Development of new calorific value adjustment system for wide range operation

Authors: Naoya Iwata, Nobuyuki Sakakibara, Kazuo Ito (Toho Gas Co., Ltd.)
Kanetoshi Hayashi, Isho Yamaguchi, Shin Kawamura (JFE Engineering Corporation)

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Background

Japanese city gas companies provide standard calorific values to secure the quality of city gas, and Toho Gas set the value at 46.05 MJ/m^3N. We use LNG as the main raw material of city gas, and when receiving low-calorie LNG, we adjust the calorific value by adding LPG to LNG before supplying city gas to customers.

As the calorific-value adjustment system (hereinafter referred to as "CVAS"), the following three methods are currently used. (Fig.1)

- Liquid-liquid CVAS
- Liquid-gas CVAS
- Gas-gas CVAS

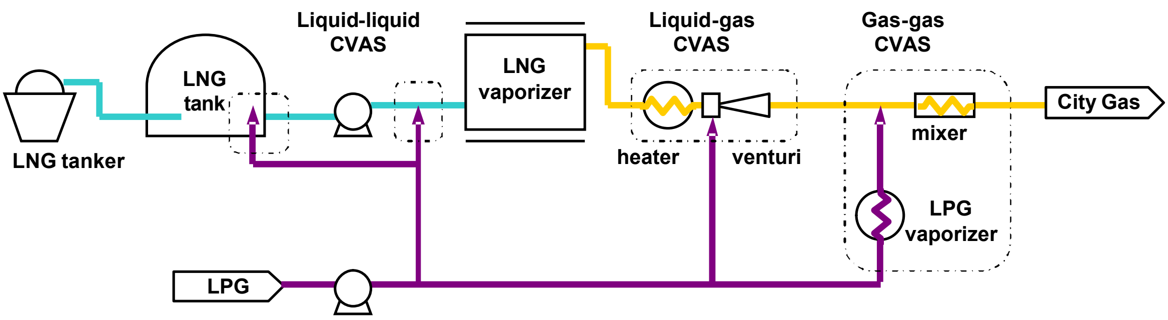


Fig.1 City gas CVAS

Since the liquid-gas CVAS uses sensible heat of NG for vaporizing LPG, it has the following merits and, therefore, has been used in many instances in recent years.

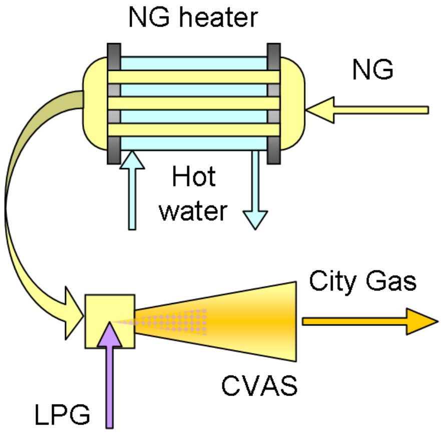
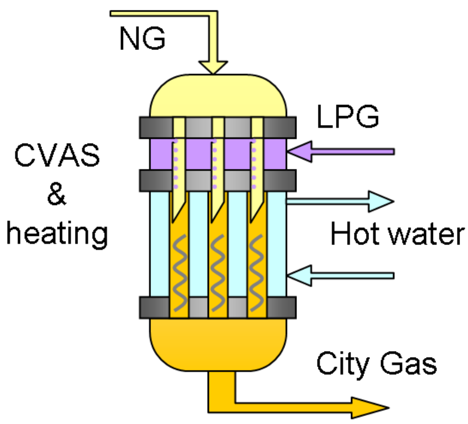
・A dedicated LPG vaporizer is not required and a saving of space can be achieved.

・Compared with the method of vaporizing LPG (gas-gas CVAS), the loss of heat supply becomes smaller, and running costs can be reduced.

As the CVAS of the liquid-gas mixing method, the "Venturi method" is widely used for a large scale operating condition and the "Shell and tube method" is widely used for a small scale operating condition. Although the "Venturi method" allows superior caloric controllability, it can be operated only in a narrow flow-rate range. The "shell and tube method" has the opposite features (Table 1).

Toho Gas uses the "Venturi method" which is suitable for a large-scale calorific-value adjustment and high pressure operating condition and has superior caloric controllability.

Table 1 Existing liquid-gas CVAS

	Venturi method	Shell and tube method
Caloric value controllability	○ Keeps good controllability even in a load-changing condition	△ Fluctuates largely in a load-changing condition
Minimum Turndown ratio*	△ 1/5	○ 1/10
Track record	Many for a large scale and high-pressure operating condition	Many for a small scale and medium-pressure operating condition
Schematic		

* Turndown ratio: The ratio of the flow rate divided by the maximum design flow rate. Minimum turndown ratio represents the operational range of CVAS.

However, the "Venturi method" liquid-gas CVAS has the disadvantage that it can be operated only in a narrow flow-rate range.

Specifically, when the flow rate is reduced to one-fifth or lower in turndown ratio, the ratio of flow-rate divided by the maximum design flow-rate, a so-called "dripping" phenomenon occurs, in which some portion of added LPG drips/flows-out without evaporation, hence, caloric adjustment is not functional. The cause of this phenomenon is that when the NG flow rate decreases, the NG flow velocity in the Venturi decreases, which reduces the atomization of LPG.

Also in cases where, because of low NG calorific value, the amount of LPG to be supplied becomes relatively larger, the atomization of LPG is reduced, resulting in the "dripping" phenomenon (Fig.2).

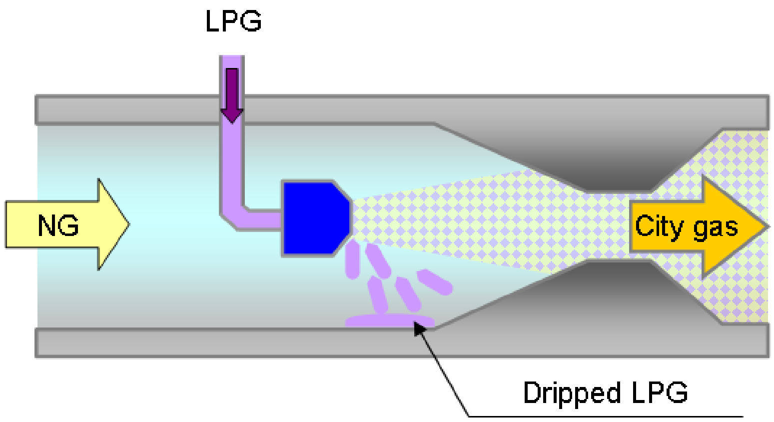


Fig. 2. "Dripping" phenomenon in the Venturi-method liquid-gas CVAS

Therefore, with regard to the conventional CVAS, when operating in wide operational flow rate range, it is necessary to combine two sizes of Venturi, large and small, as shown in Fig.3. However, such combination poses problems, including control difficulties in switching the Venturi over, the requirement of larger installation space and increased cost.

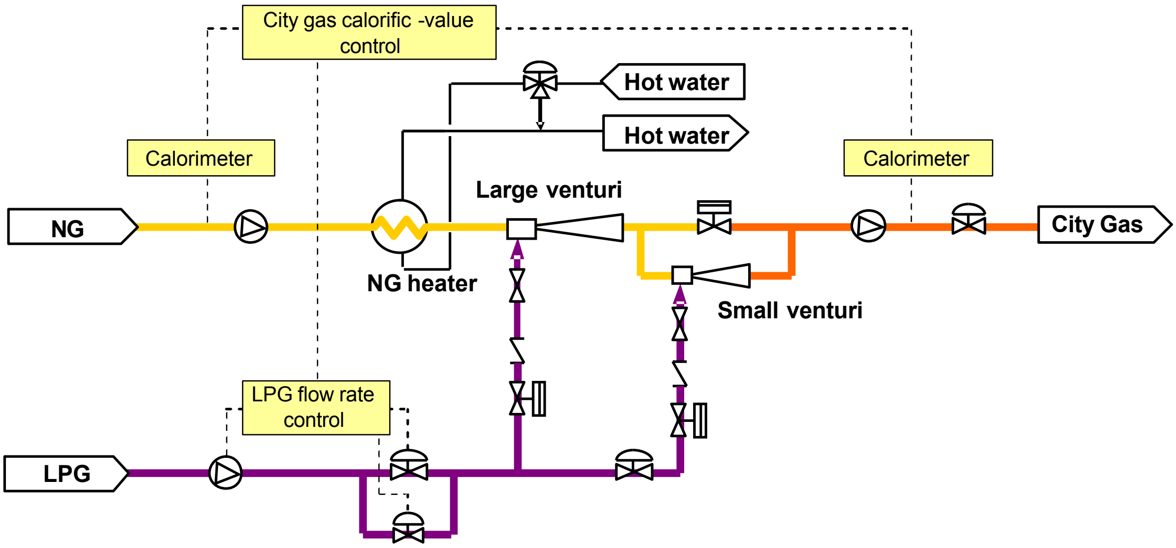


Fig.3. Example of the configuration of Venturi method liquid-gas CVAS

Toho Gas and JFE Engineering have developed a new CVAS that enables operation in the lower flow rate condition than conventional systems using one Venturi, with superior caloric controllability of Venturi method liquid-gas CVAS.

Aims

Table 2 and Fig.4 show the development target for the new CVAS.

With expanding the NG turndown ratio (horizontal axis) to 1/20, the new CVAS can be operated using only one Venturi, even under the conditions where conventional CVAS requires two sizes of Venturi, large and small, . Moreover, regarding the adjustable range of NG calorific value, we aim at the target of light LNG, 41.86 MJ/m^{3}N (10,000 kcal/m^{3}N), in all operating ranges.

Table 2: Development target

	Conventional method	Development target
NG turndown ratio (operational flow rate / rated flow rate)	1/5	1/20
Adjustable NG calorific value	Minimum 41.86 MJ/m^{3}N	41.86 MJ/m^{3}N in all operating range

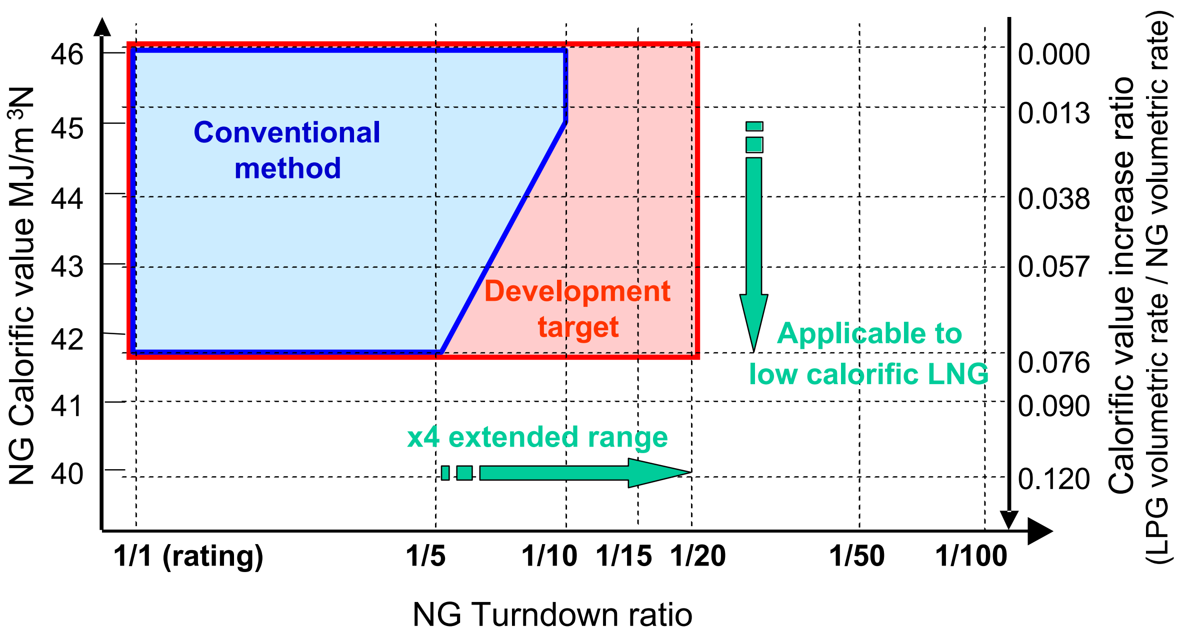


Fig.4. Development target

Methods

(Design)

In the Venturi method, LPG sprayed from the spray nozzle in the liquid state is atomized by high-speed NG flow in a Venturi. At this time, LPG is vaporized by the sensible heat of NG. Empirically, the lower limit of NG flow velocity is around 30 m/s and, if the velocity is lower than the limit, LPG is not atomized and the vaporizing and mixing do not function. On the other hand, the new system incorporates a newly-developed liquid-atomization-nozzle mechanism (hereinafter referred to as “developed nozzle”) in order to securely vaporize and mix LPG even in the low flow rate condition where the NG velocity in the Venturi decreases below 30 m/s. Fig.5 shows the structure of the conventional system and the developed system.

In the developed system, liquid is atomized when the NG is partly distributed into the developed nozzle and is mixed with the liquid LPG. By appropriately controlling the flow rate of NG to be supplied to the developed nozzle in response to the operation load, LPG can be securely atomized enabling vaporization of LPG by the sensible heat of NG even in the low flow rate condition where the NG velocity in the Venturi decreases.

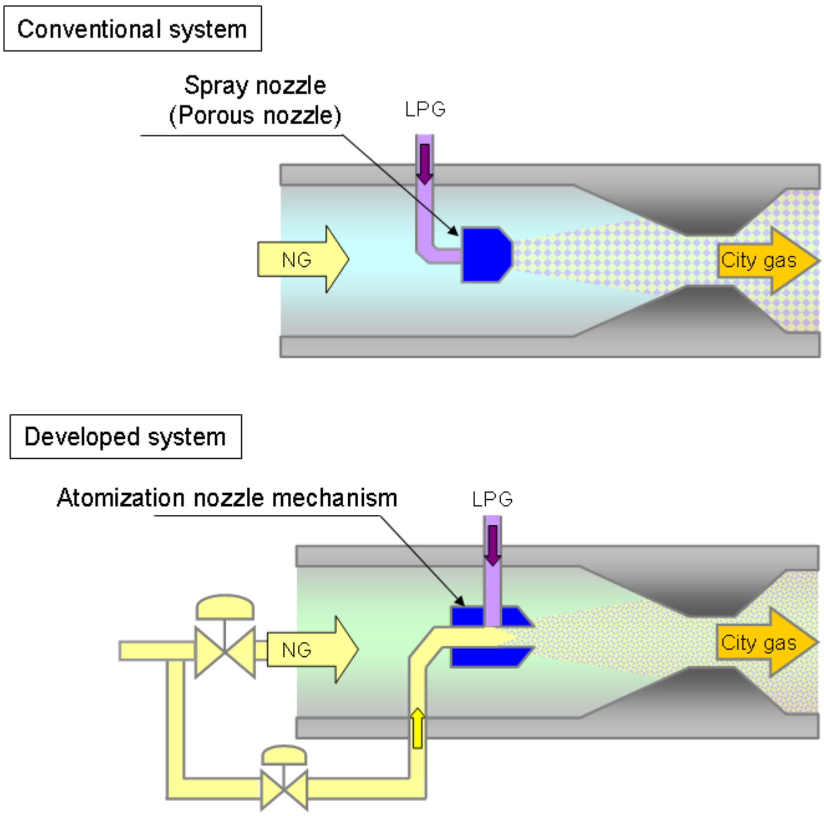


Fig.5 Design concept of the new CVAS

(Verification test)

To evaluate the effectiveness of the developed nozzle, we performed the verification test under the same conditions as the city gas that is actually produced and supplied by installing a pilot-scale verification test plant in the city gas manufacturing plant of Toho Gas. We show the capacity and configuration of the installed verification test plant. (Table 3, Photo 1, Fig.6).

Since the calorific value of NG varies with LNG composition , we measured the calorific value by NG calorimeter. NG is heated to the designated temperature by the NG heater. NG should be heated in advance because LPG is added to NG in the liquid state in the liquid-gas CVAS and the vaporization heat should be compensated by the sensible heat of NG. In this test, the three-way valve at the NG heater inlet was adjusted so that the NG temperature at the NG heater outlet was 35 to 40°C. The NG flow rate was controlled by the valve on the CVAS downstream. Moreover, the test of the developed nozzle required the adjustment of the flow rate of NG to be distributed to the nozzle, which was made by the three-way valve of the CVAS upstream.

The turndown ratio of the LPG flow rate exceeded 100 under the testing conditions (NG turndown ratio, calorific value increase ratio). To cope with such a high turndown ratio, two LPG flow control valve systems, large and small, were installed. We measured the calorific value of gas after LPG was added by CVAS using a city gas calorimeter to check if the calorific value, in accordance with the NG flow rate and the LPG flow rate, had been obtained.

we performed the verification test for one year, and table 4 shows the schedule.

Table 3. Overview of the test plant

Design pressure	2.94 MPa
Design flow	14,000 m^3N/h (about 10% of the scale of an actual plant)
Pipe size	NG/City Gas 4B, LPG 1B
Applicable law	Gas Utility Industry Law (Japan)

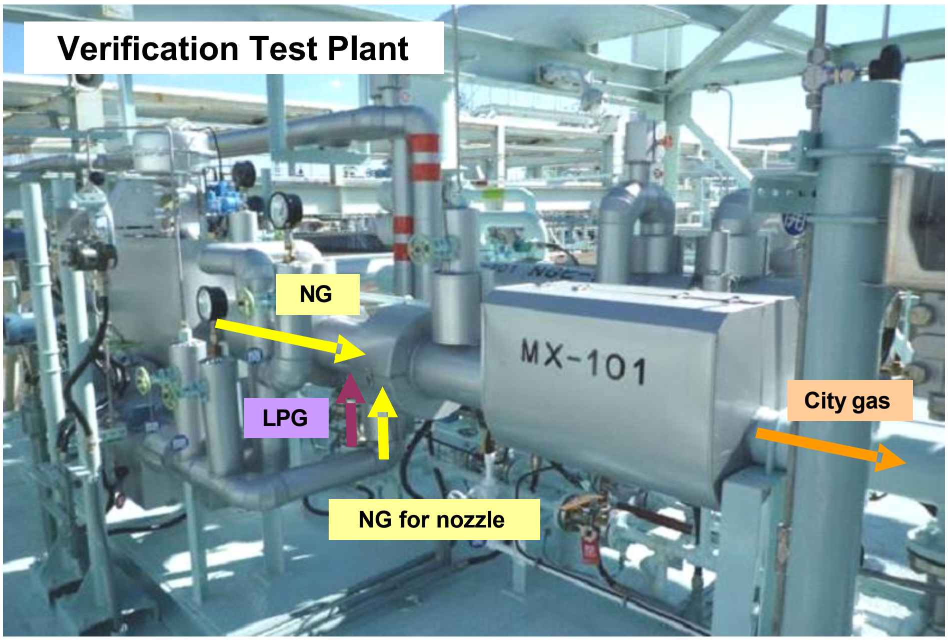


Photo 1. Appearance of verification test plant

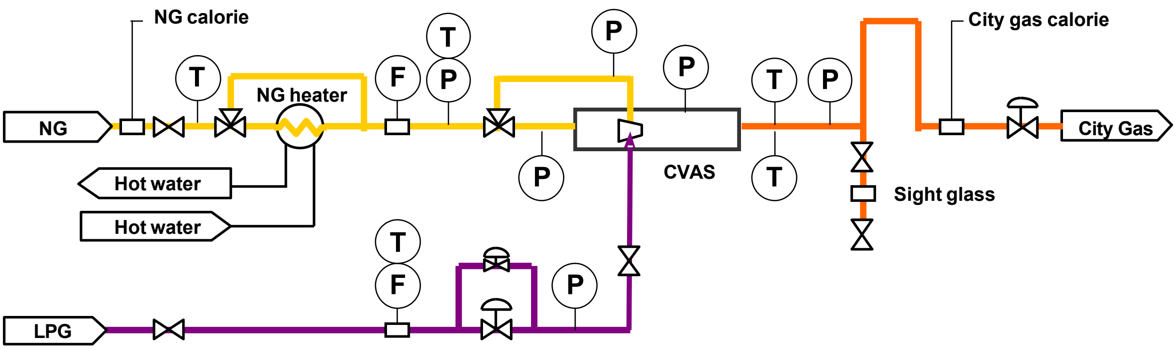


Fig 6. Configuration diagram of the verification test plant

Table 4. Test schedule

	2010	2011
Construction	Designing Construction ▼Legally-required inspection	
Verification Test	Basic experiments Run	Evaluation Run Evaluation

To assess the optimal atomization nozzle configuration, we made performance comparisons by making a total of five kinds of nozzle - four new nozzle designs and one type of conventional nozzle. In this paper, we report the results of the following three typical nozzles.

Conventional nozzle

Only LPG is supplied and is spouted out from the multiple-hole tip.

New nozzle (1)

LPG and NG are supplied, mixed and atomized inside the nozzle, and spouted out.

New nozzle (2)

It has the same mechanism as the new nozzle (1), but with a smaller diameter.

Photo 2. Photo of the appearance of the assessed nozzles

In the verification test, using the turndown ratio and the calorific value increase ratio as assessment parameters, we checked the calorific-value adjusting performance in each operational status. (See Table 5, Fig.7) We judged the calorific-value adjustment functions in each operational status and assessed the operation point that is considered to be the limit for each nozzle.

Fig.8 shows the matrix with the turndown ratio as the horizontal axis and the calorific value increase ratio as the longitudinal axis. We judged whether the CVAS functioned in each parameter and assessed if the test nozzles generally functioned within the target range.

When making the judgment on whether calorific value adjustment functioned, we generally used the following three methods.

(1) City gas calorific value: When the added LPG was appropriately vaporized and mixed, the city gas calorific value increased according to the amount of added LPG. When a "dripping" phenomenon occurred, the city gas calorific value at the outlet became lower than the calorific value expected.. We checked if the city gas calorific values corresponded to the amount of added LPG.

(2) City gas temperature: When a LPG "dripping" phenomenon occurred, there was a spatial temperature distribution in the gas pipe at the Venturi outlet. In the place where LPG in the liquid state existed (normally at the bottom of pipes), temperature decreases to the saturation temperature of LPG vaporization. We checked whether there was a spatial temperature difference in the Venturi outlet pipe.

(3) Visual observation: We checked if there was LPG in the liquid state by observing through a sight glass that was installed at the CVAS outlet.

Table 5. Test plant designed value

Parameter (1)	Calculation method
Turndown ratio	(m-G1) / (m-G0)

Turndown ratio	1/1	1/2	1/2.5	1/4	1/5	1/10	1/15	1/20	1/30	1/50	1/100
NG flow rate [m^3N/h]	14,000	7,000	5,600	3,500	2,800	1,400	933	700	466	280	140
Venturi flow rate [m/s]	128.3	64.1	51.3	32.1	25.7	12.8	8.6	6.4	4.3	2.6	1.3

Parameter (2)	Calculation method
Calorific value increase ratio	(m-L1) / (m-G1)

Calorific value increase ratio	0.000	0.013	0.038	0.057	0.076	0.090	0.120	0.150	0.200
Assumed NG calorific value [MJ/m^3N]	46.05	45.33	43.95	42.90	41.85	41.07	39.42	37.76	34.99

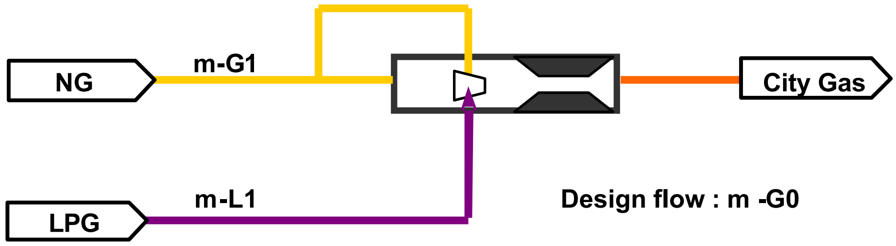


Fig.7 Measured flow rate

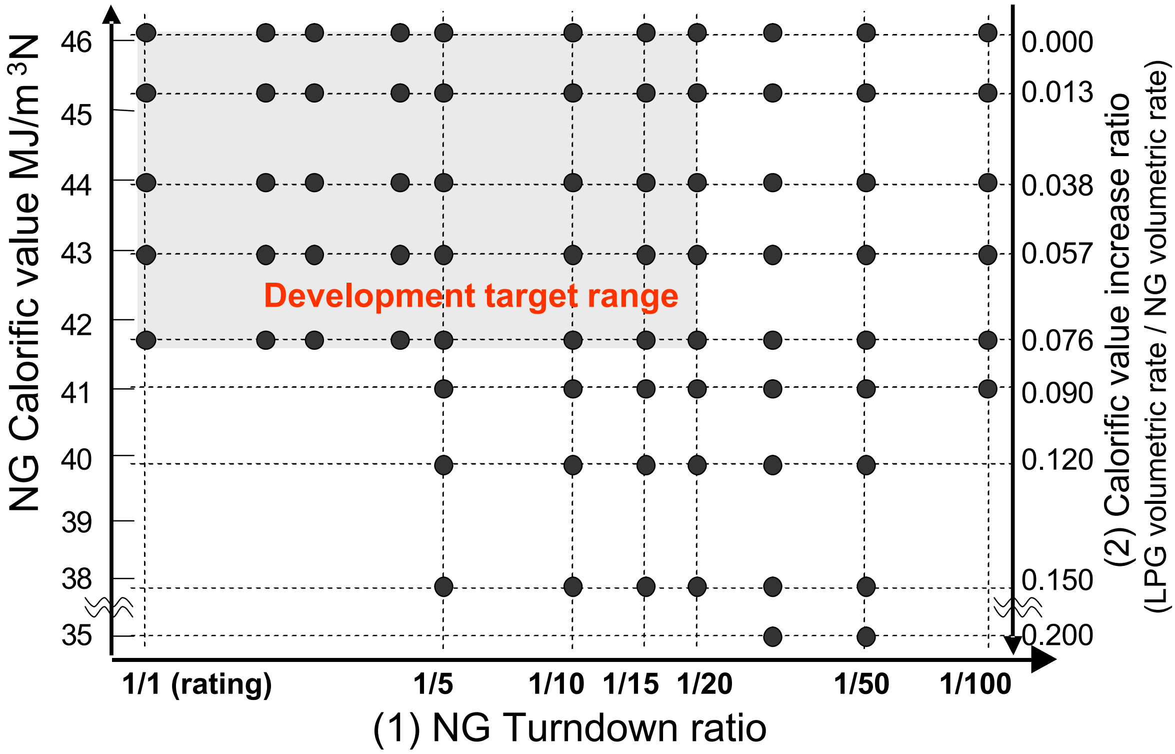


Fig.8 Test points

Results

(Performance assessment)

As a result of the verification test, a "dripping" phenomenon occurred in the conventional nozzle when the turndown ratio was 1/5 and the calorific value increase ratio was 0.076 (lean LNG calorific value adjustment range). In this test plant, the flow rate in the Venturi became around 30m/s when the turndown ratio was 1/4 to 1/5 as shown in Table 5, and it corresponded to the expected limit of the range in which the conventional nozzle functioned. When the turndown ratio was 1/10, a "dripping" phenomenon occurred, even in the calorific value increase ratio of 0.038, which is the normal calorific-value adjustment range (Fig.9).

On the other hand, the new nozzles (both (1) and (2)) functioned without causing a "dripping" phenomenon in the development target range of 1 to 1/20 for the turndown ratio and 0 to 0.076 for the calorific value increase ratio. (Table 10 and 11)

When the turndown ratio was further reduced with the calorific value increase ratio being 0.076 (lean LNG calorific value adjustment level), the new nozzle (1) functioned without problems until the turndown ratio was 1/50 (Fig.10). On the other hand, the new nozzle (2), which has a smaller diameter than the new nozzle (1), functioned until the lower limit flow rate (turndown ratio 1/100) that could be tested in this test plant and, therefore, we were unable to check the lower limit of the turndown ratio (Fig.11). That is to say, the new nozzle (2) had better atomization performance than the new nozzle (1).

In addition, a "dripping" phenomenon occurred when the calorific value increase ratio exceeded 0.150 in each nozzle. This is considered to be a inevitable "dripping" phenomenon, due to the dew point of the propane.

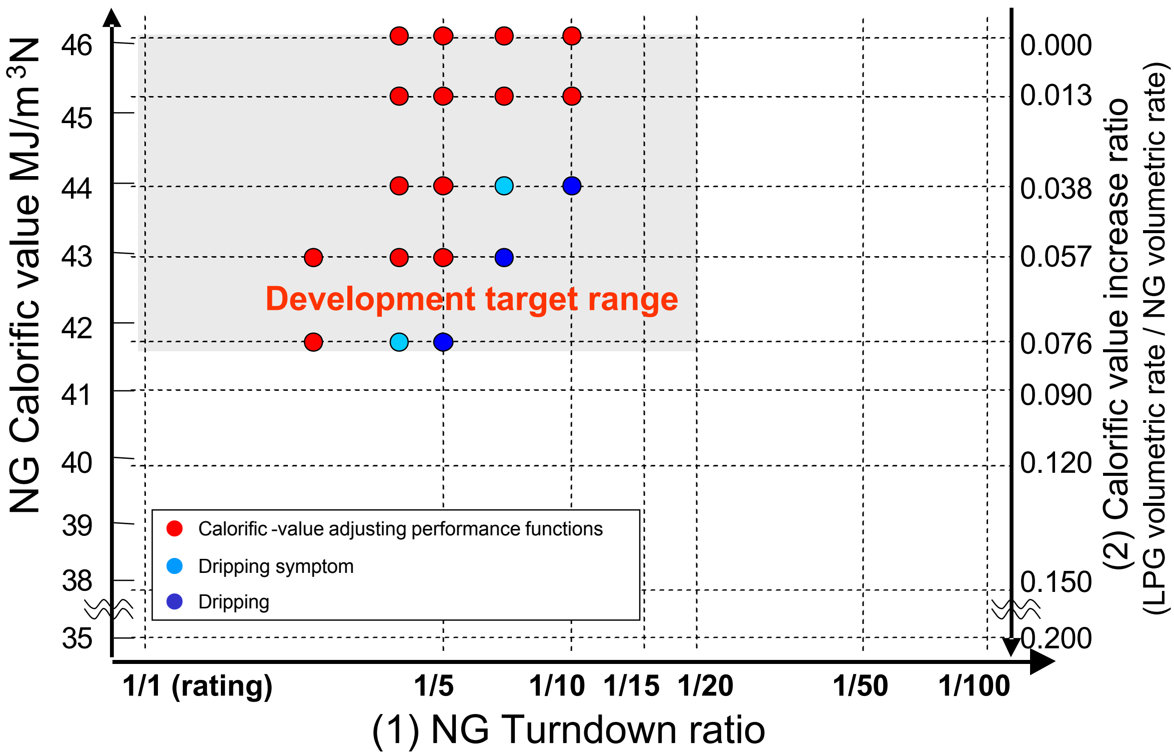


Fig.9 Conventional nozzle function range

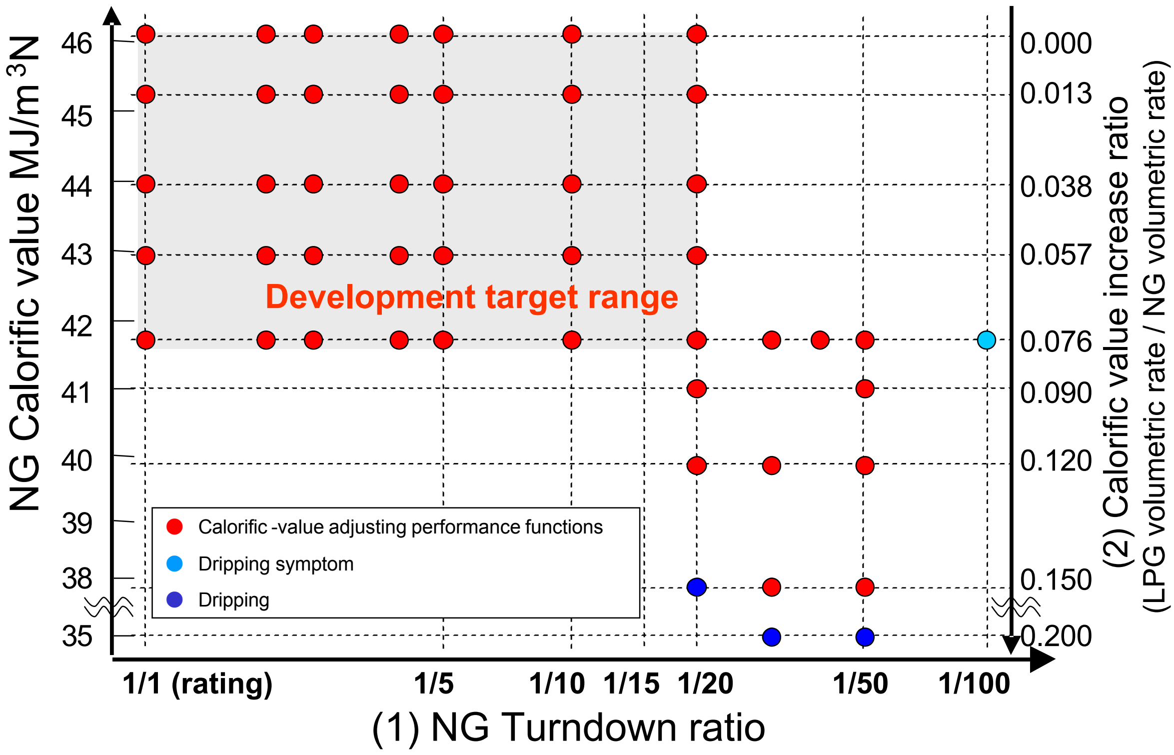


Fig.10 New nozzle (1) function range

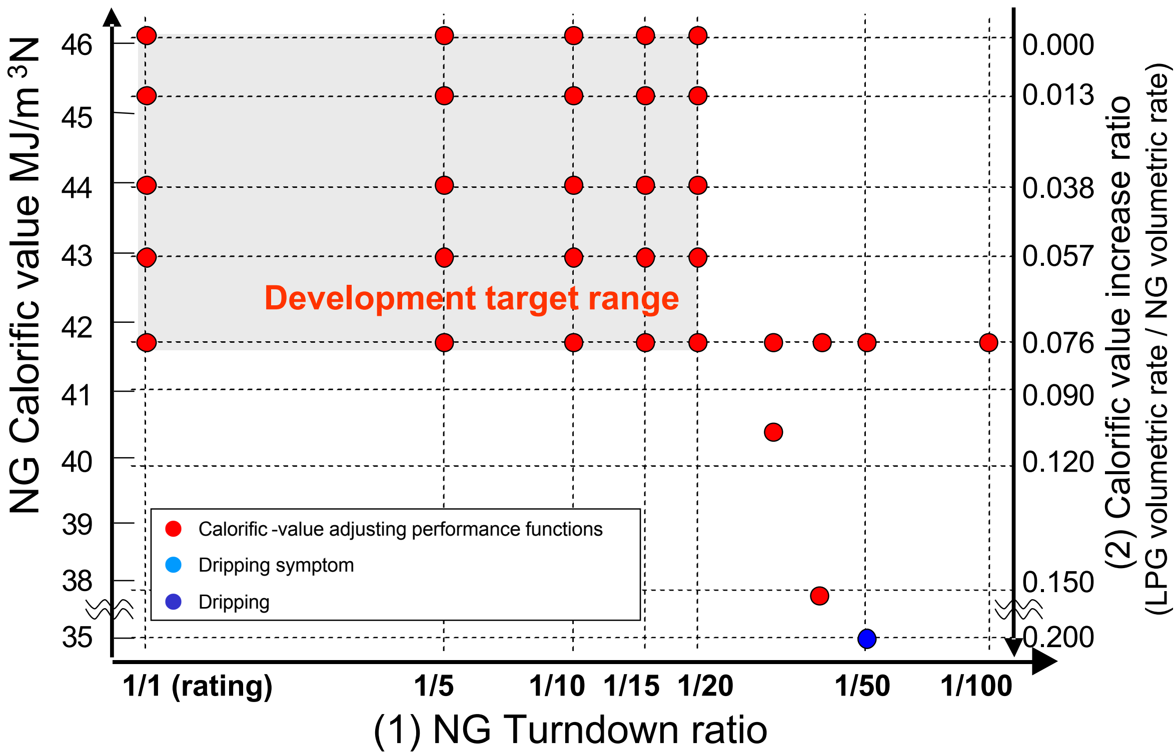


Fig. 11 New nozzle (2) function range

(Pressure loss assessment)

We assessed two pressure-losses shown in Fig.12.

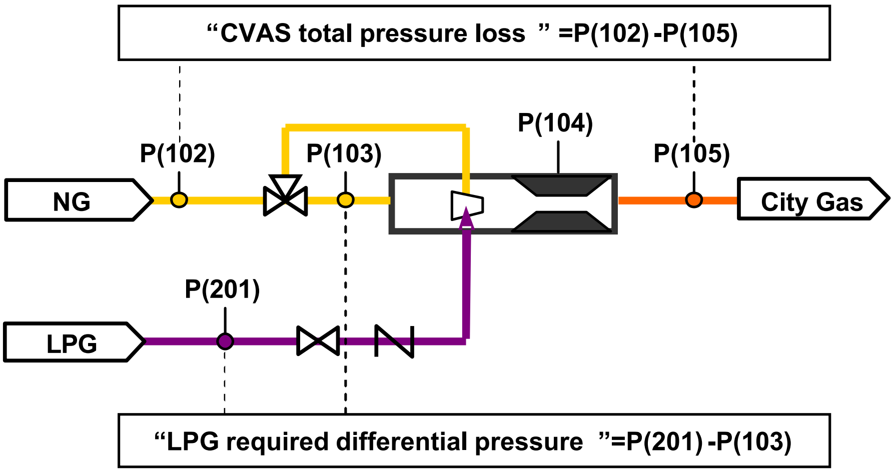


Fig. 12 Pressure loss assessment index

With regard to the "CVAS total pressure loss" (Fig.13), the new nozzle (2) with smaller diameter had higher pressure loss, but the new nozzle (1) had a pressure loss that is almost equal to the conventional nozzle. The "CVAS total pressure loss" was dominated by the Venturi diameter. Therefore, if the diameter of the new nozzle becomes not extremely small, its CVAS total pressure loss can be equal to that of the conventional nozzle.

The "LPG required differential pressures" (Fig.14) of both the new nozzle (1) and the new nozzle (2) were equal to, or even less than, that of the conventional nozzle. It can be considered that, because the conventional nozzle was structured so as to spout out LPG from the multiple-hole tip, the pressure loss of LPG became relatively higher compared with the new nozzles.

The new nozzle (2) showed better atomization performance than the new nozzle (1); on the other hand, the new nozzle (1) had less pressure loss than the new nozzle (2). Under conditions where the pressure loss was equal to or less than the conventional nozzle, the new nozzle (1) becomes the choice. It showed enough performance and could function until the turndown ratio of 1/50. The new nozzle (1) could provide sufficient performance by enabling operations in the flow rate range 10 times as large as the conventional nozzle.

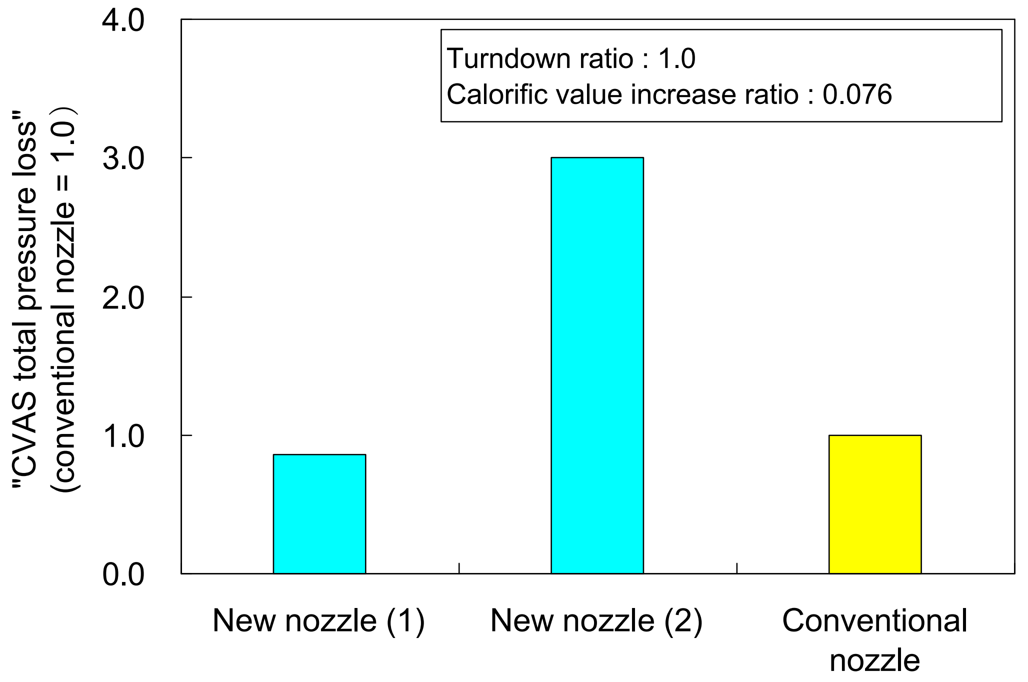


Fig.13 Pressure loss assessment results 1
("CVAS total pressure loss" = P (102)-P (105))

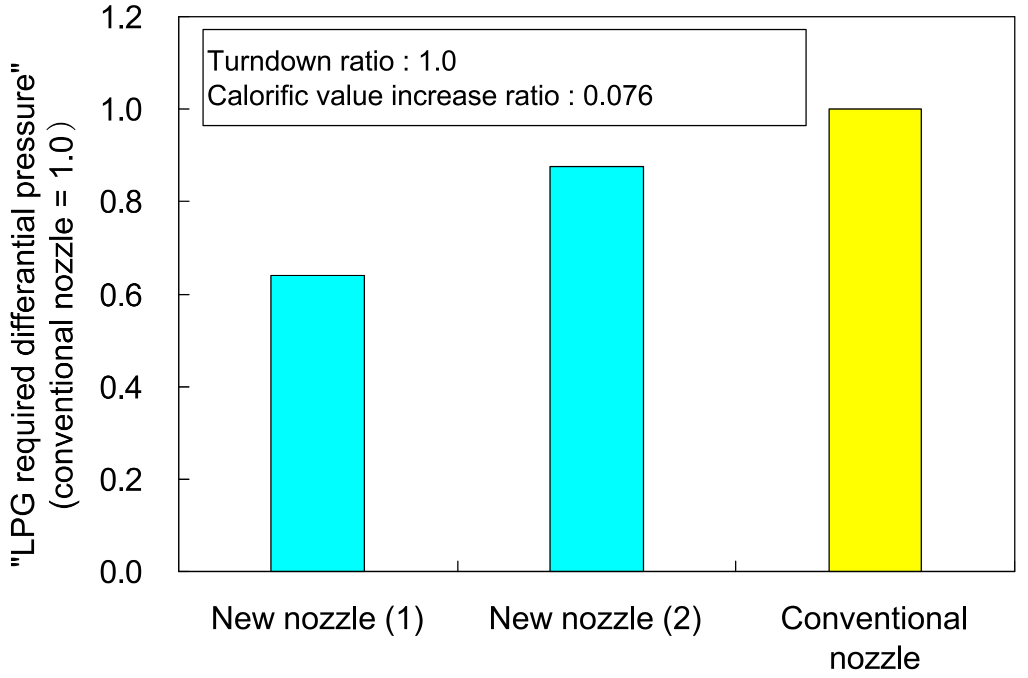


Fig.14 Pressure loss assessment results 2
("LPG required differential pressure" = P (201)-P (103))

Summary/Conclusions

We confirmed that, by utilizing a newly developed atomization nozzle mechanism, the liquid-gas CVAS could operate until the turndown ratio of 1/50 while maintaining the pressure loss at the level of being equal to, or even less than, that of the conventional system. With this mechanism, compared with the conventional system of turndown ratio 1/5, the CVAS could operate in a flow rate range about 10 times wider.

Moreover, regarding the adjustable range of NG calorific value, the new CVAS achieved the development target of NG, 41.86 MJ/m^{3}N, in all operating ranges where the atomization nozzle functioned and, therefore, it appears to be sufficiently designed for lean LNG.

Since the pressure loss of the entire whole CVAS system was equal to, or even less than, that of the conventional system, the CVAS could be designed without installing a new NG compressor or considering excess pressure loss in the process design.

As a result of this development, because the new CVAS largely exceeded the calorific value adjusting performance of the conventional system, we could realize the same functions, functional range, using just one Venturi, where two sizes of Venturi were required for the conventional system. Thus, we can expect not only improved operability but also savings in installation space and equipment cost.

Table 6 Development target and results

	Conventional system	Development target	Result	Achievement
Turndown ratio	1/5	1/20	1/50	◎
Adjustable calorific value	Minimum 41.86 MJ/m^{3}N	41.86 MJ/m^{3}N in all operating range	41.86 MJ/m^{3}N in all operating range, partially 40 MJ/m^{3}N	◎
Pressure loss	-	Equal to the conventional system	NG line: Equal to the conventional system LPG line: Equal to, or even less than, the conventional system	◎