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Full Length Research Paper

Determination of the catalytic converter performance of bi-fuel vehicle

Sameh M. Metwalley, Shawki A. Abouel-seoud and Abdelfattah M. Farahat

Faculty of Engineering, Helwan University, Cairo, Egypt.

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The reduction of pollutant emission from spark ignition engines is desirable in order to reduce the highly impact on the green environment, produced from transport release like trains, trucks, traveler vehicles and others. However, modern vehicles are equipped with catalytic converters. A bi-fuel vehicle that has been retrofitted for both fuel systems: namely, compressed natural gas (CNG) and base fuel gasoline. A locally produced three-way catalytic converter (TWC) fitted on the exhaust system. The objective of this investigation is to evaluate the effectiveness of TWC in reducing vehicle exhaust emissions. In addition, the individual conversion efficiency of the vehicle-out emissions have been calculated and presented. Operations under idle state and on-road emission test procedures were carried out on a newly registered gasoline/CNG bi-fuel vehicle in Egypt market (Hyundai-star) where is assessed against the European standard urban driving cycle (ECE-15). Two different fuel injection systems are used; namely multi-point (MPI) and venture (mixer) closed-loop. The emission results such as CO, CO_2 and THC were measured and compared between the earlier mentioned two fuels. The results show that the arrangement of TWC and operation in idle state is very effective to reduce exhaust emissions than that in transient state. Moreover, the results of this investigation will be used to develop CNG emissions based TWC.

Key words: Vehicle engine emissions, bi-fuel vehicle, idle measurement, on-road measurements, fuel injection systems, air index.

INTRODUCTION

The exhaust emissions and performance were evaluated for a computer integrated bi-fuel spark ignition engine that has been retrofitted for two fuel system: namely, compressed natural gas (CNG) and base fuel gasoline. Operations under steady state with lean burn condition. The used engine was a Proton Magma 4-cylinders spark ignition engine. The emission results such as CO, HC and NO_x were measured and compared between the earlier mentioned two fuels. A three way catalytic converter (TWC) was used to assess the emissions. The results show that the arrangement of retrofitting catalytic converter and operation with lean burn condition is very effective to reduce exhaust emissions. From the investigation, it is found that CNG produced 15% less brake power, 15 to 18% less specific fuel consumption (SFC) and 10% higher thermal efficiency than gasoline fuel. The emission results showed at the entrance of TWC that CNG produced 30% higher than NO_x emissions and lower 12 and 90% HC and CO, respectively. The details about the emissions management system together with the catalytic and engine performance results have been presented and discussed (Yaacob et al., 2002).

Motor vehicle exhaust emissions could be sharply reduced by the introduction of exhaust after-treatment systems, modern engine control concepts and cleaner fuels. However, it has not been possible to significantly improve air quality in cities with regard to particulates and ozone in the past 10 years. It appears that the reduction in vehicle exhaust emissions achieved is offset by the growth in traffic as well as by changes in the composition of exhaust emissions and the corresponding reactivity in the environment. The reduction of selected pollutants

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*Corresponding author. E-mail: metwalley1965@hotmail.com

therefore remains an important issue alongside greenhouse gas reduction. The present investigation illustrates the emissions of actual gasoline, diesel and natural gas passenger cars in the official European driving cycle and in the real-world driving cycle Artemis. The natural gas vehicles show the lowest impact on air quality (Yaacob and Rahman, 2003; Burch et al., 1996).

Uniform flow distribution inside a catalytic converter is highly desirable in order to enhance converter efficiency and extend catalyst durability. Mal-distributed flow constantly results in a penalty of deterioration performance and reduced lifetime. In addition, the formation of recirculation zone inside the catalytic sensor installed in the converter diffuser, especially with closed coupled design. In such a case, information from the oxygen sensor may not represent the overall combustion characteristics of all the cylinders, which may lead to a false feedback to the engine control system. Generally, velocity distribution is not uniform inside the catalytic converter of production engines. This because the flow distribution within the converter is a momentum transfer process and sensitive to different boundary conditions and momentum sources inside the system (Kalam et al., 2001).

Previous studies reported that uniform flow distribution at the catalyst improves the conversion efficiency and durability of the catalytic converter (Burch et al., 1996; Kalam et al., 2001; Weaver, 1989). Uniform flow distribution at the monolith inlet lowers local peak velocities and temperature gradients in the catalytic converter, and delays aging of the catalytic converter, It is possible for a reduced-volume of close-coupled catalytic converter (CCC) to have the same durability if flow distribution becomes uniform. This leads to a reduction in cost and mass of the CCC. The key factor in designing a CCC is to optimize the exhaust manifold and the CCC inlet. If they are poorly designed, flow at the monolith inlet becomes highly non-uniform, resulting in poor catalyst conversion efficiency and durability. The continuing global enthusiasm for mobility and the resultant ever increasing burden placed upon the environment lead to co-political discussions and further on to more stringent emission standards for all combustion engines (Weaver, 1989; Tong et al., 2000).

A compressed natural gas (CNG) or gasoline is being developed for the transition to alternative fuel usage in a spark ignition bi-engine. Individual conversion efficiency of the emissions have been measured for the vehicle’s engine in steady-state and transient-state conditions, where their results indicate that regulated total hydrocarbon (THC), nitrogen oxides (NO_x), carbon monoxides (CO) and carbon dioxides (CO_2) were characterized. Moreover, the equivalence ratio range over which the catalyst can relatively reduce NO_x, CO and CO_2 plays an important role in reduction (Pipitone and Beccari, 2007; Al-Shemmeri, 1993).

More stringent emissions standards around the world are challenging the auto industry to advance emissions control technology. Engine management strategies have been introduced to achieve faster exhaust heat up and tighter closed-loop operation, which results in faster converter light-off. Catalysts have achieved lower light-off temperature and higher conversion efficiency after the vehicle is at operating temperature. New exhaust manifold design and dual wall exhaust piping has been utilized for better thermal management to achieve faster light-off. Catalyst supports have been developed to achieve lower mass and higher surface area for faster light-off and higher conversion efficiencies (Kalam et al., 2004).

A driving cycle is a time series of vehicle speeds recorded at successive (equally spaced) time points USEPA (1993). It represents a typical driving pattern for the population of a city. For emission testing, a test driving cycle in the most general case, attempts to synthesize real driving conditions with respect to a number of measures, including speed, acceleration, specific power, trip patterns, road grade, and temperature. Driving cycles have been developed to provide a single speed-time profile that is representative of urban driving. Standard driving cycles have a wide range of uses (Tong et al., 1999). Vehicle manufacturers need these cycles to provide a long term basis for design, tooling and marketing. Traffic engineers require driving cycles in the design of traffic control systems and simulation of traffic flows and delays. Environmentalists are concerned with the performance of the vehicle in terms of the pollutants generated, while negotiating specific driving patterns. Furthermore, a speed-time trace can provide a convenient laboratory-based means to estimate fuel consumption and emissions of vehicles within the respective urban areas.

As known gaseous fuels, such as liquefied petroleum gas (LPG) and natural gas (NG), thank to their good mixing capabilities, allow complete and cleaner combustion than normal gasoline, resulting in lower pollutant emissions and particulate matter. Moreover, the use of natural gas, mainly constituted by methane, whose molecule has the highest hydrogen/carbon ratio, leads also to lower CO_2 equivalent emissions. Some of the automobile producers already put on the market “bi-fuel” engines, which may be fed either with standard gasoline or with natural gas. These engines, endowed of two separate injection systems, are originally designed for gasoline operations, hence they do not fully exploit the good qualities of methane, such as its high knocking resistance (Mah, 1993), which would allow higher compression ratios. Moreover, when running with gasoline at medium high loads, the engine is often operated with rich mixture and low spark advance in order to prevent from dangerous knocking phenomena: this produces both high hydrocarbon and carbon monoxide emissions (also due to the low catalyst efficiency caused by the rich mixture) and high fu

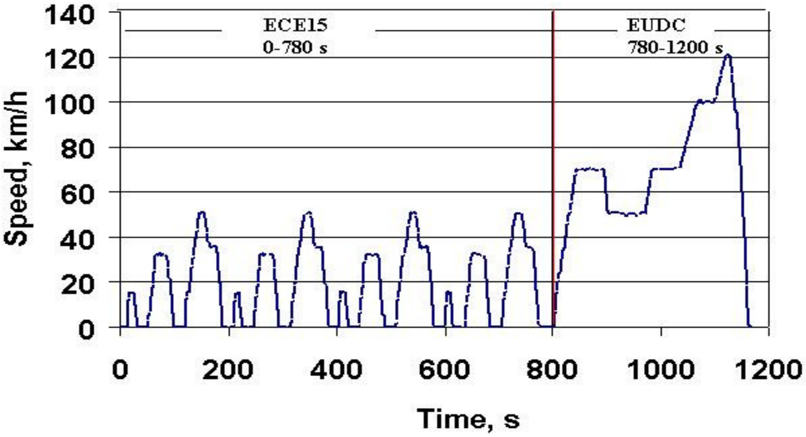

Figure 1. The European driving cycle ECE-15.

consumption.

The objective of this investigation is to evaluate the effectiveness of TWC in reducing vehicle exhaust emissions. In addition, the individual conversion efficiency of the vehicle-out emissions have been calculated and presented. Operations under idle state and on-road emission test procedures were carried out on a newly registered gasoline/CNG bi-fuel vehicle in Egypt market (Hyundai-star) where is assessed against the European standard urban driving cycle (ECE-15). Two different fuel injection systems (that is, Multi-point MPI-sequential and Closed-loop venturi-continuous) are used.

EUROPEAN DRIVING CYCLE (ECE-15)

In order to investigate the amounts of exhausted gas emissions and fuel consumption rates of vehicles traveling in Egypt, a generic driving characteristic or pattern for any vehicle traveling in the traffic of the city under consideration must be established. So far there is no such driving cycle officially developed for representing Egypt traffic. The driving cycle used for the assessment of the exhaust emissions of newly registered automobiles in Egypt is based upon the standard driving cycle of the European Community (called ECE-15 cycle) where the driving conditions are not the same. Furthermore, it is modal driving cycle which derived from various representative constant acceleration and speed driving modes contrast to the cycle that constructed from the real micro trips obtained from actual on-road driving data such as the US75 cycle and Melbourne peak cycle.

The European test driving cycle is based on Euro III and it is presented in Figure 1. The driving cycle consists of two parts, ECE15 and EUDC, that correspond to urban and highway (extra-urban) driving conditions in that order. ECE15 test cycle simulates a 4.052 km urban trip at an average speed of 18.7 km/h and at a maximum speed of 60 km/h. Its duration is 780 s. The same part of the ECE15 driving cycle is repeated four times to obtain an adequate driving distance and temperature (Figure 2). The EUDC cycle instead illustrates the aggressive, high speed driving at a maximum speed of 120 km/h. Its duration is 400 s and 6.955 km at an average speed of 62.6 km/h. In this work, only part of urban cycle with the duration of 280 s is used (Figure 3).

CATALST TECHNOLOGY

The catalytic converter

Most modern vehicles are equipped with three-way catalytic converters. Three-way refers to the three regulated emission components. The converter uses two different types of catalysts, a reduction catalyst and an oxidation catalyst. Both types consist of a ceramic structure coated with a metal catalyst, usually platinum, rhodium and/or palladium. The idea is to create a structure that exposes the maximum surface area of catalyst to the exhaust stream, while also minimizing the amount of catalyst required. There are two main types of structures used in catalytic converters, honeycomb and ceramic beads.

A locally produced three-way catalytic converter (TWC) is shown in Figure 4, and has been used to reduce and assess the unwanted pollutant gases like CO, HC and NOx from the exhaust gas stream. The catalytic material consists of platinum (Pt), palladium (Pd), rhodium (Rh) and cerium oxide (CeO_2). The Pt and Pd are used to oxidize CO and HC to CO_2 and H_2O. The Rh is used to reduce NOx to N_2 and O_2. However, the efficiency of the three-way catalytic converter depends on the availability of O_2 and the temperature in the exhaust gas stream. The role of CeO_2 in TWC is to afford as an O_2 storage capacity (OSC) which liberates or adsorbs O2 if the air to fuel ratio is perturbed. The details about work function of

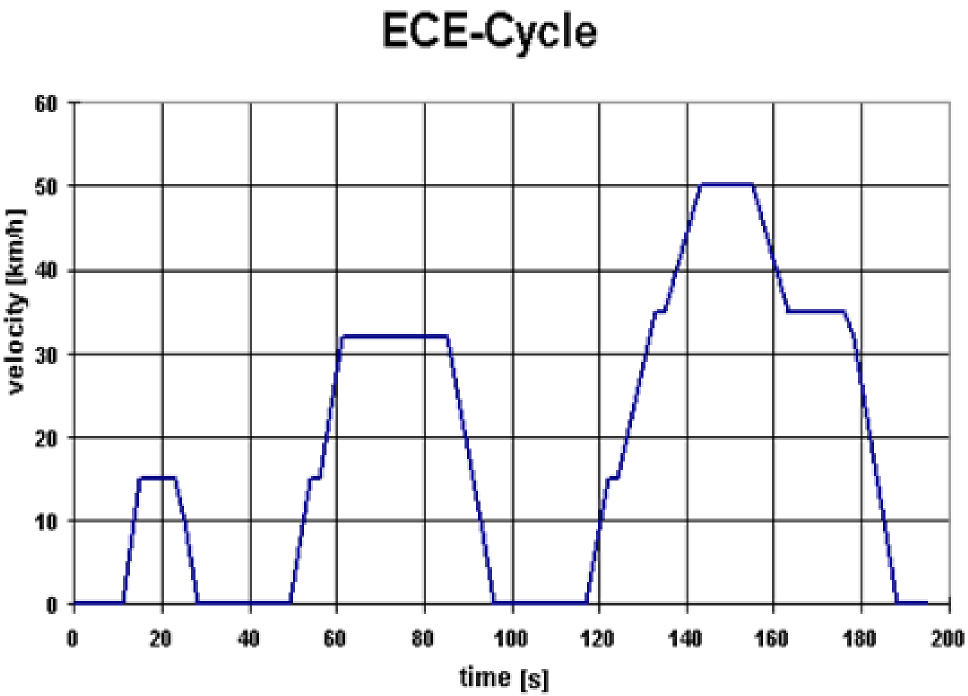

Figure 2. Part of the ECE-Cycle.

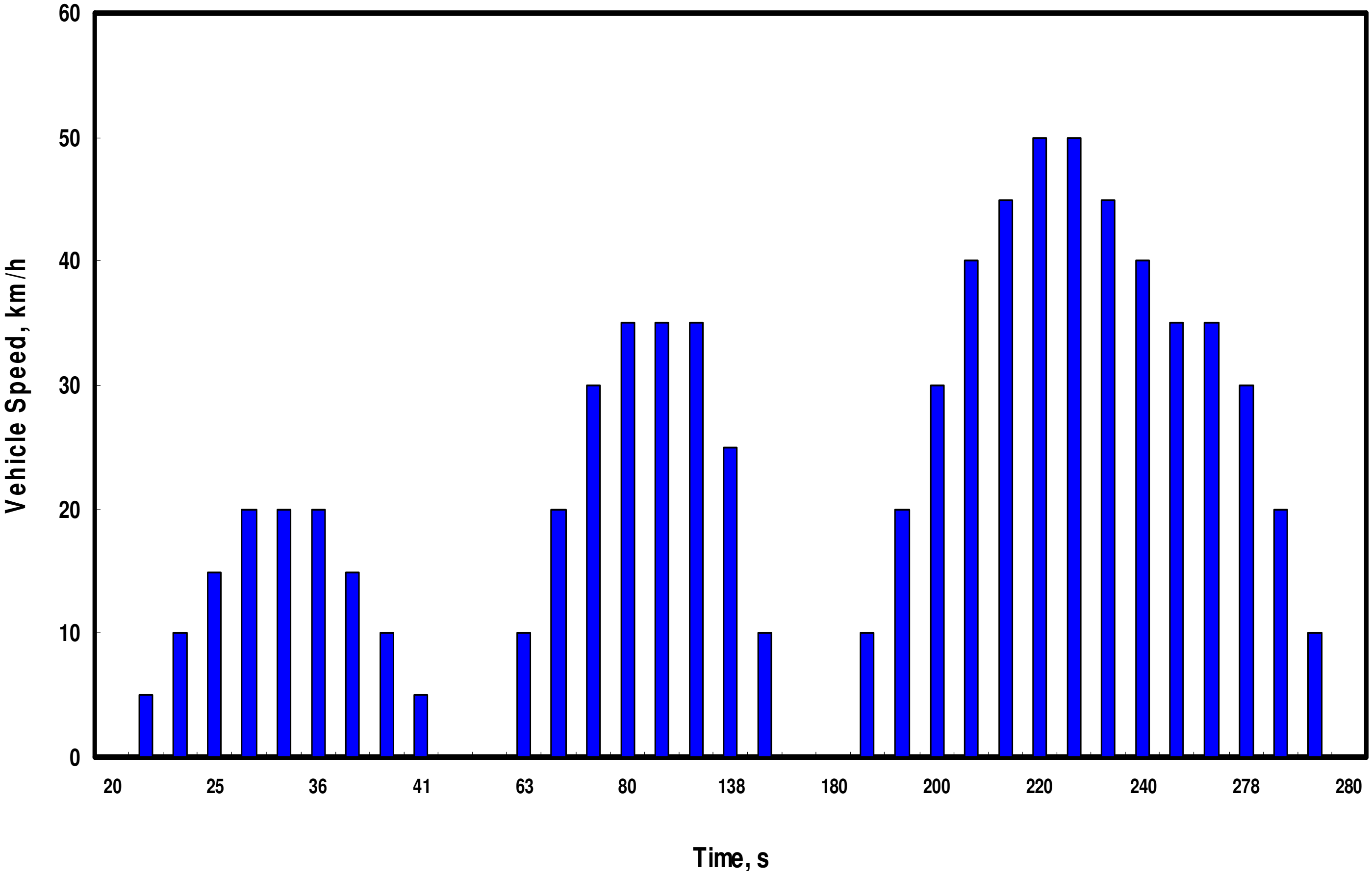

Figure 3. Part of the ECE-Cycle used.

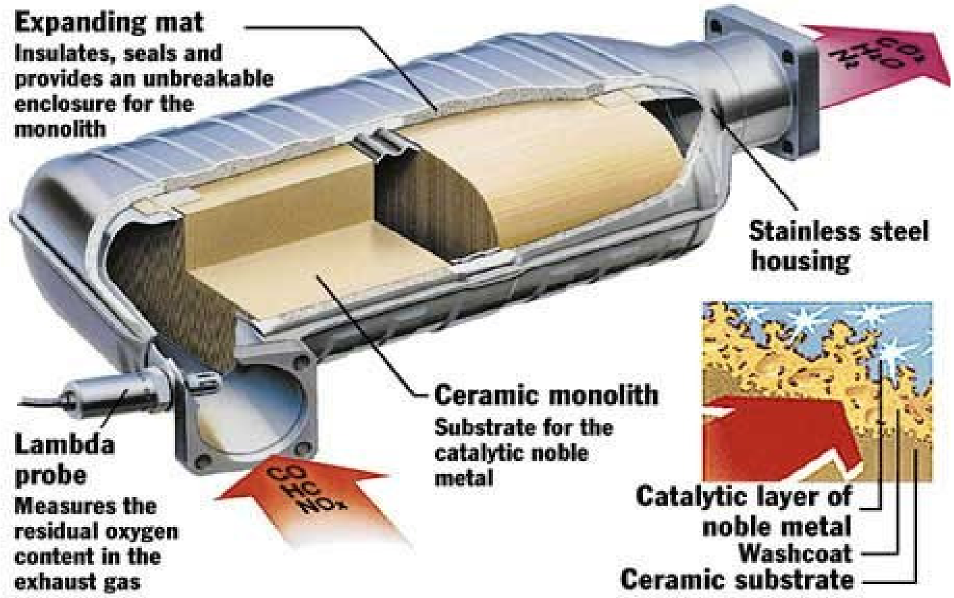

Figure 4. Structure of three-way catalytic converter.

Table 1. Types of the fuel injection system.

No	Injection system	Fuel	Remarks
1	Multi-point (MPI-sequential)	Gasoline Compressed natural gas (CNG)	
2	Closed-loop(venturi-continuous)	Compressed natural gas (CNG)	

CeO_2 in the TWC can be found elsewhere (Yaacob et al. (2002); Yaacob and Rahman (2003).

The catalytic bed was placed in the exhaust pipe (near manifold) where the maximum temperature (catalytic bed temperature) reaches about 560°C. This high temperature is required to oxidize THC (as well as unburn CH_4) in the exhaust gas from natural gas combustion. The details about the catalytic bed placement in the exhaust system can be found elsewhere (Burch et al., 1996).

The reduction catalyst

The reduction catalyst is the first stage of the catalytic converter. It uses platinum and rhodium to help reduce the NO_x emissions. When an NO or CO_2 molecule contacts the catalyst, the catalyst rips the nitrogen atoms out of the molecule and holds on to it, freeing the oxygen in the form of O_2. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N_2.

Catalyst conversion efficiency

Catalyst system conversion efficiencies were calculated for each emission constituent using the following equation:

$$\left(1- \text{(Without Catalytic Converter)}/\text{(With Catalytic Converter)}\right) \times 100 \quad (1)$$

EXPERIMENTAL METHODOLGY

The experimental work is carried out on specified vehicle to avoid vehicle-to-vehicle variation which results from different designs, operating conditions and maintenance processes. According to the aim of this study, the idle and on-road test modes are employed and applied on the vehicle that has been retrofitted for both fuels namely compressed natural gas (CNG) and base fuel gasoline together with a locally produced three-way catalytic converter (TWC) fitted on the exhaust manifold to reduce its emissions. The fuel injection system used in this work is tabulated in Table 1. The vehicle is equipped with infrared gas analyzer and rpm pickup transducer. The exhaust gas concentration, engine rotational speed and vehicle speed are recorded during the test. A newly registered

Table 2. Some of the technical data for vehicle used in the present experimental study.

S/No.	Parameters	Values	Remarks
I	Vehicle		
	Type	Hyundai-star	
II	Engine		
	Type	SOHC, 4 cyl, 4 stroke	
	Fuel type	Gasoline/CNG	
	Swept volume	1598 (cm^3)	
	Fuel supply	MPI / Closed Loop (venturi)	
	ignition system	Electronic	
	Exhaust system	Catalytic converter	
	Maximum power	106 HP@ 4300 rpm	
	Maximum torque	143 Nm @ 3000 rpm	
III	Performance		
	0-60 mph	13.2 s	
	Quarter mile	18.5 s	
	Top speed	156 km/h	

gasoline/CNG bi-fuel vehicle in Egypt market (Hyundai-star) was used. The vehicle is Verna-star, 1600 cc. The vehicle engine is spark ignition, four strokes, four cylinders in-line and water cooled. It is transversally mounted with front wheel drive technique. The vehicle is equipped with manually operated gear box mounted transversally and sharing the same oil sump of the engine. The gear box offers 4 forward speeds and single reversal speed. Some of the technical data for the vehicle used are tabulated in Table 2.

Portable version of infrared gas analyzer is used during the experimental work. The gas analyzer is equipped with gas sampling probe to collect the exhaust gas from the muffler. The gas is then filtered and dried before entering the analyzer. Magnetic inductive pickup transducer is used also to measure the vehicle speed in km/h. Figure 5 represents the layout of the gas analyzer used in the present study, while the installation of instruments and probes at different measuring points in the vehicle are shown in Figure 6.

Intensive measurements program were done at different operating condition. The selected vehicle is equipped with previously mentioned measuring instruments. The gas analyzer and its accessories are mounted in the rear seat of the passenger cabinet. Rechargeable power supply and printer are the most important attachment to the analyzer. Gas sampling probe with 3 m long inserted inside the muffler. Its other terminal is connected to the gas analyzer through the window of the rear door. Magnetic inductive transducer is clipped also to the spark plug cable to measure the engine rotational speed. Before starting the measurements, the catalyzer either removed (without) or leaved (with), and the following precautions are taken into account:

(i) The vehicle engine is warm enough before starting the measurement and runs steadily at standard idling configuration.
(ii) All electric accessories like electric fan and radio-cassette are off.
(iii) All the windows of the cabinet are closed except one of the rear windows, which is partially opened (to permit the gas sampling connection). This is to keep the drag effect within the standard value.

During the idle or on-road test, two persons are required to carry out the experimental work. The first person is the vehicle driver, which perform the test program with certain sequence. The driver is responsible to drive the vehicle steadily for enough periods required to obtain steady measurements. The second person is the instruments operator, which is responsible to review the test procedure with the driver and observe the output readings. When the signals become steady, the output readings are recorded and next step of vehicle speed is performed.

RESULTS AND DISCUSSION

The effectiveness of the catalytic converter (catalyzer) results

In Figures 7 to 9, the effectiveness of catalytic converter on the vehicle exhaust gas emissions components in the idle state is shown, where the values of carbon monoxide (CO), carbon dioxide (CO_2) and total hydrocarbon (THC) measured for the bi-fuel vehicle in steady-state when operated by multi-point injection (MPI) system are shown respectively. The fuel is being gasoline and the results are presented with and without catalytic converter (catalyzer). A substational reduction is observed for the levels of the exhaust gas emissions components of CO, CO_2 and THC when the catalyzer is used.

In Figures 10 to 12, the effectiveness of catalytic converter on the vehicle exhaust gas emissions components in the idle state is shown, where the values of carbon monoxide (CO), carbon dioxide (CO_2) and total hydrocarbon (THC) measured for the bi-fuel vehicle in steady-state when operated by multi-point injection (MPI) system are shown respectively. The fuel is being compressed natural gas (CNG) and the results are

Figure 6. The probe inside the exhaust tailpipe.

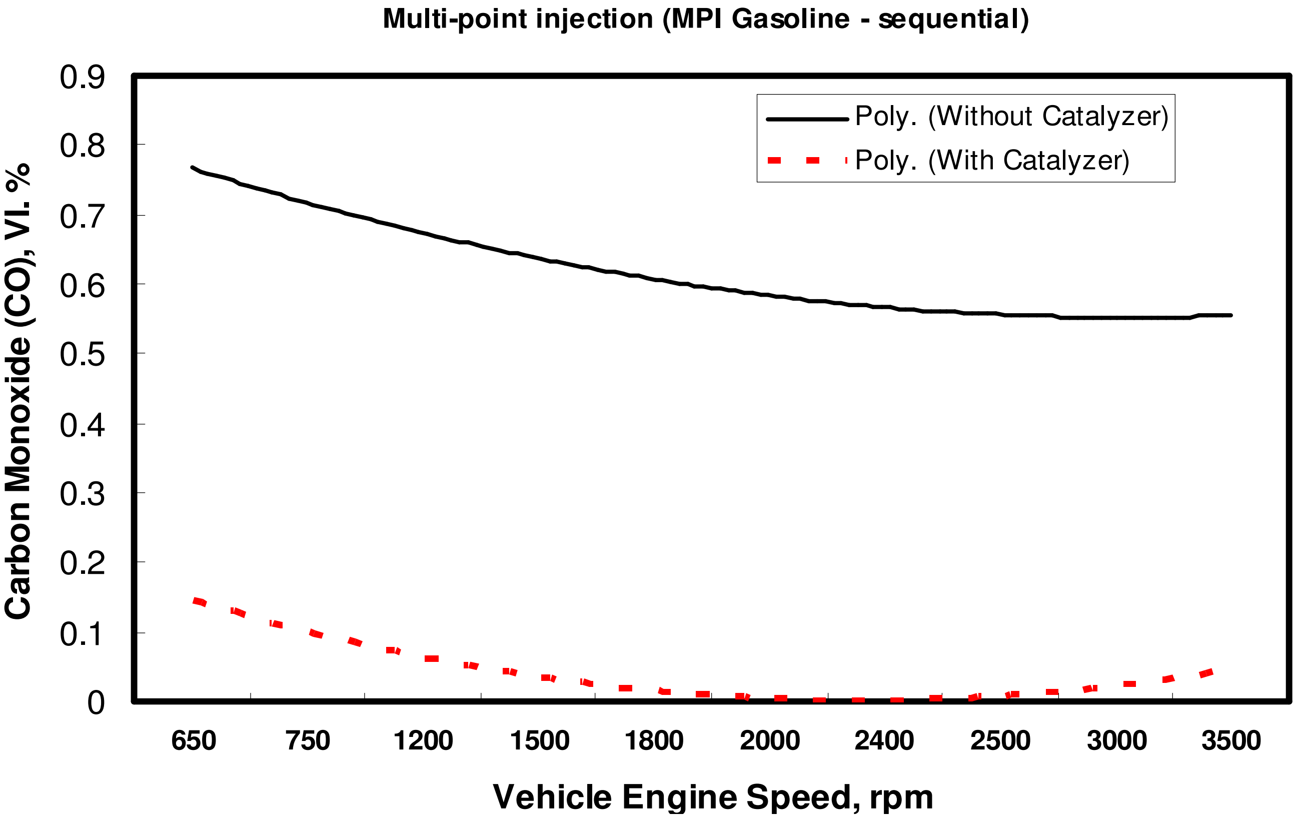

Figure 7. The influence of using catalyzer on carbon monoxide (CO).

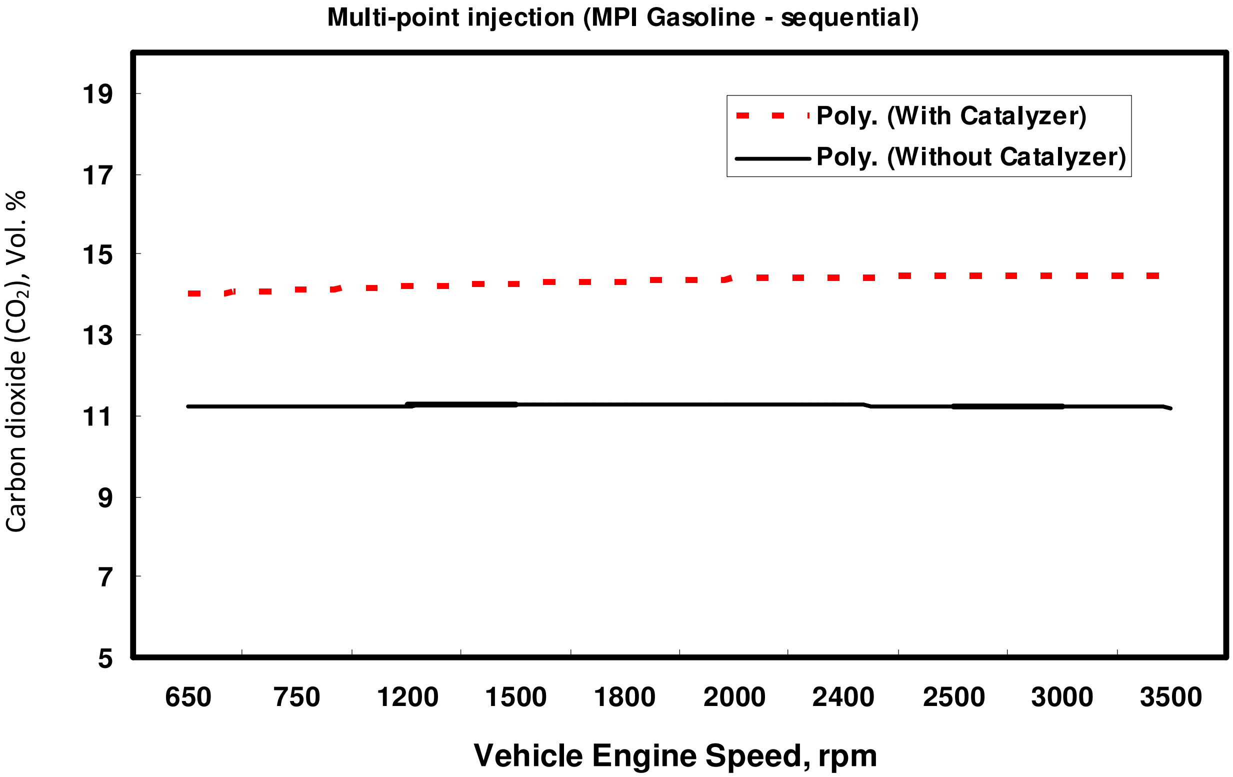

Figure 8. The influence of using catalyzer on carbon dioxide (CO_2).

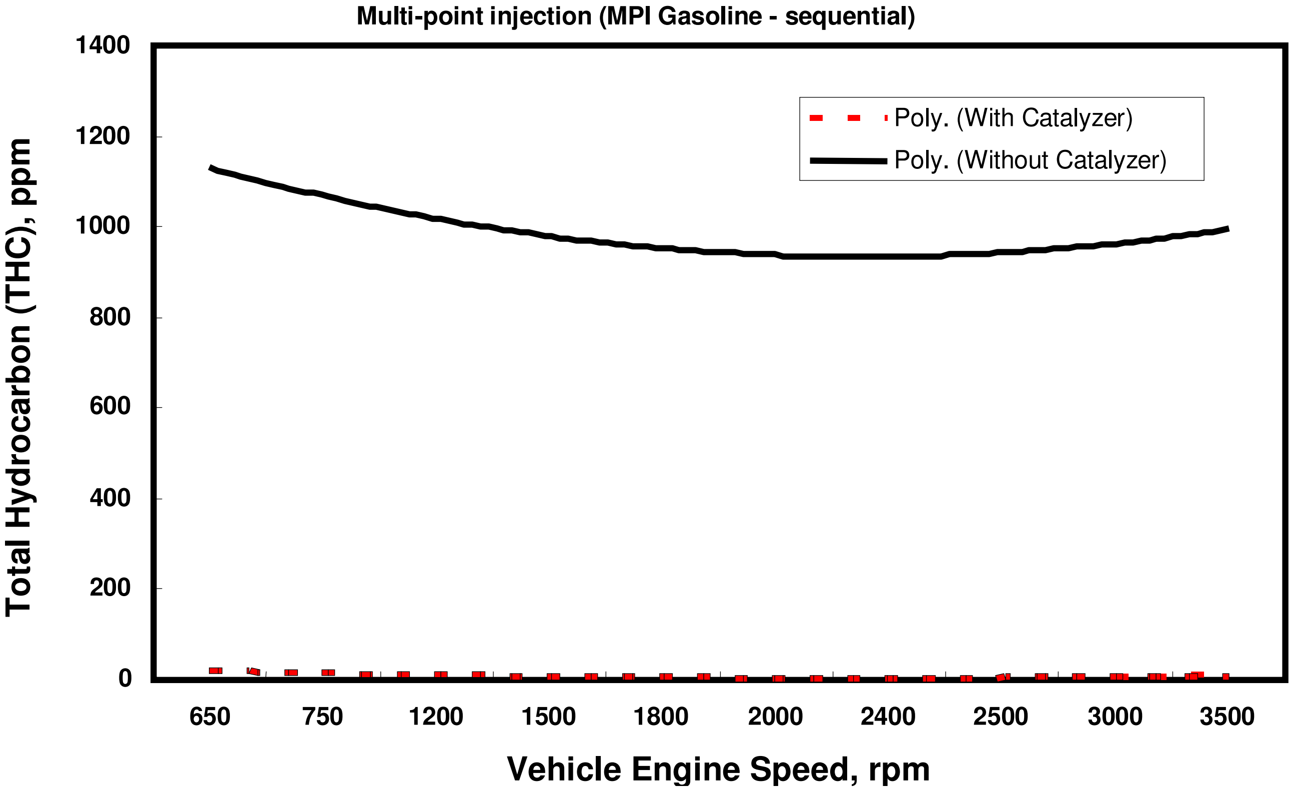

Figure 9. The influence of using catalyzer on total hydrocarbon (THC).

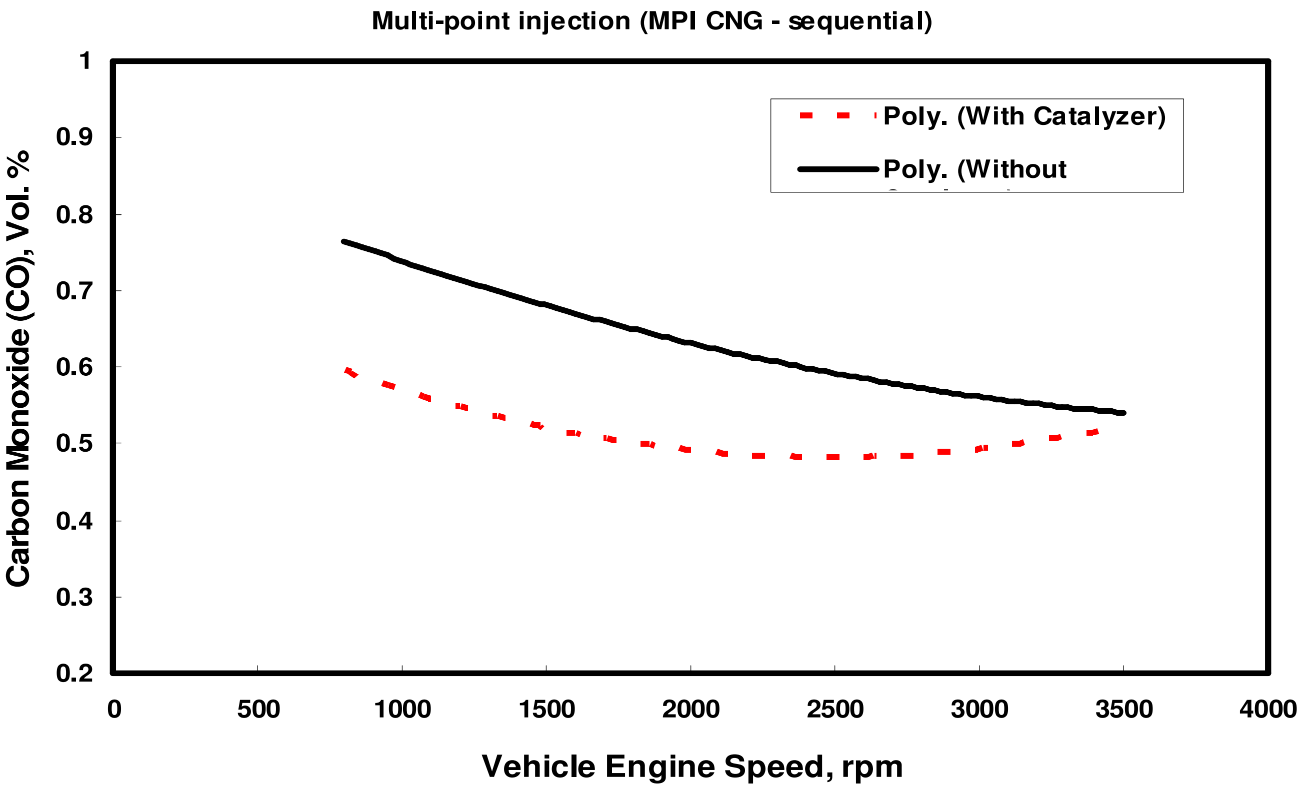

Figure 10. The influence of using catalyzer on carbon monoxide (CO).

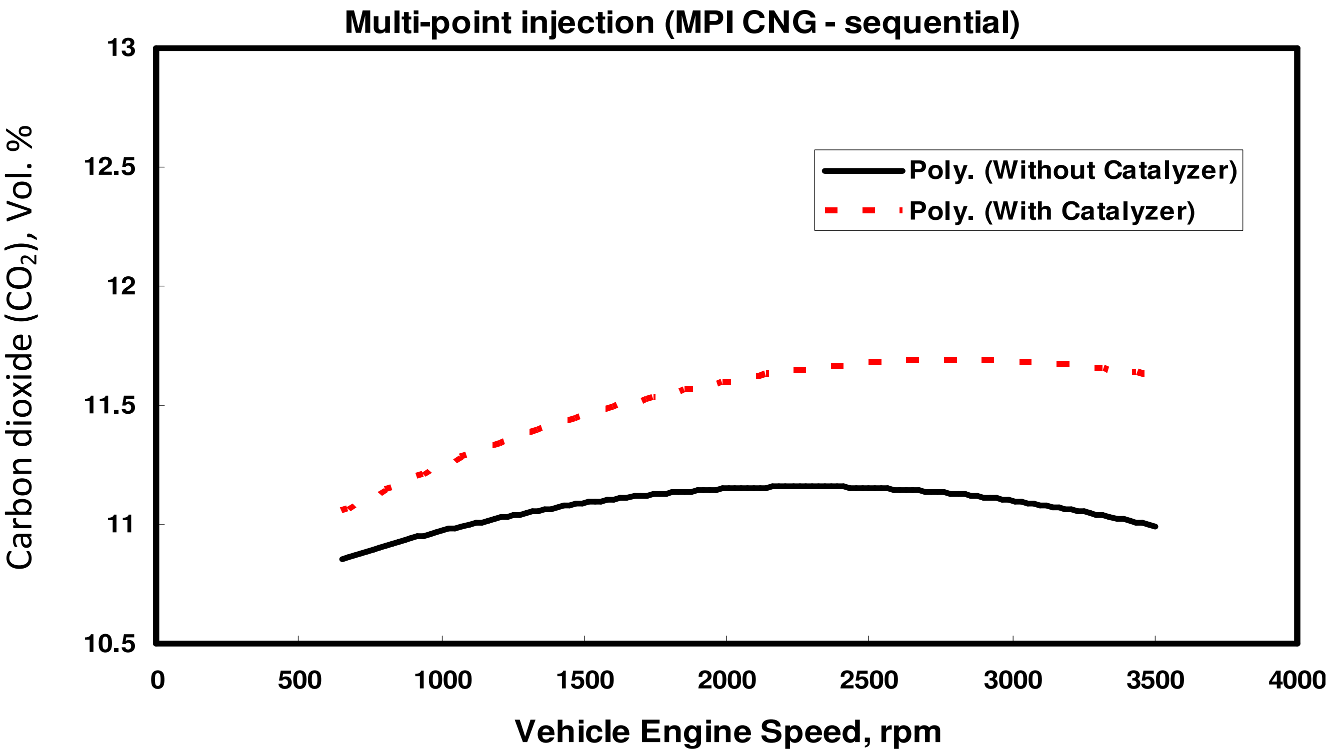

Figure 11. The influence of using catalyzer on carbon dioxide (CO_2).

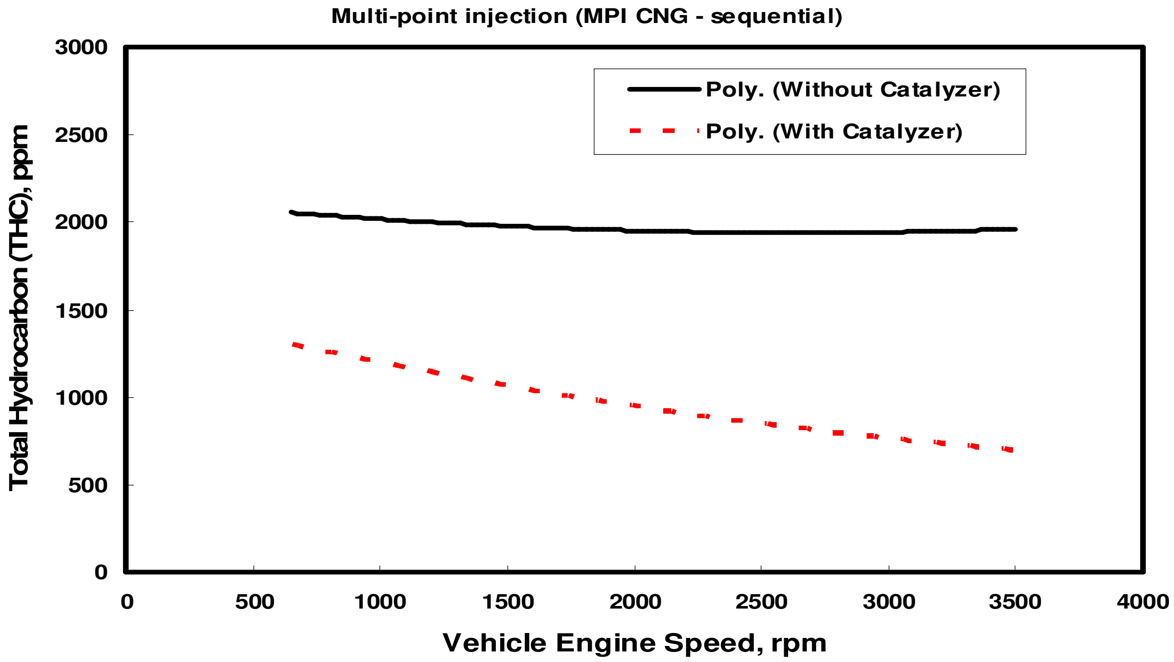

Figure 12. The influence of using catalyzer on total hydrocarbon (THC).

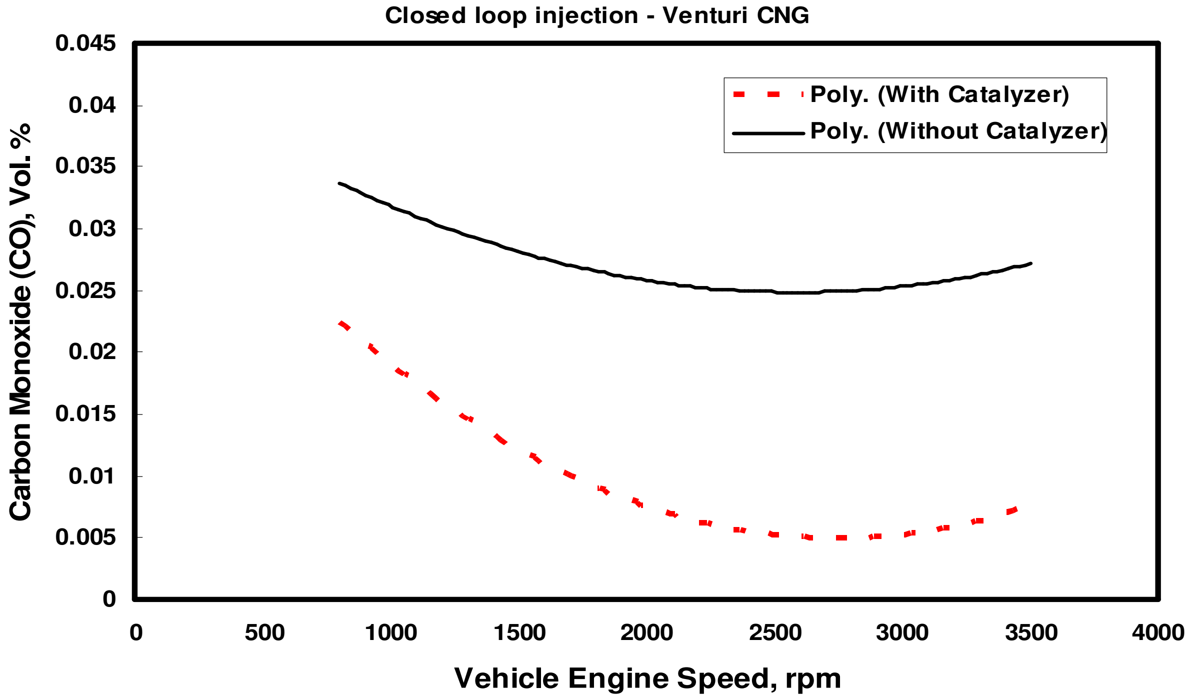

Figure 13. The influence of using catalyzer on carbon monoxide (CO).

presented with and without catalytic converter (catalyzer). A substational reduction is observed for the levels of the exhaust gas emissions components of CO, CO_2 and THC when the catalyzer is used.

In Figures 13 to 15, the effectiveness of catalytic converter on the vehicle exhaust gas emissions components in the idle state is shown, where the values of carbon monoxide (CO), carbon dioxide (CO_2) and total

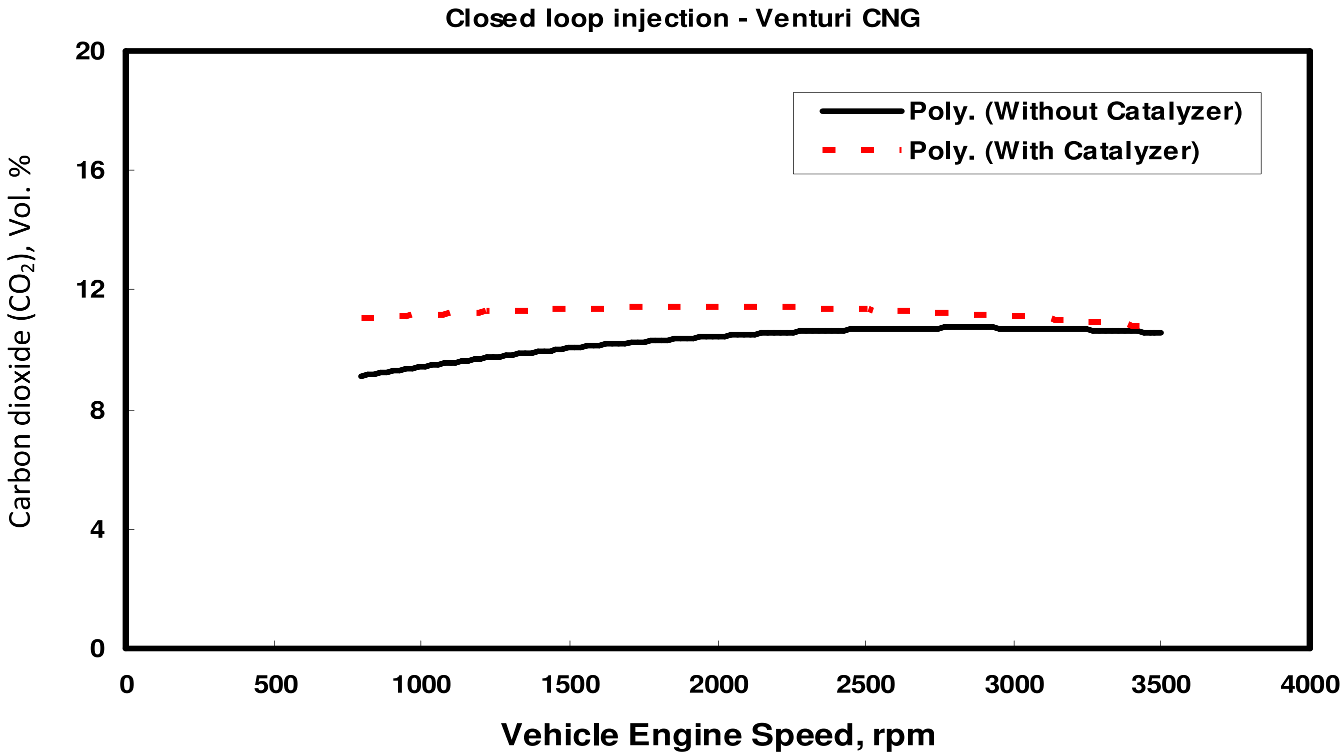

Figure 14. The influence of using catalyzer on carbon dioxide (CO_2).

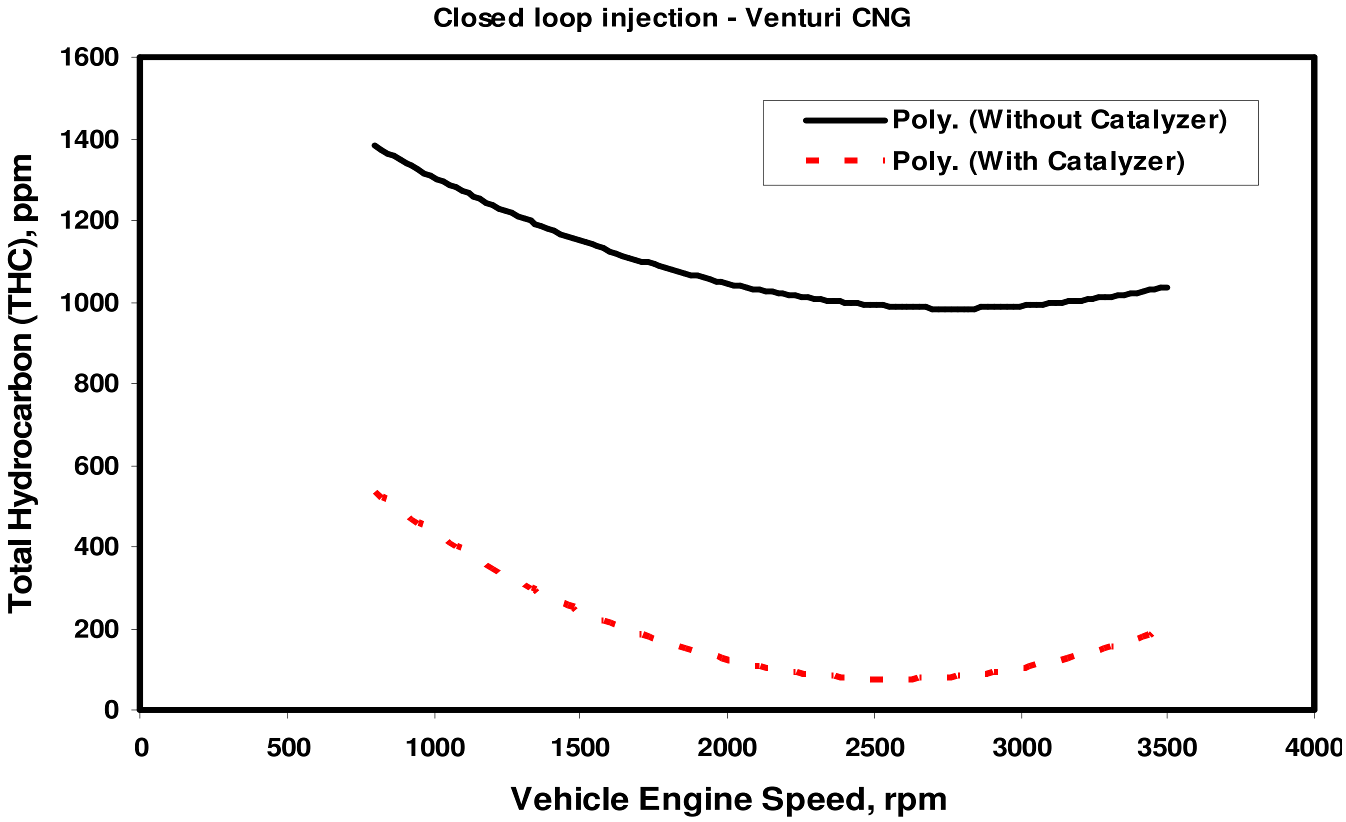

Figure 15. The influence of using catalyzer on total hydrocarbon (THC).

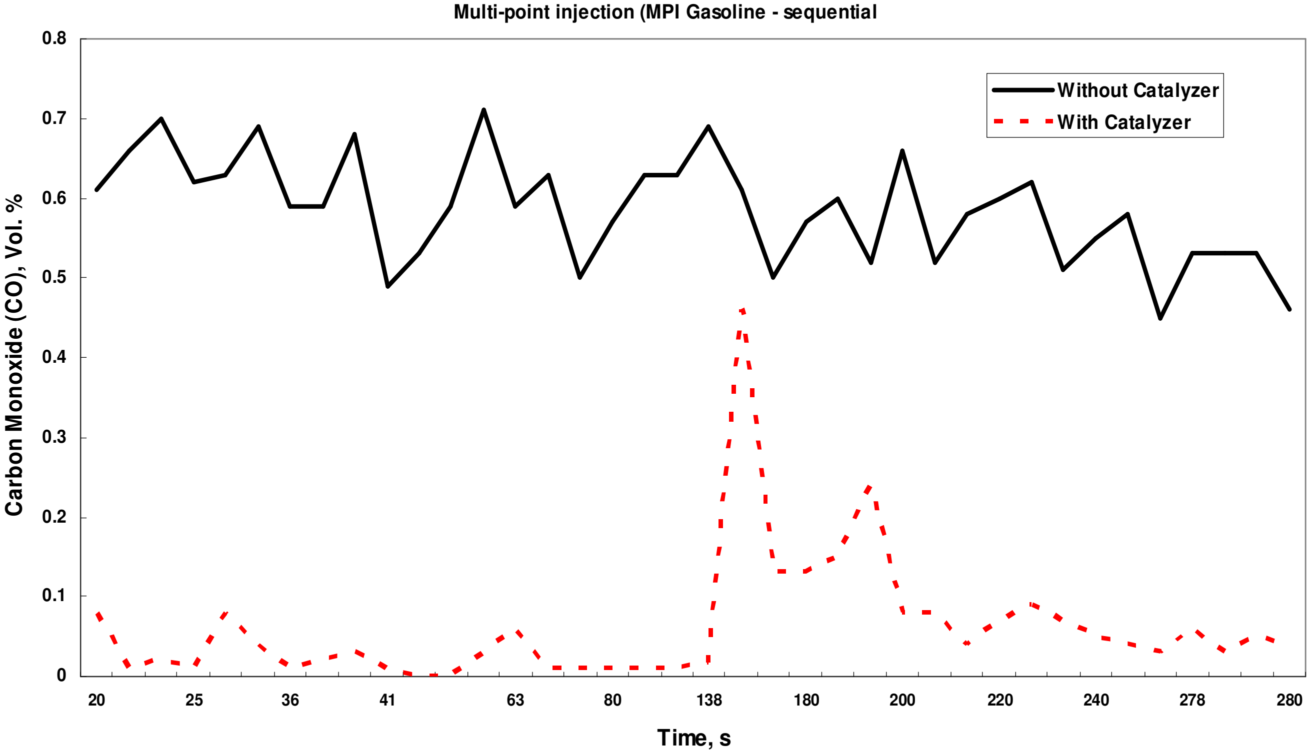

Figure 16. The influence of using catalyzer on carbon monoxide (CO).

hydrocarbon (THC) measured for the bi-fuel vehicle in steady-state when operated by closed loop (venturi) injection system are shown respectively. The fuel is being compressed natural gas (CNG) and the results are presented with and without catalytic converter (catalyzer). A substational reduction is observed for the levels of the exhaust gas emissions components of CO, CO_2 and THC when the catalyzer is used.

In Figures 16 to 18, the effectiveness of catalytic converter on the vehicle exhaust gas emissions components in the transient state based on the European Driving Cycle (ECE-15), the values of carbon monoxide (CO), carbon dioxide (CO_2) and total hydrocarbon (THC) measured for the bi-fuel vehicle when operated by multi-point injection (MPI) system are shown respectively in Figure 3. The fuel is being gasoline and the results are presented with and without catalytic converter (catalyzer). A substational reduction is observed for the levels of the exhaust gas emissions components of CO, CO_2 and THC when the catalyzer is used.

In Figures 19 to 21, the effectiveness of catalytic converter on the vehicle exhaust gas emissions components in the transient state based on the European Driving Cycle (ECE-15), the values of carbon monoxide (CO), carbon dioxide (CO_2) and total hydrocarbon (THC) measured for the bi-fuel vehicle when operated by multi-Figure 3. The fuel is being compressed natural gas (CNG) and the results are presented with and without catalytic converter (catalyzer). A substational reduction is observed for the levels of the exhaust gas emissions components of CO, CO_2 and THC when the catalyzer is used.

In Figures 22 to 24, the effectiveness of catalytic converter on the vehicle exhaust gas emissions components in the transient state based on the European Driving Cycle (ECE-15), , the values of carbon monoxide (CO), carbon dioxide (CO_2) and total hydrocarbon (THC) measured for the bi-fuel vehicle when operated by closed loop (venturi) injection system are shown respectively in Figure 3. The fuel is compressed natural gas (CNG) and the results are presented with and without catalytic converter (catalyzer). A substational reduction is observed for the levels of the exhaust gas emissions components of CO, CO_2 and THC when the catalyzer is used.

Catalyst conversion efficiency results

In idle state testing, Figures 25 to 27 show the catalyst conversion efficiencies for the CO, CO_2 and THC components resulted from the bi-fuel vehicle, where the point injection (MPI) system are shown respectively invehicle is being equipped by multi-point injection (MPI) system (gasoline), multi-point injection (MPI) system (gasoline) (CNG) and closed loop (venturi) injection

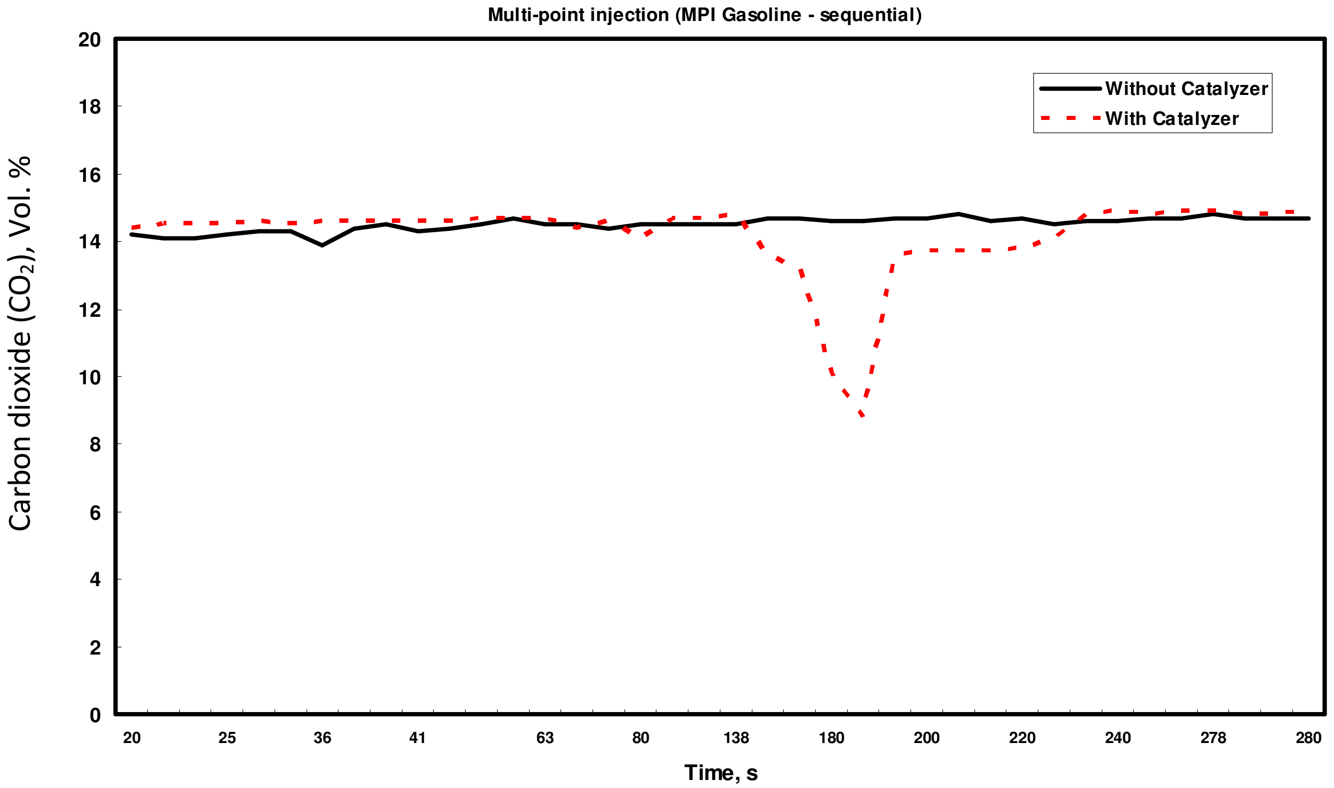

Figure 17. The influence of using catalyzer on carbon dioxide (CO_2).

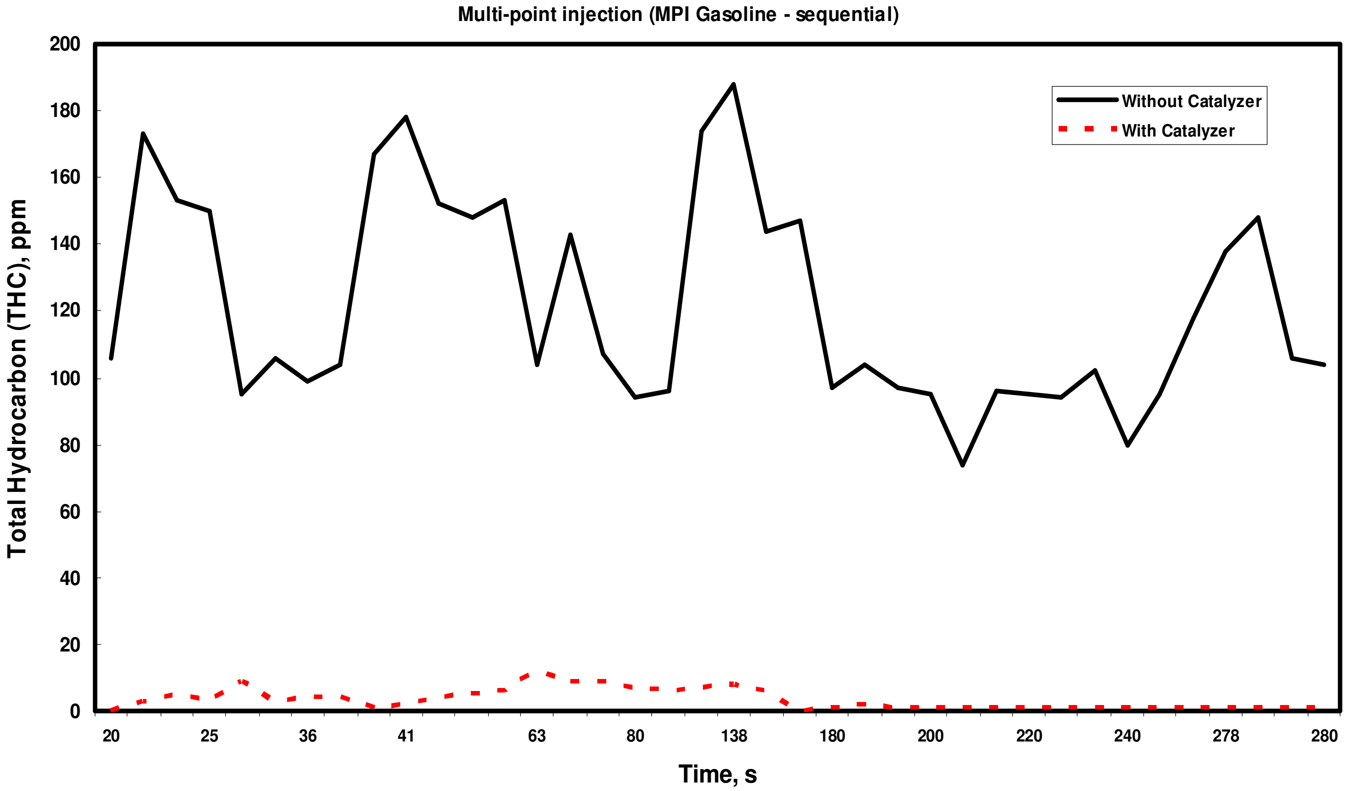

Figure 18. The influence of using catalyzer on total hydrocarbon (THC).

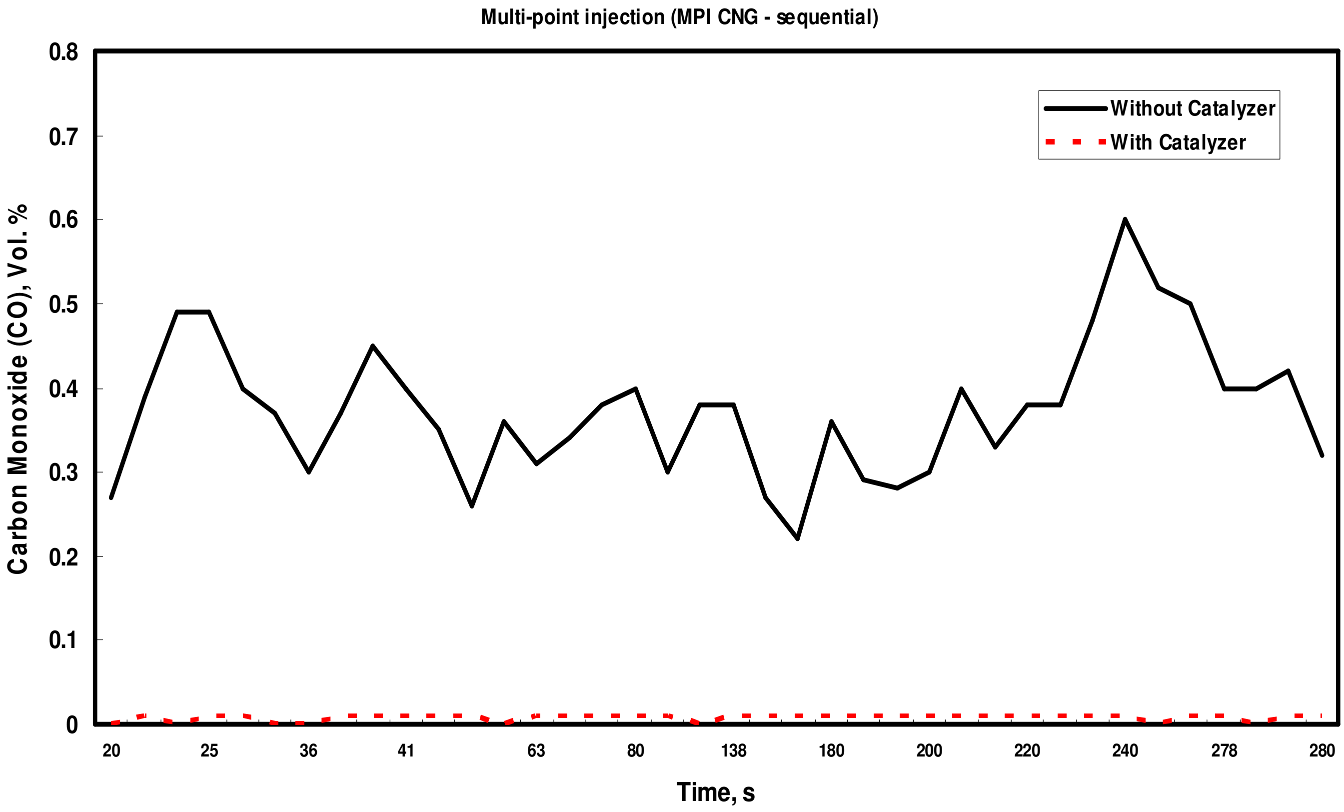

Figure 19. The influence of using catalyzer on carbon monoxide (CO).

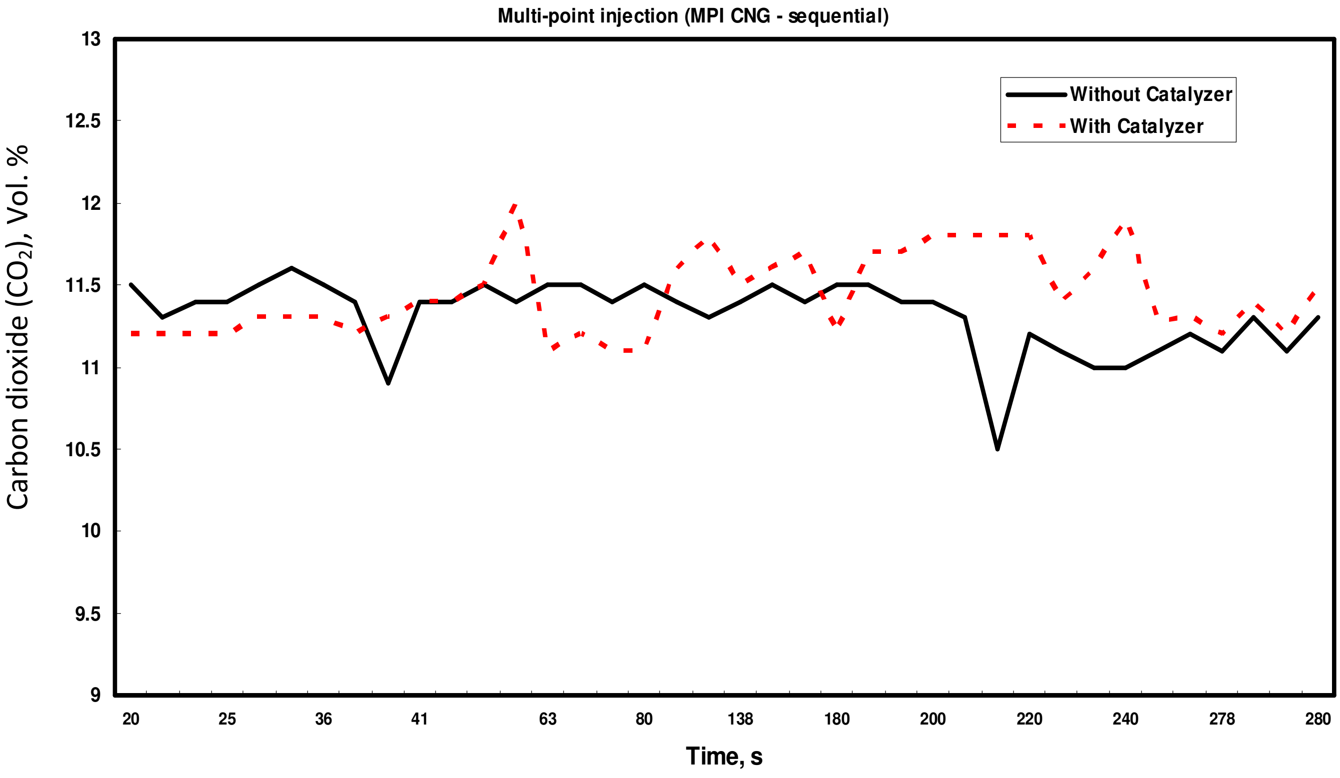

Figure 20. The influence of using catalyzer on carbon dioxide (CO_2).

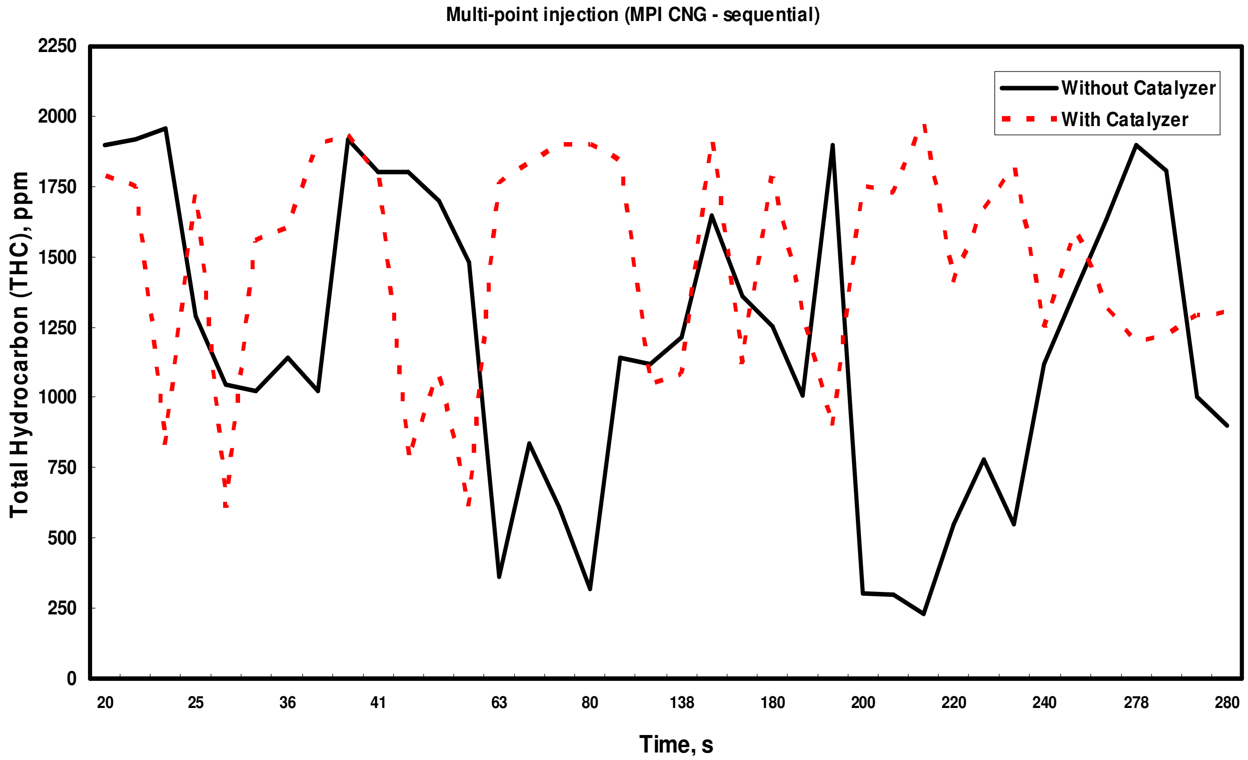

Figure 21. The influence of using catalyzer on total hydrocarbon (THC).

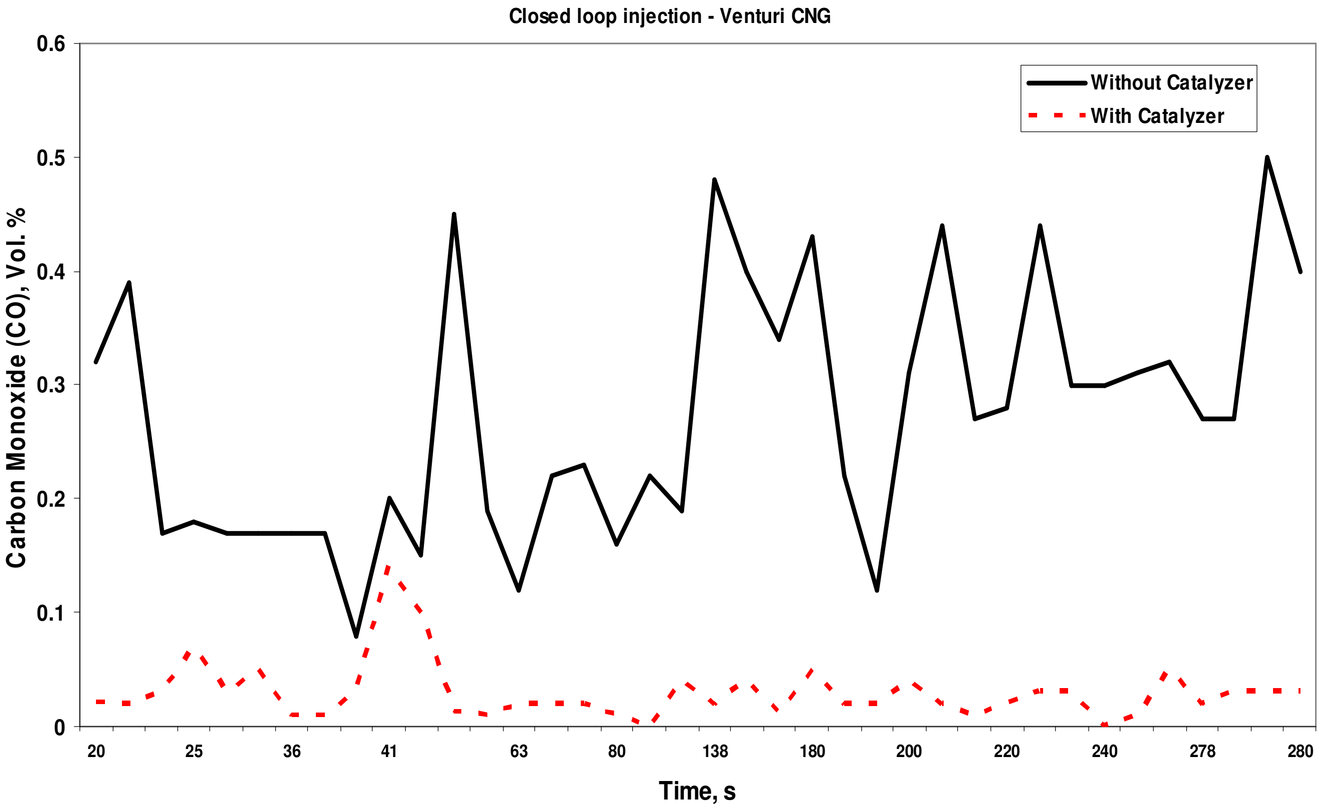

Figure 22. The influence of using catalyzer on carbon monoxide (CO).

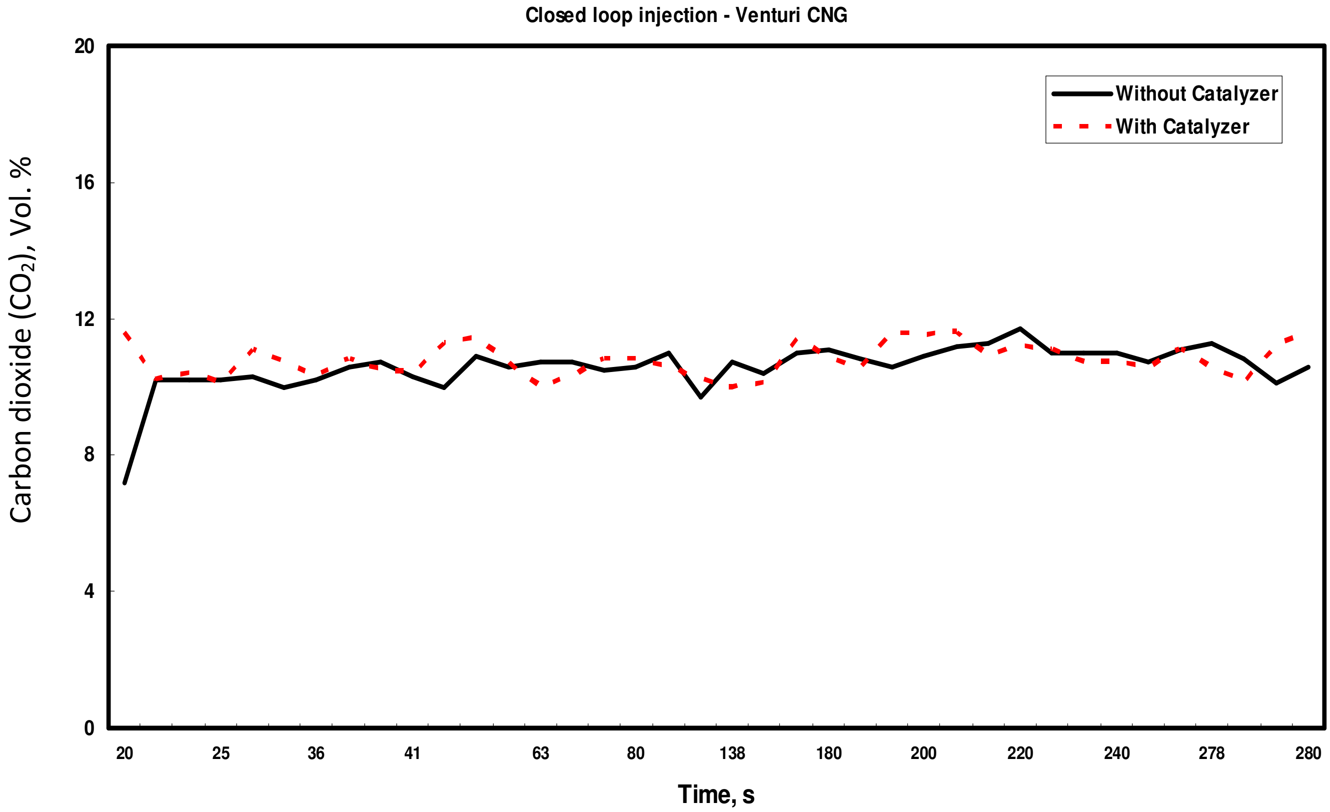

Figure 23. The influence of using catalyzer on carbon dioxide (CO_2).

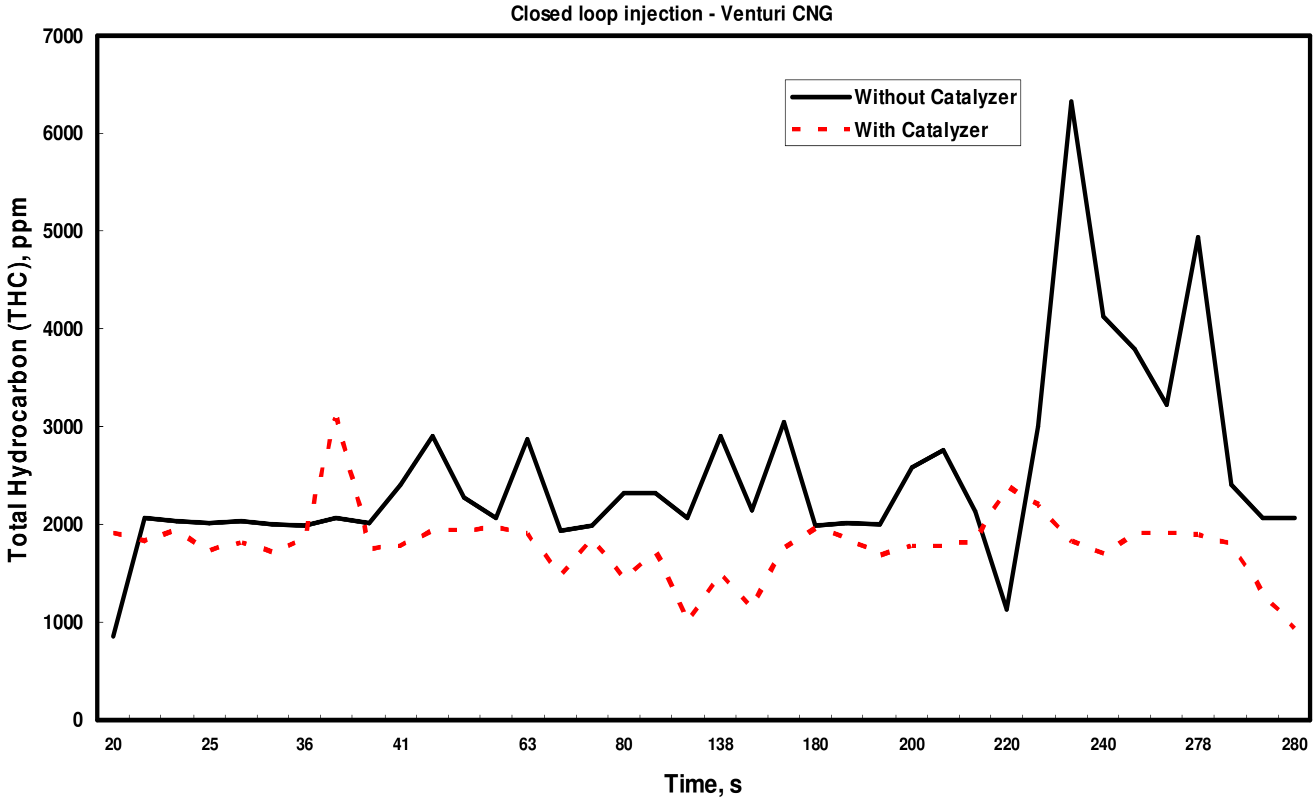

Figure 24. The influence of using catalyzer on total hydrocarbon (THC).

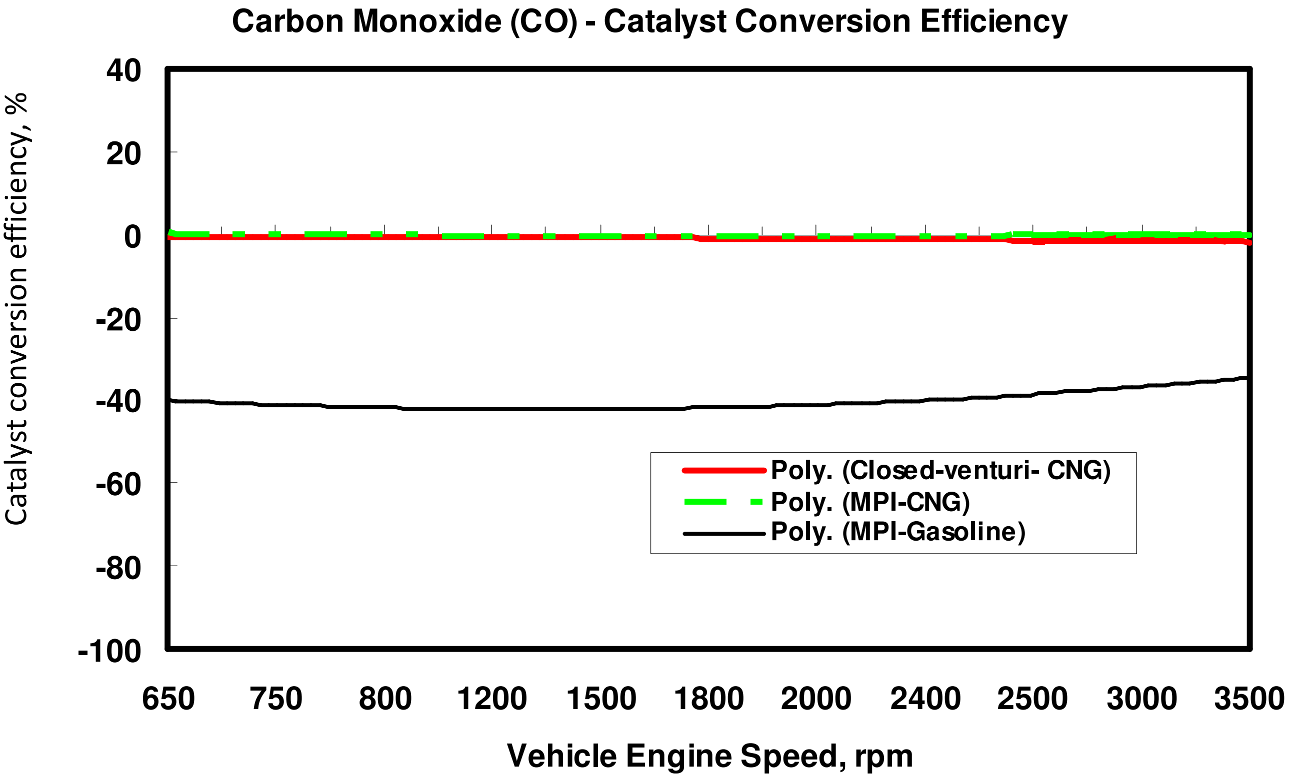

Figure 25. Catalyst conversion efficiency of carbon monoxide (CO).

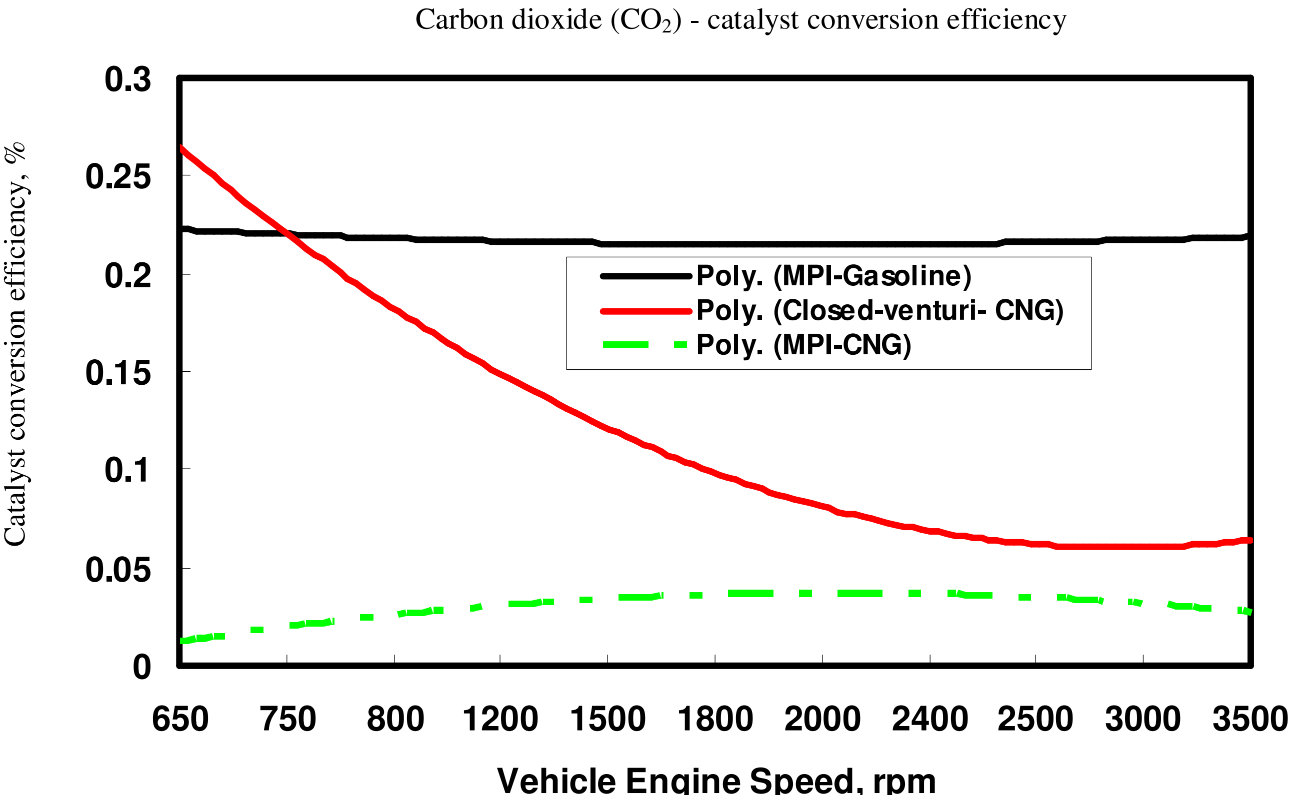

Figure 26. Catalyst conversion efficiency of carbon dioxide (CO_2).

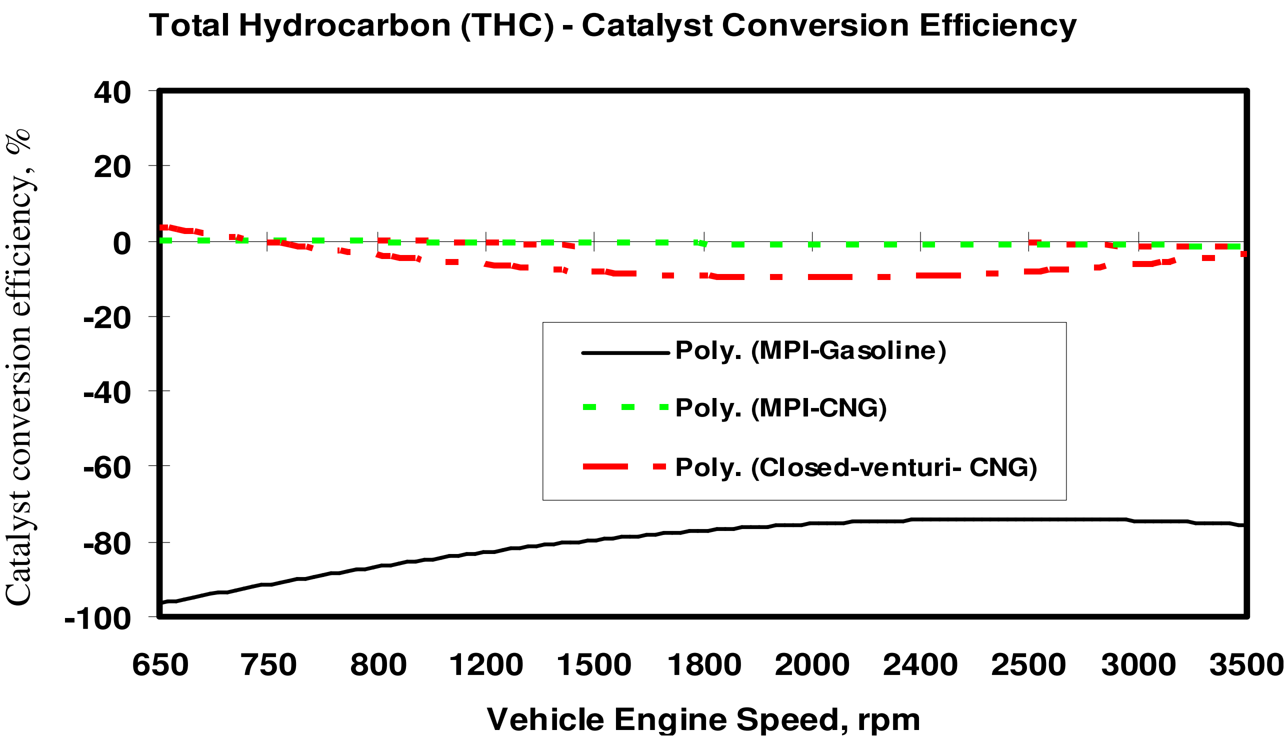

Figure 27. Catalyst conversion efficiency of total hydrocarbon (THC).

(CNG) system, respectively. The catalyst conversion efficiencies are calculated based on Equation 1. It is clearly seen that the catalyst conversion efficiencies (CCE) gained due to the use of the catalytic converter and multi-point injection (MPI) system in the gasoline fuel phase that the CCE is more effective in carbon monoxide (CO) and total hydrocarbon (THC), where they reaches over -40% and over -90% respectively. In the case of carbon dioxide (CO_2), the CCE indicates the value of about 0.22%. The use of multi-point injection (MPI) system in the CNG fuel phase is less effective, where the reduction in CO and THC are about -0.1% and -0.15% respectively, while increase in CO_2 is about 0.05%. In closed loop (venturi) injection system in the CNG fuel phase, the reduction in CO and THC are -0.0 and -10% respectively, while increase in CO_2 is ranged from 0.06 to 0.28%. However, the catalytic converter reduces the amount of both CO and THC, while increases the amount of CO_2

In on-road (transient state) testing and based on the European driving cycle (ECE-15) shown in Figure 3, Figures 28 to 30 show the catalyst conversion efficiencies for the CO, CO_2 and THC components resulted from the bi-fuel vehicle, where the vehicle is being equipped by multi-point injection (MPI) system (gasoline), multi-point injection (MPI) system (gasoline) (CNG) and closed loop (venturi) injection (CNG) system respectively. The catalyst conversion efficiencies are calculated based on Equation 1. It is observed that the catalyst conversion efficiencies (CCE) for carbon monoxide (CO) gained due to the use of the catalytic converter and multi-point injection (MPI) system in the gasoline fuel phase, multi-point injection (MPI) system in the CNG fuel phase and closed loop (venturi) injection system in the CNG fuel phase, where the values of CO for all the injection systems considered vary against the testing time within the side of reduction with the variation values for MPI-gasoline is bigger followed with MPI-CNG with the lest for closed-loop system (Figure 28). In the case of carbon dioxide (CO_2) values for all the injection systems considered only MPI- gasoline and MPI-CNG vary against the testing time in both sides (decrease and increase) with the variation values for MPI-CNG is bigger than that for MPI-gasoline with almost tiny reduction values for closed-loop system (Figure 29). In the case of total hydrocarbon (THC) values for all the injection systems considered only MPI- gasoline varies against the testing time within the side of reduction, while the other two injection systems exhibit almost tiny reduction values (Figure 30). However, the catalytic converter is more effective in MPI-gasoline than those for the other two injection systems.

It is well known that the formation of CO in internal combustion engine is a result of incomplete combustion of the fuel. This occurs when there is insufficient oxygen near the hydrocarbon (fuel) molecule during combustion. Moreover, incomplete combustion could be caused by the quenching of the hydrocarbon oxidation near a

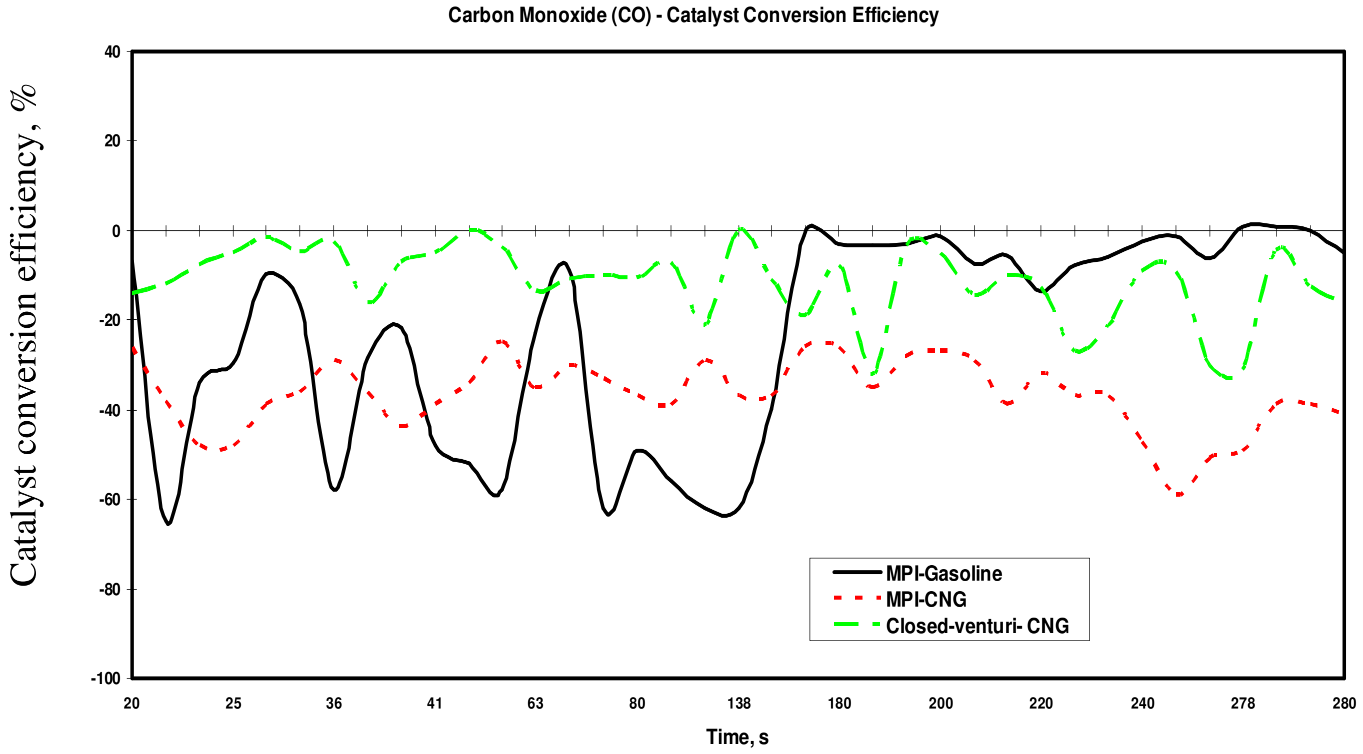

Figure 28. Catalyst conversion efficiency of carbon monoxide (CO).

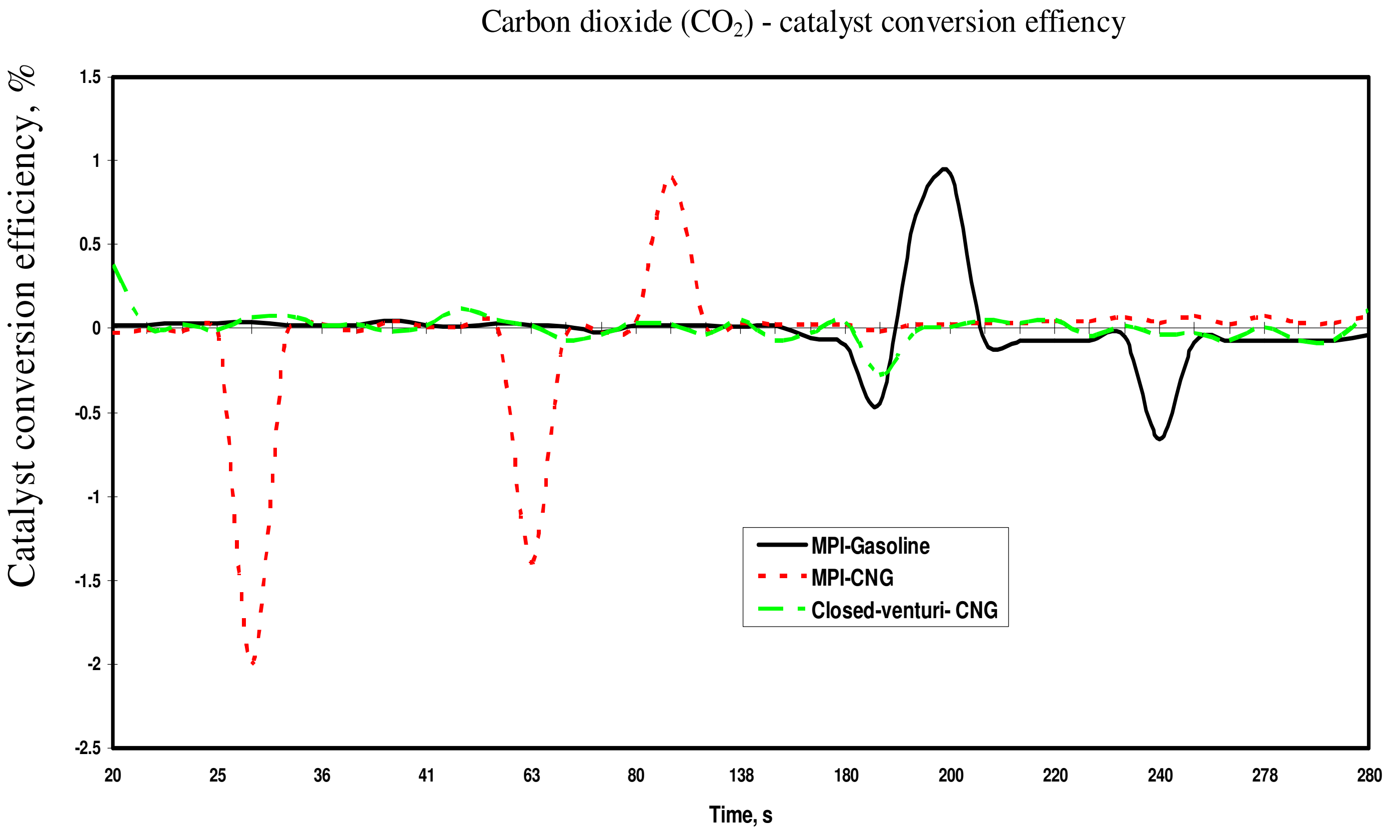

Figure 29. Catalyst conversion efficiency of carbon dioxide (CO_2).

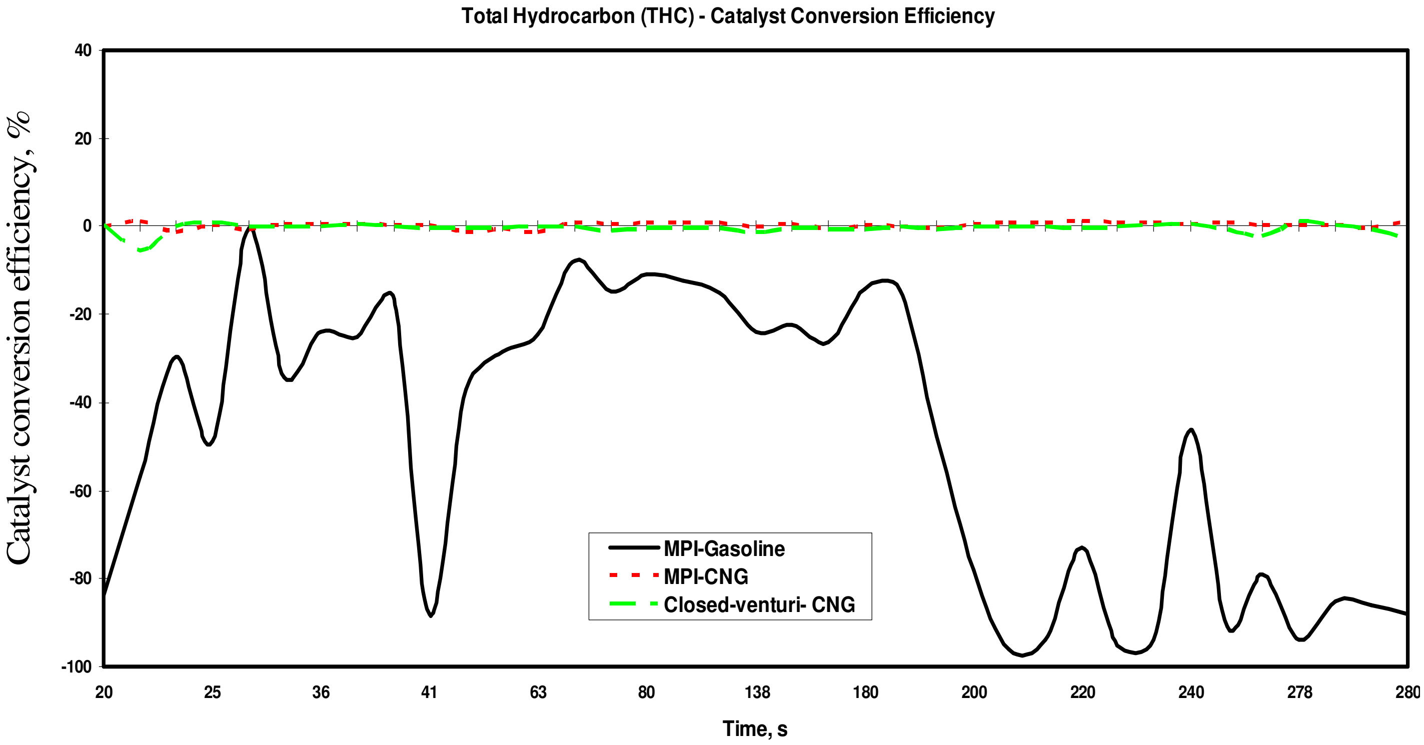

Figure 30. Catalyst conversion efficiency of total hydrocarbon (THC).

cold surface in the combustion chamber. However, in either steady or transient state and with MPI system, it is found that CNG produces a lower level of CO emissions due to lean conditions as compared to gasoline fuel. This result reveals that CeO_2 is effective as an OSC that supports platinum (Pt) to oxidize CO into CO_2 at low to high temperature. On the other hand, it is found that CNG reduces lower THC emission (non methane THC) mainly due to lean burn condition than gasoline. The catalytic material is effective to oxidize HC with increasing speed or catalytic temperature, where the conversion efficiency of CNG is lower than gasoline fuel.

Conclusions

1- It is found that the reason behind the increase of total hydrocarbon (THC) in compressed natural gas (CNG) operated vehicle over that produced in gasoline operated vehicle is due to the difficulty in oxidizing the unburned hydrocarbons in the exhaust gases, where the oxidization of hydrocarbons is one of the functions of the three–way catalyzer. The exhaust hydrocarbons of a gas-operated vehicle have a significantly different composition to those of a gasoline-operated vehicle.

2- The effectiveness of catalytic converter (catalyzer) in the condition of idle state is much better than that for transient state based on the European Driving Cycle (ECE-15) shown in Figure 3, where in the case of idle state, the catalyzer is fully warm and hence operating at it's maximum efficiency, while for the case of transient state condition the effectiveness is not very well, where the catalyzer was faced by air flow and temperature changes rapidly.

3- In the case of catalyst conversion efficiency, the catalytic converter reduces the amount of both CO and THC, while increases the amount of CO_2 (idle state). This is attributed to the fact that the vehicle emission levels are quite low and the noble metal catalyst required for the THC emissions would easy remove most of the CO under these lean conditions. Furthermore, the catalytic converter is more effective in MPI-gasoline than those for the other two injection systems (transient state).

4- It is hope that the results in this study can help to adopt and developed Cairo driving cycle, which is more realistic to represent Cairo traffic conditions, and can be used for tests of vehicles running in Cairo in future in order to report the real world performance of vehicles in service. Thus providing information for Egyptian's energy and environmental ministry on how to set up proper national standards for the motor vehicles fuel consumption and exhaust emissions. It is also hoped that the proposed methods could be used for other big cities as well as for other types of vehicle.

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