DESIGN OF A LARGE-CAPACITY FLOW CALIBRATION/TEST FACILITY FOR NATURAL GAS FLOW METER

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Abstract

A new large gas flow calibration facility, which will be owned by Kogas (Korea Gas Corporation) and operated by Kogas and KRISS (Korea Research Institute of Standards and Science), has been designed. The facility employs the closed loop, master meter method. The flow range is 20–24 000 m^3/h, the pressure range is 10–50 bara, and the expected calibration and measurement capability (CMC) is 0.22–0.24% for all pressure ranges.

As of June 2013, the design of the new calibration facility is almost completed, except for the detailed design of the circulation compressor unit and the heat exchanger. It is scheduled to be finished by the end of 2015.

Introduction

Kogas has operated the natural gas flow calibration facility since 2002. The pressure of this calibration facility is 10 bara, the flow range is 100–10 000 m^3/h, and the CMC is 0.33 %. Up until 10 years ago, the orifice meter's share of all custody transfer flow meters (about 600 units) used by Kosgas was around 80 %, and the turbine meter's share was only 20 %. In addition, turbine flow meters were confined to metering stations with a supply gas pressure of 10 bara .

However, during the past decade, the number of turbine flow meters has rapidly increased, and the amount now accounts for 65% of all meters in operation. In addition, ultrasonic flow meters have been applied to newly established metering station, and the aged flow meters of existing metering station (pressure: 40–50 bara) have been replaced with ultrasonic flow meters since 2011.

In response to the increased use of turbine flow meters and ultrasonic meters, in 2011, Kogas decided to construct a new gas flow calibration facility (named as Kogas Flow Calibration Center, KFCC). The design of the facility is now almost completed, except for the detailed design of the circulating compressor and the heat exchanger. The KFCC is currently awaiting authorization and permission from the authorities concerned.

Design specifications

Table 1 shows the design specifications for KFCC. Its pressure and flow rate ranges are 10–50 bara and 20 – 24 000 m^3/h, respectively, to include all of the flow meters used in custody transfers of natural gas in Korea. The temperature and the pressure stability are 0.1°C and 0.005 bar, respectively, to prevent the calibration time frame from becoming excessively long due to the line-pack effect at low flow. The CMC is targeted at less than 0.24 % (k=2) to reflect customers' increasing demands for small CMC.

Design details

Design considerations

The basic design concept of KFCC has two objectives: one is to secure a maximum actual flow of 24 000 m^3/h regardless of seasons, and the other is to maintain a small CMC over pressure range 10 to 50 bara. The major

Table 1 Overview of the design specification of KFCC

Type	Closed loop, master meter method
Flow	20 － 24 000 m^3/h at working pressure
MUT size	100 － 600 mm
Medium	Natural gas (re-gasified LNG)
Traceability	Weighing system, sonic nozzle bank, and working standard
Pressure range	10 － 50 bara (freely adjustable)
Temperature range	Depending on the environment temperature, but the minimum and maximum gas temperature are 5 and 25 °C , respectively.
Pressure stability	0.005 bar (per 4 minutes)
Temperature stability	0.1 ℃ (per 4 minutes)
Number of test runs	4
Expected CMC (k=2)	0.22 － 0.24 %

factors that are considered in the design of the KFCC are shown below:

- No seasonal flow swing
- Minimizing pressure loss
- Small line-pack effect
- Reducing the uncertainty contribution from critical flow function (CFF) (to the overall uncertainty) to a negligible level
- Minimizing the traceability chain for working standards
- Monitoring the drift of working standards
- Reducing the uncertainty contribution of pressure measurements to a negligible level
- Ensuring the high stability of flowing temperature, which is related to the line-pack effect and temperature measurement errors
- Ensuring high stability of flowing pressure, which is related to the line-pack effect
- Minimizing the uncertainty of temperature measurement
- Minimizing the time to reach the steady-state of flowing gas temperature
- Obtaining agreement between the designed maximum flow and the real maximum flow through working standards
- Avoiding swirl
- Protecting working standards from material deposited on meter under test(MUT)
- Reducing vibration and noise in the standard runs
- Minimizing risk of low frequency oscillations and pulsations.
- Minimizing gas leakage
- Limiting pulse and time measurement errors to 0.01%
- Complying with the length of test runs for USM required by ISO

Layout

The piping configuration of KFCC was designed to ensure that gas volumes (dead volumes) between the sonic nozzle bank and the working standards and, between the working standards and the test meters are as small as possible. For this purpose, the nozzle bank, the working standards, and the test runs are divided into those for small flow rate and those for large flow rate. The sonic nozzle bank is closely adhered to the downstream headers of the two working standards. Therefore, the line-pack effect, which has an adverse effect on measurement accuracy, is small. What little line-pack effect remains will be corrected for by increasing calibration time frame.

To reduce pressure loss along the total circuit and to minimize the risk of low frequent oscillation effects and pulsations, the main circulation line is a 28" diameter pipe.

KFCC consists of seven parts:

- Gravimetric primary standard consisting of a weighing tank of 3 m^3, a gyro scale of full capacity 150 kg with resolution 2 g, disconnection unit, and diversion unit with closing-opening time less than 50 ms. Maximum diameter of throat of sonic nozzle calibrated by this system is 16 mm with uncertainty 0.15 % or less.
- Sonic nozzle bank consisting of 12 nozzle packages. In each package, one to four sonic nozzles are installed. Flow rate is from 10 to 4 000 m^3/h at interval flow of 10 m^3/h.
- Six identical large working standard runs, each consisting of one turbine meter working standard and one ultrasonic meter monitoring standard, qmax of 4 000 m^3/h. Total flow rate adds up theoretically to 24 000 m^3/h.
- Three small working standard runs, each consisting of one turbine meter working standard and one ultrasonic meter monitoring standard. Total flow rate adds up theoretically to 4 500 m^3/h.
- Two identical test runs for 4" to 10" meters.
- Two test runs for 12" to 24" meters.
- Variable speed drive, circulation compressor, flow fine tuning valves, sonic nozzles (small flow controller), filter and heat exchanger.

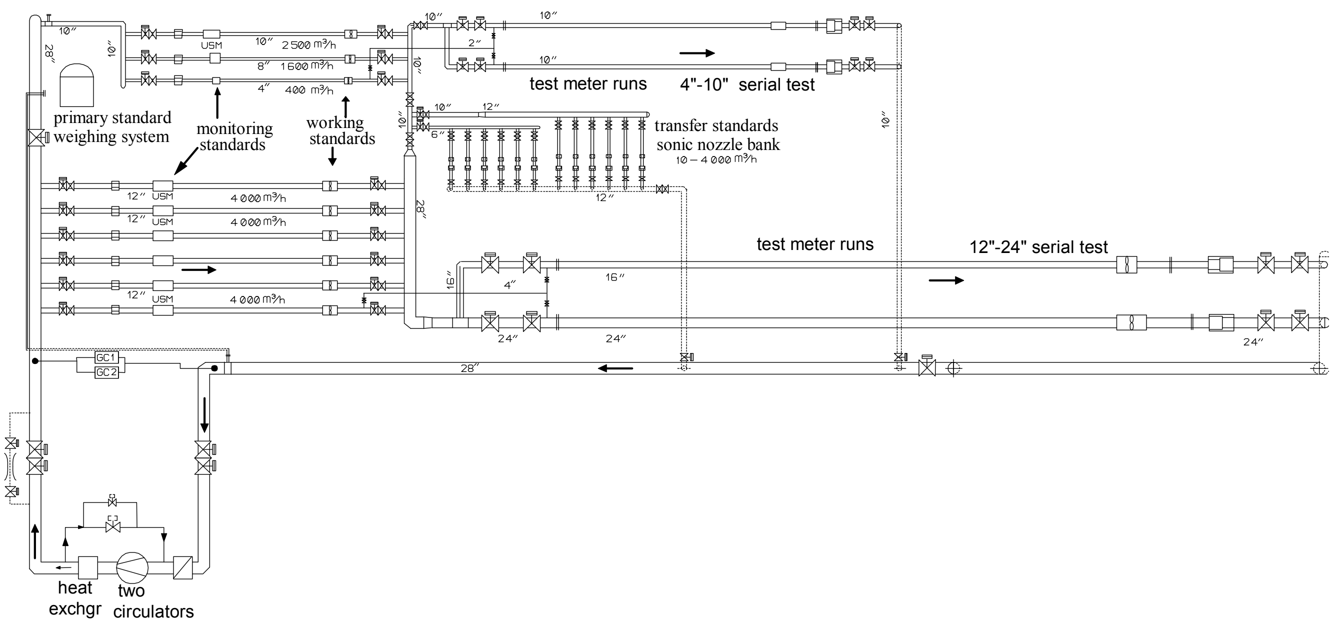

Fig. 1 Layout of KFCC

Table 2 The design specification of the circulators

Small size circulator (compressor)	
- Flow	20 – 4 000 m^3/h (at working pressure)
- Operating pressure	10 – 55 bara
- Optimum design flow	4 000 m^3/h
- Compression ratio	1.1
Large size circulator (compressor)	
- Flow	20 – 24 000 m^3/h (at working pressure)
- Operating pressure	10 – 50 bara
- Optimum design flow	10 000 m^3/h
- Compression ratio	1.04
Heat exchanger	
- Flow	20 – 24 000 m^3/h (at working pressure)
- Rate of heat exchange	10 °C (at 24 000 m^3/h, 50 bara)

Method of generating steady-state flow

The biggest problem with the current calibration facility is seasonal swings in the flow. Therefore, in designing the KFCC, the recirculating flow loop method was applied so that a maximum flow rate of 24 000 m^3/h could be maintained all year round.

To stably generate flow at ranges from 20 to 24 000 m^3/h, two compressors—a small compressor and a large compressor—are chosen. The small compressor's operating pressure, maximum flow rate, and maximum pressure ratio are set at 10 to 55 bar, 4 000 m^3/h, and 1.1, respectively, to optimize the calibration of the working standard with the sonic nozzle bank and the calibration of the nozzle with the primary standard. The large compressor's operating pressure, maximum flow rate, and maximum pressure ratio are set at 10 to 50 bar, 24 000 m^3/h, and 1.04, respectively, to optimize the calibration of the large flow meter.

To ensure that the flow remains stable, the turn-down ratio (TDR) (i.e., the maximum/minimum flow rate) of the compressor should be large. To this end, the compressors are equipped with variable speed drives, resulting in a TDR of around 3. As shown in Figure 1, two flow rate controllers (for fine controlling and main controlling) are installed parallel to each other to control low flow rates below the minimum flow rates of the compressors, and flow rates below 100 m^3/h are controlled by a sonic nozzle.

The heat exchanger has heat exchange rates of 10 °C at 50 bara and 24 000 m^3/h. These were achieved by considering only the temperature-adjusting ranges necessary to calibrate the sonic nozzle and to calibrate the working standard with the sonic nozzle bank.

Primary standard

The primary standard for gas flow in Korea is the air-gravimetric system (time-mass method) of KRISS. The sonic nozzle transfer standard may be calibrated against the primary standard for air. But in this case, as shown in formula (1), both the uncertainty in critical flow function (CFF) of air and that of natural gas contribute directly to the overall uncertainty of sonic nozzle flow rate. According to ISO 9300 [1] , the uncerainty in CFF for air is 0.1% and, it is 0.05% for natural gas when it is predicted by AGA 8-dc [2]. The uncertainty in predicting CFF of natural gas is closely related to the uncertainty in predicting the speed of sound. According to ISO 20765-1 [3] and GERG TM15 [4], the uncertainty in the speed of sound predicted by AGA8-dc is 0.2 % under the flow conditions at the throat of the nozzle. Therefore, in contrast to that reported by ISO 9300, the uncertainty in CFF for natural gas may be as high as 0.2 %.

However, the uncertainty contribution from CFF (to the overall uncertainty) may be reduced to a negligible level if the sonic nozzle is calibrated with the primary standard for natural gas and then applied to the natural gas calibration facility. As shown in formula (2), if flow condition when the nozzle is calibrated with the primary standard is almost the same as flow condition when standard flow is reproduced by sonic nozzle, the correlation coefficient between the uncertainties in CFFs calculated under the two conditions become close to 1. As a result, the uncertainty contributions from CFFs are almost offset. For this reason, KFCC introduces the primary standard for natural gas.

The gravimetric primary standard is designed almost in the same way as the KRISS's present air- gravimetric system [5], with the only difference being the volume of the weighing tank. This is increased from 2 m^3 to 3 m^3 because the medium is natural gas, which is lighter than air.

Sonic nozzle calibration with primary standard:

$$C_d = \frac{q_{m(weighing)}\sqrt{(R_u/M)\,T}}{C_*\,A_*\,p}$$

Reproducing the standard flow by the nozzle bank:

$$q_{m(nozzle)} = q_{m(weighing)}\frac{C_*^{'}}{C_*}\frac{p^{'}}{p}\sqrt{\frac{M^{'}}{M}\frac{T}{T^{'}}} \qquad (1)$$

$$r(u(C_*),u(C_*^{'}))\cong 1 \text{ if } p\cong p^{'},\ T\cong T^{'},\ X\cong X^{'} \qquad (2)$$

where C_d is the discharge coefficient of sonic nozzle, M is the molar mass, C_* is the critical flow function, A_* is the cross-sectional area of the throat of the nozzle, p is the absolute stagnation pressure at the nozzle inlet, T is the absolute stagnation temperature at the nozzle inlet, r is the correlation coefficient, X is the gas composition

Table 3 The design of the nozzle packages

The nozzle package no.	Nominal flow $q_{v,n}$ (m^3/h)	The diameter of the nozzle throat (mm)	number of nozzles installed
1	10	3.844	1
2	20	5.436	1
3	40	7.687	1
4	80	10.869	1
5	160	15.371	1
6	320	15.371	2
7	640	15.371	4
8	640	15.371	4
9	640	15.371	4
10	640	15.371	4
11	640	15.371	4
12	170	15.844	1
sum	4,000	-	28

vector, $u(C_*)$ is the uncertainty in CFF, and $q_{m(nozzle)}$ is the mass flow rate through the sonic nozzle.

Sonic nozzle bank

The nozzle calibration uncertainty of KFCC's primary standard is expected around 0.15%, except for the small sonic nozzle. Therefore, to achieve the KFCC's target CMC of 0.22 to 0.24%, the traceability chain from the primary standard to the working standard needs to be minimized. To this end, the maximum flow rate of the sonic nozzle bank is set at 4 000 m^3/h to ensure that all working standards (flow range 400–4 000 m^3/h) could be calibrated with the nozzle bank.

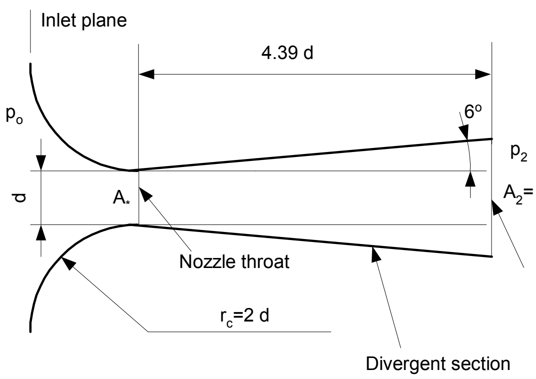

Fig. 2 Design of the Toroidal-throat Venturi nozzle

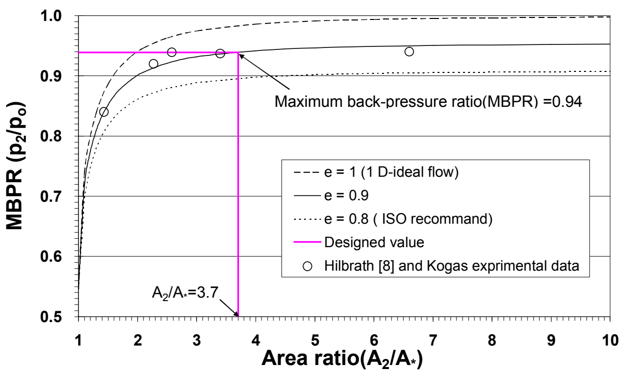

Fig. 3 Designed area ratio of Toroidal-throat Venturi nozzle

The sonic nozzle bank is comprised of 12 nozzle packages, and the flow rate of each package is determined using formula (3). Using this formula, flow rates from 10 m^3/h to 4 000 m^3/h may be created at an interval of 10 m^3/h.

$$q_{v,n} = 10 \cdot 2^{(n-1)} \qquad n = 1, 2, 3, \ldots \tag{3}$$

where n is the number of nozzle packages.

However, the diameter of the throat of the nozzle, which may be calibrated with uncertainty below 0.15% under KFCC's primary standard, is limited to 16 mm (more or less 170 m^3/h in flow rates). A flow rate of each package over 170 m^3/h is achieved by installing between two and four nozzles, as shown in Table 3 [6-7].

For the sonic nozzle, as the compression ratio of the commercially availble circulation compressor is around 1.1, a toroidal-throat type nozzle, which easily decreases pressure loss across the nozzle, is selected. The area ratio of the nozzle outlet—the ratio of the cross-sectional area of the nozzle outlet to that of the nozzle throat—is 3.7 to suppress the pressure loss across the nozzle to around 6 % (see Fig. 2, 3).

Monitoring standard

The calibration cycle of a working standards is generally one year. However, during the calibration cycle, the characteristics of the working standards may be changed, and a method to detect this is needed. When there is no method to monitor the characteristics of the working standards, the CMC of the facility may not be guaranteed. Therefore, in designing the KFCC, one multi-path ultrasonic meter is installed in the upstream of the each working standard run to continuously monitor the characteristics of the working standards. The repeatability and the reproducibility of ultrasonic meters are lower than those of turbine flow meters. However, the long-term stability of ultrasonic meters is excellent, and they do not produce pressure losses. Therefore, ultrasonic meter are very suitable as a monitoring standard.

Pressure measurement

Except when the sonic nozzle is calibrated using the gravimetric system, the pressure term in a volume flow formula of standard is always expressed in the form of a ratio such as p_1/p_2. If the correlation coefficient of uncertainties of p_1 and p_2 can be made to approximate 1, the uncertainty contribution from pressure measurements becomes very small. One way the uncertainty contribution can be reduced is to use one absolute pressure transmitter and multiple differential pressure transmitters. Using this method, the absolute pressure is measured at one location, and all the other pressures are determined by the differential pressure measurement relative to the absolute pressure reading.

However, KFCC are so extensive that the tubing lines of differential pressure transmitters are exceptionally long, giving rise to problems with measuring the differential pressures. Therefore, as shown in Figure 4, the differential pressure is measured at two stages: 1) between the location of the absolute pressure measurement and the downstream header (position 1, 2 in

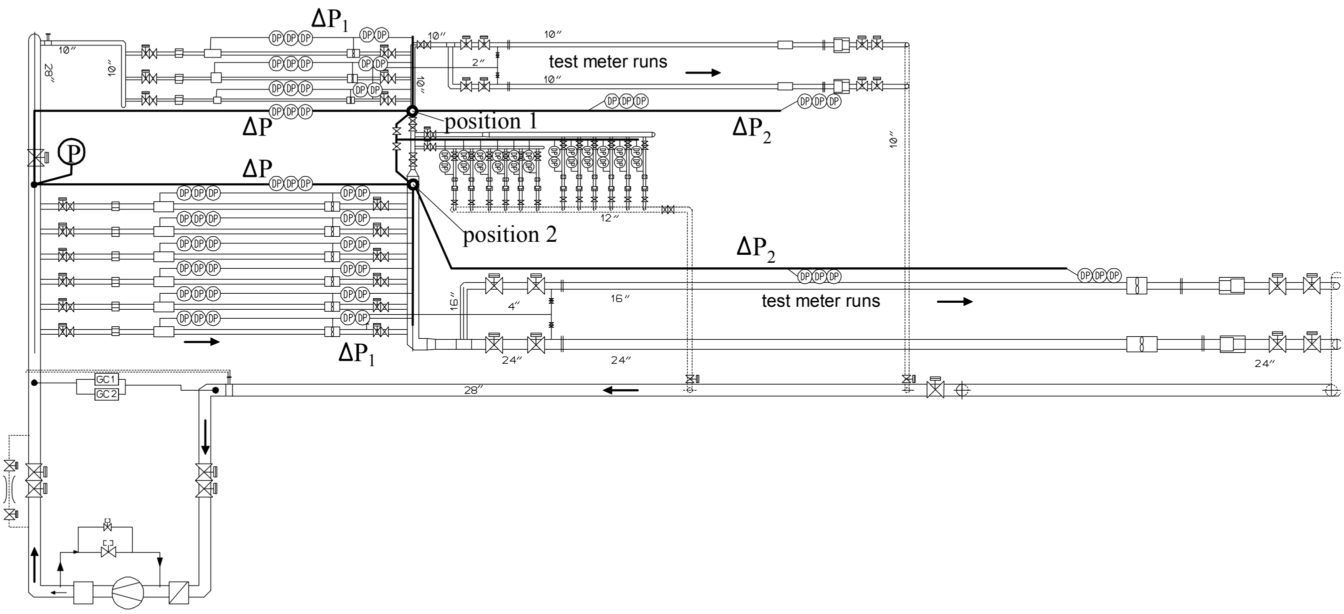

Fig. 4 The measuring locations of one absolute pressure and all differential pressures

Fig. 4) of the working standards and 2) between the downstream header and each measurement point.

One problem with this method of determining the pressure is that when there is pulsation within the flow or differential pressures at unstable flow location, there is a possibility of differential pressure error ('so-called gauge line error') occurring. Therefore, we have a plan to check this using a very accurate pressure transmitters.

Formula (4) shows the volume flow of the standard when the two-stage measurement method for differential pressure is used to determine the pressures of every measurement locations.

$$q_{v(std)} = C \frac{p + \Delta p + \Delta p_2}{p + \Delta p + \Delta p_1} \qquad (4)$$

The uncertainty of the absolute pressure transmitters is set at 0.05% FS (70 bara) because the relative sensitivity of the CFF to pressure is 0.013 and 0.11, respectively when the pressure is 10 bara and 50 bara.

Temperature measurement

One of the most difficult issues in gas flow calibration is to measure the representative bulk temperature of the flowing gas. Although the gas temperature in a pipe is measured with a very accruate temperature transmitter (including a sensor), it is very difficult to measure the temperature with an uncertainty of 0.1°C.

The difficulty is due to the delayed response of the resistant temperature detector(RTD) and the thermo-well and, the heat transfer from the ambient environment to the RTD and the well. In addition, the temperature of the gas at a low flow in large-diameter pipes has been shown to be different between the upper part and the lower part of the pipe, making it more difficult to measure the representative bulk temperature of the flowing gas[9].

To resolve this problem, the temperature difference between the gas in pipe and the environment and, the gas temperature changes during calibration time frame should be small. In designing KFCC, a temperature controller (heat exchanger) is installed on the trailing edge of its circulation compressor to ensure that the temperature difference between the gas in pipe and the calibration room is less than 5°C, and the temperature stability is less than or equal to 0.1°C. All the pipes are insulated with thick insulation (10 cm) (including the thermo-well but not the flow meter) to reduce the heat transfer from the environment to the pipes.

Conclusion

A new large gas flow calibraion facility (KFCC) has been designed. To produce a maximum flow rate of 24 000 m^3/h all year round, the recirculating flow loop method is selected, and apparatuses and equipment are designed to generating stable flow ranging from 20 to 24 000 m^3/h. The piping configuation is designed to minimize dead volumes. To reduce the uncertinty contribution of CFFs to a negligible level, the primary standard for natural gas is introduced. The maximal flow rate of the sonic nozzle bank, which is the transfer standard, is set at 4 000 m^3/h, thereby drastically decre-asing the traceability chain from the primary standard to the working standards. Individual sonic nozzles is designed to reduce the pressure loss accross the nozzle to only 6 % in consideration of the compression ratio 1.1 of the commercially availalbe circulation compressor. To reduce the uncertainty contribution caused by pressure measurements to a negligible level, all pressures are determined by addding one abolute pressure and relevant differential pressures which are measured at two-stage measuremt. To measure the representative bulk temperature of the flowing gas, a temperature controller is installed on the trailing edge of the circulating compressor and all sections of the pipes are insulated. An ultrasonic flow meter is installed in the upstream of each working standard run to monitor drift in the working standards. As of June 2013, the design of the KFCC is completed, except for detailed aspects of the circulating compressor and the heat exchanger. It is expected to be finished at the end of 2015.

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