ASIA-PACIFIC METROLOGY PROGRAMME

APMP.M.FF-K2 Bilateral Comparison
Hydrocarbon Liquid Flow

Final Report
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Pilot Institute: Center for Measurement Standards (CMS)

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SUMMARY

This bilateral comparison was carried out in the field of liquid hydrocarbon flow following the *Guidelines for CIPM key comparison*. This APMP.M.FF-K2 comparison involved two laboratories, Center for Measurement Standards (CMS, Chinese Taipei) and Vietnam Measurement Institute (VMI), which are both national standard calibration laboratories.

The bilateral comparison was conducted using light liquid hydrocarbon across a flow range of 5 L/s to 30 L/s. A Kral positive displacement meter served as the transfer standard. The Strouhal number and Reynolds number served as the key parameters for expressing the laboratories' measurement of volume and flowrate.

The *En* value of the VMI test results with reference to CMS was 0.28.

CONTENTS

1 INTRODUCTION

International comparisons are a main approach to achieve worldwide equivalence in metrology standards. The Vietnam Metrology Institute, henceforth referred to as the VMI, wanted to show its competence in measurement and calibration at the liquid hydrocarbon flow regions. The Center for Measurement Standards of Chinese Taipei, henceforth referred to as the CMS, joined the CCM-WGFF key comparison project organized by National Engineering Laboratory (NEL), UK in 2005 as a linkage laboratory. CMS and VMI embarked on a bilateral comparison of their liquid hydrocarbon flow standards. This bilateral comparison, APMP.M.FF-K2, was undertaken by the Technical Committee for Fluid Flow (TCFF) of Asia Pacific Metrology Program (APMP), and piloted by CMS. The objective of this bilateral comparison is to achieve proper linkage with the current CCM.FF-K2 reference value, to determine the degree of equivalence in the liquid hydrocarbon standards of the CMS and VMI, and to provide supporting evidence for the calibration and measurement capabilities (CMCs) claimed by the VMI.

2 TRANSFER STANDARD

The design of the transfer standard was a positive displacement (PD) meter with linear performance. This meter is insensitive to flow profile, and has a relatively small but predictable change in performance with kinematic viscosity.

The comparison package consisted of a 100 mm screw-type PD meter manufactured by Kral Volumeter, three associated pipeworks, and a cone-type filter. The package is owned by the National Metrology Institute of Japan (NMIJ).

An intercomparison CCM.FF-K2 organized by the NEL (UK) had been conducted in 2005 to 2007. The results of that study compared the calculations of Strouhal and Reynolds numbers. These dimensionless numbers served as the key parameters for expressing the laboratories' measurements of volume and flowrate, respectively.

Because both Strouhal and Reynolds numbers depend on an actual diameter, the defined pipe diameter at 20 °C must be corrected for temperature expansion for each flow tested. This temperature correction reflects, to some degree, the temperature changes of the meter under test. The correction was carried out based on the thermal coefficient of expansion of the meter material.

This temperature correction was performed using the following formula.

$$D = Dr \times (1 + \alpha \times (T - Tr)) \qquad (1)$$

D = Diameter at test temperature (m)
Dr = Defined diameter of package pipe inlet (0.1023 m at 20 °C)
α = Coefficient of linear expansion of the material (0.000 011 °C^{-1} for the Kral meter)
T = Temperature (°C)
Tr = Reference temperature (20 °C)

The Reynolds number (Re) is

$$\mathrm{Re} = \frac{10^6 \times \left(\dfrac{4 \times Q}{\pi \times D^2} \right) \times D}{\nu} \qquad (2)$$

Q = Volumetric flow rate (m^3/s)
ν = Kinematic viscosity (mm^2/s) or (cSt)

The K-factor is used to calculate the temperature-compensated Strouhal number expressed as follows:

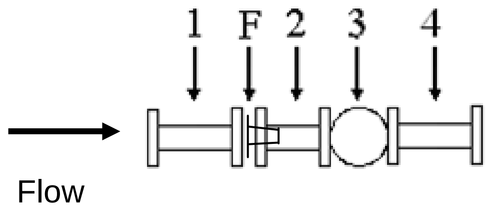
$$\boldsymbol{Strouhal = K \times D^3} \qquad (3)$$

K = K-factor (pulses per cubic meter, herein expressed as pulses per liter, p/L)

In broad terms a positive displacement flowmeter has a performance primarily related to the volume passing through the measuring chamber. Fluid properties provide second order changes to the performance.

The primary analysis of this comparison was carried out by comparing the Strouhal number at a constant Reynolds.

Figure 1 presents the layout of the transfer standard package and a photo.



1- 4" pipe, 500 mm long
F- Cone type insert filter
2- 4" pipe, 300 mm long
3- Kral meter, 450 mm long
4- 4" pipe, 500 mm long

Figure 1 Layout and photo of transfer standard package

3 ORGANIZATION

3.1 Participants

Table 1 lists the detail of participating labs.

Table 1 Detail of participating labs

#	Participating NMI (Economy)	Contact Person E-mail Address and Phone Number Shipping Address
1	CMS (Chinese Taipei)	Dr. Cheng-Tsair Yang ctyang@itri.org.tw, +886-3-5741206 Center for Measurement Standards, Industrial Technology Research Institute 30, Ta Hsueh Rd., Hsinchu, Taiwan 300, R.O.C.
2	VMI (Vietnam)	Dr. Nguyen Hong Thai thaingh@gmail.com, +84-4-38362030 Vietnam Metrology Institute 8, Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam

3.2 Test Schedule

Table 2 provides the order and dates of testing.

Table 2 Test schedule (all dates are in 2009)

Participating NMI	From	To	Remarks
CMS (#1)	June 3	August 3	Preliminary and comparison tests
VMI	September 30	October 9	
CMS (#2)	December 3	December 7	Return check

3.3 Test Method

Each laboratory used its normal test method to calibrate the flowmeter provided in the package to best reflect the capability declared in their CMC entry. Table 3 provides the test methods employed.

Table 3 Test method

Participating NMI	Test Method
CMS	Gravimetric standing start and finish
VMI	Volumetric tank standing start and finish

3.4 Test Protocol

The comparison was conducted across a flow range of 5 L/s to 30 L/s, referring to CCM.FF-K2 key comparison. Table 4 describes the test sequence. A specified number of test points along with the order (flowrates) of the test points were required. The first set of test points was specified in terms of volumetric flow, and two test points were required for each flowrate. The last set of six test points was specified in terms of Reynolds number and were to be spread across the target value of Re = 76 150. This Reynolds number was based on the 4" pipeline, Dr = 0.1023 m, used in this bilateral comparison. This arrangement created a flowrate similar to that of the cardinal point, Re = 100 000, based on a pipeline of Dr = 0.0779 m in the CCM.FF-K2 key comparison.

Table 4 Flowrates and test sequence

Flowrate (L/s)	Reynolds No.	No. of Points
5	N/A	2
10	N/A	2
15	N/A	2
20	N/A	2
25	N/A	2
30	N/A	2
27.5	N/A	2
22.5	N/A	2
17.5	N/A	2
12.5	N/A	2
7.5	N/A	2
Cardinal Point	76 150	6
Total No. of Points		28

Table 5 lists the actual test conditions at the cardinal point.

Table 5 Flowrates and test sequence

Participating NMI	Average Temperature (°C)	Average Kinematic Viscosity (mm^2/s)
CMS	19.97 34.91	4.26 3.01
VMI	33.68	1.24

4 CALIBRATION RESULTS

4.1 Initial Examination of All Data

Figure 2 shows the Kral meter calibration results, expressed by K-factor versus test flowrate, from both laboratories. Appendix A presents all the test data used in this analysis.

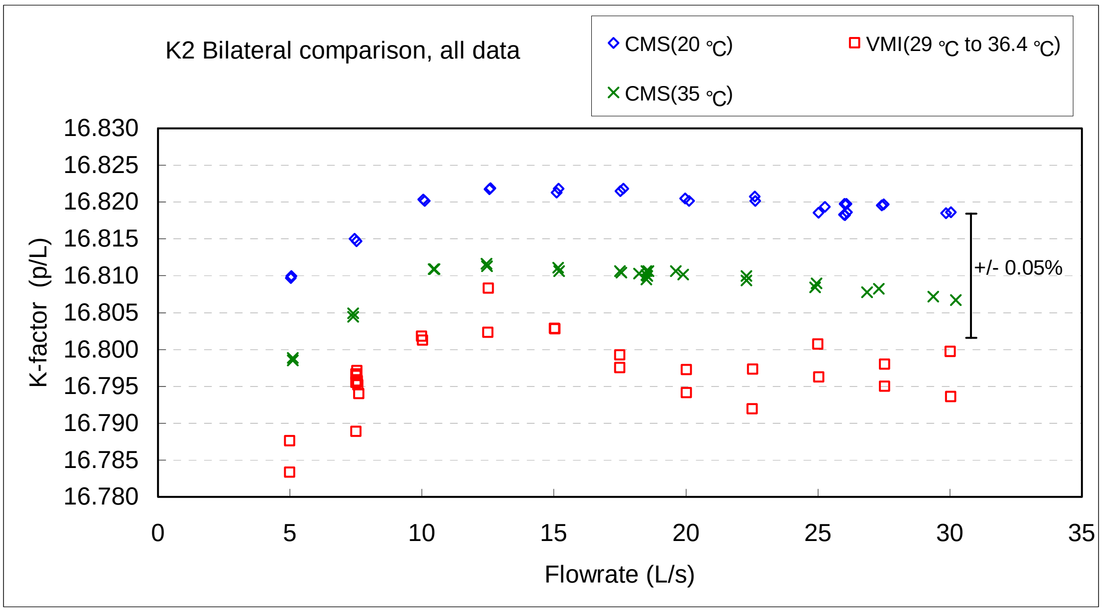


Figure 2 Test results of CMS and VMI represented by K-factor vs. flowrate

In this experimental design, the comparison, in accordance with the CCM.FF-K2 Key Comparison Reference Value (KCRV), was based on the Strouhal number and Reynolds number. The Strouhal number was then calculated and plotted against the Reynolds number, as Fig. 3 shows.

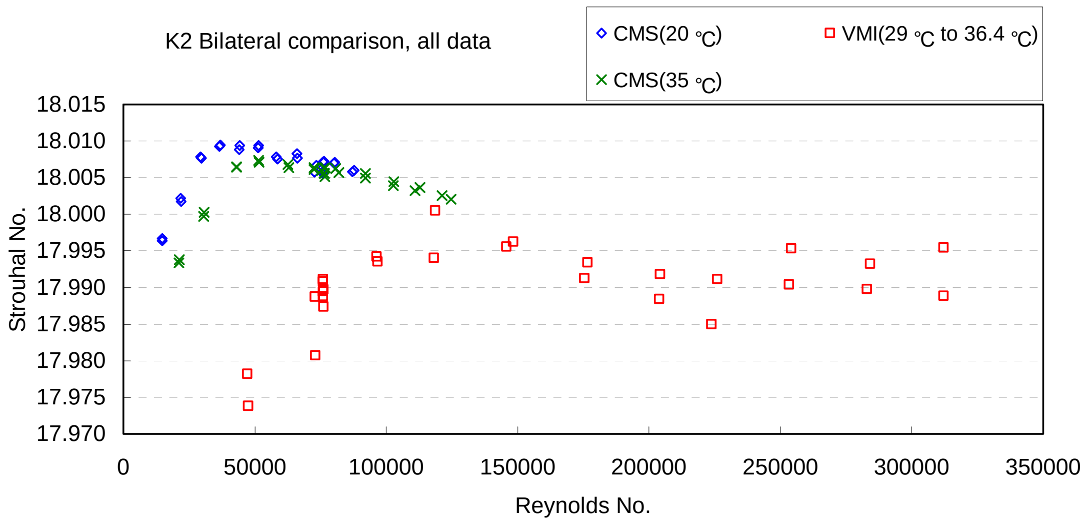


Figure 3 Test results represented by Strouhal no. vs. Reynolds no.

Table 6 gives the Strouhal number and expanded uncertainty derived for each laboratory at *Re* = 76 150. In this table, the Strouhal number is the averaged value of six test data, and U_i is the expanded uncertainty with a coverage factor (*k*) of 2.

Table 6 Calibration results reported by the participating labs (*Re* = 76 150)

NMI	Calibration Result Strouhal no.	Expanded Uncertainty U_i
CMS	18.0065 (20 °C) 18.0058 (35 °C)	0.049 %
VMI	17.9896	0.088 %

Although the cardinal point of this comparison was originally set at *Re* = 76 150, however, as can be seen in Fig.3, the transfer standard lost its typical *Re*-dependent characteristic at Reynolds number lower than approximately 120 000 when tested at VMI due to the relatively low kinematic viscosity oil used and associated lower flow rate. Therefore, it is deemed more appropriate to evaluate the degree of equivalence between VMI and CMS at *Re* = 120 000 rather than *Re* = 76 150. Table 7 gives the Strouhal number and expanded uncertainty derived for each laboratory at *Re* = 120 000. In this table, the Strouhal number is the averaged value of two test data, and U_i is the expanded uncertainty with a coverage factor (*k*) of 2.

Table 7 Calibration results reported by the participating labs (*Re* = 120 000)

NMI	Calibration Result Strouhal no.	Expanded Uncertainty U_i
CMS	18.0023 (34.86 °C)	0.049 %
VMI	17.9973 (29.30 °C)	0.088 %

4.2 Kinematic Viscosity and Temperature Effects

The kinematic viscosity of the oils used in CMS and VMI were, at the reference temperature of 20 °C, 4.26 mm^2/s and 1.55 mm^2/s, respectively. The CCM.FF-K2 intercomparison shows that there is a strong correlation between the Strouhal number and the kinematic viscosity of the fluid used. Thus, the comparison results in this report were considered to be corrected for the effect of kinematic viscosity.

Because the testing conditions in VMI were substantially different from the reference temperature, additional temperature effect on the meter characteristics should be considered. Therefore, NMIJ was invited to conduct a test to evaluate possible performance changes in the transfer standard due to kinematic viscosity and temperature effects. The test schedule in NMIJ was from February 5, 2010 to March 3, 2010.

There are two kinds of liquid hydrocarbon used in NMIJ, kerosene (KE) and light oil (LO), so that NMIJ can conduct the test for the effect of kinematic viscosity and temperature using different oils. Table 8 lists the kinematic viscosity of both oils.

Table 8 Kinematic viscosity of the oils used in NMIJ

Oil	Kinematic viscosity at 20 °C (mm^2/s)	Kinematic viscosity at 35 °C (mm^2/s)
Kerosene	2.09	1.62
Light oil	6.88	4.58

Figure 4 shows the test results at temperatures of 20 °C and 35 °C at a Reynolds number close to the cardinal point. Appendix B presents all test data.

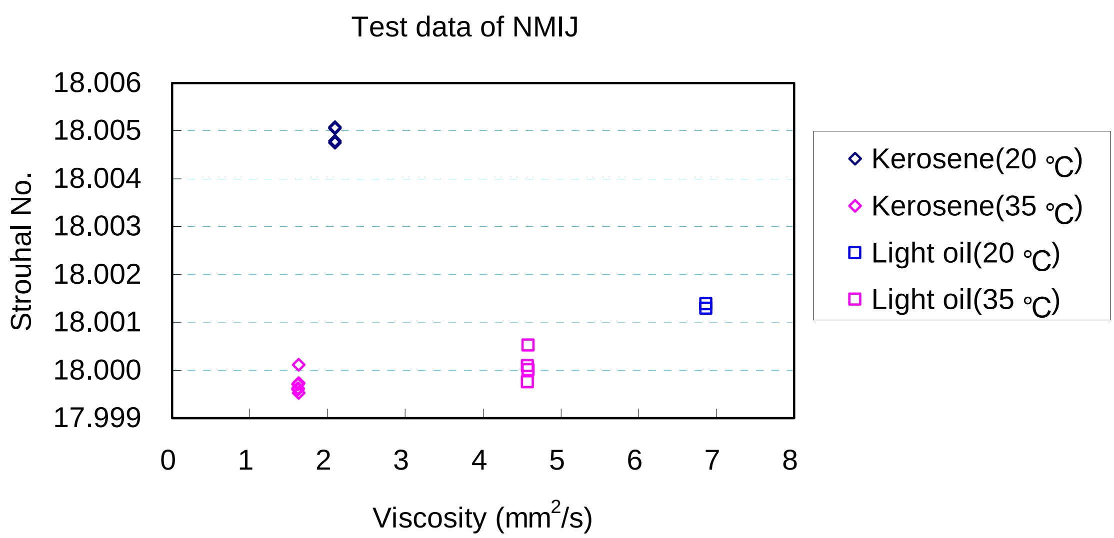


Figure 4 Test results of NMIJ represented by Strouhal no. vs. kinematic viscosity

NMIJ's test results show that both kinematic viscosity and temperature affect the meter performance. The Strouhal number increases with the kinematic viscosity at 20 °C, but an opposite trend is observed at 35 °C, suggesting that both the kinematic viscosity and temperature effects should be taken into consideration if both operated in wide ranges. However, the combined effects could not be well understood due in part to the limited information and knowledge available.

Figure 5 shows the results of combining the test data of NMIJ and CMS at both temperatures. For each set of the test data, error bars having magnitude corresponding to the claimed expanded uncertainty centered at the mean of the data set are given to facilitate comprehension. As can be seen, the regression line of Strouhal no. vs. kinematic viscosity has an estimated slope of 0.000 19 ± 0.000 39. The uncertainty of this slope exceeds its absolute value, indicating that the dependency of these two variables is not significant. Analysis of variance (ANOVA) of these test data results in a p-value of 0.63, which is lager than 0.05, suggesting that these test results with varied viscosities and temperatures do not differ significantly. Therefore, this comparison does not make viscosity and temperature corrections.

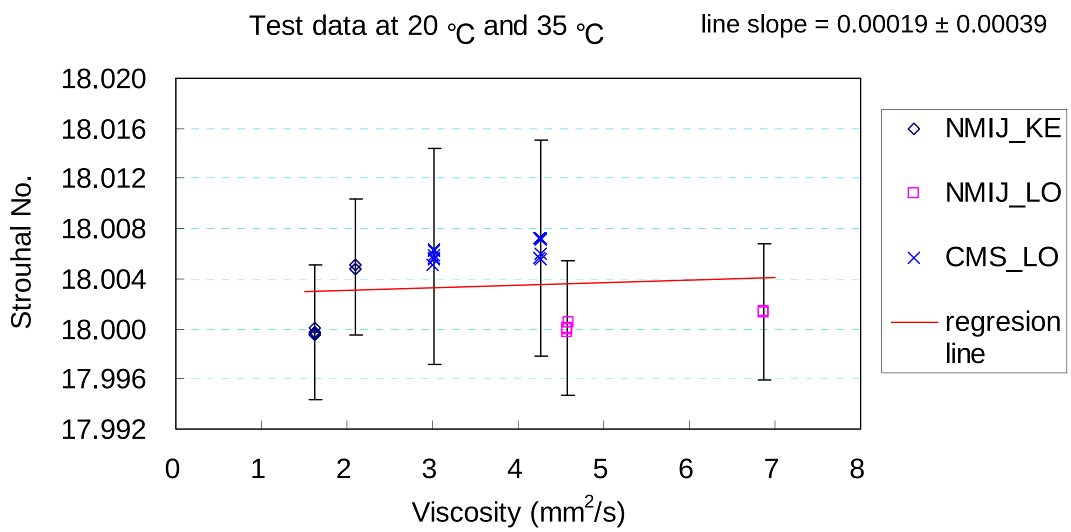


Figure 5 Test results with regression line of NMIJ and CMS at 20 °C and 35 °C

4.3 Reproducibility of the Transfer Standard Observed at CMS

Figure 6 shows the averaged calibration results of the transfer standard at a flowrate corresponding to *Re* = 76 150 during the earlier tests and after the comparison carried out in CMS. This figure shows that the Kral meter had very stable reproducibility at the cardinal point *Re* = 76 150.

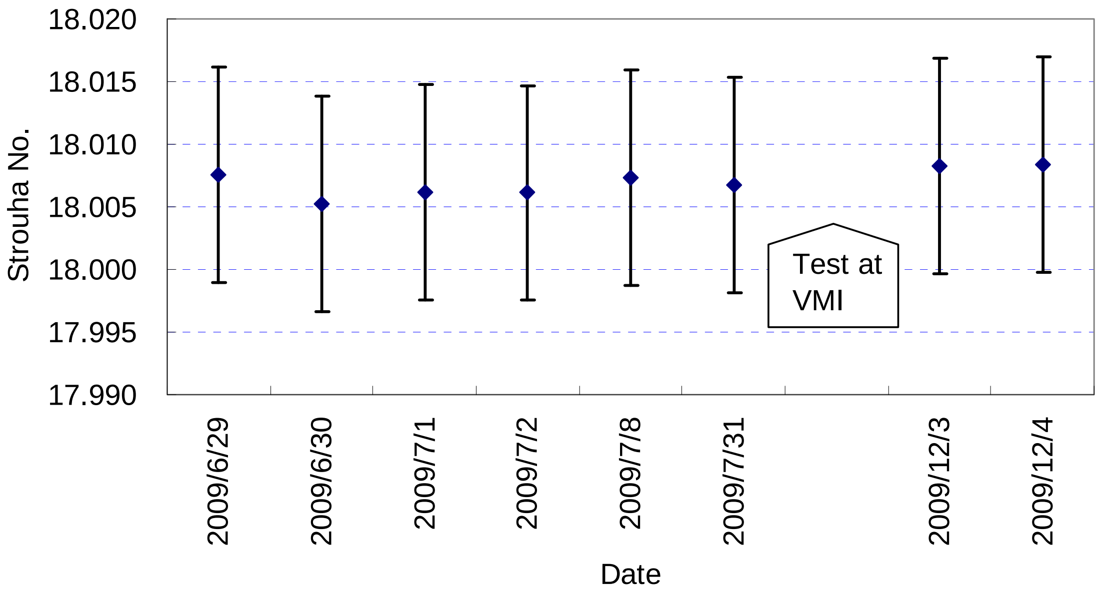


Figure 6 Result of reproducibility test

5 ANALYSIS OF COMPARISON RESULTS

5.1 Degrees of Equivalence of VMI Relative to CMS

The degree of equivalence, *d*, between VMI and CMS at *Re* = 120 000 was calculated as follows, with U_d denoting the expanded uncertainty of *d*.

$$d = St_{\mathrm{VMI}} - St_{\mathrm{CMS}} = 17.9973 - 18.0023 = -0.0050$$

$$U_{\mathrm{d}} = \sqrt{U_{\mathrm{VMI}}{}^{2} + U_{\mathrm{CMS}}{}^{2}} = \sqrt{(17.9973 \times 0.088\,\%)^{2} + (18.0023 \times 0.049\,\%)^{2}} = 0.0181$$

The results can be expressed as percentage relative to the CMS value.

$$d\ (\%)_{\mathrm{VMI-CMS}} = d \,/\, St_{\mathrm{CMS}} = -0.0050 / 18.0023 = -0.028\,\%$$

$$U_{\mathrm{d}}\ (\%)_{\mathrm{VMI-CMS}} = U_{\mathrm{d}} \,/\, St_{\mathrm{CMS}} = 0.0181 / 18.0023 = 0.10\,\%$$

Calculate the *En*-criterion.

$$En = \frac{|d|}{U_d} = \frac{|-0.0050|}{0.0181} = 0.28$$

Table 9 summarizes the results.

Table 9 Strouhal number, uncertainty and *En* value at *Re* = 120 000

Laboratory	Strouhal no.	Expanded Uncertainty (%)	*D* as % of CMS value	*En*
CMS	18.0023	0.049		
VMI	17.9973	0.088	-0.03	0.28

CMS participated in the CCM-WGFF key comparison (CCM.FF-K2) that took place during 2005 to 2007; however, for the test point at *Re* = 120 000, the operation condition of CMS in this comparison is quite different from that in CCM-WGFF key comparison. There is not enough evidence to prove the applicability of the same difference for CMS's data at this test point. Therefore, linkage of the results of this bilateral comparison to KCRV of CCM.FF-K2 will not be provided here.

6 CONCLUSIONS

A selected transfer standard, a 4-inch Kral PD meter, was circulated between VMI and CMS for five months starting July 2009. Repeated calibration results at CMS demonstrate sufficient reproducibility of the transfer standard.

Tests were carried out in NMIJ and CMS to examine the kinematic viscosity and temperature effects on the meter performance. Because the combined effects of temperature and kinematic viscosity on the transfer standard at the cardinal Reynolds number were small compared to the experimental uncertainty, this comparison does not make viscosity and temperature corrections.

Because of differences in the operating conditions at CMS between this comparison and CCM.FF-K2, this report adopts the test result of CMS as the reference value for this bilateral comparison. Comparison results showed that the *En* value between VMI and CMS was less than 1, proving consistency between the two laboratories.

7 ACKNOWDGEMENT

The author of this bilateral comparison project would like to thank the staff of the NMIJ hydrocarbon flow facility for testing the effects of kinematic viscosity and temperature on the transfer standard.

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APPENDIX A

TABLES OF FINAL RESULTS

Table A.1: CMS 1

Pt. No.	Temp °C	Volume L	Time s	Flow L/s	Visc. mm²/s	Reynolds	Pulses	K-factor p/L	Strouhal
1	19.920	6255.987	1237.35	5.056	4.265	14753	105163	16.8100	17.9967
2	19.965	6257.056	1244.16	5.029	4.260	14691	105179	16.8097	17.9964
3	20.060	6414.146	634.4	10.111	4.250	29605	107887	16.8202	18.0077
4	19.975	6416.158	638.19	10.054	4.259	29376	107922	16.8203	18.0078
5	19.945	6454.298	425.26	15.177	4.262	44314	108573	16.8218	18.0094
6	19.940	6442.729	426.48	15.107	4.263	44102	108375	16.8213	18.0088
7	19.895	6462.613	321.33	20.112	4.268	58648	108702	16.8201	18.0076
8	19.830	6478.241	324.41	19.969	4.275	58137	108967	16.8205	18.0079
9	19.790	6499.600	257.34	25.257	4.279	73458	109319	16.8193	18.0066
10	19.760	6491.585	259.39	25.026	4.282	72733	109179	16.8185	18.0058
11	19.965	6513.677	218.25	29.845	4.260	87183	109550	16.8185	18.0058
12	19.990	6526.579	217.28	30.038	4.258	87801	109768	16.8186	18.0060
13	19.995	6516.109	237.65	27.419	4.257	80156	109598	16.8195	18.0070
14	19.990	6497.456	236.28	27.499	4.258	80380	109285	16.8197	18.0071
15	19.970	6479.977	286.59	22.611	4.260	66058	108998	16.8207	18.0083
16	20.030	6477.951	286.27	22.629	4.253	66211	108960	16.8201	18.0076
17	20.015	6453.957	368.60	17.509	4.255	51212	108565	16.8215	18.0091
18	19.925	6447.752	365.75	17.629	4.265	51446	108463	16.8218	18.0094
19	19.955	6428.543	510.43	12.594	4.261	36781	108140	16.8219	18.0094
20	19.825	6434.287	512.11	12.564	4.275	36574	108236	16.8218	18.0093
21	19.960	6277.353	843.20	7.445	4.261	21745	105554	16.8150	18.0022
22	19.930	6275.83	834.62	7.519	4.264	21946	105526	16.8147	18.0017
23	19.915	6490.456	249.54	26.010	4.266	75884	109168	16.8198	18.0072
24	20.040	6503.187	249.28	26.088	4.252	76351	109382	16.8198	18.0072
25	19.945	6497.083	249.40	26.051	4.262	76061	109279	16.8197	18.0071
26	20.070	6498.542	249.60	26.036	4.249	76256	109294	16.8182	18.0056
27	19.920	6518.509	250.83	25.988	4.265	75830	109630	16.8183	18.0056
28	19.945	6494.945	248.90	26.095	4.262	76189	109236	16.8186	18.0060

Pt. No.	Temp °C	Volume L	Time s	Flow L/s	Visc. mm^2/s	Reynolds	Pulses	K-factor p/L	Strouhal
1	34.955	6340.195	1239.25	5.116	3.010	21153	106506	16.7985	17.9934
2	35.095	6343.236	1240.89	5.112	3.002	21194	106559	16.7988	17.9938
3	34.710	6382.290	610.77	10.450	3.025	42992	107292	16.8109	18.0065
4	34.720	6380.569	609.45	10.469	3.025	43082	107263	16.8109	18.0065
5	34.985	6405.292	421.55	15.195	3.009	62860	107677	16.8106	18.0063
6	34.865	6400.466	422.34	15.155	3.016	62545	107599	16.8111	18.0068
7	34.805	6441.825	323.89	19.889	3.019	81984	108288	16.8101	18.0057
8	34.785	6434.260	328.09	19.611	3.021	80807	108164	16.8106	18.0062
9	34.820	6442.636	258.32	24.941	3.018	102838	108294	16.8090	18.0045
10	34.840	6468.902	259.79	24.901	3.017	102715	108732	16.8084	18.0039
11	34.855	6478.955	214.30	30.233	3.016	124749	108890	16.8067	18.0021
12	34.860	6471.231	220.27	29.379	3.016	121236	108763	16.8072	18.0026
13	34.895	6446.955	239.93	26.870	3.014	110962	108359	16.8078	18.0032
14	34.890	6464.881	236.69	27.314	3.014	112782	108663	16.8082	18.0037
15	34.880	6437.375	288.78	22.292	3.015	92027	108212	16.8100	18.0056
16	34.945	6447.176	289.24	22.290	3.011	92140	108373	16.8094	18.0050
17	34.980	6420.657	365.73	17.556	3.009	72621	107934	16.8104	18.0061
18	35.040	6426.527	367.07	17.508	3.005	72508	108034	16.8106	18.0064
19	35.125	6400.050	513.72	12.458	3.000	51683	107593	16.8113	18.0071
20	34.975	6390.411	513.64	12.441	3.009	51460	107433	16.8116	18.0074
21	34.965	6354.623	860.09	7.388	3.010	30553	106786	16.8045	17.9997
22	35.090	6358.325	860.83	7.386	3.002	30621	106851	16.8049	18.0003
23	34.880	6422.737	352.36	18.228	3.015	75250	107968	16.8103	18.0059
24	34.970	6414.450	345.30	18.576	3.009	76827	107831	16.8106	18.0063
25	34.805	6411.151	346.40	18.508	3.019	76292	107772	16.8101	18.0057
26	34.860	6416.487	346.20	18.534	3.016	76484	107861	16.8100	18.0056
27	34.900	6419.099	347.04	18.497	3.014	76391	107909	16.8106	18.0063
28	35.050	6440.183	348.12	18.500	3.005	76633	108256	16.8095	18.0051

Table A.2: VMI

Pt. No.	Temp °C	Volume L	Time s	Flow L/s	Visc. mm²/s	Reynolds	Pulses	K-factor p/L	Strouhal
1	29.05	1993.494	398.92	4.997	1.319	47140	33,466	16.7876	17.9782
2	29.45	2011.818	401.86	5.006	1.311	47514	33,765	16.7833	17.9738
3	30.40	1994.081	198.61	10.040	1.293	96647	33,503	16.8012	17.9936
4	30.50	1992.405	199.40	9.992	1.291	96324	33,476	16.8018	17.9942
5	30.95	9932.077	661.21	15.021	1.283	145748	166,887	16.8028	17.9956
6	32.15	9962.645	662.41	15.040	1.261	148397	167,400	16.8028	17.9962
7	34.55	9994.439	499.02	20.028	1.223	203850	167,848	16.7941	17.9884
8	34.70	9968.176	497.79	20.025	1.220	204191	167,438	16.7973	17.9919
9	34.05	9977.293	398.45	25.040	1.230	253288	167,581	16.7962	17.9904
10	34.45	9971.624	398.74	25.008	1.224	254221	167,530	16.8007	17.9954
11	36.30	9984.650	332.38	30.040	1.198	312120	167,678	16.7936	17.9889
12	36.35	9987.485	332.74	30.016	1.197	312046	167,787	16.7997	17.9955
13	35.40	9959.354	361.83	27.525	1.210	283034	167,267	16.7950	17.9898
14	35.75	9973.060	362.34	27.524	1.205	284185	167,527	16.7980	17.9932
15	32.70	9957.034	442.18	22.518	1.252	223834	167,198	16.7919	17.9850
16	33.40	9989.458	443.37	22.531	1.240	226025	167,796	16.7973	17.9911
17	33.30	9953.685	568.55	17.507	1.242	175402	167,197	16.7975	17.9913
18	33.80	9976.935	569.82	17.509	1.234	176549	167,605	16.7992	17.9935
19	29.20	2005.079	160.34	12.505	1.316	118235	33,690	16.8023	17.9940
20	29.40	2008.651	160.42	12.521	1.312	118748	33,762	16.8083	18.0005
21	31.10	2004.665	267.10	7.505	1.280	72979	33,656	16.7888	17.9807
22	30.85	2001.491	266.25	7.517	1.284	72835	33,618	16.7965	17.9887
23	33.15	1996.133	261.96	7.620	1.245	76195	33,523	16.7940	17.9874
24	33.35	1997.838	263.57	7.580	1.241	75991	33,554	16.7952	17.9888
25	33.55	1994.856	263.87	7.560	1.238	75987	33,505	16.7957	17.9895
26	33.70	2001.592	265.46	7.540	1.236	75933	33,621	16.7971	17.9911
27	34.05	1997.717	266.01	7.510	1.230	75965	33,555	16.7967	17.9908
28	34.30	2001.844	266.91	7.500	1.226	76102	33,622	16.7955	17.9897

Table A.3: CMS 2

Pt. No.	Temp °C	Volume L	Time s	Flow L/s	Visc. mm²/s	Reynolds	Pulses	K-factor p/L	Strouhal
1	20.295	6263.611	1244.14	5.034	4.225	14830	105295	16.8106	17.9976
2	19.980	6261.285	1248.10	5.017	4.259	14661	105263	16.8117	17.9986
3	20.080	6297.771	633.70	9.938	4.248	29117	105929	16.8201	18.0076
4	19.975	6301.197	642.67	9.805	4.259	28651	105993	16.8211	18.0086
5	19.975	6324.591	425.03	14.880	4.259	43483	106392	16.8220	18.0096
6	19.810	6322.971	416.83	15.169	4.277	44144	106367	16.8223	18.0098
7	19.820	6356.321	319.01	19.925	4.276	57999	106926	16.8220	18.0095
8	20.020	6354.395	320.19	19.846	4.254	58058	106893	16.8219	18.0095
9	19.990	6378.553	255.16	24.998	4.258	73077	107290	16.8204	18.0079
10	19.810	6373.506	252.60	25.232	4.277	73427	107211	16.8214	18.0088
11	19.855	6389.568	213.49	29.929	4.272	87196	107475	16.8204	18.0078
12	20.035	6393.899	213.76	29.912	4.253	87539	107542	16.8195	18.0069
13	20.025	6395.995	231.15	27.670	4.254	80959	107583	16.8204	18.0079
14	19.905	6370.758	230.79	27.604	4.267	80523	107160	16.8206	18.0081
15	19.920	6343.634	284.61	22.289	4.265	65043	106709	16.8214	18.0090
16	20.010	6362.240	284.80	22.339	4.255	65337	107021	16.8213	18.0089
17	20.020	6339.554	361.49	17.537	4.254	51305	106644	16.8220	18.0096
18	19.920	6329.923	365.71	17.309	4.265	50509	106483	16.8222	18.0097
19	19.780	6309.676	514.44	12.265	4.280	35666	106143	16.8223	18.0098
20	19.900	6320.530	498.75	12.673	4.267	36963	106327	16.8225	18.0101
21	20.055	6282.451	844.67	7.438	4.251	21778	105643	16.8156	18.0028
22	20.160	6281.279	851.47	7.377	4.240	21657	105632	16.8170	18.0043
23	20.070	6387.505	245.79	25.988	4.249	76122	107444	16.8210	18.0086
24	20.090	6380.546	245.34	26.007	4.247	76216	107327	16.8210	18.0086
25	20.080	6392.150	245.85	26.000	4.248	76177	107521	16.8208	18.0084
26	20.090	6377.195	245.27	26.001	4.247	76198	107267	16.8204	18.0080
27	20.095	6370.281	244.94	26.008	4.246	76227	107151	16.8205	18.0080
28	20.140	6382.928	245.50	26.000	4.242	76290	107364	16.8205	18.0081

APPENDIX B

TABLE OF TEST RESULTS IN NMIJ

Pt. No.	Temp °C	Volume L	Time s	Flow L/s	Visc. mm^2/s	Reynolds	Pulses	K-factor p/L	Strouhal
1	20.090	11210.345	335.57	33.407	6.867	60554	188493	16.8142	18.0013
2	20.092	11208.754	335.51	33.408	6.866	60561	188467	16.8143	18.0014
3	35.024	11338.436	402.53	28.168	4.582	76508	190639	16.8052	18.0005
4	35.128	11335.901	402.43	28.168	4.571	76703	190592	16.8047	18.0001
5	35.037	11337.119	402.33	28.179	4.581	76562	190611	16.8047	18.0000
6	35.072	11332.596	402.36	28.165	4.577	76589	190533	16.8044	17.9998
7	19.882	11732.295	924.69	12.688	2.092	75501	197307	16.8175	18.0048
8	19.894	11731.072	924.63	12.687	2.091	75514	197287	16.8175	18.0048
9	19.897	11733.195	925.09	12.683	2.091	75495	197326	16.8178	18.0051
10	19.900	11732.048	924.82	12.686	2.091	75513	197307	16.8178	18.0051
11	34.881	11889.399	1204.50	9.871	1.627	75530	199898	16.8049	18.0001
12	34.915	11889.779	1194.31	9.955	1.626	76215	199900	16.8045	17.9997
13	34.978	11890.646	1194.03	9.958	1.624	76313	199913	16.8044	17.9996
14	34.974	11888.925	1204.01	9.874	1.624	75665	199885	16.8044	17.9997
15	34.970	11891.315	1204.18	9.875	1.624	75665	199924	16.8043	17.9996
16	34.925	11889.693	1203.74	9.877	1.626	75629	199896	16.8043	17.9995