Development of a real-time LNG calorimeter using a Coriolis meter

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1. Introduction

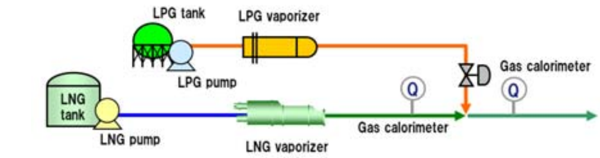
Control of calorific value is one of the most important elements in quality control of city gas. Osaka Gas maintains the most stringent adjustment of calorific value for our city gas manufacturing site because the calorific value of LNG, the raw material for city gas, varies from source to source depending on the places of origin. Considering the increasing variety of LNG sources in the future, the difference of each calorific value may become larger and the control of calorific values will be more important than ever.

This paper shows our approach to calorific value adjustment by developing a real-time LNG calorimeter and a LNG calorific value adjustment system with using the calorimeter.

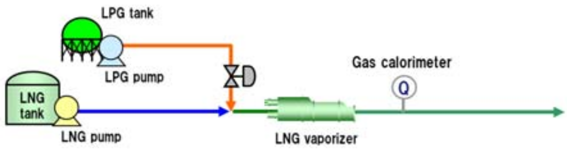
2. Osaka Gas's calorific value adjustment method of city gas

2.1 Conventional methods

Fig.1 shows the calorific value adjustment methods of city gas; (1) is the 'gas-gas system' that mixes the gases to adjust the calorie by using LNG and LPG separately processed for gasification and; (2) is the 'liquid-liquid system' that mixes LNG and LPG in its liquid state to adjust the calorific value and then gasifies.



(1) Calorific value adjustment by gas-gas system



(2) Calorific value adjustment by liquid-liquid system

Fig.1 Conventional methods

2.2 An issue with the conventional methods

Comparing these two conventional methods, liquid-liquid system that mixes LNG and LPG in its liquid state and then gasifies gets a better result in running cost than gas-gas system. However, a following issue of this method should be taken into consideration.

Calorific value of city gas (product) is adjustment depending on the calories and flow rates of LNG (raw material) and LPG (carburetant). Unlike LPG having almost a constant calorific value, LNG has various calorific values for each tank. When LNG of several storage tanks is used as low materials, it is ideal for calorific value adjustment to use measured calorific values of LNG in control calculation. However, the calorific value of LNG has been traditionally measured by a gas chromatography, which analyzes the content from vaporized gases. The procedure of gas chromatography is not convenient for the control calculation because it takes much time for sampling, vaporizing and analyzing. For this reason, we couldn't help but use an assumed constant calorific value of LNG in the control calculation.

The equation of control calculation for calorific value adjustment is as below:

$$F_{LPG\_SV} = F \times \frac{Z_{LNG}(Q_{set} - Q_1)}{Z_{LPG}(Q_{LPG} - Q_{set}) + Z_{LNG}(Q_{set} - Q_1)} \times \alpha \quad \text{(eq.1)}$$

Where,

- F_{LPG_SV} : a target value of LPG [t/h]
- F : a sum of flow rates of LNG and LPG [t/h] (target value)
- Z_{LNG} : a LNG generation coefficient before mixing with LPG [m^3N/t]
- Q_{set} : a target value of calorie for city gas [MJ/m^3N]
- Q_1 : a LNG calorific value before mixing with LPG [MJ/m^3N]
- Z_{LPG} : a LPG generation coefficient [m^3N/t]
- Q_{LPG} : LPG calorific value (fixed value) [MJ/m^3N]
- α : a corrected value by FB control

So far, an assumed fixed calorific value of LNG before mixing with LPG (Q_1) didn't cause any major issues for calorific value adjustment because the fluctuation of LNG calorific value was small. However, the fluctuation of LNG calorific value may be getting larger depending on increasing variety of received LNG. Therefore, the real-time measurement of LNG calorific value is strongly expected to be developed.

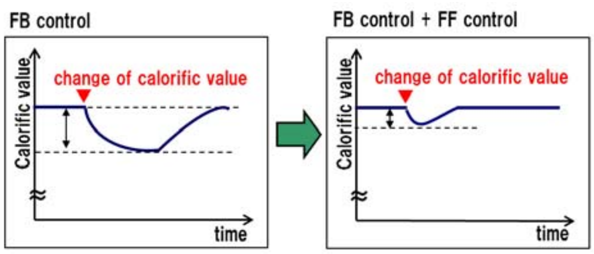


Fig.2 Control image at using LNG calorimeter

3. Development of a real-time LNG calorimeter

3.1 Development of a real-time LNG calorimeter using a Coriolis meter

A Coriolis meter, which is widely used as a mass flowmeter for liquid, is applied for direct measurement of LNG calorific value in liquid state. This flowmeter can also measure the density of liquid in real-time based on its principle. As shown in Fig.3, there is a certain amount of correlation between density and calorific value of LNG. Therefore, a measured calorific value of LNG can be obtained by combining the conversion equation to the system.

At that time, a Coriolis meter had not been used to measure the density of cryogenic LNG at approx.-155 degrees Celsius; it had only been used within normal temperature range. Therefore, we verified the applicability of a Coriolis meter in a field trial. This field trial was operated jointly with OVAL Corporation.

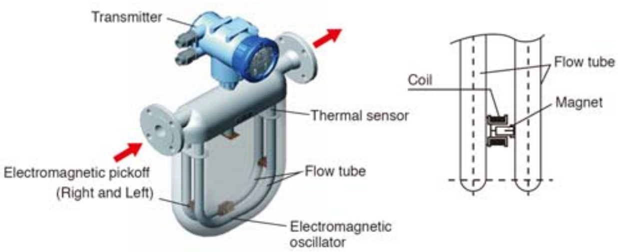


Fig.3 Structure of a Coriolis meter

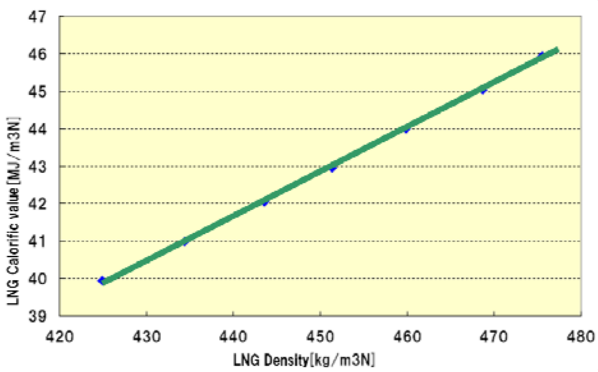


Fig.4 Correlation between LNG density and LNG calorific value

3.2 Field trial

In the field trial, a Coriolis meter was installed at a LNG line near the LNG vaporizer in Osaka Gas's Senboku terminal II. Fig.5 shows the process flow. The density measured by a Coriolis meter was evaluated by comparing with the density calculated from the analyzed value by a gas chromatography that installed at the outlet of LNG vaporizer. The process fluctuation (changes of temperature and pressure) that could occur during the operation was also taken into consideration in this trial. Additionally, the measurement process had to be protected from the vibration effect on a Coriolis meter that causes disturbance of density measurement. The arrangement of piping structure for avoiding the vibration effect was made adequately.

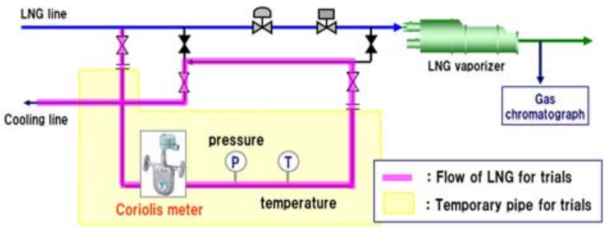


Fig.5 Process flow of the field trial

4. Result of field trial

Fig.6 shows the result of comparison between the density measured by a gas chromatography and the actual density measured while changing LNG temperature. It shows that the difference of these densities is getting larger as LNG temperature increased. Based on the correlation between temperature and density difference assured by the trial data, the temperature effect could be avoided and the density difference could be reduced by implementing the correcting function for measured density depending on the measured temperature. The change of pressure had no effect on the density in this case.

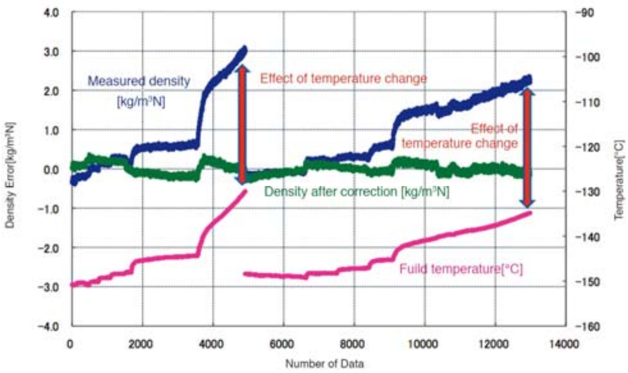


Fig.6 Density measurement error at temperature change

5. System specification of a real-time LNG calorimeter

A system using a real-time LNG calorimeter was developed by applying the correlation between LNG density and LNG calorific value to the density computing of OVAL (Fig.7), and adding the temperature correction function calculated from the field data. Fig.8 shows the actual result of LNG calorific value measured by this system. The measured values were correctly tracking the fluctuation of calorific values and the difference from the calorific value calculated by a gas chromatography was within ±0.08MJ/m3N.

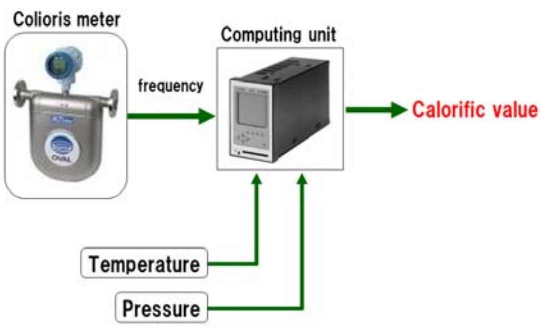


Fig.7 System flow of a real-time LNG calorimeter

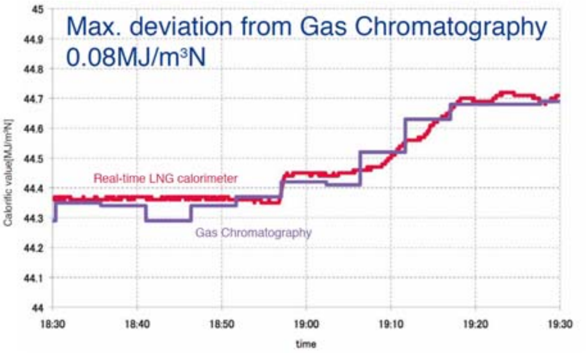


Fig.8 Comparison between the calorific values measured by a real-time LNG calorimeter and a gas chromatography

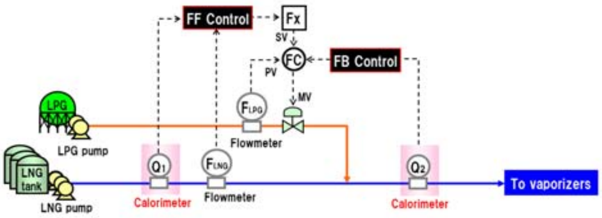


Fig.9 Process flow of calorific value adjustment system for city gas

6. Application to calorific value adjustment system for city gas

6.1 Calorific value adjustment system for city gas

The real-time LNG calorimeter we developed this time was applied to the calorific value adjustment system of 'liquid-liquid system' that directly mixes LNG and LPG in its liquid state pumped up from the storage tanks.

By using this new system, the LNG calorific value measured by a real-time LNG calorimeter was used as the LNG calorific value before mixing with LPG (Q_1) in (eq.1), though Q_1 was a fixed value in the conventional equation.

Fig.9 shows the process flow of the calorific value adjustment system. This system could also achieve the cost reduction by reducing the size of flowmeter, which was realized by adding a bypass line of small diameter at the LNG piping and installing a Coriolis meter on this line.

6.2 Result of commissioning

The construction of this system took for about 8 months from March to October in 2012. It was completed and given a trial run of full spectrum in November of the same year. The intended purpose of this commissioning was to make sure the control ability of the system that maintains the constant calorific value of city gas against the disturbance caused by the variety of LNG calorific values. In this commissioning, the target value of city gas's calorie was changed at the constant rate and tracked by the calorific value of city gas because the disturbance couldn't be generated on purpose. Tracking performance of calorific value control was verified by using three patterns of change rates for target values that increased and decreased within the range of ±0.4MJ/m3N. Fig.10 shows the result of this commissioning. It shows a good performance that the measured value (at Q_2 in Fig.9) tracks the change of target value without delay. The maximum deviation between the target value and the measured value is -0.08MJ/m3N.

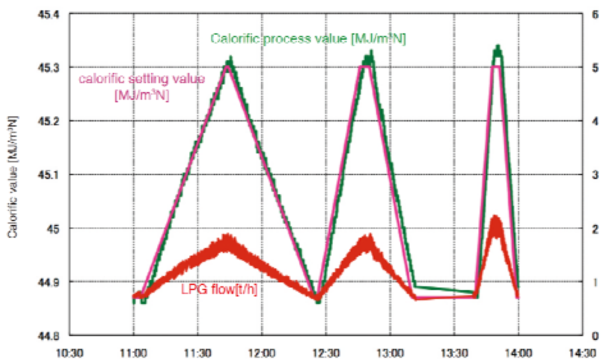


Fig.10 Tracking performance of calorific value

6.3 Dynamic simulation test

Assuming that LNG of low calorific value will be received due to increasing the variety of LNG source in the future, the effectiveness of calorific value adjustment system for LNG of low calorific value was verified by conducting a dynamic simulation test. Fig.11 shows the process flow of the simulation.

The test condition was that LNG of high calorific value is pumped up from two storage tanks; and the load is to be increased for about 50t/h. In this condition, the response performance of the calorific value adjustment system was investigated in the case when the increased load was covered by LNG of low calorific value.

Fig.12 shows the result of this simulation test. After withdrawing LNG of low calorific value from tank A depending on the load increase, the calorific value before mixing with LPG (Q_1) became lower for 1.0MJ/m3N. In this situation, the decrease of calorific value at Q_2 could be held at approx. 0.3MJ/m3N by the effect of FF control according to the measured value by the calorimeter at Q_1. On the other hand, the control by the conventional calorific value adjustment calculation (using Q_1=a constant value) resulted in decrease more than 0.8MJ/m3N of calorific value. These results verify the effectiveness of the calorific value adjustment system using a newly developed calorimeter.

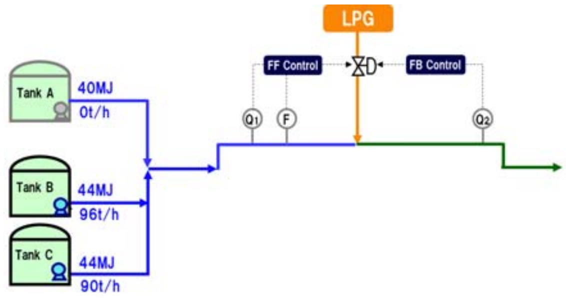


Fig.11 Process flow of simulation

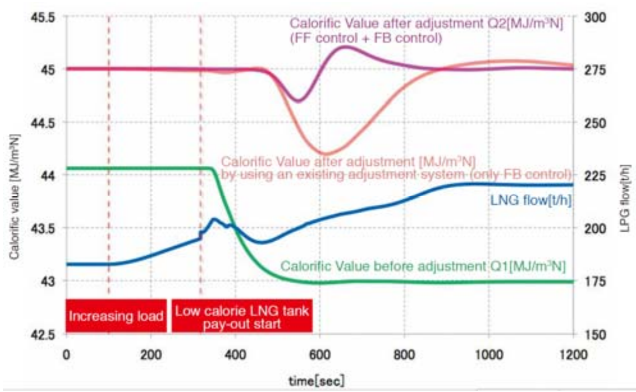


Fig.12 Result of simulation test

7. Conclusion

We developed a calorimeter that can measure LNG calorific value in real-time for the purpose of improving the quality of city gas, and we achieved an improvement of calorific value control response by FF control for LNG calorific value adjustment system using our developed calorimeter. We could contribute to quality improvement of city gas.

However, it is still necessary to deal with the influence of inert ingredients in LNG. The influence of inert ingredients, such as nitrogen, can cause errors in measurement by the developed calorimeter which uses the correlation between LNG density and LNG calorific value.

There is a possibility of increasing use of various LNG that contains much inert ingredients depending on the variety of LNG sources. We are planning to make the LNG calorific value measurement system more developed aiming at relieving the influence of inert ingredients in LNG.

Lastly, the authors would like to express their appreciation to OVAL Corporation, for having great helps in cooperative development.