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EXHAUST GAS AFTER TREATMENT BY ABSORPTION SYSTEM TO REDUCE ODOR AT IDLING IN DI DIESEL ENGINES

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ABSTRACT

DI diesel engine vehicles are increasing worldwide because of the low CO_2 emissions. But, DI diesel engines emit a far more disagreeable exhaust odor at idling than gasoline engines. There is no proper system of reducing odor at idling in DI diesel engines. The absorption system of exhaust gas after treatment may be one good method of odor reduction at idling condition of the engine. This study developed an absorption type exhaust gas after treatment system. And the effect of this system on odor reduction is investigated at different engine conditions. The exhaust gas was first passed through a charcoal-absorber. Charcoal has the property of absorbing odorous gas components. Here odor is reduced about 0.1 to 0.2 points (5%-10%). Exhaust gas was then passed through water in the water-washing system. Water is used to dissolve the aldehydes and organic acids, the main odorous components. Odor is reduced again about 0.2 to 0.3 points (10%-20%). Exhaust gas then left to the atmosphere. It was found that odor is reduced more than 0.75 points (30%-40%), a significant odor reduction, by using total absorption system (combination of charcoal-absorber and water-washing system). Noise is also significantly reduced with the system.

Keywords: DI Diesel Engine, Exhaust Odor, Absorption System.

1. INTRODUCTION

There are advantages with DI diesel engines in fuel economy and CO_2 emissions, but such engines emit 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. It is easier to reduce exhaust odor if the main odorous components in the exhaust gas are known. Much research has been conducted to learn about the main odorous components in diesel exhaust where aldehydes have been shown to be responsible for the odor [1, 2]. It has also been shown that aldehydes as well as NO_2, SO_2, and other water-soluble components like organic acids may play a role in the exhaust odor [2, 3]. There are two main ways of odor reduction: in-cylinder combustion improvement and the use of exhaust gas after treatment system. Exhaust odor reduction by in-cylinder combustion improvement is not so significant and not cost effective. Odor reduction by optimized engine parameters is only about 10% [4, 5]. Alternative fuel like n-Decane is very prospective to odor reduction [6]. 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 lower than 200^0C, and catalyst does not work in this low temperature condition [5]. Aldehydes and organic acids are highly soluble in water, and exhaust gas that has been washed in water is expected to show lower odor levels. Further charcoal has the property to absorb many odorous components. This study developed an absorption system of odor reduction in DI diesel engines at idling. This study used charcoal-absorber and water-washing system separately to observe the odor reduction capability. They are also used in combination, and it is found that in combination it has a remarkable odor reduction capability and odor is reduced more than 0.75 points (30%-40%).

2. EXPERIMENTAL SET-UP

Fig.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 rpm during warm-up and at various engine speeds 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 exhaust gases was used. The diesel fuel used in this study is readily available in the local market. Table 2 shows different properties of the tested fuel.

2.1 Sensual Assessment

This study used an odor intensity scale to evaluate the discomfort level of exhaust gases. The intensity scale and corresponding explanation of odor ratings are shown in Table 3. A difference of 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 [6]. This study used four experienced assessors.

2.2 Instrumental Assessment

Aldehyde components are the important odorous components in the exhaust [2]. Also organic acids have an effect on the exhaust odor. The pH value of exhaust gases condensed in an aqueous solution is one indicator to evaluate the odor intensity of diesel exhaust. The pH measurement technique using a cold trap method is proposed and it has been shown that there is a good correlation between the pH value and the odor rating as assessed by professional perfumers [3]. In reference [3], the pH measurement technique using a cold trap method at about -50°C is proposed. It has also been shown that the odor rating decreases with the increase in pH values and vice-versa.

In another study, pH measurements by cold trap methods under various conditions were attempted [8], but due to the poor reproducibility of the tests, the authors suggested the bag sampling method. This study also 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 10 minutes to condense the odorous components. After that, the pH value is measured by a pH meter.

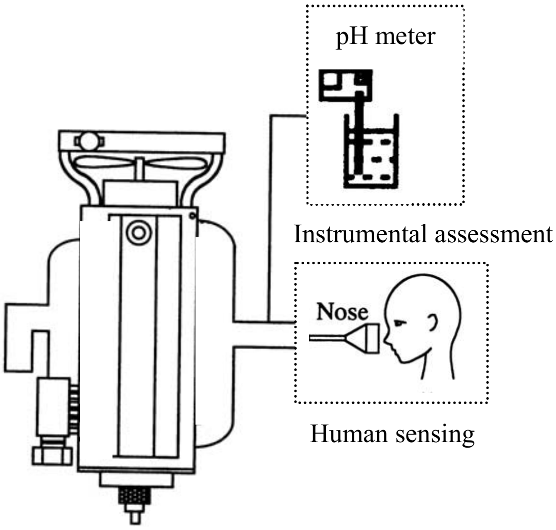

Fig. 1. Schematic diagram of the experimental system

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 (cP)	4.9
H. C. V. (kJ/kg)	44735
Cetane number	50
Flash point (°C)	50

Table 3.Odor rating scale

Intensity rating	Verbal description	Explanation
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 for even 1 or 2 s impossible

3. THE ABSORPTION SYSTEM

This study developed a new absorption-type exhaust gas after treatment system. The absorption system consists of a water-washing system with a charcoal-absorber. This system is constructed without any proper design since this is performed for the first time and the main objective was to observe the odor reduction capability of the system.

In charcoal-absorber (Fig. 2), cylindrical charcoal container, funnels and connecting pipelines made up of stainless steel sheets are used. After attaching funnels with the container, the wiring and carton tapes are rolled over the joints to prevent gas leaks. The charcoal used is readily available in the market. Also jute net is used in between funnel and container to support the charcoal and for the filtration purpose of the exhaust gas from PM. The jute net used in the experiment had not any designed mesh size.

In water-washing system, the water tank made of hard plastic and available in the market was used (Fig. 3). The capacity of the water tank is of 40 liter. There is an intake pipe to enter gas from tail pipe or from charcoal-absorber and an outlet pipe to let the gas out to the atmosphere.

Fig. 4 shows the total absorption system. The exhaust gas is carried by the connecting pipelines from the tailpipe through the jute net and charcoal container to the water tank for washing and then the clean gas leaves to the atmosphere.

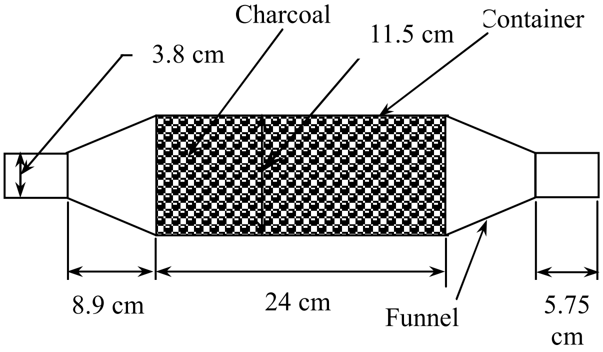

Fig. 2. The charcoal-absorber system

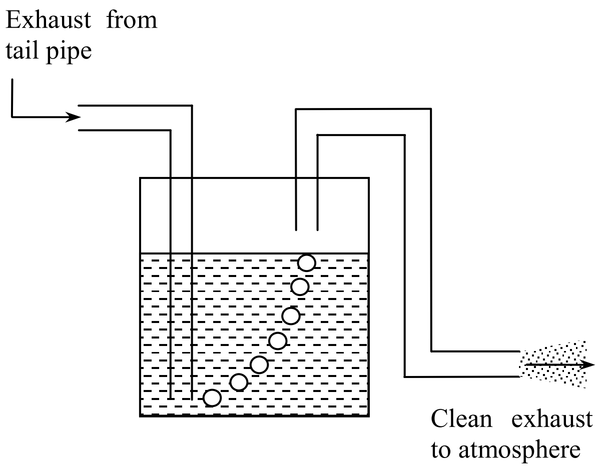

Fig. 3. The water-washing system

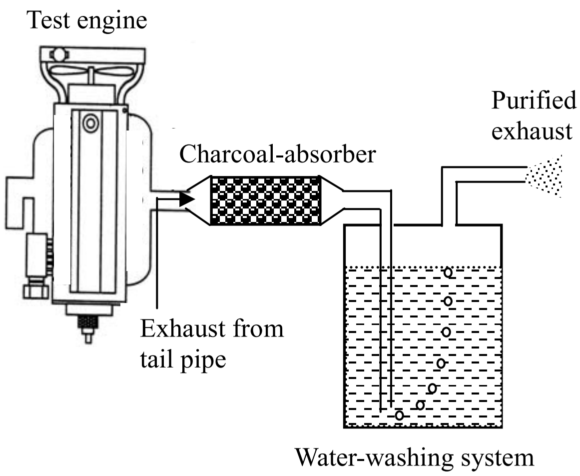

Fig. 4. The total absorption system

4. EXPERIMENTAL RESULTS AND DISCUSSION

The experiment is done in two engine conditions: one is during warm-up and the other is after warm-up at various engine speeds. During warm-up the engine speed was 700 rpm that is usual idling speed. First, the correlation between pH and odor was established at different engine conditions which is shown in Fig.5.

It is found that odor is decreased with the increase in pH value of exhaust gases. It is also found that the decrease in odor rating by 1 point is equivalent to the increase in pH value by 1 point. The pH values were in the acidic range and when the gas was less acidic the odor level was lower and vice-versa. This indicates that the odorous components are acidic in nature.

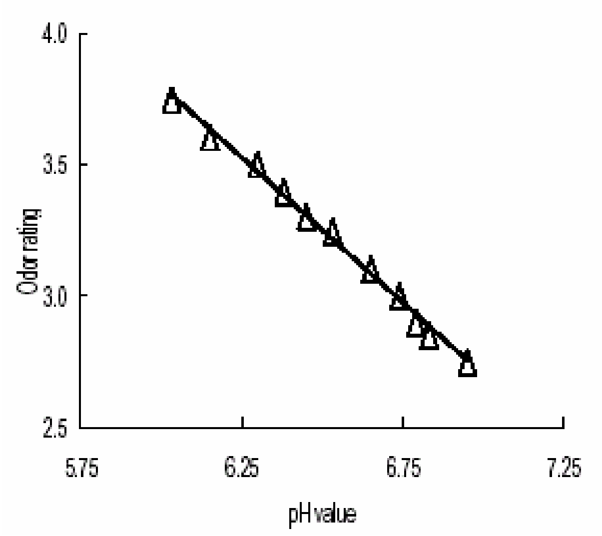

Fig. 5. Odor - pH relationship

4.1 Results during Engine Warm-Up

Exhaust odor was checked up to 16 minutes during engine warm-up. Fig. 6 shows the results of odor rating during engine warm-up at 700 rpm with and without charcoal-absorber. It shows that odor with charcoal-absorber is reduced about 0.1 to 0.15 points than without absorber.

Fig. 7 shows the odor rating during warm-up before and after water-washing system. It is found that odor is reduced about 0.25 to 0.3 points with the use of water-washing system. Here odorous components (mainly acidic components) are dissolved in water while the gas passes through water. The acidic nature of water used in washing system was confirmed by measuring pH values. The pH of water is changed from 7 (pure water) to about 6.75 (odorous gas dissolved in water).

Fig. 8 shows odor rating with and without total absorption system (combination of charcoal-absorber and water-washing) during warm-up. Here odor with total system is reduced more than 0.5 points (a significant odor reduction) than that of without system.

4.2 Results after Engine Warm-Up

After 30-35 minutes of engine start the cooling water

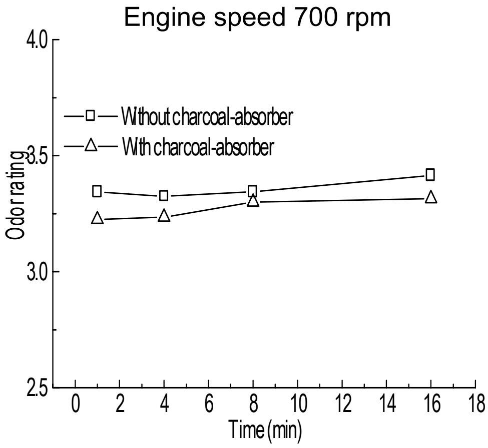

Fig. 6. Exhaust odor without and with charcoal-absorber during engine warm-up

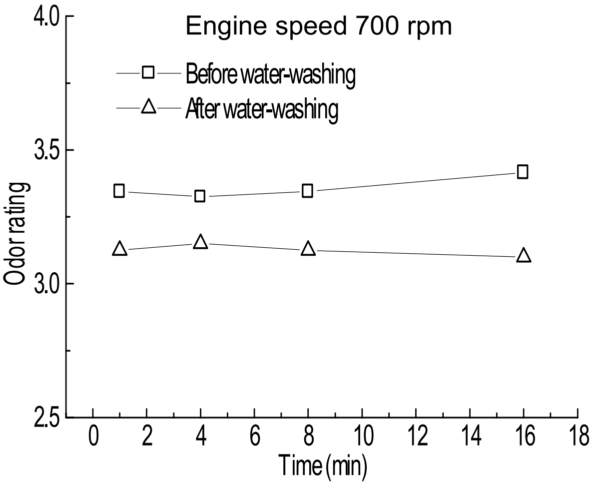

Fig. 7. Exhaust odor before and after water-washing during engine warm-up.

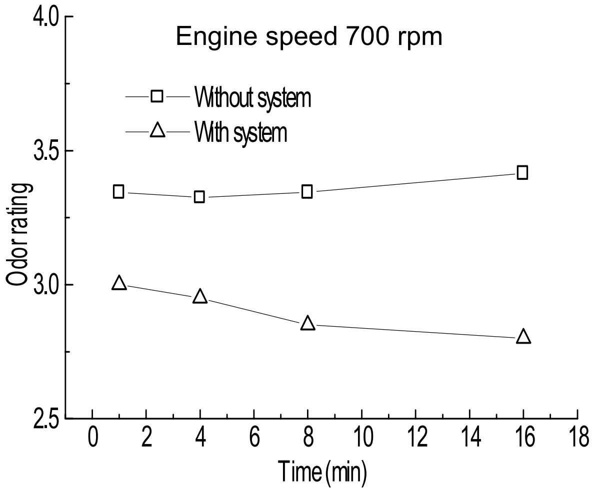

Fig. 8. Exhaust odor without and with absorption system during engine warm-up

temperature became constant. At this condition the emissions became almost constant. This is the warmed-up condition of the engine. Fig. 9 shows the odor ratings without and with charcoal-absorber after engine warm-up at various engine speeds. Engine speeds were changed from 700 to 1100 rpm. Here odor is reduced 0.1 to 0.2 points by using charcoal-absorber.

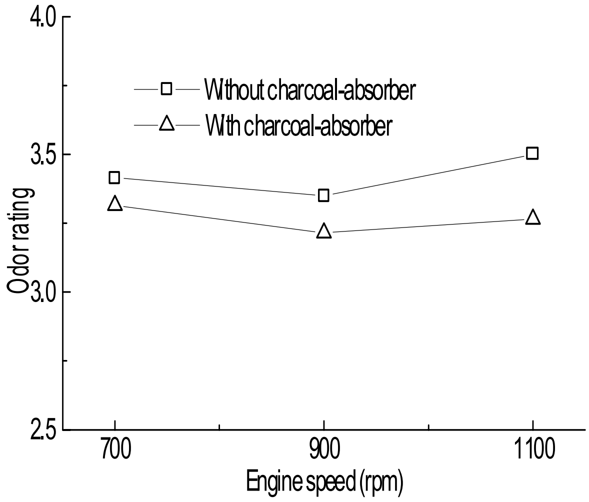

Fig. 9. Exhaust odor without and with charcoal-absorber at various engine speeds.

Fig. 10 shows the odor ratings at different engine speeds after engine warm-up before and after water-washing. This figure shows that odor reduction is 0.3 to 0.5 points, a significant odor reduction with the use of water-washing.

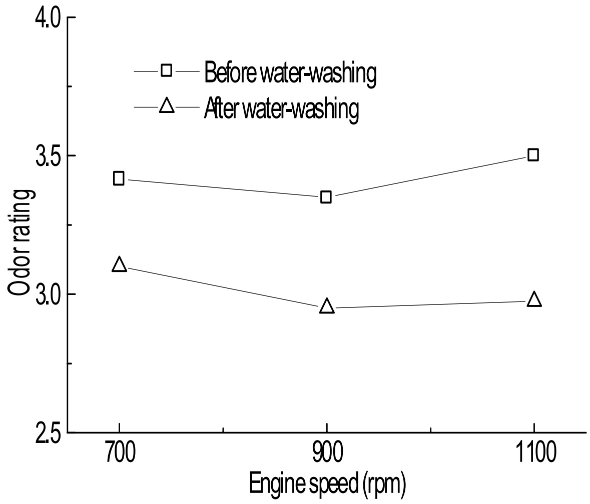

Fig. 10. Exhaust odor before and after water washing at various engine speeds.

Fig. 11 shows the results of odor rating without system and with total absorption system at various engine speeds after engine warm-up. This graph shows that the odor is reduced up to 0.8 points, more significant odor reduction while using the total absorption system.

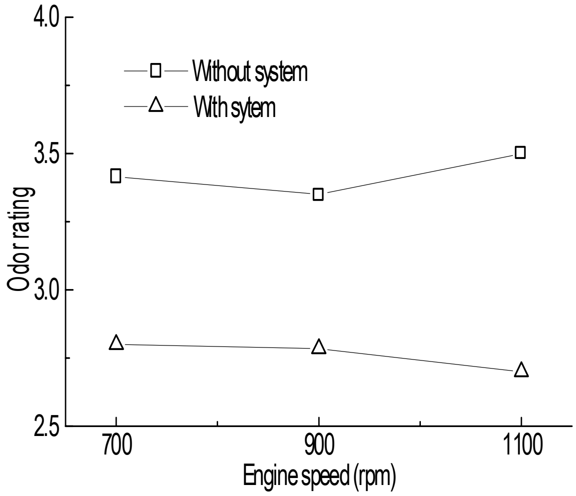

Fig. 11. Exhaust odor without and with absorption system at various engine speeds

4.3 Noise Level and Fuel Consumption

This study also investigated the noise level and fuel consumption with and without the system. Fig. 12 shows noise level comparison at 700 rpm after engine warm-up with and without the total absorption system. It is found that the noise level is decreased from 85 dB to 70 dB (about 20% reduction) with the system. This means that the absorption system may be used as an alternative to the silencer system of the engine.

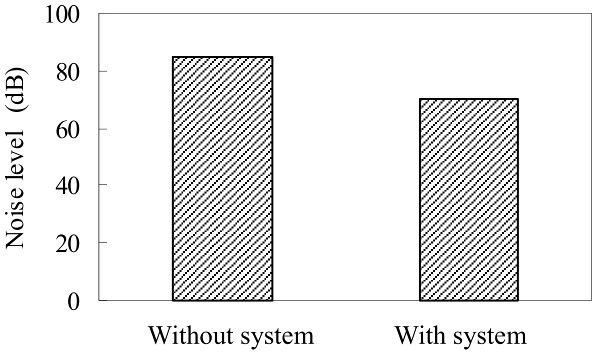

Fig. 12. Noise level comparison with and without absorption system

It was expected that fuel consumption would be increased with the use of the absorption system due to the increase in back pressure of the engine. Fig. 13 shows the comparison of fuel consumption at 700 rpm after warm-up. Fuel consumption is increased only about 0.5% with the system than without system.

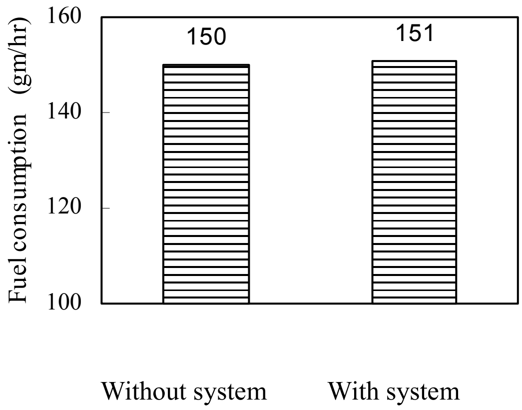

Fig. 13. Comparison of fuel consumption with and without absorption system

5. CONCLUSIONS

The following conclusions can be made from the experimental results.

1) Exhaust odor has a good correlation with the pH values of the aqueous solution of exhaust gas, and exhaust odor increases with the decrease in pH values and vice-versa.
2) A new absorption system with the combination of charcoal-absorber and water-washing is developed to reduce exhaust odor at idling in DI diesel engines. The charcoal-absorber system alone can reduce odor about 10% during or after engine warm-up, while water-washing system alone can reduce odor up to 30%.
3) The total absorption system can reduce odor about 40% than without system at idling condition of the engine, which is a significant odor reduction.
4) Noise level is significantly reduced with the absorption system, while the fuel penalty is insignificant.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning
DI	Direct injection
CO_2	Carbon dioxide
NO_2	Nitrogen dioxide
SO_2	Sulfur dioxide
n-Decane	Normal Decane
°C	Degree centigrade
pH	Hydrogen ion concentration
cc	Cubic centimeter
kW	Kilo-watt
rpm	Revolution per minute
MPa	Mega Pascal
BTDC	Before top dead center
cm	Centimeter
PM	Particulate matter
min	Minute
cP	Centi poise
kJ/kg	kilojoules per kilogram
H. C. V.	Higher calorific value