Establishment of a standard supply system for large gas flow rate to meet the requirements of markets

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Key words

JCSS, ISO/IEC 17025, expansion of calibration range, traceability, uncertainty, gas flowmeter, sonic nozzle, critical nozzle, pressurized calibration, large gas flow rate

Throughout the world, flow measurement is important for energy management and energy trading, but Japan has lagged in recognizing the importance of gas flow traceability as compared with the traceability of other physical quantities. One causal factor, among others, was that the range of services undertaken by the registered service provider, the Japan Calibration Service System (JCSS), was limited. The azbil Group, too, had a need to enhance the standard supply system for large flow rates. Against this background, the Azbil Kimmon Calibration Service Center has expanded its calibration range capabilities since becoming a JCSS registered service provider for gas flowmeters in 2003. Currently, it provides JCSS calibration in a calibration range that cannot be supplied by the National Measurement Standards. This paper describes how that is done.

1. Introduction

1.1 Overview of the Calibration Service Center

The Azbil Kimmon Calibration Service Center is a registered JCSS service provider that calibrates critical nozzles and many different gas flowmeters used for gas flow measurement.

Since becoming a registered JCSS service provider for medium gas flow rates (50–1,000 m^3/h) in 2003, the Center has provided calibration services with the ability to calibrate actual flows under pressure that mimic pressure conditions actually used in the field. In 2007, we expanded our flow rate range to flow rates as low as 6 m^3/h. In 2013, we launched field calibration (at customers' sites) for gas flow rates for the first time in Japan (according to our research as of July 2013). In 2016, we again expanded our flow rate range to 4,000 m^3/h, which is the highest in Japan (according to our research as of September 2016), far exceeding the national measurement standard's high limit of 1,000 m^3/h. Additionally, we expanded the calibration pressure range to 0.98 MPa in December 2021. As a result, we can now provide JCSS calibration over a range that covers approximately 40,000 m^3/h at standard conditions (0 °C, 1 atm).

In addition, we periodically calibrate the references and standard instruments used in inspection equipment at the azbil Group's manufacturing sites, including gas flowmeters and venturi valves, to ensure traceability, taking advantage of our qualifications as a registered JCSS service provider.

Figure 1 gives an overview of the traceability system for gas flow rates provided by the Center. As a registered JCSS service provider, the Center has working standard flowmeters in addition to critical nozzles, which are secondary measurement standards and working standards (standard instruments for work). The Center ensures traceability by relating general measurement instruments with the national measurement standards through an unbroken calibration chain.

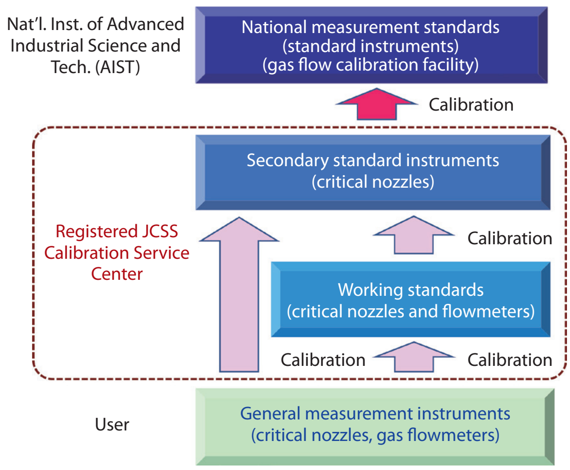

Fig. 1. Traceability system

1.2 Calibration Service Center facilities

The high-flow calibration room where flowmeters are calibrated (fig. 2) is a very large facility with a size of 53 m × 13 m and approx. 130 m of pipes. Accordingly, the pipes between the flowmeter to be calibrated, the standard nozzle, and the standard flowmeters take up a lot of space and their heat capacity affects the fluid temperature. Therefore, it is important for the room temperature to be controlled to ±0.5 °C of the set temperature.

Fig. 2. High-flow calibration room

Because the room has 12 standard nozzles and 5 standard flowmeters as permanent equipment for the gas flow rate standards, the standard instrument that best suits the test conditions for calibration can be selected. Figure 3 is a photograph of the standard nozzle line.

Fig. 3. Standard nozzle line

Table 1 shows the JCSS calibration ranges for permanent equipment (for calibration at the Center) and for field calibration (outside the Center).

Table 1. JCSS calibration range

	Pressure range (MPa)	Flow rate range (m^3/h)	Expanded uncertainty (%)
Permanent equipment	0.09–0.98	6–4000	0.25–0.54
Field calibration	0.09–0.115	6–4000	0.29–0.40

2. Overview of gas flow rate calibration

2.1 Gas flow rate measurement

Generally speaking, there are two gas flow rate measurement methods. One method is to measure the volume of gas that flows per second. This is the volumetric flow rate, and the units are m^3/s or m^3/h. Alternatively, the mass of gas that flows per second can be measured. This is the mass flow rate and the unit is kg/s. Most flowmeters measure the volumetric flow rate. By calculating the density of the gas based on the measured temperature, pressure, and humidity, one can convert between the mass flow rate and the volumetric flow rate. (Volumetric flow rate [m^3/s] = Mass flow rate [kg/s] ÷ Density [kg/m^3])

During measurement, it must be remembered that the volume of a gas readily changes because gas is more compressible than liquid. This means that the flow rate, temperature, and pressure must be stabilized to eliminate the effects of expansion and contraction. This is very difficult to do because these factors all affect one another. Our method of generating a stable gas flow rate for precise measurement is to use a critical nozzle.

2.2 Characteristics of the critical nozzle

The critical nozzle is used to keep the gas flow rate in the pipe constant in order to perform a high-precision gas flow rate calibration.

The critical nozzle contains a constriction as shown in figure 4. When the differential pressure between the upstream side and the downstream side exceeds a certain value, the speed of the gas flow passing through the throat section reaches the speed of sound and does not change further. If the temperature is constant, the speed of sound is a fixed value. Therefore, the volumetric flow rate can be determined by multiplying the speed of sound by the known cross-sectional area of the throat. This characteristic enables the generation of a stable volumetric flow rate. Although the flow that passes through the critical nozzle has a constant speed as described above, the actual flow rate is lower than the theoretical rate. This is because the effective cross-sectional area of the throat is reduced by the presence of a boundary layer and other factors. Therefore, calibrating the critical nozzle means determining the discharge coefficient (Cd) to correct for the difference between the theoretical flow rate (Q_{theo}) and the actual flow rate (Q_{meas}).

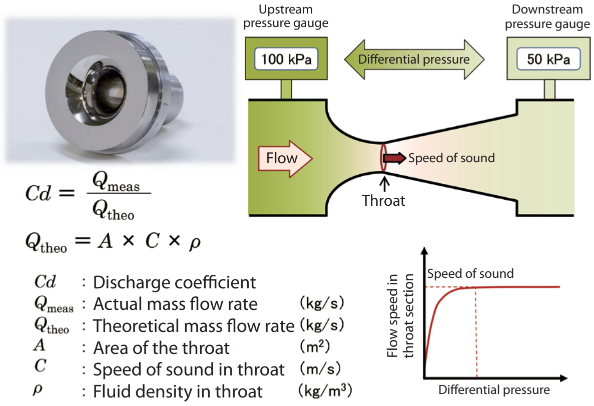

Fig. 4. Illustration of the critical nozzle

For higher flow rates, the flow rate can be doubled or tripled by using critical nozzles in parallel to maintain high precision. The shape of the critical nozzles used as standards at the Center conforms to the toroidal throat venturi nozzle described in JIS Z 8767. The calibration range can be increased up to 1,000 m^3/h according to the Technical Requirements Application Guidelines [1] published by the National Institute of Technology and Evaluation (NITE).

2.3 Gas flow rate calibration methods

Generally speaking, there are two gas flow rate calibration methods. The flowmeter being calibrated can measure a precise flow rate generated by a standard nozzle (calibration method 1) or the standard flowmeter and the flowmeter being calibrated can be compared with regard to a flow rate adjusted by the blower (calibration method 2).

Figure 5 is a schematic of calibration method 1. This method of generating a highly precise stable flow rate for calibration takes advantage of the characteristics of the standard nozzle to keep the volumetric flow rate constant in the pipe while the temperature is constant. The standard nozzle and the flowmeter to be calibrated are installed in series and connected to a blower that generates a differential pressure between the upstream and downstream sides of the standard nozzle to bring its flow speed to the speed of sound. Then, once the temperature and pressure in the closed pipe (a closed loop) have stabilized, the flow rate values Q_N and Q_1 are compared. This is the most precise calibration method used to calibrate standard flowmeters at the Center. The calibration and measurement capability of this method is represented with an expanded uncertainty of 0.25 to 0.29 % (confidence level of approx. 95 %).

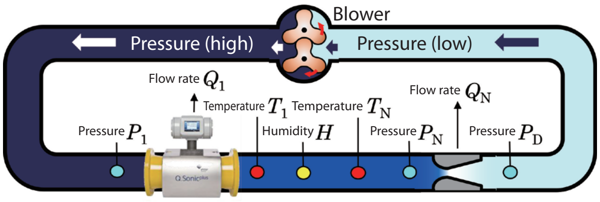

Fig. 5. Gas flow rate calibration with a standard nozzle (method #1)

Figure 6 is a schematic of calibration method 2. This is a method of generating a gas flow in a closed loop by installing the standard flowmeter and the flowmeter to be calibrated in series, using a blower to generate a flow rate, and then comparing the flow rate values Q_0 and Q_1 when the flow rate, temperature, and pressure are stable.

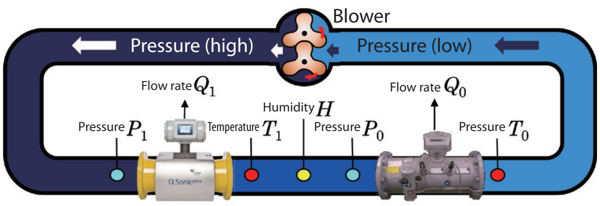

Fig. 6. Gas flow rate calibration with a standard flowmeter (method #2)

The volumetric flow rate depends on the temperature and pressure of the gas. Therefore, even a slight difference in temperature or pressure between the flowmeter to be calibrated and the standard flowmeter makes the calibration inaccurate. It is therefore necessary to correct the flow rate of the standard flowmeter to reflect the conditions.

Assuming that the volumetric flow rate of the standard flowmeter after correction is Q, the volumetric flow rate of the standard flowmeter is Q_0, the pressure of the standard flowmeter is P_0, the temperature of the standard flowmeter is T_0, the pressure of the flowmeter to be calibrated is P_1, and the temperature of the flowmeter to be calibrated is T_1, the following compensation formula holds according to the combined gas law.

$$Q = Q_0 \times \frac{P_0}{T_0} \times \frac{T_1}{P_1} \qquad \text{Equation (1)}$$

An accurate calibration can be performed by comparing the volumetric flow rate of the corrected standard flowmeter (Q) and that of the flowmeter being calibrated (Q_1). Calibration method 2, which uses the standard flowmeter, is more uncertain than calibration method 1, which uses the standard nozzle. However, with calibration method 2, the flow rate can be freely adjusted between a low flow rate and a high flow rate. The calibration range of JCSS covers pressures from 0.09 to 0.98 MPa and flow rates of 6 to 4,000 m³/h. The calibration and measurement capability in this range is represented with an expanded uncertainty of 0.29 to 0.54 % (confidence level of approx. 95 %).

3. Expansion of the gas flow rate calibration range

3.1 Expansion of the flow rate range above 1,000 m³/h

Back in 2016, the demand for calibration of flowmeters that could measure high flow rates was increasing as the scale of buildings and plants expanded. Because the highest calibration flow rate covered by JCSS at the time (1,000 m³/h) was insufficient, there was an urgent need to increase the limit, in part to maintain traceability in the azbil Group. On the other hand, to maintain traceability, we also had to avoid a large-scale facility alteration that would put calibration on hold for a long time. Alterations had to be limited enough to allow completion within a short period by leveraging the existing facilities. Under these circumstances, we increased the flow rate range as outlined in figure 7.

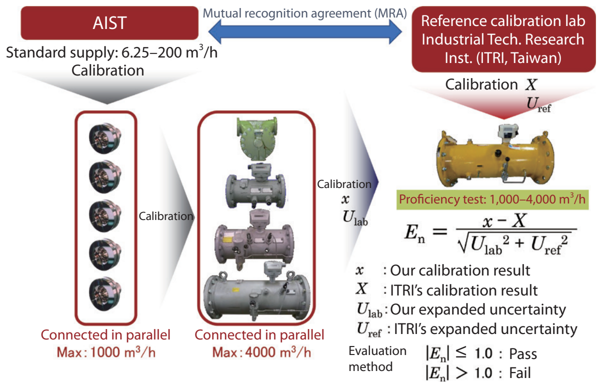

Fig. 7. Expansion of the flow rate

First, we calibrated standard flowmeters up to 1,000 m³/h using five standard 200 m³/h nozzles in parallel. This method is authorized by the Technical Requirements Application Guidelines published by NITE. Next, we built up calibration to 4,000 m³/h by using multiple standard flowmeters in parallel. Ideally, the flow rate can be easily quadrupled by using four standard flowmeters in parallel with the same bore and pipe shape. However, to make the most effective use of the existing equipment we combined different existing standard flowmeters (80-A CVM300, 150-A G650, 200-A G1000, and 300-A G2500) to reach 4,000 m³/h.

It is possible for a facility to prove that it has the proper technical competences as a registered JCSS service provider by passing a proficiency test with the National Institute of Advanced Industrial Science and Technology (AIST), which it provides up to 1,000 m³/h. The proficiency test is a technical competence confirmation test where both parties calibrate the same flowmeter and compare the calibration results. However, we had to implement our test with an overseas calibration laboratory with which we had a mutual recognition agreement for the above 1,000 m³/h range because no calibration laboratory in Japan could conduct a test at that flow rate.

At the time, although we quadrupled the 1,000 m³/h flow rate, the validity of our calibration result was only self-declared based on our evaluations, so whether the flowmeter would pass the proficiency test was uncertain. Also, in terms of time and cost it is difficult to send a flowmeter to an overseas calibration laboratory for a proficiency test, so we repeatedly validated the flowmeter beforehand. For the test, we selected a turbine flowmeter that had been recognized as a standard flowmeter and had demonstrated long-term stability and great flow rate characteristics. Then, we took as many precautionary measures as possible based on our accumulated insights and expertise, and carefully estimated the flowmeter's behavior in the flow rate region above 1,000 m³/h. We estimated the optimal flow volume that would sufficiently reduce variations among the standard flowmeters used in parallel, adjusted the division ratio to ensure a flow rate that each flowmeter could reliably measure even if the overall flow rate changed, and stabilized the overall flow rate of the standard flowmeters used in parallel. As a result, we succeeded in achieving calibration results with high reproducibility in a wide range of flow rates (fig. 8).

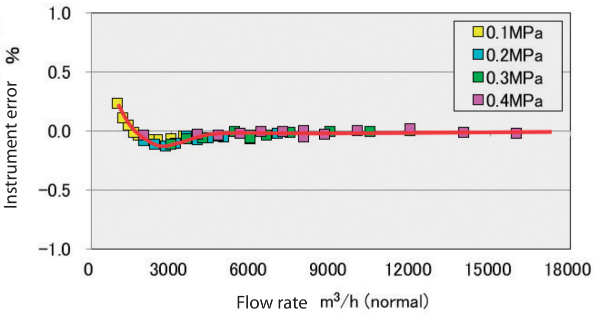

Fig. 8. Evaluation of flow rate range expansion

With this result, we sent the calibrated flowmeter to the Industrial Technology Research Institute (ITRI), a calibration laboratory in Taiwan with which we had a mutual recognition agreement, for the proficiency test. The result was $|En| \leq 1.0$, the En number being the acceptance criterion. In other words, as of September 2016 we were authorized to perform JCSS calibration for a maximum pressure of 0.4 MPa and a maximum flow rate of 4,000 m³/h. This made us the only registered JCSS service provider in Japan that can calibrate flow rates above 1,000 m³/h, supplying a standard not covered by the national measurement standards.

3.2 Expansion of the pressure range to above 0.4 MPa

Although we had expanded our JCSS calibration range to pressures of 0.09–0.4 MPa and flow rates of 6–4000 m³/h before 2019, *Measuring methods of quantity of natural gas* (JIS M 8010) was revised in 2020, adding ultrasonic flowmeters to the standard and making them usable in addition to the conventional orifice flowmeters, volumetric flowmeters, and vortex flowmeters. We therefore expected that it would be increasingly necessary to calibrate ultrasonic flowmeters. However, because the maximum calibration pressure covered by JCSS at that time (0.4 MPa) was insufficient as an upper limit, there was an urgent need to expand the supported pressure range. In this context, we expanded our pressure range to above 0.4 MPa as shown in figure 9.

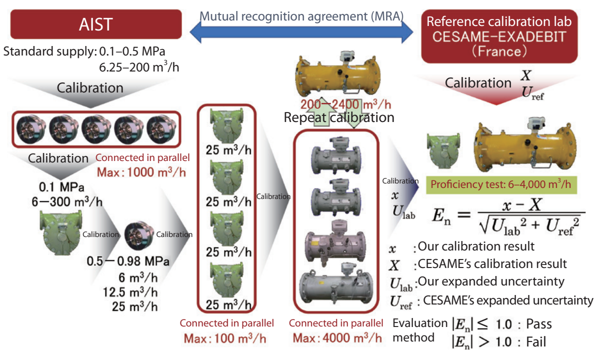

Fig. 9. Expansion of the flow rate above 0.4 MPa

The challenge we faced was to find a standard supply method that ensured traceability and would allow us to quickly complete the expansion while making the most of our existing facilities. Our secondary standard instruments are calibrated to the national measurement standards in the 0.1–0.5 MPa pressure range. Because traceability was not assured at pressures above 0.5 MPa, we had to calibrate the instrument up to the desired pressure range and prove that the calibration result was correct through a proficiency test. Therefore, we calibrated the target nozzle (a secondary standard instrument) in the pressure range between 0.5 and 0.98 MPa using the standard flowmeter. Figure 10 is a schematic of the calibration.

We installed in series a 10 m³ surge tank at 2 MPa of pressure, a pressure regulating valve, the nozzle to be calibrated, and the standard flowmeter calibrated according to JCSS at atmospheric pressure, controlled the pressure upstream of the nozzle being calibrated at an arbitrary pressure (0.5 to 0.98 MPa), and generated a constant flow velocity. The gas expands when the pressure reaches atmospheric pressure on the downstream side of the nozzle being calibrated, causing the flow rate to increase by the pressure ratio. We measure this flow rate with the standard flowmeter to calibrate the target nozzle. For example, if the pressure upstream of the 25 m³/h nozzle being calibrated (fig. 10) is 0.5 MPa, the flow rate is multiplied by a factor of 5, reaching around 125 m³/h at atmospheric pressure (0.1 MPa). The discharge coefficient is determined based on the ratio of the theoretical flow rate of the nozzle to be calibrated and the actual flow rate obtained from the standard flowmeter. The discharge coefficient is a function of the Reynolds number, which indicates the state of the flow. Because the Reynolds number is proportional to density as long as the flow speed remains the same, the Reynolds number can be changed by changing the pressure upstream of the nozzle being calibrated. In other words, the relationship between the discharge coefficient and the Reynolds number can be determined by calibrating at several flow rate points.

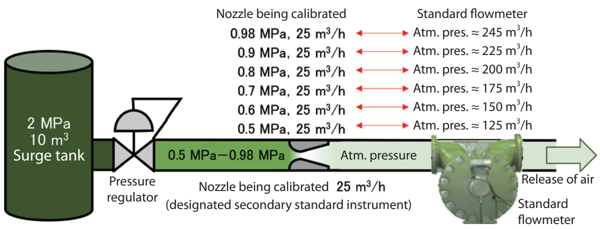

Fig. 10. Standard supply method above 0.5 MPa

In order to build up flow rates to expand the pressure range to the desired highest flow rate of 4,000 m³/h, we needed to calibrate standard nozzles having as high a flow rate as possible as the flow rate standards. We selected 6.25, 12.5, and 25 m³/h, at which sufficient measurement time could be ensured by maintaining a constant pressure of 2 MPa in the 10 m³ surge tank. Figure 11 shows the calibration result at 25 m³/h. The relationship between the discharge coefficient and the Reynolds number obtained from the calibration result closely matches the extrapolated value calculated from the relational expression in the range where the nozzle can be used as the secondary standard instrument (0.1–0.5 MPa).

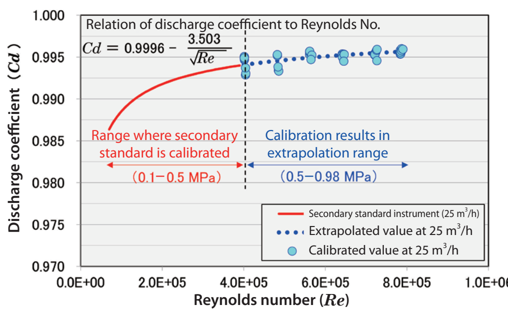

Fig. 11. Extrapolated value calibration result for a secondary standard instrument

We then calibrated the standard flowmeter on the basis of which we would build up calibration to 4,000 m³/h in the pressure range above 0.4 MPa by using three standard nozzles calibrated to 0.98 MPa. Figure 12 is a schematic of the calibration.

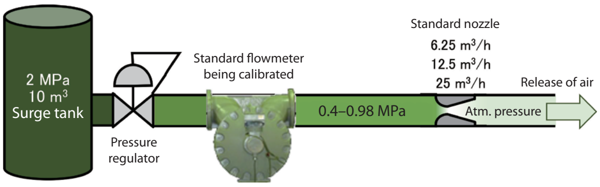

Fig. 12. Calibration method using standard nozzles above 0.4 MPa

We installed in series the surge tank at 2 MPa, the pressure regulating valve, the flowmeter to be calibrated (standard flowmeter), and the standard nozzles, maintained the upstream pressure of the standard nozzles at an arbitrary pressure, and compared it with the flowmeter to be calibrated at a constant flow velocity for calibration.

To do a build-up calibration to 4,000 m³/h, we installed four standard flowmeters calibrated with the calibration method in figure 12 in parallel on a closed loop line, then calibrated three 100 m³/h standard flowmeters using four 25 m³/h standard flowmeters (step 1 in figure 13), and then calibrated 300 m³/h standard flowmeters with the three 100 m³/h standard flowmeters (step 2 in figure 13). Through repetition in this way, we built up calibration at various flow rates to 4,000 m³/h (fig. 13).

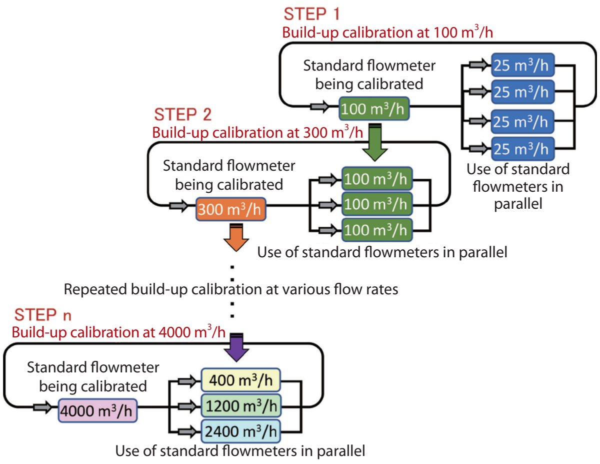

Fig. 13. Concept of build-up calibration

Because no calibration laboratories in Japan supported the proficiency test, we sent calibrated flowmeters to CESAME-EXADEBIT, a calibration laboratory in France with which we had a mutual recognition agreement for the proficiency test, and obtained a positive result (fig. 14). The result was $|En| \leq 1.0$, the En number being the acceptance criterion. In other words, as of December 2021 we were authorized to perform JCSS calibration for a maximum pressure of 0.98 MPa and a maximum flow rate of 4,000 m³/h. This allowed us to further expand our calibration range to a level not covered by the national measurement standards.

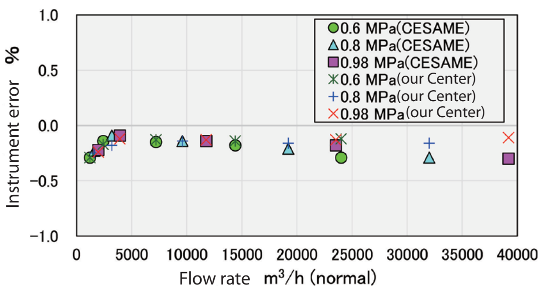

Fig. 14. Proficiency test result

4. Conclusion

Since becoming a registered JCSS service provider for gas flow rates, the Center has made various attempts to expand its calibration range. As a result, we are now the only registered JCSS service provider that can provide gas flow rate calibration at the highest flow rates and pressures in Japan. We intend to continue making new attempts to satisfy a wide range of customers' needs by improving our calibration capabilities and calibration technology.

Reference

[1] International Accreditation Japan (National Institute of Technology and Evaluation), "JCT20810 technical requirements application guidelines (flow rate and flow velocity, gas flowmeters)" (in Japanese), available at https://www.nite.go.jp/data/000001459.pdf.

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