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Research Paper

ON THE EVALUATION OF DIESEL ENGINE EXHAUST SYSTEM RETROFIT FOR IMPROVED THERMAL PERFORMANCE AND REDUCED EMISSIONS

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Diesel engine exhaust system retrofit capable of suppressing the wave that offends the exhaust gas flow has been introduced in the vicinity of the exhaust port of a single cylinder naturally aspirated four stroke 7 HP 1500 rpm direct injection diesel engine and experimented. The retrofit considerably reduces the smoke, hydrocarbon, carbon monoxide and oxides of nitrogen levels while improving the thermal efficiency moderately (1% to 3%). The impact of retrofit on smoke and oxides of nitrogen are pronounced at higher loads. While the influence of retrofit on UBHC reduction is more or less uniform with increasing load, that on carbon monoxide is pronounced at lower loads. Exhaust gas temperature, cylinder peak pressure and peak heat release rate decline with the use of retrofit. Retrofit of area factor 7 (area factor is the ratio of flow dissipation area with retrofit to that with conventional straight exhaust pipe) is found better than those with 4 and 8.

Keywords: Exhaust retrofit, Diesel engine, Emissions, Thermal performance, Exhaust system

INTRODUCTION

Diesel engines with better torque characteristics, being efficient in energy conversion from hydrocarbon fuels continue to power land and sea transport, farm machinery and equipment, earth movers and electric generators (Raja *et al.*, 2003; and Ramajayam *et al.*, 2004). The pollutants from diesels include Particulate Matter (PM) in the smoke, Oxides of Nitrogen (NOx), Carbon monoxide (CO) and Unburnt Hydro Carbon (UBHC). Carbon dioxide is the green house gas emitted by diesels. The extractable organic fraction of diesel particulate contains Carcinogenic compounds. Polynuclear Aromatic compounds in UBHC are

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Carcinogenic. UBHC has a definite role in smog formation. Carbon monoxide affects nervous system through reduced oxygen transit and intensifies Cardiovascular and Pulmonary disorders. Oxides of nitrogen are pulmonary irritants and while in excess can cause pulmonary hemorrhage.

Differing approaches and attempts continue worldwide to combat engine exhaust emissions and to improve thermal efficiency (to reduce green house gas emissions) (Lin and Huang, 2003; Mohamed, 2003; Cherng-Yuan and Kuo-Hua, 2004; Sethi and Sakariya, 2004; Ramajayam *et al.*, 2004; Ramanathan *et al.*, 2005; Li *et al.*, 2006; Xingcai *et al.*, 2008; Sathiyagnanam and Saravanan, 2008; and Qi *et al.*, 2010). Periodic intake and exhausting together with the pressure rise due to combustion makes the flow in the internal combustion engine manifolds unsteady (Winterbone and Pearson, 1999; Huang *et al.*, 1999; Winterbone and Pearson, 2000; Vítek and Polášek, 2002; Koehlen *et al.*, 2002; and Obodeh and Ogbor, 2009). The exhaust system is designed to conduct exhaust gases away, to reduce polluting emissions and to minimize the influence of back pressure and cross scavenging on the performance and noise. Torregrosa (2005) evaluated emission models used for internal combustion engines noise prediction on the basis of the volume velocity fluctuations (Torregrosa, 2005). Some researchers attempted exhaust tuning to reduce pumping loss and residual gas concentration, to enhance combustion oxygen and trapping efficiency and to lower diluents (Adair *et al.*, 2006; Gustafsson, 2006; and Obodeh and Ogbor, 2009). Tuning involves the timing of low pressure rarefaction wave to arrive downstream the exhaust valve during the valve overlap period through changing the exhaust pipe length. Blair and Coats (1973) compared analytical and experimental exhaust noise radiation characteristics of a straight pipe. Davies and Holland (1999) assessed the intake and exhaust noise of four cylinder four stroke internal combustion engine. In the present work to suppress the wave that offends the exhaust gas flow a retrofit with manifold flow dissipation area compared to tail pipe cross section is proposed and tested for engine emission levels and thermal efficiency.

MATERIALS AND METHODS

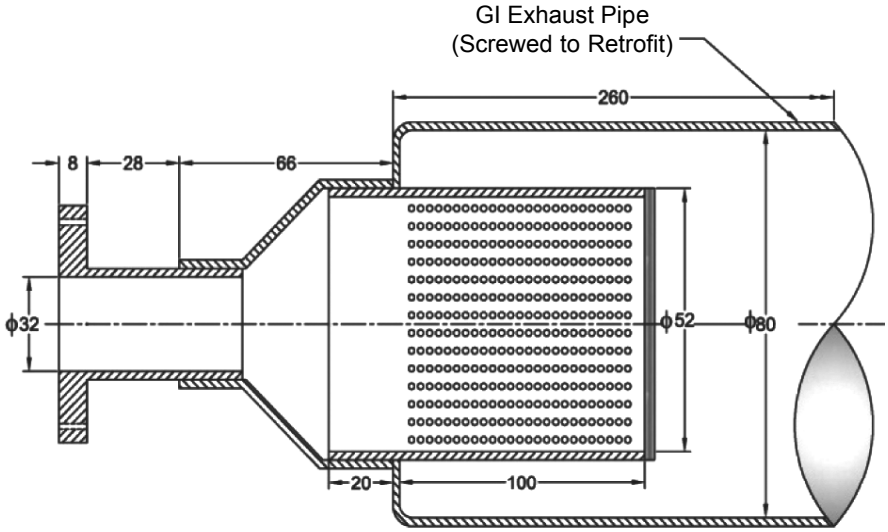
Retrofit Design and its Working

Retrofit with manifold flow dissipation area eases the exhausting, suppresses the wave, reduces the In-cylinder peak pressure and residuals. Improved combustion brings down the levels of CO, HC and smoke levels. Lower peak pressure and long combustion temperature (reflected by lower EGT) result in reduced NOx levels. The retrofit design is shown in Figure 1 and details in Table 1.

EXPERIMENTATION

Test engine was a stationary single cylinder, four stroke, water cooled, naturally aspirated, direct injection diesel engine rated 7 HP at 1500 rpm. Engine coupled to the dynamometer along with the setup is shown in Figure 2. AVL smoke meter, AVL gas analyzer for CO, HC, and NOx and AVL combustion analyzer for In-cylinder pressure and heat release rate were employed for measurements. Load tests were conducted at rated 1500 rpm, cooling water flow maintained at 7 lit/min, with each of the three retrofits (area factor 4, 7, 8) and without retrofit (base line).

Figure 1: Retrofit-Exhaust Pipe Assembly



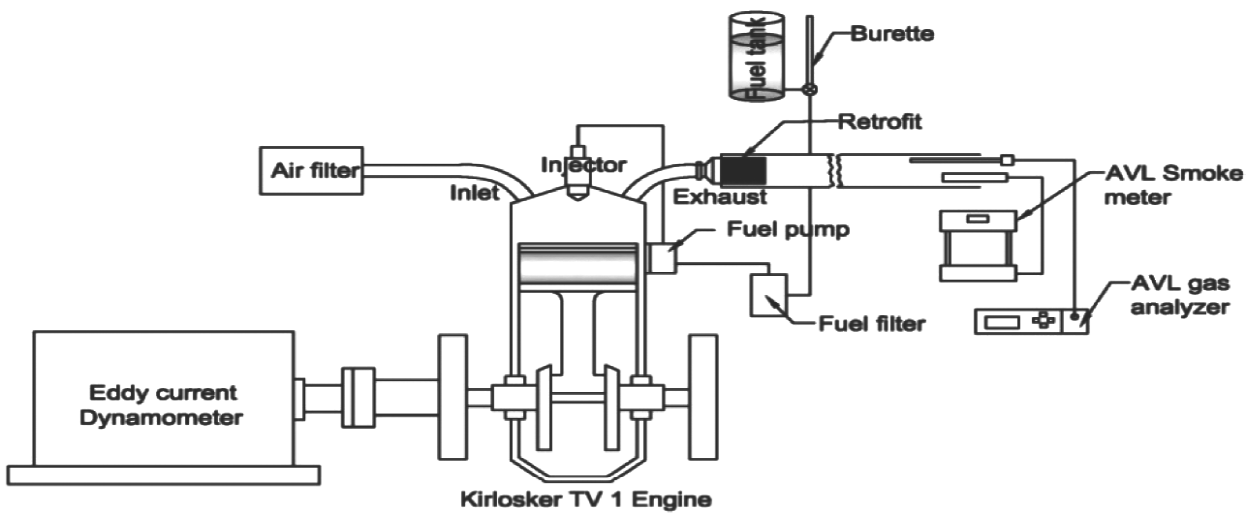
All Dimensions in mm

Table 1: Details of Retrofit Configurations Used

AF	d_h (mm)	n_h
4	4	257
7	4	447
8	4	512

Load was varied from no load to full load in steps of 25%. Fuel consumption was measured using a stop watch and burette. Smoke density (HSU), carbon monoxide (volume %), hydrocarbon (ppm) and oxides of nitrogen (ppm) levels were observed for each load condition. In-cylinder pressure and heat release rate were also recorded.

Figure 2: Experimental Setup



RESULTS AND DISCUSSION

The experimental results of the present work are on the expected lines and encouraging. As shown in Figure 3 the retrofit results in 1% to 3% thermal efficiency enhancement (1% at 25% load 3% at 75% load both with retrofit of area factor 7). This improvement correlates with reduction in combustion related emissions CO, HC and smoke. It is interestingly noticed that smoke, un burnt hydrocarbon (UBHC),

Figure 3: Brake Thermal Efficiency Against Brake Power

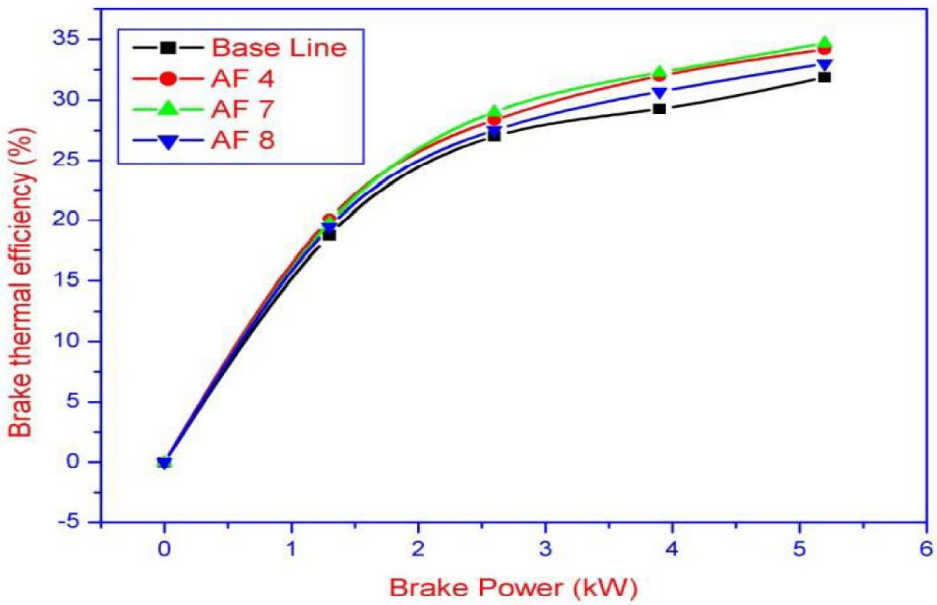
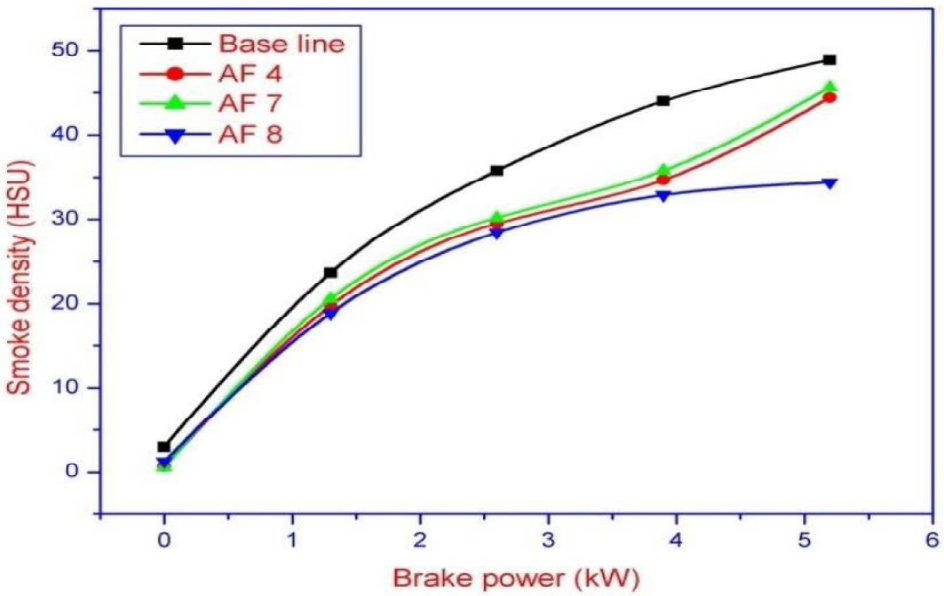


Figure 4: Smoke Density Against Brake Power



Carbon Monoxide (CO) and Oxides of Nitrogen (NO_x) all simultaneously reduce due to the retrofit (Figures 4 to 7). Usually smoke, CO, HC group trades off with NO_x. Thermal efficiency enhancement, reduction in smoke levels and reduction in oxides of nitrogen level become more favourable with increasing load. Though carbon monoxide level is considerably reduced from the base line (without retrofit) values (60% reduction at 50% load with all the

Figure 5: HC Against Brake Power

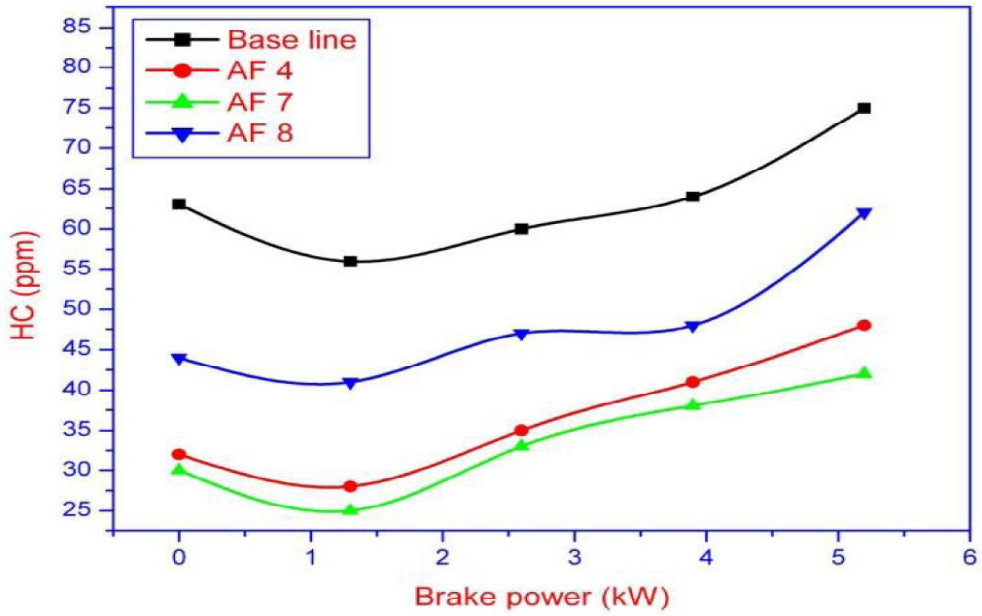


Figure 6: CO Against Brake Power

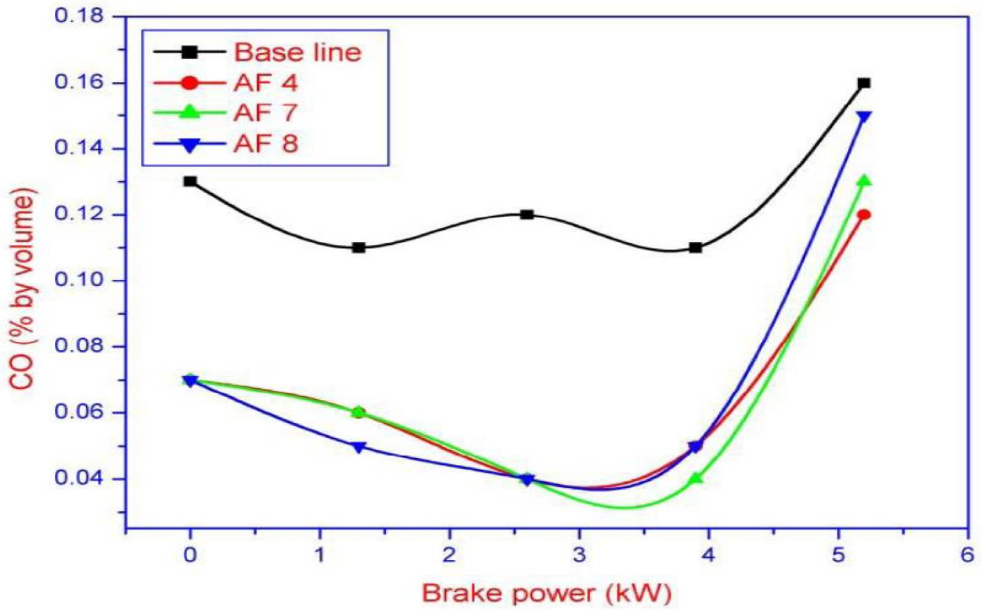
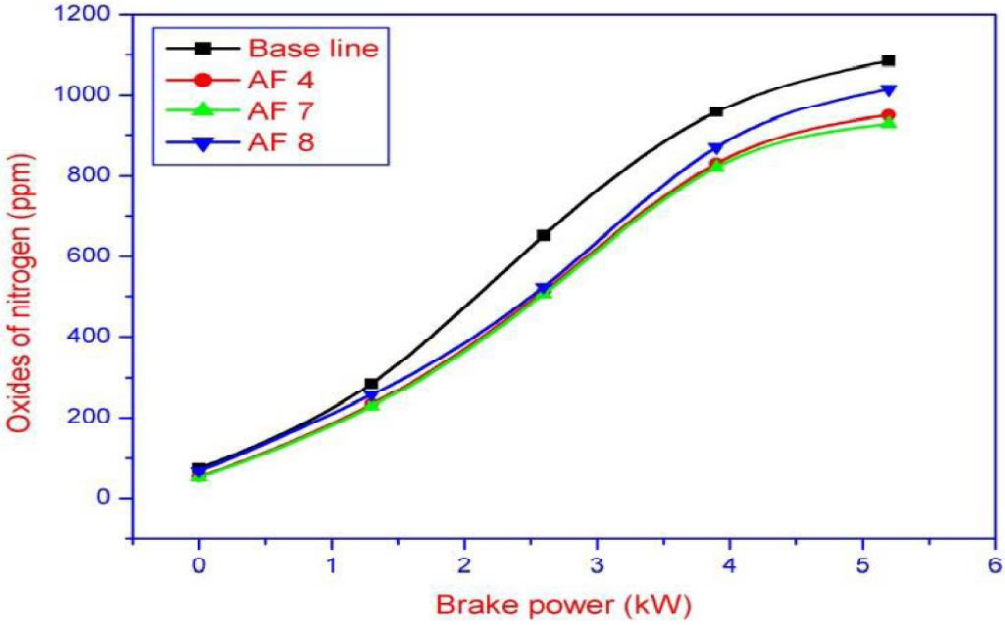
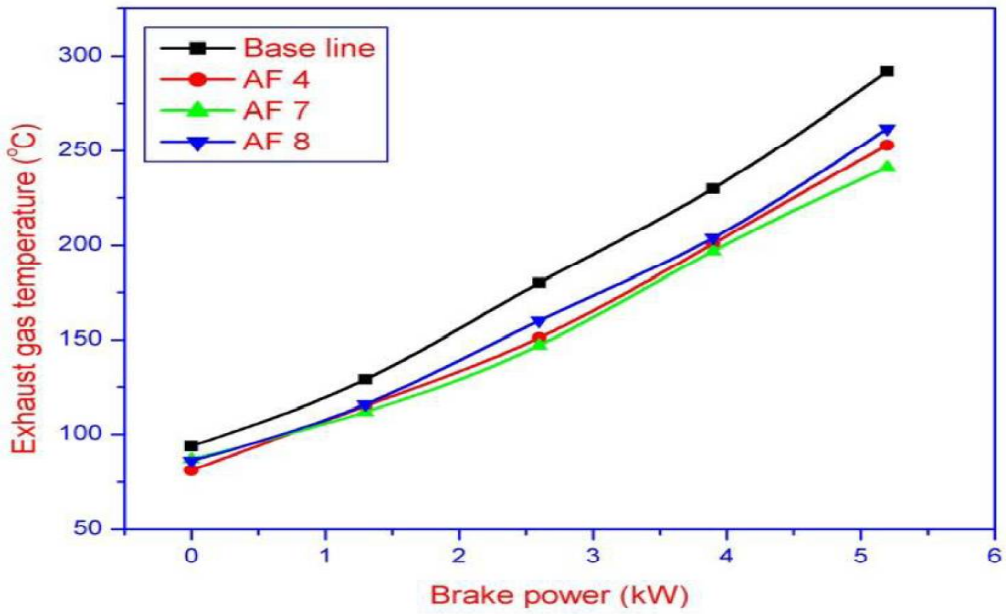


Figure 7: Oxides of Nitrogen Against Brake Power



three retrofits), the reduction is more favourable at lower loads and the impact of retrofit area factor is insignificant. Carbon monoxide level reduction varies from 0.01 volume % at full load with retrofit of area factor 8 to 0.08 volume % at 50% load with all the three retrofits. Reduction in UBHC level from base line values due to the retrofit is considerable and similar at the all loads including part load conditions. At lower loads

Figure 8: EGT Against Brake Power



oxidation reactions are slower due to lower temperature and lean mixture, and at higher loads combustion becomes poor. This is the reason for higher values of UBHC at lower and higher loads beyond 25% load (Sethi and Sakariya, 2004). Smoke level reduction varies from 1.7 HSU at no load with retrofit of area factor 8 to 14.5 HSU at 75% load with retrofit of area factor 7. NO_x level reduction ranges from 8 ppm at no load with retrofit of area factor

Figure 9: Crank Angle Against Maximum Pressure

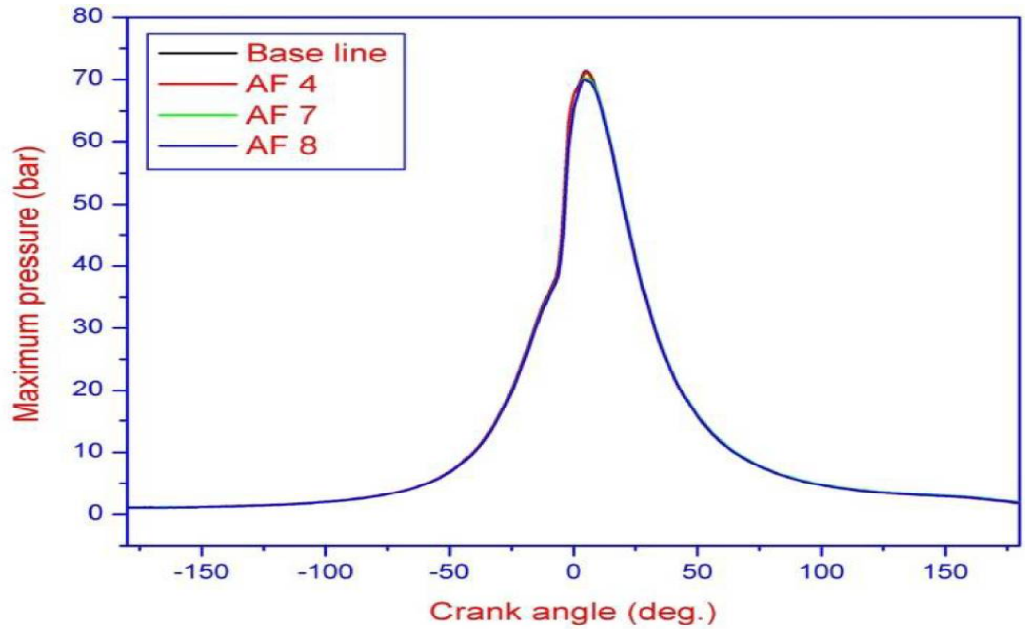
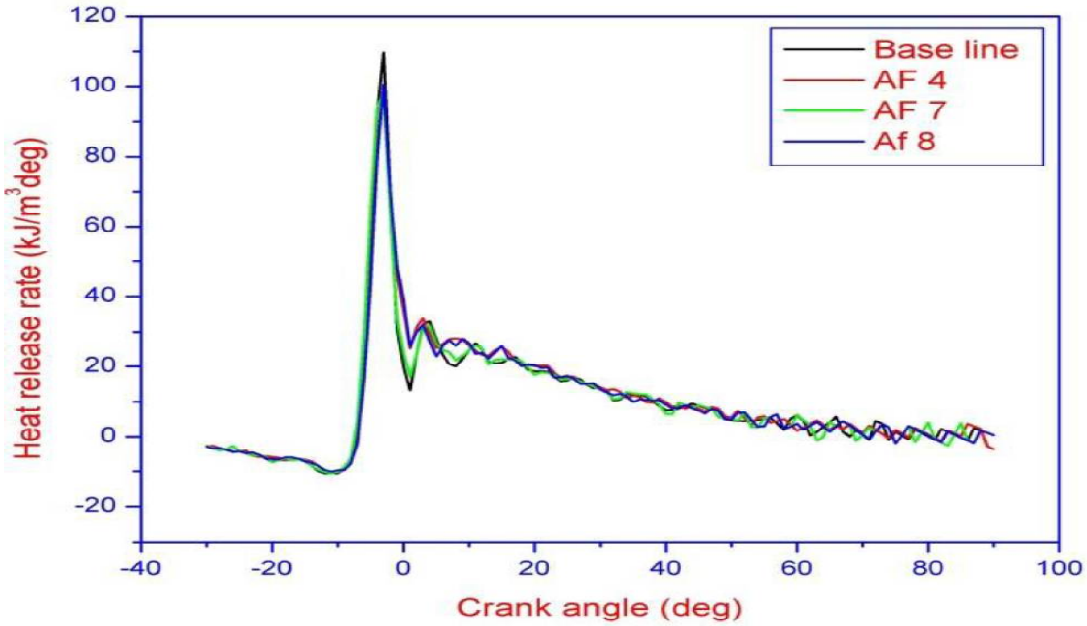


Figure10: Crank Angle Against Heat Release Rate



8 to 156 ppm at full load with retrofit of area factor 7. NO_x level a dependent on combustion temperatures increases with increasing load (Sethi and Sakariya, 2004). Lower EGT (exhaust gas temperature) (Figure 8) lower In-cylinder peak pressure (Figure 9) and lower heat release rate Figure 10 with the use of retrofit are in correlation with the NO_x reduction. UBHC level reduction is observed to be in the range of 1 ppm at full load with retrofit of area factor 8 to 54 ppm at no load with retrofit area factor 7.

CONCLUSION

- Use of exhaust system retrofit in the vicinity of exhaust port helps suppression of waves offending the exhaust flow.
- Lower residuals, lower In-cylinder peak pressure and lower heat release rate help achieving improved thermal efficiency and lower emission (CO, HC, smoke, NO_x) levels together.
- Retrofit facilitates simultaneous reduction in emissions of CO, HC, smoke group that is related to degree of combustion and NO_x that is related to combustion temperature.
- Thermal efficiency is moderately higher widely in the range of 2% to 3% from the base line values.
- Reduction in emission levels are in the ranges mentioned as in CO (volume) = 0.01-0.08%, HC = 1-54 ppm, Smoke density = 1.7-14.5 HSU, and NO_x = 8-156 ppm.
- Of the three retrofits tested that with area factor 7 is found to provide overall better performance. Area factor in the range of 7-8 is worth for the engine tested.
- Retrofit can be designed to as well work with any engine version like two stroke/ multi cylinder/petrol/mobile/flexible fuel engines.

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APPENDIX

Nomenclature		
AF	–	Area Factor
CI	–	Cast Iron
CO	–	Carbon monoxide (volume %)
d_h	–	Diameter of tiny holes in the retrofit (mm)
EGT	–	Exhaust gas temperature
GI	–	Galvanized iron
HSU	–	Hartridge smoke unit
PM	–	Particulate matter
P	–	In-cylinder pressure
n_h	–	Number of tiny holes in the retrofit
NO_x	–	Oxides of nitrogen (ppm)
UBHC	–	Un burnt hydrocarbon
θ	–	Crank angle (degree)