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Impact of Magnetic Tube on Pollutant Emissions from the Diesel Engine

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ABSTRACT

Magnetic field applied to fuel can alter its characteristics in terms of forces that hold the hydrocarbons together. This principle was used to investigate the impact of incorporating a magnetic tube in the fuel intake in a diesel generator on specifically the energy performance and pollutant emissions. A diesel generator was fitted with a magnetic tube in the fuel intake, which had valves to switch from without magnetic tube case to with magnetic tube case. The diesel generator was operated at constant speed of 1800 rpm at idle condition, 25% and 50% loads, respectively. Additionally, two real diesel cars were deployed with magnetic tube and their fuel consumption compared with that of a car without magnetic tube. With application of magnetic tube, the brake specific fuel consumption and fuel consumption were decreased by an average of 3.5% and 15%, respectively, while the brake thermal efficiency was improved by approximately 3.5%. The particulate matter, carbon monoxide, hydrocarbons and carbon dioxide emissions reduced in the range of 21.9–33.3%, 5.4–11.3%, 29.4–64.7% and 2.68–4.18%, respectively. Both the total PAH concentrations and total BaPeq concentrations can be reduced by about 63%, 45% and 51%, respectively for idle condition, 25% and 50% loads, respectively. These results show that application of magnetic tubes in the diesel engine is a promising technology in pollutant reduction and energy saving.

Keywords: Diesel engine; Magnetic tube; Regular pollutant; Energy performance; PAHs.

INTRODUCTION

Over the years, diesel engines are preferred by car manufacturers for their high power output and thermal efficiency (Rakopoulos *et al.*, 2010) as well as lower carbon monoxide (CO) and unburned hydrocarbon (HC) emissions compared to gasoline engines (He and Yu, 2005). They have been used commonly in buses, heavy-duty trucks and generators. However, the emissions of particulate matter (PM) (Yao *et al.*, 2015), nitrogen oxides (NO_x), sulfur dioxide (SO_x), unregulated pollutants such as polycyclic aromatic hydrocarbons (PAHs) (Cheruiyot *et al.*, 2015), carbonyls (Yao *et al.*, 2015) and halogenated persistent organic pollutants (POPs) from diesel engines are a major concern (Mwangi *et al.*, 2015a; Cheruiyot *et al.*, 2016), since they are are toxic to the human health (Popovicheva *et al.*, 2013). Several techniques to reduce diesel engine emissions have been put forward including improving the mechanical design of the engine, but the diesel engine has been developed over century and the technology has matured. Other techniques include altering the characteristics of the diesel fuels by lowering the lower sulfur content to decrease SO_x and adding additives such as alcohols, water containing acetone and dimethyl ethers (Mwangi *et al.*, 2015b; Tsai *et al.*, 2015a, b; Yao *et al.*, 2015). Alternative fuels such as biodiesel and biodiesel-diesel blends have as also been considered (Chang *et al.*, 2014a, b; Popovicheva *et al.*, 2013; Mwangi *et al.*, 2015b, c). Biodiesel can reduce some of the pollutants like PM, CO, HC and POPs, because of its higher oxygen content, it results in a more complete combustion (Raheman and Ghadge, 2007; Lin *et al.*, 2010; Yu *et al.*, 2014). On the other hand, the cost of production, higher viscosity and lower heating value are the main shortcomings of using biodiesel in the diesel engine (Saxena and Maurya, 2016).

Apart from changing the quality of diesel fuel, other methods include application of after-treatment devices such as such as diesel particulate filter (DPF), exhaust gas recirculation (EGR) and selective catalytic reduction (SCR). However, these technologies are not without drawbacks. For

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example, the DPF may results in PCDD/Fs enhancement (Heeb *et al.*, 2007; Heeb *et al.*, 2008; Chen *et al.*, 2017), while the EGR may create more incomplete combustion, which lead to increased emission of HC and CO (Maiboom *et al.*, 2008). The use of SCR has the potential to emit secondary pollutant (Koebel *et al.*, 2000). Therefore, as a result of shortcomings experienced when using conventional emission control technologies, some researchers have focused their attention and efforts in application of magnetic field in diesel engines to achieve pollutant reduction as well as fuel saving.

Previously, few studies have evaluated the impact of magnetic field on the diesel engine and diesel fuel as well as gasoline engines in terms of pollutant emissions and energy performance (Govindasamy and Dhandapani, 2007b; El Fatih and Saber, 2010; Faris *et al.*, 2012; Jain and Deshmukh, 2012; Patel *et al.*, 2014; Chaware and Basavaraj, 2015). It is worth noting that while other pollution control devices are placed at post-combustion zones, the devices using magnetic field are applied on the fuel line prior to combustion in most cases. Patel *et al.* (2014) has reported 8%, 27.7%, 30% and 9.72% reduction in fuel consumption, NO_x, HC and CO_2 respectively when using a 2000 gauss magnet on a single cylinder four stroke diesel engine. In another study, Ugare *et al.* (2014) used a 5000 gauss magnet and achieved 12%, 22% and 7% reduction in fuel consumption, HC and CO emissions, respectively, but reported 19% and 7% increase in NO_x and CO_2 respectively. Similarly, Faris *et al.* (2012) applied a range of 2000–9000 gauss magnets and achieved a 9–14% reduction in fuel consumption, which was proportional to magnetic strength, while the reduction of CO and HC were 30 and 40%, respectively, and CO_2 increased by up to 10%.

In this study, a magnetic tube fitted on the fuel line was used to evaluate the impact of magnetic field on the energy performance of a diesel engine generator in terms of the brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE). Additionally, the effects of magnetic field on the emissions of PM, CO, HC, NO_x as well as PAHs were also studied. While most studies place permanent magnet on the fuel line without a choice of bypassing the magnetic tube, in this study a magnetic tube was fitted between the engine and the fuel tank with valves to allow the bypassing of the magnetic tube.

EXPERIMENTAL SECTION

Engine, Magnetic Tube and Driving Cycle

In this study, a diesel engine generator with a maximum power output of 30 kW and a speed of 1800 rpm was used and the specifications are as listed in Table 1. The diesel engine was run with diesel fuel obtained from CPC Corporation Taiwan. The diesel engine generator was fitted with a 150 gauss magnetic tube (details in Table 1) between the fuel tank and engine as shown in Fig. 1. During the experiments, valves were used to switch the fuel lines to be with or without magnetic tube. The tests on the diesel engine generator were carried at three different loads at constant speed of 1800 rpm. For each load, the tests were carried with and without the magnetic tube for an average of 20 minutes. Finally, the sampled flue gas volumes were normalized to the condition of 760 mmHg and 273 K, and denoted as Nm^3.

Sampling Procedures

During the tests, the engine warmed up for 30 min before each sampling cycle and a minimum of 3 min period was allowed between two consecutive test modes. At least three PM and PAHs samples were collected during each load test and obtained the average after analysis. The exhaust samples for PAH analyses were collected by using isokinetic sampling systems (Fig. 1), which comprised of a glass fiber filter (Whatman International Ltd., 25 × 90 mm), flow meter, condenser, two-stage glass cartridges, and a vacuum pump. The PAHs in the particulate phase were collected by the glass fiber filters. The condenser located before the two-stage glass cartridges was used to lower the exhaust temperature to < 5°C and remove water from the exhaust stream. The PAHs in the gaseous phase were then collected by the two-stage glass cartridges. Specifically, each cartridge, which was previously pretreated via Soxhlet, was packed with a 5.0 cm thick (approximately 15 g) of XAD-16 resin sandwiched between two 2.5 cm-thick polyurethane foam plugs.

Analysis of Pollutant Emissions from Diesel Engine

The PM results were calculated by weighting the glass fiber filter before and after each sampling. The difference between the two results was the PM mass. After the determination of PM, the glass fibers were used to extract

Table 1. Specifications of the tested engine.

Specifications of the tested engine		Specifications of the magnetic Tube	
Diesel engine generator	KAIXIN	Material	Neodymium-iron-boron (Nd-Fe-B)
Model	KX4100D1	Dimension	379 mm × ψ54 mm
Output	30 kW	Foot hole	ψ8.5 (355 mm × 30 mm
Weight	380 kg	Side holes	1/4" (Pitch 273 mm)
Speed	1800 rpm	Weight	2.06 kg
Current	57 A	Operation Temp.	–20°C–250°C
Voltage	380 V	Surface magnetic	Average < 150 Gauss
Frequency	60 Hz	Application	Gasoline, diesel car and natural gas boiler
Power factor	0.8	Patent Number	M 483318 (Taiwan)
Insulation	H class	Of Magnetic Tube	ZL201420223457.4 (China)
Phase number	3 phases		

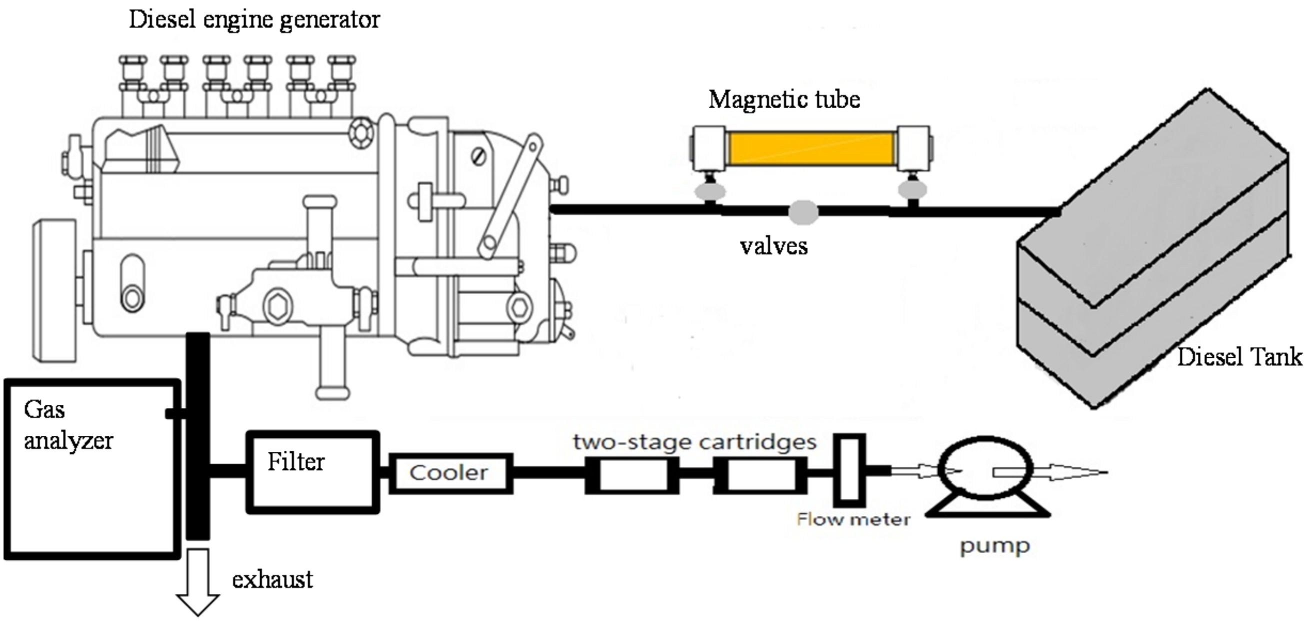

Fig. 1. The schematic diagram of magnetic tube experiment.

the PAHs. The CO, CO_2, HC and NO_x were analyzed using a combustion gas analyzer (E instruments international LLC. 1500-E4500). The CO, CO_2 and NO_x were determined using an electrochemical sensor, where HC were measured by Pellistor sensor. All gas concentrations were normalized to the condition whereby O_2 concentration was equal to zero.

For PAHs, each sample was extracted by a Soxhlet extractor using a mixed solvent (n-hexane and dichloromethane; vol/vol, 1:1) for 24 hours. The extracts were concentrated by gently purging to a dimple by ultra-pure nitrogen. After that, the solution was cleaned up by passing through a column containing silica gel (15 g with a droplet of deionized water for activation; stored in 105°C), anhydrous sodium sulfate (3 g) and glass wool. The effluents and 200 mL n-hexane used to clean the sample were re-concentrated to exactly 1 mL in vial. PAH contents were detected with gas chromatography/mass spectrometry (GC/MS).

The GC/MS (Agilent 5890A and Agilent 5975) for PAH measurement was equipped with a capillary column (HP Ultra 2–50 m × 0.32 mm × 0.17 µm). The 16 PAHs considered in this study were Naphthalene (Nap), Acenaphthylene (AcPy), Acenaphthene (Acp), Fluorene (Flu), Phenanthrene (PA), Anthracene (Ant), Fluoranthene (FL), Pyrene (Pyr), Benz[a]anthracene (BaA), Chrysene (CHR), Benzo[b]fluoranthene (BbF), Benzo[k]fluoranthene (BkF), Benzo[a]pyrene (BaP), Indeno(1,2,3-cd)pyrene (IND), Dibenzo(a,h)anthracene (DBA), and Benzo(ghi)perylene (BghiP). The pertinent operating conditions were as follows: the injection volume of 1 µL; a splitless injection at 300°C; the ion source temperature at 310°C; the oven temperature held at 45°C for 1 min, from 45 to 100°C in 5 min, 100 to 320°C at 8 °C min^{-1}, and held at 320°C for 15 min. The masses of primary and secondary PAHs ions were determined by using the scan mode for pure PAH standards. The PAHs were qualified using the selected ion monitoring (SIM) mode.

Quality Assurance and Quality Control (QA/QC) for PAH Analysis

Prior to the sampling, the glass fiber filters were placed in an oven at 450°C for 8 h, to burn off all organic compounds. The cleaned filters were stored in a desiccator for at least 8 h to equilibrate their humidity levels before and after the sampling.

For PAHs, a breakthrough test was conducted by a three-stage glass cartridge in preliminary sampling work. The results showed the mass of 16 individual PAHs in the third stage was only 0.437–4.13% of that in the total three stages. Thus, a two-stage glass cartridge deployed in this study should ensure more than 95% collection efficiency. Before sampling, the new cartridges were pretreated with methanol, dichloromethane and n-hexane by Soxhlet Extraction for 24 hours each. After the pretreatment, the cartridges were covered by aluminum foil and put it in a desiccator.

The PAH blank samples contained less than 1% of the lowest concentration in this experiment. For the particle phase PAHs, only phenanthrene (0.148 µg Nm^{-3}) and pyrene (0.0945 µg Nm^{-3}) were detected in the blanks. As for the gas phase the following PAH homologues were detected naphthalene (0.404 µg Nm^{-3}), acenaphthylene (0.0480 µg Nm^{-3}), acenaphthene (0.083 µg Nm^{-3}), fluorine (0.170 µg Nm^{-3}), phenanthrene (0.052 µg Nm^{-3}), anthracene (0.0442 µg Nm^{-3}), fluoranthene (0.0905 µg Nm^{-3}), and pyrene (0.111 µg Nm^{-3}).

RESULTS AND DISCUSSION

Impact of Magnetic Tube on Energy Performance

The BSFC, BTE, and fuel consumption were used to evaluate the energy performance. The brake specific fuel consumption (BSFC) is expressed as the fuel consumption per unit electrical energy generation and in appropriate units. Brake Specific fuel consumption (BSFC, g kW^{-1} h^{-1})

is a scale that represents engine performance, whereby a higher BSFC means a lower engine performance. On the other hand, the brake thermal efficiency (BTE, %) is a dimensionless performance measure of a device, such as an internal combustion engine. It indicates how well energy transfer process is accomplished. The BTE (brake thermal efficiency) is defined as the break power of an engine as a function of the thermal input of the fuel or the ratio of brake thermal power to the input fuel energy in appropriate units (Chang *et al.*, 2013; Mwangi *et al.*, 2015a). Fuel consumption is the amount of fuel used per distance ($L\ km^{-1}$) during the real tests drives on the road.

The BSFC and BTE were determined according to Eqs. (1) and (2), where V represents the weight of fuel consumed in each sampling run (g), P is the power generated in (kW), and t represents the sampling time (h) and H represents the heating value ($kJ\ g^{-1}$) of the diesel fuel.

$$BSFC = \frac{V}{Pt}\ \left(g\ kw^{-1}\ h^{-1}\right) \quad (1)$$

$$BTE = \frac{Pt}{VH}\ (\%) \quad (2)$$

The fuel consumption was determined using the Eq. (3), where Vr is the volume of fuel consumed (L) used in real diesel car test, and D is the total distance travelled in kilometers.

$$Fuel\ consumption = Vr/D\ (L\ km^{-1}) \quad (3)$$

Table 2 shows the results of BSFC and BTE at 2 loads of 25% and 50% at two different conditions of with and without application of magnetic tube. After increasing the load from 25% to 50%, the BSFC decreased by 41% and 42%, for the case without and with magnetic tube respectively. On the other hand, the BTE increased with increasing engine loads by approximately 71% and 72% for the scenario without and with magnetic tube, respectively. This is an indication that at higher loads, the combustion in the diesel engine is more efficient. At higher loads the in cylinder temperatures are higher (Chang *et al.*, 2013) which improves fuel atomization and evaporation that enhances fuel air mixing and hence better combustion conditions.

After the magnetic tube was applied, the BSFC reduced by 3% and 4% for the load of 25% and 50%, respectively. Similarly, with application of magnetic field, the increase in BTE was 3% and 4% for 25% and 50% loads, respectively. Chaware and Basavaraj (2015) recently reported an average reduction in BSFC when using 1000, 2000, 3000 and 4000 gauss magnets. Habbo *et al.* (2011) used 1000 and 2000 gauss magnets in a single cylinder four stroke engine and the specific fuel consumption reduced by 12.9 and 21.3% respectively. In their study, (Patel *et al.*, 2014) reported a 2% increase in BTE when applying a 2000 gauss magnet, while Habbo *et al.* (2011) showed 4% and 7.6% for 1000 and 2000 gauss magnetic fields in single cylinder four stroke engines.

Two real diesel cars were used to evaluate the impact of magnetic field on the fuel consumption (Table 3). One was set as control with no magnet tube attached, while the other was fitted with a magnetic tube. It was observed that the fuel consumption decreased by 15% when the magnetic field was applied. In comparison, Faris *et al.* (2012) showed that reduction in gasoline consumption ranged from 9–12% by subjecting the fuel to 2000–9000 gauss magnets.

The reduced BSFC and fuel consumption and increased BTE can be attributed to better combustion efficiency induced by application of magnetic field to the fuel. The diesel fuel is made up of hydrocarbons that are clustered due to various attraction forces (Govindasamy and Dhandapani, 2007a; Patel *et al.*, 2014), which do not allow oxygen penetration for oxidation during combustion resulting in incomplete combustion (Jain and Deshmukh, 2012). Additionally, the hydrogen in the hydrocarbons can exist as either para or ortho giving it opposite nucleus spins (Petkar and Khamkar, 2016). The ortho hydrogen state is the most reactive for combustion thus magnetic field realigns the para state hydrogen to achieve ortho configuration (Chaware and Basavaraj, 2015). The ortho state is characterized by weaker bonds, therefore the magnetic field serves to decluster the fuel hydrocarbons and reduce surface tension allowing them to atomize easily and react better with oxygen (Govindasamy and Dhandapani, 2007a; Faris *et al.*, 2012). Improved fuel oxidation results in a better combustion efficiency, a higher combustion temperatures, a greater power output and reduced fuel consumption for the same power output.

Table 2. The effect of magnetic tube on the energy performance of diesel engine generator.

Engine Load	Energy performance	Without magnetic tube	With magnetic tube
25%	BSFC ($g\ kW^{-1}\ h^{-1}$)	1109	1073
	BTE (%)	2.42	2.50
50%	BSFC ($g\ kW^{-1}\ h^{-1}$)	649	623
	BTE (%)	4.14	4.31

Table 3. The result of the energy performance for real diesel car test without and with the magnetic tube.

	Distance (km)	Fuel Consumption (L)	Average consumption ($L\ km^{-1}$)	Ratio of Saving Energy (%)
Without Magnetic tube	3487	2082	0.6	15.1
With Magnetic tube	6061	3074	0.51	

Impact of Magnetic Tube on Regulated Pollutants

Table 4 shows the emissions of the regulated pollutants from the diesel engine generator with and without magnetic tube at idle state and two loads (25% and 50%). In the presence of magnetic field, the PM, CO, HC and CO_2 emissions reduced by about 21.9–33.3%, 5.4–11.3%, 29.4–64.7% and 2.68–4.18%, respectively. For these pollutants, the highest emissions were registered during idle state due to low combustion efficiency and decreased with increasing engine loads. On the other hand, the NO_x emissions increased by about 1.24–13.4% when the magnetic tube was used. Additionally, the highest NO_x emissions were at higher loads as a result of better combustion achieved at higher loads as the engine performance approaches optimal conditions.

Ugare *et al.* (2014) using a single cylinder four stroke diesel engine reported reductions in CO (11%) and HC (27%) and an increase in NO_x by 19% when they applied 5000 gauss magnet and Faris *et al.* (2012) found out that CO and HC reduced by 30% and 40%, respectively. In the study of Habbo *et al.* (2011), the HC and CO decreased by 80% and 44% for 1000 gauss magnet and 90% and 58% for 2000 gauss magnet, respectively. Contrary to this study, the CO_2 increased by 7% (Ugare *et al.*, 2014) and 10% (Faris *et al.*, 2012). Patel *et al.* (2014) noted 30%, 27% and 9.72% reduction in HC, NO_x and CO_2, respectively, with effect of magnetic field.

The reduction of PM, HC, CO and CO_2 can be attributed to better combustion efficiency, which is induced by the magnetic field that converts para hydrogen into more reactive ortho configuration and weakens the bonds in fuel hydrocarbons making them easy to atomize, mix and react with oxygen in the air. On the other hand, the NO_x emission increased with application of magnetic field in the fuel intake. In the diesel engine, the major NO_x source is the thermal-NO_x, which is controlled by combustion temperatures. Application of magnetic field improves combustion efficiency, which results in higher in cylinder temperatures, which encourage thermal-NO_x formation.

Impact of Magnetic Tube on Total PAH and Total BaPeq Concentrations in The exhaust of Diesel Generator

To the best of our knowledge, no study has focused on the effect of magnetic field on semi-volatile organic pollutants such as PAH emissions from the diesel engine. Fig. 2 shows the impact of magnetic tube on PAH emissions in terms of total PAH mass concentrations and total BaPeq concentrations (toxicity concentrations), respectively, while Table 5 shows the congener profiles for PAHs at different conditions of with and without magnetic tube.

Results shown in Fig. 2 indicate that among the different engine loads, the idle state had the highest PAH emissions due to inefficient combustion conditions. The total PAH and total BaPeq concentrations during the idle state were three times higher than at 25% and 50% loads. The total PAH and total BaPeq concentrations reduced with increased load as the higher loads provided better combustion efficiencies that led to a complete combustion of aromatic and other PAH precursors.

Upon application of magnetic field, the total PAH

Table 4. The effect of magnetic tube on the pollutant emissions from diesel engine generator.

N = 3, conc ± std	Idle			25%			50%		
	Without magnetic tube	With magnetic tube	Reduction (%)	Without magnetic tube	With magnetic tube	Reduction (%)	Without magnetic tube	With magnetic tube	Reduction (%)
PM (mg Nm^{-3})	**88.5** ± 2.55	**59** ± 18.0	**33.3**	**56.7** ± 19.6	**44.3** ± 9.05	**21.9**	**39.6** ± 5.17	**27.6** ± 1.01	**30.4**
CO (ppm)	**2220** ± 36.2	**1970** ± 27.5	**11.3**	**2028** ± 12.5	**1920** ± 8.14	**5.4**	**2018** ± 27.0	**1860** ± 18.9	**7.95**
HC (%)	**0.17** ± 0.00	**0.12** ± 0.00	**29.4**	**0.17** ± 0.00	**0.17** ± 0.00	**0**	**0.17** ± 0.00	**0.06** ± 0.00	**64.7**
NO_x (ppm)	**282** ± 0.00	**320** ± 6.13	**−13.4**	**315** ± 6.06	**333** ± 3.90	**−5.96**	**344** ± 3.00	**348** ± 4.68	**−1.24**
CO_2 (%)	**2.71** ± 0.03	**2.60** ± 0.00	**4.15**	**2.80** ± 0.02	**2.73** ± 0.00	**2.68**	**2.99** ± 0.196	**2.86** ± 0.05	**4.18**

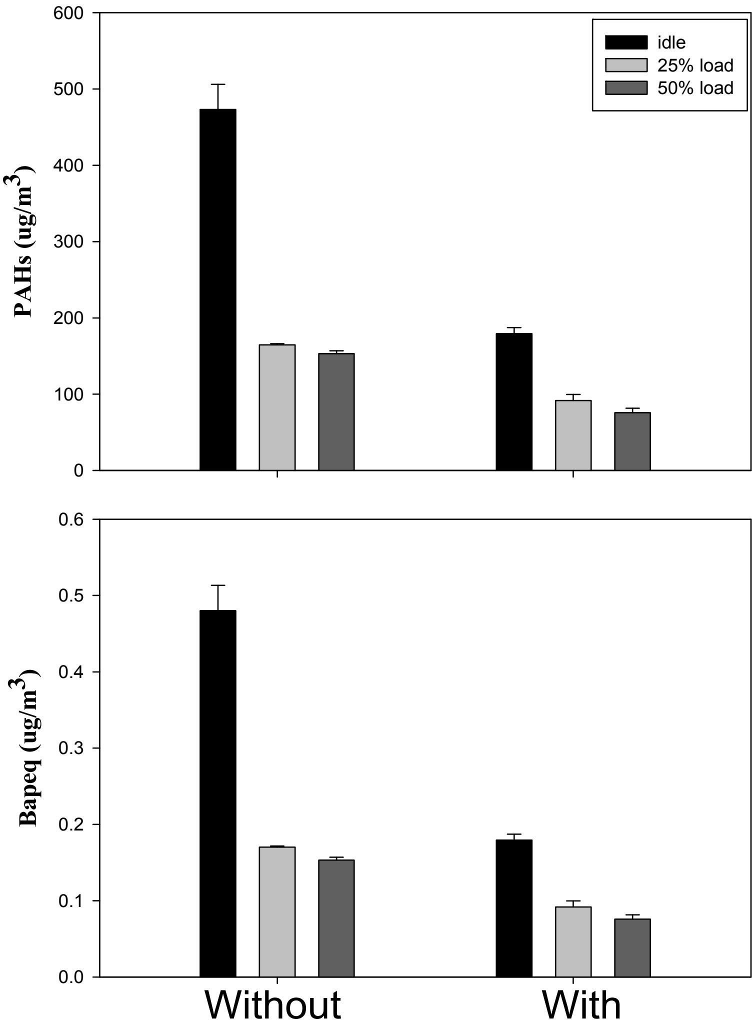

Fig. 2. The impact of the magnetic tube on the total PAH and total BaPeq concentrations in the exhaust of diesel engine generator.

Table 5. The congener profile of PAHs emitted from diesel generator without and with the magnetic tube.

	Idle state		25% Load		50% Load	
	Without magnetic tube	With magnetic tube	Without magnetic tube	With magnetic tube	Without magnetic tube	With magnetic tube
Naphthalene (Nap)	97.2	98.6	90.8	93.2	98.6	95.7
Acenaphthylene (AcPy)	N.D.	N.D.	1.11	0.427	N.D.	0.408
Acenaphthene (Acp)	N.D.	1.44	0.770	0.579	N.D.	N.D.
Fluorene (Flu)	0.456	N.D.	1.64	0.840	N.D.	N.D.
Phenanthrene (PA)	1.15	N.D.	3.09	4.97	1.21	3.87
Anthracene (Ant)	0.168	N.D.	0.380	N.D.	N.D.	N.D.
Fluoranthene (FL)	0.257	N.D.	0.531	N.D.	0.174	N.D.
Pyrene (Pyr)	0.738	N.D.	1.68	N.D.	N.D.	N.D.
Benz[a]anthracene (BaA)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Chrysene (CHR)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Benzo[b]fluoranthene (BbF)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Benzo[k]fluoranthene (BkF)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Benzo[a]pyrene (BaP)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Indeno(1,2,3-cd)pyrene (IND)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Dibenzo(a,h)anthracene (DBA)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Benzo(ghi)perylene (BghiP)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

concentrations were reduced by 62%, 44% and 51% at idle condition, 25% and 50% loads, respectively. Similarly, the total BaPeq concentrations were reduced by 63%, 46% and 51%, respectively. These observations can be attributed to the fact that, when fuel is subjected to magnetic field, which realigns the para hydrogen to more reactive ortho states and weakens the intermolecular forces, allowing better atomization and opens up the hydrocarbons to be more receptive to oxygen resulting in better and more efficient combustion. Efficient combustion means most of the PAHs in the fuels and PAH precursors are destroyed at high temperatures, leading to decreased PAH emissions.

The results of Table 5 show that Naphthalene (Nap) (90%–97%) was the dominant congener followed by Phenanthrene (PA) (1.1%–5.0%). For both the idles state and 25% load, it is clear that application of magnetic field resulted in formation of more gaseous and low molecular PAHs as the Nap fraction increased slightly when magnetic field was applied. This can be infer that application of magnetic field will enhance the destruction of middle molecular weight PAHs such as Fluorene (Flu), Phenanthrene (PA), Anthracene (Ant), Fluoranthene (FL) and Pyrene (Pyr), whose fraction were reduced to ND (non-detectable) in some instances.

CONCLUSIONS

In this study, the application of magnetic tube in the fuel intake resulted in reduction in BSFC and fuel consumption by an average of 3.5% and 15%, respectively while the BTE was improved by approximately 3.5%. In terms of pollutant control, the PM, CO, HC and CO_2 emissions reduced by about 21.9–33.3%, 5.4–11.3%, 29.4–64.7% and 2.68–4.18%, respectively while NO_x emissions were increased by about 1.24–13.4%. This study being a first of its kind to investigate the effect of magnetic field on PAH emissions shows that at idle condition, 25% and 50% loads, both the total PAH and total BaPeq concentrations in the exhaust of diesel engine generator can be reduced by about 63%, 45% and 51%, respectively. These results are good indicators of the promising potential when using magnetic tube in the diesel engine to save energy and reduce pollutant emissions.

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