Promotion of Utilization of Renewable Energy for Biogas/Natural Gas Dual Fuel Engine

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ABSTRACT

We promote the biogas/natural gas dual fuel engine to evolve an efficient use of biogas. Until now, many dual fuel engines have been in operation at sewage disposal plants , food and beverage plants. Additionally to encourage the efficient use of biogas, we also developed the smart and low-cost biogas/natural gas dual fuel engine. We are confident about the high performance and simple design of this engine. This system can contribute to the promotion of biogas/natural gas dual fuel engine in the future. Moreover, this system can contribute to the efficient use of biogas as a renewable energy and the increasing of natural gas usage accordingly.

TABLE OF CONTENTS

Introduction

In recent years, the biogas generated from food waste and sewage disposal is focused as the renewable energy. In Kansai area where Osaka Gas supplies the natural gas, there are many sources of biogas production such as food and beverage plants or sewage disposal plants. B ut most of these biogas sources are not used effectively at many factories and plants.

Recently, there has been an increase of development and production of gas engine generators using biogas as a fuel. However, it is difficult for the biogas generators to keep constant power generation due to instable biogas production and shortage of heat values per hour. In Japan, the electric power company forces the constant power generation on the private power generators by the demand-penalty rule.

As the effective solution for this difficulty, a dual fuel gas engine system of biogas and natural gas are usable as one of the key technology. In case of instable biogas production or shortage of biogas heat values, this system can keep working by adding natural gas or by switching from biogas to natural gas operation. When we promote the effective use of biogas as a renewable energy source, it is very important to consider the way to generate power by dual fuel gas engine systems. Also, these systems can contribute to increase in natural gas consumption for the gas companies.

Potential amount of biogas in Osaka Gas location

Osaka Gas working on gas supply business has been managing the gas pipe line network in Kansai area(including 6 prefectures), Japan. We sell natural gas approx. 8 billion m^3 to about 7 million of customers annually. Also, we are actively involved in selling gas appliances in addition to city gas supply business. In recent years, we started the promotion of efficient use of biogas as a renewable energy source.

In Kansai area where Osaka Gas supplies natural gas, there are several sewage disposal plants, food factories and beverage factories. Assuming that these all plants and factories generate biogas from their waste materials, the biogas can be produced about 400 million m^3 for a year (natural gas count). Then, if all of the biogas can be used efficiently, we can realize CO_2 emission reduction as much as 900,000 tons for a year.

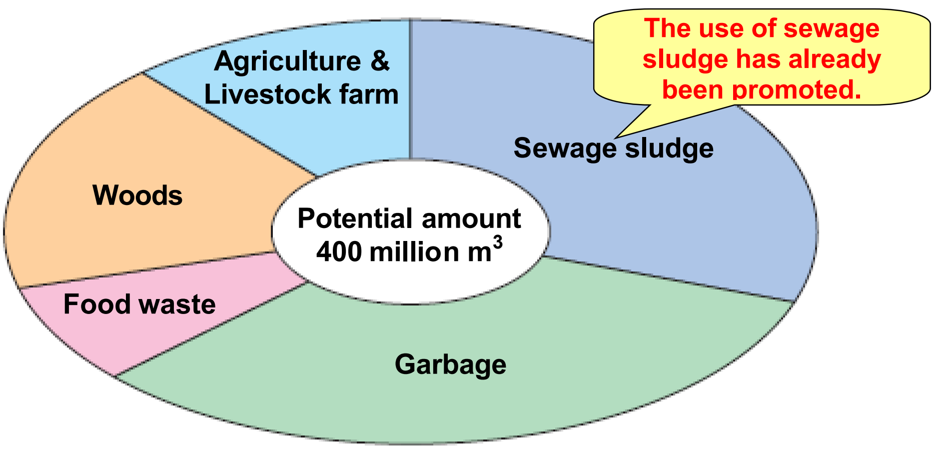

Figure 2.1: Potential Amount of Biogas in Kansai Area (6 prefectures)

However, only a few % of the biogas is used efficiently at this time. There is a possibility for realizing CO_2 emission reduction if the rate of utilization of the biogas is to be increased. It is also important to develop the biogas appliances for encouraging broad use of biogas production facilities.

The biogas has been mainly used as a fuel for boilers. In the use of biogas for boilers, the biogas production facility and the establishments requiring heat supply must be at the adjacent site. If the biogas was produced enough, it could not be used effectively for boilers at the site of lower heat demand.

Biogas power generators have potential for a solution applicable to this problem. Nowadays, gas engine generators that can use biogas have being developed. Interconnecting these generators to the grid of electric utilities, it is not necessary to locate the biogas production facility next to the establishments requiring power supply. Power generated from efficient use of biogas can be supplied to almost all plants and factories, establishments regardless of heat utilization equipment. Moreover, it is possible to recover heat liberated at generating and reuse it as thermal energy by using the CHP systems. Such invaluable systems can lead the high energy efficiency.

Promotion of utilization of biogas by developing dual fuel system with natural gas

Biogas production is still unstable to keep constant quantity and heat values per hour. Therefore it is difficult for biogas generators to generate constant electricity continuously. In Japan, the electric power company forces the constant power generation on the private power generators by the demand-penalty rule. Under this rule, the penalty is needed to be paid due to the excess amount of power selling over the maximum limit when the privately-owned electrical power facility is stopped at your site. Private power generator must be kept driving continuously.

This problem can be solved by using the dual fuel gas engine of biogas and natural gas. Dual fuel gas engines can generate continuously by adding natural gas to make up for the shortage of biogas or switching to natural gas operation from biogas operation when the biogas supply is low or stopped. It can be a solution to avoid the demand-penalty. In the past, Osaka Gas introduced the biogas/natural gas dual fuel engines to several sites. Table 3. 1 shows the examples of these engines installed.

Table 3. 1: Running biogas/natural gas dual fuel engine generator
in Osaka Gas service area

site	kW	number	CH_4 conc. in Biogas
food factory A	520	1	72%
food factory B	520	1	71%
beverage factory A	730	1	78%
beverage factory B	2100	1	84-90%
sewage plant A	520	2	57-59%
total	4910	6	-

There are 2 dual fuel engines of 520 kW installed at one sewage plant, 2 of 520kW installed in 2 food factories, 1 of 730kW in a beverage factory and 1 of 2100kW installed in a beverage factory. A total of 6 dual fuel engines (total 4910kW) are working at each site.

All of these engines are biogas/natural gas dual fuel engine generators equipped with CHP systems having exhaust heat recovery equipment. These plants consume 3 million m^3 of biogas for a year. All of the generators installed these plants consume natural gas for almost the same amount as biogas in total however the detailed rate of utilization between biogas and natural gas varies depending on circumstances of plants. Also, these plants contribute the CO_2 emission reduction by using biogas efficiently. In addition, Osaka Gas can expand our customer base because the dual fuel engine generators also consume natural gas.

Development of the low-cost biogas/natural gas dual fuel engine system

Outline of development

Biogas/natural gas dual fuel engine has an important role to make efficient use of biogas and to expand the sales of natural gas. However, the system of dual fuel engine used to have a complicated composition and the total cost of the system was higher as a matter of course. Therefore, the low-cost biogas/natural gas dual fuel engine was desired to be developed for promoting the utilization of biogas in the future.

In this circumstance, JFE Engineering and Osaka Gas jointly launched the development of the simple designed and low cost biogas/natural gas dual fuel engine system. We produced the engine system that has comparatively simple composition, and has the efficient ability of absorbing the biogas even when the production quantity and heat values of biogas vary. We developed the line up engines for 250 – 1,000kW classes. These classes of engines are in high demand in the market of biogas generators.

System composition and operation control

In a plant that produces relatively large amount of biogas relative to the capacity of generators, the engines mainly generate only by using biogas. These engines can generate constant power continuously by switching to natural gas operation from biogas operation when the biogas is in short supply or stopped.

On the other hand, in a plant that produces relatively small amount of biogas relative to the capacity of generators, the engines generate in the mixed-combustion operation with biogas and natural gas. These engines can generate continuously by switching to the operation using natural gas only when the biogas is in short supply.

Gas engine may have the problems, such as misfiring, knocking and NOx concentration increasing, when there is a difference of air-fuel ratio. Though the fuel supplied to the gas engine is switched to another of different property, the system has to control its air-fuel ratio constant.

Today, we produce a smart biogas/natural gas engine system applicable to the both cases in the above. This system is mainly composed of the mixture unit that controls switching and mixing of biogas and natural gas, and the gas engine that runs by using the mixed gas. This gas engine is based on the capability architecture of mixture pressure control method; it runs at the mixture pressure corresponding to the output of power generation controlled by the output of generator and the compressed mixture supplied to the engine.

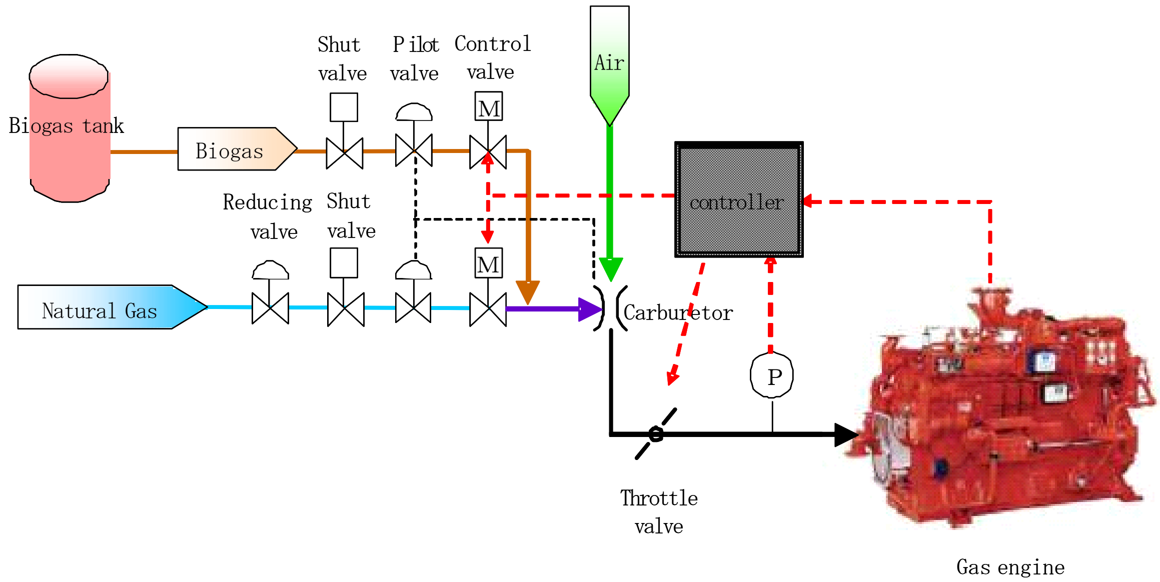

Figure 4.1 : Biogas/natural gas dual fuel engine system

This mixture unit has both biogas line and natural gas line as the fuel supply lines, and these lines flow together in the unit. As the feature of this system, each biogas line and natural gas line has independent flow control valves. After the flow control valves, these two lines join together and lead to the gas engine. In the gas engine, this fuel gas flows into the carburetor. The mixture gas is produced by mixing fuel gas with air in the carburetor. Next, the mixture is compressed by the turbocharger. Then the compressed mixture is fed to each cylinder on the engine through the throttles. The mixture is combusted in cylinders and the exhaust gas is produced. The exhausted gas is emitted from the gas duct after processing through the turbocharger.

The speed and output of the engine generator is controlled by the throttle. Air-fuel ratio is controlled by the flow control valve on the gas side to have a proper mixture pressure corresponding to the output of the power generation according to monitoring of the mixture pressure.

The flow control valves installed at the biogas line and city gas line also have the function of flow path change valve. The flow control valve on the natural gas line is closed when the system is operated by biogas only, and air-fuel ratio is adjusted only by the flow control valve on the biogas line. On the other hand, the flow control valve on the biogas line is closed when the system is operated by city gas only, and air-fuel ratio is adjusted only by the flow control valve on the natural gas line. In case of the dual fuel operation, the flow control valves on the both line are controlled precisely to keep the specified flow rate. The operation methods can be selected among the operation of only biogas use, dual fuel use and only natural gas use by monitoring the level signal of gas tank placed at the upper flow of biogas line. For the stable generating operation at changing the methods, the action of the flow control valves on the biogas line and the city gas line is needed to be defined beforehand. This feature of flow control valve realizes the switching operation among biogas, dual fuel and natural gas by comparatively simple operation. The gas engine generation system, that can control the air-fuel ratio even though the heat value of biogas varies, is achieved.

Result of the performance test

Figure 4.2 : Outline view of the test system

We verified the performance of a prototype gas engine generator using the dual fuel mixture system in the above. The gas engine used in this performance test was Waukesha VGF250 modified by JFE Engineering. Synchronous generator was used, and its engine speed was 1,800 times/min. The heating value of natural gas used in the test was 40.6 MJ/Nm3 at LHV. The artificial biogas produced from the natural gas attenuated with CO_2 was used for the test. In this performance test, the artificial biogas having the 24.4 MJ/Nm3(natural gas 60%, CO_2 40%) of heating value was mainly applied. Dry load resister was used for loading. However the actual system has the function of exhaust heat recovery, this test was done by island operation of a gas engine generator without recovering heat from exhaust gas.

- Fundamental property of biogas operation and city gas operation

At each output level, 125 kW(50%), 188 kW(75%) and 250 kW(100%), the following items were measured for each case of the operations by using city gas and artificial biogas: variable rotating speed, power generation efficiency, NOx and O_2 concentration in exhaust gas. The boost pressure corresponding to the output was determined beforehand for adjusting the air ratio. In this test, for the purpose of obtaining the equal NOx concentration in both of natural gas and artificial biogas operations, the pressure of mixture was controlled respectively for each operation. The ignition timings were set by identical terms.

Table 4.1 : Fundamental property of this engine generator

item	unit	natural gas			biogas		
		125kW	188kW	250kW	125kW	188kW	250kW
speed deviation	1/min	2	2	2	2	2	4
electrical effic.	%	28.4	31.5	33.4	26.4	29.8	32.0
NOx conc. at 02=0%	ppm	289	437	443	441	451	478
02 conc.	%	8.3	8.1	8.4	5.5	5.8	6.8

Table 4.1 shows the fundamental property of this engine generator. We verified that this generator could achieve stable generation for each output in both cases of natural gas and biogas operation. The power generation efficiency for natural gas operation was a little better than that for biogas operation. NOx emission standard of gas engine is regulated at 600 ppm by Air Pollution Control Low in Japan. This engine generator realizes substantially lower NOx concentration in exhaust gas than the emission standard.

Next, we verified the fundamental property at mixed combustion. In rated operation, the following items were measured at 0 – 100% of mixed combustion ratio; engine speed deviation, power generation efficiency, NOx and O_2 concentration in exhaust gas. The mixture pressure was changed depending on each mixed combustion ratio.

Table 4.2: Fundamental property at mixed combustion

biogas/natural gas ratio	%	0	25	50	75	100
speed deviation	1/min	2	3	5	2	3
electrical effic.	%	33.4	33.1	33.2	32.5	32.0
NOx conc. at 02=0%	ppm	443	481	517	533	482
02 conc.	%	8.4	7.9	7.4	7.1	6.8

Table 4.2 shows the fundamental property of this engine generator at mixed combustion of biogas and natural gas. We verified that this engine generator could achieve stable generation while mixed combustion ratio was changed. The power generation efficiency showed little change within lower mixed combustion ratio than 50% of biogas.

- Variability characteristics of biogas heating value (at increasing / decreasing)

The compositions and heating value of produced biogas vary according to the characteristics of waste materials. The gas engine generator using biogas is required to run stable even when the heating value of biogas is changed. So, we verified the response of this system when the heating value of biogas was changing. In the test of increasing, heating value of artificial biogas was increased from 23.6 MJ to 26.9 MJ in 4 minutes. In the test of decreasing, heating value of artificial biogas was decreased from 27.2 MJ to 23.6 MJ in 1 minute. These tests were conducted in the combustion mode using biogas only.

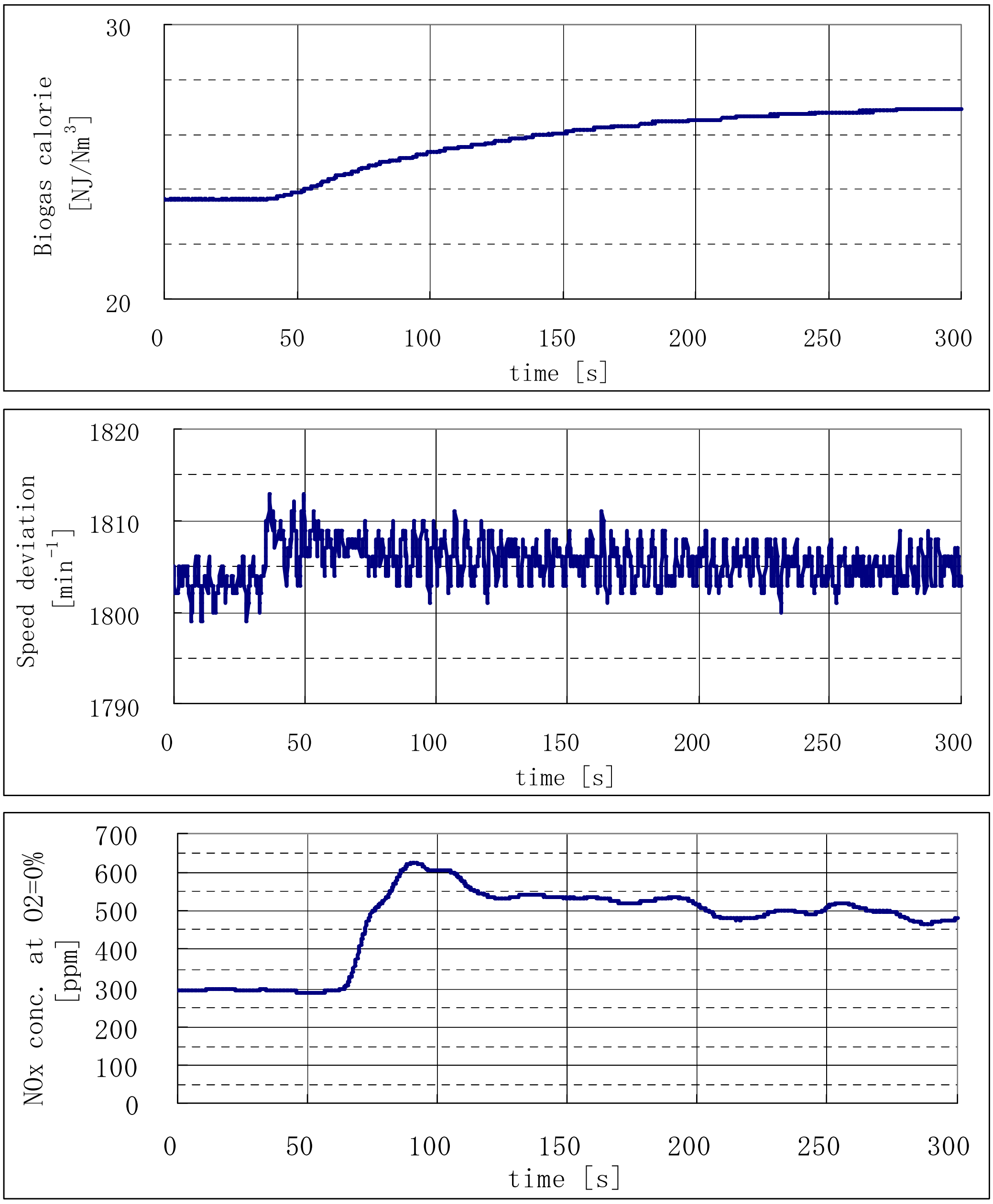

Figure 4.3: Characteristics of generator at increasing heating value of artificial biogas

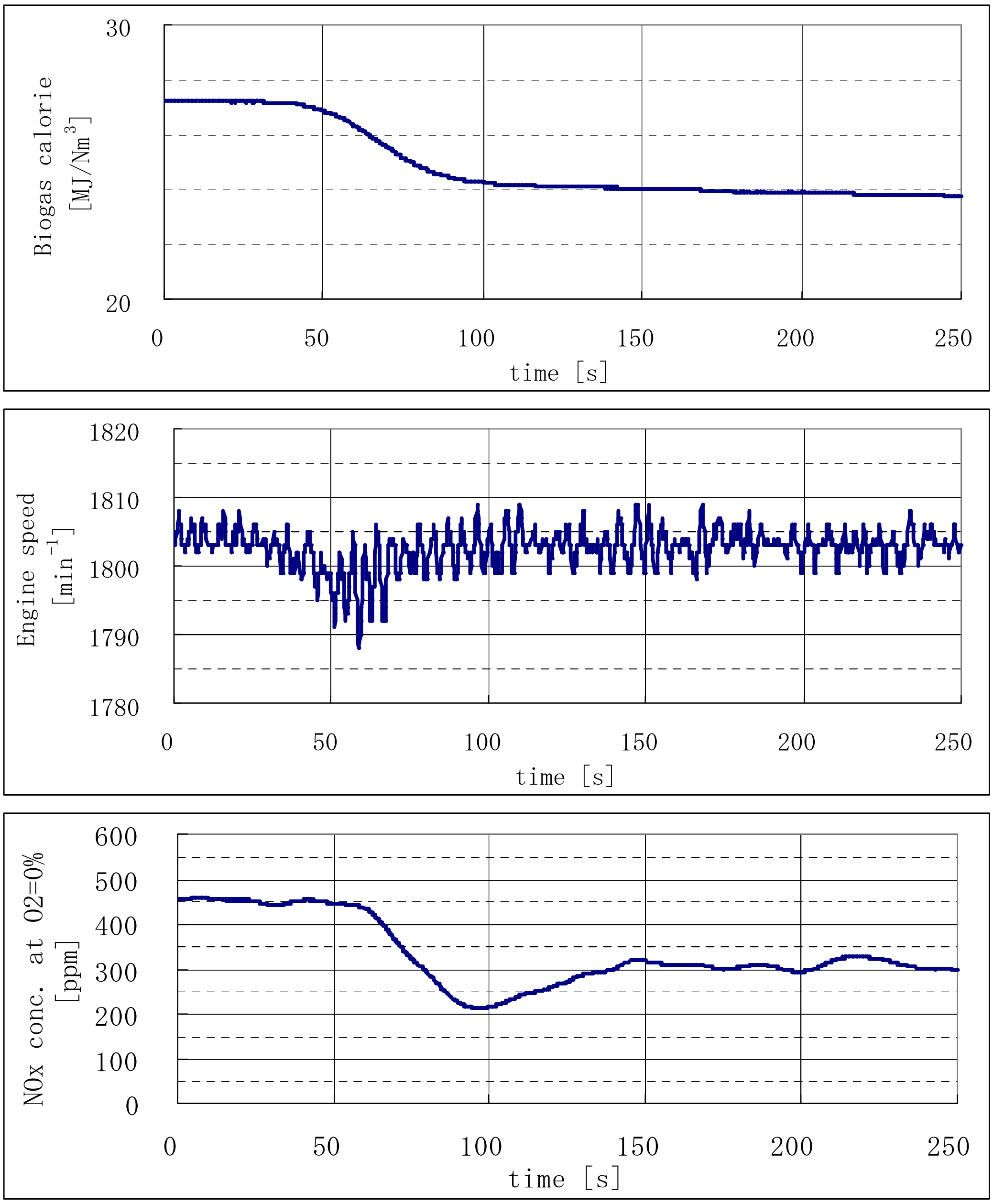

Figure 4.4: Characteristics of generator at decreasing heating value of artificial biogas

Figure 4.3 shows the result of the test at increasing heating value of artificial biogas. Figure 4.4 shows the result of the test at decreasing heating value of artificial biogas. Both of the tests verified that the generator could achieve stable operation within a few minutes though NOx concentration in exhaust gas changed significantly just behind the heating value change in both cases. Engine speed also varied after the heating value change but was lower than 20 times/min. We assumed that this system also has the sufficient ability to control the heating value change of biogas.

- Characteristics of switching gas

This system has a switching function that switches the operation mode from biogas to city gas when the lower level of biogas tank is detected due to the produced biogas falling off. The switching time is needed to be shortened as mush as possible for efficient use of biogas tank. We adopted the method of using pre-programmed switching pattern for this system to control the gas flow control valves installed at the biogas line and the natural gas line.

Figure 4.5 shows the result of switching test from biogas to natural gas. Figure 4.6 shows the result of switching test from natural gas to biogas. Both of the tests verified that the generator could achieve stable operation within 10 seconds though engine speed slowed down a little after switching fuels in both cases. Also, the generator could be stabilized within about 2 minutes though NOx concentration in exhaust gas changed just behind switching. We assumed that this system can realize the stable operation continuously by the optimized switching pattern even though the fuels are switched in a short time between biogas and natural gas.

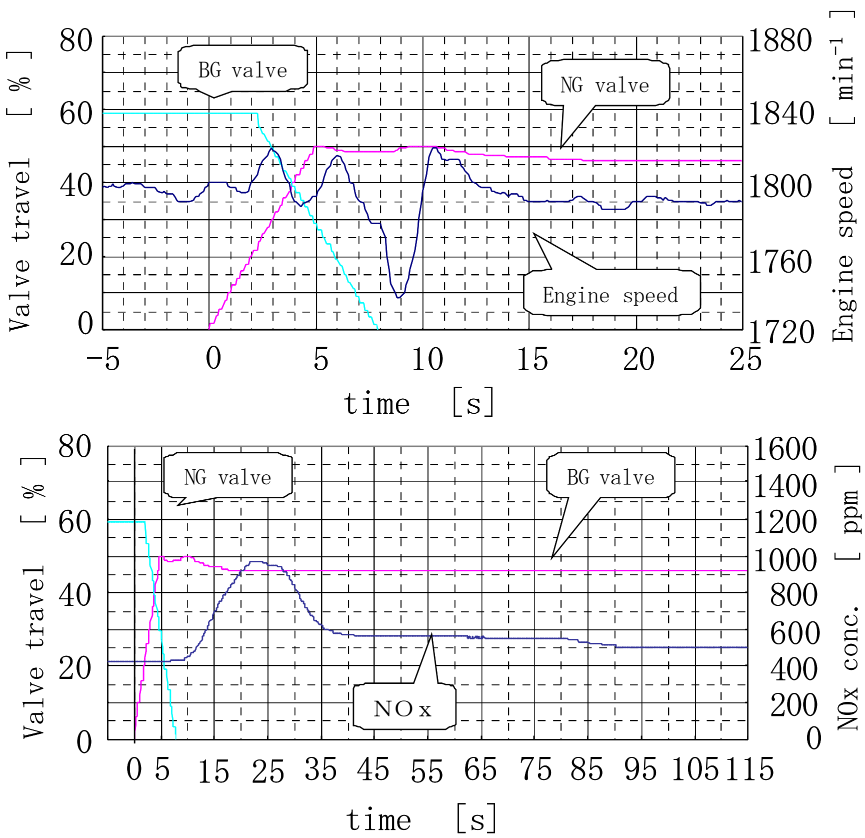

Figure 4.5: Result of switching test from biogas to natural gas

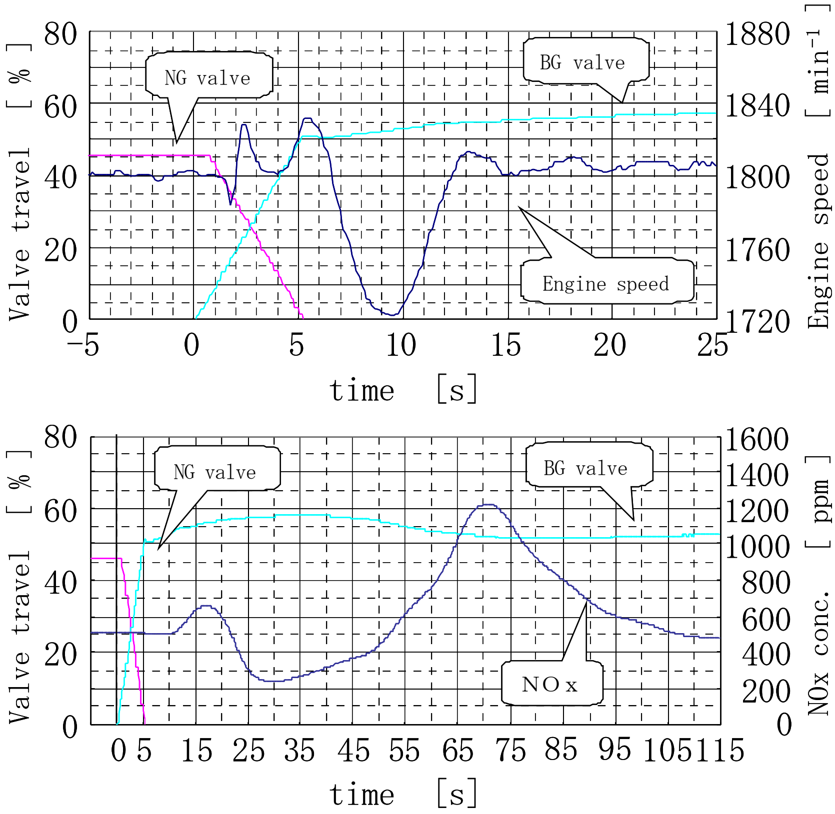

Figure 4.6: Result of switching test from natural gas to biogas

Summary of development

JFE Engineering and Osaka Gas jointly launched the development of simple designed and low cost biogas/natural gas dual fuel engine system. We verified that this engine system that has comparatively simple composition, and has the efficient ability of absorbing the biogas even when the production quantity and heating value of biogas vary.

Conclusion

We promote the biogas/natural gas dual fuel engine to evolve an efficient use of biogas. Until now, many dual fuel engines have been in operation at sewage disposal plants , food and beverage plants. Additionally to encourage the efficient use of biogas, we also developed the smart and low-cost biogas/natural gas dual fuel engine. We are confident about the high performance and simple design of this engine. This system can contribute to the promotion of biogas/natural gas dual fuel engine in the future. Moreover, this system can contribute to the efficient use of biogas as a renewable energy and the increasing of natural gas usage accordingly.