Effect of Engine Backpressure on the Performance and Emissions of a CI Engine

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ABSTRACT

This study investigated the effect of engine backpressure on the performance and emissions of a CI engine under different speed and load conditions. A 4-stroke single cylinder naturally aspirated direct injection (DI) diesel engine was used for the investigation with the backpressure of 0, 40, 60 and 80 mm of Hg at engine speed of 600, 950 and 1200 rpm. Two parameters were measured during the engine operation: one is engine performance (brake thermal efficiency and brake specific fuel consumption), and the other is the exhaust emissions (NOx, CO and odor). NOx and CO emission were measured by flue gas analyzer (IMR 1400). The engine backpressure produced by the flow regulating valve in the exhaust line was measured by Hg (mercury) manometer. The result showed that, the brake thermal efficiency and brake specific fuel consumption (bsfc) are almost unchanged with increasing backpressure up to 40 mm of Hg pressure for all engine speed and load conditions. The NOx emission became constant or a little decreased with increasing backpressure. The formation of CO was slightly higher with increase of load and back pressure at low engine speed condition. However, under high speed conditions, CO reduced significantly with increasing backpressure for all load conditions. The odor level was similar or a little higher with increasing backpressure for all engine speed and load conditions. Hence, backpressure up to a certain level is not detrimental for a CI engine.

Keywords: DI diesel engine, performance and emissions, backpressure.

1. INTRODUCTION

Backpressure usually refers to the pressure exerted on a moving fluid by obstructions against its direction of flow. The average pressure in the exhaust pipe during the exhaust stroke is called the mean exhaust pressure and the atmospheric pressure is called the ambient pressure. The difference between these two pressures is defined as backpressure [1]. Diesel engine causes emissions in the environment; some of them are harmful for human being. Exhaust systems including catalytic converter, muffler and resonator in diesel engine reduce the engine emissions [2, 3]. Increase in exhaust back pressure decreases nitric oxide, due to the increased exhaust gas remaining in the cylinder, as has also been demonstrated by others. Hydrocarbon emissions are also reduced as exhaust back pressure is increased [4]. Long term application of the system causes significant effect on engine performance and emissions. Particulate matter and other exhaust product adhere with flow passage of exhaust systems and the passage is reduced and backpressure is building up on the engine. The performance and emissions of a diesel engine can control by backpressure [2]. Excessive backpressure in the exhaust system create excessive heat, lower engine power and fuel penalty in the engine cylinder, that may cause damage of the engine parts and poor performance [5]. The amount of power loss depends on many factors, but a good rule-of-thumb is that one inch (25.4 mm) of mercury backpressure causes about 1.0% loss of maximum engine power [6]. Hence, backpressure can be used up to a certain level to improve the engine performance and reduce emissions. In modern diesel engine, diesel oxidation catalyst (DOC) is inevitably used to control CO and HC emissions. A new DOC is very effective mean of controlling CO and HC without any significant penalty in fuel consumption and power output and efficiency. When DOC becomes older, its activity is diminished, and it develops significant backpressure deteriorating engine performance with fuel penalty. An experimental investigation was performed at RUET, Bangladesh to obtain the allowable level of backpressure for which, there is no significant change in engine performance and fuel penalty. Its effect on exhaust emissions including odor was also investigated.

2. EXPERIMENTAL SETUP AND MEASUREMENT

A four-stroke single cylinder naturally aspirated DI diesel engine with specification as in Table 1 was used in this experiment. All experimental data were taken at various engine speeds of 600, 950 and 1200 rpm with low, medium and high load conditions after engine warm-up. The diesel fuel used in this study is available in the local market. Loads were measured by electric dynamometer. Exhaust emissions were measured after diesel oxidation catalyst and fuel consumption rate were measured by taking time for consumption of 10cc of fuel. The calculation of thermal efficiency and bsfc were measured by following formulae-

$$\text{Thermal efficiency} = \frac{\text{Power (kW)}}{\text{Heating value of fuel (kJ/kg)} \times \text{Fuel consumption (kg/s)}}$$

$$\text{bsfc} = \frac{\text{Fuel consumption rate (kg/hr)}}{\text{Brake power (kW)}}$$

The schematic of diesel engine with gas analyzer and odor measurement arrangement is shown in Figure 1.

Tab le 1. Engine specifications

Engine type	4-stroke DI diesel engine
Number of cylinders	One
Bore x Stroke	80 x 110 mm
Swept volume	553 cc
Compression ratio	16.5:1
Rated power	4.476Kw@1800 rpm
Fuel injection timing	24^0 BTDC

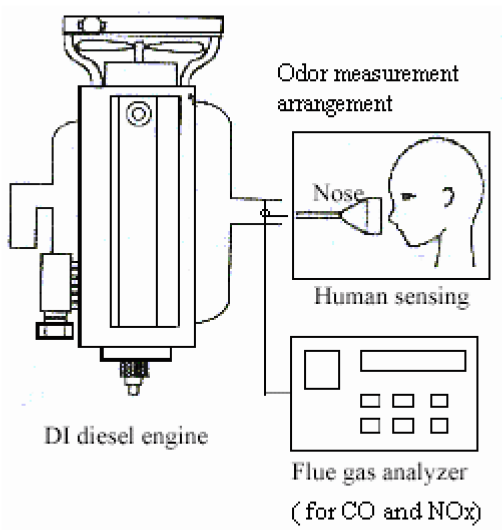

Fig.1: Schematic of diesel engine with gas analyzer and odor measurement arrangement

A flue gas analyzer (IMR 1400) was used to measure carbon monoxide (CO) and NOx of exhaust gases. A mercury manometer was used to measure the exhaust backpressure in the exhaust line. Gate valve in the exhaust line was used to regulate the backpressure. The arrangement of backpressure measurement is shown in Figure 2.

Fig.2: Arrangement of mercury manometer to measure exhaust backpressure.

2.1. Human assessment

Sensual assessment by human nose is one technique to asses the odor level of exhaust gases. This study used an odor intensity scale to evaluate the discomfort level of exhaust gases. The intensity scale and corresponding explanation of odor rating are shown in Table 2. A difference in 1 point has been reported as equivalent to a 10 fold the change in the concentration of odorous gases [7]. This means that one point improvement in the odor scale is a significant improvement in exhaust odor. Deviations in sensual assessment vary from person to person when the test personnel are inexperienced, while reliable results can be obtained with experienced personnel [8]. This study used three experienced assessors.

Table 2. Odor rating scale

Intensity rating	Verbal	Description
1	Not detectable	No odor
2	Slight	Odor but not uncomfortable
3	Moderate	Uncomfortable odor
4	Strong	Imitating odor, long time exposure not possible
5	Very strong	Very imitating odor, exposure even 1 o 2s impossible

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Engine performance

After the engine reached the stabilized working condition for each test, fuel consumption, load and exhaust emissions were measured from which bsfc and efficiency were computed. The variations of these parameters with backpressure are presented.

Figure 3 shows the variation of brake thermal efficiency (η_{th}) with engine backpressure. Figure 3(a), (b) and (c) represent the effect of backpressure on thermal efficiency at 600, 950 and 1200 rpm engine speed respectively. Brake thermal efficiency was almost constant for low, medium and high load condition with backpressure at low engine speed of 600 rpm. At 950 rpm, it slightly decreased for low, medium and high load condition. At 1200 rpm, it is decreased with increase in backpressure. Medium and high load condition could not be examined due to unacceptable level of black smoke.

Figure 4 shows the variation of bsfc with backpressure at various engine load and speed condition. Figure 4 (a), (b) and (c) represent the effect of backpressure on bsfc at 600, 950 and 1200 rpm respectively. From the figure, it is seen that bsfc has no significance change for low speed condition. of 600 rpm. At 950 rpm bsfc increased with the increase in backpressure for all load condition. At 1200 rpm at low load condition bsfc also increased with backpressure. Hence, up to a certain limit of speed and backpressure, there is no significant effect on engine performance. Excessive backpressure at high speed causes decrease in the engine performance and fuel penalty.

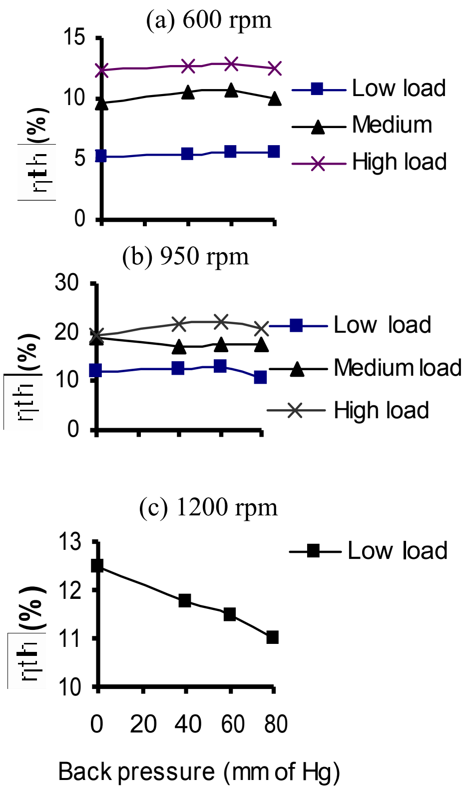

Fig. 3: Effect of backpressure on brake thermal efficiency with various engine loads

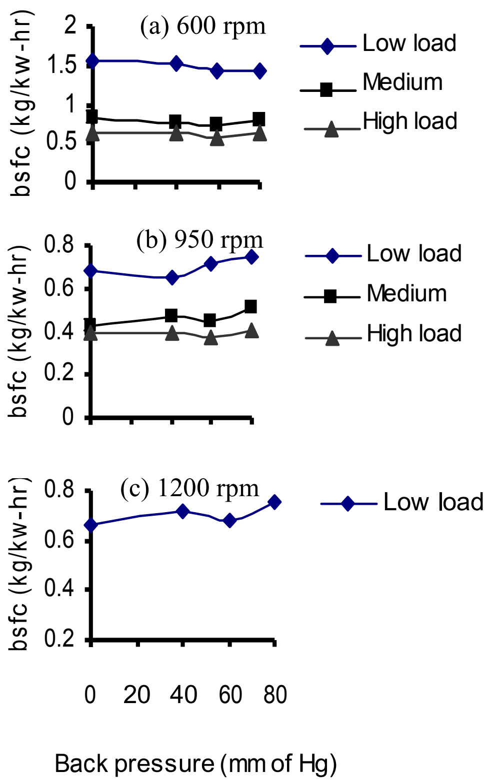

Fig. 4: Effect of backpressure on bsfc with various engine loads

3.2. Engine emissions

Figure 5 shows the variation of CO emission with backpressure at various load condition. Figure 5 (a), (b) and (c) represents the effect of backpressure on CO emission at 600, 950 and 1200 rpm respectively At 600 rpm CO increases with increasing backpressure at various engine load condition. At low load condition, CO is higher than other test load. At 950 rpm high load condition, CO decreases significantly with backpressure. At low and medium load condition CO slightly decreases with backpressure. Also at 1200 rpm CO decreases with backpressure and at no load condition it is higher than at low load. Hence, at low engine speed CO is higher with increased backpressure. However, CO decreased with increase in backpressure at high engine speed.

Figure 6 illustrates the variation of NOx emission with backpressure at various engine load condition. From the figure, it is seen that NOx emission decreases with backpressure and increases with increasing engine load at various test load and engine speed. Increased backpressure causes increased exhaust gas remaining in the cylinder, which have higher specific heat and act as a heat sink in the engine cylinder. Hence, NOx is reduced.

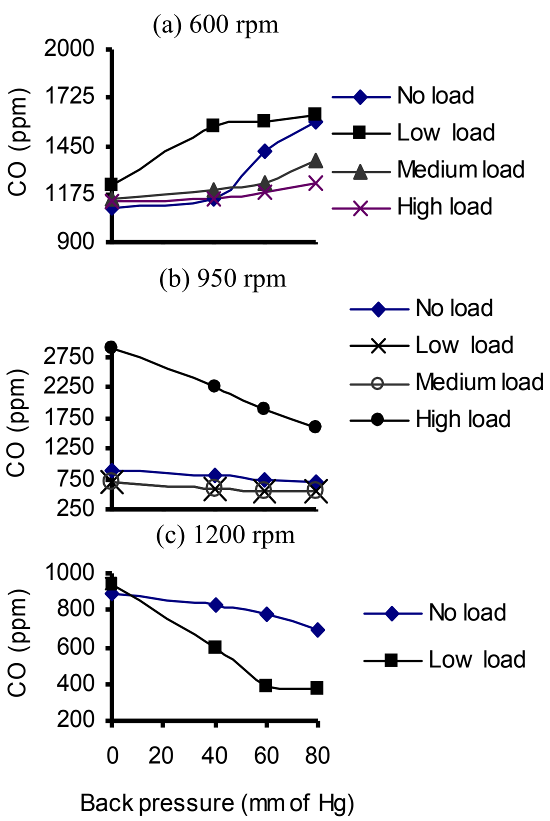

Fig. 5: Effect of backpressure on CO emission

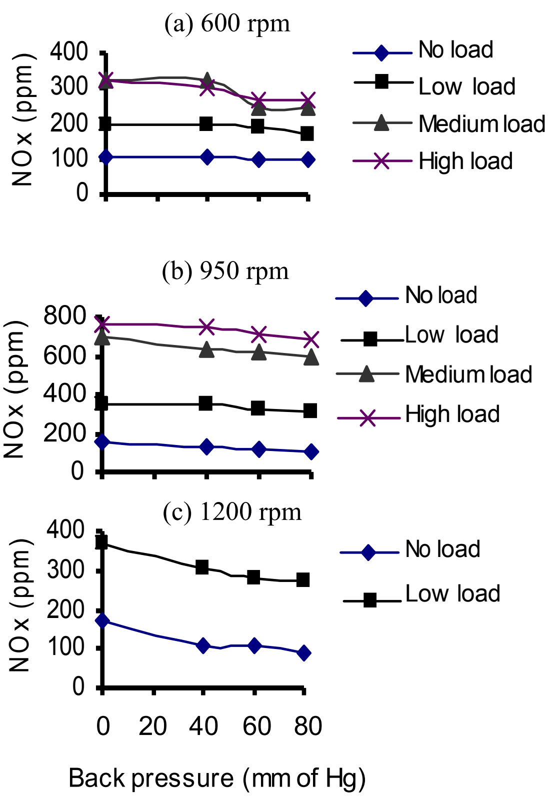

Fig. 6: Effect of backpressure on NOx emission

Figure 7 shows the variation of odor with backpressure for different load condition. From the figure, it is seen that the trend is similar for all load condition at 600, 950 and 1200 rpm engine speed, i.e., odor slightly increases with increasing backpressure.

Figure 8 illustrates the variation of exhaust gas temperature with backpressure for various load condition. It is seen that, gas temperature increases with increasing backpressure for 600, 950 and 1200 rpm engine speed and all load condition. Gas temperature is low at low load and high at high load. Hence, backpressure causes increase in the exhaust gas temperature due to exhaust gas present longer time in the exhaust line before being exhausted.

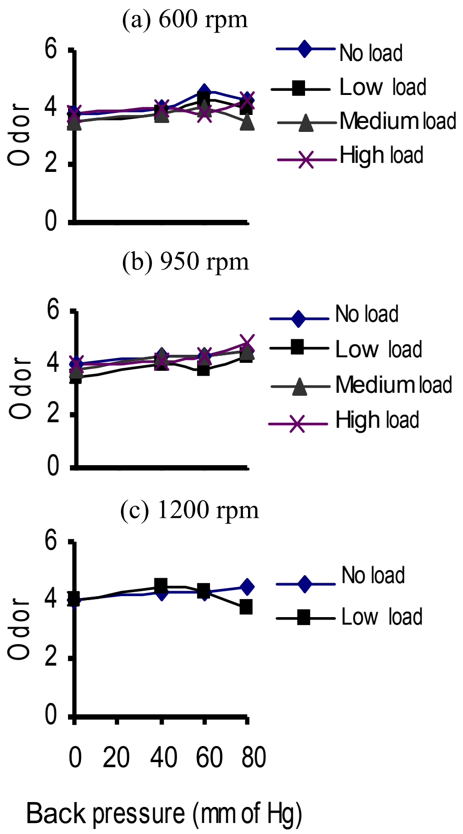

Fig. 7: Effect of backpressure on odor

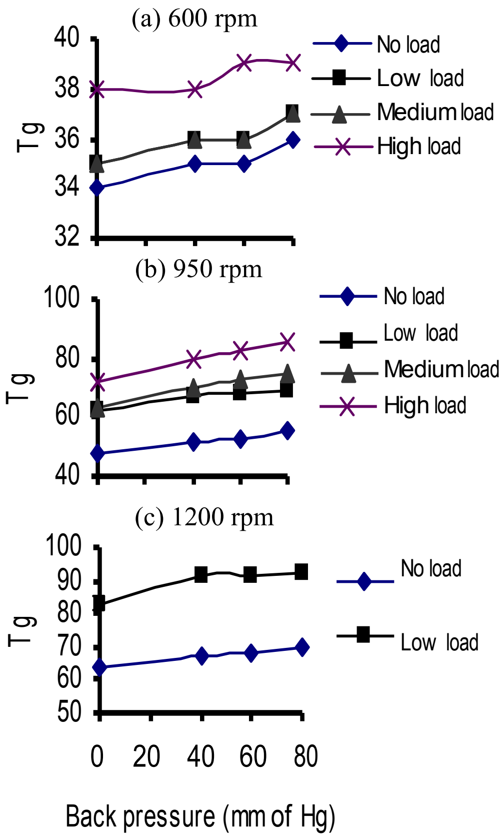

Fig. 8: Effect of backpressure on exhaust gas temperature

4. CONCLUSION

The following conclusions can be drawn from the experimental investigation.

1. At low engine speed the backpressure has no significant effect on engine performance with various load conditions. At medium and high engine speed the performance remains constant up-to a certain backpressure (40 mm of Hg) and then decreased. At low speed condition, bsfc is almost constant. However, at medium and high speed, bsfc is little higher for all load conditions.

2. CO is higher at low engine speed for all load condition with increased backpressure. However, CO decreased with increased backpressure for higher engine speeds and loads.

3. NOx emission always decreased at low, medium and high engine speed with increased backpressure for various load conditions.

4. Backpressure has no significant effect on odor level up to 40 mm of Hg pressure. However, odor is increased above the backpressure of 40 mm Hg. The exhaust gas temperature was always increased with higher backpressure and engine load.

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