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ORIGINAL PAPER

Potential for improving vehicle fuel efficiency and reducing the environmental pollution via fuel ionization

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Abstract In order to reduce the level of atmospheric pollution caused by vehicle engine emissions, application of a novel technique based on fuel magnetization has been tested in this study aiming at improving fuel efficiency and reducing the rate of gas emissions into the environment. Two experiments were conducted, each using a different type of magnetic device. The first type of magnetic device is installed within the fuel tank and the second is installed onto the fuel line. Each experiment was performed on ten separate vehicles from the Dubai Taxi Corporation fleet. When compared to the baseline data, reductions of 70 % for both hydrocarbon and carbon monoxide emissions, and 68 % for oxides of nitrogen were recorded. Results also demonstrated an average fuel consumption reduction of 18 %. These results clearly indicate that the introduction of magnetic field within the fuel supply of engine enhances the combustion process, thereby economizing fuel consumption and reducing the environmentally harmful emissions.

Keywords Exhaust emission · Fuel consumption · Ionization · Magnetic device · On road testing

Introduction

Vehicles have brought many perceived improvements to people's lives, but they have also changed many cities into sprawling conurbations, developed a huge thirst for oil, become a major source of air pollution, and are now the most rapidly growing contributor to climate change (Walsh 2009). The move to improve air quality in cities across the world is made even more difficult as the number of vehicles produced, owned, and operated continues to increase. The emissions from this growing number of vehicles not only contribute to climate change, but also exacerbate adverse health effects for the populace. In Dubai, motor vehicles are the largest producers of greenhouse gases and pollutants; they account for more than half of regulated emissions (Road and Transportation Authority 2009). This becomes all the more worrying as Dubai's vehicle usage (in total miles traveled) increases and even outstrips Dubai's population growth. Studies showed that private vehicles emit about 95 % more carbon monoxide, 92 % more volatile organic compounds and about twice as much carbon dioxide and nitrogen oxide than public vehicles for every passenger mile traveled (Al-Zubaidi and Sabie 2004). The oxides of nitrogen are considered to be the major cause of pollution in the emirate of Dubai (Alkemade and Schumann 2006; Manzie et al. 2007). Already, vehicle emissions are linked to degraded air quality, impaired visibility, global warming, and toxic contaminants that threaten the environment and public health. For many years, researchers have tried designing combustion systems that would allow complete combustion of the hydrocarbon to take place, in order to reduce air pollution. Although technological advancement has been made in areas such as air–fuel mixing, ignition, and temperature control of combustion chambers and catalysts, the problem of air pollution still remains unresolved.

To counter the increasing harmful emissions, new emissions control systems and advances in vehicle propulsion that improve upon the conventional internal

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combustion engine need to be explored. Aksoy (2011) reported that lower emission or clean engines depend on high-quality fuels that must be treated as part of the overall vehicle system.

Fuel treatment concerns the reformulation of conventional fuels (Zhu et al. 2003; Shi et al. 2009), treatment of fuels (Mushrush et al. 2011) and choice of alternative fuels (Rassafi et al. 2006). Future improvements, though not guaranteed, will depend on advancements in both fuel and vehicle technologies such as to promote the use of alternative fuels such natural gas (Hassan et al. 2009), liquefied petroleum gas (Bayraktar and Durgun 2005; Ceviz and Yuksel 2006), hydrogen (Rahman et al. 2009; Genovese et al. 2011) and vegetable oils (Kalam and Masjuki 2004; Yavuz et al. 2008; Refaat 2010). Several research efforts have focused on controlling emissions with existing methodologies. In fact, partial recirculation of exhaust gas, which is not a new technique, has become essential, in combination with other techniques, for attaining lower emission levels (Lapuerta et al. 2000; Abd-Alla 2002; Zheng et al. 2004). Among all of the engine control variables, air–fuel ratio (AFR) is related to fuel efficiency, pollution reduction, and drivability improvement. Maintaining AFR to be the stoichiometric value (14.7) can obtain the best balance between power output and fuel consumption. AFR can also influence the effect of emission control because its stoichiometric value ensures the maximum efficiency of three-way catalysts (Wang et al. 2006). Variations of >1 % below 14.7 can result in significant increase of CO and HC emissions. An increase of more than 1 % will produce more NO_x up to 50 % (Manzie et al. 2001, 2002). These techniques were usually able to reduce the CO and HC outputs and to control NO_x, but did not improve the fuel consumption efficiency. Recent legislations have ensured that all new cars are fitted with catalytic converters in order to reduce emission of pollutants. Though catalytic converters do offer some improvements, they also have their failings. For example, the converters do not work when the engine is first started and the parts are cold and this happens to coincide with the engine's highest output of pollutant exhaust gases. Furthermore, catalytic converters produce more carbon dioxide, which promotes greenhouse effects and runs contrary to political promises to reduce CO_2 emissions. Perhaps most problematic with catalytic converters is that they reduce the efficiency of the engine and thereby increase fuel consumption. A novel technique, based on fuel magnetization, has been used to alleviate the above problems. Magnetization of hydrocarbon fuel is able to break clusters of hydrocarbon molecules and changes the electron spin direction of para state (low energetic) into ortho state (high energetic). They become normalized and independent, distanced from each other, having more surface available for binding (attraction) with more oxygen (better oxidation) (Saksono 2005). The concept of exposing fuel molecules to magnetic field dates back to J.D. Van der Waals and his experiments in the field (Okoronkwo et al. 2010). Fuel molecules subjected to external magnetic field will lead to more re-orientation in order to accommodate the applied external magnetic field (Song et al. 2003). To reduce global warming, it makes sense to look into the treatment of fuel prior to combustion by a short pulse magnetic field. Fuel treatment by short pulse magnetic field before combustion can affect changes in the molecular structure of crude oil and derivative fuels thereby increasing the thermal efficiency of pressurized kerosene (Saksono 2005). Savage (1992) carried out tests to determine the effect of installing a magnetic device to reduce exhaust pipe emissions. The device was fitted around the fuel line upstream of the carburetor. The vehicle used for these tests was a 1988 model Vauxhall Cavalier 1.61 naturally aspirated estate car with an accumulated mileage of 106,700 and was a pool car serviced and maintained by the local agents. He found that carbon monoxide emissions increased by an average of 12.9 %; the hydrocarbon emissions increased by an average of 6.9 % but the oxides of nitrogen emissions decreased by an average of 18 %. A more recent study, carried out in laboratory conditions using a diesel engine, has shown that fuel ionization, achieved by utilizing a magnetic frequency resonator fitted to the fuel supply line, achieved an overall fuel saving of 1.61 % compared to test cycle that was done without ionization (John et al. 2006).

Thus, magnetic devices can play a complementary role to the catalytic converter. Both devices reduce different aspects of pollutant emissions, and the magnetic device can counter the increased fuel consumption caused by the catalytic converter. The magnetic device is designed to condition fuel prior to combustion, thereby increasing output power, saving fuel, and consequently reducing emissions. The device's installation is simple to perform and is designed to be compatible with any engine's nozzle pipes, fuel line, or carburetor fuel line. Successful implementation of such a device has the potential for economic benefits for motorists and significant improvements to air quality in Dubai.

The aim of this study is to devise a series of tests using two different magnetic devices and evaluate their performance. Fuel consumption, vehicle emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen (all measured in g/km) will be measured. This study was conducted in the city of Dubai using the Dubai Taxi Corporation taxi fleet and their laboratory facilities from February to November 2010.

Materials and methods

Magnetic treatment of fuel

To understand how the fuel ionization is achieved using the magnetic device, it is important to understand some chemical aspects of internal combustion. Most fuels for internal combustion are liquid and will not combust efficiently until they are vaporized and mixed with air. The liquid gas is composed of long molecules. Each molecule is composed of a set of atoms and each atom is composed of electrons orbiting a nucleus. The rotating electrons within the molecule create positive (+) and negative (−) charges which inherently give the molecule a degree of magnetic moment. The positive and negative charges within the molecule help hold it together, rather than splitting into smaller molecules, but they also limit the molecule's capacity to actively interlock with oxygen during the combustion process, thereby causing incomplete combustion.

To improve the degree of combustion, the fuels must be decomposed and ionized. This can be achieved if the fuel particles are exposed to a magnetic force. Fuel is principally composed of hydrocarbons. When groups of hydrocarbons flow through a magnetic field, they change their magnetic orientation to be opposite to that of the magnetic field. In the magnetic field, hydrocarbons also change their configuration, which considerably reduces intermolecular forces. These hydrocarbons changes in orientation and configuration are believed to help finely divide and disperse the oil particles within the fuel. Further assistance in atomizing the fuel is believed to come from magnetized hydrogen ions in the fuel and oxygen ions within neighboring air or steam. All of these reactions on the molecular level perpetrate the crushing of the associates of fuel molecules to smaller associates, up to mono molecules. This results in a fuel made up of single and energized molecules that are more readily ionized by oxygen. Consequently, better oxidized fuel combusts more efficiently, resulting in more kilometers traveled per liter of fuel; this is essentially an increase in octane that results in less unburned fuel.

An important consequence of the increased octane is better fuel efficiency. Indeed, higher-octane fuels burn more slowly at high pressures and there is slightly less energy in a gallon of high-octane fuel than low-octane. In this case, the combustion of the fuel results in reduced exhaust levels of HC, CO, and NO_x. An added benefit is that magnetically charged fuels dissolve carbon build-up in carburetor jets, fuel injectors, and combustion chambers, which helps to clean up the engine and extend engine life.

Selection of vehicles

The experiments for this study were performed on ten taxi vehicles by installing a magnetic device on each vehicle. The vehicles were Toyota Camry models for 2008 and 2009. There were two main reasons to choose these vehicles. First, Camry accounts for more than 56 % of the Dubai Taxi Corporation (DTC) fleet and second, the 2008–2009 models sustain high mileage (>400,000 km) and are thus considered to be high-pollution vehicles (HPV). Further impetus for their selection came from their average mileage of 20,000 km per month, which is a large enough base for good data analysis. All vehicles were fitted with an advanced emission control system such as a catalytic converter.

Experimental setup

Magnetic devices come in many different types, varying in model, vehicle capacity, size, installation method, and price. For this study, two types of magnetic device were selected because they proved to be economical, flexible, and easy to be fitted to the fuel line of a car. Both types in the study differ in their installation method. The first magnetic device (MD1) is installed into the fuel tank while the second device (MD2) is fixed with a pipe connection onto the fuel line.

First magnetic device is a solid steel immersion tube that works from inside the fuel tanks for hydrocarbon-driven engines (gas or diesel). It is made of a tin alloy catalyst that acts like a permanent octane booster, combustion enhancer, and combustion chamber carbon deposit cleaner. As soon as the fuel flows through the device, the chemical reaction begins. The shape, temperature, and speed of fuel ignition are transformed, making combustion more complete and even, thereby contributing to greater engine efficiency. The MD1 installation procedure is rather simple and fast (within 20–30 min). First, the fuel tank aspiration pump is taken out of the fuel tank and the magnetic device is installed on the opposite side of the floater. Then, the aspiration pump and the fuel tank are repositioned. MD1 is submerged until it touches the bottom of the tank, such that it leans at an angle of 5°–10°. Figure 1, shows the simple installation of MD1 inside a vehicle's fuel tank. The device is placed into the gas tank and is connected to the fuel pump. The end of the cable may then be hooked to a suitable point on the fuel tank cap.

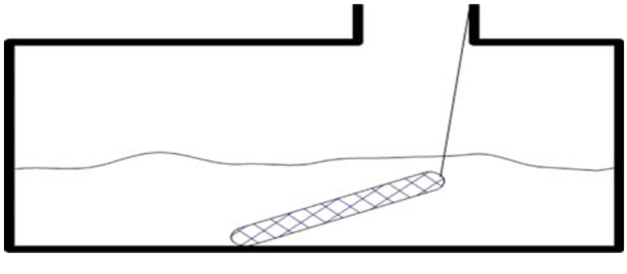

Fig. 1 Installation of the magnetic device MD1 inside the fuel

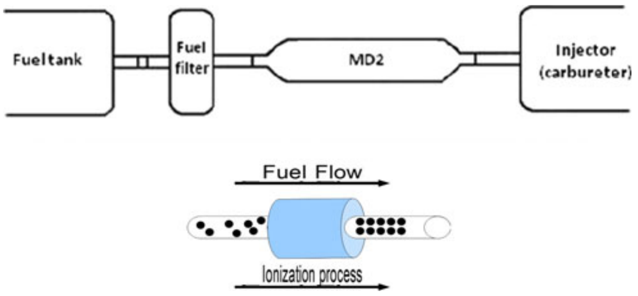

Fig. 2 Installation of the magnetic device MD2 onto the fuel line and illustration of ionization process

Second device ionizes fuel by directing a specific and powerful static magnetic field into the fuel supply line. The device is based on the process of magneto hydrodynamics, where magnetic fields affect fluids in motion. As a result, the fuel's ability to combine with oxygen is improved and greater energy is released. The device is strategically placed on the inbound fuel line near the combustion chamber so that a strong magnetic field penetrates the fuel line perpendicular to the flow of the fuel (Fig. 2). The flowing fuel molecules are subjected to this abrupt magnetic field just before combustion, energizing and dispersing the molecules as described in the previous section. MD2 is held into place on the fuel line using a pipe connection onto the fuel line itself, as shown in Fig. 2. The installation does not necessitate any pipe cutting or electrical connections. The body of the magnetic device is a plastic cylinder (Ø30 × 60) with inlet and outlet branch tubes (Ø12 × 30). The magnetic device should be placed onto the fuel line as close to the injector (carburetor) as possible with the branch tubes inserted into the fuel hose and the entire device held in place with clips.

Testing conditions

Although chassis dynamometer drive cycles have been deployed in vehicle tests in laboratory conditions (Durbin et al. 2002; Kannan and Tamilporai 2011), on-road tests are used for emission measurement under real-world operating conditions (Pelkmans and Debal 2006; Frey et al. 2007). Here, a real-world driving cycle is tested for fuel economy and emission testing. In these tests, the selected vehicles are first run unmodified for 5 months to create base line data. Then, they are converted to a new fuel efficiency device and run for another 5 months. After about 10 months of testing, the data from both experiments are compared. The problem with the real-world approach to testing is that it usually lacks control over four key variables: actual testing conditions, the measurement of fuel consumption, the driver, and the actual data collection process. Unless the data can be normalized for conditions, measurement tolerances, and driver habits that differ between the baseline test and the trial test, they are usually not very relevant. To alleviate this anomaly, some precautions had been taken during the 10 months long experiment. In addition to the baseline data, historical data is available in the DTC system for each vehicle during its life cycle within the taxi fleet. The historical data is used to evaluate the seasonal changes. As for the measurement of the fuel consumption, the DTC fuel tracking system that connects and generates data from the fuel pumping station is more accurate than a dashboard trip computer that would usually be used in real-world tests. Moreover, enough miles have been accumulated during the trial to average out any instantaneous swings. Furthermore, the same driver has been assigned to drive each vehicle on a fixed course to a tightly controlled time/waypoint standard, to accurately duplicate driving in the before and after trial tests.

For both magnetic devices, the tests were conducted on two stroke vehicles (petrol 2.4 cc engine and 75 L fuel tank capacity) over a period of 5 months from July to November 2010 at the Dubai Taxi Corporation. All tests were performed with a minimum mileage of 15,000 km in order to avoid running-in effects of the engines and of the catalysts. A sample of ten taxi vehicles is tested in real driving conditions for each device. These taxi vehicles are assigned to the same taxi drivers in actual daily circumstances. They are subjected to actual hot summer conditions with temperatures above 45 °C and with heavy traffic congestion. It should be underlined that the opacity tests were taken every month on all ten vehicles for each device.

The scheme of the experimental set-up for the exhaust emissions measurement is shown in Fig. 3. For the measurement of gaseous emissions, a gas test bench MAHA MGT 5 was used in conjunction with a MAHA Eurosystem network. A probe connected to the analyzer is placed directly at the end of the exhaust pipe and an average of 1–2 min is needed for the warm-up phase. This extremely short warm-up phase at unit switch-on is due to the very compact measurement chamber equipped with active temperature recognition. The temperature sensor registers the actual measurement chamber temperature erasing the need for the obligatory 10 min warm-up phase.

One baseline test was carried out with each vehicle in its original condition, and the device was then attached and a monthly test was carried out. According to a previous fuel ionization study (Savage 1992), the device gained in effectiveness as the car was further driven. To this end, it was decided to test the vehicles on a monthly basis at a mileage of roughly 20,000 km.

Exhaust samples, taken at the end of each month, as well as the data observed during the preventive maintenance schedule, were analyzed for HC, CO, NO_x (g/km) together with the fuel consumption (km/L). The analyzer measures CO and HC by infrared sensors and NO_x by

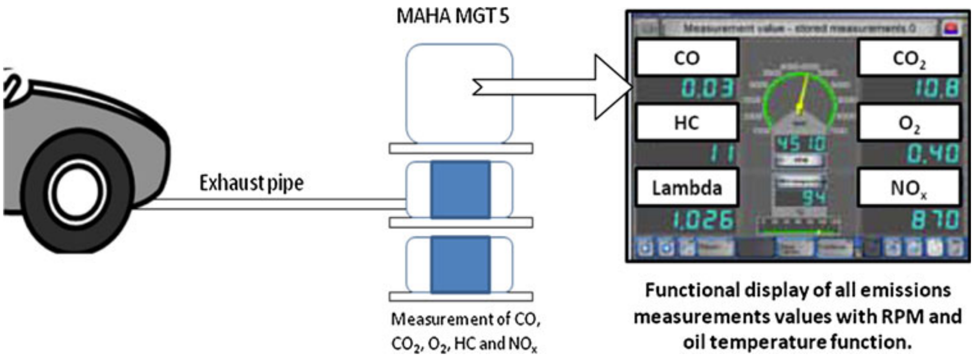

Fig. 3 Experimental set-up

Table 1 Exhaust gas analyzer properties

Exhaust gas	Measurement range	Measurement principle	Accuracy
CO	0–15 vol%	Infrared	±0.03 vol%
HC	0–2,000 ppm	Infrared	±10 ppm vol
CO_2	0–20 vol%	Infrared	±0.5 vol%
O_2	0–25 vol%	Electrochemical	±0.1 vol%
NO_x	0–5,000 ppm	Electrochemical	32–120 ppm vol

electrochemical sensors while the engine operates in normal idle condition. The range and accuracy of the 5-gas analyzer is given in Table 1.

Results and discussion

Since the vehicle tests were carried out on road conditions rather than with the use of a dynamometer under laboratory conditions, it must be accepted that results will vary from car to car and driver to driver; and although there are many variables that affect fuel consumption, the underlying factor must be that all vehicles fitted with the magnetic devices have benefited from reduced emissions after the initial saturation or 'running in' period. This very fact indicates that the engine runs more efficiently and therefore produces more power.

Emission reduction

Exhaust emissions are those pollutants emitted through a vehicle's exhaust system or tail pipe. There are multiple categories under the heading of exhaust emissions, and these include ignition emissions, running emissions, and evaporative emissions. Levels for each of these categories are dependent on several factors including the vehicle's model year, weight class, mileage, maintenance record, and fuel type. The emissions can also vary significantly depending on the model and age of the vehicle, as well as the fuel chosen for operation. The temperature of the engine can also cause the emissions rate to vary, with a cold engine producing more than twice the pollution of a warm engine.

One method of evaluating the effectiveness of a magnetic device is to measure its ability to reduce emissions. The emission results, when using MD1, are displayed in Fig. 3. These show that the CO emission is about 70 % less in comparison with the baseline vehicle and almost 68 % below the emission standard (5.5 g/km). This can be explained by the device's effectiveness in reducing high carbon monoxide emissions caused by incomplete fuel combustion. Indeed, the device contains magnets that eliminate 90 % of the bacteria flora in the fuel tank, increasing effective combustion in the engine, reducing fuel consumption by as much as 18 %, and reducing emissions by 70 %. The movement of the vehicle charges the magnets, creating an electromagnetic field that provides the fuel with more oxygen, allowing it to burn cleaner.

In the case of the NO_x emissions shown in Fig. 3, the average reduction is about 69 % in comparison with the baseline vehicle, which is 45 % below the NO_x emission standard of 0.3 g/km. This can be explained by an improvement in the temperature and burn rate that makes combustion more complete and even and contributes to greater engine efficiency, which in turn makes the maximum in-cylinder pressure and temperature lower and prohibits the formation of NO_x.

The HC emissions from a sample of ten HPV vehicles are also shown in Fig. 3. It can be seen that the average reduction of HC emissions after using MD1 is about 70 % in comparison with the baseline vehicle, which is almost 64 % below the HC emission standard of 1.2 g/km. These lower hydrocarbon emissions may be attributed to the magnetic device's ability to increase the octane, which gives the engine more power and leads to a substantial reduction of emissions (unburned fuel), which can result in extremely low hydrocarbon emissions.

The emission rates of all three pollutants (CO, NO_x and HC) were monitored at the scheduled preventive maintenance, after travelling 15,000 km during the 5 months of

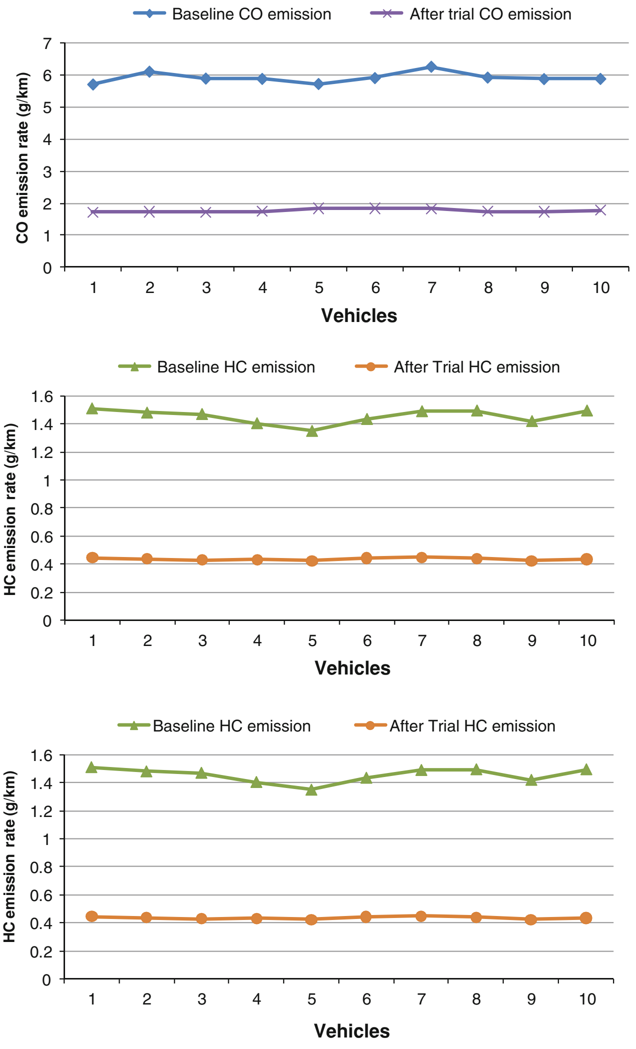

Fig. 4 Emission rate (CO, NO_x, and HC) before and after using MD1

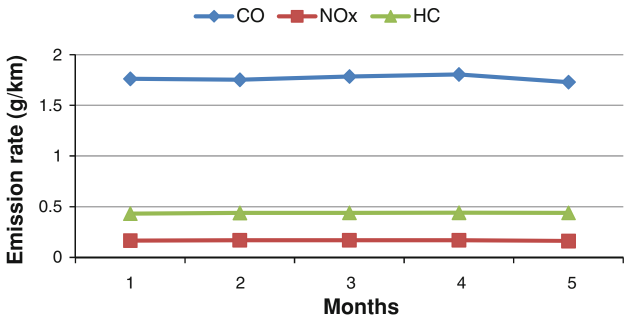

Fig. 5 Emission rates during 5 months

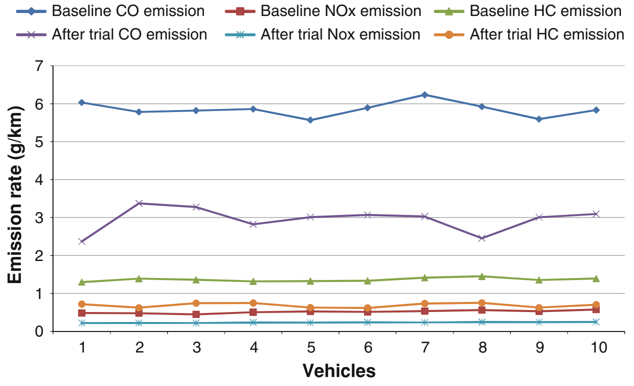

Fig. 6 Comparison emission rate (CO, NO_x, and HC) before and after using MD2

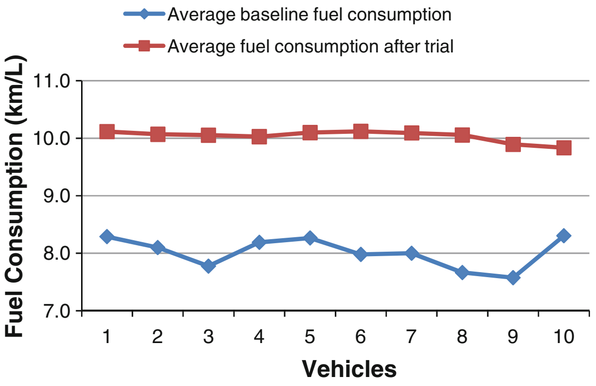

Fig. 7 Fuel consumption before and after trial (km/L) using MD1

the experiment. As shown in Fig. 4, the outcome was below the target, which means this scheme is recommended for application in all fleet organizations in order to reduce emissions.

Significant emission benefits were also achieved when using the second device, MD2, as depicted in Fig. 5. The latter shows the comparison between the emissions rate before the trial and after the trial, as well as the target. The results after the trial were below the Euro II target. In the case of CO, NO_x, and HC emissions shown in Fig. 5, the average emission reduction after using MD2 is about 50, 55, and 86 %, respectively, in comparison with the baseline vehicle and almost 46, 22 and 43 % below the emission standards of 5.5, 0.3, and 1.2 g/km, respectively.

Fuel economy

The overall average reduction in fuel consumption when using MD1 was 18 %, as shown in Fig. 6. In the case of MD2, the overall average reduction in fuel consumption was 10 %, as displayed in Fig. 7. In both figures, fuel consumption is considered as a distance per volume (km/L) measure and not a volume per distance (L/km) measure. Hence, with (km/L) measurement, the higher the number the more efficient is the engine. This fuel saving is due to the magnetic field that makes the natural chemical associations (grape-like molecular clusters) break-up into single, energized fuel molecules. This outcome improves combustion efficiency and results in more kilometers travelled for less fuel consumed.

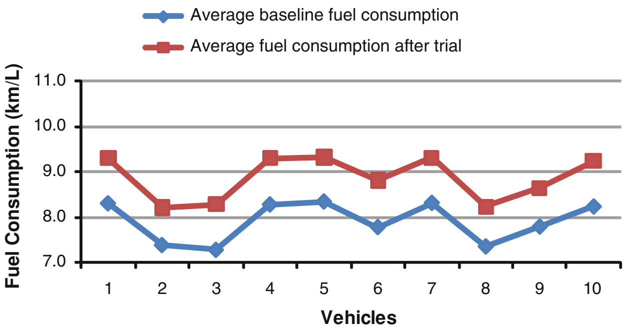

Fig. 8 Fuel consumption before and after trial (km/L) using MD2

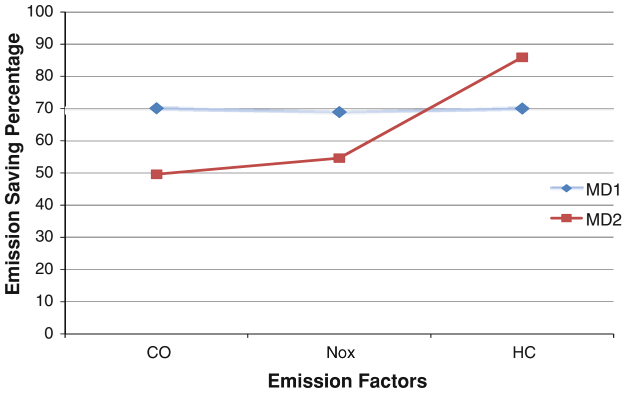

Fig. 9 Saving comparison emission rate (CO, NO_x, and HC) between MD1 and MD2

Comparative analysis

This study revealed that use of magnetic devices in gasoline-powered taxis has the potential to reduce both vehicle emissions and fuel consumption. However, of the two devices, MD1 results demonstrated a greater efficiency than those for MD2. Indeed, as shown in Fig. 8, MD1 reduced gas emission by 29 % for CO and 21 % for HC in comparison with the MD2. In contrast, MD2 reduced gas emission by 22 % for NO_x in comparison with the MD1. Figure 9 shows that MD1 achieved a relevant fuel consumption reduction of 11.60 % when compared to MD2. The additional success of MD1 over MD2 is attributed to its different installation position, and such results hold great interest for high mileage vehicles such as those in the DTC taxi fleet. Assuming an annual traveled mileage of 230,000 km, and a fuel price of 0.38 US$, Table 2 depicts a sample calculation of annual fuel cost saving applied to one taxi vehicle with a magnetic fuel treatment device installed. A fuel cost savings of 10.9 and 20.1 % can be achieved when using MD2 and MD1, respectively.

Table 3 provides a general comparison of gasoline vehicle exhaust emissions with those of natural gas, propane, ethanol, and electric vehicles. In general, alternative fuels such as natural gas, propane, ethanol, and biodiesel have significantly reduced emissions compared to gasoline and diesel vehicles. Electric vehicles are zero-emission vehicles. These alternative fuels are considered to be good solutions for emissions reduction, but they are not yet ready for deployment across an entire fleet due to lacking infrastructure, technology requirements, and high cost. The magnetic devices evaluated here provide an alternative that is both easy to install and available at a reasonable cost. As can be seen in Table 3, the emissions reduction results obtained from the magnetic treatment of gasoline were comparable to natural gas powered vehicles and better than propane and ethanol powered vehicles. It should be noted, however, that the experimental results of the current study are only valid for a period of 5 months and continued study will be necessary to see if results over a longer period of time remain as positive.

Conclusion

This present work has shown that complete combustion of fuel can be obtained using a magnetic field around the fuel line of an internal combustion engine. This magnetic field

Table 2 Fuel cost savings using magnetic devices

Magnetic device	Fuel consumption (km/L) after installation	Fuel consumption (km/L) before installation	Annual fuel cost without device (US$)	Annual total fuel cost with device (US$)	Savings % age
MD1	10.0345	8.0145	10,791.06789	8,618.767	20.1
MD2	8.87037	7.9045	10,941.23773	9,749.877	10.9

Table 3 A general comparison of alternative fuels vehicle exhaust emissions

Pollutant	Natural gas	Propane	Ethanol	Electric	Our experimental results
HC	50–90 % lower	50–60 % lower	20–25 % lower	Over 95 % lower	70–86 % lower
NO_x	30–50 % lower	30–50 % lower	25–32 % lower	60–90 % lower	55–69 % lower
CO	50–75 % lower	40–50 % lower	12–24 % lower	98 % lower	50–70 % lower

can increase the internal energy of the fuel and cause specific changes at a molecular level that provided as much as a 70 % reduction in hydrocarbon emissions, a 70 % reduction in carbon monoxide emissions, a 69 % reduction in nitrogen oxides, and an 18 % increase in mileage. The magnetic treatment of the fuel reduces fuel intake in the engine, increasing fuel economy and reducing the rate of gas emissions into the environment, thereby making it less polluting. The two magnetic devices tested give drivers the opportunity not only to reduce their motoring costs but to make a major contribution in reducing the traffic pollutants that are having a detrimental effect on the environment. In view of these results, it can be suggested that both the inlet manifold and the top cylinder to be manufactured using magnetic material in future engine design projects.

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