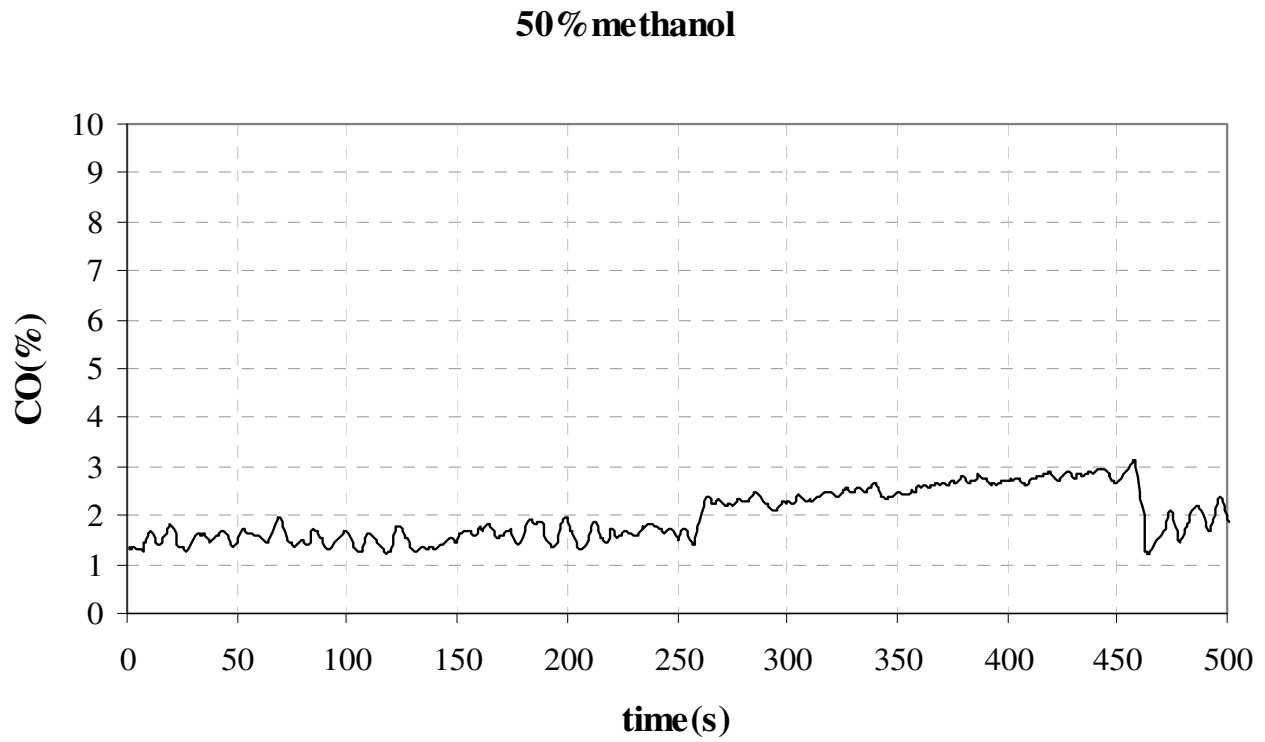
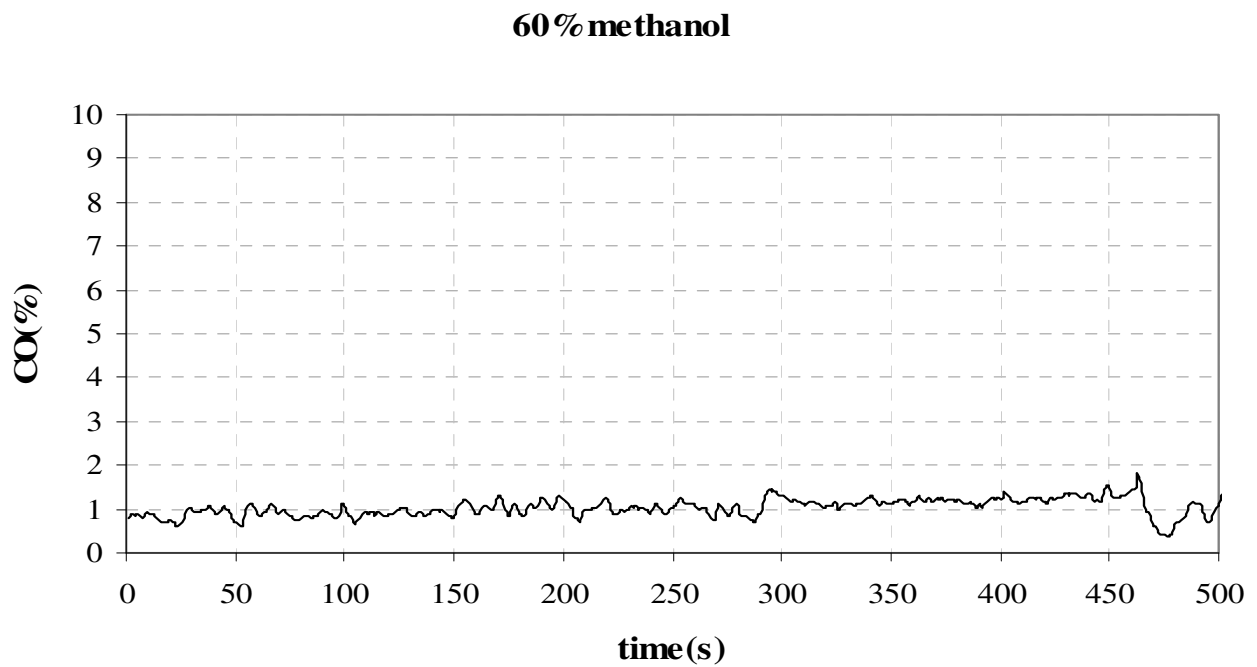


Figure 6. The CO variation when mixture of gasoline-40%methanol is used as fuel



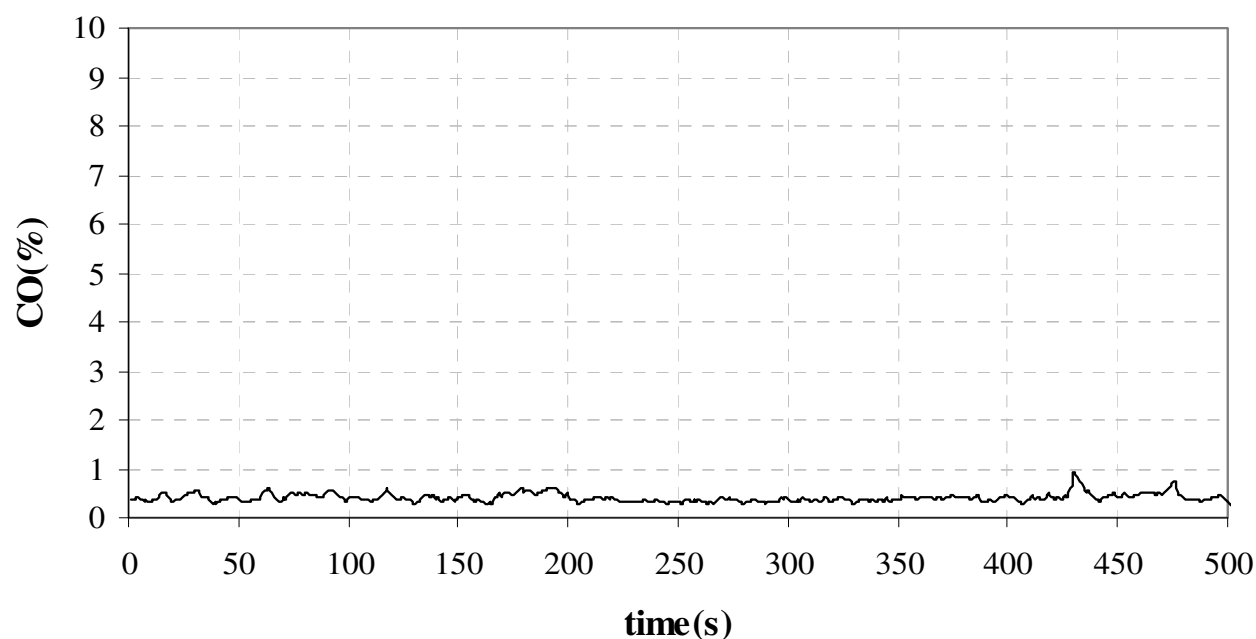
**Figure 7.** The CO variation when mixture of gasoline-50%methanol is used as fuel.



**Figure 8.** The CO variation when mixture of gasoline-60%methanol is used as fuel



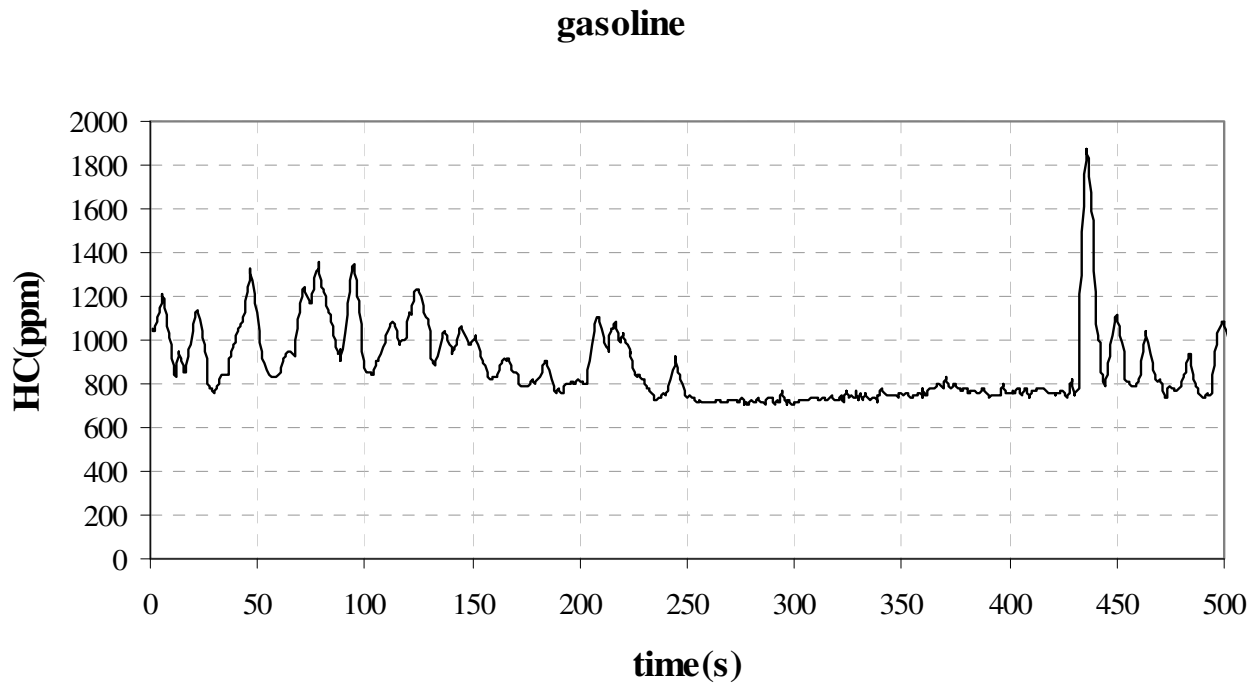
### 70% methanol



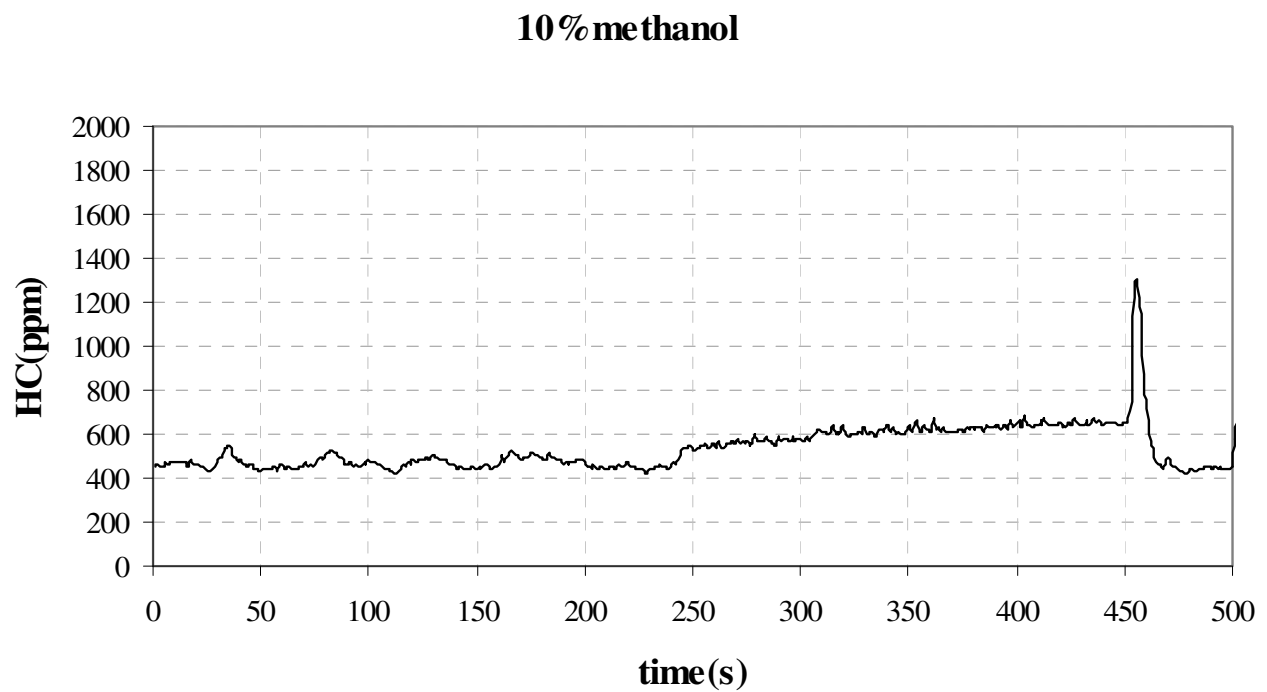
**Figure 9.** The CO variation when mixture of gasoline-70%methanol is used as fuel.

Figure 2 represents CO emissions when the fuel that is used is gasoline. The engine functions without load at first and then (after 250s) functions under full load conditions (1KW). The average value of CO emissions during the function of the engine without load is 6,41%, while at full load conditions the average value of CO emissions is 8,7%. Following, a mixture of gasoline with 10% methanol is used (fig. 3) and the same test is conducted with this mixture. From figure 3 it is being observed that the average value of CO emissions without load conditions of the engine is 4,87%, while at full load conditions the percentage of CO emissions is 6,9%. The same tests are conducted while increasing the percentage of the methanol in the fuel, using the mixtures: gasoline-20%methanol(fig. 4), gasoline-30%methanol(fig. 5), gasoline-40%methanol(fig. 6), gasoline-50%methanol(fig. 7), gasoline-60%methanol(fig. 8), and gasoline-70%methanol(fig. 9).

The HC emissions when the fuel that is used is gasoline are represented at figure 10. As it was mentioned above, the engine functioned without load at first and then (after 250s approximately) functioned under full load conditions (1KW). During the function of the engine without load the average value of HC emissions is 1091ppm, while at full load conditions the average value of HC emissions is 730ppm. The mixture of gasoline with 10% methanol is illustrated at figure 11. At this figure is being observed that the average value of HC emissions without load conditions of the engine is 496ppm, while at full load conditions the HC emissions is 613ppm. When the percentage of the methanol in the fuel increases: gasoline-20%methanol(fig. 11), gasoline-30%methanol(fig. 13), gasoline-40%methanol(fig. 14), gasoline-50%methanol(fig. 15), gasoline-60%methanol(fig. 16), and gasoline-70%methanol(fig. 17).



**Figure 10.** The HC variation when gasoline is used as fuel.



**Figure 11.** The HC variation when mixture of gasoline-10%methanol is used as fuel

### 20% methanol

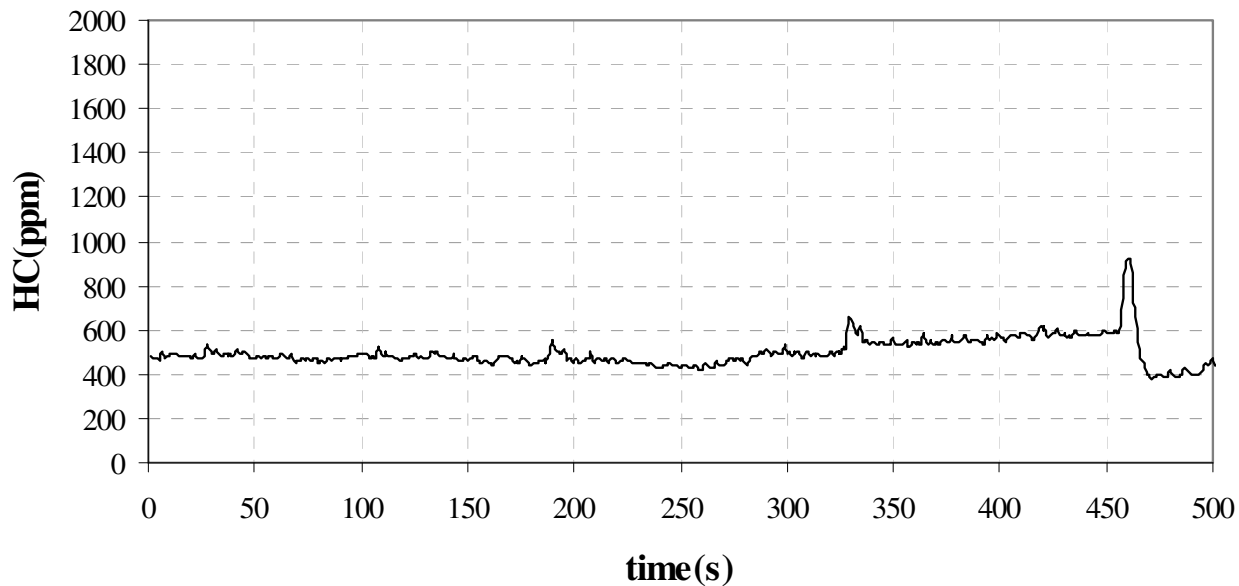


Figure 12. The HC variation when mixture of gasoline-20%methanol is used as fuel.

### 30% methanol

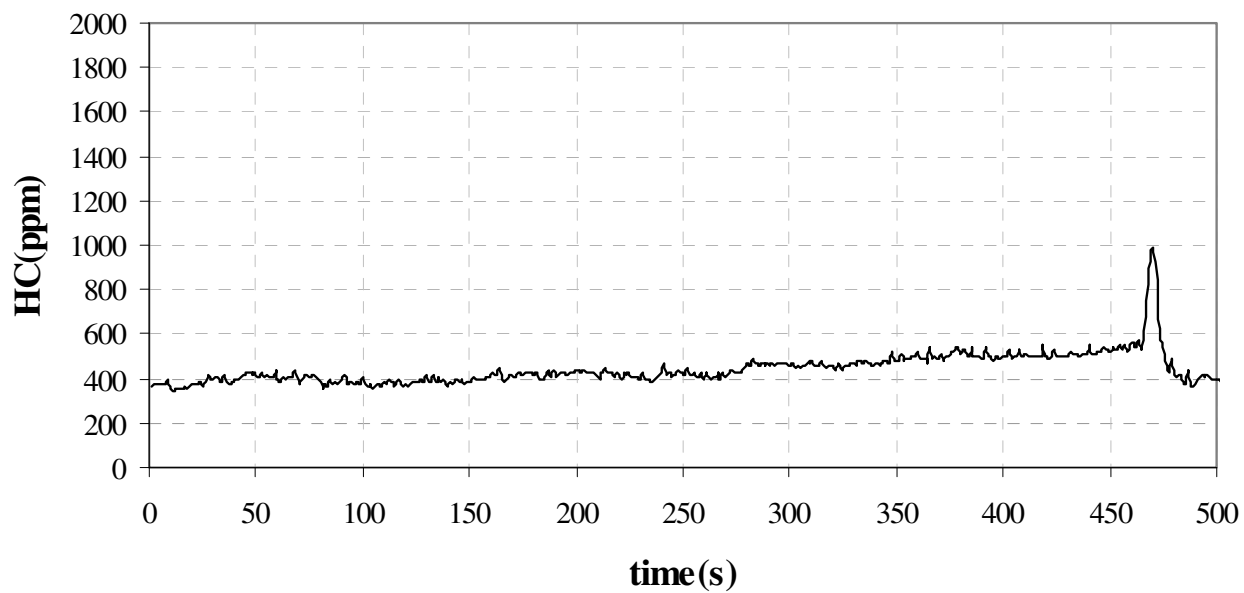


Figure 13. The HC variation when mixture of gasoline-30%methanol is used as fuel

### 40% methanol

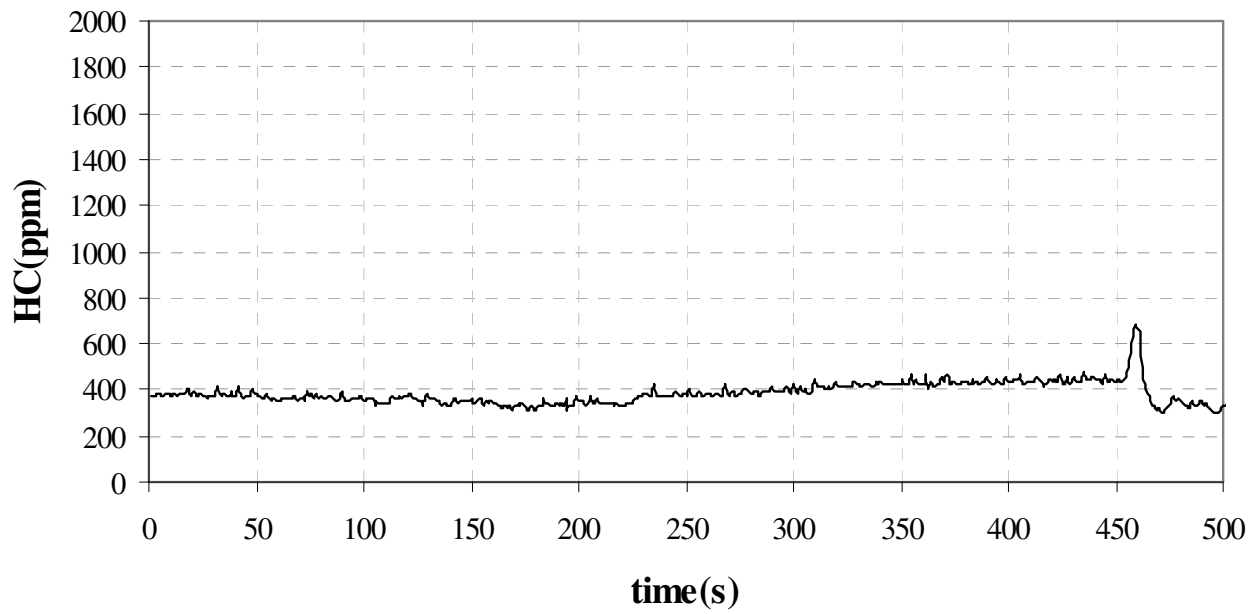


Figure 14. The HC variation when mixture of gasoline-40%methanol is used as fuel.

### 50% methanol

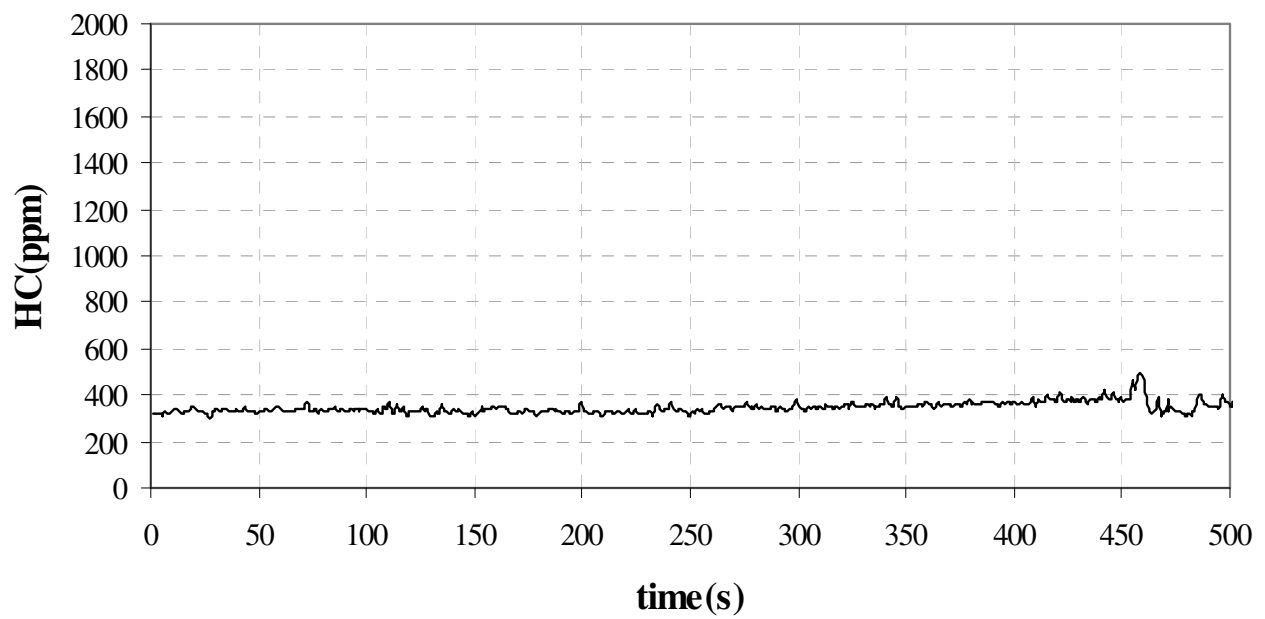


Figure 15. The HC variation when mixture of gasoline-50%methanol is used as fuel.

### 60% methanol

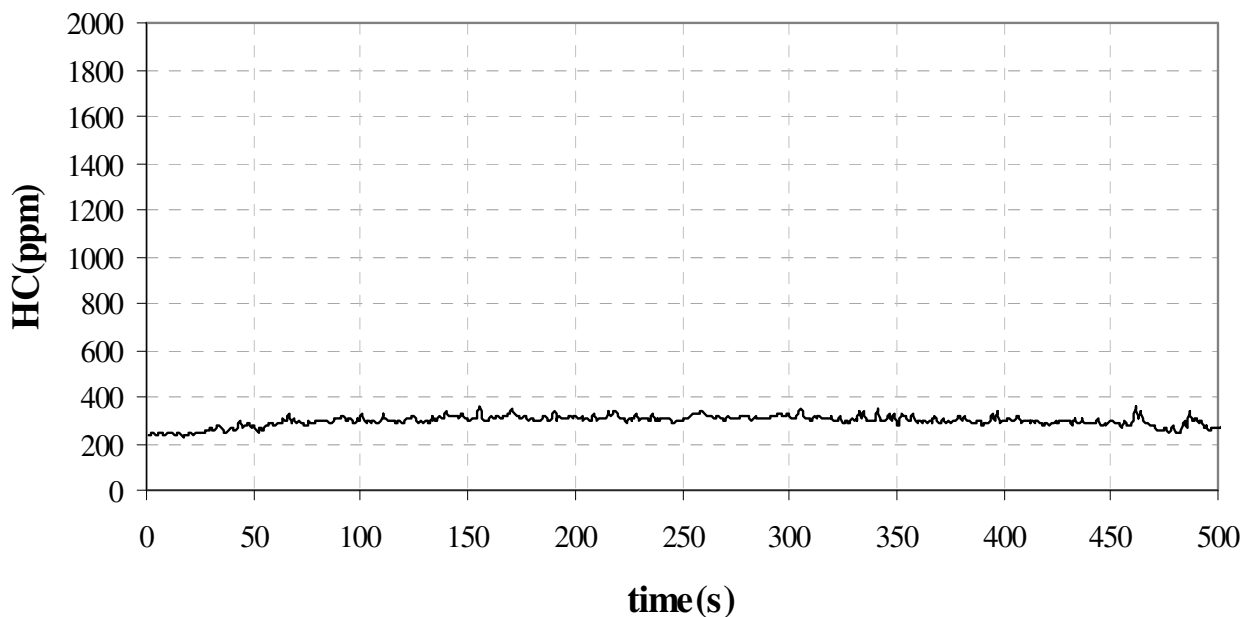


Figure 16. The HC variation when mixture of gasoline-60%methanol is used as fuel.

### 70% methanol

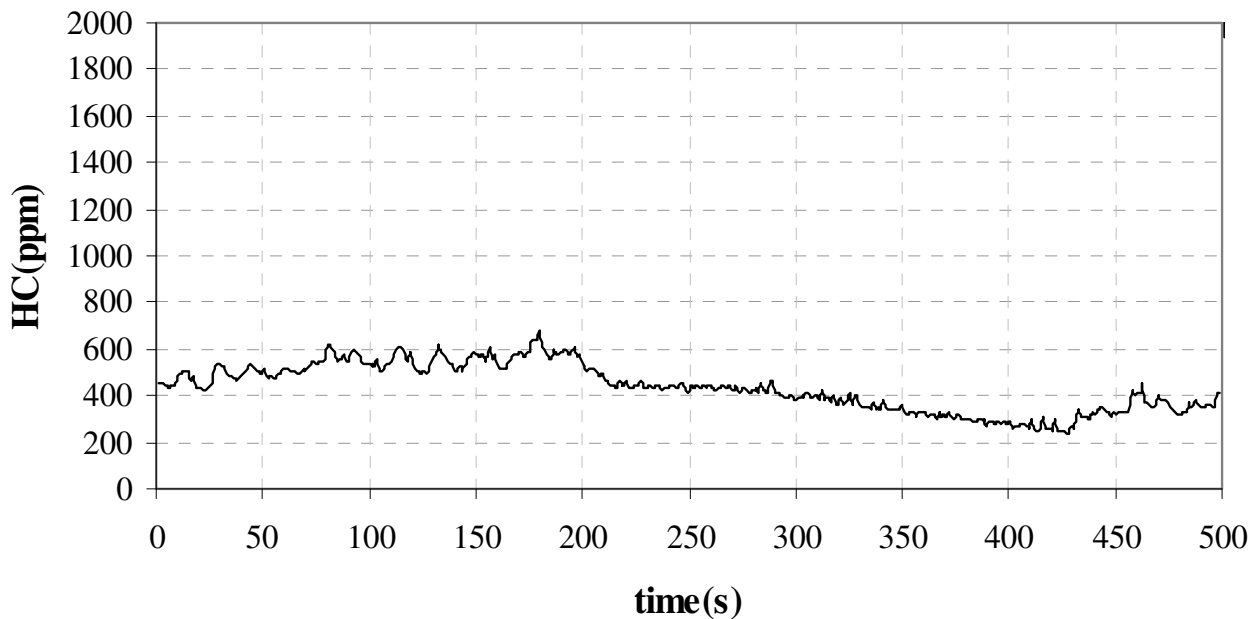


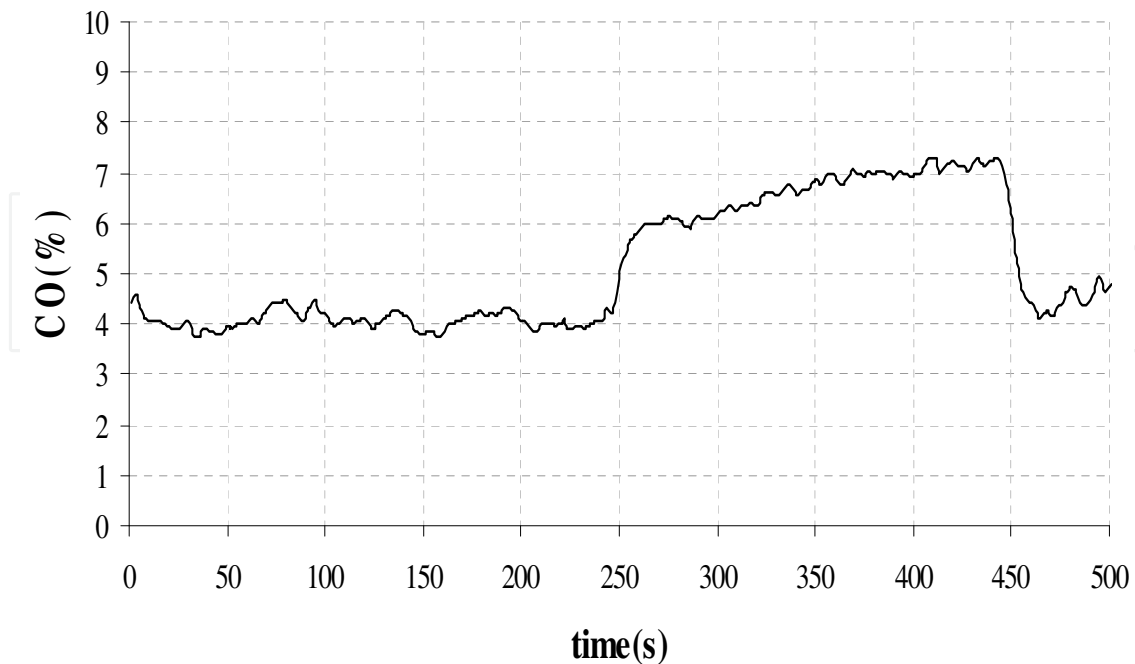
Figure 17. The CO variation when mixture of gasoline-70%methanol is used as fuel.

In the case of HC emissions there is also a decrease of emissions when the percentage of methanol in the fuel increases at idle and under full load conditions. There is an exception at the mixture gasoline-70%methanol where the average value of HC without load is 534ppm and under full load is 367ppm. These values are higher than the values that correspond to the mixture of gasoline-60%methanol (295ppm, 298ppm). This is explained by mentioning the fact that during the use of the mixture gasoline-70%methanol there was a malfunction of the engine that was caused by the bad mixture of the air with the fuel(gasoline-70%methanol), since the engine was not regulated(ratio air/fuel) for every mixture maintaining the adjustments for gasoline. Also it must be reported that the addition of methanol in the fuel led to HC decrease for the same mixture but for different load conditions. When gasoline was used HC emissions were higher at no load conditions than at full load conditions(1KW), while during the use of gasoline-methanol mixtures this was reversed. This is due to the better combustion under full load conditions because methanol has a higher octane number than gasoline [4-7].

It is important to mention that when mixture gasoline-80%methanol was tested the engine could not function properly.

The CO and HC emissions are represented in the figures below, for the mixtures: gasoline, gasoline-ethanol, for every fuel and for every load condition. For these mixtures the average values of the emissions (CO, HC) are presented at the figures below. From the average values, the variation of those emissions can be better understood.

### 10% ethanol



**Figure 18.** The CO variation for the gasoline-10% ethanol mixture is used as fuel

### 20% ethanol

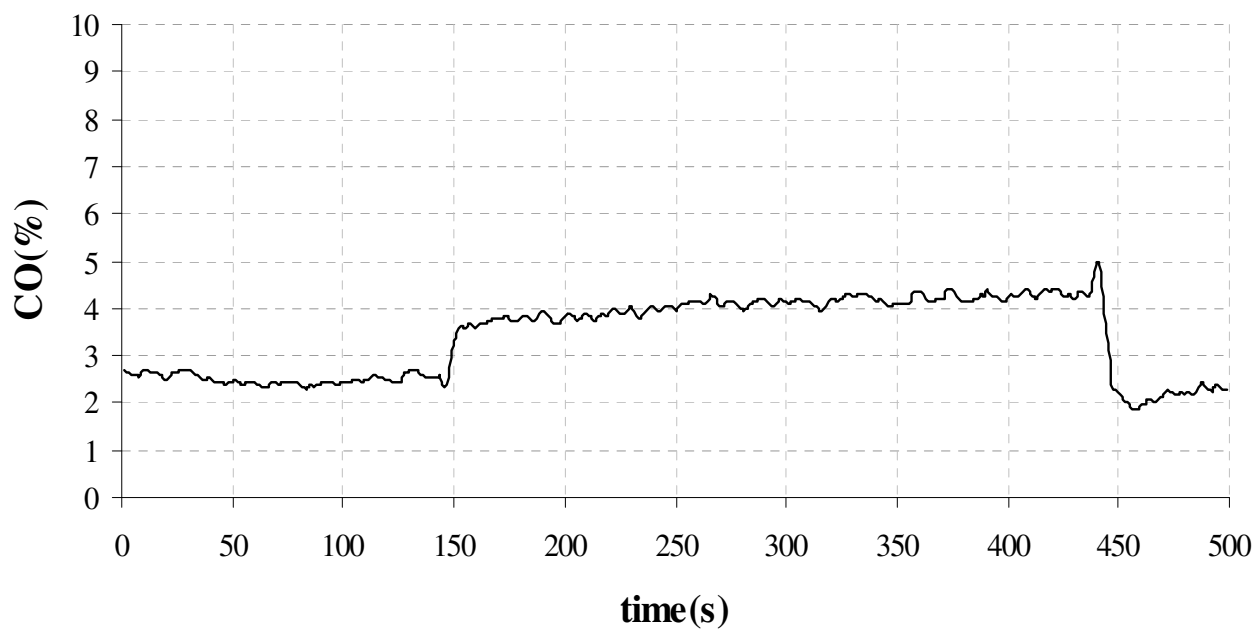


Figure 19. The CO variation for the gasoline-20% ethanol mixture is used as fuel

### 30% ethanol

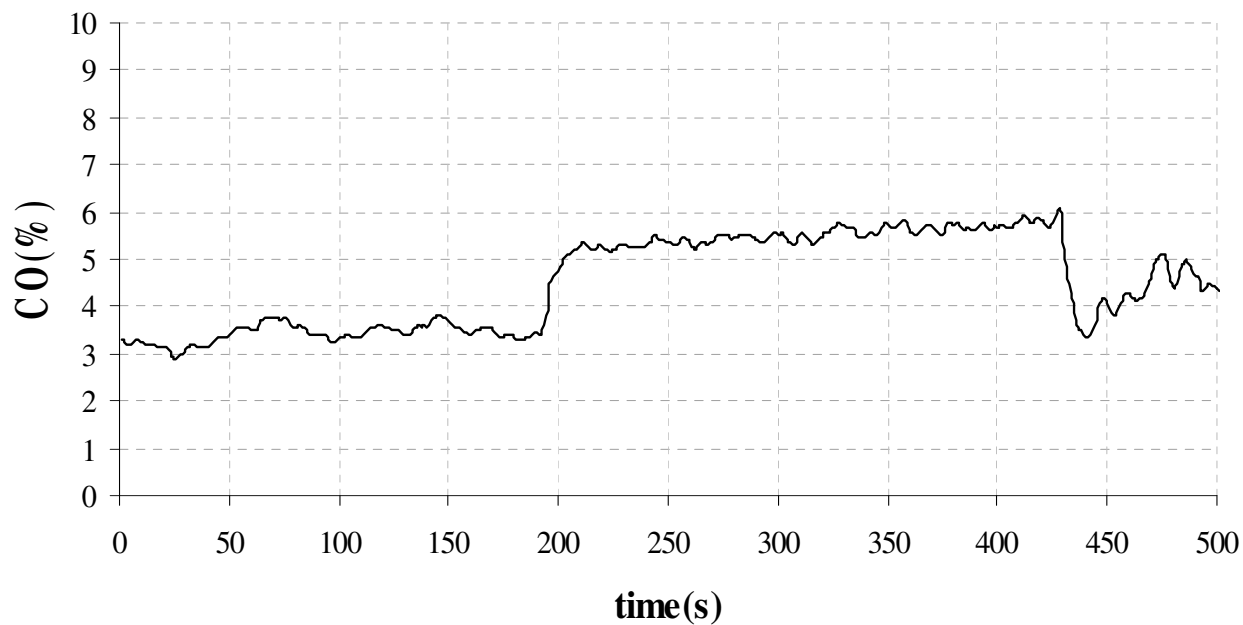


Figure 20. The CO variation for the gasoline-30% ethanol mixture is used as fuel

### 40% ethanol

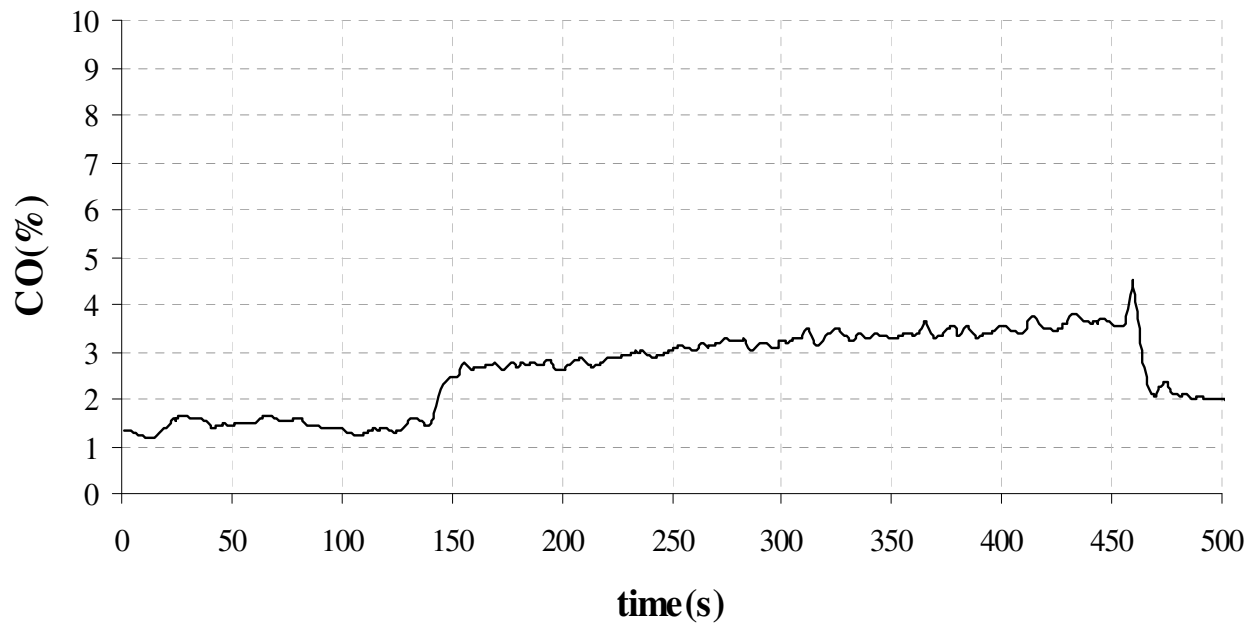


Figure 21. The CO variation for the gasoline-40% ethanol mixture is used as fuel

### 50% ethanol

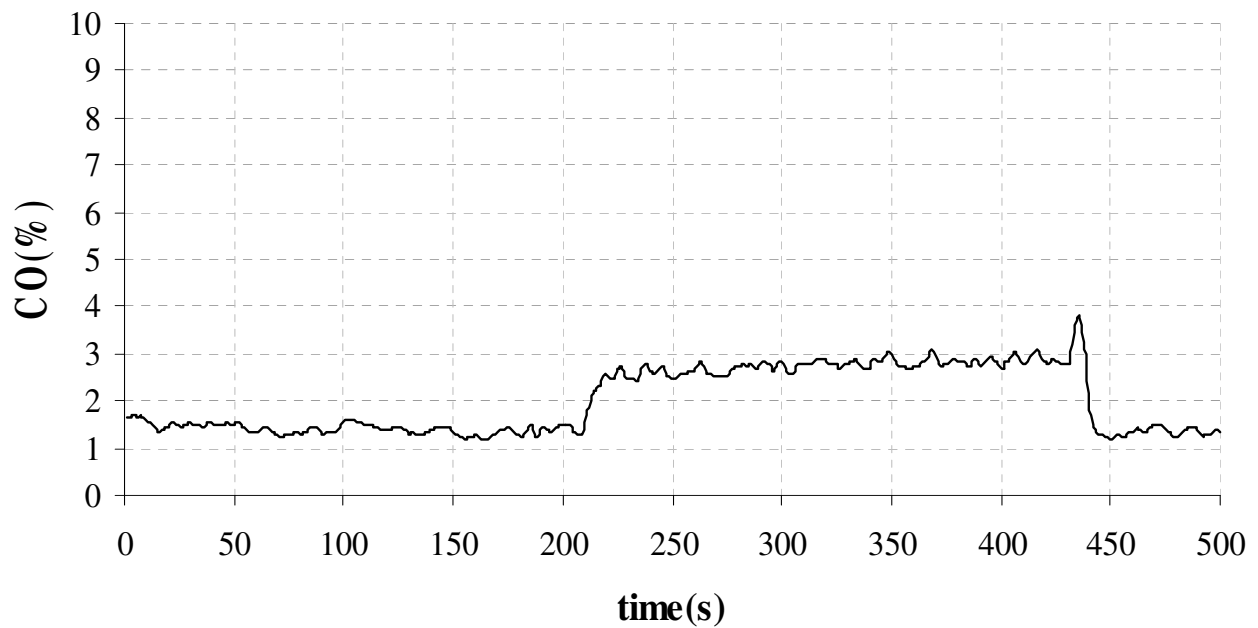


Figure 22. The CO variation when gasoline-50% ethanol mixture used as fuel



### 60% ethanol

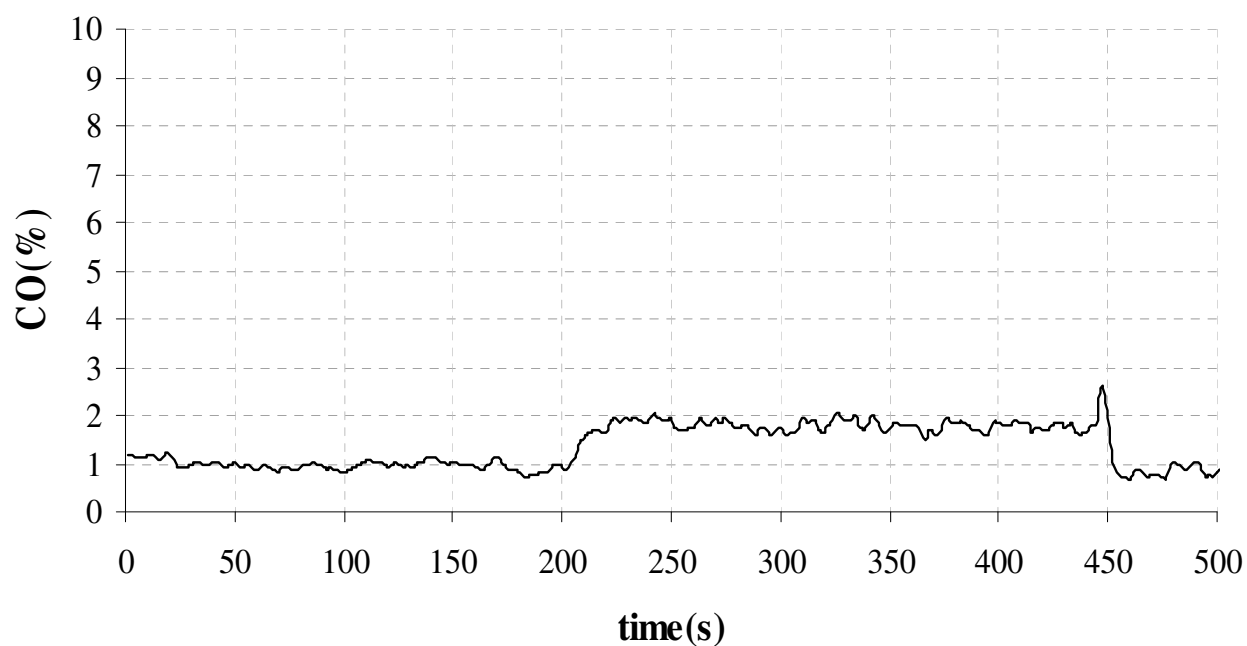


Figure 23. The CO variation when gasoline-60% ethanol mixture used as fuel

### 70% ethanol

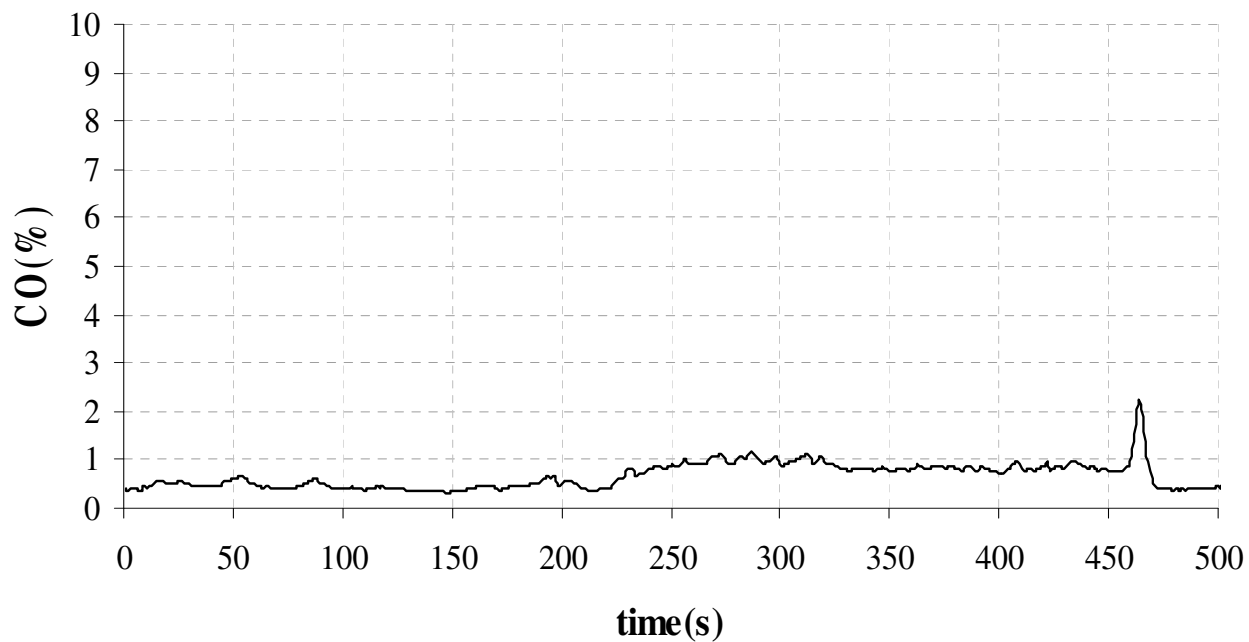


Figure 24. The CO variation when gasoline-70% ethanol mixture used as fuel

### 80% ethanol

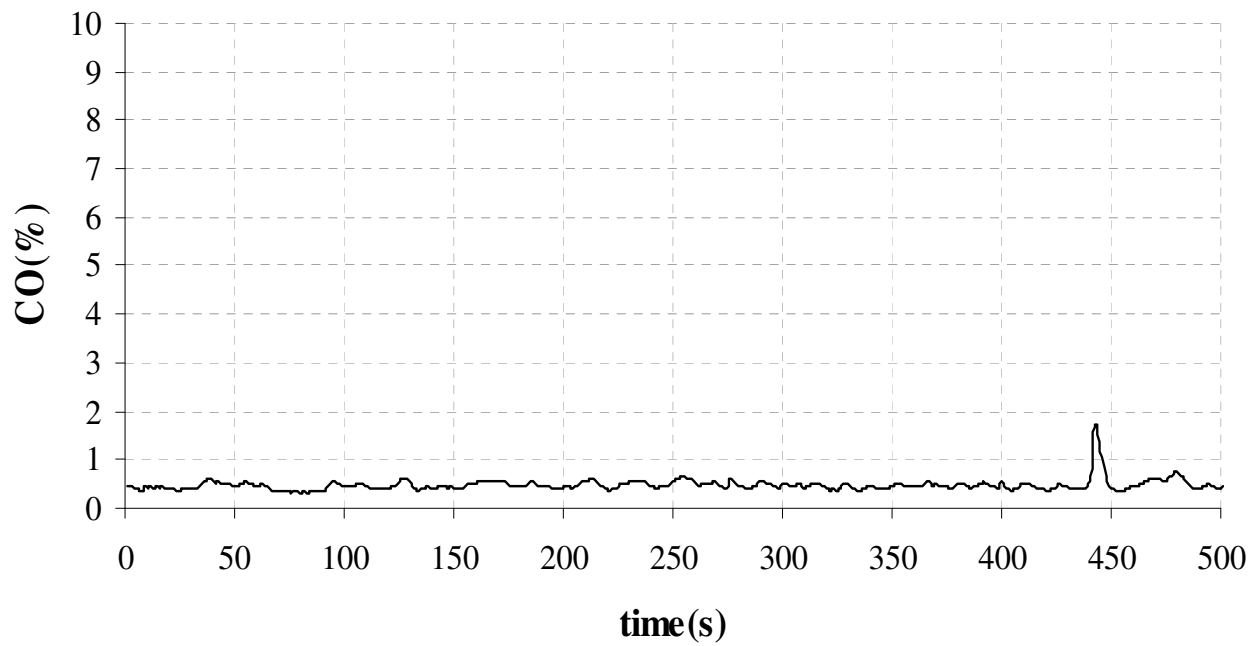


Figure 25. The CO variation when gasoline-80% ethanol mixture used as fuel

### 90% ethanol

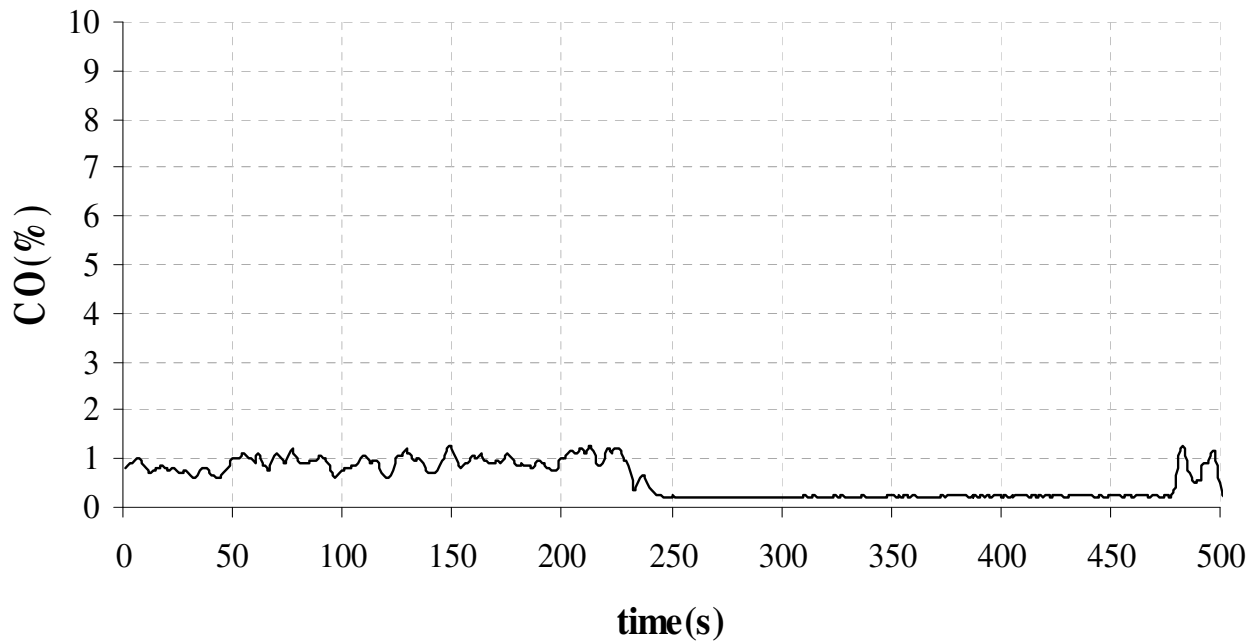


Figure 26. The CO variation when gasoline-90% ethanol mixture used as fuel

### 100% ethanol

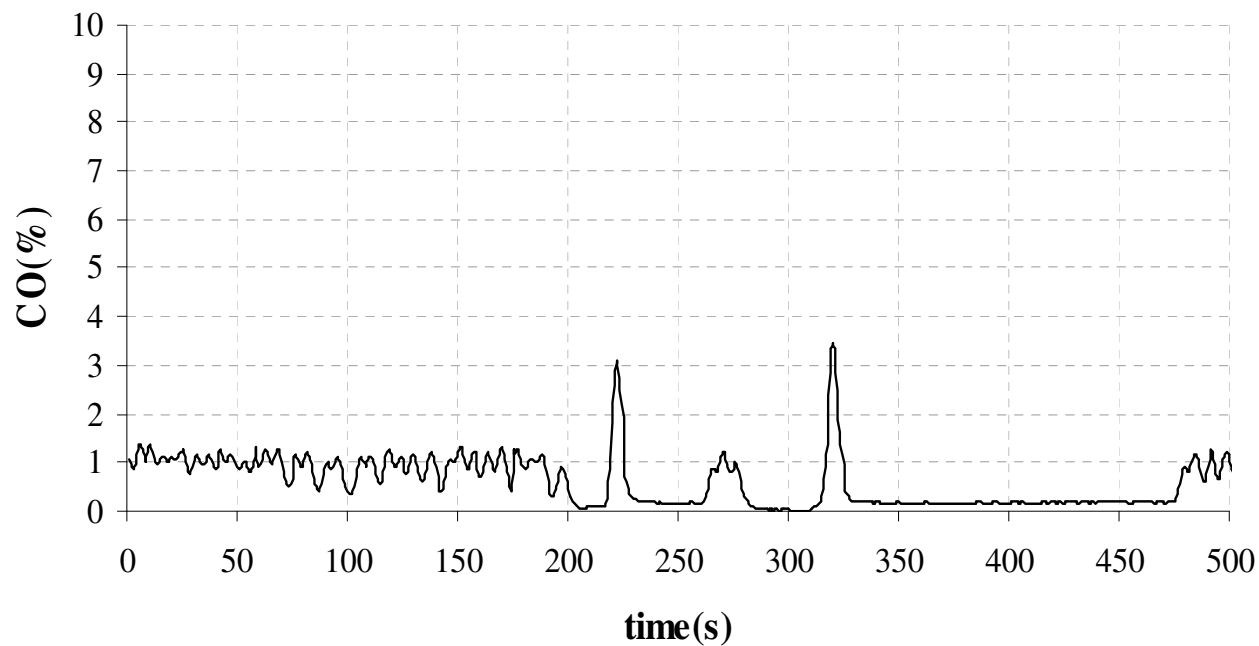


Figure 27. The CO variation when 100% ethanol used as fuel

### 10% ethanol

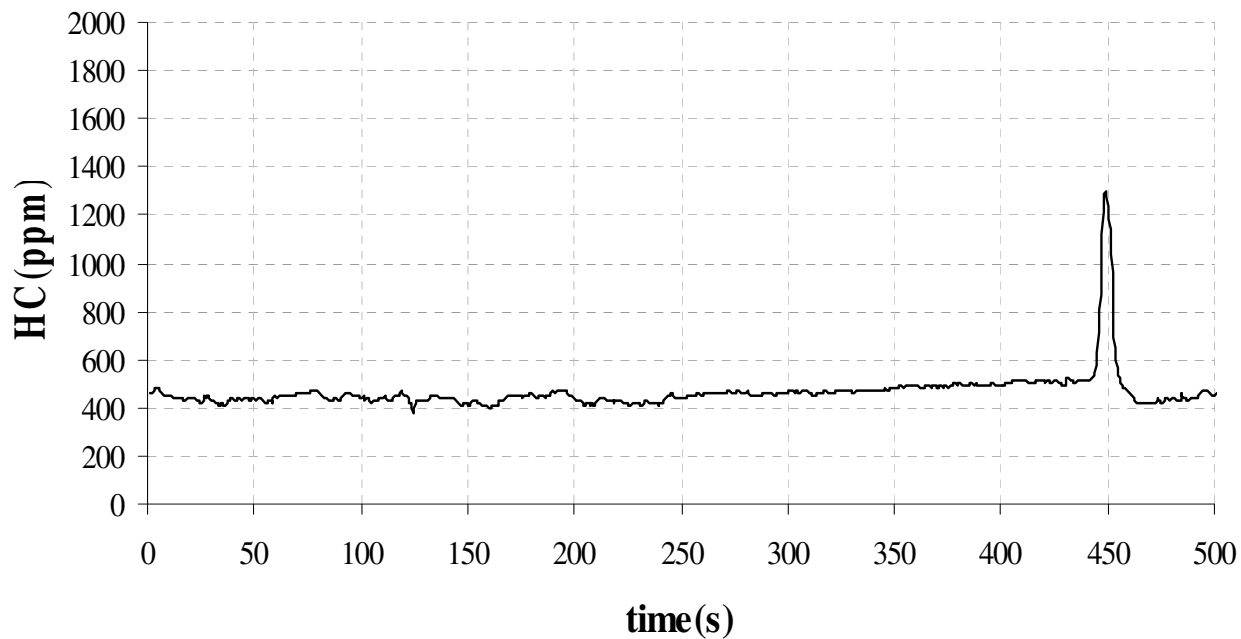


Figure 28. The HC variation when gasoline-10% ethanol mixture used as fuel

### 20% ethanol

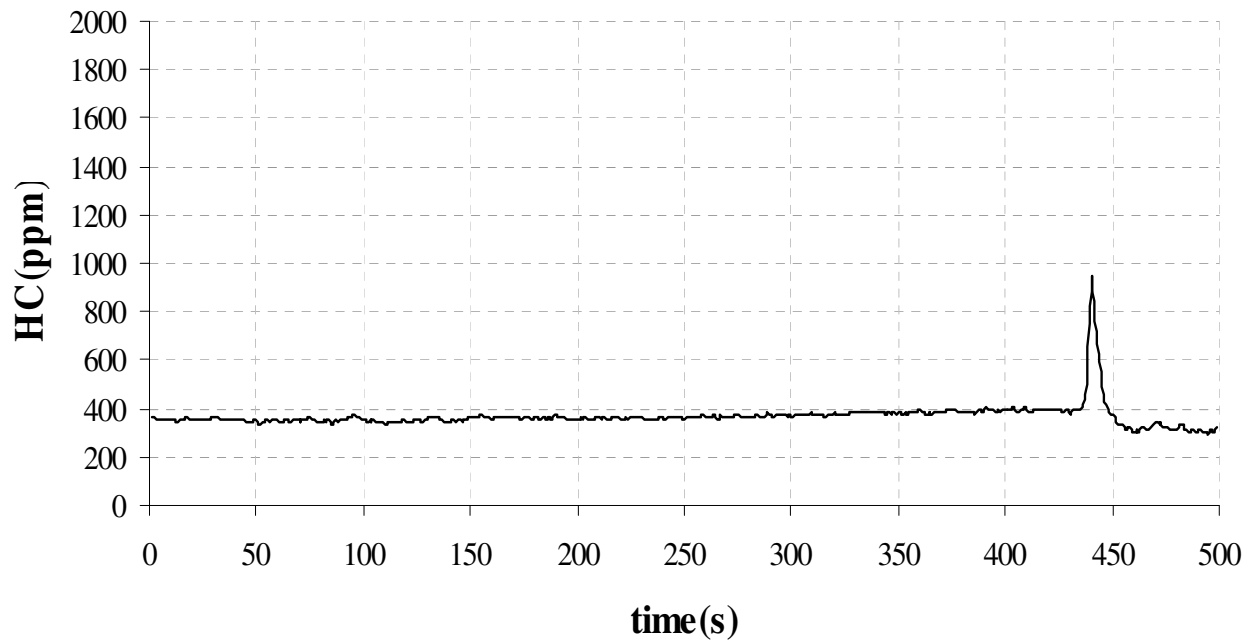


Figure 29. The HC variation when gasoline-20% ethanol mixture used as fuel

### 30% ethanol

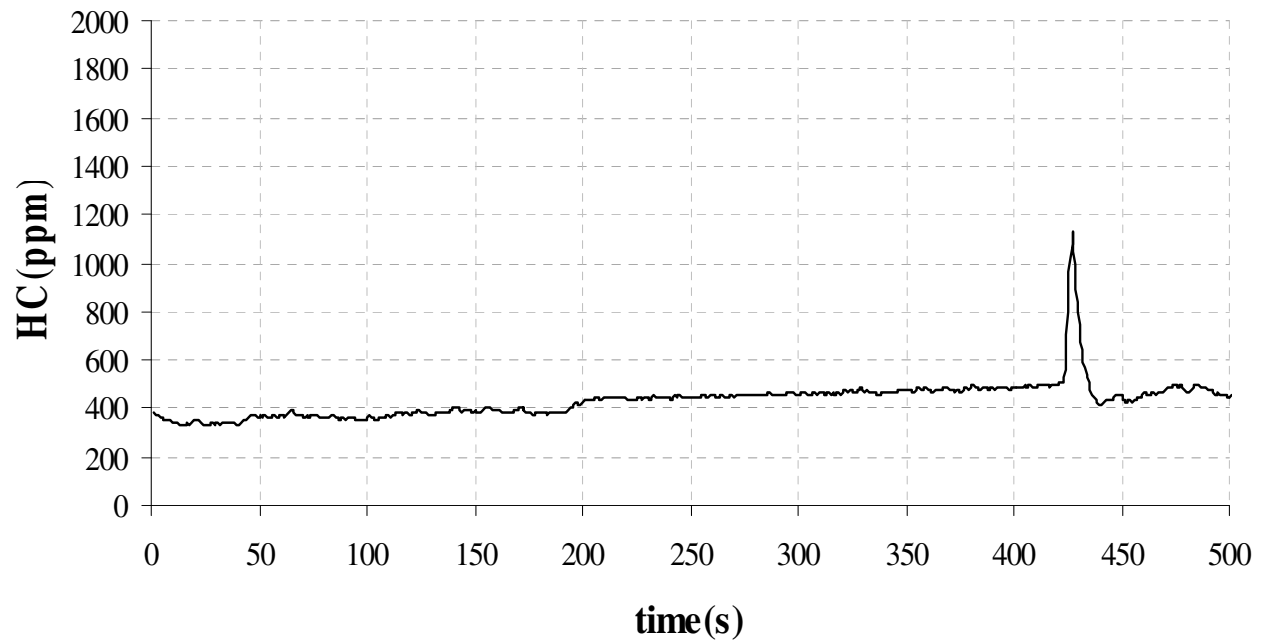


Figure 30. The HC variation when gasoline-30% ethanol mixture used as fuel

### 40% ethanol

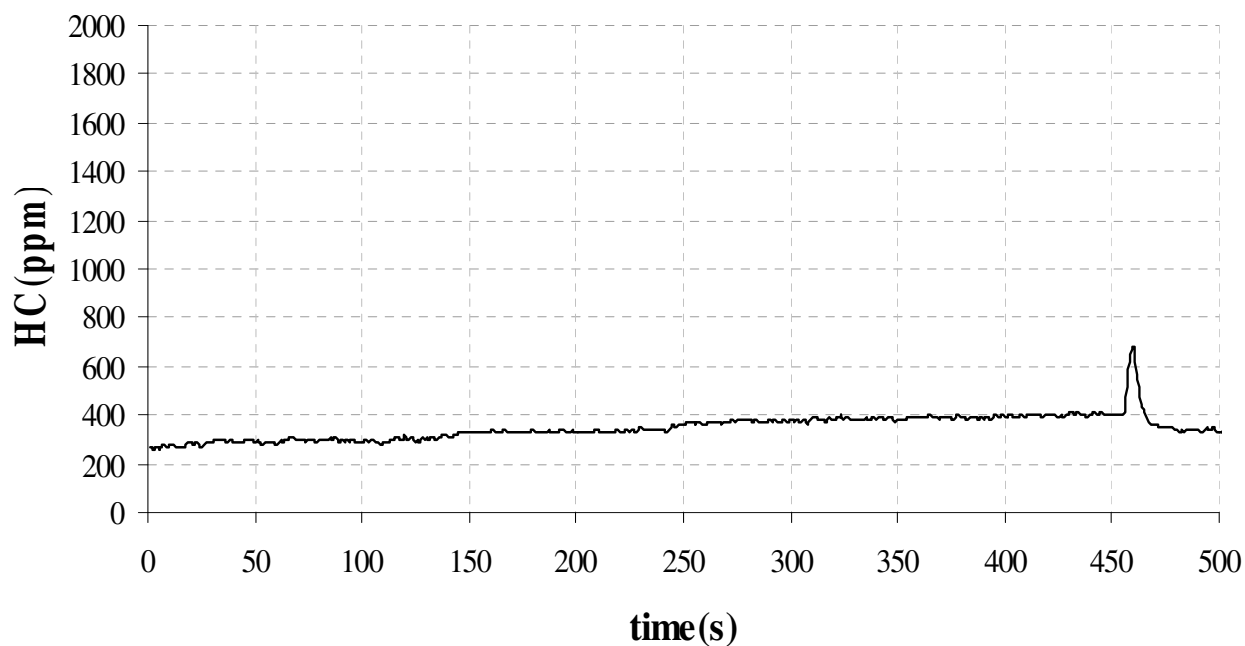


Figure 31. The HC variation when gasoline-40% ethanol mixture used as fuel

### 50% ethanol

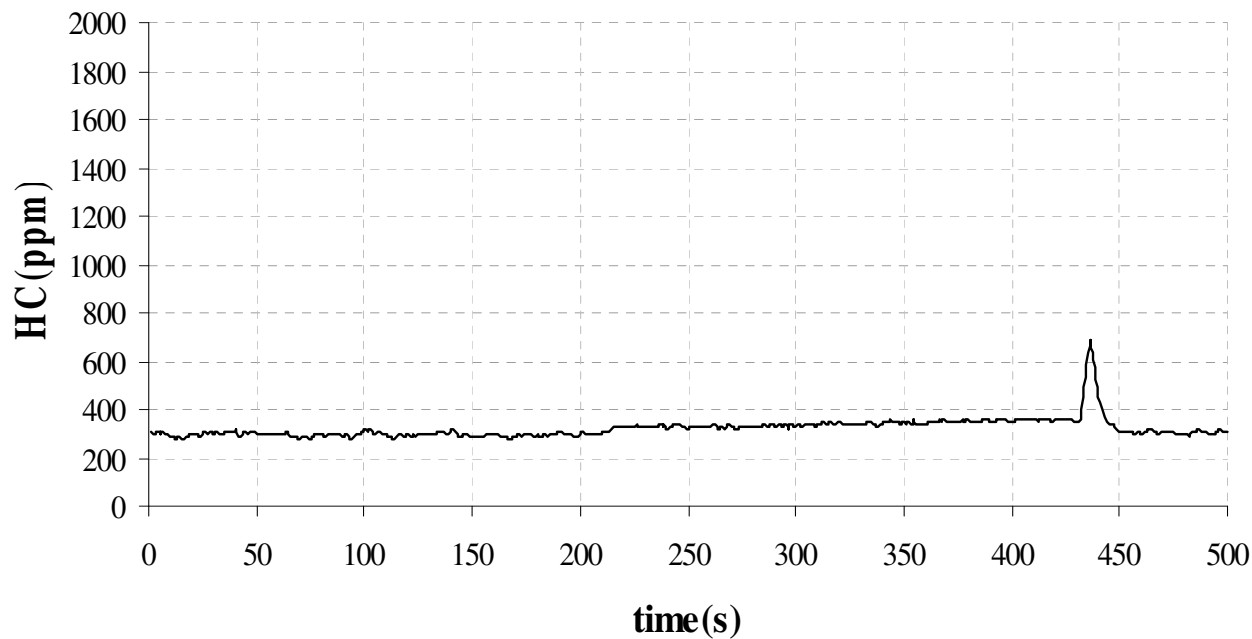


Figure 32. The HC variation when gasoline-50% ethanol mixture used as fuel

### 60% ethanol

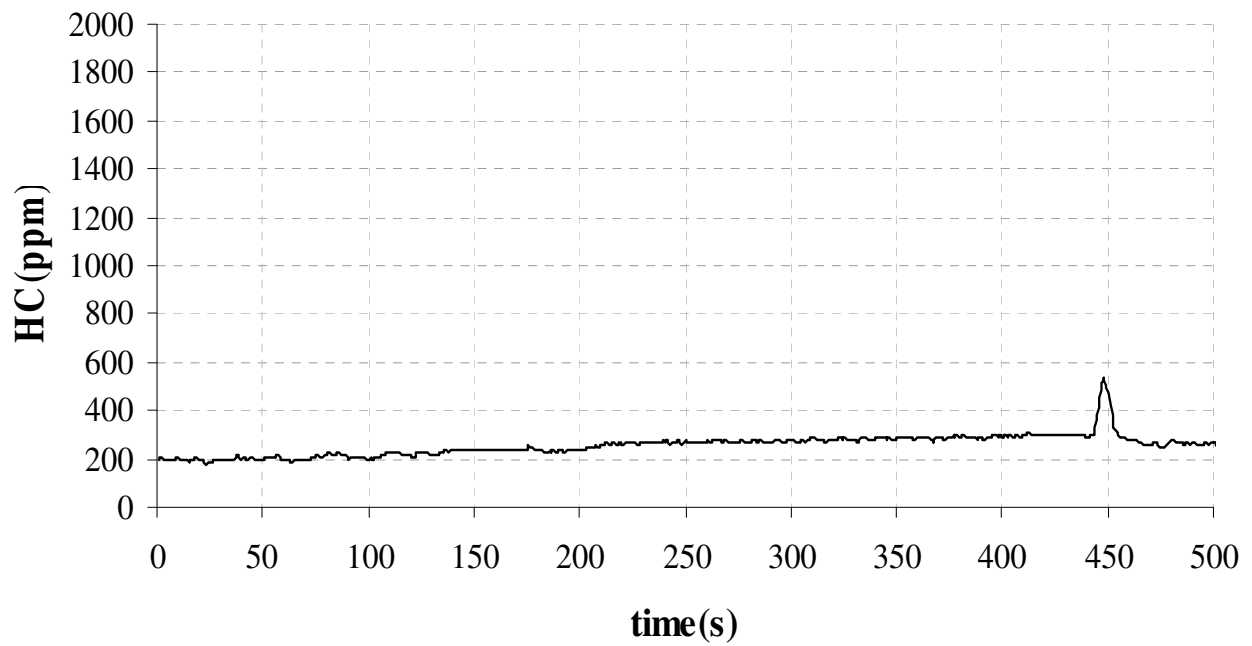


Figure 33. The HC variation when gasoline-60% ethanol mixture used as fuel

### 70% ethanol

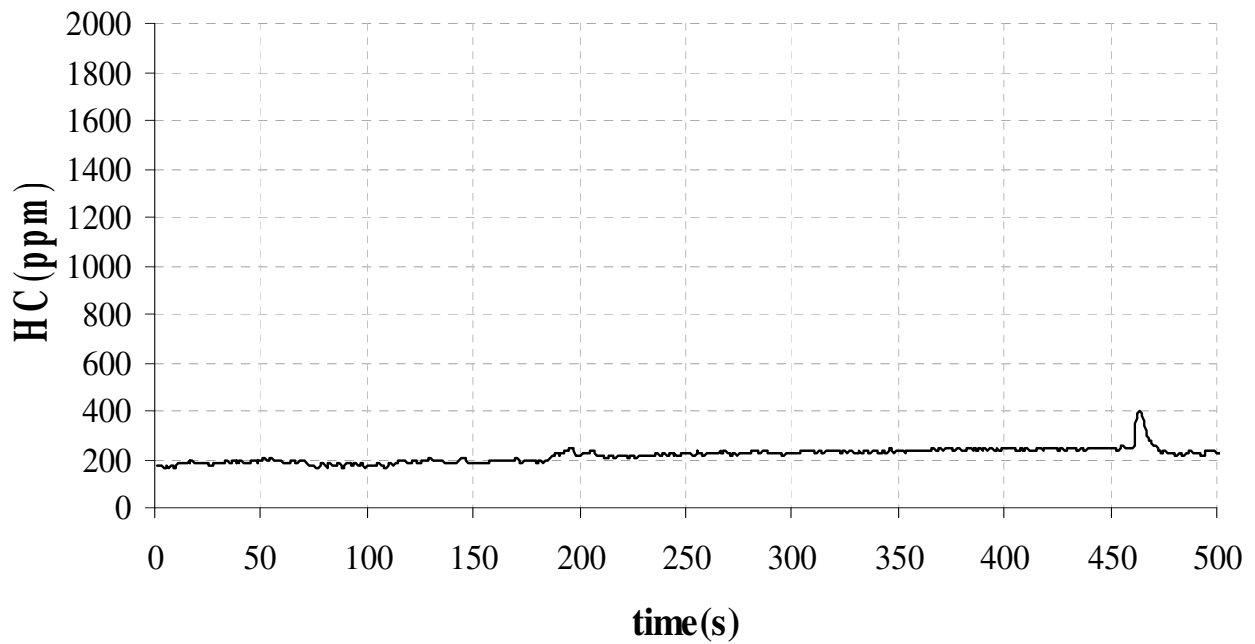


Figure 34. The HC variation when gasoline-70% ethanol mixture used as fuel

### 80% ethanol

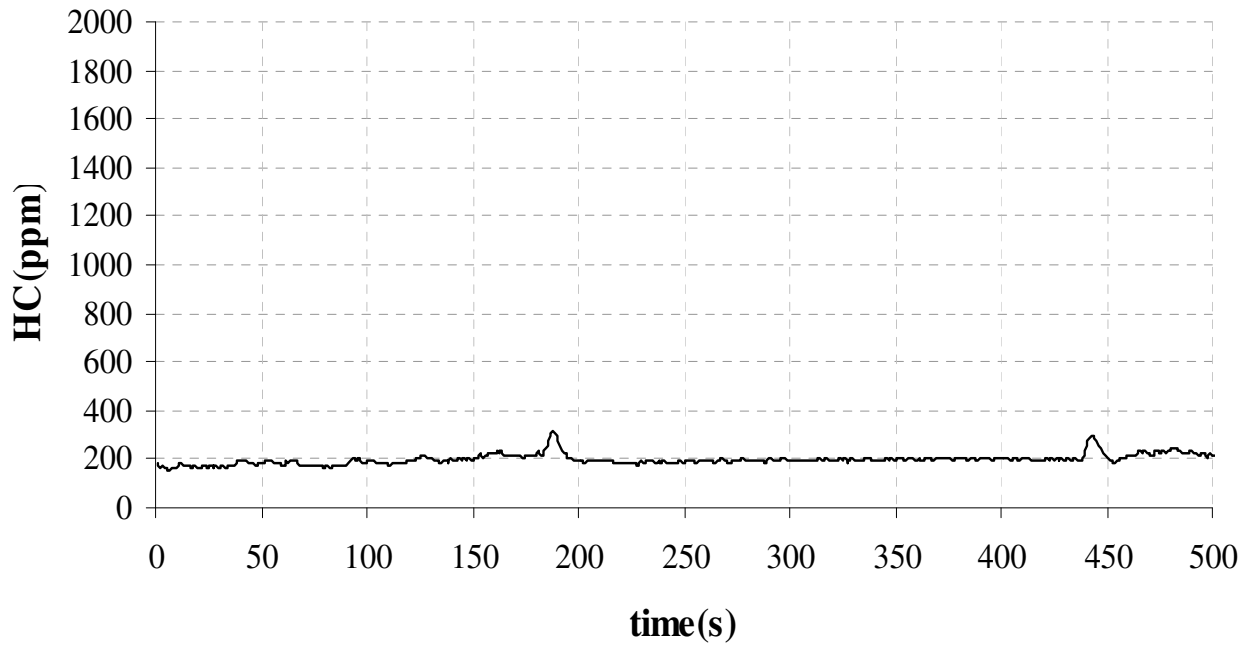


Figure 35. The HC variation when gasoline-80% ethanol mixture used as fuel

### 90% ethanol

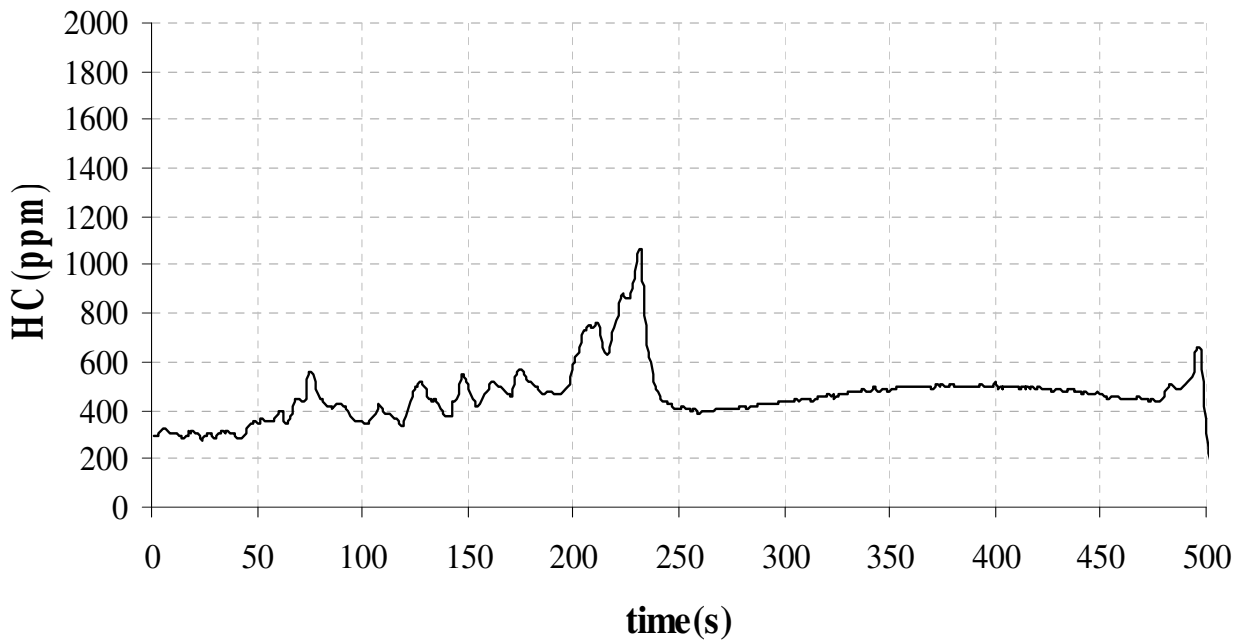
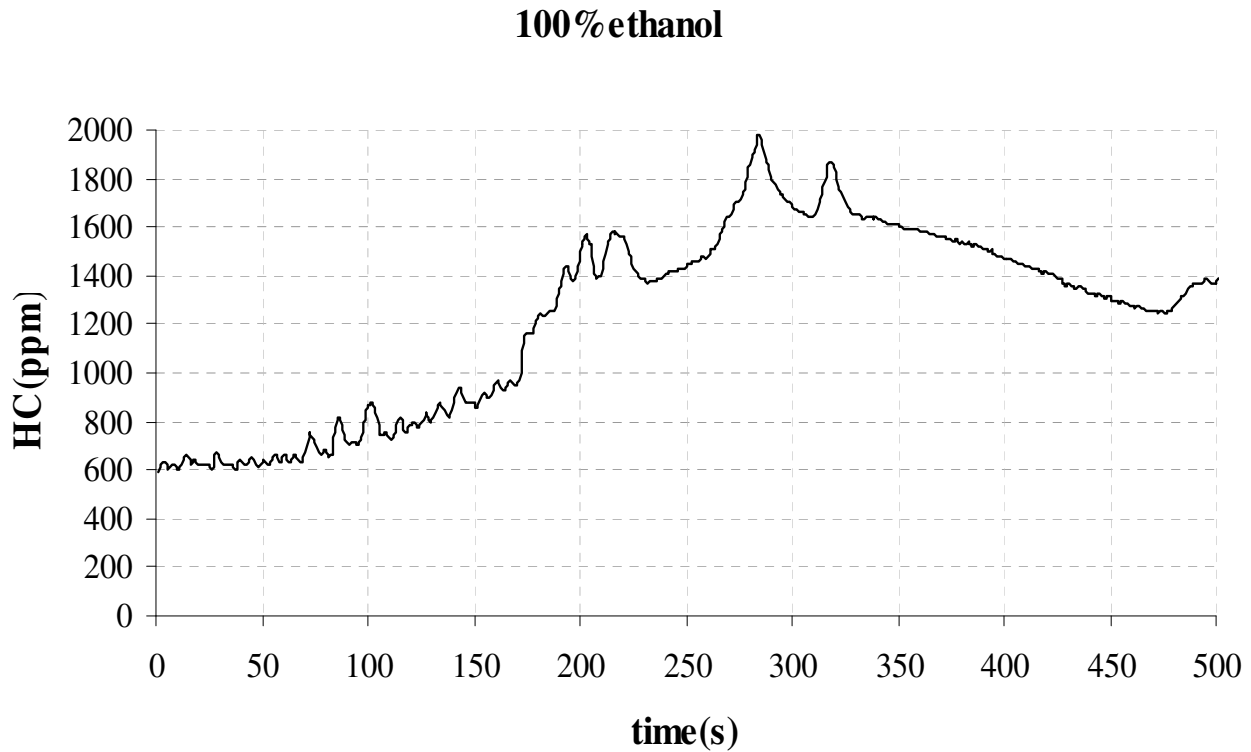


Figure 36. The HC variation when gasoline-90% ethanol mixture used as fuel



**Figure 37.** The HC variation when 100% ethanol used as fuel

Figures 18 - 28 present the CO variation when as fuel is used gasoline –ethanol and gasoline –methanol mixtures when the engine functioned without load and under full load conditions(1KW). From these figures is observed lower CO emissions when gasoline-ethanol mixtures are used compared to the mixtures gasoline-methanol, until the mixture of 70% ethanol and methanol. Over the 70% percentage of methanol the engine could not function and that is why there is no further presentation of comparative curves of CO emissions. It must also be mentioned that for the mixtures of gasoline –70% methanol, gasoline –90%ethanol and 100%ethanol the engine malfunctioned. The average values of CO emissions for the above mixtures and for both load conditions are presented in the figure 38 below [4-7]:

In the figures 28 - 37 is observed higher decrease of HC in the case were methanol is used, with exception of the use of gasoline –70%methanol mixture where the HC are higher compared to the mixture gasoline-70%ethanol. This is due to the malfunction that occurred during the use of gasoline-70%methanol mixture. There was also malfunction of the engine when the mixtures of gasoline-90%ethanol and 100%ethanol were used, which had as result the HC increase during the use of those mixtures. These observations are presented more clearly in the figure 38 below [4-7]:



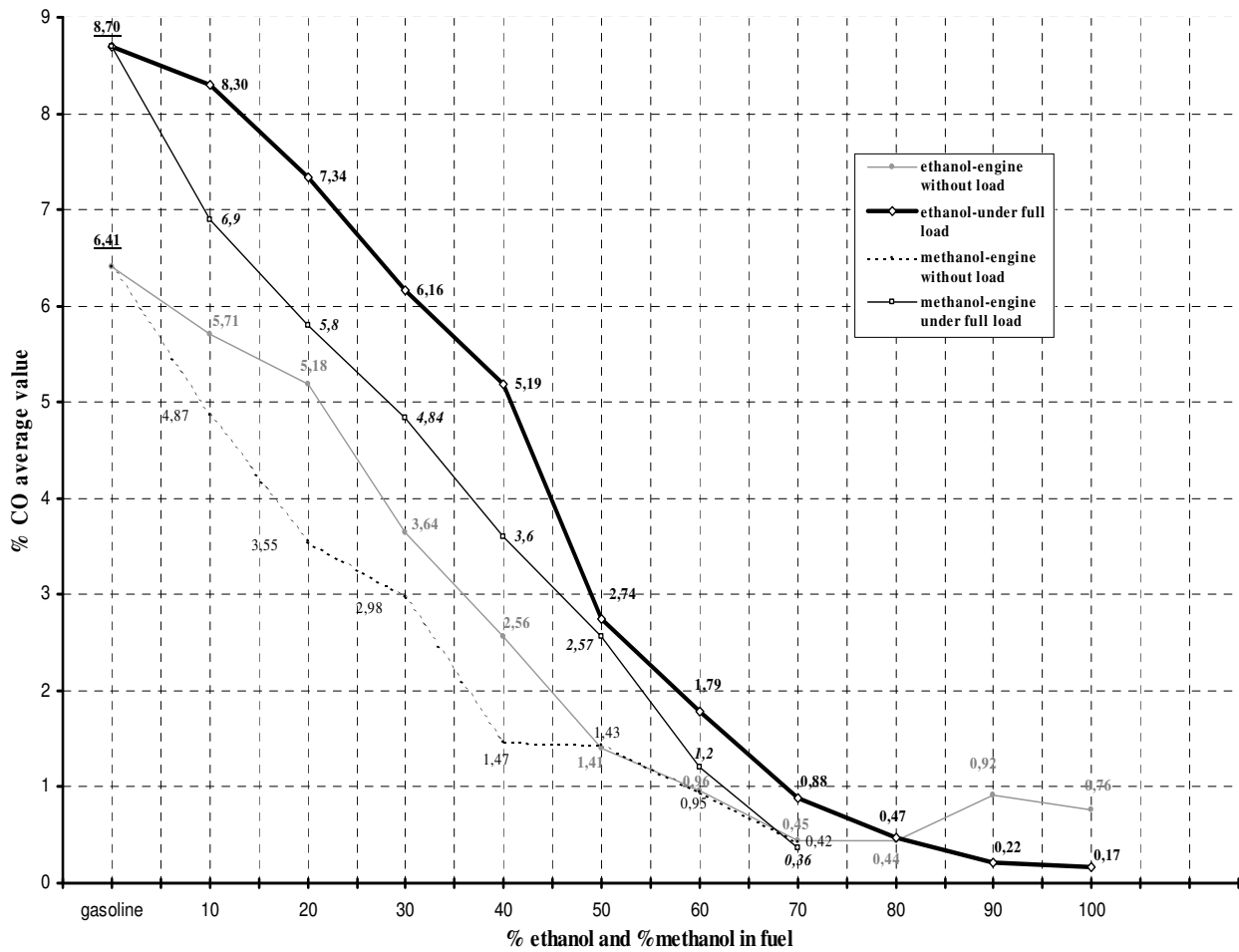


Figure 38. The CO emission average value for every gasoline-ethanol and gasoline-methanol mixture

Figure 39 shows the average values of HC for every mixture, when the engine functions without load and under full load conditions. It is being observed greater decrease of HC during the use of methanol in the fuel contrary to the use of ethanol.

Also is shown HC emissions decrease compared to gasoline, while the percentage of methanol and ethanol in the fuel increases without load and under full electrical load conditions (1KW). At higher percentage of ethanol in the fuel 90%ethanol and 100%ethanol it is observed HC emissions increase, which is due to incomplete combustion. Indeed, during the tests of the mixtures: gasoline-70%methanol, gasoline –90%ethanol and 100%ethanol, there was an engine malfunction mostly at without electrical load, as it was mentioned above. This malfunction is showed from the rounds per minute recording in the figures below:

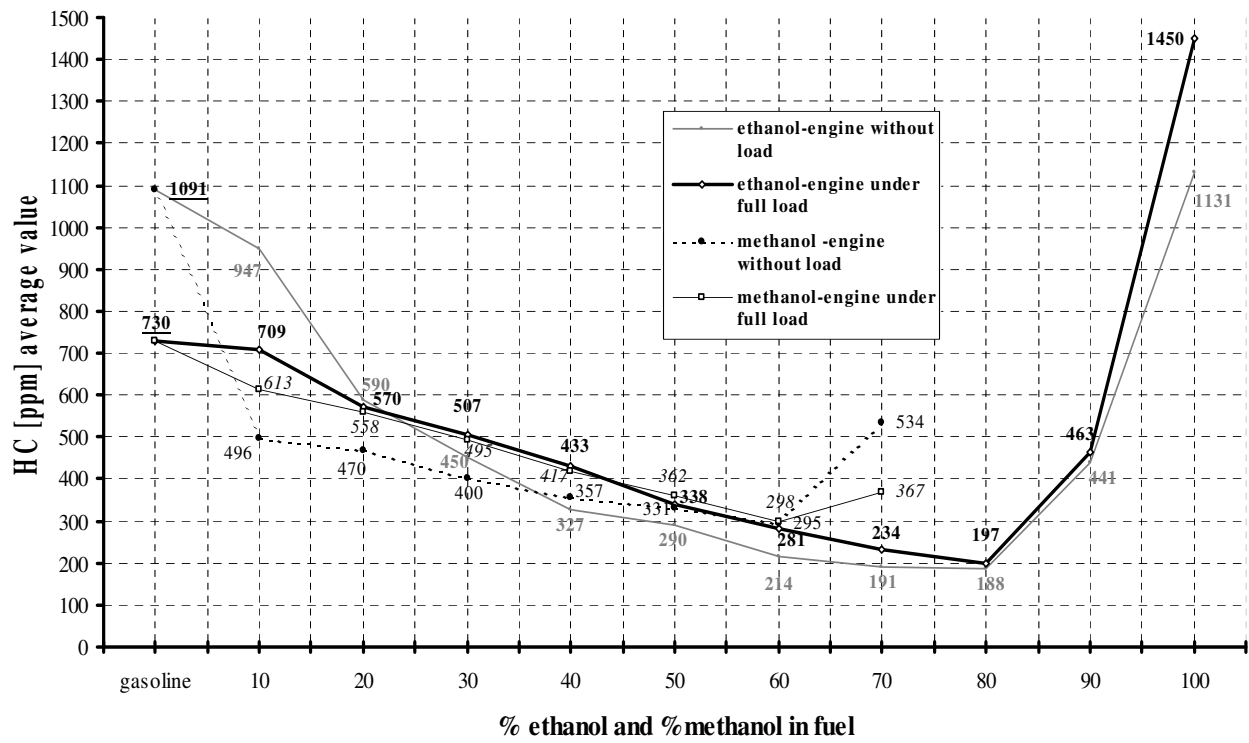


Figure 39. The HC emission average value for every gasoline-ethanol and gasoline-methanol mixtures

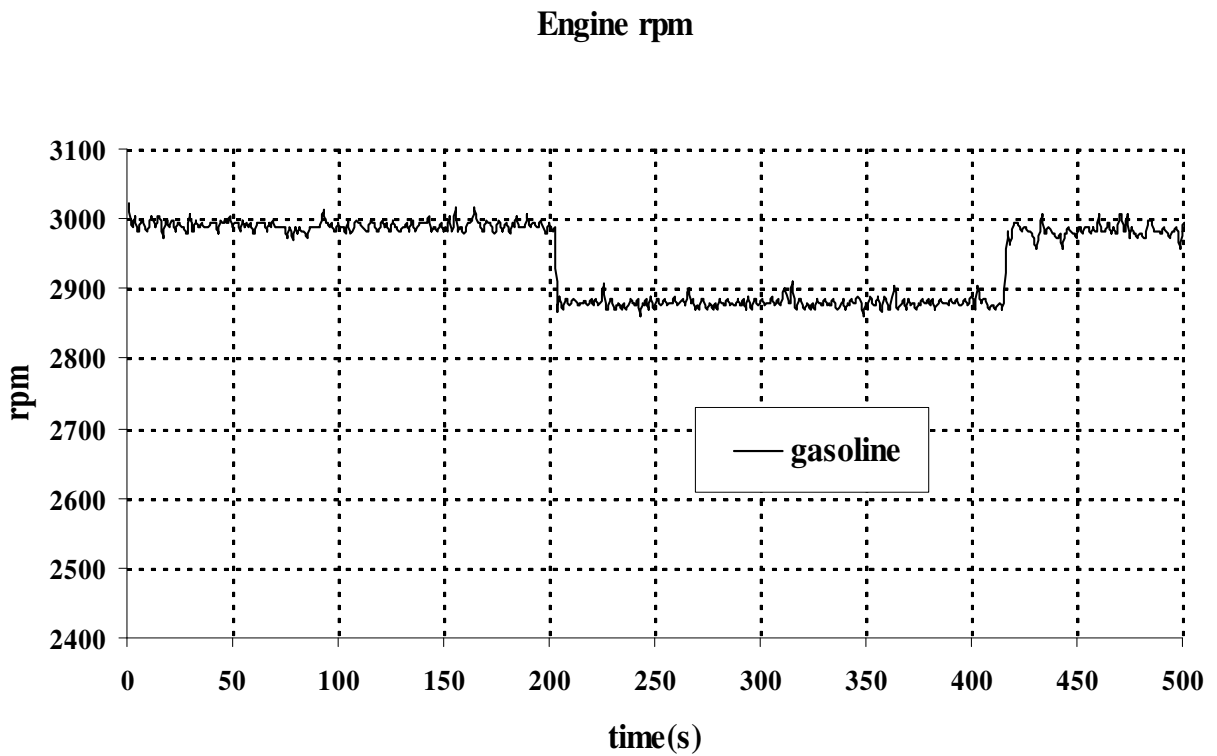


Figure 40. The rpm variation when used fuel gasoline

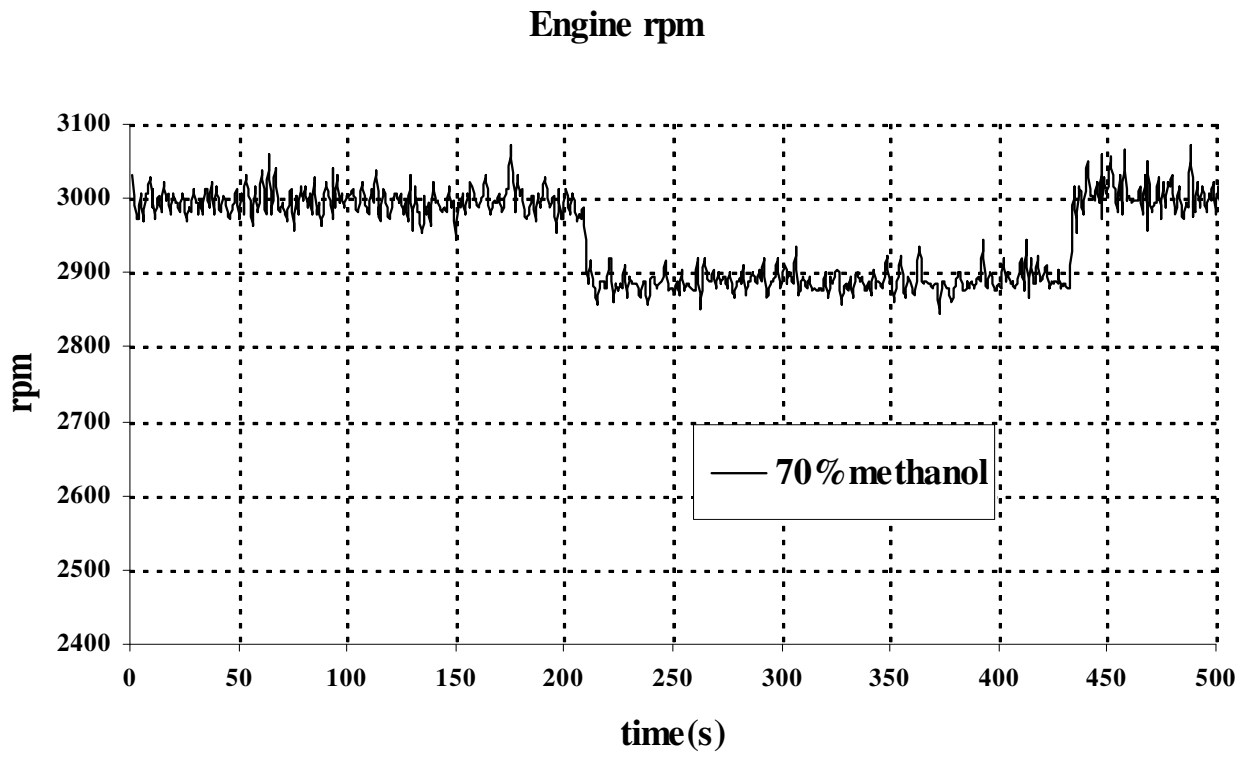


Figure 41. The rpm variation when used fuel gasoline –70%methanol

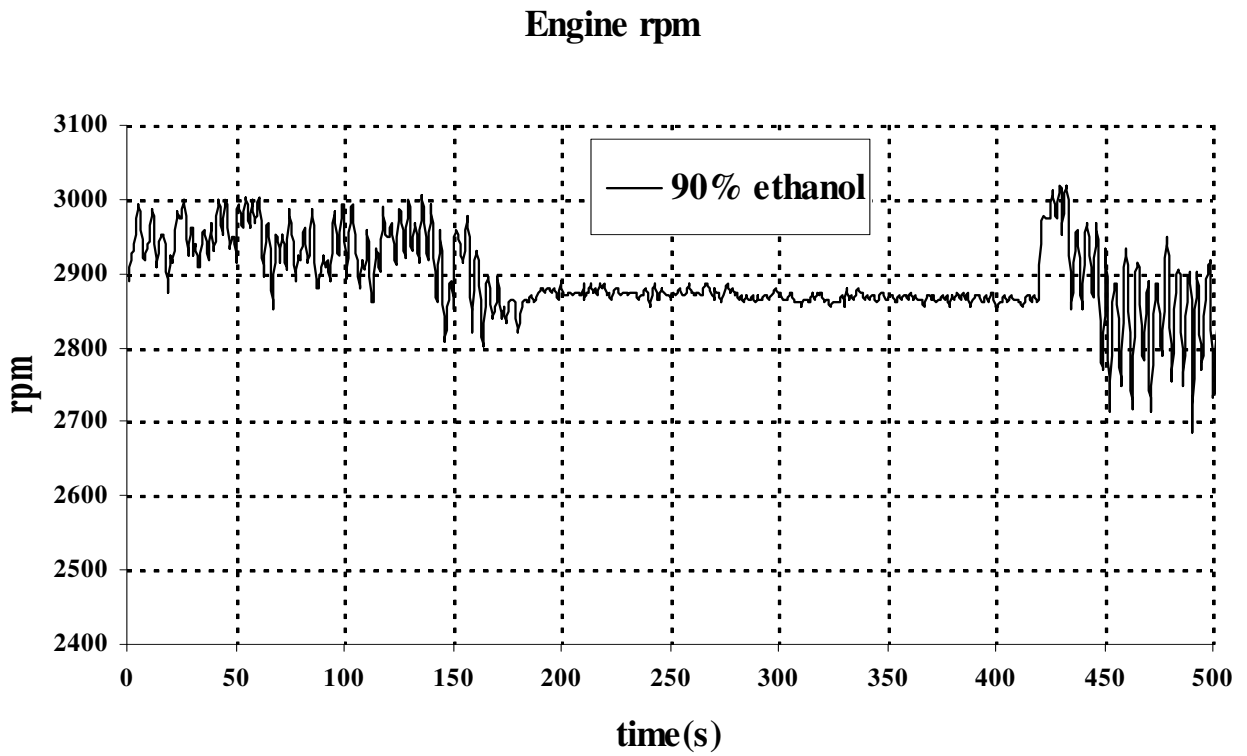
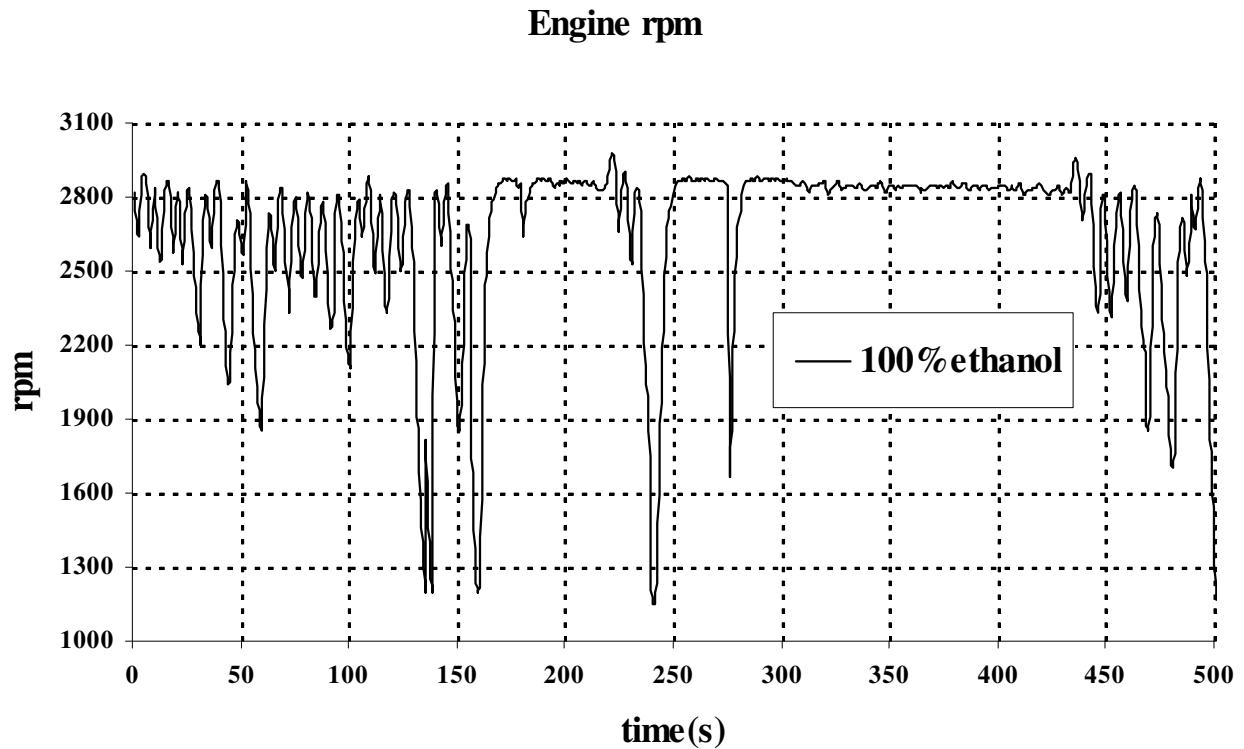


Figure 42. The rpm variation when used fuel gasoline –90%ethanol



**Figure 43.** The rpm variation when used fuel 100%ethanol

During the tests the rounds per minute of the engine were recorded as it was mentioned above. The normal variation of the engine rpm appears in figure 40. The same variation that is illustrated in this figure corresponds to the mixtures gasoline until the mixtures gasoline-90% ethanol and gasoline-60%methanol, without any change. As it is presented in figure 39, the average value of the engine rpm without load (0-200s and 420-500s) is approximately 2990rpm while at full load conditions (200-420s) the average value of the engine rpm is 2880rpm. It must be noted that the engine has a round stabilizer. In figures 41, 42 and 43 the mixtures gasoline-70%methanol, gasoline-90%ethanol and 100%ethanol are illustrated and irregular variation of the engine rpm is presented, which is caused from the engine malfunction. Higher irregular variation is observed at without load condition, and lower at full load conditions in the case of use ethanol. This malfunction is due to the smaller calorific value of methanol and ethanol than the gasoline, and to the fact that there is no adjustment of the air/fuel ratio during the use of gasoline-methanol and gasoline-ethanol mixtures. The initial adjustment that corresponds to gasoline as fuel is maintained [6,7].

Furthermore, during the tests the consumption of the fuel was recorded for every mixture separately and for every load conditions. The results of the consumption recording are illustrated in the figure below:

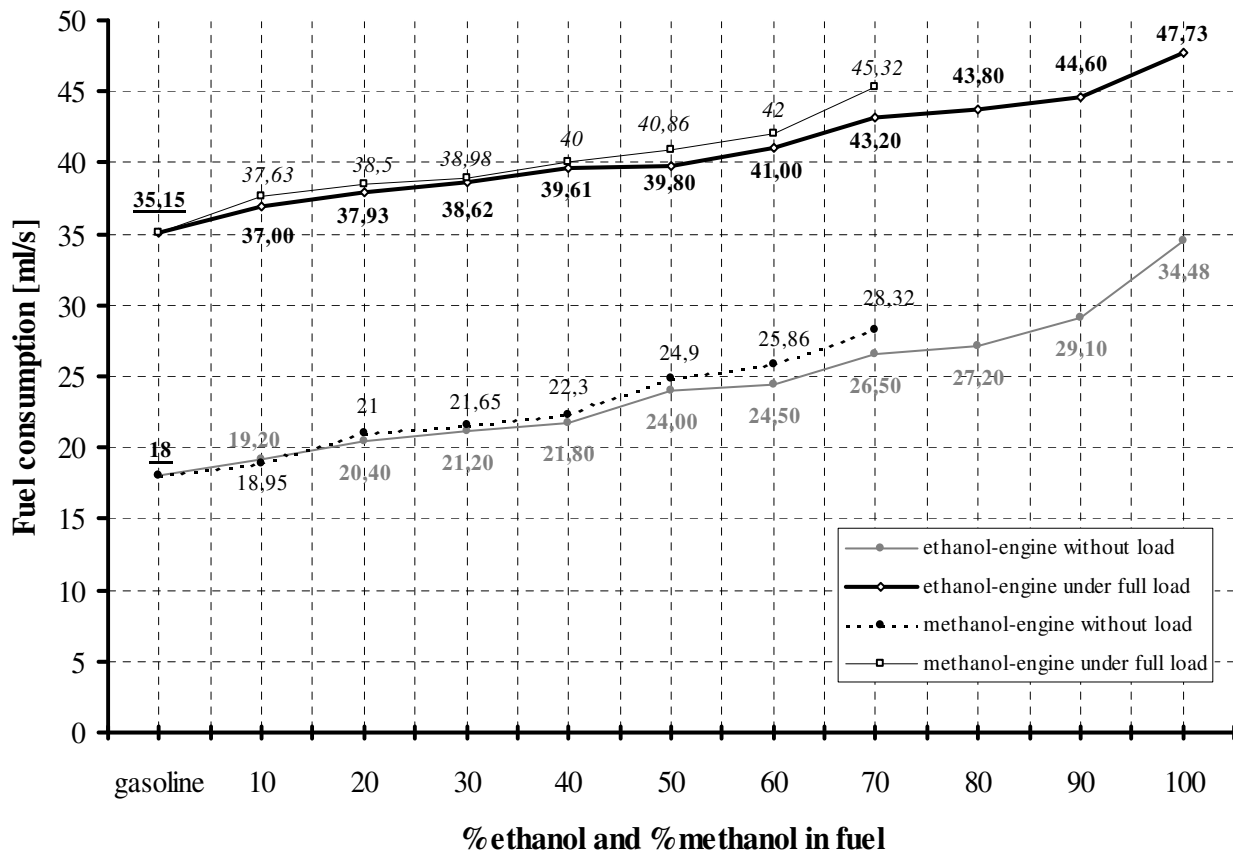


Figure 44. The fuel consumption

Figure 44 shows an increase of fuel consumption when the percentage of methanol and ethanol in the fuel increases than gasoline. Also, between the use of the mixtures of methanol and ethanol is observed small increase during the use of methanol because of the smaller calorific value that methanol has compared to ethanol. The smaller calorific value of methanol and ethanol compared to gasoline and also the lack of regulation (ratio air/fuel) of the engine, results to the consumption increase contrary to the use gasoline. This increase of consumption happens automatically for the rounds regulator that the engine has, for the maintaining of the rounds constant.

### 3. Conclusion

From the observations above is appeared that methanol and ethanol as mixture with gasoline results in an emissions (CO and HC) decrease when the engine functions without load and under full load conditions. There is an exception in the use of the mixtures: gasoline-70%methanol, gasoline -90% ethanol and 100%ethanol where there is observed an HC emissions increase because of the incomplete combustion and consequently due to engine malfunction. Also, it must be mentioned that the adjustment of the engine (air/fuel ratio) was that which referred to the use of gasoline as fuel. From the aspect of consumption, there was a consump-

tion compared to gasoline increase when the percentage of the methanol and ethanol in the fuel was increased in both load conditions. Between the use of methanol and ethanol mixtures is observed higher increase of consumption when the mixtures of methanol are used due to the fact that methanol has lower calorific value compared to ethanol. From the aspect of emissions, when the mixtures of gasoline with methanol and ethanol are compared, there is greater reduction of emissions in the case where methanol is used. It can be said that this is caused because of the smaller carbon chain of the methanol molecule, which results to the better combustion of methanol. It is also observed that the engine functions with the mixtures of methanol until the use of 70% methanol mixture with gasoline, while with ethanol mixtures until 100% ethanol as fuel (with the initial adjustment of the air/fuel ratio that is made for gasoline). This is due to the fact that ethanol has higher octane number compared to methanol. Finally, it is important the fact that methanol and ethanol are a renewable fuels, which present emissions decrease compared to gasoline, when they are used, in a time period where petroleum reservations are depleted and the environmental pollution is one of the most important problems that humanity faces [4-7].

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