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Retrofitting Diesel Engine Generators for a Sustainable Environment

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Abstract: Diesel Generator Sets (DGS) are used to generate electric power. Although, diesel engine generators have high efficiency, high torque and outstanding longevity but at the same time polluting the environment with toxic air pollutants such as Particulate Matters (PM), Oxide of Nitrogen (NOx), etc. This study has investigated the effect of retrofitting a 15 kVA DGS using Retrofitted Diesel Fuel (RDF) and Pure Diesel Fuel (PDF). The datas obtained were used in matlab environment in the generation of codes and the codes were eventually used to obtain the corresponding mathematical models and the results obtained were interpreted graphically in the matlab environment. By retrofitting there will be an improvement in climate change, ozone depletion and global warming due to gradual reduction in PM, sharp reduction in CO and an improvement in NOx emission for sustainable environment.

Key words: DGS, PM, NOx, CO, retrofitting, sustainable environment

INTRODUCTION

A DGS is a combination of a diesel engine, a generator and various ancilliary devices. The diesel engine which acts as a prime mover, drives the alternator to produce electricity using the compressed air at a pressure of 25 bar with the injection of diesel fuel into the cylinder. An electric generator consists of a rotor spinning in a magnetic field produced by field coils. The process of generating a magnetic field by means of electric current is called excitation and the generator output voltage is proportional to the magnetic field and excitation current (Theraja and Theraja, 2005). The governor controls the speed variation and keeps the speed within restrained limits despite load variation using the governor spindle, flyweights, control spring, pilot valves, speed sensor, etc., depending on the type of governors employed.

Diesel Generator Sets (DGS) are used routinely to supply electrical power. Hospitals, businesses and small communities use DGS to augument load levelling and to provide emergency power during blackouts (either scheduled or unscheduled). Power failures or outages in Nigeria have led to an increase in the purchase of DGS by industrial, commercial and residential consumers primarily for providing emergency power. In addition to providing value associated with load levelling and emergency power, DGS have the added value that they can be installed relatively rapidly. Diesel engines are easy to repair, inexpensive to operate and extremely durable. It is common for a diesel engine to last 15-20 years and achieved a one million-mile life (Gilmore *et al*., 2006). Although, DGS are in principle under Environmental Protection Agency (EPA) regulation in US and Federal Environmental Protection Agency regulation in Nigeria (FEPA). Many of these DGS are being rapidly installed with minimal concern for EPA and FEPA permissions, focusing exclusively on providing backup power to avoid blackouts. The effect of these events is an increase in air pollutants upon the installation of these DGS (Johnson and Miller, 2007). However, DEGs emit toxic air pollutants PM and NOx that pollute the air in which health experts have concluded that pollutants emitted by diesel engines adversely affect human health and contribute to acid rain, ground-level ozone and reduced visibility (Chameides and Cowling, 1995). Long term exposure to PM is highly dangerous, since it is associated with an increase in the long term risk of cardiopulmonary mortality by 6-13% $\mu g/m^3$ (Beelen *et al*., 2008). Also, the black carbon part of PM which results from incomplete combustion has detrimental effects on health as well as on climate (Stanek, 2011). Studies have shown that exposure to diesel exhaust causes lungs damage and respiratory problems and there is increasing evidence that diesel emissions may cause cancer in humans (US EPA, 1995). Therefore, in order to reduce these pollutants, many retrofitting options are considered and Xtreme Fuel Treatment (XFT) is chosen as a case study.

MATERIALS AND METHODS

This experiment was conducted using a 15 kVA 400 series, sound proof DGS. About 223 L of transparent and callibrated jerrycans are used. Each filled up with diesel fuel one with additive of 10 mL of Xtreme Fuel Treatment (XFT) and the other without additive. The natural (control) experiment was conducted on the

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Table 1: Readings with diesel at full load (controlled model)

Period	Run time (min)	Amb. temp. of	SO_2 (ppm)	Pure PM (mg/m^3)	O_2 (%)	CO (ppm)	CO_2 (%)	NOx (ppm)
9:45	30	110.4	24	0.648	11.32	105	6.95	302.2
10:15	60	107.4	37	0.459	11.72	91	6.68	318.6
10:45	90	100.5	34	0.503	11.86	93	6.67	315.4
11:15	120	101.0	34	0.254	11.89	86	6.71	213.3
11:45	150	96.2	35	0.170	11.84	88	6.77	319.0
12:15	180	94.7	31	0.196	11.95	89	6.59	303.9

Table 2: Readings with diesel plus additive at full load (retrofitted model)

Run time (min)	Amb temp. of	SO_2 (ppm)	PM (mg/m^3)	O_2 (%)	CO (ppm)	CO_2 (%)	NOx (ppm)
30	97.6	34	0.227	11.24	94	7.02	314.6
60	93.4	37	0.049	11.75	89	6.66	317.5
90	93.5	42	0.108	11.83	92	6.62	307.0
120	82.5	31	0.106	12.78	89	5.94	282.6
150	80.9	31	0.117	12.68	97	3.06	284.4
180	80.2	34	0.037	12.72	83	5.99	298.6

Table 3: Reading diesel consumption rate at full load (both models)

Run time (min)	Pure diesel (L)	Diesel with XFT	Temp. pure diesel	Temp. diesel+XFT	Remark
0	23.00	23.00	48	48	At start
30	0.80	0.46	48	80	0.34
60	1.20	0.86	78	80	0.34
90	0.93	0.73	80	80	0.2
120	1.26	0.96	80	70	0.3
150	0.73	0.50	80	72	0.23
180	1.00	0.70	80	75	0.3

Table 4: Comparison of experimental values and fitted values for pure diesel (control)

	Temperature (°F)	
Time (min)	Experimental readings	Fitted values
30	110.4	110.68
60	107.4	106.21
90	100.5	102.49
120	101.0	99.40
150	96.2	96.81
180	94.7	94.62

Table 5: Comparison of experimental values and fitted values for pure diesel with additives (retrofitted)

	Temperature (°F)	
Time (min)	Experimental readings	Fitted values
30	110.4	110.680
60	107.4	106.210
90	100.5	102.490
120	101.0	99.400
150	96.2	96.810
180	94.7	94.620

generator on full load wthout any variable manipulation in the first 3 h. The retrofitted (diesel plus XFT) experiment was done also on full load after a lagging cooling period of 2 h for the next 3 h. The records of all variables were collated using Testo 350, a digital flue gas analyzer and these were used in matlab environment in the generation of codes and the codes were eventually used to obtain the corresponding mathematical models and the results obtained were interpreted graphically in the matlab environment (Table 1-5).

The data collated from the experiment was used in matlab environment in the generation of code and the code was eventually used to obtain the corresponding mathematical model and the results obtained were interpreted graphically in the matlab environment.

The mathematical model of temperature response with time for pure diesel: The resulting equation in its general form is given in Eq. 1:

$$f_1(x) = a_1x^3+b_1x^2+c_1x+d_1 \quad (1)$$

Where:

f_1 = Ambient temperature
x = Run time
a_1 = -7.202×10^{-7}
b_1 = 0.0005423
c_1 = -0.1931
d_1 = 116

The mathematical model is:

$$f_1(x) = -7.202\times10^{-7}x^3+5423\times10^{-7}x^2+-1931\times10^{-4}x+116 \quad (2)$$

Similarly, the mathematical model of temperature response with time for diesel with additives: The resulting equation in its general form is given in Eq. 2:

$$f_2(x) = a_2x^3 + b_2x^2 + c_2x + d_2 \quad (3)$$

Where:

f_2 = Ambient temperature
x = Run time
a_2 = 1.526×10^{-5}
b_2 = 0.004595
c_2 = 0.2618
d_2 = 92.97

The mathematical model is given as:

$$f_2(x) = 1526\times10^{-8}x^3+-4595\times10^{-6}x^2+2618\times10^{-4}x+92.97 \quad (4)$$

RESULTS AND DISCUSSION

Figure 1 has shown that the system can be operated on with any length of time with corresponding temperature responses which also dictate the rate of emission reduction. Figure 2 has also shown that there was improved temperature response with time which is associated with better performance, longer engine life and reduction in engine wearing. Figure 3-5, vis-a-vis Table 1

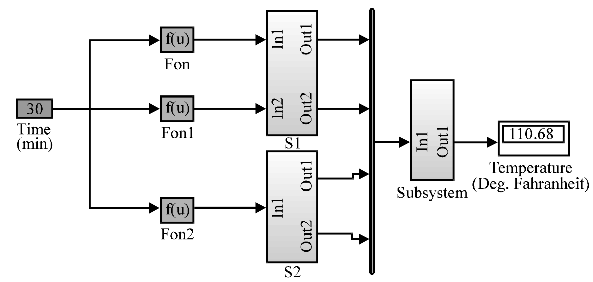

Fig. 1: Simulink model validation of temperature response with time for pure diesel

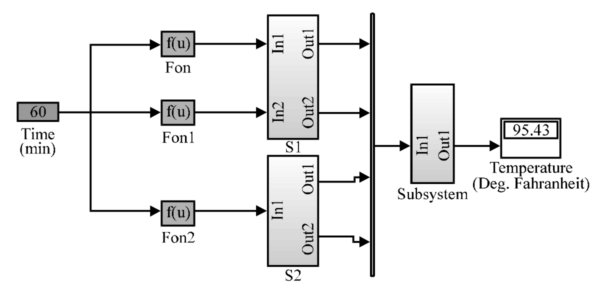

Fig. 2: Simulink model validation of temperature response with additives

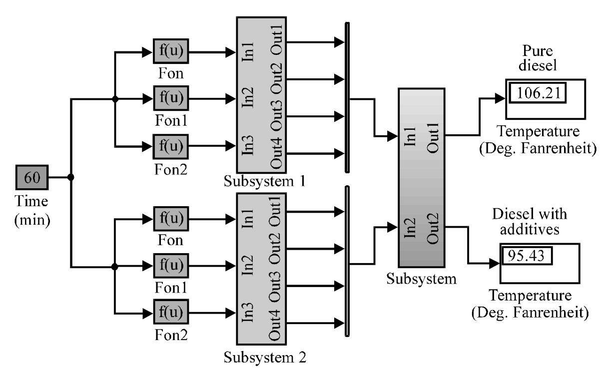

Fig. 3: Simulink model validation of temperature response with time for diesel with/without additives

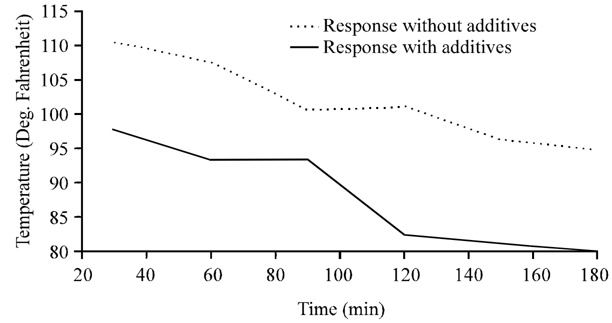

Fig. 4: Temperature response with time of diesel with/without additives at full load

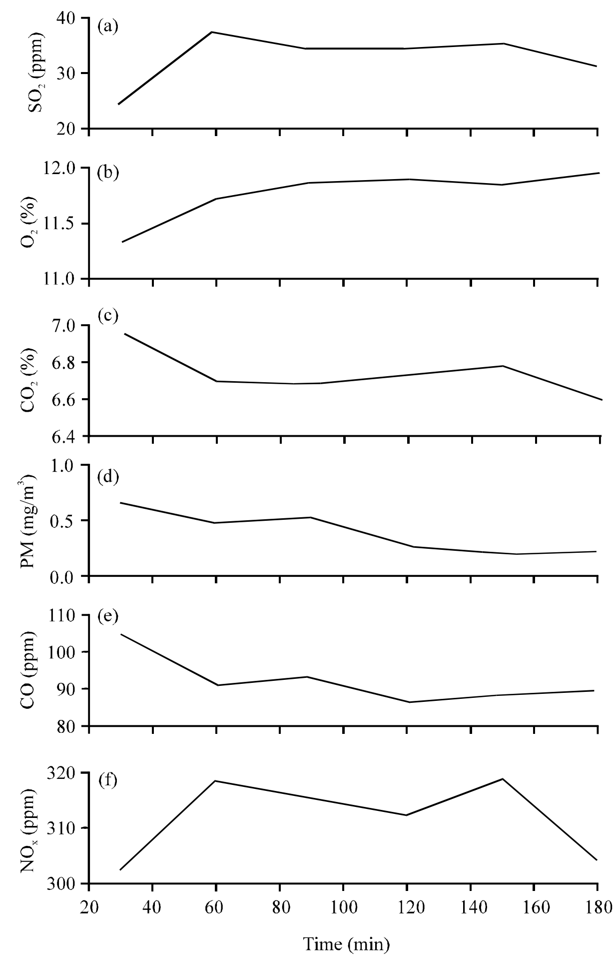

Fig. 5: Subplot graphs of gases emission with time for pure diesel: a) graph of SO_2 with time for pure diesel; b) graph of O_2 with time for pure diesel; c) graph of CO_2 with time for pure diesel; d) graph of PM with time for pure diesel; e) graph of CO with time for pure diesel and f) graph of NOx with time for pure diesel

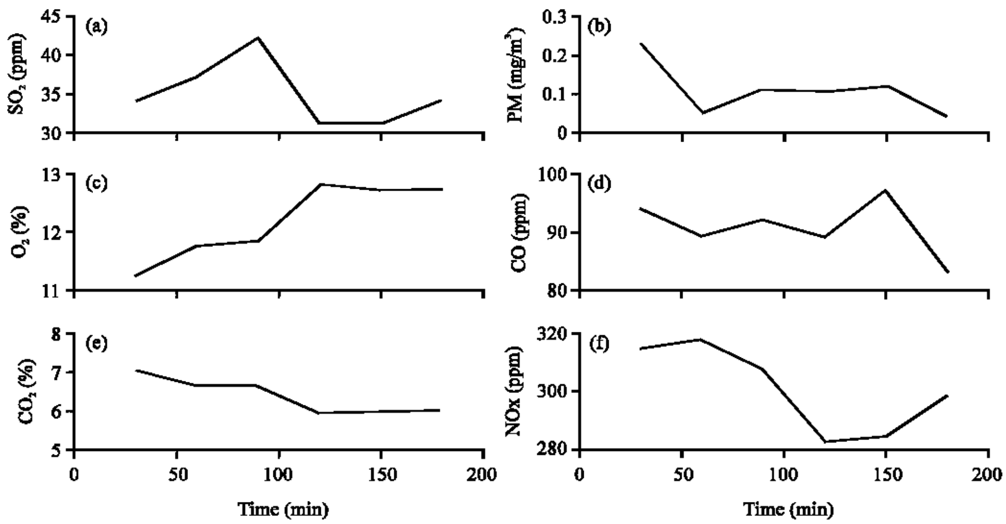

Fig. 6: Subplot graphs of gases emission with time for diesel with additive: a) graph of SO_2 with time for diesel plus additives; b) graph of PM with time for diesel plus additives; c) graph of O_2 with time for diesel plus additives; d) graph of CO with time for diesel plus additives; e) graph of CO_2 with time for diesel plus additives and f) graph of NOx with time for diesel plus additives

and 2 revealed that the levels of NOx, PM, CO, etc., emissions were reduced with retrofitted diesel fuel compared with pure diesel fuel which are dangerious particles in the environment that affect human health. Table 3 and 4 has shown that the generated data are well fitted for the experimental data (Fig. 6).

CONCLUSION

It was shown that diesel engine generators generally release pollutants from their exhausts which carry a very large percentage of Green House Gas (GHG) release, resulting in consequential depletion of earthly body oxygen contents, depletion of ozone layers that is protecting the planet and climate change leading to the anomalies in systems behaviour. Hence, the need for every diesel engine generator to be retrofitted. The levels of NOx, PM, CO, etc., emissions were reduced with retrofitted diesel fuel which are indicator of reduced hospital admission and lower motality rates associated with inhailing of these toxics, coupled with saving in fuel usage and longer life time associated with lower temperature at a longer duration of generator usage which resulted in sustainable environment.

RECOMMENDATIONS

There must be emission rules/standards on all diesel engine generators to be complied with by all diesel engine generator manufacturers. The government organs, EPA in US and FEPA in Nigeria responsible for satisfying these diesel engine generators free from polluting the atmosphere must be up to the task. Enacting laws by the government that will mandate every citicenry to plant a tree in a year will go along way in reducing carbon dioxide in the atmosphere which is the by-product of chemical reaction between carbon monoxide and the retrofit.

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