

Emission Reduction Technology Using Secondary Air for Generator Engine

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ABSTRACT

An emission reduction system that uses secondary air injection and a catalyst was developed to meet emission standards for domestic gasoline engine generators enacted by India in 2014.

Gasoline engine generators require a compact size and high portability, so there are many restrictions on the exhaust system layout, and it has been a challenge to realize secondary air injection using the exhaust pulsation effect.

This development discovered the proper exhaust pipe and secondary air pipe lengths that increase the pulsation effect of the secondary air pipe, and realized a compact system that complies with both emission and generator noise standards and fits within the mass-production generator chassis.

In addition, regarding emission measurement methods, the raw gas measurement method and dilute gas measurement method were compared and verified, and a measurement method that does not influence the secondary air quantity was found.

1. Introduction

Environmental issues such as air pollution are increasing in severity around the world, and emission standards even for general-purpose engines are becoming stricter every year.

Gasoline engine generators are used for a wide range of applications such as leisure, commercial, household, and emergency use. Generators in India in particular are used as emergency power sources due to the country's power situation with frequent power outages.

Typical use cases often involve operation near houses and shops (Fig. 1), and when a power outage occurs in an urban area, households and shops start their generators



Fig. 1 Example of generator usage in India

all at once, so emissions and noise are becoming social issues. For this reason, both emissions and noise are strictly regulated for generators sold in India.

This paper introduces the technology of an emission reduction system that uses secondary air injection and a catalyst, which was installed in generators to meet emission standards that were strengthened in 2014, and the method used to verify this system.

2. Development Goals and Target Values

2.1. Emission Standard Values

Emission standards for gasoline engine generators are being led by the Small Off-Road Engines (SORE) regulations established by the Air Resources Board (ARB) of the State of California, U.S.A. and by Indian emission standards for generator sets on petrol and kerosene⁽¹⁾ established by the Indian Ministry of Environment and Forests. The emission standards enforced by India in 2014 are currently the strictest known to date, and mandate a carbon monoxide (CO) level 1/2 or less than that of the ARB regulation, and an HC+NO_x level 1/6 that of the ARB regulation for the displacement class of 99 cm³ or less (Figs. 2 and 3).

Next, Figs. 4 and 5 show the CO and HC+NO_x emission levels of conventional mass-production generators relative to Indian emission standard values.

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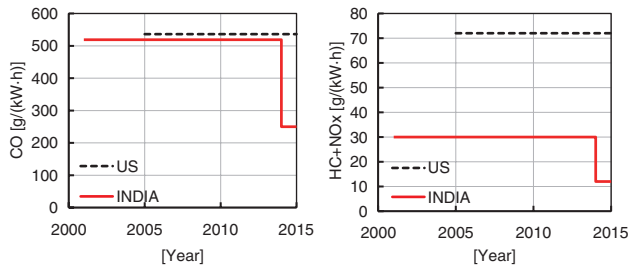


Fig. 2 Emission standard values for displacement of 50 to 80 cm³ in CARB and up to 99 cm³ in India

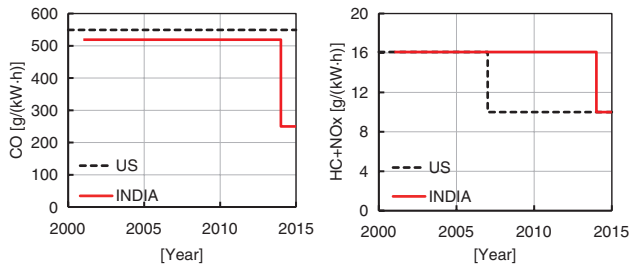


Fig. 3 Emission standard values for displacement of 80 to 225 cm³ in CARB and 99 to 225 cm³ in India

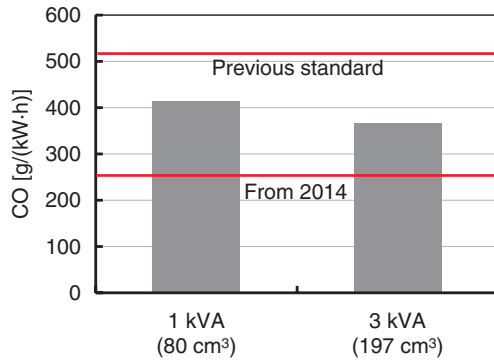


Fig. 4 CO values of conventional models

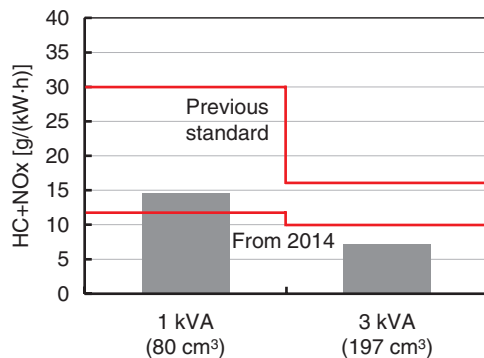


Fig. 5 HC+NOx values of conventional models

Table 1 Indian emission standards for generator sets on petrol and kerosene

Emission class	Displacement [cm ³]	CO [g/(kW·h)]	HC+NOx [g/(kW·h)]
1	≤ 99	≤ 250	≤ 12
2	> 99 ≤ 225	≤ 250	≤ 10
3	> 225	≤ 250	≤ 8

Table 2 Test cycle for emission testing

Mode no.	1	2	3
Load percent	100	75	50
Weighting factor	0.3	0.5	0.2

Table 3 Indian noise standard for generators

Output	3/4 of rated power
Sound power level (L _{WA}) [dB]	86

Table 4 Specifications of each model

Generator output class		1 kVA	2 kVA	3 kVA
Model name		EP1000	EX2400	EU30i
Engine displacement	cm³	80	163	197
Fuel system		Carburetor	Carburetor	Carburetor
Air fuel ratio (Average)		12.5	12.6	12.4
Max AC output	VA	850	2100	3000
Dimensions (L × W × H)	mm	404 × 352 × 431	965 × 470 × 327	710 × 422 × 570
Emission class		1	2	2
Sound power level 3/4 load (L _{WA})	dB	85	85	85

2.2. Development Goals

The goals of this development were to achieve the following three items for the 1-, 2- and 3-kVA class gasoline engine generators sold for use in India.

- (1) Compliance with emission standards (Tables 1 and 2)
- (2) Compliance with the noise standard for generators (Table 3)
- (3) A layout that fits within the current mass-production chassis

Table 4 lists the specifications of the applicable gasoline engine generators.

3. Investigation of Methods for Meeting Standards

Fuel is supplied to gasoline engine generators using an inexpensive carburetor with a simple structure. The ratio of the air-fuel mixture supplied to the engine during operation is around 12.5, and while this met the old emission standards, it is unable to comply with the new standards. The two methods considered here for reducing the CO emission level are as follows.

- (1) Adjustment of the air-fuel mixture to the stoichiometric air-fuel ratio
- (2) CO reduction by adding secondary air injection to the exhaust pipe and a catalyst

When the carburetor in a gasoline engine generator is used to adjust to the stoichiometric air-fuel ratio, combustion becomes unstable and engine speed stability and load fluctuation tracking performance drop, resulting in issues such as increased frequency fluctuation range. For this reason, it is a challenge to apply adjustment of the air-fuel mixture to the stoichiometric air-fuel ratio as a CO reduction technology for gasoline engine generators. A secondary air injection system was therefore adopted that uses the pulsation effect of the exhaust pipe, and a catalyst was built into the muffler to increase the oxidation effect.

4. Achieved Technology

4.1. Secondary Air Injection System

4.1.1. Secondary air quantity requirement values

The secondary air quantity requirement values were set based on the air quantity that satisfies the emission standard values, noise standard values and catalyst temperature. Figure 6 shows the CO emission level, HC+NO_x emission level, catalyst temperature, and noise value characteristics relative to the 1-kVA and 3-kVA class secondary air quantities as an example of the settings.

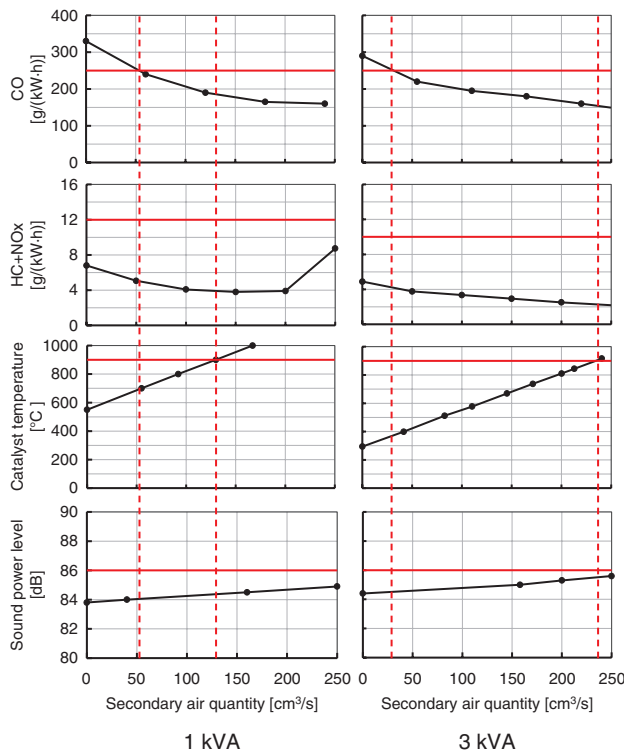


Fig. 6 Relationship between secondary air quantity and performances

The secondary air quantity requirement values were set as follows based on the characteristics shown in Fig. 6.

1 kVA: 55 to 130 cm³/s

3 kVA: 30 to 230 cm³/s

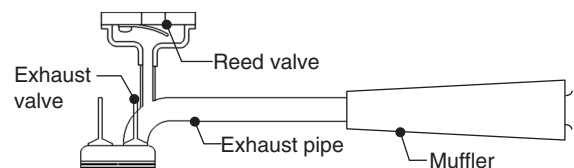
Examples of development for the 1 kVA and 3 kVA models are described below.

4.1.2. Optimization of the exhaust pipe and secondary air pipe

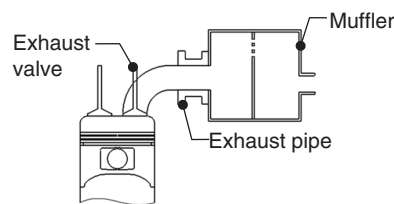
Secondary air injection used a system that makes use of the negative pressure component of the exhaust pipe to take in outside air using a reed valve in the same manner as a motorcycle engine. Motorcycle engines have a long pipe length from the exhaust valve to the exhaust pipe outlet (exhaust pipe length), which makes it easy to obtain the negative pressure component of the exhaust pipe pressure. In contrast, gasoline engine generators require compactness, so the exhaust pipe length is as short as possible. This makes it a challenge to obtain a negative pressure component inside the exhaust pipe, which is a structural issue for secondary air injection. Figure 7 compares the exhaust system layouts of a motorcycle and a generator. The exhaust pressure pulsation of a gasoline engine generator with a lengthened exhaust pipe was measured, and the results confirmed an increase in the amplitude of the negative pressure component (Fig. 8).

However, this development had the constraint of a layout that fits within the current mass-production chassis, so the issue was to secure the required secondary air quantity by some element other than the exhaust pipe length.

Therefore, design calculations were performed for the exhaust pipe and secondary air pipe that determine the secondary air quantity, and the pulsation effect of the



(a) Motorcycle engine



(b) Generator engine

Fig. 7 Comparison of exhaust layouts

secondary air pipe was used to amplify the negative pressure component of the exhaust pipe inside the secondary air pipe⁽²⁾.

Figure 9 shows a schematic of an emission reduction system using secondary air injection and a catalyst.

Figures 10 and 11 show the air quantity characteristics

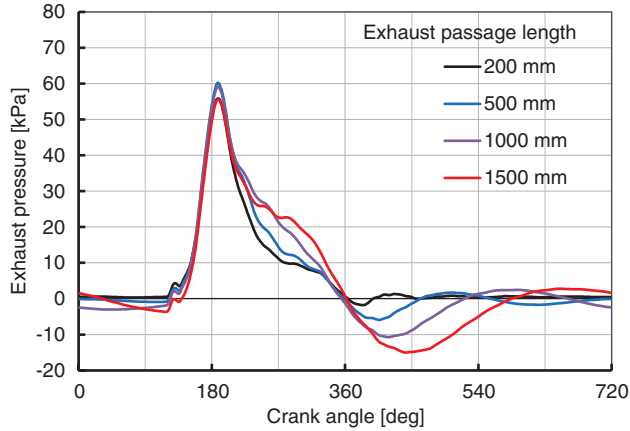


Fig. 8 Relationship between length of exhaust passage and pressure at rated load

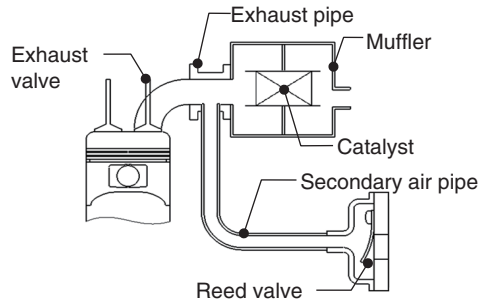


Fig. 9 Secondary air system

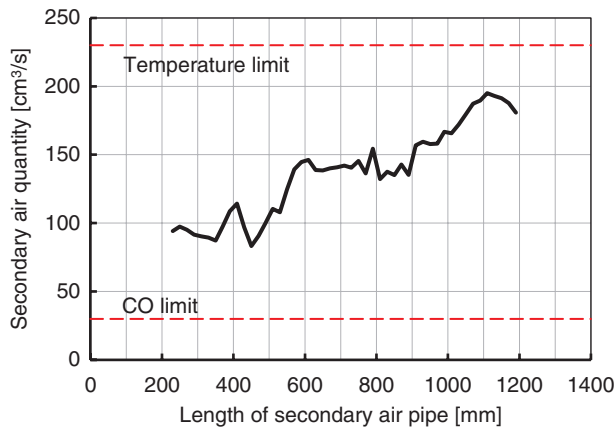


Fig. 10 Relationship between length of secondary air pipe and secondary air quantity at rated load (3 kVA)

Table 5 Exhaust system length

Length [mm]	1 kVA		3 kVA
	Current	Developed	Developed
Exhaust passage	550	750	1050
Secondary air pipe	900 or more	400	850

relative to the secondary air pipe length for the 3 kVA and 1 kVA models, respectively.

As shown in Fig. 10, the 3 kVA model has a secondary air pipe length range that satisfies the required air quantity, so a length of 850 mm was selected based on the constraint of fitting within the chassis. In contrast, given the exhaust pipe length of the current mass-production muffler, the 1 kVA model requires a secondary air pipe length of 900 mm or more to satisfy the required air quantity (Fig. 11), so a layout that fits within the chassis is not feasible. The exhaust pipe was therefore lengthened by 200 mm and a secondary air pipe length was set to 400 mm in order to satisfy the required air quantity and fit the exhaust pipe and secondary air pipe within the chassis (Table 5).

4.2. Catalyst

The catalyst used to convert the HC and CO in exhaust gas is the same catalyst with a metal honeycomb carrier widely used in motorcycles. Therefore, in consideration of the following points, the catalyst was positioned inside the muffler.

- (1) The catalyst temperature is the catalyst activation temperature or more, but lower than the temperature leading to degradation.
- (2) The structure passes all of the engine exhaust gas and secondary air through the catalyst to prevent a drop in the reduction rate.

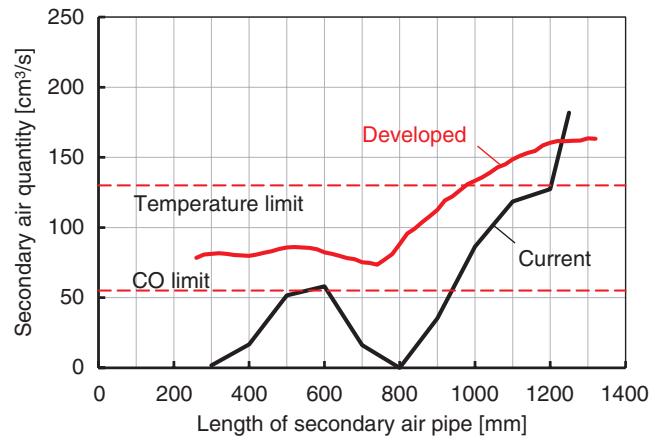


Fig. 11 Relationship between length of secondary air pipe and secondary air quantity at rated load (1 kVA)

Figure 12 shows a schematic of the muffler based on the above considerations.

4.3. Packaging

Figures 13 and 14 show the 1-kVA class and 3-kVA class systems that achieved the required secondary air quantity target values with layouts that allowed fitting within the exterior dimensions. Compared to the mass-production model, the 1 kVA model has a longer exhaust pipe and adds a secondary air pipe. This is achieved by bending the exhaust pipe and secondary air pipe into “U” shapes that cross over and under each other, and realized a compact layout that fits within the current mass-production chassis.

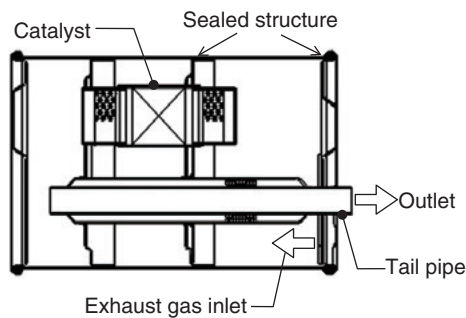


Fig. 12 Schematic of muffler

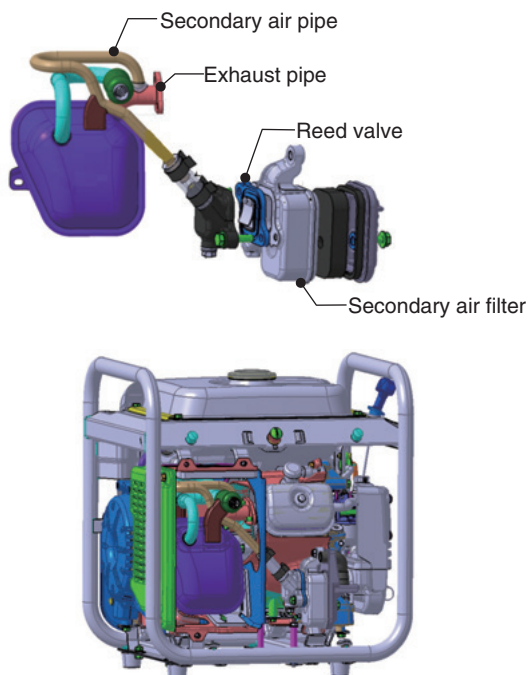


Fig. 13 1 kVA (EP1000)

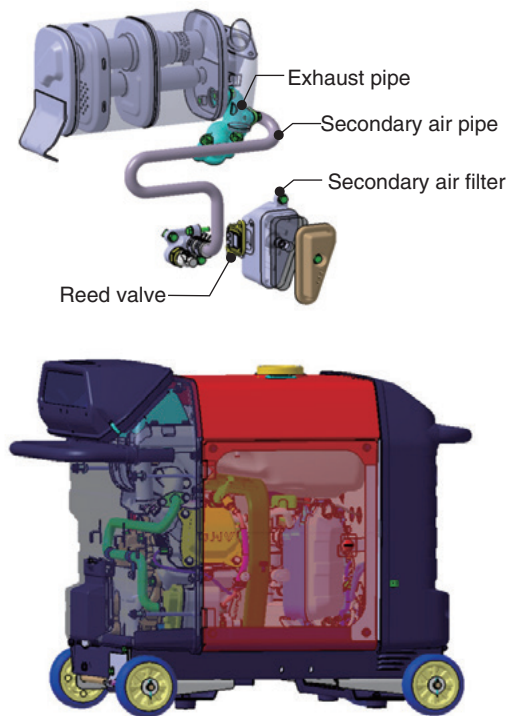


Fig. 14 3 kVA (EU30i)

5. Verification Method

5.1. Emission Quantity Measurement Methods

There are two major exhaust emission measurements⁽³⁾.

- (1) Raw gas measurement method
- (2) Dilute gas measurement method

Both measurement methods were verified during the course of this development, and the results showed that in a secondary air injection system that uses exhaust pulsation, the raw gas measurement method and dilute gas measurement method give different secondary air quantity values. Figure 15 shows the difference in the air quantity measurement values for both methods.

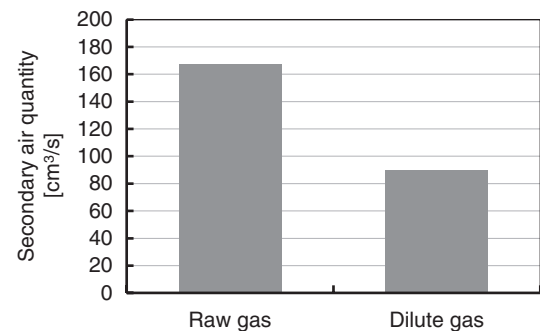


Fig. 15 Comparison of raw gas sampling and dilute gas sampling (1 kVA)

Figures 16 and 17 show schematics of the measurement environment for both methods, and Fig. 18 shows the difference in the exhaust emission measurement values. The raw gas measurement method requires that the exhaust pipe be lengthened, which has the effect of increasing the secondary air quantity as described above, making it

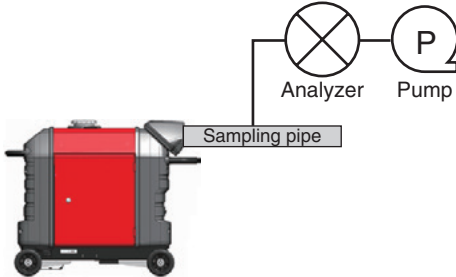


Fig. 16 Raw gas emission analysis method

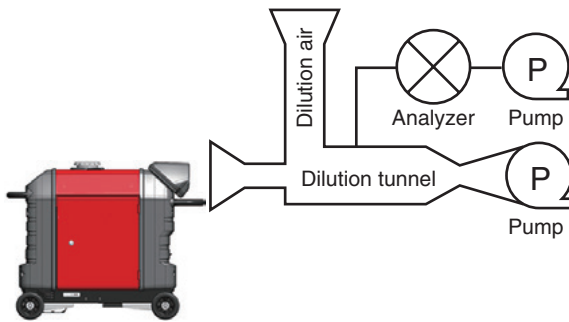


Fig. 17 Dilute gas emission analysis method

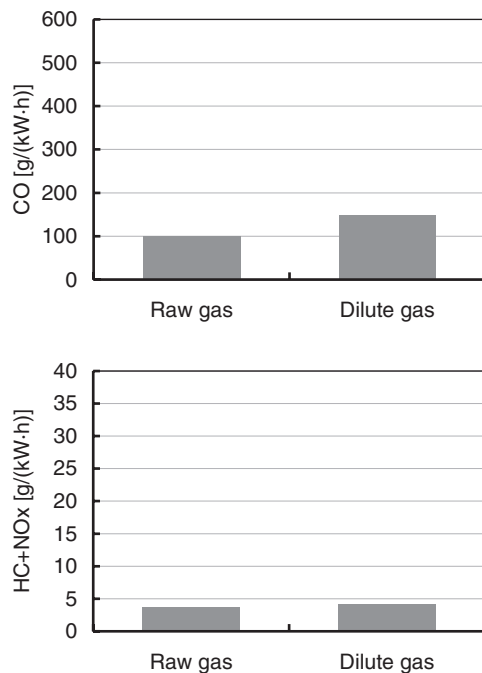


Fig. 18 Comparison of raw gas sampling and dilute gas sampling (1 kVA)

unsuitable for measuring the true value. Therefore, the dilute gas measurement method was used.

The regulatory authorities were lobbied based on these verification results, and the dilute gas measurement method, which was previously not accepted, was formally added to the applicable laws and regulations.

6. Achieved Values

6.1. Achieved Emission and Noise Values

The 1 kVA, 2 kVA and 3 kVA models all cleared both the emission and noise standards for gasoline engine generators used in India. Figure 19 shows the achieved emission values.

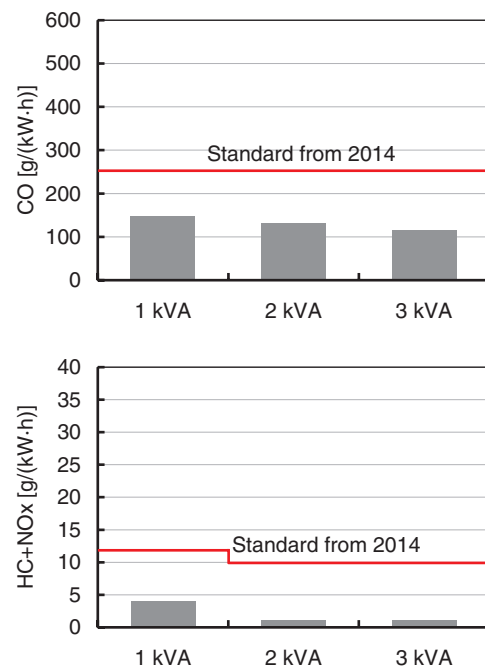


Fig. 19 Emission results of new models

7. Conclusion

An emission reduction system for generator engines was created using secondary air injection and a muffler with built-in catalyst, which is a first for Honda Power Products. This system achieved the following results.

- (1) The developed system complied with Indian emission standards and generator noise standards, even for generator engines with different displacements.
- (2) Honda Power Products' original optimization of the secondary air pipe and exhaust pipe enabled creation of a compact layout that fits within the mass-production chassis.

- (3) The influence of the exhaust pipe length on the secondary air quantity in this system was clarified, permitting establishment of an accurate exhaust emission measurement method.

References

- (1) Indian emission standards for generator sets on petrol and kerosene
(2) Yasoshina, S., Saito, R.: Pulsed Secondary Air Injection System for Emission Reduction in Small Generator Sets, SAE Technical Paper, 2014-32-0035, (2014)
(3) ISO 8178-1:2006 2nd edition: Exhaust emission measurement

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