Investigation of Exhaust Gas Smoke Cleaners with Effect of Exhaust Noise Reduction for Diesel Engines (2nd Report, On the Effect of the Cyclone Separator for Smoke Cleaning and Noise Reduction)

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Investigation of Exhaust Gas Smoke Cleaners with Effect of Exhaust Noise Reduction for Diesel Engines

(2nd Report, On the Effect of the Cyclone Separator for Smoke Cleaning and Noise Reduction)

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In the first report, the diesel exhaust smoke was studied for various operating conditions of specific engines, that is, for various engine speeds, quantities of injected fuel and engine cooling water temperature.

In the present report, the cyclone is used as an exhaust gas smoke cleaner which is, at the same time, effective on the exhaust noise reduction. Both effects of smoke cleaning and noise reduction are well recognized under some operating conditions of the engine.

1. Introduction

Diesel smoke is so visible in compared with other exhaust gas that everyone feels unpleasant to find it. Therefore this problem must be solved.

There are two methods of diesel smoke reduction; to prevent an engine from generating black smoke by improving or adjusting an engine and to remove black smoke from exhaust gas by cleaners. On the latter method it is convenient that exhaust noise is reduced by the cleaner simultaneously. Our investigation was carried out on the latter method. The cyclone was used as an exhaust smoke cleaner with effect of noise reduction.

Many investigations on cyclone separators have been tried in detail, and the papers and books have been proposed. But many of them are the experiments on the steady continuous flow; few studies are on the such pulsative flow as the engine exhaust gas flow. On the other hand, the cyclone can be also considered to have the another effect as fundamental muffler of the expansion chamber type or resonant chamber type. In the present experiment, the cyclone was installed at the end of exhaust pipe, and both effects of smoke cleaning and noise reduction were studied. The effect of cyclone on

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the engine performances was also measured.

2. Test Method and Apparatus

2.1 On the Specific Cyclone; it is considered that the collection efficiency of a cyclone depends mainly on the flow velocity at the inlet of the cyclone,the shape of the cyclone, the characteristics of dust and so on. Since there were few data of cyclone used on the pulsative flow, the test cyclone was specified on the data of the steady continuous flow and of the preliminary experiments. The specific cyclone is shown in Fig. 1.

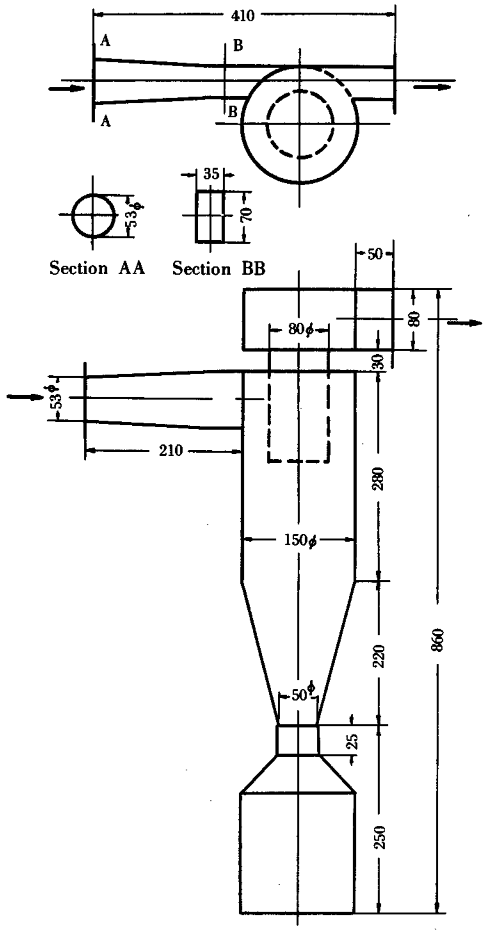

Fig. 1. Specific Cyclone

At first the cyclone was studied on the blower test. Powders used in the test were talc and carbon. The latter was collected from exhaust gas by a filter type cleaner. So the specific gravity of the collected carbon is equal to that of carbon particles flowing in exhaust gas. But mean diameters of carbon particles under two conditions may not be equal, for carbon particles agglomerate or segragate under various conditions. The results of the cyclone blower test on the constant powder density (about 1000 mg/m^3) and various flow velocity (10~40m/s) at the inlet of the cyclone are shown in Figs. 2, 3. Collection efficiency of the cyclone is shown in Fig. 2, and at the constant flow velocity (35 m/s) and various powder density (300~3000 mg/m^3), the collection efficiency is shown in Fig. 3.

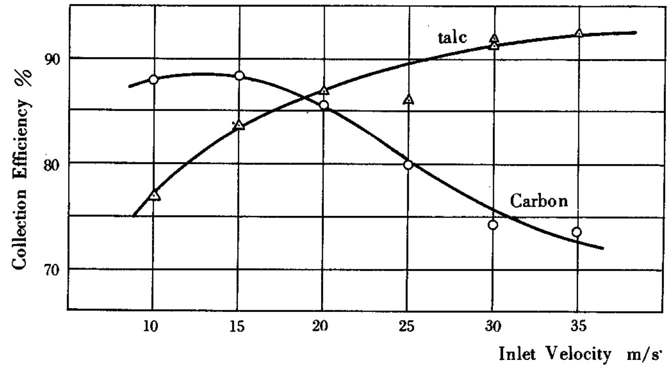

Fig. 2. Collection Efficiency of the Cyclone on the steady continuous flow test.

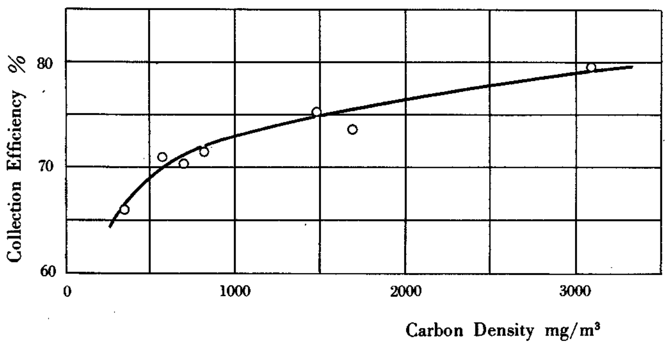

Fig. 3. Relation between Carbon Density and Collection Efficiency of the Cyclone on the Blower Test.

2.2 Engine Dynamometer Test; the engine used in this experiment is the same of the first report. The apparatus used in the engine dynamometer test is shown schematically in Fig. 4. The test cyclone was installed at the end of exhaust pipe. In the test, the engine was operated under the conditions of various loads, speeds (1000~2500 rpm) and the quantities of injected fuel (Injection pump rack positions A, B and C). At the engine speed of 2000 rpm, engine performances are shown in Table 1.

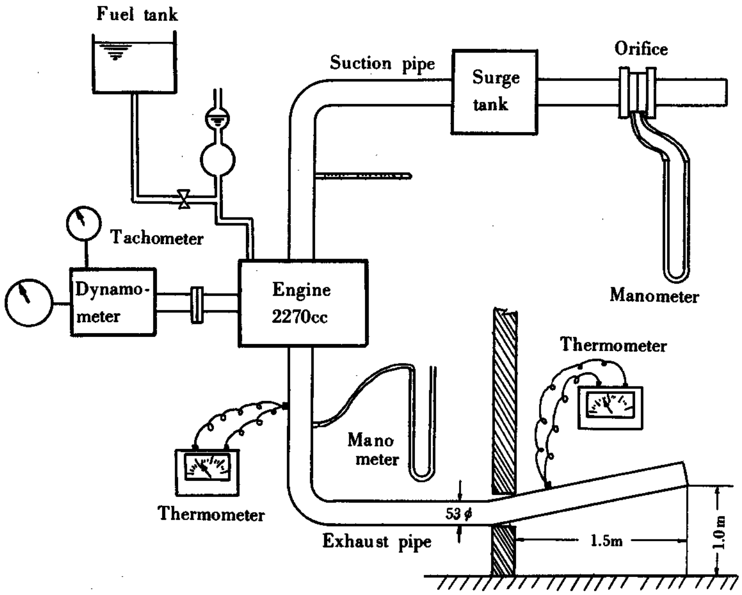

Fig. 4. Apparatus of Engine Dynamometer Test

Table 1. An example of the Engine Performance
(Engine speed 2000 rpm const., unmuffled exhaust pipe)

Injection pump rack position	Quantity of injected fuel mgr/stroke	Brake horse power PS	Specific fuel consumption gr/PS-h	Exhaust pressure mmAq
A	33.8	35.8	226.5	146
B	31.4	34.4	218.5	138
C	26.2	30.6	206.0	120

The exhaust noise was analyzed by the one-third octave band analyzer on three exhaust systems; unmuffled exhaust pipe, the specific cyclone installed and the muffler installed. The microphone was set perpendicular to the exhaust pipe at the 30 cm distance from the exhaust pipe exit.

3. Experimental Results

3.1 On the Exhaust Noise

3.1.1 Exhaust noise; exhaust noise under each engine speed at constant quantity of injected fuel (Rack position A) was analyzed by the one-third octave band analyzer. The result is shown in Fig. 5(a). There are 3 peaks in the lower frequency range. They are the first, second and third harmonics of the cylinder firing frequency. Measuring the exhaust noise through the exhaust pipe, sound pressure level (SPL) does not increase monotonously according to the increase of engine speed because of the exhaust pipe resonance and exhaust gas temperature. In this experiment SPL increased monotonously until engine speed 1750 rpm and decreased at 2000 rpm and increased again up to 2500 rpm. Though the quantity of injected fuel was decreased (Rack positions B and C), the pattern of frequency analysis is the same as A and SPL in the case of B and C reduce only several dB in compared with A.

3.1.2 Exhaust noise reduction; the cyclone was installed at the end of exhaust pipe and the quantity of injected fuel was varied (Rack positions A, B and C), and the exhaust noise spectra under each engine speed were measured. The spectra in the case of A are shown in Fig. 5(b). In Fig. 5(b), it is shown that the level of noise spectrum at 2000 rpm is higher than that at 2500 rpm. It may be considered that the specific frequency of the cyclone is harmonic with the engine firing frequency. This resonant phenomenon reduces the collection efficiency of the cyclone.

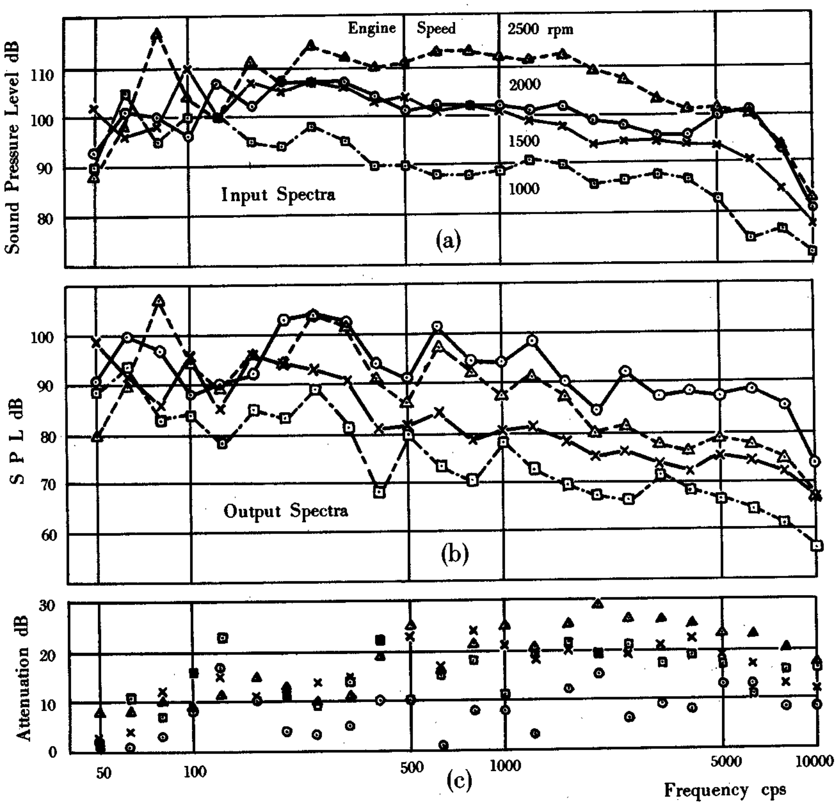

Fig. 5. Sound Pressure Level on the unmuffled Exhaust pipe (a) and Cyclone installed (b), and Attenuation between (a) and (b)

Now, it defines that attenuation of exhaust noise is given by SPL difference between the unmuffled exhaust pipe and the cyclone (or muffler) installed. Attenuation of exhaust noise for each frequency is shown in Fig. 5(c). These are very scattered, but it is a tendency that attenuation at 2000 rpm is the least, for the reason as mentioned above. On the muffler installed, it is also shown in Fig. 6. Fig. 7 shows over-all SPL (using the C net-work) of the exhaust noise on unmuffled exhaust pipe and the cyclone or the muffler installed under each engine speed.

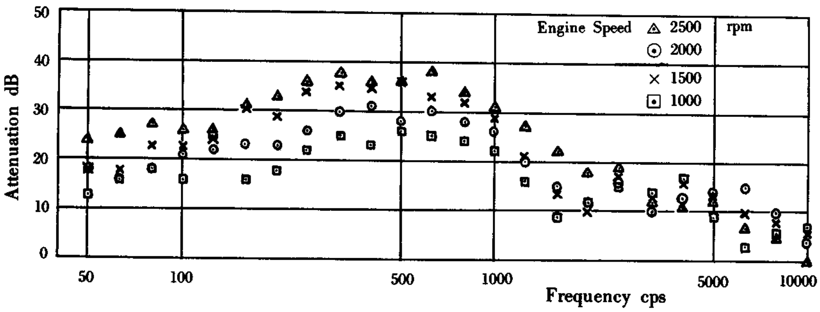

Fig. 6. Attenuation of the Exhaust Noise on Muffler installed.

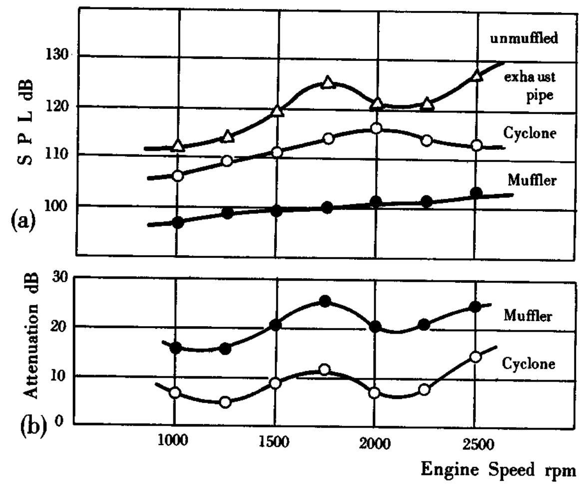

Fig. 7. Over All S P L (a) and Attenuation (b)

3.2 On Exhaust Smoke

3.2.1 Collection efficiency of the cyclone for exhaust carbon particles; cyclone was installed at the end of exhaust pipe and the quantity of injected fuel under each engine speed 1000~2500 rpm was varied (Rack positions A, B and C), and smoke densities (**Bosch Blackness**) at the inlet and the outlet of the cyclone are shown in Fig. 8 with the dash lines and broken lines respectively.

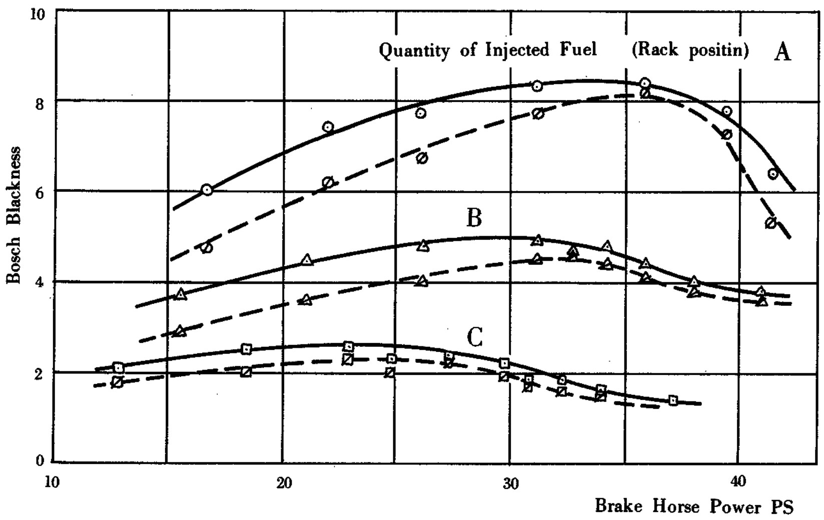

Fig. 8. Bosch-Blackness at Inlet (dash line) and Outlet (broken line) of the Cyclone.

By these **Bosch Blackness Numbers,** carbon densities were obtained using the relation of Fig. 4 in the first report.[1] Collection efficiency of the cyclone was calcurated from above results and was presented by gravity percentage in Fig. 9. The efficiency reduces with engine speed increase and is discontinuous at about 2000 rpm. It is considered to be the cause derived from cyclone resonant phenomenon mentioned above. The collection efficiency of the cyclone in Fig. 9 is lower than that obtained on steady continuous flow test in Fig. 3. The main reasons are the following three;

1) on the engine test, exhaust gas flow is pulsative under high temperature and loud noise,

2) carbon density is so lean,

3) mean diameters of the carbon particles on two conditions differ each other.

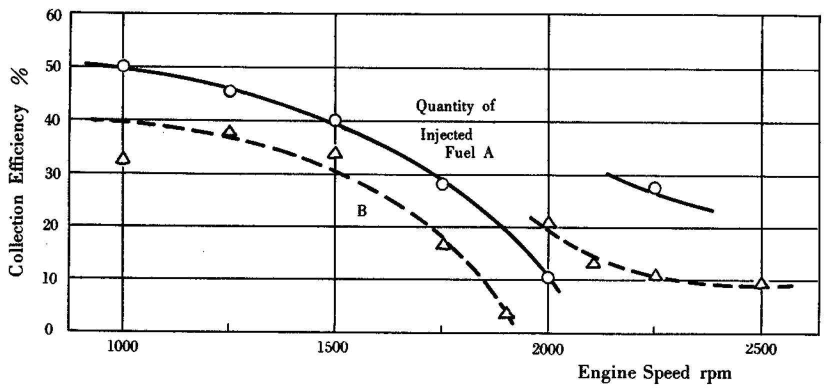

Fig. 9. Collection Efficiency of the Cyclone on the Engine Test

3.3 On the Effect of Engine Performances under each Exhaust Condition: the difference of the exhaust gas temperature among the unmuffled exhaust pipe and the cyclone or muffler installed was little observed. The higher engine speed and the more quantity of injected fuel increase, the higher the exhaust gas temperature rises. When engine speed was varied from 1000 rpm to 2500 rpm on each quantity of injected fuel (Rack positions A, B and C) exhaust gas temperature varied from 400°C to 650°C at A, 300°C~600°C at B and 250°C~500°C at C. Exhaust gas pressure values are very scattered for the effect of exhaust gas temperature. These values were affected remarkably by the exhaust gas temperature. Under the condition mentioned above the pressure values were 0~22 mmHg in the case of unmuffled exhaust pipe, 5~50 mmHg (about twice) in the case of cyclone installed and 20~150 mmHg (about sixtimes) in the case of muffler installed. These various exhaust conditions affected the engine perfomances. The results are shown in Fig. 10. When the cyclone or the muffler is installed, engine performances decrease a little. In Fig. 11 the specific fuel consumptions are shown under each engine speed for constant injected fuel about 32.5 mg/stroke (by broken line) and 29.5 mg/stroke (by dash line). It is recognized that the specific fuel consumption in the case of the cyclone installed is superior than in the case of the muffler installed.

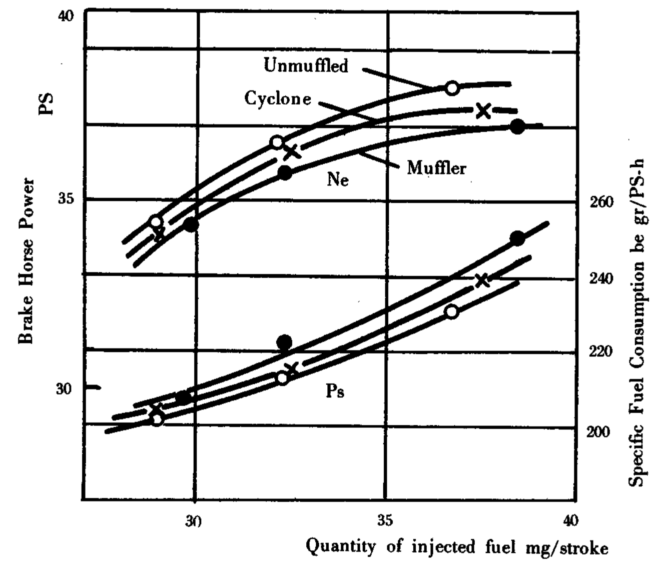

Fig. 10. Engine Performance
(at 2000 rpm const.)

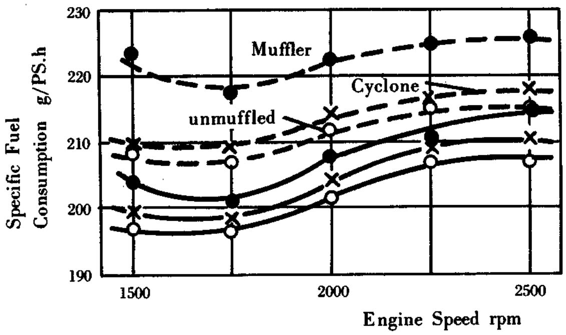

Fig. 11. Specific Fuel Consumption
Broken lines ; injected fuel, about 32.5 mg/stroke
Dash lines ; injected fuel, about 29.5 mg/stroke

4. Conclusion

The specific cyclone was used as exhaust smoke cleaner with effect of noise reduction. The cyclone was installed at the end of the exhaust pipe and both effects of smoke cleaning and noise reduction were investigated. The influences of the cyclone and the muffler on the engine perfomances were also presented.

We conclude from the experiment described above:

1) the over-all attenuation of exhaust noise by the cyclone is about half as much as by the muffler. On the cyclone, especially, the attenuation decreases at some engine speed because of the resonance with pulsative exhaust gas,

2) the collection efficiency of the cylone for the exhaust carbon is about 50% on good condition and remarkably decreases at the resonant point,

3) the cyclone is better than muffler considering their influences on the engine performances; power loss is less and specific fuel consumption is better,

4) in this experiment, carbon density of the exhaust smoke is 1 g/m^3 at most. It is very lean in compared with the density on which cyclone is used commonly,

5) for the purpose of enhancing the collection efficiency of cyclone, it is considered that the radius of the cyclone body needs to be smaller and several small cyclones are used together (multi-cyclone),

6) by means of installing simple fundamental muffler in front of the cyclone and damping the pulsative exhaust gas, the better effect of smoke cleaning and noise reduction is seemed to be obtained.

Acknowledgement

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Tsujimura.

Reference

1) Yuzuru Matsuura, Yoshio Hirako etal, Bull. of Univ. of Osaka Pref., **A17** 2, (1968).