Analysis of CO_2, CO, NO, NO_2, and PM Particulates of a Diesel Engine Exhaust

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Abstract—**Exhaust emissions of a diesel engine are considered to be a substantial source of environmental pollution. Diesel engines are mainly used in vehicles and power generation. The usage of diesel engines is unavoidable as they give more power and performance, but at the same time, higher usage of diesel engines leads to increased air pollution, sound pollution, and emissions to the environment. Therefore, various attempts have been made to control the harmful emissions of engines. For this reason, different devices have been made such as catalytic convertors to overcome emission problems and purify the harmful gases. In order to meet these ends, a new system was designed that would contribute to controlling the air pollution of the engines. The system is also known as an aqua silencer, and its design is somehow different but still can be used as a silencer. The newly designed emission controller was installed in a test-bed diesel engine and a total of twenty experiments were conducted with and without the new emission controller at constant speed and at constant load. During these experiments, exhaust gases were analyzed with flue gas analyzers measuring CO_2, CO, NO_2, NO, and PM. The study concluded that the contaminants of diesel engine exhaust gases were) controlled by the developed emission controller.**

Keywords-emission control; diesel engine; aqua silencer; carbon dioxide; nitrogen oxide

I. INTRODUCTION

Internal combustion (IC) engines have become highly imperative in transportation and industry. Diesel engines are the most commonly preferred engines, especially in the application of heavy-duty vehicles. Besides other sources, these engines are counted as one of the largest environmental pollution contributors due to their exhaust emissions (Figure 1). The use of TI Nano tubes in an aqua silencer along with charcoal can absorb toxin gases [1]. The performance and emissions using alcohol fumigation in the presence of hot Exhaust Gas Recirculation (EGR) were examined in [2]. The EGR results to great reductions in NOx emission, amounting up to 30 to 40% at higher loads [2]. In [3], the aqua silencer was used in the reduction of toxic gases and noise. This experiment gives an effective way to reduce emission gases from the engine exhaust. Moreover, aqueous ammonia solution can be used as an absorber for the reduction of CO_2, SO_2, and NO_x from exhaust gases of IC engines. The aqueous ammonia process can simultaneously remove CO_2, SO_2, NO_x and also hydrocarbons that may be present in the exhaust gas. A study was conducted on a single cylinder four stroke cycle direct injection diesel engine at a constant speed with a fuel injection pressure of 200bars. Tests were conducted using commercial diesel fuel and diesel fuel with 10% and 20% water by volume. It was found that the water emulsification has the potential to improve brake thermal efficiency and brake specific fuel consumption [4]. In order to check the system's performance an aqua silencer was directly integrated in the exhaust of the engine and its effects were studied in [6]. The use of a new catalyst converter to replace the noble metals Platinum (Pt), Palladium (Pd), and Rhodium (Rh) has been studied. Materials such as zeolite, nickel oxide, and metal oxide have been found to effectively reduce emissions. Beside this, ultrasonic treatment with a combination of electroplating technique, citrate method and Plasma Electrolytic Oxidation (PEO) have been carried out on producing an effective catalyst in reducing exhaust emissions [7]. Aqua silencer covers the effect of black smoke, NO_x emissions, and sound from the exhaust gases. After implementing the aqua silencer, the engine tended to

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have NO_x emissions and sound completely eliminated, whereas carbon monoxide (CO) emission reduced up to 53%, unburned hydrocarbon (UBHC) was reduced up to 41% and CO_2 emission reduced up to 44% in comparison with the existing system [8].

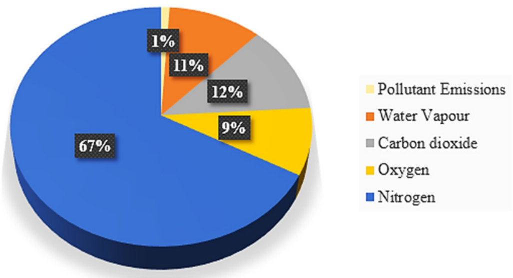

Fig. 1. Composition of Diesel exahust gases [5]

Aqua silencer is thermally effective and technically feasible for use at reducing engine noise and toxic emissions but certain improvements so as to fit in the application with the engine exhausting unit are in order [9]. In [10], the toxic contents in petrol engine exhausts at various running speeds were studied by changing the limestone content in the RTP silencer. Reduction of HC and CO emissions were observed by changing the limestone content from 25 to 150 grams. In [11], CO emissions were reduced up to 53% with the use of an aqua silencer. UBHC can be reduced by 41% and CO_2 emissions by 44%. The catalytic converters are used to reduce the amounts of nitrogen oxides, CO, and UBHC in automotive emissions. During vehicle use, the converter is exposed to heat, which causes the metal particles to agglomerate and their overall surface area to decrease. As a result, catalyst activity deteriorates [12]. The effect of various engine parameters on the control of these emissions is reported with different versions of the engine in [13]. Authors in [14] reported that the UBHC emission in a twin spark engine is reduced up to 12% as compared to the single spark engine while the CO emission in the twin spark engine is reduced to a great extent. In [15], a prototype emission control system was designed and tested on a gasoline-fueled vehicle. Federal Test Procedure (FTP) emission results show a 35% reduction in hydrocarbons emitted during the cold transient segment due to adsorption.

II. MATERIALS AND METHODS

The design of a new emission controller was carried out based on the engine parameters and material requirements. In the first step, a CAD model was designed on Creo Parametric 3.0 with all suitable dimensions. The section view of the emission control unit is shown in Figures 2 and 3. The emission controller was installed, and the experiments were carried out on low speed of the diesel engine. The research and test bed model was the DWE-6/10-JS-DV (Figure 4), which is available at the Thermodynamics Laboratory of Quaid-e-Awam University of Engineering, Science & Technology. The detailed specifications of this test bed diesel engine are given in Table I. The gases obtained from the diesel engine exhaust were analyzed by the flue analyzer (Flue Gas Analyzer model no. Testo 350- XL), whether they were purified or not and the purification extent was estimated. To measure the Total Suspended Particles (TSP) in the flue gases a device named AEROCET 531S was used to count the PM.

TABLE I. SPECIFICATIONS OF DIESEL ENGINE TEST UNIT

Number of cylinders	01
Bore	80mm
Stroke (piston displacement)	95mm (477cc)
Compression ratio	23:1
Starting method	Manual (cell starter upon request)
Output/rational speed	8.5ps/2200 rpm (max)
Cooling System	Water cooled
Type	Horizontal

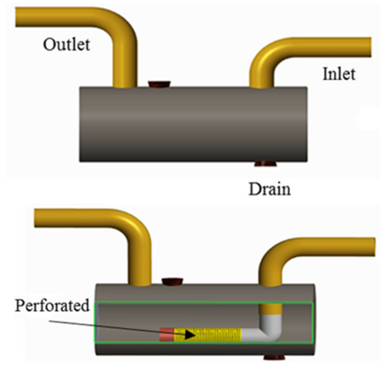

Fig. 2. Section view of emission control unit

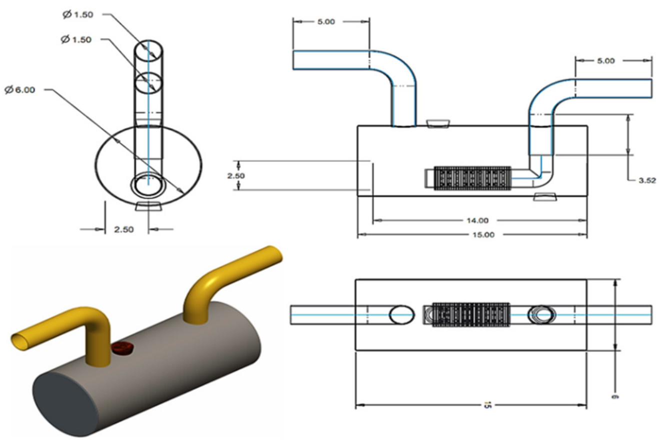

Fig. 3. Detailed drawing of the emission control unit (dimensions are given in inches)

Figure 4 shows the complete unit of aqua silencer. When the exhaust gases of the diesel engine enter the device, they pass through the perforated tube. The holes in the perforated tube are designed in a way that the large mass gases form smaller gas bubbles. It is a closed end tube and all the gases can pass through the holes. The perforated tube is completely immersed in a lime water solution where the gases chemically react and less precipitates are created. Around the circumference of the perforated tube, there is double activated charcoal. The charcoal is highly porous and possesses extra free valences, so it has the ability to absorb flue gases.

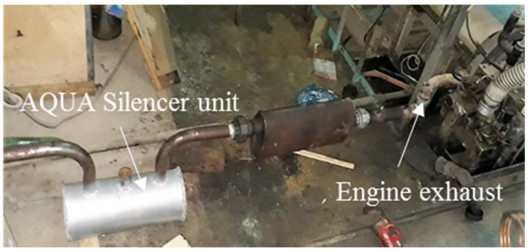

Fig. 4. Assembly of the system

Fig. 5. Hand held PM and flue gas analyzer

III. RESULTS

Measurements were taken in order to compare the emissions of the test bed diesel engine with and without installation of the newly designed system at different loads and different speeds (rpm). A total of twenty experiments were performed at constant load and constant speed to observe the behavior of emissions with respect to these parameters.

A. *Performance Evaluation*

The performance evaluation experiment data sheets for constant load and constant speed are illustrated in Tables II and III.

TABLE II. ENGINE EMISSIONS AT CONSTANT SPEED

Systems	Speed	Torque	CO_2 (PPM)	CO (PPM)	NO_2 (PPM)	NO (PPM)	PM (mg/l)
Without	950	0.2	990	283	9.0	52	0.09
		0.4	1505	298	8.4	54	0.088
		0.6	4020	240	6.4	58	0.103
		0.8	7605	330	4.1	56	0.144
		1.0	9700	382	4.3	50	0.212
With		0.2	690	325	3.0	46	0.101
		0.4	1150	320	6.1	48	0.108
		0.6	3410	230	5.4	55	0.105
		0.8	4024	265	2.6	48	0.107
		1.0	5500	308	1.2	44	0.148

B. *CO_2 Emissions*

Carbon Dioxide (CO_2) is a colorless and non-combustion gas released when fuels with carbon content burn fully. Consequently, CO_2 is a significant parameter in exhaust emissions from engine. The CO_2 emissions at constant speed and at constant load of the diesel engine, with and without the emission control unit, are shown in Figures 6 and 7 respectively. These graphs show that the CO_2 obtained from the newly developed emission controller is less than without it.

TABLE III. ENGINE EMISSIONS AT CONSTANT TORQUE

Systems	Torque	Speed	CO2 (PPM)	CO (PPM)	NO2 (PPM)	NO (PPM)	PM (mg/l)
Without	0.4	950	1508	298	8.5	53	0.088
		1050	3900	200	10.2	48	0.112
		1150	6690	220	13.6	60	0.086
		1250	8660	290	16.5	77	0.094
		1350	9800	188	17.8	80	0.142
With		950	1206	242	6.3	48	0.086
		1050	3875	296	5.6	42	0.094
		1150	4300	180	12.5	51	0.096
		1250	5560	290	15	63	0.103
		1350	6078	205	17.2	77	0.118

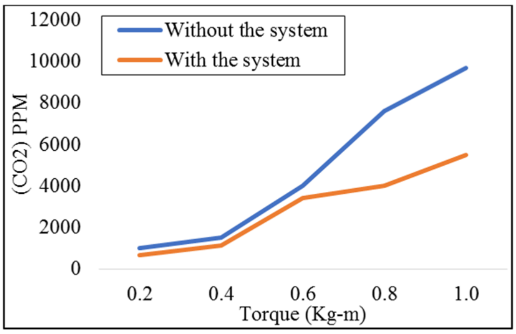

Fig. 6. Comparative results of CO_2 emissions at constant speed

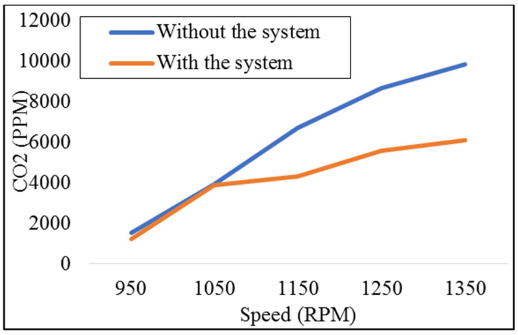

Fig. 7. Comparative results of CO_2 emissions at constant load

C. *CO Emissions*

Carbon monoxide emissions are colorless, odor free and toxic gases produced as an effect of incomplete burning of carbon. The emission of CO results from oxidation of fuel consisting of carbon and hydrogen with oxygen. CO is produced as a result of the deterioration of the resulting yield. The CO emissions at constant speed and load, with and without the emission control unit, are shown in Figures 8 and 9. It can be seen that CO emission is more in the absence of the emission controller.

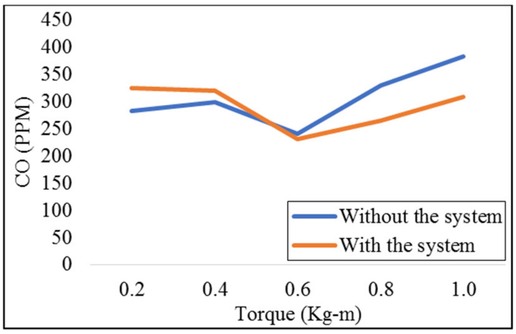

Fig. 8. Comparative results of CO emissions at constant speed

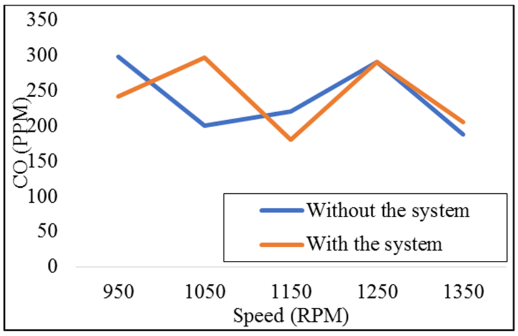

Fig. 9. Comparative results of CO emissions at constant load

D. NO_x Emissions

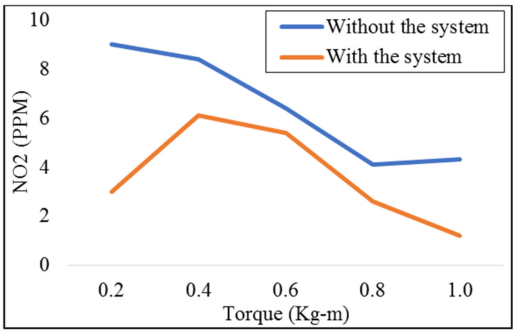

Fig. 10. Comparative results of NO_2 emissions at constant speed

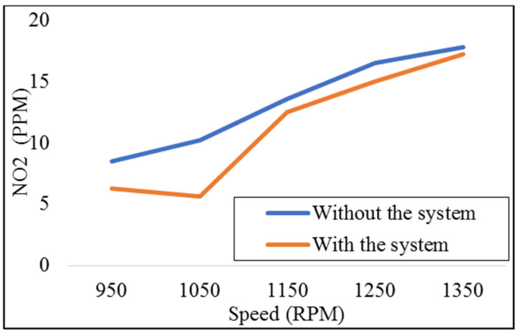

Fig. 11. Comparative results of NO_2 emissions at constant load

The emissions of nitric oxides (NO_x) are affected by the emission controller due to the use of limewater. The hydroxides in the water absorb noxious thus noxious emissions are less than the actual emissions from the diesel engine. The NO_2 emissions at constant speed and at constant load of the diesel engine, with and without the emission control unit, are shown in Figures 10 and 11. The NO emissions at constant speed and at constant load of the diesel engine with and without the emission control unit are shown in Figures 12 and 13 respectively. We can see that the NO_x emissions decreased when using the newly developed emission controller.

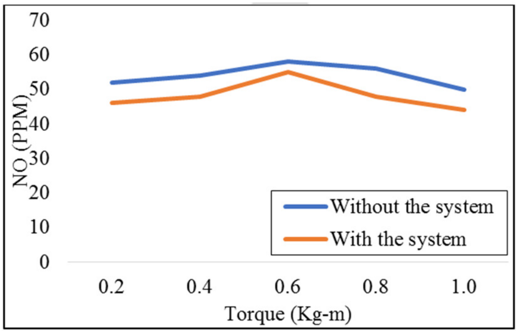

Fig. 12. Comparative results of NO emissions at constant speed

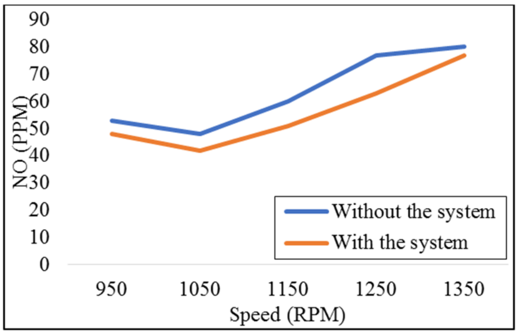

Fig. 13. Comparative results of NO emissions at constant load

E. Particulate Matter (PM) Emissions

Particulate Matter (PM) air pollution is an air suspended combination of solid and liquid particles depending upon the size, shape, surface area, number, chemical composition, solubility, and source. It is known that diesel fuel is a major emitter of PM generation. The PM emissions at constant speed and at constant load of the diesel engine with and without the emission control unit are shown in Figures 14 and 15.

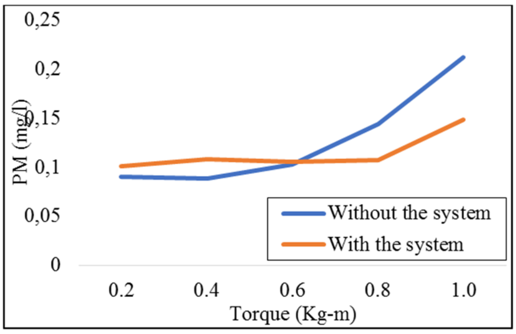

Fig. 14. Comparative results of PM emissions at constant speed

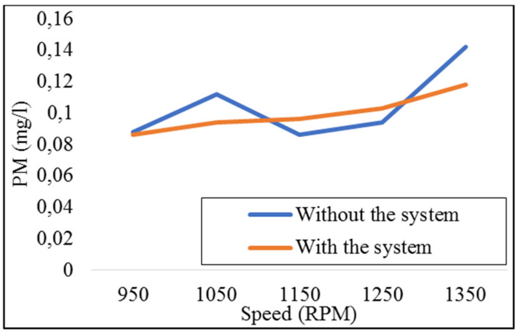

Fig. 15. Comparative results of PM emissions at constant load

IV. COMPARATIVE STUDY

A comparative study was conducted between the developed system (with and without the implementation of the control unit at the exhaust of the diesel engine) and the standardized values of diesel engine exhaust. The comparison is illustrated in Table IV.

TABLE IV. COMPARATIVE STUDY RESULTS

	Standard	With the system	Without the system
CO (ppm)	100	325	382
CO_2 (ppm)	5000	5500	9700
NO (ppm)	25	55	58
NO_2 (ppm)	5	6.1	9
PM (mg/l)	0.02	0.148	0.212

V. CONCLUSION

In this study, experiments were conducted on a diesel engine with an emission control system (commonly known as an aqua silencer) to investigate its impact on the engine's emission characteristics. The study concluded that this system can be used along with or instead of a catalytic converter. With this unit the emissions at the tailpipe of an exhaust system can be easily lowered below the specified levels. With the use of lime water in the silencer, the toxic levels of NO_X gases are decreased along with the temperature of the final exhaust gases which has also a positive effect on the environment. The water contamination is found to be negligible, because of the amount of the acidity level inside which plays the role of absorbing the noxious products of combustion. CO is not highly controlled due to its negligible presence in the emissions (0.20% by volume) and does not pose any health hazard when compared to gasoline engines. The double layer of activated charcoal used helped in adsorbing several harmful constituents. By using the perforated tubing, there will not be any excessive back pressure formation as high mass bubbles get converted into low mass bubbles and the noise is slightly reduced due to tubing and water. Fuel consumption remains the same after the implementation of this system. This system is also cheap to build and maintain as compared to other emission control methods.

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