Development of primary standard for hydrocarbon flow and traceability system of measurement in Japan

— Approach to construction of an effective and reliable traceability system —

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It is of importance to establish the hydrocarbon flow standard which acts as the basis for vast dealings and taxation for hydrocarbons, enforcement of the policy on energy savings and high quality management of industries. As a result of investigation into calibration methods, reliability, and effectiveness, the specification of the national primary standard and the traceability system for hydrocarbon flow in Japan was designed. We took the technical initiative in establishing the traceability system using JCSS (Japan Calibration Service System) as basis of the national primary standard in the limited region of flow rates and various kinds of liquids. The national primary standard of high accuracy and safety has been developed. This project was evaluated through verification of international consistency by way of international key comparisons.

***Keywords* :** Flow rate, uncertainty, measurement, traceability, national primary standard

1 Introduction

The measurement of hydrocarbon flow is important as a basis of quantity for the trade and taxation of petroleum products, and for the production control at the petrochemical plants. The accuracy of the flowmeter used in flow measurement is influenced by the property of liquids, the condition of flowmeter installation, and the condition of the flow. Therefore, to operate the flowmeter in a condition that ensures high accuracy, it is necessary to conduct a calibration where the flowmeter is adjusted to indicate the correct value or to calculate the correction value by flowing the liquids in the flowmeter at a standard flow rate and comparing the standard flow rate and the readings of the flowmeter. Also, regular calibration is necessary to guarantee the performance of the flowmeter currently used.

Until now, strict quality control for the hydrocarbon flowmeter used in trade was practiced according to the law, but with the advances in measurement technology, there is a rising demand for the ability to conduct voluntary advanced quality control using high accuracy flowmeters. There are demands for accuracy, low cost, and coverage of varied calibration subjects, including the demand for establishment of a highly accurate flow standard for diverse petroleum products, as well as the demand for international integrity. However, in flow measurements, National Institute of Advanced Industrial Science and Technology (AIST) possessed the national primary standards for water and air flow only. There was no national primary standard for hydrocarbon flow, and the demands of industry could not be met. Therefore, AIST newly constructed the national primary standard facility for hydrocarbon flow in 2001, and after conducting the uncertainty evaluation and building up the quality system, it was designated as the specific standard for hydrocarbon flow according to the Measurement Law of Japan in 2005. Since the range of the national primary standard for hydrocarbon flow was limited, under a government-supported research project and with cooperation from private petroleum companies, the technologies to expand the range of liquid types and flow range were developed at the level of secondary standards that were in possession of the calibration laboratories. This completed the traceability system of measurement in Japan, and the Japan Calibration Standard Service (JCSS) for hydrocarbon flow was established utilizing the capabilities of the private companies.

2 Social objective for creating the hydrocarbon flow standard

The annual petroleum trade in Japan is approximately 29 trillion yen[1], and the merchandise value is said to be several times that amount. Tens of thousands of hydrocarbon flowmeters that provide the basis for the quantity entered on the trading certificates are in operation in the petrochemical complexes throughout Japan. Accurate measurement using the hydrocarbon flowmeter is in demand by industry and society. The range of flow measurement is mostly 1~1000 m^3/h, and particularly the measurement of several hundred m^3/h used for tanker truck is most frequently used. There are many types of petroleum, including gasoline, kerosene, light oil, heavy oil, and crude oil. Positive displacement flowmeter and turbine flowmeter are

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used most frequently. Currently, the precision demanded of flowmeters is very strict, and the level of uncertainty required for hydrocarbon flow standard is high.

Until now, the standard tested (accepted or rejected) by AIST was used to test many hydrocarbon flowmeters. This standard is a device used by the prefectural inspection agencies to test the small-diameter hydrocarbon flowmeters for commercial use, to prevent disadvantage to the general consumers of Japan, that is, to guarantee fairness. In a system using this standard, the public institute tests a certain function using an appropriate method, and this is expected to greatly reduce the cost of managing the measurement device in society as a whole.

On the other hand, with the advance in measurement technology, there has been a recent increase in the demand for highly accurate flow measurement exceeding the range of this system, as well as for measurement of more types of petroleum products and wider flow range, so that the companies can perform voluntary highly accurate quality control on their own. Moreover, with the internationalization of economic and production activities, the international trade of the Japanese petroleum products is increasing, and it is mandatory to guarantee the integrity of the international flow measurement values. Therefore, there is a demand to provide a standard with international integrity to the users and to also offer choices of maintaining the metrological traceability in accordance to the international system. However, there was no calibration facility that could be used as the national primary standard of hydrocarbon flow, and the work of setting up the flow rate using physical quantities such as mass, volume, time, density, temperature, pressure, and others were left to the flowmeter manufacturers and users. Also, since the definition of metrological traceability was scientifically established, the metrological traceability could no longer be maintained with the conventional system that did not address uncertainty.

The petroleum tax on the domestic trade of petroleum products is very large at about 6 trillion yen annually[1], and measurement is socially very important. Therefore, the tax office meter (hydrocarbon flowmeter) must have a highly accurate control of instrument error (deviation from standard value) within ± 0.2 %[2]. Currently, several tens of thousands of custody meters are said to be in operation at the petrochemical facilities throughout Japan, as mentioned before, and rationalization is highly in demand since great cost and human resources are needed to maintain precision.

3 Technological objective for creating the hydrocarbon flow standard

Some people may misunderstand that to measure the hydrocarbon flow or the quantity (volume or mass) of the petroleum products, the flowmeter can be easily calibrated with high accuracy by calibrating the volume tank (volume prover) or the weighing scale (mass comparator) with high accuracy because they are parts of the calibration device. Although the uncertainty of the volume or mass is part of the source of calibration uncertainty, there are several other sources that significantly affect the calibration uncertainty such as: temperature, pressure, and density measurements; leakage of test liquid from the branch of the connecting pipe used in calibration; and the effect of the flow velocity distribution and flow velocity fluctuations in the pipes. In practice, these factors may turn out to be dominant in the overall calibration uncertainty in many cases, and it is necessary to evaluate these uncertainties. In the actual measurements using the flowmeter, there are many cases where the conditions in which the flowmeter was calibrated and the condition in which it is actually used are different. Therefore, it is necessary to evaluate the effects of the pipe formation, temperature, pressure, properties of the test liquid, and others on the flowmeter characteristic, and to estimate the measurement uncertainty in the actual measurement condition. Since it is impossible to conduct these evaluations for all measurement conditions due to cost and time restraints, it is necessary to pinpoint the source of uncertainty according to the requirements and to estimate the uncertainty efficiently.

In petroleum products, liquid expansion of about 0.1 % is seen every 1 ºC. However, in the petroleum products trade, the measured volume is used as is without necessary corrections according to the temperature of the measurement environment. On the other hand, the petroleum products, which are energy resources, technically should be traded by mass, and it is necessary to supply the flow standard as mass flow in addition to volume flow for the new national flow standard.

4 Investigation of method for the provision of hydrocarbon flow standard

4.1 Provision of hydrocarbon flow standard

In the actual on-site measurement of the hydrocarbon flow, it is necessary to conduct the flow measurements with minimum uncertainty using minimum resources (cost, time, etc.), and the reliability must be guaranteed. Since the flow standard is set up using other physical quantities such as mass, volume, time, density, temperature, and pressure, it is necessary to clarify "who and where" the set up of the standard flow from other standards will be done in providing the national standard. Since there was no calibration device for hydrocarbon flow that could be used as a national standard in Japan, the work of setting up the flow rate from other physical quantities was left to the flowmeter manufacturers and users, and the reliability was unknown. The provision of the flow standard can be categorized roughly into the following three:

(1) Method where the NMI provides the flow standard

If the national metrology institute (NMI) sets up the flow standard as a national standard, it will be highly reliable, and an ideal traceability system could be constructed. However, there is a diversity of petroleum products and the range of flow rate is extremely wide, and it is not realistic to create and provide the flow standards for all liquid types and flow ranges used in society. Even if all flow standards with small uncertainties at a national standard level can be provided to fulfill the diverse flow measurement conditions actually used, such systems will be extremely expensive. As a result, the user who pursues a balance of uncertainty and cost will most likely select the service of the calibration laboratory described in (2).

(2) Method where the calibration lab calibrates the flowmeter using the standards for other physical quantities (such as volume)

This is a method where the calibration laboratory conducts the calibration of flowmeters using not the national flow standard, but instead, for example, the mass and density standards. In this method, even in a case where the calibration lab uses the mass and density standards, if the calibration of the flowmeter is done using inappropriate combinations, it may lead to problems such as missing an important correction value or underestimating the uncertainty. Also, establishing the technology to achieve small uncertainty is a great burden on individual calibration labs, and it may result in increased social cost of measurement control. It is also difficult to guarantee reliability, and this may be a disadvantage to the users. On the other hand, this method is highly expandable, and the calibration lab can adapt this method to diverse liquid types and flow rates.

(3) Method of using the flow standard provided by overseas institutes

Although the flow standard is employed in many countries, this method will force dependence on foreign standards, and it is difficult to achieve small uncertainty required in Japan. Also, the flowmeter must be transported abroad for calibration, and the reliability decreases in that process.

Figure 1 shows the outline of the representative standard service systems for hydrocarbon flow. In Europe, basically method (1) is employed, and in ranges where the flow standard is not supplied, the approved institution verifies the adequacy of the set-up of flow rates using method (2). To guarantee the performance capacity of the calibration lab, the international standard (ISO17025) requires a skill test, but in several cases this is not conducted appropriately and this is becoming a problem. Therefore, the expansion of the provided range of flow standards is in progress, such as constructing the calibration facility at the level of the national standard for hydrocarbon high-flow (maximum flow of 5000 m^3/h).

In the United States, method (2) is mainly employed, and the calibration labs set up the flow rates according to the principle of market mechanism. The accreditation of the calibration lab is done by the accreditation authorities. However, there are some labs that are accredited for technologically inadequate uncertainty, where they claim uncertainty much smaller than the national standard with the least uncertainty in the world. To address this issue, the United States has a law to collect a certain ratio of the sales of petroleum products for the American Petroleum Institute (API), and this fund is used to establish and enforce the technical standard (API standard) for guaranteeing the reliability of flowmeter calibration. There is effort for maintaining the reliability of the standard at a civilian level, without depending on the government agencies, but aiming for a small government. For Japan that does not have such a system, it is probably difficult to introduce method (2) directly.

Since there was no national standard for hydrocarbon flow in Japan until now, method (2) was employed using a standard established by the law for the calibration and testing of specific measurement devices for trade. However, it became necessary to establish a national flow standard due to the recent increasing

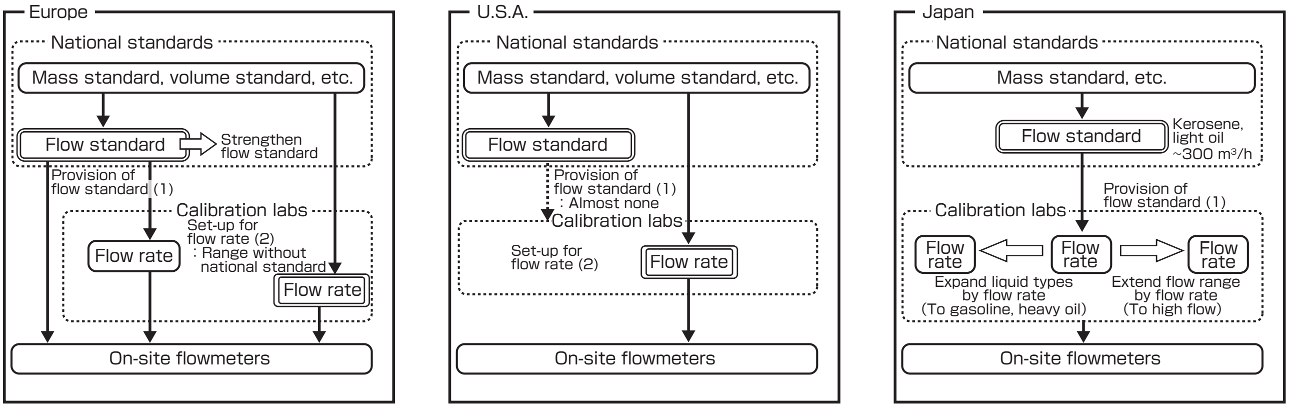

Fig. 1 Outline of the hydrocarbon flow standard system.

demand for the calibration of devices that cannot be covered by method (2), including highly accurate flow measurement, measurement of diverse liquid types and flow ranges, and measurement that guarantees international integrity. Therefore, the combination of method (1) that achieves reliability and (2) that focuses on expandability was selected. This is a method where AIST provides the flow standard with high accuracy (small uncertainty) for core flow rates and liquid types, and the calibration lab extends the ranges of standard flow rates and expands the liquid types using the calibration device it already owns, by utilizing the JCSS. Figure 2 shows details of the division of labor between AIST and the calibration lab for the liquid types and flow ranges. Assuming the flow ranges of the flowmeter used for tanker shipment, 300 m^3/h was set as the maximum flow rate in this national standard, and the liquid type was set as kerosene and light oil because their viscosity is of medium level.

4.2 Calibration method of the national standard and survey and comparison of the elemental technologies

When the calibration lab tries to expand the range of liquid types and flow rates, its calibration uncertainty increases compared to the uncertainty of the national standard on which it is based. To reduce the burden on the calibration lab in attempting to reduce the uncertainty, it is necessary to conduct calibration using the national standard at uncertainty as small as possible. The flowmeter used for measuring the quantities for taxation of the petroleum product must maintain an instrument error (deviation from the standard value) within 0.2 %[2]. Therefore, the goal value of the uncertainty of the national standard for hydrocarbon flow was set at 0.04 % or less for the volume flow standard. This is the highest-level goal value compared to the NMIs of other countries. Several technological challenges were expected, but we decided to overcome those challenges to establish the national standard.

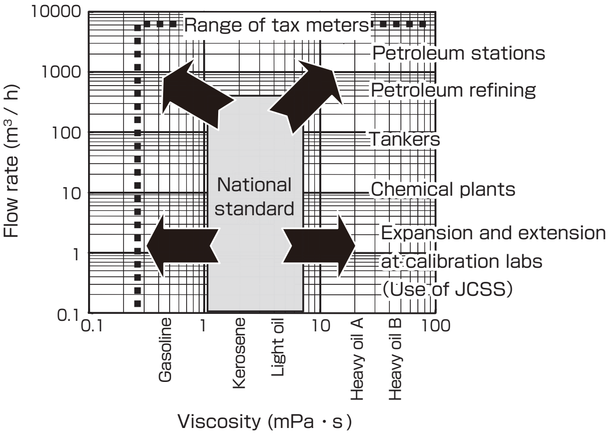

Fig. 2 Diagram for the work division according to liquid types and flow ranges between the national standard and the calibration labs.

The calibration of the flowmeter is conducted by comparing readings of the flowmeter to be calibrated to the readings of the flowmeter through which the standard flow passes. The representative methods for calibrating the hydrocarbon flowmeter are categorized below[3][4]. The eliminated methods include: the comparison method in which the flowmeter is used to calibrate another flowmeter, because this necessitates the calibration of the flowmeter used as standard to be calibrated at a calibration facility; and the dynamic calibration method where the instant flow passing the flowmeter is measured because it is difficult to keep the uncertainty small.

(1) Categorization by types of flow

- Standing start and stop method: The method in which the flow of the flowmeter to be calibrated is stopped before and after the calibration. While the calibration facility can be constructed at relatively low cost, the transient state between the stop state and the flow state may affect the flowmeter.
- Flying start and stop method: The method where the flow rate of the flowmeter to be calibrated is not changed between the calibrations. There is no effect of the transient state of the flow.

(2) Categorization by types of reference standard

- Volumetric method (volume tank): The method where the volume is measured by sending the test liquid into the volume tank equipped with preliminarily calibrated volume scale. While it has been used widely in general petroleum facilities, it is necessary to evaluate the effect of the test liquid that may remain on the inner wall of the volume tank, and to take highly accurate temperature measurement of the test liquid in the volume tank to reduce the effect of volume expansion by temperature.
- Volumetric method (pipe prover): The method where the flowmeter is calibrated by calibrating the volume displaced by a piston moving inside the pipe. Calibration is then conducted using the conduit. Since there is no part open to the atmosphere (closed loop), the effect of evaporation does not have to be taken into account, and this has been used in many petroleum facilities. To achieve high accuracy, it is necessary to investigate the effects of the device to detect the position of the moving body, the temperature measurement in the measurement volume, the leakage between the moving body and the wall of the pipe, and the expansion/contraction of the moving body.
- Gravimetric method (weighing scale): The method where the test liquid is introduced into the weighing tank, and the mass of the liquid is measured using a weighing scale. While high accuracy can be achieved, the scale may be affected by the impact of the test liquid when the test liquid is poured into the tank from a high place. It is also necessary to have a mechanism

where any exterior load on the weighing tank be eliminated during the mass measurement.

(3) Categorization by a flow switching method in the flying start and stop method

- High-speed valve method: A method in which the flow of the test liquid from the test line is switched to the storage tank and the standard, by rotating the valve at high speed. While it is less expensive than the diverter method, large pressure change occurs when switching is done at high speed, and there is a limit to the switching speed. The effect of switching on the flowmeter to be calibrated cannot be neglected. Also, there are problems in the symmetry of the flow, and achieving high accuracy is limited.
- Diverter method: A diverter is a device for switching the test liquid that jets out of the nozzle opened to the air to the storage tank and standard. Since the flow fluctuation during switching is small, it has absolutely no effect on the flowmeter to be calibrated. It has been used in water flow standard facilities, and there is a possibility for achieving high accuracy. On the other hand, since the liquid flows freely as a jet from the nozzle, there are dangers of explosion due to static electricity generated by mist. Also, the oil vapor and droplets released into the air may become sources of uncertainty. When the test liquid is poured in torrents into the weighing tank, large amount of air bubbles are formed, and when the test liquid containing the bubbles are circulated in the test line, the remaining gas may be a source of uncertainty.

Table 1 shows the calibration capacities and the methods of the NMIs of other countries for the hydrocarbon flow

Table 1 Uncertainties and calibration methods of the national standard for hydrocarbon flow of various countries.

Country	NMI (National Metrology Institute)	Flow rate (m^3/h)	Uncertainty** (%)	Test liquid	Temperature (℃)	Pressure (MPa)	Viscosity (mm^2/s)	Calibration method	Reference
Austria	BEV	0.0018 ～90	0.07 ～0.1	Gasoline, light oil	14 ～ 17	0.05 ～ 0.6		Volumetric method, standing method	Volume tank
Taiwan	CMS	18 ～360	0.05	Light oil, spindle oil (machine oil)	10 ～ 45	< 0.5	2.5 ～ 150	Gravimetric method, standing method	Weighing tank
Cuba	INIMET	3 ～ 300	0.1 ～ 0.2	Gasoline, kerosene, light oil, heavy oil	Wait-and-see	< 0.8		Volumetric method	
Czech Republic	CMI	0.29 ～396	0.15 ～0.30	Kerosene, light oil, petroleum, LPG	0 ～ 85	0.1 ～ 3.5		Volumetric method, flying method	Pipe prover (piston)
Denmark	FORCE	0.4 ～400	0.03	Petroleum products				Volumetric method, flying method	Pipe prover (piston)
Germany	PTB	0.6 ～250	0.1	Petroleum	Wait-and-see	0.35	0.77 mPas	Volumetric method, standing method	Volume tank
Italy	IMGC	0.0036 ～3.6	0.1	Kerosene, light oil	Wait-and-see	0.15		Volumetric method, flying method	Pipe prover (piston)
Japan	NMIJ*	15(3)～ 300	0.03	Kerosene, light oil	15 ～ 35	0.1 ～ 0.7	1.4～1.9, 4.4～7.8	Gravimetric method, flying method	Weighing tank
Korea	KRISS	1～ 14.8	0.11	Spindle oil (machine oil)	15 ～ 30	0.1 ～ 0.3	600 ～ 2200	Gravimetric method, standing method	Weighing tank
Mexico	CENAM	0.002 ～ 340	0.06 ～ 0.08	Petroleum products	0 ～ 82	0.1 ～ 0.4	0.5 ～ 10	Volumetric method, flying method	Pipe prover (piston)
Poland	GUM	0.4～ 400	0.1	Light oil	Wait-and-see		0.3 ～ 300	Volumetric method, flying method	Pipe prover (piston)
Sweden	SP	0.36～ 1260	0.1	LPG, light oil, etc.	−20 ～ 120		LPG～300	Volumetric method, flying method	Pipe prover (prover)
The Netherlands	NMi -VSL	0.001～ 250	0.04	Gasoline, kerosene, light oil		0.4	0.7, 1.8, 5	Volumetric method, standing method	Volume tank
U.K.	NEL	0.00012 ～720	0.03 ～0.08	Kerosene, light oil, heavy oil	5 ～ 50	0 ～ 0.8	2.2 ～ 30	Gravimetric method, standing method	Weighing tank

*) NMIJ : National Metrology Institute of Japan, AIST

**) Uncertainty: Here, for simplification, the values for expanded uncertainty (95 % confidence level) are presented.

standard. Here, the calibration capacity is presented quantitatively by the uncertainty based on the international comparison conducted under the Convention du Mètre. This can be considered the evaluation result of the most authoritative national standard, where all the participating institutes agree to the technological basis of the uncertainties that are presented by each other. In the calibration of the hydrocarbon flowmeter in overseas national standards, the liquid flow method using the volume pipe and the stop method using the volume tank are used frequently. However, as mentioned earlier, these methods have several technological issues in achieving the high level of uncertainty. Also, in the standing method, the transient state of the flow may become a major source of uncertainty, depending on the type of the flowmeter. In some calibration methods, the type of the flowmeter to be calibrated may be limited. On the other hand, the gravimetric method with flying start and stop using the diverter, which is frequently employed in the calibration facilities for water flowmeter, is rarely employed for petroleum products since they are hazardous materials with risk of explosion due to static electricity. If this point can be overcome, there is high possibility for achieving small uncertainty. Therefore, AIST selected the "gravimetric method with flying start and stop using the diverter" as the calibration method of the national standard facility, to realize a national standard with the highest accuracy in the world, and developed the elemental technologies to achieve the high accuracy and took measures to ensure safety.

5 Construction of the hydrocarbon flow standard

5.1 Calibration facility for hydrocarbon flow

Since this facility will store and use large amounts of kerosene and light oil, it must be designed in accordance with the Fire Service Law as a place for handling hazardous materials. Also, a safety management system must be established, and measures to prevent the leakage or outflow of the test liquid are required in consideration of the surrounding environment. Because the risk factor increases, as mentioned in the previous chapter, in the "gravimetric method with flying start and stop using the diverter," it is mandatory to take sufficient safety measures. In Japan, there were almost no cases of a large indoor facility where a large amount of petroleum products, which are hazardous materials, was allowed to flow, but its construction was approved by the fire service authority because of its importance as a national standard and the implemented special safety measures. Figure 3 shows the safety measures and the relationships to the elemental technologies for uncertainty.

To prevent leakage of oil, dual measures were taken where the entire facility was surrounded by an oil dike, and a pit and an oil-water separator were installed around the building. The roof was made of light corrugated sheets with an explosion-release structure to release the pressure upward in case of an explosion, but had insulation to improve the temperature stability in the building. The hazardous area containing the test line through which the petroleum products will circulate and the nonhazardous area such as the operating room where the control computer will be installed were clearly demarcated. The test line would be monitored from the operating room, and a refractory glass and refractory shutters were installed to enable quick response in case of emergency. In the hazardous area, oil-proof floor was installed to prevent underground permeation of oil, the two 43 m^3 storage tanks were placed in the underground pit, and the weighing tank was installed in the room with the underground pit, to prevent leakage to exterior environment in case of any accident.

Figure 4 shows the diagram of the hydrocarbon high-flow calibration facility[5] which is a real-flow calibration facility for hydrocarbon flowmeter, and Table 2 shows the sources of uncertainty[6][7]. This calibration facility is composed of two test lines for kerosene and light oil, and the flow range

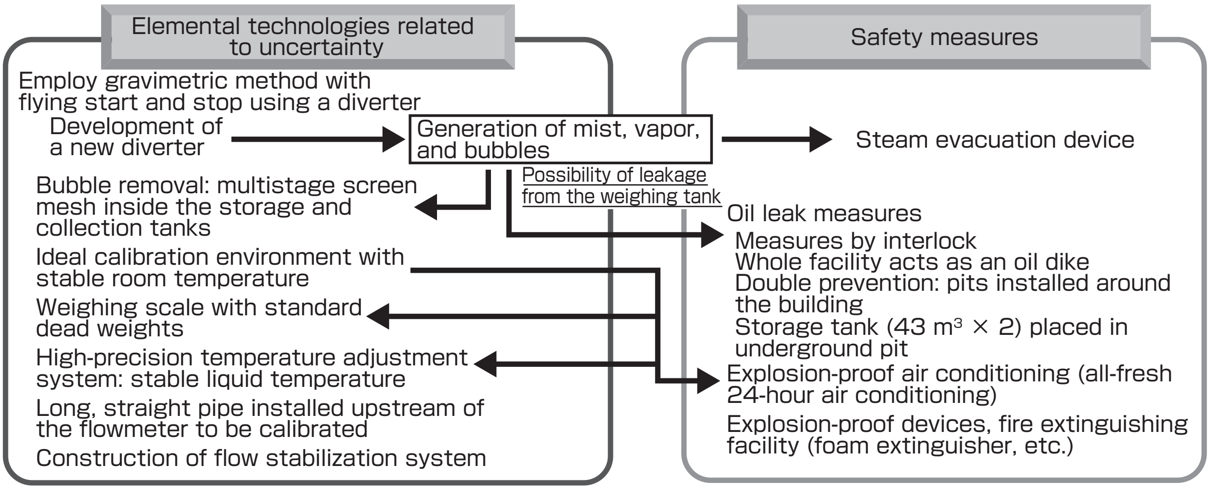

Fig. 3 Elemental technology developed for hydrocarbon high-flow standard.

is 3~300 m^3/h for both lines. The facilities for kerosene and light oil are completely independent of each other, but since they have common temperature adjustment device for the test liquid, the two facilities cannot be operated simultaneously.

This facility employs gravimetric method with flying start and stop using diverters. The test liquid (kerosene or light oil) that passes the flowmeter to be calibrated is run for a certain time from the diverter nozzle to the weighing tank installed above the weighing tank, the standard mass flow rate is obtained by dividing the inflow mass measured by the weighing scale by duration time, and the figure is converted to standard volume flow rate by dividing the mass flow rate by the density of the test liquid. The calibration is done by comparing these standard flow rates and the readings of the flowmeter to be calibrated.

As mentioned in the previous chapter, the characteristic of the calibration method using diverters is that there is little change in flow rate during the measurement compared to switching the flow using a valve. A newly developed diverter was used[8]. This diverter shifts the diverting wing in the same direction and at the same speed as the free jet flow at the beginning of the measurement when the flow is diverted to the weighing tank and at the end of measurement when the flow is diverted to the bypass. It has been employed in the national standard (water flow) of the United States and France, as well as calibration labs (water flow) of Japan, and is becoming a world standard in the liquid calibration labs. Although the diverter could not be used directly in the hydrocarbon flow calibration facility due to safety concerns, the generation of static electricity was successfully controlled while increasing the jet flow speed, by controlling the outlet surface area of the free jet flow inside the diverter, and this in turn led to successful decrease of the uncertainty of collection time in the calibration uncertainty of the flowmeter.

To prevent the vapor or droplet of the test liquid generated in the free jet flow from flowing into the measurement room, adjustments were made so the interior of the diverter would be slightly lower in pressure than the atmospheric pressure, the vapor was forcefully evacuated from the room, and the oil vapor and droplets were condensed and collected as waste oil. Due to the forced evacuation of the vapor and droplets, the calibration uncertainty in the kerosene line deteriorated, and it was found that this was a dominating source in the kerosene line for certain flow range. Compared to the kerosene line, the effects of vapor and droplets were smaller in the light oil line. To remove the large amount of bubbles caused by the diverter, multistage screen mesh was installed in the 43 m^3 storage tank and the buffer tank, and the bubbles could be sufficiently removed.

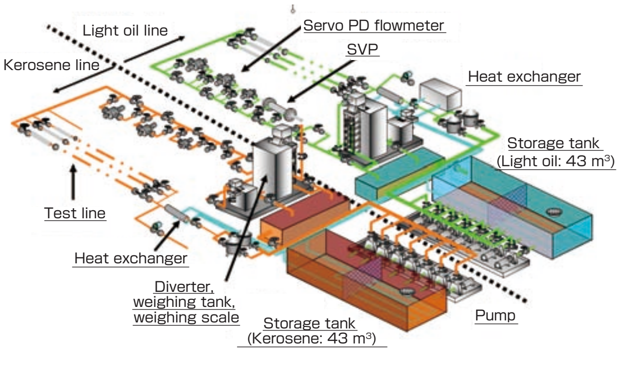

Fig. 4 Diagram of the hydrocarbon high-flow calibration facility.

Table 2 Sources of uncertainty in the national standard (kerosene test line).

Source of uncertainty	Relative uncertainty
1) Flowmeter pulse counting time	0.0028 %
2) Mass change in the connecting pipe	0.0008 %
3) Effect of fluctuation in flow or density	0.0002 %
4) Mass measurement of test liquid (the effect of vapor and droplets)	0.0054 ~ 0.0154 % (0.0030 ~ 0.0146 %)
5) Density measurement of test liquid in flowmeter	0.0124 ~ 0.0146 %
6) Collection time to the weighing tank	0.0032 ~ 0.0042 %
Calibration uncertainty of volume flow (relative) : 1) +2) +3) + 4) + 5) + 6)	0.016 ~ 0.022 % (Simplified to 0.03 %)
Calibration uncertainty of mass flow (relative) : 1) +2) + 4) + 6)	0.008 ~ 0.016 % (Simplified to 0.02 %)

Note) Relative uncertainty: The components that are considered to be the cause of the sources of each uncertainty are given, among the relative amount (calibration uncertainty) obtained by dividing the uncertainty of flow rate indicated by the flowmeter by the flow value.

The flowmeter to be calibrated was set in the test line with a diameter of 50~150 mm. To create an ideal flow, a straight pipe with a diameter 100 times larger (15 m) was installed upstream of the flowmeter to be calibrated. To reduce the pulsations caused by the pump, three centrifugal pumps with equal performances were operated in parallel. We also developed a method for reducing the flow fluctuation during supplying into the weighing tank[5].

In the weighing room where the weighing scales were installed, the temperature was controlled within room temperature of 20 ± 5 ºC and the humidity at 30 % or above, as countermeasures against statics throughout the year using an explosion-proof air conditioning device. These also contribute to the reduction of the uncertainty of the weighing system. By calibrating the weighing scale before the measurement by loading ten 1000 kg standard dead weights for the 10 t scale and five 200 kg standard dead weights on the 1 t scale, the effect of reproducibility of the weighing scale was minimized[7]. Also, since several sources of vibrations such as the pump were installed in the same building, sufficient anti-vibration measures were taken by devising the pile foundation, to improve the uncertainty of the weighing scale that is sensitively affected by very small vibrations.

To reduce the uncertainty due to the temperature expansion of the test liquid, it is necessary to stabilize the temperature of the test liquid. Sufficient temperature stability of the test liquid (± 0.05 ºC or less) was obtained by devising ways to reduce the time change of the load on the heat exchanger, such as maintaining a stable room temperature using the explosion-proof air conditioning facility, and keeping the constancy of flow that passes through the heat exchanger that controls the temperature of the test liquid. As a result of such technological developments, the uncertainty of "5) Density measurement of test liquid in the flowmeter" and "2) Mass change rate in the connecting pipe" in Table 2 were minimized[6].

For the purpose of checking the reproducibility of the calibration system, a servo positive displacement (PD) flowmeters with excellent reproducibility[9] were developed, and three of them were installed permanently in the test line for kerosene and light oil. The adequacy of the calibration could be checked at all times by calibrating the servo PD flowmeter while calibrating the flowmeter, and then comparing the result with the past calibration values.

As an assumption of calibration, the check of residual gas in the pipe and the check of leakage of the test liquid that occurs from the valve at the branch pipe are incorporated in the calibration routine.

By incorporating the above safety measures and elemental technologies for reducing the uncertainty, the calibration uncertainty of the volume flow was 0.03 %, which was superior than the goal value 0.04 %. The world's highest accuracy of 0.02 % was achieved for mass flow[5].

5.2 Verification of the validity of the developed flow standards

The developed hydrocarbon high-flow calibration facility is designated as the specific standard for hydrocarbon flow by the Measurement Law. It is extremely important to verify the validity of the absolute value and the uncertainty of the value of the hydrocarbon flow to be calibrated, and to check the international equivalency, to guarantee the reliability of the hydrocarbon flowmeter of Japan.

As a result of conducting bilateral international comparison with the SP Technical Research Institute of Sweden (SP) (see Table 1), the calibration results at the calibration facilities of NMIJ and SP matched in the range of each other's uncertainties[5]. We also participated in the international comparison test for hydrocarbon flow conducted under the Convention du Métre, with National Engineering Laboratory (NEL) of U.K. as the officiating country[10]. The initial participants included five European countries, two Asian countries (including Taiwan), and two North American countries, a total of nine nations. Since a flowmeter for international comparison with excellent reproducibility and flow characteristic was damaged during transportation, the comparison was carried out over a two-year period from 2005 to 2007. The calibration values of the flowmeters of all participating countries are shown in Fig. 5. The calibration values of the two countries, Mexico and Canada that were dropped midway in the comparison, were greatly divergent from the values of other countries. For these two countries, the calibration was conducted by transporting the calibration device using the pipe prover (small volume prover) or the volume tank to external facilities (such as the petroleum company). This implies that it is technologically difficult to set up a highly accurate flow standard just by maintaining the traceability for individual measurement devices such as the volume tank, as mentioned before, and it is necessary to reduce the uncertainty source of the entire calibration device including the calibration environment. The Japanese national standard values are distributed in the center of the overall calibration values, as can be seen in Fig. 5. Moreover, it was confirmed that the Japanese values match within the range of the internationally agreed values and uncertainties obtained by statistic analysis[10].

6 Effort to create an efficient JCSS traceability system

To respond to the demands of industry that uses the flowmeter for diverse petroleum products at wide flow range, it is necessary to expand the flow range and the range of liquid types from the national standard through the Japan Calibration Service System (JCSS). Therefore, in a government-supported research project[11], we developed the technology to enable easy expansion to different liquid types by adding an advanced analysis to the characteristic of the flowmeter that is dependent on the liquid viscosity, and the technology to extend the flow range by the parallelization of the flowmeters[11][12]. Figure 6 shows

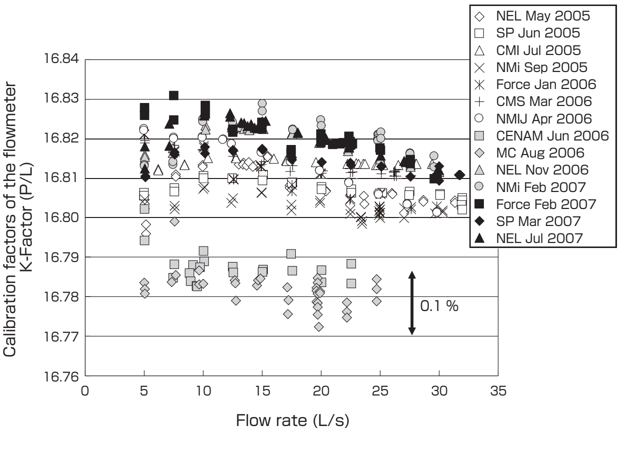

Fig. 5 Measurement results of the international comparison for hydrocarbon flow.

The participating organizations and countries are: NMIJ: Japan, NEL: UK, SP: Sweden, CMI: Czech Republic, NMi: The Netherlands, Force: Denmark, CMS: Taiwan, CENAM: Mexico, and MC: Canada. The data in Fig. 2 of the *International Key Comparison*[10] were re-plotted.

cases where the calibration capacity of Japanese calibration laboratories was surveyed to verify the adequacy of these new calibration technologies. As shown in the result for 2005, the calibration facility that originally had deviations of − 0.05 % ~ + 0.10 % from the national standard significantly improved the calibration capacity to match within ± 0.03 % of the national standard, by calibrating its facility using the flowmeter calibrated by the national standard. Moreover, the values for heavy oil that is out of the range of calibration using the AIST national standard matched ± 0.03 % of the values of the overseas calibration institutes, and this implies that the method for expanding the liquid types, developed for the project, was adequate.

We also drafted the Guidelines on the Technological Requirement[13] to technologically support the National Institute of Technology and Evaluation (NITE) that accredits the calibration labs that receive the national standard. As a result, the number of accredited and registered calibration labs are increasing as a new business.

We are also continuing the development of the high-precision flowmeter jointly with flowmeter manufacturers to improve the work efficiency and to reduce the uncertainty arising from the viscosity property of the flowmeter, by applying the expansion technology for liquid types.

By dividing the roles with the JCSS calibration labs, the national standard has become a facility with the world's highest precision level, although in a limited range, and is taking on an important function as a development platform for the flowmeters among the measurement device industry.

7 Summary

In this paper, we discussed the positioning of the national standard for hydrocarbon flow from the perspective of pursuing socially practical application, and reported on the selection process of the calibration method for the national standard of hydrocarbon flow, the elemental technologies to reduce the uncertainty, and the maintenance of safety. We also reported on the adequacy of the national standard and the construction of the traceability system that could be used by the user. Currently, we are providing technical support to calibration labs that wish to register to the JCSS, to achieve efficiency of the precision management of the flowmeters used in practice. There is a movement away from petroleum due to environmental issues, but with the rising prices of petroleum products as exemplified by the recent rise in the crude oil price, further high-precision measurement will be in demand. In the future, it is necessary to design traceability systems for LPG and LNG that are low temperature liquids for which the systems of flow rate standard have not been organized, as well as for highly viscous grade C heavy oil. Since high-performance mass flowmeter is being developed, there is a possibility of a shift from the currently used volume-based trade to mass-based trade. In the future, there are necessities for the establishment of new technological standards, the technological advices for changed regulations, and the improvement of the traceability systems to meet the social demands.

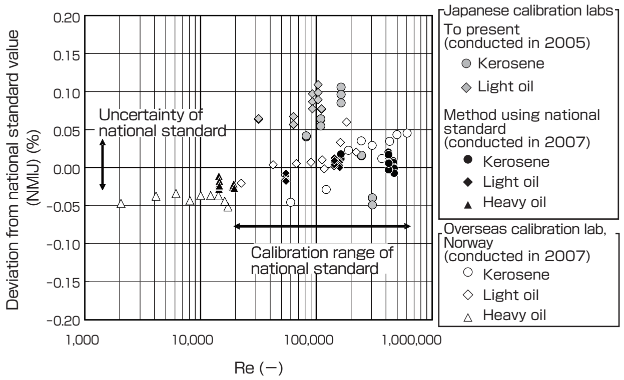

Fig. 6 Deviation from the national standard value (NMIJ).

The Re number on the horizontal axis do not match since the flowmeters used in 2005 and 2007 were different. The calibration range of the national standards is provided as reference.

Acknowledgements

The surveys of the technological trend among the flowmeter calibration laboratories and the NMIs of various countries played important roles in this research. These were obtained as the research results of the Hydrocarbon Flow Research Consortium Session, in which the petroleum companies and the flowmeter manufacturers participated, organized by the Japan Measuring Instruments Federation. Also valuable were the cooperations of: the International Accreditation Japan, National Institute of Technology and Evaluation; the Measurement and Intellectual Infrastructure Division, Ministry of Economy, Trade and Industry; and the Petroleum Refining and Reserve Division, Agency for Natural Resources and Energy.

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Discussions with Reviewers

1 Standard and the calibration of the tax meter

Comment (Mitsuru Tanaka, Research Coordinator, AIST)

In the researches for measurement standards, I think the methodology to present the technological basis on which the government makes decisions in the management of the system is “synthesiology”. The content of the paper steps deeply into the discussion assuming the decision by the government, and I am afraid that it may mislead the readers. Therefore, why don’t you focus on the descriptions for technology synthesis and the evaluation only from the objective attributes such as precision, cost, diversity of calibration subject and range, or international competition?

Answer (Takashi Shimada)

In chapter 1 and chapter 2, we corrected that the new service system for hydrocarbon flow standard was constructed, because there were rising demands for ranges that fall outside of the precision, liquid type, and flow range of the conventional standard system.

2 Title of the paper

Comment (Mitsuru Tanaka)

The original title “Establishment of the hydrocarbon flow standard" makes it unclear what point is described, in the range of topics from elemental technology development to political decisions. To emphasize "synthesiology", please revise the title so one can readily see whether the subject is a measurement standard for the entire Japan, is limited to national measurement standard for which AIST is responsible, or encompasses the international measurement standards.

Answer (Takashi Shimada)

Since the subject is a system for the entire Japan and the Japanese national measurement standard, we revised the title from that standpoint.

3 Elimination of overlap with existing research papers

Comment (Yasuo Hasegawa, Energy Technology Research Institute, AIST)

Since there are already detailed papers written for this research, and to have the readers understand the essence of "synthesiology", why don't you eliminate the descriptions that overlap with the existing papers and simplify the text?

Answer (Takashi Shimada)

We added figures and tables to briefly present the technological content, and rewrote the paper so the relationship between the result of synthesiology research and the administration in charge of metrology can be seen more clearly.