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EXHAUST ODOR REDUCTION BY CHARCOAL-ADSORPTION SYSTEM IN DIRECT INJECTION DIESEL ENGINES

Murari Mohon Roy[1], Azizur Rahman[2] and S. M. Moshiar Rahman[3]

[1]Department of Mechanical Engineering, Rajshahi University of Engineering & Technology (RUET), Rajshahi-6204
[2]Organon (Bangladesh) Ltd., 97/98, Tongi Industrial Area, Tongi, Gazipur
[3]Global Capsules Ltd., Rupatali, Barisal

ABSTRACT
Direct injection (DI) diesel engines have the lowest fuel consumption and carbon dioxide (CO_2) emissions. So, DI diesel engine vehicles are becoming popular day by day. But, DI diesel engines emit a far more disagreeable exhaust odor at idling than gasoline engines. There is no proper system of odor reduction at idling in DI diesel engines. The attention of the authors is to reduce the unpleasant exhaust odor of DI diesel engines at idling. This study developed a charcoal-adsorption system of exhaust gas treatment to reduce odor at idling. The effect of this system on odor reduction is investigated at different engine conditions. The exhaust gas was passed through a charcoal-adsorber. Charcoal has the property of adsorbing odorous gas components. Here odor is reduced about 0.5 to 0.75 points, a significant odor reduction depending on the engine and adsorber conditions. Noise, nitrogen oxides (NOx) and eye irritation are also significantly reduced with the system. This study further investigated back pressure and fuel consumption of the engine.

Keywords: DI Diesel Engine, Exhaust Odor, Charcoal-Adsorption System.

1. INTRODUCTION
There are advantages with DI diesel engine in fuel economy and CO_2 emissions, but such engine emits more unpleasant exhaust odor than gasoline engines, especially at low temperatures and at idling. With increasing number of DI diesel engines, reductions in exhaust odor to acceptable levels are an urgent need. There are two main ways of odor reduction: in-cylinder combustion improvement and the use of exhaust gas treatment system. Exhaust odor reduction is not so significant by in-cylinder combustion improvement and not cost effective [1-3]. Odor reduction by optimized engine parameters is attempted, but there is no substantial odor reduction [1, 2]. Alternative fuel like normal Decane (n-Decane) is very prospective to odor reduction [3]. But, the cost of n-Decane is many folds than the cost of diesel fuel. The use of oxidation catalyst to reduce diesel odor is a very attractive and effective method. But, this can be used only at high exhaust gas temperature condition, i. e. at running condition of DI diesel engine. When the engine is at idling, the exhaust temperature is low, and catalyst does not work in this low temperature condition [4]. Charcoal can be used as adsorbents for the removal of sulphur dioxides (SOx), NOx, volatile organic compounds (VOC) and some other organic chemicals like phenol and others from gaseous pollutants [5]. They are also used in refrigerators to remove general food odors. As there is no proper system of odor reduction in DI diesel engine at idling and charcoal is a very attractive adsorbent of many gaseous pollutants including odorous gas components, this study investigated the prospect of charcoal to be used in an exhaust gas treatment system for the reduction of exhaust odor in DI diesel engine at idling. This study develops a charcoal-adsorption system and it is found that it has a remarkable odor reduction capability and odor is more than 0.75 points (30-40%) reduced by this system.

2. EXPERIMENTAL SET-UP
Figure 1 shows the schematic diagram of the experimental system. A 4-stroke single cylinder DI diesel engine with specifications described in Table-1 was used. Test data were taken at an idling speed of 700-1100 rpm after engine warm-up. Odor is measured by human sensing and by instrumental method. In instrumental method, a glass electrode pH meter for the measurement of the pH value of the aqueous solution of exhaust gases was used. A flue gas analyzer and a sound level meter were used to measure the NOx emissions and noise level of exhaust gases. The diesel fuel used in this study was taken from the local market. Table-2 shows different properties of the tested fuel.

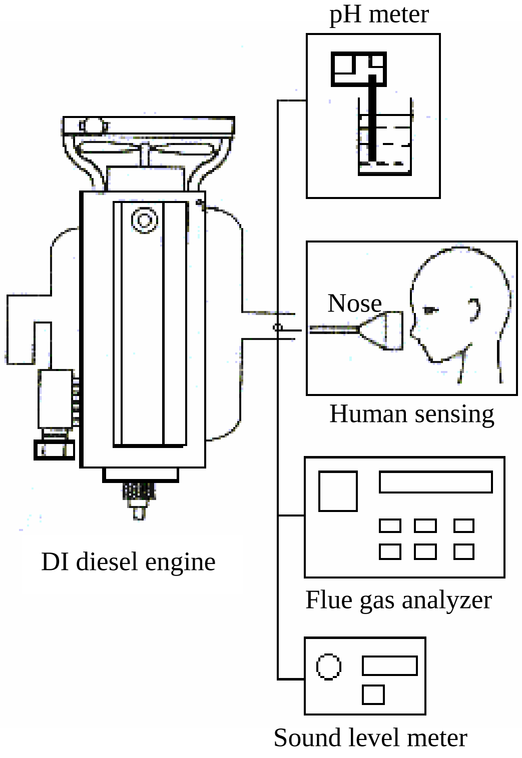

Fig 1. Schematic diagram of the experimental system

Table 1: Engine specifications

Engine type	4-stroke DI diesel engine
Number of cylinder	One
Bore × Stroke	80 × 110 mm
Swept volume	553 cc
Compression ratio	16.5:1
Rated power	4.476 kW @ 1800 rpm
Fuel injection pressure	14 MPa (900-1099 rpm) 20 MPa (1100-2000 rpm)
Fuel injection timing	24° BTDC

Table 2: Important properties of the test fuel

Fuel properties	Diesel fuel
Specific gravity	0.84
Viscosity (cSt)	4.7
H. C. V. (kJ/kg)	44735
Cetane number	50
Flash point (°C)	50

2.1 Sensual Assessment

Sensual assessment by human nose is one technique to assess 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-3. A difference in 1 point has been reported as equivalent to a 10-fold the change in the concentration of odorous gases [6]. 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 [3]. This study used three experienced assessors.

2.2 Instrumental Assessment

To eliminate the biasness of sensual assessment only, instrumental assessment is usually used to correlate the instrumental results with sensual assessment. This study used pH measurement as an instrumental method. Aldehyde components are the main odorous components in the exhaust [7]. Also organic acids have an effect on the exhaust odor. The amount of aldehydes or organic acids condensed in the aqueous solution of exhaust gases change the pH value of the solution and the pH value of exhaust gases is one indicator to evaluate the odor intensity of the diesel exhaust. The pH measurement technique using a cold trap has been proposed and it has been shown that there is a good correlation between the pH value and the odor rating as assessed by professional assessors [8]. In other study, pH measurements by cold trap methods under various conditions were attempted [9], but due to the poor reproducibility of the tests, the author suggested the bag sampling method. This study used bag sampling method for pH determination. The bag used to sample gas is of 15 liter volume and the sampling time is only about 5 seconds. After sampling the gas, 25 cc of pure water is poured into the bag to create a solution. The bag containing the sample solution is then cooled to -10°C about 5 minutes to condense the odorous components. After that, the pH value is measured by a pH meter.

Table 3: Odor rating scale

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

3. CHARCOAL-ADSORPTION SYSTEM

This study developed a new charcoal-adsorption system of exhaust gas treatment. This system is constructed without any proper design, since this is the very beginning of this type of work and the main objective was to observe the odor reduction capability of charcoal-adsorber system in DI diesel engine.

In charcoal-adsorber system (fig. 2), cylindrical charcoal container, funnels and connecting pipelines made up of galvanized plane sheet are used. After attaching funnels with the container, the wiring and cartoon tapes are rolled over the joints to prevent the gas leaks. The charcoal used is readily available in the market. Also jut net is used in between funnel and container to support the charcoal and for the filtration purpose of the exhaust gas from particulate matters. The jut net used in the experiment had not any designed mesh size. The exhaust gas is carried by the connecting pipelines from the tailpipe through the jute net. Charcoal in the container adsorbs odorous components of exhaust gases and then the clean gas leaves to the atmosphere.

Charcoal-adsorber with diameters of 10 cm and 15 cm and variable lengths of 91.5 cm, 122 cm and 152.5 cm are used. From the investigation, it has been found that the 15 cm diameter and 152.5 cm length adsorber shows the best results.

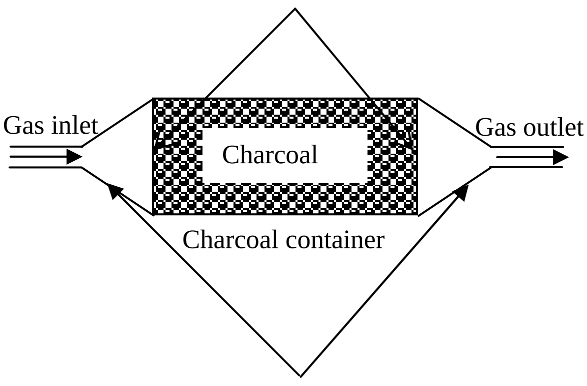

Fig 2. Charcoal-adsorber system

4. EXPERIMENTAL RESULTS AND DISCUSSION

Experiments have been done after engine warm-up at various engine speeds of 700, 900 and 1100 rpm. First the correlation between pH and odor was established at different engine conditions, which is shown in Fig. 3. There is a very good correlation between odor and pH. The higher the pH value, the lower the odor rating and vice versa. Moreover, one point odor change is equivalent to about one point pH change of exhaust gases.

4.1 Odor with Different Diameter Charcoal-Adsorbers

Exhaust odor was checked first with a fixed length charcoal-adsorber of 91.5 cm with diameters of 10 and 15 cm. Exhaust odor was checked after engine warm-up at the engine speed of 700, 900 and 1100 rpm. The results are compared with those of without adsorber. Figure 4 shows the results of odor rating with and without charcoal-adsorber. It shows that odor is reduced about 0.2 to 0.3 points with charcoal-adsorber than without adsorber. With adsorber diameter of 15 cm, the odor is more reduced (about 0.1 points more) than that of the 10 cm diameter adsorber. From then on all the experiments had been done by using 15 cm diameter adsorber with different lengths.

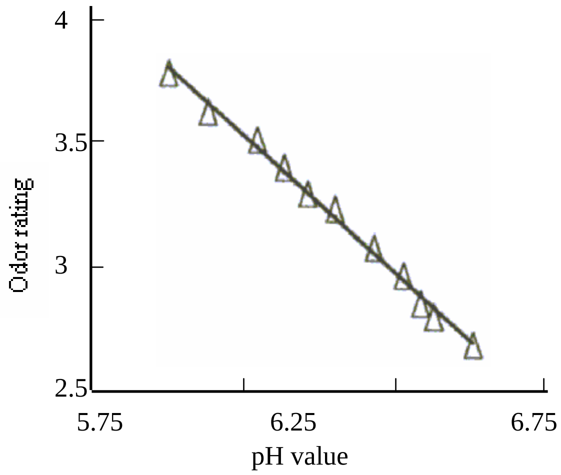

Fig 3. Odor-pH correlation

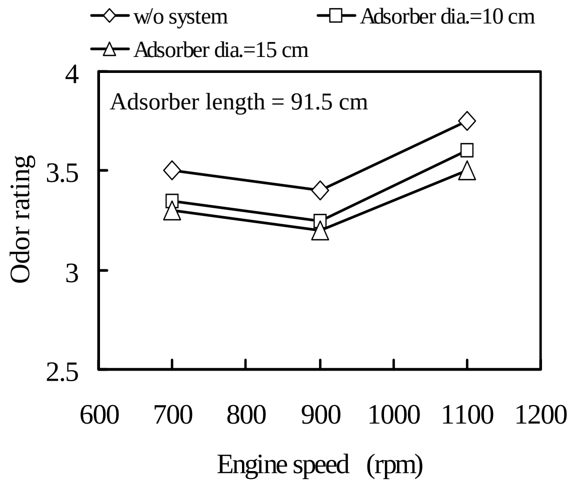

Fig 4. Odor rating without and with different diameter charcoal-adsorbers after engine warm-up

4.2 Odor with Different Length Charcoal-Adsorbers

Figure 5 shows similar results of odor rating without and with different adsorbers after engine warm-up at the engine speed of 700, 900 and 1100 rpm. At all speeds there is a similar trend in odor reduction with adsorbers in comparison without adsorber. It is found that odor rating is decreased with the increase of adsorber length. And with the adsorber of length 152.5 cm the odor is reduced about 0.75 points which is a significant odor reduction. This suggests that when the exhaust passes through more amount of charcoal, the exhaust become cleaner from odorous components due to greater adsorber surfaces. This seems that the more the adsorber length, the more the odor reduction to be for the same diameter of the adsorber. The only constraint is the back pressure developed in the engine. The back pressure and fuel consumption are also investigated in this study and to be shown in the next section.

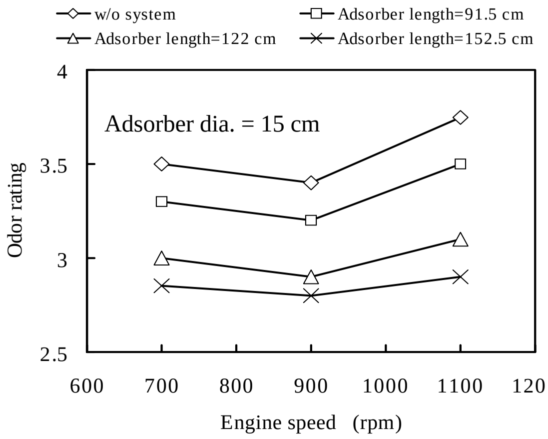

Fig 5. Odor rating without and with different lengths charcoal-adsorbers after engine warm-up

4.3 Other Emissions

4.3.1 Noise Emission

Figure 6 shows noise level without and with different charcoal-adsorbers after engine warm-up at the engine speed of 700, 900 and 1100 rpm. Noise level is gradually decreased with the increase of adsorber length at all engine speeds. The trend shows that at higher engine speed the noise reduction with adsorber is more. With the longest adsorber noise is reduced about 15 to 20 dB (about 20-25%), a substantial noise reduction. Therefore charcoal-adsorber system can be used as a substitute of a silencer as well.

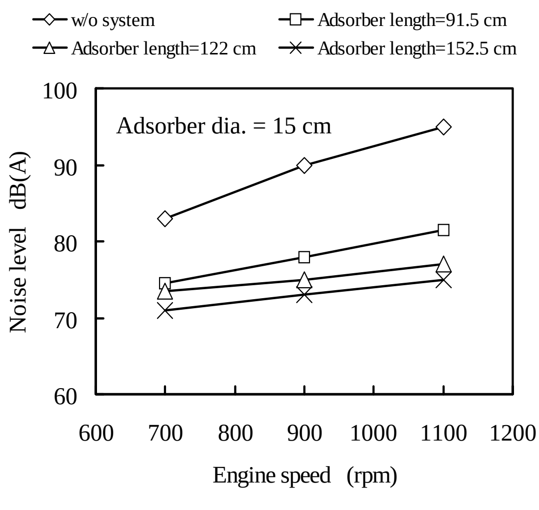

Fig 6. Noise level without and with different charcoal-adsorbers after engine warm-up

4.3.2 Eye Irritation

This investigation includes not only odor but also irritation of exhaust gases. Irritation was expressed by the term 'eye irritation time' which is measured by the time required to irritate the eyes when the eyes are exposed to the exhaust. The longer time required to irritate the eyes indicates that there are less irritants in the exhaust and vice versa. The detail of the measurement of eye irritation time has been presented in a previous SAE paper [3]. Figure 7 shows eye irritation time without and with charcoal-adsorber system after engine warm-up at 700 rpm. Without the system the eyes irritate only after 3 seconds of exposure to the exhaust, while it takes 30 seconds for the irritation of eyes when charcoal-adsorber of length 152.5 cm was used. This is a significant improvement in eye irritation with the system.

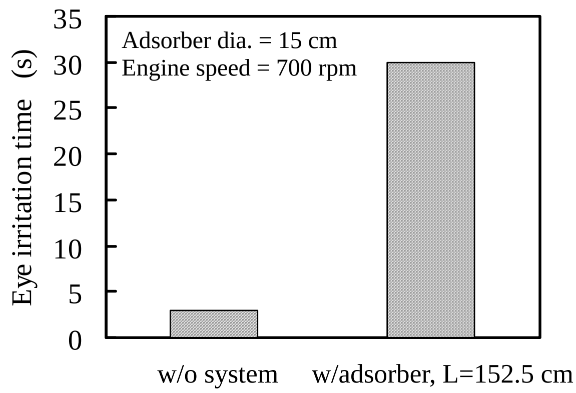

Fig 7. Eye irritation time without and with system after engine warm-up

4.3.3 NOx Emission

NOx, especially nitrogen dioxide (NO_2) is odorous in nature, and as odorous components are adsorbed by charcoal, it was expected that NOx might be adsorbed by charcoal. Figure 8 shows NOx emission without and with the system after engine warm-up. In the engine speed range of 700 to 900 rpm NOx is reduced about 40 ppm (20% or more). Therefore, charcoal-adsorber system acts as a NOx-adsorber also in the usual idling speed of the engine.

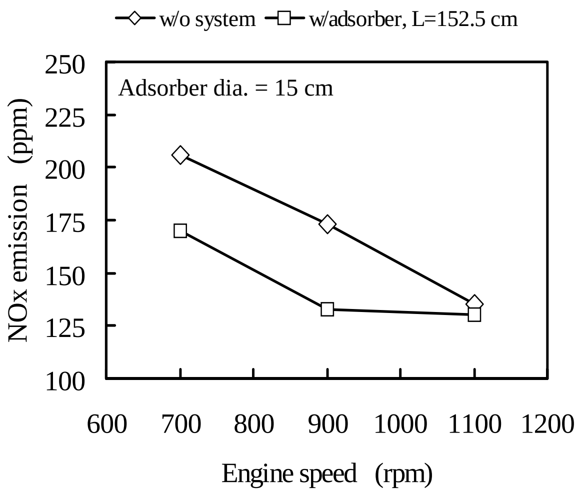

Fig 8. NOx emission without and with system after engine warm-up

4.4 Back Pressure and Fuel Consumption

It was said earlier that longer adsorber adsorbs more exhaust components. It was suspected that with longer adsorber there will be a problem of higher exhaust back pressure deteriorating fuel consumption. Therefore, exhaust back pressure and fuel consumption were investigated. Figure 9 shows back pressure without and with the system after engine warm-up. Here the longest adsorber is considered. There is very small back pressure without system in the range of 0.1 to 0.2 mbar. With the system, back pressure increases to 1.5 to 2 mbar. But still

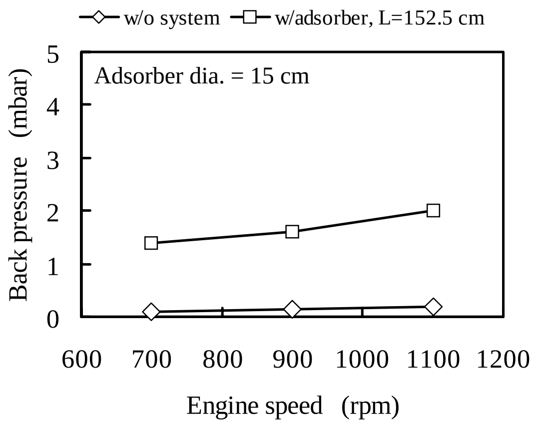

Fig 9. Back pressure without and with system after engine warm-up

this back pressure is very low to create any trouble for engine running or for fuel consumption.

Figure 10 shows fuel consumption comparison without and with the system. There is no significant change in fuel consumption without or with the system. This indicates that charcoal-adsorber system which can reduce not only odor, but also eye irritants, NOx and sound level can be a very prospective measure to reduce exhaust emissions in DI diesel engines at idling where no other measures are effective.

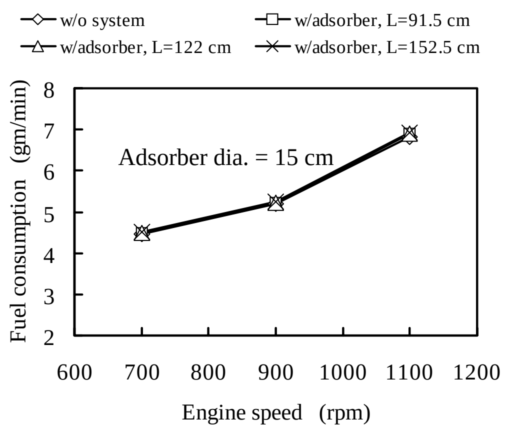

Fig 10. Fuel consumption without and with different charcoal-adsorbers

5. CONCLUSIONS

The following conclusions can be made from the investigation.

1) The charcoal-adsorber system shows effective and significant odor reduction more than 0.75 points (about 40%) at idling where there is no other way of odor reduction.

2) Sound level is decreased 15 to 20 dB (more than 20%) using this system. Therefore, charcoal-absorber system can be used in place of silencer in DI diesel engine.

3) NOx is reduced significantly (about 20%) with this system. So, charcoal-adsorber system can be a prospective NOx reducer in the idling condition of DI diesel engine.

4) There is no significant increase in back pressure and fuel consumption for the use of this system.

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7. NOMENCLATURE

Symbol	Meaning	Unit
BTDC	Before top dead center	(-)
cc	Cubic centimeter	(-)
cm	Centimeter	(-)
CO_2	Carbon dioxide	(-)
cSt	Centistokes	(-)
dB	Decibel	(-)
°C	Degree centigrade	(-)
DI	Direct injection	(-)
gm/min	Gram per minute	(-)
H. C. V.	Higher calorific value	(kJ/kg)
kJ/kg	Kilojoules per kilogram	(-)
kW	Kilowatt	(-)
L	Length	(m)
mbar	Millibar	(-)
min	Minute	(-)
mm	Millimeter	(-)
MPa	Megapascal	(-)
n-Decane	Normal Decane	(-)
NO_2	Nitrogen dioxide	(-)
NOx	Nitrogen oxides	(-)
pH	Hydrogen ion concentration	(-)
ppm	Parts per million	(-)
rpm	Revolution per minute	(-)
s	Second	(-)
SOx	Sulphur oxides	(-)
w/o	Without	
w/	With	
%	Percentage	