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Reducing Exhaust Gas Emissions of Stationary Diesel Engines Using Water Bath

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Abstract. This work was conducted with the aim of reducing exhaust gas emissions of stationary diesel engines, particularly those used locally by the private sector for electric power generation. A specially designed water bath equipped with perforated tubes submerged in water and supplied with water circulation to maintain the cleanness of water was used for this purpose. The diesel engine exhaust gas was admitted to the water bath through the perforated tubes such that the exhaust gas is "cleaned up" thoroughly before being released to the atmosphere. An experimental work was conducted on a four-stroke, air-cooled, one-cylinder diesel engine to verify the feasibility of using this technique in reducing exhaust gas emissions before applying it to large size diesel engines. The experimental results indicated that the use of the proposed water bath led to enormous reductions in oxides of Nitrogen (NOx), unburnt Hydrocarbons (HC), Carbon Monoxide (CO), and exhaust gas temperatures. In addition to a relatively small reduction in exhaust noise. For the engine power range considered in this work (0.4-2 kW), NOx was reduced by 62-73%, unburned HC was reduced by 72-85%, CO was reduced by 41-68%, exhaust gas temperature was reduced by 89-91% and exhaust noise was reduced by 1-7%.

1. Introduction

Diesel engines are characterized by many advantages including high reliability, high power output and fuel efficiency. They are easily repaired, inexpensively operated and very durable. They provide 30-40 % fuel economy advantage over gasoline engines which results in 20 % reduction in carbon dioxide (CO_2) emissions [1]. These features made diesel engines the most preferable power source for heavy duty applications. They are used for transporting goods, generating electricity and as a power drive for heavy mobile and stationary equipment [2].

On the other hand, one of the main disadvantages of diesel engines is their emission of large amounts of nitrogen oxides (NOx) and particulate matter (PM), and smaller amount of carbon monoxide (CO), hydrocarbon (HC), and poisonous air pollutants [3]. Diesel emissions reduce visibility, cause acid rain and contribute to ground-level ozone. It was reported by health experts that diesel engines emissions have adverse effects on human health. They cause respiratory problems and lung damage, in addition to the accumulative evidence that cancer in humans may be caused by diesel emissions [4]. The World Health Organization (WHO) reported that every year approximately two and a half million people die because of air pollution [5].

These health concerns led to imposing worldwide stringent legislations to reduce diesel engine emissions [6]. In recent years, there has been considerable research work on modifying diesel engines, employing electronic control of the injection system and improving diesel fuel properties to comply with these legislations [7]. However, the aforementioned attempts could not fulfill the desired emission standards without the use of technologies such as Exhaust Gas Recirculation (EGR), Lean NOx Trap (LNT), Selective Catalytic Reduction (SCR), Diesel Oxidation Catalyst (DOC) and Diesel Particulate Filter (DPF) [8]. Among diesel pollutants, NOx is considered the most serious pollutant to deal with [9]. Diesel engines produce large amounts of NOx due to high combustion temperature in the presence of large amounts of nitrogen and oxygen [10], bearing in mind the health hazards associated with NOx ability to form smog and ozone [1].

EGR systems recirculate the exhaust gas and mix it with fresh air during intake stroke which decreases combustion temperature and consequently reduces the formation of NOx [6]. EGR has the ability to reduce NOx emissions by up to 50% [1]. However, it causes an increase of 3-6% in fuel consumption, as well as an increase in PM emissions which requires coupling it with a DPF [11].

LNT uses catalysts with a Platinum base to store NOx during lean operating conditions and then during rich operating conditions it reduces NOx to nitrogen and releases it to the atmosphere. LNT has an efficiency of reducing up to 80% of NOx [12].

SCR uses ammonia, urea or hydrocarbon to reduce NOx to nitrogen and water [13]. It can reduce the emission of NOx by 75-90% as well as reducing HC and PM emissions by 80% and 30% respectively [1].

DOC consists of a honeycomb structure coated with a catalyst material such as platinum, palladium and other metal catalysts [14]. DOC was developed originally to reduce HC and CO, however it also proved its ability to reduce PM by 20-50% [1].

DPF has honeycomb channels with a silicon carbide substrate which captures particulate matter and prevents its release to the atmosphere [14]. The two types of DPF; flow through and wall flow designs achieved a reduction in particulate matter of up to 75% and 90% respectively [1].

It is worth mentioning that the diesel emission control technologies discussed above are expensive and diesel engines manufacturers as well as users were compelled to adopt them due to the stringent emission control legislations [15 and 16].

In Iraq, the shortage of electric power has led to the extensive use of diesel engines for generating electric power by the private-sector. For more than two decades, diesel engine power generators have been commonly used in every neighborhood and in every city. Most of the diesel engines used in these generators are very old, they are not equipped with any type of emission control technology and their exhaust emission is disastrous (Figure1). Since these generators operate without any official supervision by authorities and due to the lack of local legislations imposed on diesel engine emissions, there is no way to compel the owners to use expensive emission control technologies.

Figure 1. Diesel engine exhaust emissions by private sector electric power generators.

The objective of this work is to develop a simple, efficient and low cost diesel emission control method with the prospect of using it for reducing emissions of diesel engines used for electric power generation by the private sector. The proposed emission control method involves admitting the diesel engine exhaust gases to a water bath before releasing it to the atmosphere.

To verify the feasibility of using this method for reducing diesel engine emissions, a specially designed water bath was developed and experimented on a four-stroke, air-cooled, one-cylinder diesel engine equipped with the necessary instrumentations to measure exhaust emissions such as NOx, unburned HC, CO, as well as other parameters such as exhaust gas temperature and exhaust noise.

2. Materials and methods

The water bath which was constructed and used in the experimental work is shown in Figure 2. It consists of a galvanized steel box (0.36 m x 0.3 m x 0.25 m) equipped with a float to maintain the level of water inside the tank. The water bath is fitted with perforated tubes submerged in water such that when the exhaust gas is admitted to the water bath through these perforated tubes the pollutants are mixed with water and the exhaust gas is cleaned up thoroughly before being released to the atmosphere. Water inside the water bath is circulated to maintain the cleanness of water. As for the water contaminated with exhaust pollutants, water filters could be fitted at the outlet of the water bath to purify it before being discharged into the sewage.

Figure 2. Water bath; 1- water inlet, 2- exhaust gas inlet, 3- exhaust gas exit, 4- perforated tubes, 5- water outlet.

The experimental work was carried out at the Automotive Workshop/Machine and Equipment Department/Institute of Technology-Baghdad. The diesel engine used is a single-cylinder, four-stroke, naturally aspirated, air-cooled, direct-injection diesel engine type TD212 (TQ-UK) coupled to a hydraulic dynamometer test bed type TQ's TD200. Engine specifications are listed in table 1. The test set-up is shown in Figure 3.

Table 1. Specifications of diesel engine Type TD212.

Item	Specification
Absolute maximum power	3.5 kW at 3600 rpm
Continuous rated power	3.1 kW at 3000 rpm
Bore	69 mm
Stroke	62 mm
Compression ratio	22:1

Figure 3. Test set-up: 1- diesel engine, 2- hydraulic dynamometer, 3- water bath.

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Exhaust gas analyzer type (Texa-Italy), shown in Figure 4, was used to measure the exhaust gas content of NOx, HC and CO. Exhaust gas temperature was measured using thermocouples inserted inside the exhaust tailpipe and temperature recorder type Lutron BTM-4208SD – Taiwan, shown in Figure 5. Exhaust noise was measured using sound level meter type Lutron SL-4011- Taiwan, shown in Figure 6.

Figure 4. Exhaust gas analyzer.

Figure 5. Termocouple and Temperature recorder.

Figure 6. Sound level meter.

The experimental procedure involved running the diesel engine to produce a brake power of 0.4, 0.8, 1.2, 1.6 and 2 kW. At each engine brake power, measurement of NOx, unburned HC, CO, exhaust gas temperature and exhaust noise were carried out before and after using the water bath.

3. Results and discussion

The experimental results are shown in Figures 7-11. In general, all the exhaust emissions considered in this study; NOx, HC and CO, as well as exhaust gas temperature and exhaust noise increased with the increase of engine brake power. This is logical and in accord with the general trend reported by experimental results of previous investigations [17-20].

The experimental results indicate that using the water bath to control diesel engine emissions resulted in enormous reductions in NOx, HC, CO and exhaust gas temperature and a relatively small reduction in exhaust noise. For the diesel engine power range considered in this work (0.4-2 kW), the use of the water bath resulted in reducing NOx emission by 62-73% as shown in Figure 7. This is much more superior to the results obtained by Raman et al [18] who used exhaust gas recirculation (EGR) to reduce NOx content by only 3.38-6.17% for 5-20% EGR ratio. Moreover, the use of EGR resulted in an increase of 27.5- 28.8% in HC emission and an increase of 8.7-14.3% in CO emission. Roy et al [19] reported a reduction in NOx of 24%, 47% and 77% at EGR ratio of 10%, 20% and 30% respectively. However, this was achieved at the expense of increasing particulate matter emission by 12%, 65% and 156% respectively.

The reduction in unburned HC as a result of using the water bath was found to be 72-85% as shown in Figure 8. It has been reported by previous investigations that the use of EGR led to an increase in HC emissions [18 and 19]. The use of the water bath resulted in reducing CO emission by 41-68% as shown in Figure 9. The use of EGR, as reported previously, results in increasing CO emission [18]. The exhaust gas temperature was reduced by 89-91% as a result of using the water bath as shown in Figure 10. The significant reduction of exhaust gas temperature from 286-384° C before using the water bath to 30-36 ° C after using the water bath could participate in the reduction of global warming. The effect of using the water bath on exhaust noise is shown in Figure 11. A reduction of 1-7% in noise level is achieved with the use of water bath.

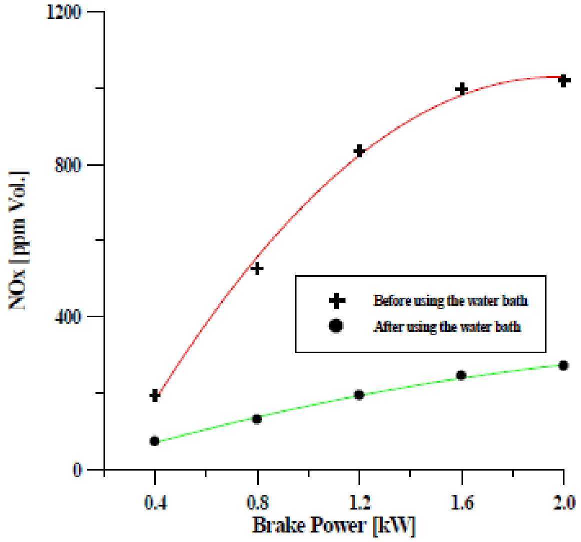

Figure 7. The effect of using water bath on NOx emission

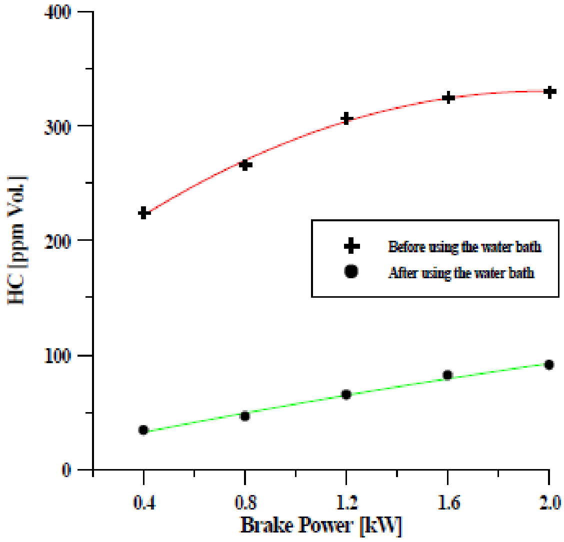

Figure 8. The effect of using water bath on HC emission.

These results indicate that the use of water bath provides higher reduction in diesel engine emissions than the methods commonly employed for this purpose and at minimal cost. In addition to that, no single method of the ones employed previously can reduce all diesel engine emissions. On the contrary, as pointed out earlier, whereas one technology can reduce a specific pollutant it increases the others. This led to the use of more than one technology at the same time to overcome this limitation which increases the cost of an already expensive solution. Moreover, some of these technologies adversely affect engine performance such as engine thermal efficiency and fuel consumption as reported previously [2].

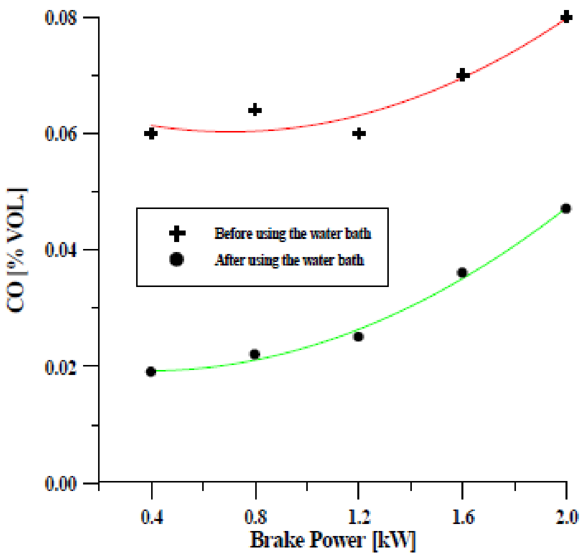

Figure 9. The effect of using water bath on the emission of CO.

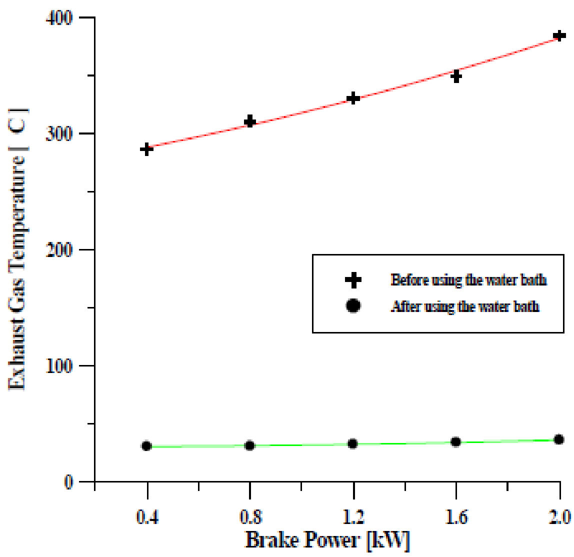

Figure 10. The effect of using water bath on the exhaust temperature.

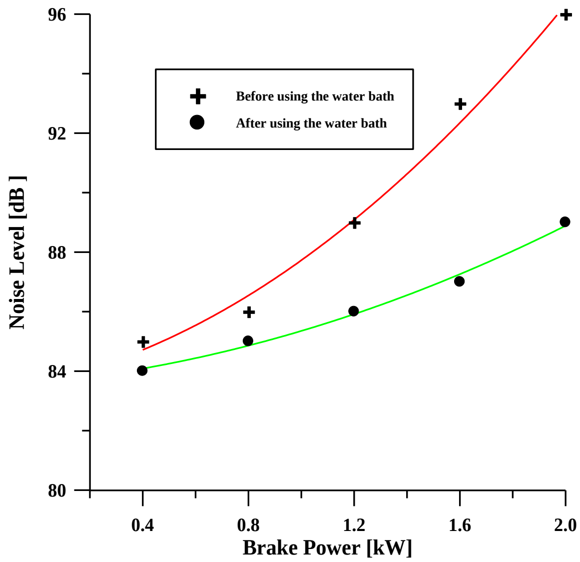

Figure 11. The effect of using water bath on exhaust noise.

4. Conclusions

1. The experimental results verified the feasibility of using a water bath in reducing diesel engine emissions.
2. The use of water bath resulted in enormous reductions in NOx, unburned HC, CO, and exhaust gas temperature, as well as a relatively small reduction in exhaust noise.
3. Unlike other methods used for the control of diesel engine emissions which reduce some pollutants and increase others, the water bath reduced all the emissions considered in this work.
4. The proposed method of using a water bath to reduce the emissions of diesel engines used by the private sector for electric power generation seems very promising, bearing in mind the simplicity of adopting it and its low cost.

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