

INVESTIGATION ON CALIBRATION OF FUEL ETHANOL FLOW METER

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Abstract

Calibrations with ethanol, water and kerosene have been conducted by using a transferable test package which consisted of positive displacement (PD), turbine (TB), Coriolis (CMF) flowmeters and a small volume prover (SVP). Flowmeter performances and establishment a temporary ethanol flow standard have been investigated. It is founded that liquid replacement in the PD and the TB induced transitions of K-factor over several days. Performances of mass and volume flow output of CMF were also evaluated.

Introduction

The amount of fuel-ethanol trade is rapidly increasing in this decade. In case of direct mixing, gasoline after mixed with ethanol can absorb water. The ethanol mixed gasoline should not be kept for a long time. Ethanol should be mixed with base gasoline just before loading to a tank truck. So fuel ethanol flowmeters will be needed more but there is no special calibration facility for ethanol flow in Japan. In many cases, water is used as alternative calibration liquid although there are viscosity and density differences between ethanol and water. Liquid replacement and rinsing problems were also suspected.

Experimental calibrations have been conducted in order to investigate flow meter performance on ethanol measurement and how to establish ethanol flow standard. A transferable flowmeter package was constructed by combining PD, turbine, Coriolis flow meters and a small volume prover (SVP). These flowmeters and the SVP were calibrated with kerosene and water at NMIJ's hydrocarbon flow standard facility [1] and water flow standard facility [2]. And the package was transported to an ethanol blending station.

Experimental method

Subjects and methods

Performance of flowmeters on ethanol

Four types of flowmeter were selected to investigate their performances on ethanol and other liquids. In this paper these flowmeters are identified as follows. "PD" is an oval gear type positive displacement flowmeter which has 25 mm inlet diameter. "TB" is a turbine flowmeter of 20 mm inlet diameter with upstream pipe and tube-bundle straightener. "CMF-M" indicates mass flow output of Coriolis mass flowmeter. The mass flow output of CMF-M was converted to volume flow on calibration data sheet with a density value of sampled liquid to be

compared with other volume flowmeters and standard. The liquid density at the flowmeter was estimated by using measured density value of an off-line type density meter with the temperature and the pressure measurement data at the flowmeter. Many Coriolis flowmeter can output also volume flow rates because they can measure density at the same time. "CMF-V" means volume flow output from Coriolis flowmeter. CMF-V output had already been converted to volume flow with internal density measurement in the flowmeter. Actually the tested Coriolis flowmeter was only one. The setting of CMF-M and CMF-V was changed through communications software.

There are two main subjects for flowmeter performance investigation. To evaluate how much the differences of liquid properties between ethanol and alternative calibration liquid effect on calibration factor. The other is to confirm whether an implementation of replacing liquid of the flowmeter raises concerns or not.

To determine these subjects, these flowmeters have to be calibrated by using something of ethanol standard. So, an ethanol flow standard needed to establish at least temporarily.



Figure 1 : Photo of PD and TB.

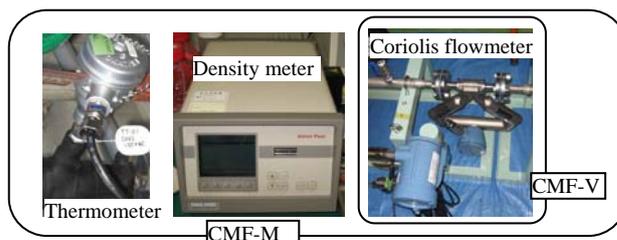


Figure 2 : Photo of CMF-M and CMF-V.

How to establish ethanol flow standard

Two methods of ethanol flow standard were evaluated in comparison with each other. The first way was that the CMF-M calibrated by using another liquid flow standard was adopted for a master meter of ethanol flow. The calibration factor of Coriolis flowmeter is essentially stable to changing of liquid properties (density, viscosity) within the specification. The stability over different liquids was evaluated.

The other method was a small volume prover (SVP). A free piston type SVP was designed and constructed in this project. The cylinder was a precisely honed 4-inch stainless steel pipe. Intrinsic safety type magnetic sensors detected the magnet inside the piston

from outside the cylinder. The standard volume between the two detectors was about 4 L and calibrated by using kerosene and water national standard facilities via transfer flowmeters. Flow direction was changed by using 4 valve units. Each valve unit consisted of two valves and a bleed valve as a block-and-bleed system.



Figure 3 : Photo of SVP.

Transferable flowmeter package

The flowmeters and the SVP have been packed so that the package can be transferred round the three different facilities. The ethanol blending station in Miyako Island is 2100 km away from the national flow standard facilities in Tsukuba. The package consisted of flowmeters, the SVP, pipe lines, valves, thermometers, pressure gauges, pulse counters and measurement recording system. Calibrations had been conducted in order of kerosene (Kerosene 1), ethanol, water and second kerosene (Kerosene 2) during about half year.

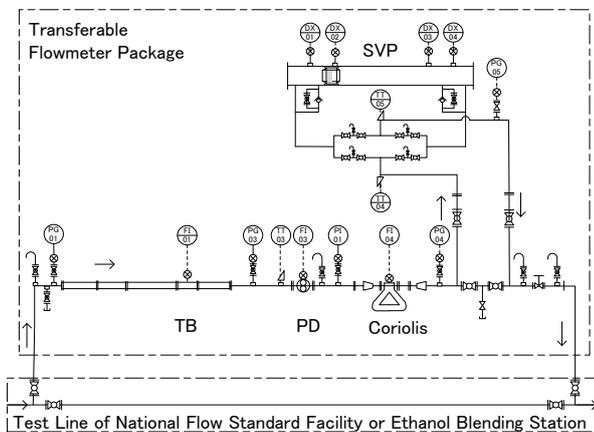


Figure 4 : Schematic flow diagram of test package.

Calibration at national flow standard facility

The national hydrocarbon and water flow standard facilities have static gravimetric systems with flying start and finish by using double wing diverter [3]-[5]. The SVP couldn't be calibrated by using the facilities directly. So these flowmeters were calibrated with the facility, and then the SVP was immediately calibrated against these flowmeters.

These calibrations were conducted from 0.5 to 3 m³/h with kerosene (15 – 38 °C) and water (13 °C). Calibration capability ($k=2$) of kerosene flow standard facility is 0.020 % at mass flow and 0.030 % at volume flow. That of water flow standard facility is 0.044 % at mass flow and volume flow.

Ethanol blending station in Miyako-Island

The flowmeter package was set into an ethanol temporary circulation line. Calibrations were conducted by using master meter method and SVP method.

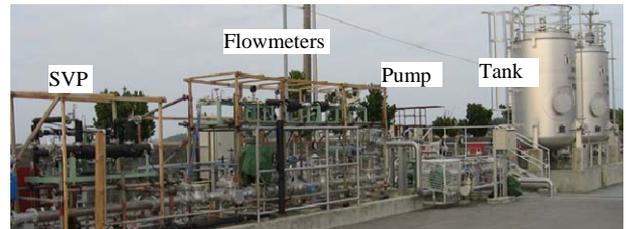


Figure 5 : Photo of test rig in ethanol blending station.

Results and discussion

Evaluation of standards for ethanol

Calibration results of CMF-M

As shown in Figure 6, the CMF-M was calibrated by using the flow standard facilities (kerosene and water). Some scatters were seen at low flow rates, which were considered as a zero point stability effect of the Coriolis meter. The results at all conditions were mostly within ± 0.05 % except for the low flow rates.

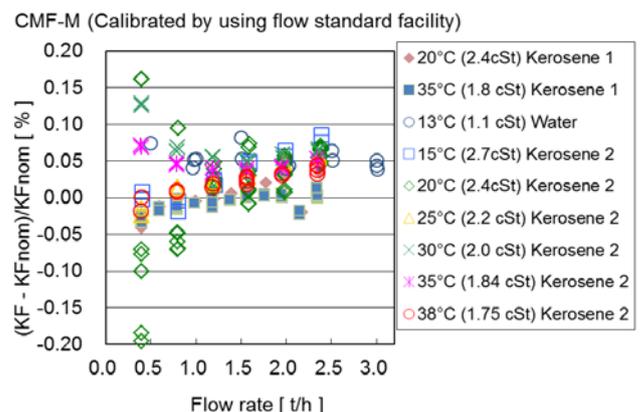


Figure 6 : Calibration of CMF-M.

Calibration of SVP

The SVP was calibrated by using the flow standards via flowmeters. SVP coefficients (Ratio of estimated volume and nominal standard volume) calibrated via the PD are shown in Figure 7.

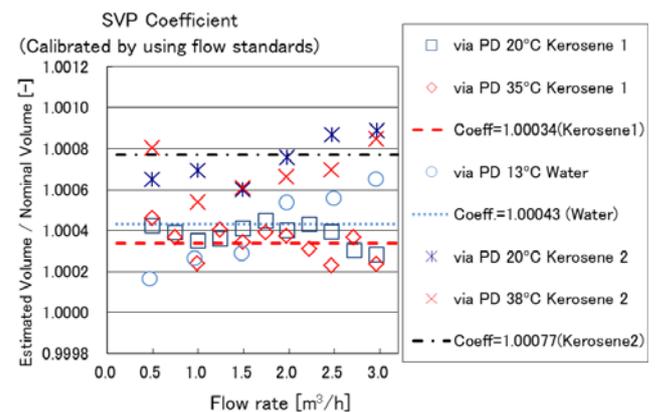


Figure 7 : SVP coefficients.

The SVP did not have a large difference of the coefficient between kerosene and water. However the calibration coefficients of the SVP had changed about 0.04 %: 1.00034 (Kerosene 1), 1.00043 (Water) and 1.00077 (Kerosene 2). The detector sensors were suspected but the cause of the drifts has not been identified. The drift was taken into account of a long term reproducibility of the SVP.

Evaluation as a reference standard in ethanol flow

Figure 8 shows deviations of K-factor of the CMF-M calibrated by using the SVP (Coeff.=1.00077) in kerosene, ethanol and water. The CMF-M and the SVP have displayed their ability of stability against changing of liquid properties in Figure 6 and Figure 7. In Figure 8, there was no significant difference between ethanol and other liquids. It suggested that the both of measurements (CMF-M and SVP) kept the stability also in ethanol. If both of the CMF-M and the SVP made the same drift in ethanol, these could not be distinguished. But it is thought that the possibility was very small because these measurement principles were quite different.

From these results, it was confirmed that these two methods (CMF-M and SVP) can be used as reference standards of ethanol flow within the reproducibility.

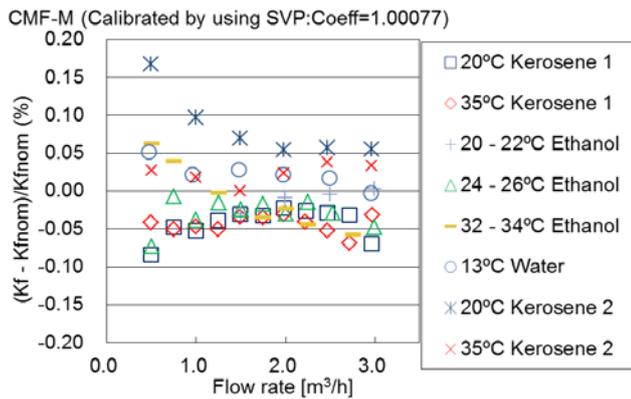


Figure 8 : Calibration of CMF-M by using SVP.

Investigation of flowmeter performance

Influence of replacing liquids

A preliminary test had been conducted in previous year. As shown in Figure 9, transitions of K-factor of the PD were observed over first three days at ethanol test after kerosene 1. A correlation plot with two calibration methods was shown in Figure 10. The trend of transition was almost the same in both calibration methods. The TB also drifted largely as shown in Figure 11. From ethanol to water, transitions of both the flowmeters were observed again. The PD and the TB had mechanical movement parts. It was suspected that the implementation of replacing liquid could affect calibration factors due to incompleteness of rinse between ethanol and other liquid.

In order to avoid the drifts at liquid replacing, 24 hours preparation-flow-run (8 hours * 3 days) had been conducted before calibrations. After the long preparation flow run, calibration results became stable. This is a point to note for an alternative liquid calibration method between ethanol and other liquids. It would depend on type of flowmeter how long it needs the preparation flow

run. Anyway, a calibration operator should know the problem.

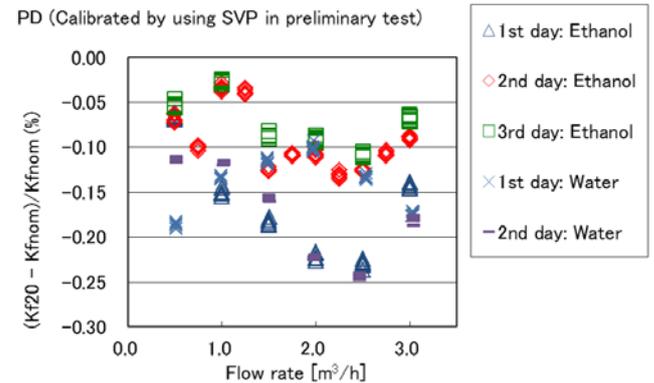


Figure 9 : Transition of PD after liquid replacing.

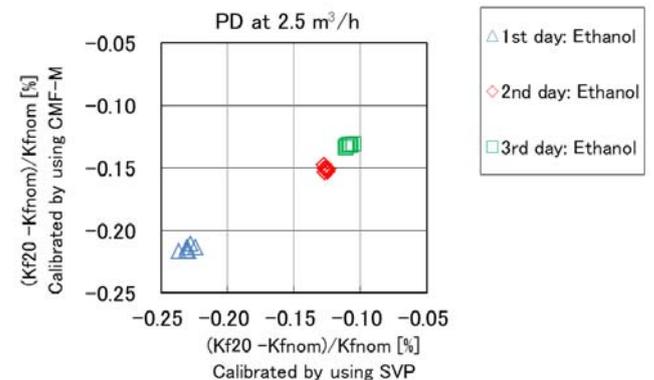


Figure 10 : Correlation plot of PD.

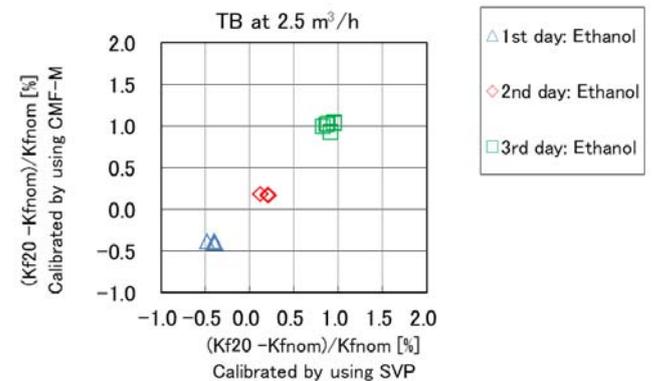


Figure 11 : Correlation plot of TB.

Performance of PD meter

Figure 12 shows deviations of K-factor calibrated by using the SVP over kerosene, water and ethanol. K-factors had been corrected to 20 °C condition (Kf20) with thermal expansion coefficient of the rotor and the case. Generally a positive displacement flowmeter has changing characteristics of K-factor to viscosity. Manufacturer commented that the PD meter should have characteristics that K-factor decreases with proportion to reciprocal of viscosity. The PD showed similar characteristics among Ethanol, Water and Kerosene 2. And the range was within about ±0.1 % over 1 - 2 mPas.

There was no significant transition in the same test because of the preparation-flow-run. However the K-factors in kerosene were different between Kerosene 1 and Kerosene 2. Figure 13 shows the PD K-factors calibrated

by the national flow standard. It seemed that the characteristics of the PD had changed between Kerosene 1 and Ethanol test. It suggested that the PD was not suitable for a liquid replacing operation between ethanol and other liquids. However the PD could be a good flowmeter as long as it is kept and calibrated in ethanol.

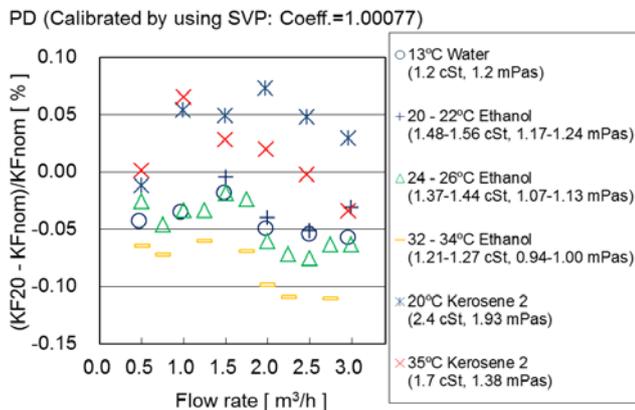


Figure 12 : Calibration of PD by using SVP.

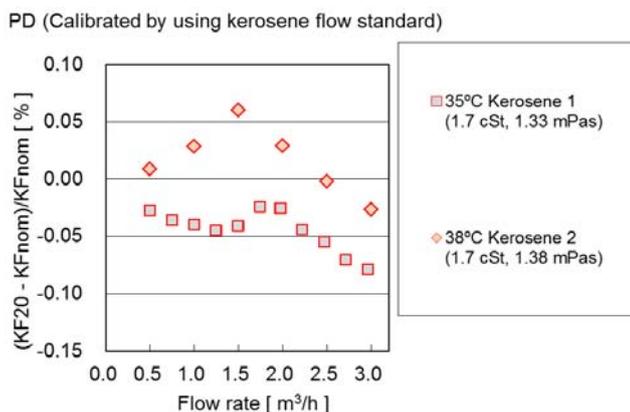


Figure 13 : Calibration of PD by using flow standard.

Performance of TB meter

Figure 14 shows calibration results of the TB by using the SVP. In case of this TB, these flow rates were in large linearity region. However a turbine flowmeter generally has Reynolds number characteristics. Figure 15 was plotted with Reynolds number in the horizontal axis. It suggested that alternative liquid calibration could work by using Reynolds number matching method after enough rinsing.

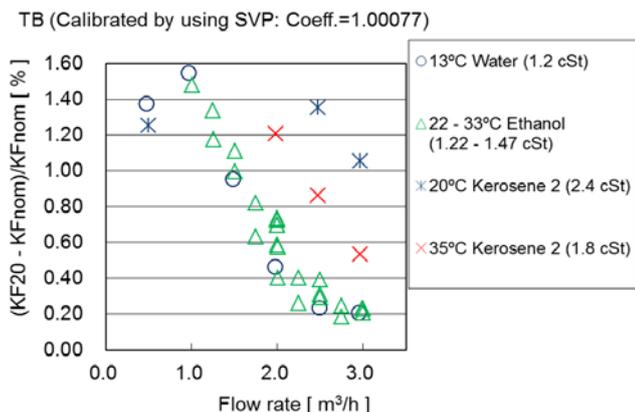


Figure 14 : Calibration of TB by using SVP (Flow rate).

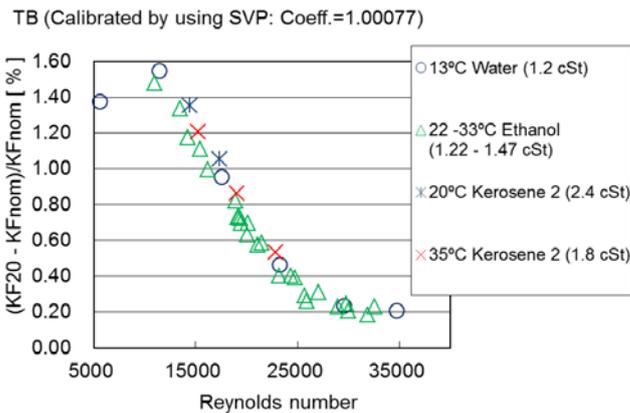


Figure 15 : Calibration of TB by using SVP (Reynolds number).

Performance of CMF-M

As shown in Figure 8, the difference between ethanol and other liquid conditions seemed to be similar level to the reproducibility of the CMF-M. On the other hand, zero point stability could be significant at low flow rates; severe environmental condition like large difference between liquid temperature and ambient temperature might affect reproducibility at some degree.

A mass flow output type Coriolis flowmeter could be a candidate in case that a flowmeter which measures ethanol flow needs to be calibrated in an alternative liquid. And in case that volumetric type ethanol flowmeters like a positive displacement flowmeter and turbine flowmeter need to be calibrated in ethanol pipe line (ex. field calibration), a mass flow output type Coriolis flowmeter combined with an accurate density measurement system could be a field master meter system in ethanol line.

Performance of CMF-V

Figure 16 shows K-factor deviations of the CMF-V calibrated by using the SVP and water flow standard in preliminary test. The results of the SVP with water were close to those of the national water flow standard. But there was about 0.2 % difference between water and ethanol. According to density values of the Coriolis flowmeter via the communication software, the differences of K-factors were consistent with density differences between the Coriolis flowmeter and the off line density meter system. It showed that an uncertainty of the volume flow output of Coriolis flowmeter could not be estimated appropriately if its density measurement was not calibrated as mentioned in the ISO standard document [6].

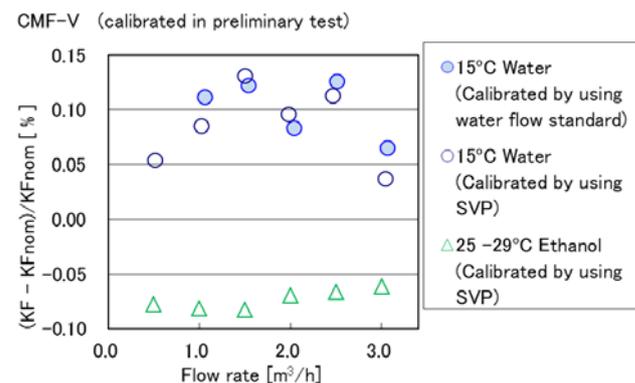


Figure 16 : Calibration of CMF-V in preliminary test.

Conclusions

Ethanol flow standard

The CMF-M and the SVP have displayed their ability of stability against changing of liquid properties. These two methods (CMF-M and SVP) could be candidates for working standard of ethanol flow after being calibrated with water or hydrocarbon standard.

Flowmeter performance

Transitions of K-factor of the PD and the TB were observed over several days after liquid replacement. This point should be paid attention in case of an alternative liquid calibration for ethanol flowmeters. How long a flowmeter needs the preparation flow run should be confirmed. A mechanical type flowmeter which is hard to rinse might be unsuitable for a liquid replacing operation between ethanol and other liquids. However these flowmeters could be a good ethanol flowmeter as long as they are kept and calibrated in ethanol line.

A mass flow output type Coriolis flowmeter could be a good ethanol flowmeter even if it needs to be calibrated in an alternative liquid. And it could be a field master meter from another liquid flow standard.

A volume flow output of Coriolis flowmeter should be cared in use for different liquid from calibration condition.

References

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