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INTERNATIONAL KEY COMPARISON OF LIQUID HYDROCARBON FLOW FACILITIES CCM-FF-K2 (Final Report)

A Report for

BIPM
Pavillon de Breteuil
F-92312 Sevres
France

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SUMMARY

This international key comparison was carried out in the field of liquid hydrocarbon flow. The intercomparison initially involved nine laboratories each designated as national standard calibration laboratories. The comparison was carried out using the BIPM guidelines for key comparisons and will be included in the BIPM database to support the capability statements of the institutes as part of the MRA. The intercomparison was designated as being comparison CCM-FF-K2 by WGFF.

The key comparison was carried out using light liquid hydrocarbon across a flow range 5 to 30 l/s. Two meters, a Kral positive displacement meter and a turbine meter, were used in the intercomparison package; however, the primary comparison used the Kral positive displacement meter. Strouhal and Reynolds number were used as the key parameters to express the laboratories' (dynamic) measurement of volume and flowrate.

Six laboratories finally provided results to allow the calculation of a KCRV (based on Strouhal number), and all six sets of results were consistent with the KCRV. The deviations from the KCRV using the Kral meter lay within a band of ±0.026%.

CONTENTS

1 INTRODUCTION

Key comparisons have been established as the means to demonstrate equivalence of metrology standards across the world. The Bureau International des Poids et Measures (BIPM), working through the Comité International des Poids et Mesures (International Committee of Weights and Measures) (CIPM) has established the methodology and processes by which these intercomparisons are carried out. The objective is to provide confidence in measurements provided by National laboratories which are signatories to the CIPM mutual recognition agreement (MRA). High-quality transfer standards are circulated between the Institutes and the degree of equivalence established relative to the declared uncertainties. This supports the laboratories statements of Calibration and Measurement Capability (CMC) submitted to CIPM [1].

Within the CIPM, the Working Group for Fluid Flow (WGFF) has established the key comparisons for the measurement of flow and volume. Several key comparisons have been established covering volume, water, oil and gas flow measurement.

Key comparison CCM-FF-K2 was undertaken to demonstrate the degree of equivalence of participating laboratories in the measurement of light liquid hydrocarbon (viscosity range 1 to 10 cSt) flows at rates between 5 and 30 litres/second.

The draft A report was prepared according to the Guidelines for CIPM Key Comparisons [2],[3]; comments were received from participants; and draft B has been prepared.

The intercomparison was led by NEL (TUV NEL - UK) as the designated pilot laboratory. After expressing an early interest, three countries, France, USA, and Brazil, withdrew before the start of the intercomparison owing to the NMI not designating the identified laboratories. The other participants were SP (Sweden), CMI (Czech Republic), NMi (NMi Van Swinden Laboratory - Netherlands), FORCE (Denmark), NMIJ (Japan), CMS (Chinese Taipei), CENAM (Mexico) and MC (Canada). CENAM, MC and CMI withdrew during the course of the project. The reasons for this are more fully explained in Section 3.3.

The performance of the meter package was expressed in terms of Reynolds number rather than of volumetric flowrate as a means to include the effect of fluid properties (viscosity and density) on the intercomparison package. Strouhal number was used as the performance indicator and to express the KCRV rather than error or K-factor. Strouhal number is a function of K-factor and temperature compensated pipe diameter and is a means of incorporating the effect of temperature on the performance of the meter package.

As Strouhal number is a function of K-factor, and the temperature variation is very small, the percentage uncertainty in Strouhal number is very similar to that in K-factor and reflects the primary measurement of volume (m^3). Although Strouhal number is an unfamiliar performance indicator, the deviation of each result from the KCRV will be effectively the same as it would be if K-factor or meter error had been used. As the absolute value of the KCRV is not of concern in expressing the result of an intercomparison the use of Strouhal number is acceptable as it expresses adequately the percentage deviation of institutes' results from the KCRV.

The analysis of the results has been carried out according to the methods specified by Cox [4].

2 TRANSFER STANDARD

2.1 Transfer Standard Concept

The design of the transfer standard was based on a number of criteria:

- Two meters were to be employed.
- The meters chosen were to have a proven performance in light hydrocarbon oil.
- The package should be able to provide one clear derivation of the Key Comparison Reference Value (KCRV) using one meter. The second meter should support this if required.
- The package should be able to identify facility installation issues but is not expected to quantify these.
- The flow range should match the capability of the participants.
- The package should utilise standard and easily obtainable components to allow duplicate packages to be produced.

An intercomparison had been carried out in 1995 [5] organised by SP (Sweden) using a combination package of two flowmeters. This comparison package consisted of a positive-displacement-type (Kral) meter placed downstream of a turbine meter which itself was placed downstream of an optional tube-bundle flow conditioner.

This package allowed an intercomparison to be carried out based on the positive displacement meter which had a linear performance, was insensitive to flow profile, and had a relatively small but predictable change in performance with viscosity.

The second meter installed upstream of the positive displacement meter was a turbine meter: it was less linear and more sensitive to changes in viscosity than the positive displacement meter. The turbine was sensitive to flow profile disturbances present in the flow line, particularly swirl. The installation of a tube bundle upstream of the turbine would remove most of the swirl component of any flow disturbance. This allows testing to proceed with and without this conditioner to indicate the presence of flow disturbance in the test facility.

This package was utilised to good effect in the reported intercomparison and was used as the basis for this intercomparison package.

The SP package was available to support the intercomparison; however, a package of identical design was procured by the pilot laboratory.

During the 1995 intercomparison, the results were compared based on the calculation of volumetric flowrate and meter K-factor. For this project it was decided to alter this analysis method to work primarily in terms of Reynolds number and Strouhal number. As both flowmeters were of different diameters, it was decided for calculation purposes to use a single reference diameter based on that of the inlet pipe. As both Strouhal and Reynolds numbers are dependent on an actual diameter, the defined diameter at 20°C has to be corrected for temperature expansion for each flow test. This temperature correction will reflect to some degree the temperature changes to the meters under test. For each meter the correction was carried out based on the thermal coefficient of expansion of the material of that meter.

This temperature correction was carried out using the formula below.

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

D = Diameter at test temperature (m)
Dr = Defined diameter (0.0779 m at 20°C)
α = Coefficient of linear expansion of material (steel for Kral, stainless steel for turbine)
T =Temperature (°C)
Tr = Reference temperature (20°C)

Reynolds number is expressed as

$$\boldsymbol{Re} = \frac{\mathbf{1000} \times \rho \times \left(\dfrac{\mathbf{4} \times \boldsymbol{Q}}{\pi \times \boldsymbol{D}^2} \right) \times \boldsymbol{D}}{\eta}$$

Q = Volumetric flowrate (m^3/s)
ρ = Density (kg/m^3)
η = Dynamic viscosity (mPas) or (cP)

(Note: this equation is expressed in the form used in the NEL software. It can be re-arranged to a more classical form or to express flowrate in terms of a given Reynolds number).

For each meter the K-factor is used to calculate Strouhal number (temperature compensated) expressed as:

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

K = K-factor (p/m^3)

The decision and limitations of deciding to use Reynolds and Strouhal numbers as the flowrate and performance indicators are discussed in more detail later in the report. The use of Strouhal number rather than K-factor is relatively unimportant for both meters. The choice of Reynolds number, however, can be shown to work well for the turbine flowmeter where the use of Reynolds number compensates for a significant proportion of the viscosity effect on the turbine meter performance.

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. A turbine meter however infers the volume flowrate from the interaction of the flow with the blades, making it highly dependent on the fluid properties, and hence the performance is better expressed in terms of Reynolds number than volume flowrate.

The primary analysis of this intercomparison has been carried out through comparison of Strouhal number at a constant Reynolds number as originally agreed.

The analysis was carried out in line with the internationally agreed methods for key comparisons [4].

This calls for the definition of a Key Comparison Reference Value (KCRV) with which the results from each laboratory are compared. It was decided to analyse the data at a fixed Reynolds number of 10^5 and derive the KCRV at this value. This means that the comparison will take place at a constant Reynolds number but at a very different volumetric flowrate for each laboratory. This difference is related to the different viscosities of the oil used. The concern over taking this decision is that the meters, particularly the positive displacement meter, are volumetric devices and therefore for the chosen Reynolds number the meter is operating at a different point on the flowrate characteristic curve. For this reason an alternative analysis method was tried based on comparing flowrate characteristics across the volume flow range. As a method of comparison across a range is not covered within the standard analysis methods [4] a preliminary comparison method has been defined.

2.2 Design of the Transfer Standard

The package circulated during the exercise was based on a design used in the earlier EU-funded intercomparison exercise [5] and was made up of two meters and associated pipework. The upstream meter was a 3-inch turbine meter and the downstream meter was a 4-inch screw meter manufactured by Kral. Two configurations were tested: in the first, a flow conditioner was placed upstream of the turbine meter and, in the second, the conditioner was removed. The two configurations have been designated Configuration 1 (C1) and Configuration 2 (C2). The layout of the package is shown in Figure 1, and the testing protocol is summarised in Section 3.2.

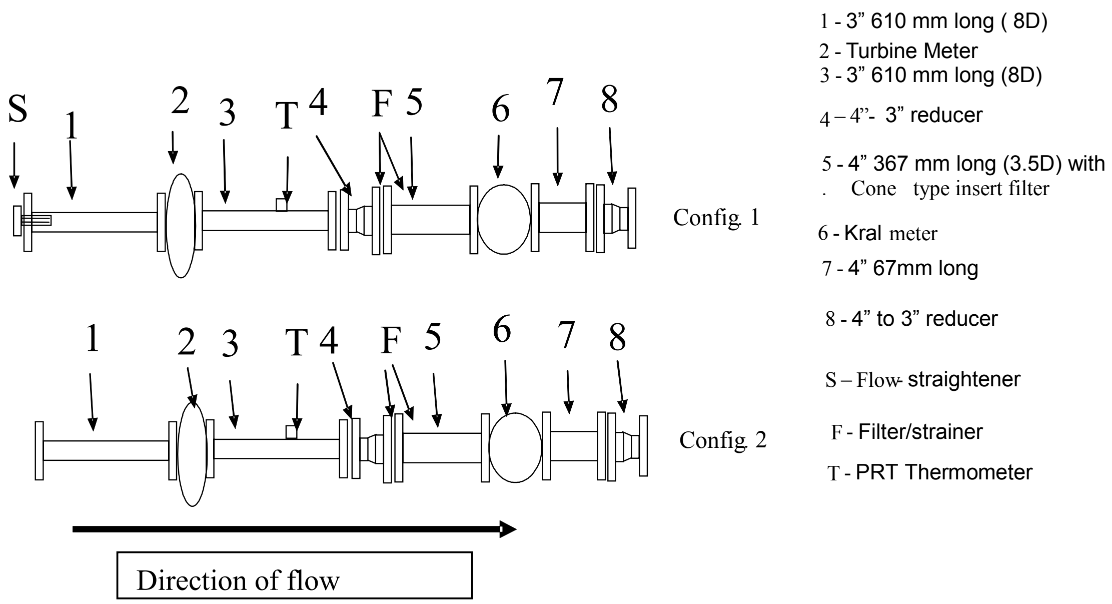

Figure 1 Test Package Configurations

Prior to its use for the intercomparison, the package was thoroughly tested at NEL and at SP to verify its performance against that of the earlier EU project package. The results of this verification testing are available from NEL [6].

3 ORGANIZATION

3.1 Test Schedule

The order and dates of testing are given in Table 1a.

TABLE 1(A)
TEST SCHEDULE

Laboratory	Country	Test dates	Comments
NEL	UK	May 2005	
SP	Sweden	June 2005	
CMI	Czech Rep	July 2005	
NMi	Netherlands	September 2005	Kral meter electronic pick up was damaged before testing and repaired
FORCE	Denmark	January 2006	Kral found with badly damaged bearings. Was repaired by FORCE before testing.
CMS	Chinese Taipei	March 2006	
NMIJ	Japan	April 2006	
CENAM	Mexico	June 2006	Results withdrawn
MC	Canada	August 2006	Results withdrawn
NEL	UK	October 2006	Confirmatory testing only
NEL	UK	November 2006	
NMi	Netherlands	February 2007	
FORCE	Denmark	February 2007	
SP	Sweden	March 2007	
CMI	Czech Rep.	June 2007	Results invalid and withdrawn
NEL	UK	July 2007	

The package was successfully calibrated at NEL (UK), CMI (Czech Republic) and SP (Sweden). NMi (Netherlands) reported that the Kral meter was dropped while being installed. The electronic pickup was damaged. NMi effected a repair and, as a pickup can be replaced without affecting meter performance, testing was continued. No significant change in performance was noted based on receiving preliminary results from NMi.

The package was then sent to FORCE (Denmark). FORCE installed the package and immediately reported erratic behaviour from the Kral meter. The meter was removed and examined. It was identified that there was damage to the internal bearings. As FORCE had experience of maintaining this type of meter they were commissioned to obtain the required parts and carry out a repair. This was carried out and FORCE successfully tested the package.

From FORCE the package was tested at CMS (Chinese Taipei), NMIJ (Japan), CENAM (Mexico) and MC (Canada) returning to NEL in September 2006.

NEL carried out an initial examination of the data. Although small, there appeared to be a change in the characteristic of the Kral meter and this was assumed to be a result of the repair.

As had been previously agreed with the participants, the package was immediately re-calibrated by NEL and returned to the laboratories who had received the package prior to the breakdown, hence completing a circuit.

This involved returning the package to NMi, SP, FORCE and CMI. The order was chosen to suit the laboratories' availability. CMI reported that they were unable to test in configuration 2 and, on completion of the tests, reported their results were unacceptable owing to a high degree of scatter.

Each laboratory used the test method identified by them as the normal method used to calibrate flowmeters of the type provided in the package while best reflecting the capability declared in their CMC entry. The test methods employed are summarised in the table 1b.

TABLE 1(B)
TEST METHODS

Laboratory	Test Method
NEL	Gravimetric standing start and Finish
SP	
CMI	
NMi	Volumetric tank Standing start and finish
FORCE	Reference meter calibrated before and after each run against Small Volume prover.
CMS	Gravimetric standing start and finish
NMIJ	Gravimetric Flying start and finish via diverter.
CENAM	Small volume prover
MC	Volumetric proving tank – standing start and finish
NEL	Gravimetric standing start and Finish
NEL	Gravimetric standing start and Finish
NMi	Volumetric tank Standing start and finish
FORCE	Reference meter calibrated before and after each run against Small Volume prover.
SP	
CMI	Small volume prover, Sequential testing of each meter
NEL	Gravimetric standing start and Finish

3.2 Test Protocol

Each laboratory tested the package twice, with and without the flow conditioner installed. As in Section 2.2 these configurations have been designated configuration 1 (C1) and configuration 2 (C2) respectively. A specified number of test points along with the order (flowrates) of the test points were required. The first test points were specified in volumetric flow terms and two test points were required at each flowrate. The last set of six test points were specified in terms of Reynolds number and were to be spread across the target value of $Re = 10^5$. The actual test matrix is set out in Table 2. It was expected that both meters in the package would be calibrated simultaneously.

TABLE 2
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	100000	6
Total No of points		28

This test sequence was mandatory for the configuration 1 test. If the laboratory was short of time, it was permitted to use a reduced test sequence for configuration 2; however, the six tests at the cardinal point were mandatory. Where a laboratory had reason to suspect a test point this could be repeated and reported but the suspect or the extra test point, as appropriate, would be omitted from the analyses. All laboratories were asked to carry out only a single C1 and C2 test. If desired, additional test sequences could be reported to allow an indication of reproducibility for internal purposes. Additional tests or test points would not be included in the analysis.

The original test sequence allowed for an initial and final test by the pilot laboratory. Despite the breakage and repair of the Kral meter this sequence was retained; three tests were provided by the pilot: initial, at the start of the second round, and on completion, with a confirmatory test prior to the start of the second round. To maintain the integrity of the round, FORCE also provided two sets of results, one immediately after the repair and one during the second round. The work at the pilot laboratory before the start of the test sequence and the confirmatory test has not been included in the report.

3.3 Countries Withdrawing from the Key Comparison

On examination of the data received from all the participants, the pilot laboratory observed that the results from CENAM and MC appeared to be anomalous. In accordance with the CIPM guidance rules, these laboratories were asked to check their results for computational errors. Neither institute was informed of the magnitude or sign of the anomaly. Both laboratories independently confirmed that they were happy with the calculations but reported that, on reviewing their test procedures, they were no longer confident of the results.

Both laboratories submitted formal requests to withdraw from the intercomparison. The text of these can be found in Appendix A for CENAM (Mexico) and Appendix B for MC (Canada). These requests were circulated to the other participants, all of whom agreed to allow both laboratories to withdraw.

CMI reported the results from their second calibration in configuration 1 showed unacceptable repeatability. Available time did not allow a calibration in configuration 2. After consultation CMI therefore withdrew these tests from the intercomparison. At this time it was believed that the results of the first calibration might have been valid. Subsequently it has been found that results taken before the repair could not be incorporated and as a result CMI has had to withdraw from the comparison. No agreement with participants was required as effectively no valid results are available from CMI.

Final analysis of the data was based on the reduced number of participants, and the individual results from the laboratories who have withdrawn are discussed further in Section 4. The results provided from all the laboratories included in the final analyses are given in Appendix C.

4 INITIAL EXAMINATION OF RESULTS

All laboratories were requested to submit their results on a pro-forma provided to them. This standardised the result formats. The valid results included in the analyses are provided in Appendix C.

4.1 Initial Examination of all Data

The results from the calibration of the Kral meter in configuration 1 from all laboratories are shown graphically below.

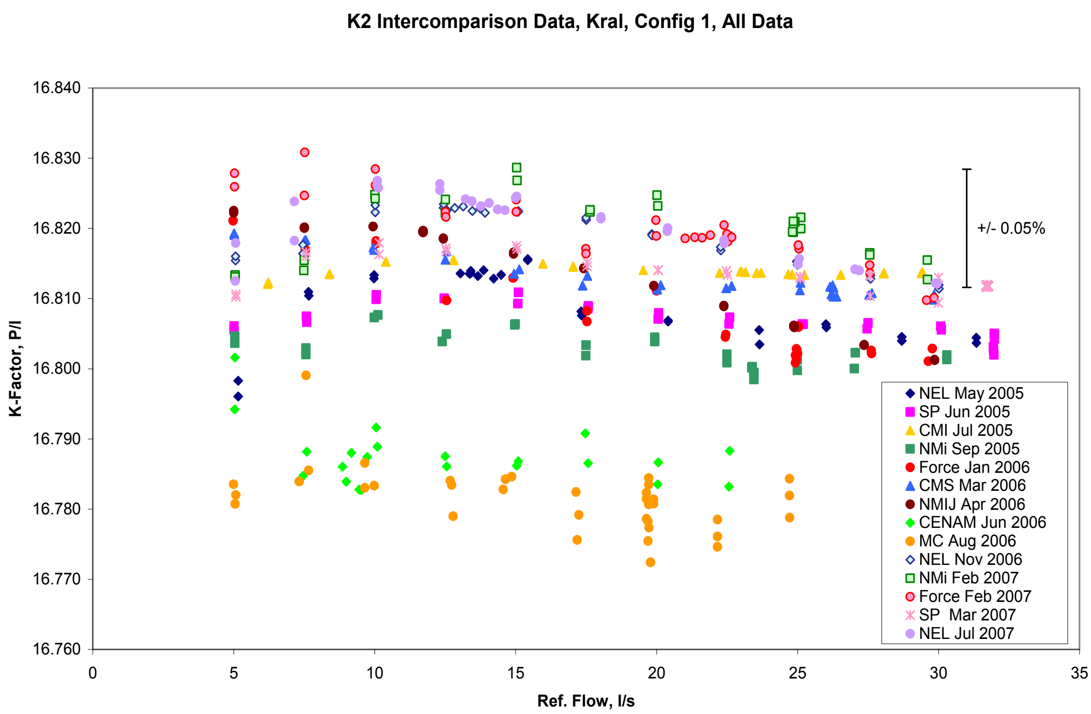

Figure 2 All Returned Results from Kral Meter, Configuration 1

It is immediately clear that the results from MC (Canada) and CENAM (Mexico) are significantly different from the other laboratories'. This is confirmed by the results from the turbine meter and the Kral configuration 2 results.

The relatively close agreement between these two sets of results, both from the same regional metrology area, gave rise to a concern that a procedural, or calculation, method specific to this region may have been an underlying cause of the differences. Examination of the data by the pilot laboratory could not identify any error or discrepancy in the data or calculation and so both laboratories were asked, independently, to review their results and calculations. Both laboratories identified procedural and hardware problems within their own calibration facilities and requested to withdraw their results. No common issue was identified. Withdrawal was agreed by the other participants.

As a result no further results from MC or CENAM are included in this report.

4.2 Effect of the Kral Meter Repair

Three laboratories, (NEL, SP and NMi) successfully tested the package both before and after the repair to the Kral meter bearings. By comparing the pre- and post-repair results from these laboratories, it has been possible to quantify the shift in performance of the Kral meter resulting from the damage and subsequent repair.

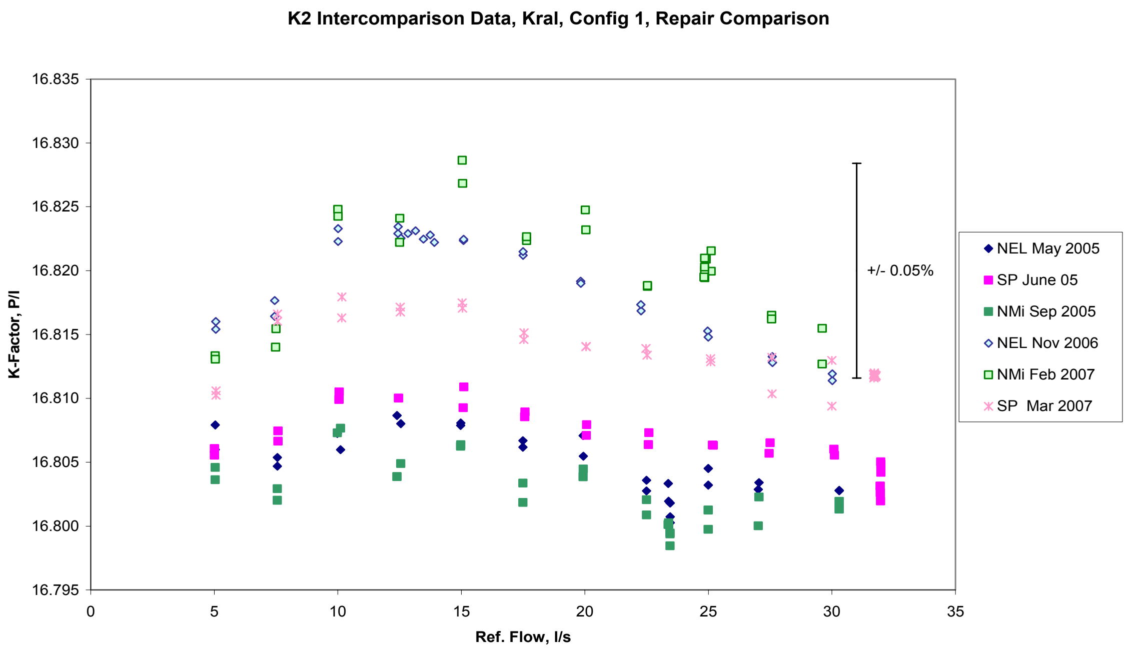

Figure 3 Pre- and Post-Repair Results from Kral Meter Configuration 1

The results from Configuration 1 are shown graphically above. Examining these data it is clear that an increase in K-factor of around 0.06%, has occurred in the meter performance. The magnitude of the change has been confirmed by the results from the configuration 2 test results. Examination of the results from the turbine meter does not show a similar trend.

The magnitude of the change varies between the laboratories and across the flow range; however, a clear difference is observed. As, however, the difference is not consistent in magnitude as observed by the three laboratories, it was not considered prudent to derive or to apply any correction to the data.

As a change in meter performance of the magnitude similar to the spread of results has occurred, the results taken prior to the repair cannot be considered to be acceptable for comparison.

4.3 Results from CMI (Czech Republic)

CMI did not follow the specified test method by calibrating the Kral and turbine meter simultaneously. A Small Volume Piston Prover (SVP) was used as the reference standard. Unless modified, electronic data collection employed by an SVP can only record pulses from one meter at a time. For each test point a calibration of the Kral meter was provided and immediately followed by a calibration point from the turbine meter. As the calibration points were carried out immediately after one another, and the flow in the system was very stable, it was believed that these results could be accommodated in the analyses. A verification of this assumption is not possible with the data currently available.

When the package was returned to CMI for a second calibration, the calibration results showed high degrees of scatter. CMI indicated that they did not believe the results to be valid and informed the pilot laboratory accordingly. Not having sight of the data from other laboratories, the results were supplied to the pilot laboratory for consideration. These data were, however, provided with the condition that CMI would not wish these included in the comparison unless they were in line with the repeatability of the other laboratories. The pilot laboratory agreed that the results were unacceptable and hence the CMI results from the second test have not been included in this report.

Based on this combination of factors, CMI has therefore had to withdraw from the programme. From an examination of all the returned results as shown in Figure 2, there is no reason to suspect that the first CMI test results were significantly different from other results.

5 STATISTICAL EXAMINATION OF KRAL METER RESULTS

The results provided by the laboratories are given in Appendix C.

5.1 Returned Results

The valid results from the Kral meter (post-repair) are shown graphically below in Figures 4 and 5. In this case the graph shows the results as K-factor plotted against flowrate.

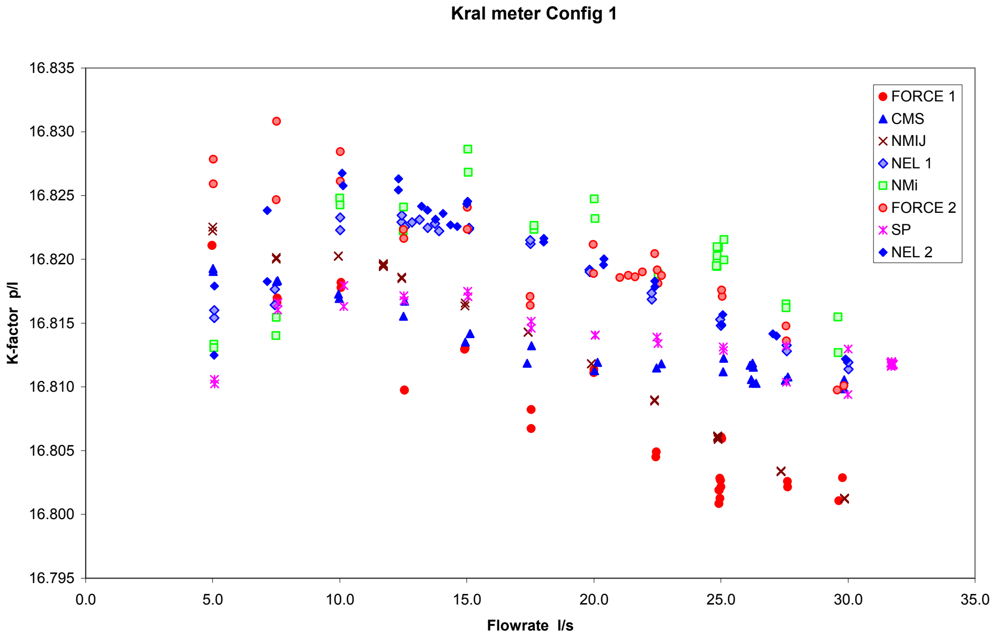

Figure 4 Kral Meter, Configuration 1, Post-repair, K-factor v. Flowrate

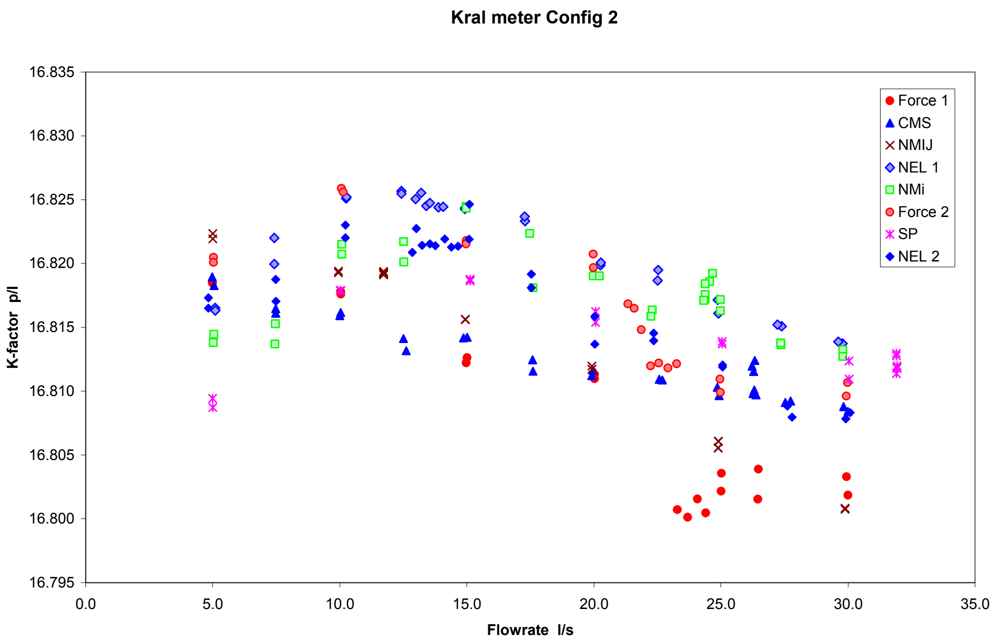

Figure 5 Kral Meter, Configuration 2, Post-repair, K-factor v. Flowrate

It is noted that the results from all laboratories show the same trends and characteristics in both configurations except those from the first FORCE calibration, where there is an apparent difference in behaviour.

The cardinal points, where six test results are recorded across a very narrow flow range corresponding to a common Reynolds number, are distributed widely across the volumetric flow range of the meter. This is due to the variation in viscosity from the laboratories.

In the design of the experiment, the comparison and the derived KCRV were based on Strouhal number and Reynolds number. The Strouhal number plotted against Reynolds number is therefore shown in Figures 6 and 7.

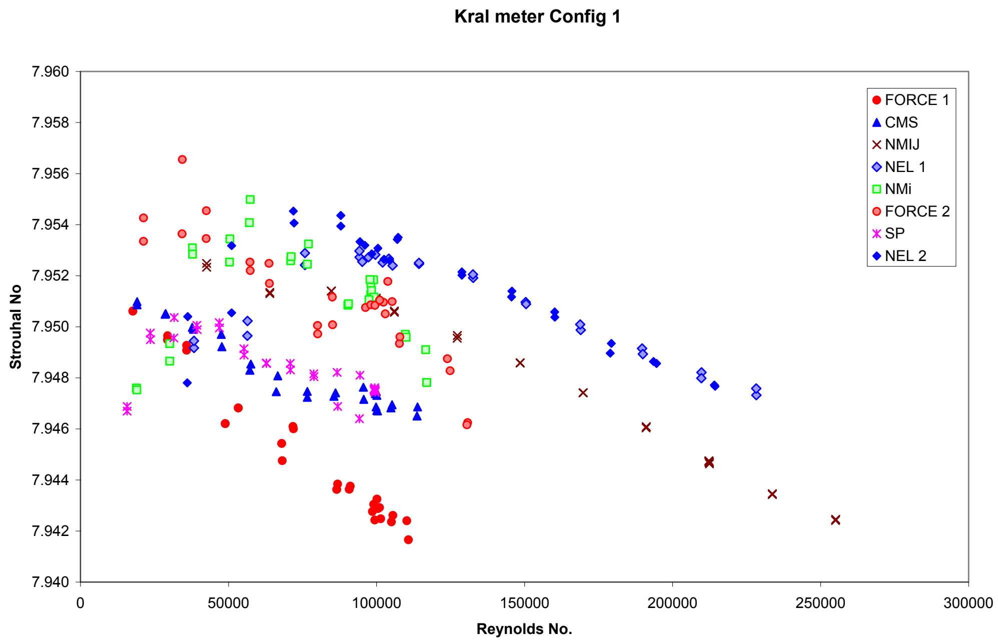

Figure 6 Kral Meter, Configuration 1, Post-repair, Strouhal no v. Reynolds No

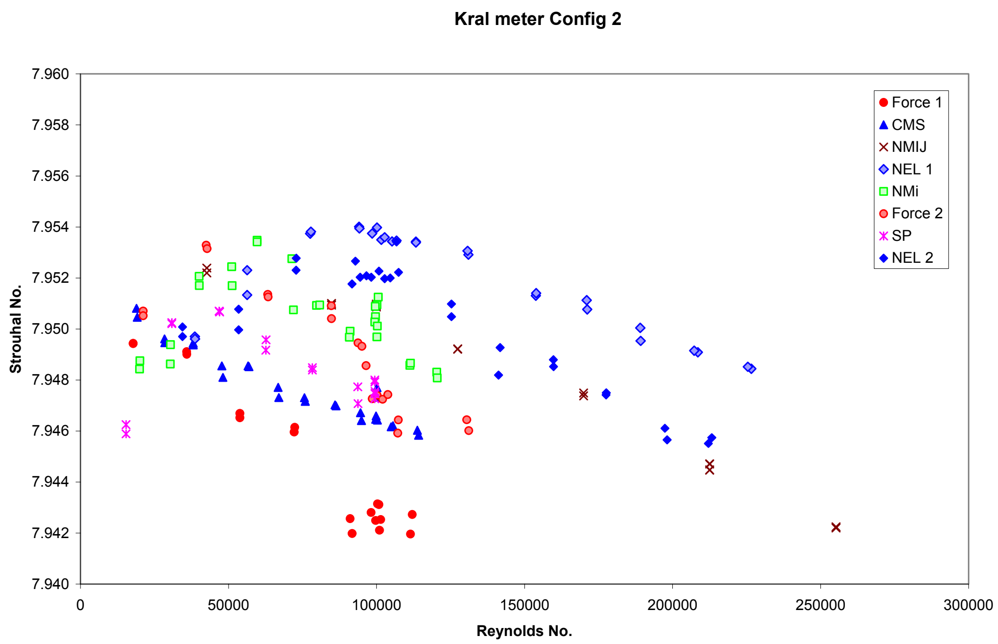

Figure 7 Kral Meter; Configuration 2, Post-repair, Strouhal No v. Reynolds No

This presentation of the results shows that the spread of Strouhal number is very similar to that shown in the K-factor graphs.

5.2 Derivation of Cardinal Point

The analysis of the comparison data has to be made at a Reynolds number of 10^5. Each laboratory was requested to provide six measurement points close to, this value. To produce a calculated result at a Reynolds number of 10^5 the procedure required that the results be produced at Reynolds numbers spread across a specified range either side of the target value. This allows the calculation of a value at 10^5 based on linear interpolation of this data. For most laboratories the data spanned the required value; however, in others the linear fit had to be extrapolated. Generally this interpolation or extrapolation was shown to give a result which would match with the physical expectation of the meter performance. In the case of SP, however, extrapolation was required, and this was based on a sloping characteristic which, although reflecting the performance of the meter as observed in the region close to 10^5, did not match the slope observed by other laboratories. This is particularly true of the turbine-meter results. The extrapolated values have been used throughout.

The Strouhal number derived for each laboratory at $Re = 10^5$, for each laboratory and configuration, is given in Table 4.

5.3 Viscosity Effect

First examination of the results confirms a strong correlation between the Strouhal number and the kinematic viscosity of the fluid used. By using Reynolds number a pattern emerges which indicates that the results show a distinct correlation to the viscosity of the fluid as can be seen in Figure 8.

For reference the base viscosity of the oils used is given in Table 3 below.

TABLE 3
BASE VISCOSITY FOR EACH LABORATORY

Lab	Viscosity at 20°C		Lab	Viscosity at 20°C
	mPas (cP)			mPas (cP)
FORCE 1	3.43		NMi	3.43
CMS	3.46		FORCE 2	3.00
NMIJ	1.51		SP	4.32
NEL 1	1.71		NEL 2	1.82

It is probable that using Reynolds number over-compensates for the inherent effect of viscosity on the meter performance. As there is a strong correlation, a correction for viscosity can be derived and applied to the results.

Figure 8 shows the calculated Strouhal number at a Reynolds number of 10^5 plotted against kinematic viscosity for the six laboratories accepted as contributing to the KCRV. Both the C1 and C2 results are shown separately and the slopes of the Strouhal number to kinematic viscosity lines calculated. As physically there is no reason to believe that there will be different behaviour in terms of viscosity effect between C1 and C2, the correction is based on the average of the two slopes. The best estimate for the slope of this function has been derived as -0.00158 ± 0.00096.

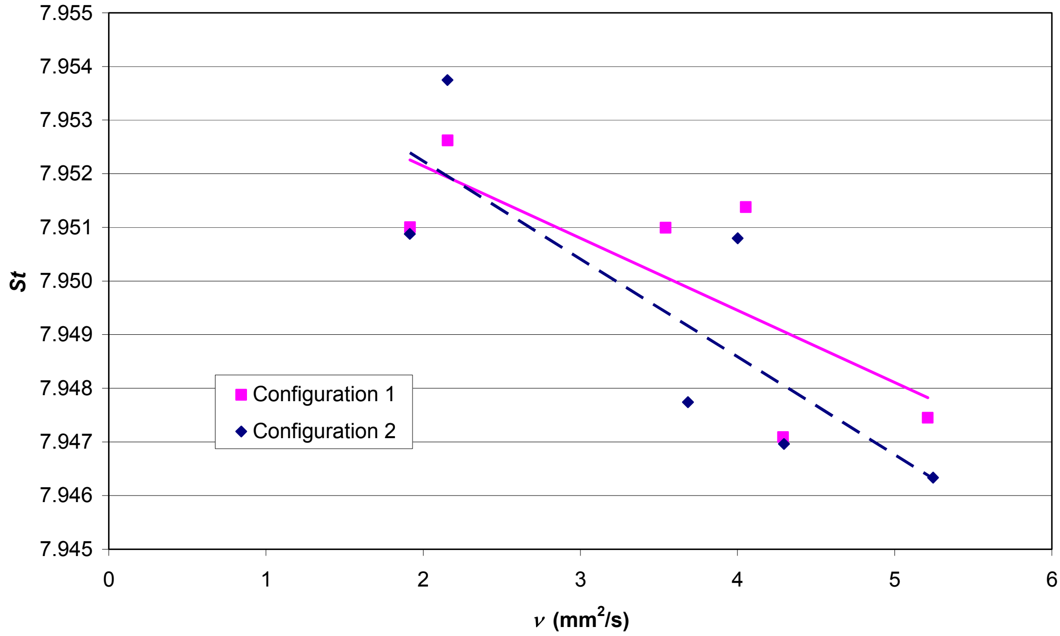

Figure 8 Strouhal Number v Kinematic Viscosity for the Kral Meter at *Re* = 10^5

The Strouhal number that would be obtained at a chosen (close to average) kinematic viscosity of ν = 3.5 mm^2/s has then been calculated for each laboratory. The expanded uncertainty in the Strouhal number that would be obtained at ν = 3.5 mm^2/s has been calculated from each laboratory's data and in every case it exceeds the laboratory's expanded uncertainty by 0.007% or less.

The viscosity-corrected values for Strouhal number at *Re* = 10^5 are given in Table 4.

5.4 KCRV and Analyses

The KCRV is calculated through the evaluation of the uncertainty-weighted mean.

$$KCRV = \frac{\sum_{i=1}^{n} \frac{x_i}{u_i^2}}{\sum_{i=1}^{n} \frac{1}{u_i^2}}$$

u is the standard uncertainty of each result
(u=U/2 where U is the expanded uncertainty at k = 2)
x is the result (Strouhal number) from each laboratory

Working with the Configuration 1 results, a provisional KCRV was computed. The results were tested against this provisional KCRV through a Chi-squared test.

The Chi-squared test is carried out in three stages.

a) Calculate the standard uncertainty associated with the KCRV:

$$\frac{1}{u_{KCRV}^2} = \sum_{i=1}^{n} \frac{1}{u_i^2}$$

b) Form the Chi-squared value (χ^2_{obs})

$$\chi^2_{obs} = \sum_{i=1}^{n} \frac{\left(x_i - KCRV\right)^2}{u_i^2}$$

c) For the appropriate degrees of freedom (n-1) find the Chi-squared value (χ^2) for 95 % confidence from statistical tables. The consistency check will fail at the 0.05 (95 %) confidence level if χ^2_{obs} is greater than χ^2 .

The Chi-squared value, χ^2_{obs} , for this set of data is 24.1 when the 95% confidence value χ^2 is 14.1 showing the data are not equivalent. Comparison of each laboratory with the provisional KCRV showed that the first FORCE result is inconsistent. The *En* value, as described later, for this first FORCE data set is 2.19 showing this laboratory to be discrepant. Based on this the first data set from FORCE was removed from the calculation of the final KCRV.

The calculation of a KCRV and the subsequent testing will only be valid if single independent results are used. For this reason only one NEL result should be included. It was decided therefore also to exclude the second NEL result (of the two post-repair NEL results) from the calculation of the KCRV. The first NEL result was used simply because it was chronologically central in the project.

This final KCRV has been calculated using the unmarked results shown in Table 4a. The two results excluded from inclusion in the KCRV have been retained in the tables and all graphical representations.

The Kral KCRV (C1) is calculated as a Strouhal number = 7.9502 at *Re* =10^5.

When the six single data sets, one from each laboratory, were analysed, the set passed the consistency test. In this case the Chi-squared value for the data set is 4.6 to be compared with the 95% value of 11.1.

The process was repeated for the configuration 2 results. This gave the same conclusion regarding the first FORCE result, and hence the same two data sets have been excluded.

The Kral KCRV (C2) is calculated as a Strouhal number = 7.9496 at *Re* =10^5.

For C2 the Chi-squared value for the data set is 7.1 to be compared with the 95% value of 11.1.

When the final KCRV has been produced, the degree of equivalence, *En*, is calculated for each result (laboratory).

This is again calculated in a number of stages.

a) Calculate the difference (d_i) between the laboratory result and the KCRV.

b) Calculate the expanded uncertainty in the difference (U_{di}) where

$$U_{di} = \sqrt{U_i^2 - U_{KCRV}^2}$$

where U_i is the expanded uncertainty in the laboratory result
U_{KCRV} is the expanded uncertainty in the KCRV

c) Calculate the *En*-criterion

$$En_i = \frac{|d_i|}{U_{di}}$$

d) The *En*-criterion for inter-laboratory comparison is calculated using a similar formula, and details are given in Section 7.

The results (except for those under d) are all summarised in Tables 4a and 4b.

TABLE 4A
STROUHAL NUMBER, UNCERTAINTY AND *En* VALUE
FOR THE KRAL METER IN CONFIGURATION 1 (C1) at *Re* = 10^5

Laboratory	Strouhal no	Strouhal no Viscosity Corrected	Expanded Uncert.	d_i as % of KCRV	U_{di} as % of KCRV	*En*
			%			
FORCE 1 *	7.9429	7.9438	0.035	*-0.081*		
CMS	7.9471	7.9483	0.045	-0.023	0.044	0.54
NMIJ	7.9510	7.9485	0.03	-0.022	0.032	0.66
NEL 1	7.9526	7.9505	0.025	0.004	0.026	0.14
NMi	7.9514	7.9523	0.04	0.026	0.038	0.68
FORCE 2	7.9510	7.9511	0.035	0.011	0.032	0.34
SP	7.9474	7.9502	0.028	-0.001	0.032	0.02
NEL 2 *	7.9529	7.9510	0.025	*0.010*		
Final KCRV		**7.9502**	**0.015**			

* Result not included in KCRV

TABLE 4B
STROUHAL NUMBER, UNCERTAINTY AND *En* VALUE
FOR THE KRAL METER IN CONFIGURATION 2 (C2) at *Re* = 10^5

Laboratory	Strouhal no	Strouhal no Viscosity Corrected	Expanded Uncert.	d_i as % of KCRV	U_{di} as % of KCRV	*En*
			%			
FORCE 1 *	7.9427	7.9436	0.035	*-0.076*		
CMS	7.9470	7.9482	0.045	-0.018	0.044	0.41
NMIJ	7.9509	7.9484	0.03	-0.016	0.032	0.49
NEL 1	7.9537	7.9516	0.025	0.025	0.026	0.96
NMi	7.9508	7.9516	0.04	0.025	0.038	0.65
FORCE 2	7.9477	7.9480	0.035	-0.020	0.032	0.63
SP	7.9463	7.9491	0.028	-0.007	0.032	0.21
NEL 2 *	7.9521	7.9501	0.025	*0.006*		
Final KCRV		**7.9496**	**0.015**			

* Result not included in KCRV

6 EXAMINATION OF TURBINE METER RESULTS

6.1 Statistical Examination of Turbine Results

The retained results from the turbine meter (after the repair of the Kral meter) for configuration 1 are shown graphically below in Figure 9. In this case the graph shows the results as K-factor plotted against flowrate.

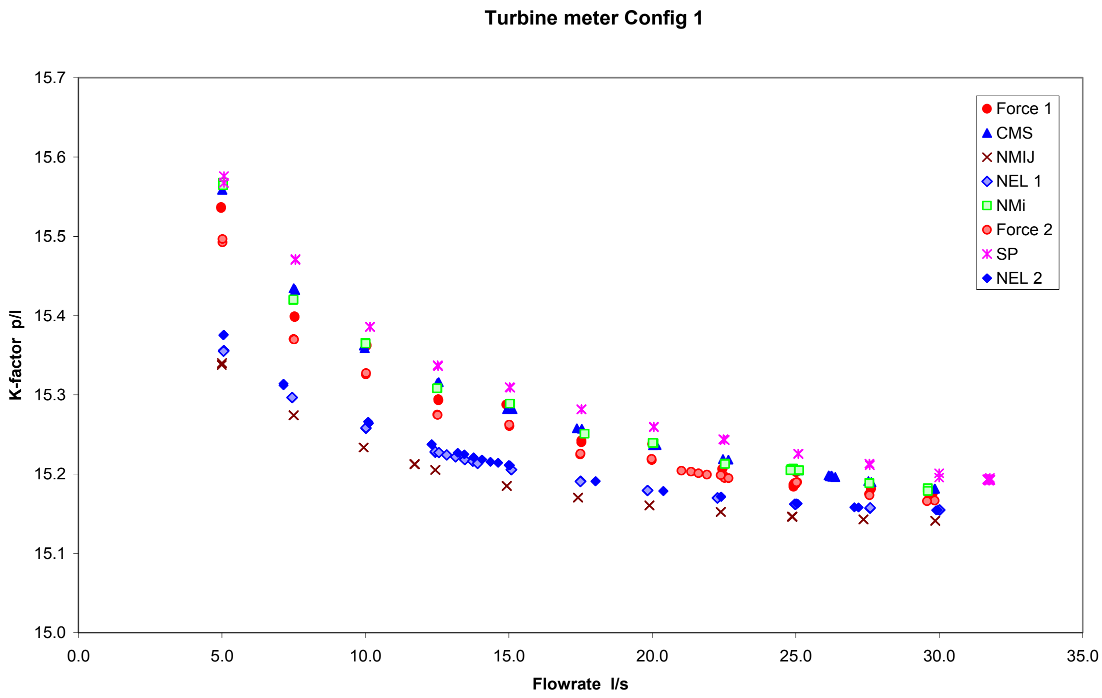

Figure 9 Turbine Meter, Configuration 1, K-factor v. Flowrate

Figure 9 shows that the cardinal points where six test results are recorded across a very narrow flow range corresponding to a common Reynolds number are distributed widely across the flow range of the meter.

As there is an acknowledged relationship between turbine-meter performance and Reynolds number these results have also been shown as Strouhal number plotted against Reynolds number (Figure 10).

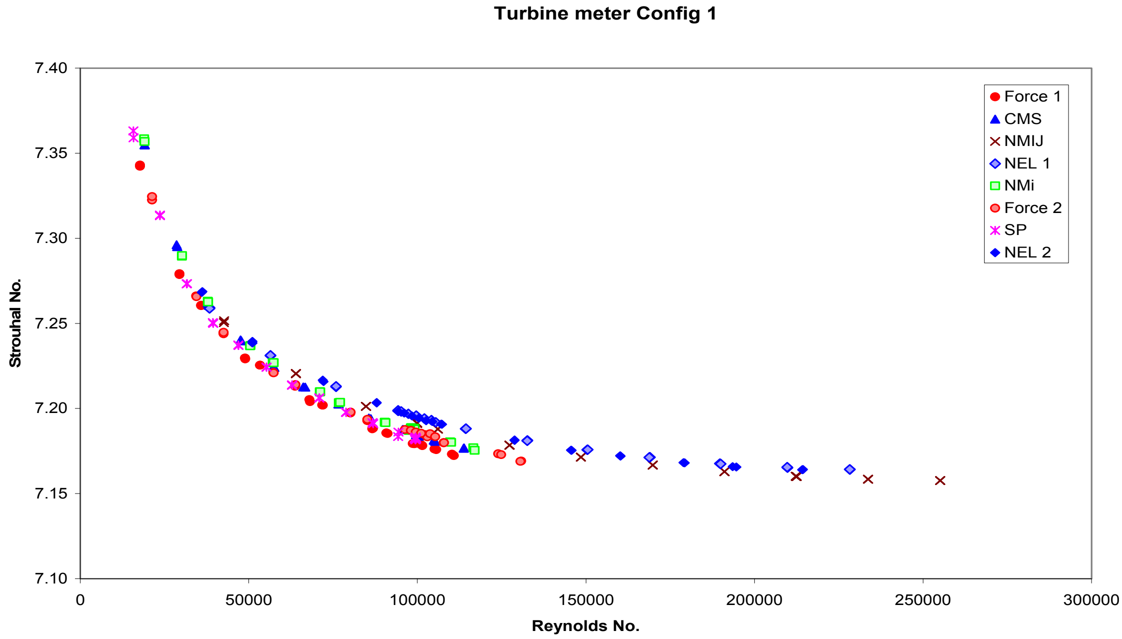

Figure 10 Turbine Meter, Configuration 1, Strouhal No v. Reynolds No

The first step of this analysis was therefore to derive the Strouhal number at a common Reynolds number of 10^5. From each of the data sets a line fit was placed through the six points close to the cardinal point. From this line fit the Strouhal number at a Reynolds number value of 10^5 was calculated. Where a set of data did not encompass the required Reynolds number, the line was extrapolated. This is explained in more detail for the Kral meter analyses. The results are given in Table 5a.

As with the Kral meter the remaining viscosity dependence was tested and a correlation observed. The dependence of Strouhal number on kinematic viscosity at a Reynolds number of 10^5 for the final group of laboratories is given in Figure 11.

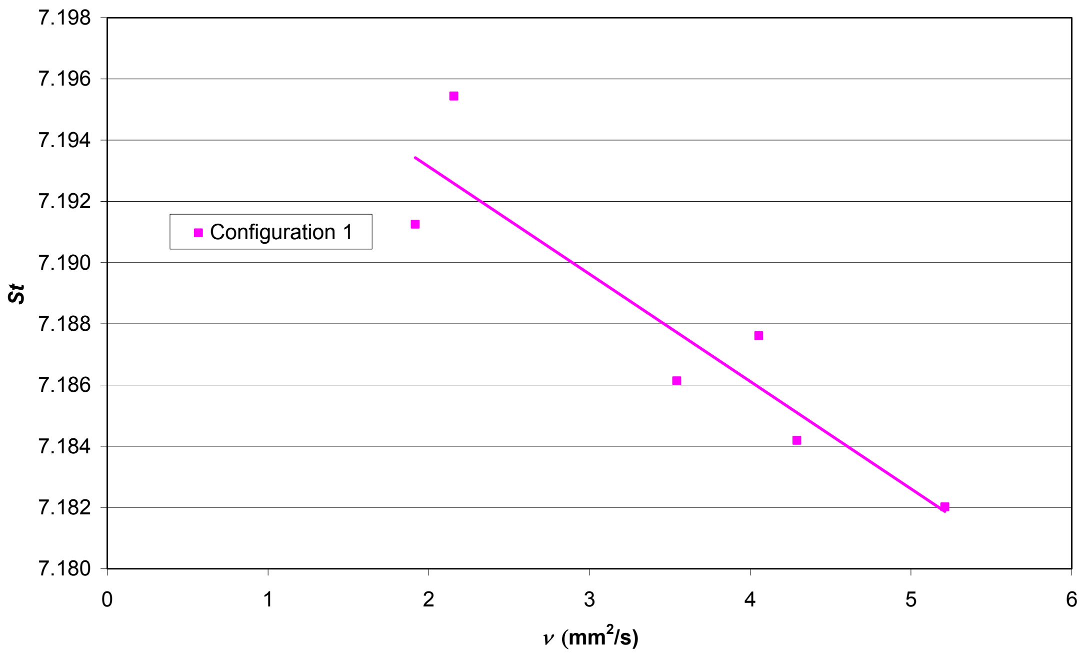

Figure 11 Strouhal Number v Kinematic Viscosity for the Turbine Meter at *Re* = 10^5

A linear trend is observed and a line fitted with a slope of -0.00351 ± 0.00211

This allows a correction to the results for viscosity and gives the resultant values in Tables 5a and 5b.

Using the viscosity-corrected data the analysis was carried out in the same way as for the Kral meter. Provisional KCRVs were calculated, and again the FORCE 1 data failed the consistency check. Although once FORCE 1 was omitted the remaining seven sets passed consistency, NEL 2 was again omitted.

The remaining laboratory results from Configuration 1 passed the consistency test and the equivalence values have been included in Table 5a.

The Turbine KCRV (C1) is calculated as a Strouhal number = 7.1878 at *Re* =10^5.

The Chi-squared value for the data set is 7.1 to be compared with the 95 % value of 11.1.

TABLE 5A
STROUHAL NUMBER, CMC UNCERTAINTY AND *En* VALUE FOR THE TURBINE METER IN CONFIGURATION 1 (C1) at *Re* = 10^5

Laboratory	Strouhal no	Strouhal no Viscosity Corrected	Expanded Uncert.	d_i as % of KCRV	U_{di} as % of KCRV	***En***
			%			
FORCE 1 *	7.1794	7.1814	0.035	*-0.090*		
CMS	7.1842	7.1870	0.045	-0.012	0.047	0.26
NMIJ	7.1913	7.1857	0.03	-0.030	0.052	0.57
NEL 1	7.1954	7.1907	0.025	0.040	0.043	0.94
NMi	7.1876	7.1895	0.04	0.024	0.039	0.61
FORCE 2	7.1861	7.1863	0.035	-0.022	0.030	0.73
SP	7.1820	7.1880	0.028	0.003	0.054	0.05
NEL 2 *	7.1948	7.1905	0.025	*0.037*		
Final KCRV		**7.1878**	**0.019**			

* Result not included in KCRV.

TABLE 5B
STROUHAL NUMBER, CMC UNCERTAINTY AND *En* VALUE FOR THE TURBINE METER IN CONFIGURATION 2 (C2) at *Re* = 10^5

Laboratory	Strouhal no	Strouhal no Viscosity Corrected	Expanded Uncert.	d_i as % of KCRV	U_{di} as % of KCRV	***En***
			%			
FORCE 1 *	7.1141	7.1159	0.035	*-0.775*		
CMS	7.1695	7.1723	0.045	0.011	0.041	0.27
NMIJ *	7.1675	7.1620	0.03	*-0.133*		
NEL 1	7.1766	7.1719	0.025	0.006	0.036	0.16
NMi *	7.1773	7.1791	0.04	*0.106*		
FORCE 2 *	7.0811	7.0818	0.035	*-1.251*		
SP	7.1637	7.1698	0.028	-0.024	0.050	0.47
NEL 2 *	7.1792	7.1750	0.025	*0.048*		
Final KCRV		**7.1715**	**0.030**			

* Result not included in KCRV.

It was expected that it would not prove possible to establish a KCRV for the turbine meter configuration 2. For this configuration the turbine meter is affected by the upstream flow profile which is itself dependent on the pipework installation in the laboratory. For interest, however, the results from configuration 2 were analysed according to the same procedure. Analysing the six results provided three results which were not conforming. When these three results (FORCE 2, NMIJ and NMi) were omitted, a very high degree of equivalence was found. The Chi-squared value for the data set is 0.9 to be compared with the 95% value of 6.0. The results are shown in Table 5b and discussed further in Section 10.

7 INTER-LABORATORY EQUIVALENCE

The equivalence of each laboratory when compared with the other laboratory results has been calculated. The comparison has been expressed in terms of equivalence or *En*-Criterion. The *En* number is calculated as follows:

$$En_{ab} = \frac{|d_{ab}|}{U_{d(ab)}}$$

d_{ab} is the difference between the two laboratories' results, and $U_{d(ab)}$ is calculated as follows:

$$U_{d(ab)} = \sqrt{U_a^2 + U_b^2} \; ,$$

where U_a and U_b are the expanded uncertainties of the two laboratories.

The comparison has only been carried out for the six consistent laboratory sets. The differences between laboratories and the expanded uncertainty of the differences, both expressed as a percentage of the KCRV, and the *En* values are given in Tables 6, 7 and 8 for the Kral meter for both configurations and for the turbine meter for configuration 1. It was not considered necessary to make these comparisons for the turbine meter configuration 2 results.

TABLE 6A
INTER-LABORATORY EQUIVALENCE: KRAL METER CONFIGURATION 1: d_{ab} AS A PERCENTAGE OF THE KCRV

Lab	**CMS**	**NMIJ**	**NEL 1**	**NMi**	**FORCE 2**	**SP**
CMS		0.002	0.027	0.049	0.034	0.023
NMIJ			0.025	0.047	0.032	0.021
NEL 1				0.022	0.007	-0.004
NMi					-0.015	-0.026
FORCE 2						-0.011
SP						

TABLE 6B
INTER-LABORATORY EQUIVALENCE: KRAL METER CONFIGURATION 1: $U_{d(ab)}$ AS A PERCENTAGE OF THE KCRV

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.058	0.055	0.061	0.058	0.058
NMIJ			0.046	0.054	0.050	0.050
NEL 1				0.050	0.046	0.046
NMi					0.054	0.053
FORCE 2						0.049
SP						

TABLE 6C
INTER-LABORATORY EQUIVALENCE: KRAL METER CONFIGURATION 1: *En* VALUES

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.03	0.49	0.80	0.59	0.40
NMIJ			0.54	0.88	0.65	0.42
NEL 1				0.44	0.16	0.09
NMi					0.28	0.49
FORCE 2						0.23
SP						

TABLE 7A
INTER-LABORATORY EQUIVALENCE: KRAL METER CONFIGURATION 2: d_{ab} AS A PERCENTAGE OF THE KCRV

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.002	0.043	0.042	-0.002	0.011
NMIJ			0.041	0.041	-0.004	0.009
NEL 1				0.000	-0.045	-0.032
NMi					-0.045	-0.031
FORCE 2						0.013
SP						

TABLE 7B
INTER-LABORATORY EQUIVALENCE: KRAL METER CONFIGURATION 2: $U_{d(ab)}$ AS A PERCENTAGE OF THE KCRV

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.058	0.055	0.061	0.058	0.058
NMIJ			0.046	0.054	0.050	0.050
NEL 1				0.050	0.046	0.046
NMi					0.054	0.054
FORCE 2						0.050
SP						

TABLE 7C
INTER-LABORATORY EQUIVALENCE: KRAL METER CONFIGURATION 2:
***En* VALUES**

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.03	0.78	0.69	0.04	0.19
NMIJ			0.88	0.75	0.08	0.18
NEL 1				0.01	0.98	0.69
NMi					0.84	0.58
FORCE 2						0.27
SP						

TABLE 8A
INTER-LABORATORY EQUIVALENCE: TURBINE METER CONFIGURATION 1:
d_{ab} AS A PERCENTAGE OF THE KCRV

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		-0.018	0.052	0.036	-0.009	0.015
NMIJ			0.070	0.054	0.008	0.032
NEL 1				-0.016	-0.062	-0.038
NMi					-0.045	-0.021
FORCE 2						0.024
SP						

TABLE 8B
INTER-LABORATORY EQUIVALENCE: TURBINE METER CONFIGURATION 1:
$U_{d(ab)}$ AS A PERCENTAGE OF THE KCRV

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.075	0.069	0.067	0.062	0.077
NMIJ			0.072	0.070	0.066	0.080
NEL 1				0.064	0.058	0.074
NMi					0.055	0.072
FORCE 2						0.067
SP						

TABLE 8C
INTER-LABORATORY EQUIVALENCE: TURBINE METER CONFIGURATION 1:
***En* VALUES**

Lab	CMS	NMIJ	NEL 1	NMi	FORCE 2	SP
CMS		0.23	0.76	0.54	0.15	0.19
NMIJ			0.97	0.76	0.13	0.41
NEL 1				0.26	**1.06**	0.51
NMi					0.82	0.30
FORCE 2						0.36
SP						

To provide a satisfactory equivalence, the *En* values should be less than 1. More precisely 95% of the *En* values should be less than 1. In fact all but one of the inter-laboratory equivalence values are less than 1. In the one instance, NEL 1 compared with FORCE 2, where the *En* value is above one, *En* is only just above 1.

8 YOUDEN PLOT EXAMINATION

A common pictorial way to provide an overview of an intercomparison is by means of a Youden plot. This method plots the result from one meter against the result from the second meter at a constant condition. The method gives clear indication of the variability of results which are due to variations in the laboratories. This is shown by the spread of results along a diagonal axis from bottom left to top right. The spread of results along the opposite diagonal axis is indicative of variations introduced by one or other of the package meters.

This approach has been followed for the six results accepted for inclusion in the KCRV and the two results accepted for reporting. The data have been viscosity-corrected. To ensure that two independent calibrations from each laboratory are compared and to give a view of reproducibility, the results from the turbine meter in configuration 1 have been plotted against those from the Kral meter for configuration 2. All the results are expressed as a percentage of the mean of the Strouhal numbers used for the KCRV. The diameter of the circle is 0.023% and is indicative of the uncertainty of the package (rather than that of the facilities).

The result is shown in Figure 12.

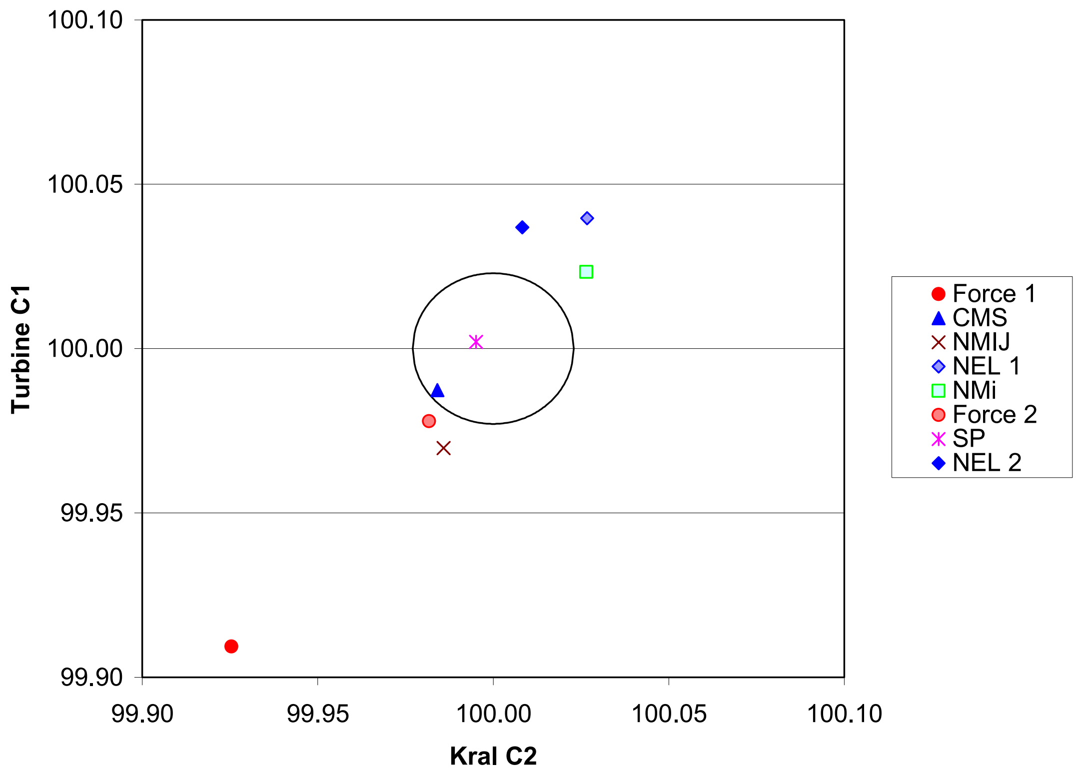

Figure 12 Youden Plot of Results at *Re* = 10^5
(Circle Based on Data except FORCE 1 and NEL 2)

The results show clearly that the FORCE 1 results are different from the main grouping of the tests. Excluding this result, the results spread across a range of ±0.04 % while the package is stable to ±0.02 %.

A second Youden plot has been prepared based on the turbine C2 results and the Kral C1 results. All the data have been viscosity-corrected. A different pattern emerges from this plot.

Again the FORCE 1 result is seen to be discrepant; however, the FORCE 2 result is also significantly different owing to a significant difference in the turbine result. This is the effect of flow profile on the turbine meter. This plot is shown as Figure 13.

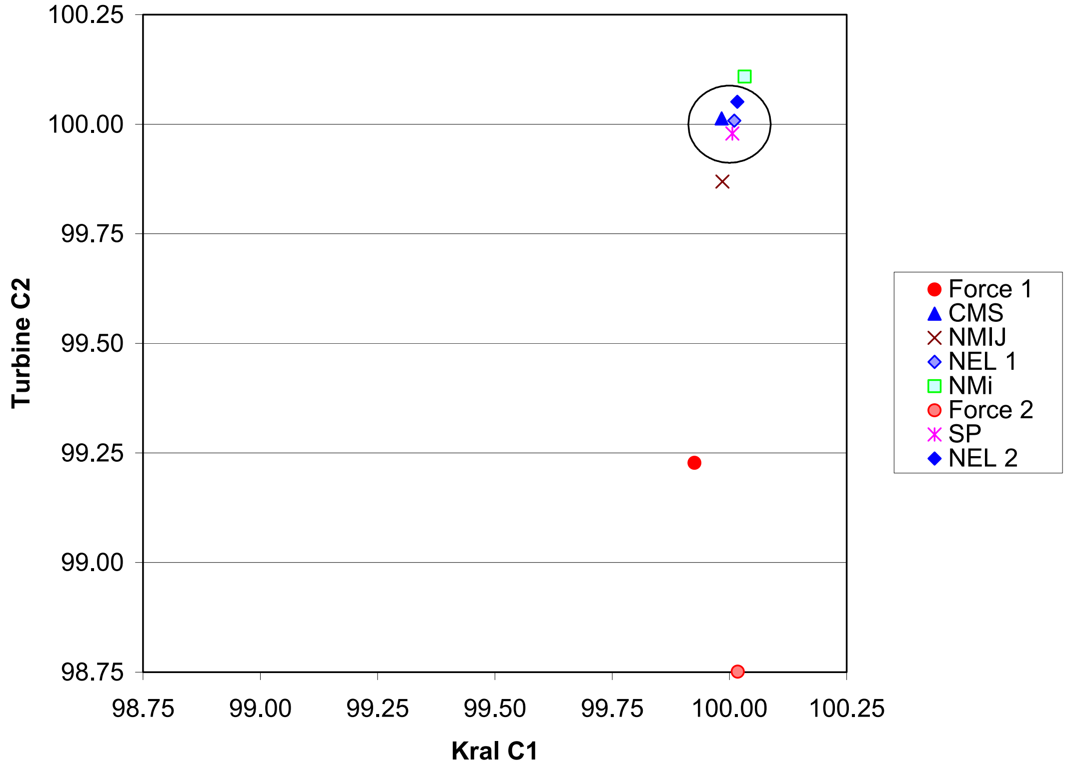

Figure 13 Youden Plot of Results at *Re* = 10^5
(circle based only on CMS, NEL 1 and SP)

9 ALTERNATIVE ANALYSES

When the experiment was designed, it was decided to base the KCRV on a single flowrate or Reynolds number. It has been argued that this method did not fully describe the degree of equivalence of the participants across the flow range of the package and show whether that degree of equivalence was maintained across that range. An alternative experiment would have been to specify a number of fixed flowrates (or Reynolds numbers) and base the results on repeated test points at each of these flowrates. This would effectively create a number of KCRVs for comparison. This is not the ideal method of obtaining a comparison as a small number of discrete comparison points would not fully reflect the differences in the laboratories' determination of the performance curve of the flowmeters across the range.

As an alternative analysis method, the differences between the calibration curves of the two meters have been examined using linear fits and comparisons at discrete points.

The data from the Kral meter (Figures 4 and 5) have been analysed by fitting the data collected at nominal flowrates of 10 l/s and above. To give the same pattern of flowrates from each laboratory the data collected explicitly at *Re* = 10^5 have been excluded from the fit. Linear fits have been used. Some sets of data have much larger scatter about the line fits than others.

It is now possible to consider the data at three flowrates: 10.2, 20.0 and 29.6 l/s. The effect of kinematic viscosity was calculated in each case and the values from different laboratories corrected to give predicted values of K-factor at ν = 3.5 mm^2/s. The uncertainty of each laboratory's measurement includes components from the laboratory's uncertainty, the line fit and the effect of viscosity. The KCRV is obtained using a weighted mean on each occasion: The expanded uncertainty in the K-factor that would be obtained at ν = 3.5 mm^2/s never exceeds the laboratory's expanded uncertainty by more than 0.012%. The six sets CMS, NMIJ, NEL 1, NMi, FORCE 2 and SP satisfy the chi-squared test at all three points for both configurations; the *En* values are less than 1 for all the points except that at the high flowrate in configuration 1 NMIJ has an *En* of 1.08 and at the high flowrate in configuration 2 NMIJ has an *En* of 1.00 and NEL 1 has an *En* of 1.27. If FORCE 1 is included with the six sets then the chi-squared test is satisfied for both configurations for the low flowrate, for neither configuration for the high flowrate, and only for configuration 2 for the middle flowrate. Further work on other analysis methods remains desirable.

10 UNCERTAINTY

When the protocol was prepared it was recognised that the uncertainty quoted by each laboratory may be based on different criteria depending on the convention used. Some laboratories provide uncertainty based on the assessed uncertainty excluding an assessment of the repeatability of the facility; some others include a 'best case' estimate of facility repeatability. Other differences are also observed where some laboratories quote the best uncertainty at each test point, some the uncertainty across the range used for the particular test or meter, and others the uncertainty across the full range of the test facility. Some may quote the largest value of uncertainty across the range of the particular test facility working under normal working procedures (but best conditions within this) while others quote the uncertainty under best possible procedures. For this reason each laboratory was asked to provide an uncertainty statement with the following descriptions:

> **i) The CMC uncertainty:** this should be the uncertainty statement given in the laboratory's CMC which covers the flowrate range of the package. It is assumed that this figure is the uncertainty of the volume of fluid passed through the package. Please give an explanatory note giving the main components of uncertainty included in this figure.
>
> **ii) The 'volume' uncertainty**: this is the uncertainty in the measurement of the volume of oil passed through the package. This excludes uncertainty components introduced by the package and **excludes estimates of repeatability of the test rig**. This figure will be a single figure which gives confidence to encompass the flow range tested.

iii) The 'facility' uncertainty: this is the 'volume uncertainty' combined with an estimate of the uncertainty due to the repeatability of the facility. It will exclude all uncertainty associated with this particular test and the flowmeters.

iv) The 'test point' uncertainty: this is the 'facility' uncertainty with the addition of uncertainty introduced by the package flowmeters. This will normally just be the pulse resolution uncertainty. It again excludes the test and package flowmeter repeatability estimates.

v) Reynolds Number uncertainty: to allow a calculation of the uncertainty in Reynolds number, an uncertainty estimate of the measured viscosity and density should be provided.

In each case the uncertainty was quoted as a percentage figure with coverage factor k = 2. The information is shown in Table 9.

TABLE 9
SUMMARY OF UNCERTAINTY STATEMENTS

	Type of Uncertainty (%) all at coverage *k* = 2						
Laboratory	**Certificate**	**CMC**	**Volume**	**Facility**	**Test Point**	**Viscosity**	**Density**
FORCE	0.035	0.03	0.028	0.035	0.035	0.5	0.03
CMS	0.05	0.05	0.039	0.045	0.045	0.62	0.035
NMIJ	0.03	0.03	0.030	0.030	0.030	3.0	0.04
NEL	0.03	0.03	0.015	0.025	0.025	3.0	0.01
NMi	0.05 / 0.1	0.04	0.040	0.040	0.040	0.42	0.01
SP	0.046	0.10	0.020	0.028	0.028	0.50	0.10

By asking for this information, the analyses could be carried out based on whichever uncertainty was thought appropriate. All the laboratories provided figures.

The analysis was carried out using the test point uncertainty.

In all cases except for FORCE, the test point uncertainty was lower than or equal to the CMC uncertainty. For FORCE the CMC value was lower than the uncertainty claimed for this test. This is due to the CMC value being based on calibrations against the primary Small Volume Prover. To allow calibration of two flowmeters of this type the intercomparison was carried out against a reference meter in series with the SVP and the package. The reference meter was calibrated before and after each run; however, using a reference meter added uncertainty to the measurement.

NMi provided two uncertainties in the calibration certificates: 0.1% for individual results based on two test points at each flow and 0.05% based on the mean of the six points at the cardinal point.

It was noted that in general the CMC value was the same as, or close to, the uncertainty estimated for this test. In the case of SP, however, the CMC value was significantly higher than the estimated uncertainty for the test.

Before analysing the results two further uncertainties, arising from the measurements and the analysis, have been considered. The first is the uncertainty assigned to the linear interpolation used to derive the laboratory value at the cardinal point. This has been evaluated for all the linear fits. In each case the additional uncertainty is considered to be insignificant.

The second is the uncertainty due to the viscosity correction factor. This uncertainty is derived from the uncertainty of the line fitted through the Strouhal number to kinematic viscosity data from all laboratories. For the Kral meter both C1 and C2 data were evaluated separately and the slope averaged; for the turbine meter only data from C1 were used. The uncertainty in the Strouhal number due to the viscosity correction factor was assessed as being $0.0121|\nu - 3.5|$% and $0.0294|\nu - 3.5|$% at the 95% confidence level for the Kral and turbine meters respectively.

It is recognised that there is correlation between the data used to derive the viscosity correction factor and those used to derive the Strouhal number. It is possible (but in some ways irrational) to avoid this correlation for the Kral meter by using the viscosity correction from the C2 data for the C1 data (and vice versa). This was done and the conclusions of the analysis were unchanged.

11 INDICATION OF TEST RIG FLOW CONDITIONS

A turbine flowmeter is sensitive to the flow profile entering it. Its K-factor depends on the velocity profile, in particular, the degree of asymmetry and the degree of swirl. The effect on the meter is not easily quantified and no specific figure can be placed on the change of K-factor in relation to the degree of flow profile distortion from a fully developed profile.

The turbine meter was installed in the test package, downstream of a straight pipe of the same diameter as the meter. The pipe is approximately 8 diameters long. This will provide some degree of flow conditioning but is inadequate if the test rig itself is presenting a disturbed profile. This is one of the reasons for choosing the turbine meter as a test device since it would detect where a test rig was not providing a good profile, hence placing doubt on the accuracy of calibration of particular meter types.

To achieve this aim, the turbine was calibrated by each laboratory in two configurations. Configuration 1 is with the test package installed with a tube bundle flow conditioner installed at the upstream end of the inlet pipe section. This conditioner will remove substantial amounts of swirl and some asymmetry from the flow profile and provide a consistent, if not fully developed, flow profile to the meter. The meter was then calibrated in configuration 2 where the laboratory installed the meter in a manner they considered suitable for a turbine meter calibration.

The laboratories were asked to provide details of the pipework upstream of the package. It is difficult to obtain enough information to describe fully the upstream conditions as the configuration of bends and pipe expansions upstream of the test line are not easy to record in a consistent way.

A summary of the upstream pipework is given below in Table 10.

TABLE 10
UPSTREAM PIPEWORK

Laboratory	Immediate Upstream Pipe Length, D	Upstream of Immediate Pipework
FORCE	No Info	No Information
CMS	50	Zanker Flow conditioner, 6D pipe then no information
NMIJ	90	Reducer from 100mm, then 6D from bend
NEL	26	Reducer from 150 mm, 20 D pipe and complex branch valves and bend.
NMi	12	Reducer from 150 mm, tube bundle straightener, 180° bend slightly out of plane
SP	76	Complex SVP outlet, mesh straightener, bend and 10D of pipe

Based on the analysis of the results, it is clear that FORCE shows the largest change in turbine meter performance between the C1 and C2 configurations. This gives concern over the installation in this laboratory. Subsequent information obtained from FORCE explained that they misunderstood the instructions for the testing and because the C1 configuration has a flow straightener they removed the straightener normally located within their upstream pipework and did not replace this before testing for C2.

12 CONCLUSIONS

Nine laboratories entered into the intercomparison. Three withdrew for different reasons during the course of the intercomparison leaving six participants from two metrology regions.

The Kral meter was damaged early in the intercomparison and the repair caused a small but significant change in the characteristic. NEL and Force each submitted two data sets. Both were retained in the presentation of the results but only one of each provided input to the determination of the KCRV. KCRVs based on Strouhal number at a Reynolds number of 10^5 were derived for two installations of the Kral meter and one for the Turbine meter.

Initially there was a lack of consistency between the laboratories and the KCRVs. Examination of the data showed a clear viscosity dependence of the data. A correction was derived and, when applied, consistency was achieved between the six laboratories using the chosen data sets.

All six laboratories have *En* values which show consistency with both the relevant KCRV and each other within the 95% probability expectation (one inter-laboratory *En* value is 1.06 out of the 45 values produced). Three valid KCRVs have been generated and are given below along with the uncertainties.

	KCRV Strouhal number	**Uncertainty (*k* = 2)%**
Kral C1	7.9502	**0.015**
Kral C2	7.9496	**0.015**
Turbine C1	7.1878	**0.019**

Deviations of the institutes' results from the KCRV for the Kral meter lie within a band of ±0.026 % as shown by reference to Tables 4a and 4b.

REFERENCES

1 Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes. Technical report, Comité International des Poids et Measures, October 1999, Paris, France.

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APPENDIX A

REQUEST FOR WITHDRAWAL FROM CENAM, MEXICO

I am writing in regards to our participation on the key comparison ***CCM.FF-K2***, which is being kindly piloted by NEL.

According to the comparison schedule, CENAM received the transfer package after NMIJ participation. Once received (Mid May 2006), the package was moved to a facility that is located 100 km away from CENAM. Such a facility is what we call ***Storage and Distribution Terminal*** for refined oil products, operated by the state owned Mexican Petroleum Company (PEMEX).

We decided to test the transfer artifacts outside CENAM because our Hydrocarbon Liquid Facility is yet under construction. In order to perform our tests on the transfer package, we made use of an EG&G Compact Prover as the reference standard. While testing, we faced up several metrological disadvantages:

1.- **Limited space**. An on/off valve was located 10 D upstream of the inlet of the transfer package. There were no possibilities of enlarging the upstream straight pipe.
2.- **Pumping control**. The operation of the pump was not controlled by the ***Storage and Distribution Terminal*** but by the ***Refinery.*** Flowrate was controlled by means of throttling valves and by by-pass devices.
3.- **Fluid Temperature**. Temperature of the fluid was consistently higher than the protocol temperature limit. There were no means of controlling temperature of the fluid.
4.- **Maximum flowrate**. The test facility was not able to reach but only 75% of the protocol maximum flowrate.

According to our data, the biggest contribution to the expanded uncertainty, for K values, is related to reproducibility issues. We think that the poor reproducibility values are more correlated to “facility performance” rather than to the “meter performance”. In this sense, we understand that the quality of our data would hardly be of benefit in computing a representative KCRV. Therefore, we would like to submit, to the participating NMIs, a proposal of withdrawal. We understand this is difficult resolution to take; and want to express that we will fully understand and accept the decision of the participating NMIs.

In connection to the above information, I can also tell you that CENAM no longer perform calibration services for the oil industry by using the compact prover. Actually, the compact prover has been installed on a permanent basis to the Water Flow Facility at CENAM. We are now in the process of eliminating the corresponding CMC entry on the KCDB.

At present, we at CENAM are building our Liquid Hydrocarbon Flow Facility. This facility will include a Unidirectional Pipe Prover as the reference system for flowmeter calibrations. We think this facility will be operational by mid 2008, and will consider taking part in bi-lateral or multilateral comparison.

I thank you so much for your efforts in conducting this important comparison, and look forward hearing from you.

With my best regards

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APPENDIX B

REQUEST FOR WITHDRAWAL FROM MEASUREMENT CANADA

I would like to confirm that we wish to withdraw from the comparison. As mentioned before, we identified and recognised equipment failure that occurred during our testing of the artefact which renders our data invalid. The identified problem was with faulty valve operation that caused unmeasured product bypass during the testing of the artefact. Due to the nature of the problem and because this was identified in December 2006 and sent to your attention in Jan 2007 before the release of any results, we believe that abandoning the comparison is the preferred way of proceeding and does not contravene protocol.

It is our intention to pursue a bilateral comparison so that we can demonstrate and maintain our laboratory capabilities. You have indicated that NEL may be willing to participate in such a comparison using the same or similar package following the conclusion of the K2. We would welcome this opportunity and request that you keep us informed of the availability of the package so that we can proceed accordingly.

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APPENDIX C

TABLES OF FINAL RESULTS

Table C.1: FORCE 1

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	15.45	1301.164	261.44	4.977	0.839595	3.85	17734	20214	15.5353	7.34232	21887	16.8211	7.95061
2	15.45	1304.314	262.10	4.976	0.839595	3.85	17733	20265	15.5369	7.34307	21940	16.8211	7.95062
3	15.55	1319.437	131.31	10.048	0.839524	3.84	35898	20270	15.3626	7.26074	22190	16.8178	7.94908
4	15.55	1325.410	131.90	10.049	0.839524	3.84	35899	20361	15.3620	7.26046	22291	16.8182	7.94927
5	15.55	1831.973	122.70	14.931	0.839524	3.84	53340	28007	15.2879	7.22542	30801	16.8130	7.94682
6	15.65	1815.507	121.77	14.909	0.839453	3.83	53401	27755	15.2877	7.22539	30524	16.8129	7.94681
7	15.75	2437.698	121.89	19.999	0.839383	3.82	71816	37146	15.2381	7.20198	40981	16.8114	7.94609
8	15.85	2429.941	121.53	19.995	0.839312	3.81	71983	37027	15.2378	7.20186	40850	16.8111	7.94600
9	16.15	3046.900	121.70	25.036	0.839099	3.78	90826	46323	15.2033	7.18567	51206	16.8059	7.94363
10	16.35	3039.914	121.52	25.016	0.838957	3.76	91214	46214	15.2024	7.18530	51089	16.8061	7.94375
11	16.95	3622.476	121.62	29.785	0.838532	3.70	110257	54976	15.1764	7.17321	60868	16.8029	7.94240
12	17.35	3630.841	122.49	29.642	0.838248	3.66	110828	55095	15.1742	7.17232	61002	16.8011	7.94165
13	18.05	3362.009	121.69	27.628	0.837752	3.60	105101	51041	15.1817	7.17613	56489	16.8022	7.94235
14	18.25	3360.077	121.66	27.619	0.837610	3.58	105585	51009	15.1809	7.17583	56458	16.8026	7.94261
15	18.65	2722.187	121.32	22.438	0.837327	3.55	86625	41395	15.2065	7.18808	45745	16.8045	7.94362
16	18.75	2727.419	121.46	22.455	0.837256	3.54	86903	41476	15.2071	7.18837	45834	16.8049	7.94383
17	18.85	2140.917	122.12	17.531	0.837185	3.53	68013	32633	15.2425	7.20517	35985	16.8082	7.94543
18	18.95	2129.861	121.48	17.533	0.837114	3.52	68184	32459	15.2400	7.20400	35796	16.8067	7.94475
19	19.05	1527.626	121.78	12.544	0.837043	3.51	48903	23364	15.2943	7.22973	25679	16.8097	7.94621
20	19.05	1524.355	121.44	12.552	0.837043	3.51	48935	23312	15.2930	7.22911	25624	16.8097	7.94620
21	19.15	1317.089	174.83	7.534	0.836972	3.50	29441	20282	15.3991	7.27930	22149	16.8166	7.94949
22	19.15	1384.792	183.74	7.537	0.836972	3.50	29453	21323	15.3980	7.27876	23288	16.8170	7.94964
23	19.55	3026.514	121.06	25.000	0.836688	3.47	98654	45965	15.1874	7.17938	50852	16.8022	7.94276
24	19.75	3056.538	122.35	24.982	0.836547	3.45	99062	46420	15.1871	7.17930	51358	16.8027	7.94305
25	19.95	3023.227	121.11	24.963	0.836405	3.43	99466	45915	15.1874	7.17951	50794	16.8013	7.94243
26	20.25	3117.154	124.89	24.959	0.836192	3.41	100177	47345	15.1885	7.18015	52377	16.8028	7.94325
27	20.45	3025.966	121.41	24.924	0.836050	3.39	100520	45955	15.1869	7.17945	50842	16.8019	7.94287
28	20.65	3082.152	123.61	24.934	0.835909	3.37	101052	46804	15.1855	7.17886	51786	16.8019	7.94292
29	20.85	3020.978	121.21	24.924	0.835767	3.35	101497	45870	15.1838	7.17814	50755	16.8008	7.94248

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	15.62	1316.169	263.92	4.987	0.839475	3.83	17848	20278	15.4068	7.28166	22136	16.8185	7.94944
2	15.62	1309.750	262.46	4.990	0.839475	3.83	17860	20180	15.4075	7.28199	22028	16.8185	7.94942
3	15.62	1339.949	133.49	10.038	0.839475	3.83	35925	20443	15.2566	7.21064	22535	16.8178	7.94911
4	15.62	1369.280	136.37	10.041	0.839475	3.83	35936	20889	15.2555	7.21012	23028	16.8176	7.94901
5	15.72	1866.216	124.33	15.010	0.839404	3.82	53859	28296	15.1622	7.16609	31376	16.8126	7.94668
6	15.82	1840.685	122.92	14.975	0.839333	3.81	53870	27910	15.1628	7.16641	30946	16.8122	7.94652
7	15.92	2441.857	121.97	20.020	0.839262	3.80	72204	36889	15.1069	7.14003	41050	16.8110	7.94596
8	16.02	2426.521	121.19	20.022	0.839191	3.79	72397	36659	15.1076	7.14040	40793	16.8113	7.94614
9	16.32	3014.956	120.51	25.018	0.838978	3.76	91154	45420	15.0649	7.12030	50662	16.8036	7.94256
10	16.62	3019.552	120.75	25.007	0.838766	3.73	91804	45483	15.0628	7.11943	50735	16.8022	7.94198
11	17.12	3632.517	121.10	29.996	0.838411	3.69	111511	54619	15.0361	7.10699	61033	16.8018	7.94196
12	17.42	3602.745	120.33	29.941	0.838199	3.66	112139	54175	15.0371	7.10758	60538	16.8033	7.94272
13	17.92	3207.471	121.15	26.475	0.837844	3.61	100395	48278	15.0517	7.11465	53898	16.8039	7.94314
14	18.22	3188.279	120.53	26.452	0.837631	3.58	101051	47979	15.0486	7.11326	53568	16.8015	7.94211
15	21.72	2969.739	121.70	24.402	0.835150	3.28	101492	44675	15.0434	7.11207	49893	16.8005	7.94253
16	22.02	2905.387	120.69	24.073	0.834937	3.26	100857	43717	15.0469	7.11382	48815	16.8015	7.94312
17	22.22	2851.945	120.38	23.691	0.834796	3.24	99742	42914	15.0473	7.11408	47913	16.8001	7.94249
18	22.32	2802.500	120.38	23.280	0.834725	3.23	98252	42176	15.0494	7.11513	47084	16.8007	7.94280

Table C.2: CMS

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	20.07	6259.658	1248.57	5.013	0.806473	3.45	19129	97391	15.5585	7.35499	105283	16.8193	7.95099
2	20	6262.598	1247.77	5.019	0.806521	3.46	19116	97437	15.5586	7.35498	105331	16.8191	7.95086
3	20.185	6287.298	630.13	9.978	0.806394	3.44	38181	96565	15.3587	7.26059	105733	16.8169	7.94990
4	19.885	6293.235	632.41	9.951	0.806601	3.47	37792	96677	15.3621	7.26205	105835	16.8173	7.94998
5	20.23	6324.795	423.31	14.941	0.806363	3.44	57239	96656	15.2821	7.22437	106342	16.8135	7.94830
6	19.95	6322.638	417.98	15.127	0.806556	3.47	57541	96622	15.2819	7.22419	106310	16.8142	7.94854
7	20.205	6339.555	316.59	20.024	0.806380	3.44	76665	96591	15.2362	7.20269	106576	16.8113	7.94723
8	19.935	6355.966	315.49	20.146	0.806566	3.47	76607	96843	15.2366	7.20274	106856	16.8119	7.94747
9	19.98	6368.215	253.65	25.106	0.806535	3.46	95576	96825	15.2044	7.18756	107064	16.8122	7.94763
10	20.08	6371.117	253.96	25.087	0.806466	3.45	95745	96871	15.2047	7.18774	107106	16.8112	7.94716
11	20.065	6379.916	213.76	29.846	0.806476	3.46	113864	96858	15.1817	7.17686	107250	16.8106	7.94686
12	20.01	6398.096	214.35	29.849	0.806514	3.46	113717	97132	15.1814	7.17669	107551	16.8098	7.94651
13	20.015	6370.654	231.38	27.533	0.806511	3.46	104908	96778	15.1912	7.18134	107094	16.8105	7.94683
14	20	6396.792	231.47	27.636	0.806521	3.46	105258	97167	15.1900	7.18074	107535	16.8108	7.94694
15	19.94	6361.186	280.77	22.656	0.806563	3.47	86162	96806	15.2182	7.19408	106943	16.8118	7.94741
16	20.015	6350.423	282.66	22.467	0.806511	3.46	85603	96646	15.2188	7.19439	106760	16.8115	7.94728
17	20.015	6335.295	364.65	17.374	0.806511	3.46	66198	96661	15.2575	7.21269	106508	16.8118	7.94745
18	19.92	6338.284	361.23	17.546	0.806576	3.47	66696	96705	15.2573	7.21253	106567	16.8132	7.94808
19	20.09	6312.671	504.75	12.507	0.806459	3.45	47743	96677	15.3148	7.23976	106151	16.8155	7.94922
20	19.81	6304.618	502.18	12.554	0.806652	3.48	47588	96562	15.3161	7.24029	106023	16.8167	7.94970
21	20.015	6275.380	835.86	7.508	0.806511	3.46	28606	96856	15.4343	7.29624	105541	16.8183	7.95049
22	20.02	6282.728	831.67	7.554	0.806507	3.46	28787	96956	15.4321	7.29523	105665	16.8183	7.95052
23	19.97	6369.259	241.46	26.378	0.806542	3.46	100393	96789	15.1963	7.18371	107069	16.8103	7.94670
24	20.02	6363.965	243.40	26.146	0.806507	3.46	99635	96721	15.1982	7.18465	106989	16.8117	7.94738
25	20.02	6366.577	242.33	26.272	0.806507	3.46	100116	96754	15.1972	7.18416	107032	16.8115	7.94731
26	19.995	6368.418	242.68	26.242	0.806525	3.46	99938	96787	15.1980	7.18452	107065	16.8119	7.94746
27	20.05	6374.442	243.32	26.198	0.806487	3.46	99908	96873	15.1971	7.18413	107158	16.8106	7.94686
28	20.035	6370.623	242.55	26.265	0.806497	3.46	100127	96811	15.1965	7.18383	107092	16.8103	7.94672

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	19.98	6259.126	1256.12	4.983	0.806535	3.46	18969	97269	15.5403	7.34637	105272	16.8190	7.95081
2	19.87	6259.438	1238.71	5.053	0.806611	3.47	19183	97261	15.5383	7.34536	105273	16.8183	7.95046
3	19.84	6290.853	626.74	10.037	0.806632	3.48	38076	96535	15.3453	7.25411	105788	16.8162	7.94945
4	19.995	6290.824	629.24	9.997	0.806525	3.46	38074	96533	15.3450	7.25405	105786	16.8159	7.94937
5	20.005	6316.337	424.76	14.870	0.806518	3.46	56645	96378	15.2585	7.21315	106204	16.8142	7.94855
6	19.82	6322.862	421.13	15.014	0.806645	3.48	56926	96476	15.2583	7.21297	106314	16.8142	7.94852
7	19.82	6335.016	317.36	19.962	0.806645	3.48	75684	96338	15.2072	7.18883	106502	16.8116	7.94730
8	20.05	6361.590	319.46	19.914	0.806487	3.46	75942	96737	15.2064	7.18854	106946	16.8112	7.94716
9	20	6375.921	255.81	24.924	0.806521	3.46	94932	96743	15.1732	7.17280	107177	16.8096	7.94641
10	19.985	6369.663	256.29	24.853	0.806532	3.46	94625	96655	15.1743	7.17332	107076	16.8103	7.94672
11	20.005	6383.050	212.78	29.998	0.806518	3.46	114272	96709	15.1509	7.16228	107289	16.8084	7.94583
12	20.085	6396.652	214.47	29.825	0.806463	3.45	113843	96917	15.1512	7.16245	107520	16.8088	7.94603
13	20.02	6392.839	232.16	27.536	0.806507	3.46	104933	96918	15.1604	7.16677	107458	16.8091	7.94617
14	19.965	6366.204	229.50	27.739	0.806545	3.46	105560	96513	15.1602	7.16666	107011	16.8092	7.94620
15	19.975	6369.090	280.65	22.694	0.806538	3.46	86382	96721	15.1860	7.17886	107070	16.8109	7.94699
16	20.005	6361.217	281.82	22.572	0.806518	3.46	85983	96609	15.1872	7.17943	106938	16.8109	7.94702
17	19.99	6338.792	360.14	17.601	0.806528	3.46	67021	96520	15.2269	7.19818	106565	16.8116	7.94731
18	19.9	6339.585	360.50	17.586	0.806590	3.47	66811	96536	15.2275	7.19844	106584	16.8125	7.94771
19	20.11	6312.731	504.80	12.505	0.806445	3.45	47763	96535	15.2921	7.22907	106143	16.8141	7.94855
20	20.085	6311.183	500.29	12.615	0.806463	3.45	48151	96495	15.2895	7.22784	106111	16.8132	7.94810
21	19.985	6281.417	839.35	7.484	0.806532	3.46	28493	96869	15.4215	7.29020	105629	16.8161	7.94946
22	19.92	6275.695	838.75	7.482	0.806576	3.47	28441	96787	15.4225	7.29064	105535	16.8165	7.94961
23	19.945	6391.546	242.29	26.380	0.806559	3.47	100335	96934	15.1660	7.16938	107440	16.8097	7.94642
24	19.91	6371.043	242.63	26.258	0.806583	3.47	99785	96627	15.1666	7.16966	107096	16.8098	7.94646
25	19.875	6375.574	242.33	26.309	0.806607	3.47	99891	96693	15.1662	7.16944	107174	16.8101	7.94659
26	20.08	6382.284	242.76	26.291	0.806466	3.45	100337	96795	15.1662	7.16953	107296	16.8115	7.94732
27	19.95	6368.034	241.86	26.329	0.806556	3.47	100157	96576	15.1657	7.16927	107062	16.8124	7.94770
28	20.02	6375.762	243.13	26.224	0.806507	3.46	99931	96696	15.1662	7.16951	107189	16.8120	7.94750

Table C.3: NMIJ

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	19.904	11781.347	1184.90	9.943	0.791863	1.52	84793	179472	15.2336	7.20131	198165	16.8203	7.95140
2	19.899	11781.013	1184.82	9.943	0.791867	1.52	84788	179467	15.2336	7.20131	198160	16.8203	7.95140
3	19.912	11792.937	790.10	14.926	0.791857	1.52	127304	179076	15.1850	7.17838	198314	16.8164	7.94956
4	19.914	11793.711	789.89	14.931	0.791856	1.52	127351	179090	15.1852	7.17846	198330	16.8166	7.94966
5	19.921	11806.872	593.21	19.903	0.791851	1.52	169785	178997	15.1604	7.16672	198495	16.8118	7.94741
6	19.938	11804.771	593.14	19.902	0.791838	1.52	169828	178967	15.1606	7.16681	198460	16.8118	7.94742
7	19.954	11815.900	475.12	24.869	0.791826	1.52	212272	178970	15.1466	7.16021	198580	16.8062	7.94475
8	19.959	11819.486	475.24	24.871	0.791822	1.52	212303	179024	15.1466	7.16020	198639	16.8061	7.94471
9	19.981	11826.137	396.01	29.864	0.791806	1.52	255024	179061	15.1411	7.15763	198693	16.8012	7.94241
10	20.004	11825.348	396.02	29.861	0.791790	1.51	255102	179049	15.1411	7.15766	198681	16.8013	7.94246
11	19.993	11823.608	432.12	27.362	0.791798	1.52	233711	179042	15.1427	7.15840	198677	16.8034	7.94346
12	19.989	11820.180	432.04	27.359	0.791800	1.52	233670	178991	15.1428	7.15846	198619	16.8033	7.94343
13	19.96	11812.420	527.59	22.389	0.791822	1.52	191123	178986	15.1523	7.16293	198555	16.8090	7.94608
14	19.957	11810.877	527.56	22.388	0.791824	1.52	191101	178961	15.1522	7.16287	198528	16.8089	7.94604
15	19.975	11814.766	474.98	24.874	0.791811	1.52	212395	178948	15.1461	7.16000	198559	16.8060	7.94468
16	19.967	11817.646	475.08	24.875	0.791817	1.52	212371	178992	15.1462	7.16002	198607	16.8060	7.94468
17	19.885	11786.892	1005.82	11.719	0.791877	1.52	99903	179311	15.2127	7.19147	198249	16.8195	7.95102
18	19.914	11787.981	1006.07	11.717	0.791856	1.52	99938	179323	15.2123	7.19129	198267	16.8194	7.95101
19	19.911	11787.296	1006.14	11.715	0.791858	1.52	99921	179315	15.2126	7.19139	198256	16.8195	7.95103
20	19.909	11787.704	1006.20	11.715	0.791859	1.52	99914	179321	15.2125	7.19136	198263	16.8195	7.95104
21	19.9	11786.022	1005.81	11.718	0.791866	1.52	99922	179298	15.2127	7.19147	198237	16.8197	7.95112
22	19.896	11784.394	1005.92	11.715	0.791869	1.52	99890	179271	15.2125	7.19137	198208	16.8196	7.95107
23	19.915	11798.296	677.55	17.413	0.791855	1.52	148527	178986	15.1705	7.17151	198380	16.8143	7.94859
24	19.922	11798.679	677.63	17.412	0.791850	1.52	148533	178990	15.1703	7.17141	198386	16.8143	7.94858
25	19.985	11813.412	474.76	24.883	0.791804	1.52	212505	178928	15.1462	7.16003	198535	16.8059	7.94463
26	19.97	11813.968	474.70	24.887	0.791815	1.52	212484	178940	15.1464	7.16015	198546	16.8060	7.94470
27	19.892	11785.980	947.61	12.438	0.791872	1.52	106045	179209	15.2053	7.18795	198224	16.8186	7.95061
28	19.903	11789.242	947.75	12.439	0.791864	1.52	106079	179258	15.2052	7.18790	198277	16.8185	7.95057
29	19.923	1196.319	159.45	7.503	0.791849	1.52	64006	18273	15.2740	7.22044	20122.3	16.8201	7.95135
30	19.922	1195.911	159.392	7.5029	0.791849	1.52	64005	18267	15.2743	7.220596	20115.3	16.82	7.9513
31	19.918	1189.301	237.818	5.0009	0.791852	1.52	42658	18244	15.34	7.251616	20007.1	16.8225	7.95248
32	19.92	1189.633	238.13	4.9957	0.791851	1.52	42615	18246	15.3377	7.250542	20012.3	16.8222	7.95233

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	19.907	11782.739	1184.60	9.947	0.791861	1.52	84828	178920	15.1849	7.17831	198177	16.8193	7.95094
2	19.905	11782.922	1184.42	9.948	0.791862	1.52	84839	178926	15.1852	7.17845	198182	16.8194	7.95100
3	19.922	11794.411	789.55	14.938	0.791850	1.52	127433	178498	15.1341	7.15430	198331	16.8156	7.94922
4	19.915	11792.364	789.37	14.939	0.791855	1.52	127422	178467	15.1341	7.15430	198296	16.8156	7.94921
5	19.932	11804.976	592.54	19.923	0.791843	1.52	169981	178383	15.1109	7.14332	198462	16.8117	7.94738
6	19.931	11805.360	592.51	19.924	0.791843	1.52	169995	178397	15.1115	7.14362	198471	16.8120	7.94749
7	19.96	11818.256	474.69	24.897	0.791822	1.52	212530	178469	15.1011	7.13872	198618	16.8061	7.94471
8	19.962	11815.152	474.60	24.895	0.791821	1.52	212521	178422	15.1012	7.13874	198566	16.8061	7.94471
9	19.992	11826.802	395.80	29.881	0.791798	1.52	255220	178553	15.0973	7.13694	198700	16.8008	7.94224
10	19.987	11828.569	395.82	29.884	0.791802	1.52	255224	178576	15.0970	7.13679	198729	16.8007	7.94220
11	19.91	1189.059	237.57	5.005	0.791859	1.52	42687	18208	15.3131	7.23894	20002.8	16.8224	7.95239
12	19.91	1188.813	237.47	5.006	0.791858	1.52	42698	18206	15.3141	7.23938	19998.1	16.8219	7.95220
13	19.979	11820.557	474.95	24.888	0.791808	1.52	212528	178496	15.1005	7.13842	198651	16.8056	7.94447
14	19.967	11817.112	474.74	24.892	0.791817	1.52	212511	178450	15.1010	7.13866	198593	16.8056	7.94446
15	19.887	11787.186	1005.48	11.723	0.791876	1.52	99942	178723	15.1624	7.16769	198253	16.8194	7.95098
16	19.905	11787.539	1005.45	11.724	0.791862	1.52	99981	178726	15.1623	7.16763	198256	16.8191	7.95086
17	19.897	11788.147	1005.88	11.719	0.791868	1.52	99928	178737	15.1625	7.16770	198268	16.8193	7.95092
18	19.899	11785.632	1005.52	11.721	0.791867	1.52	99946	178695	15.1621	7.16752	198225	16.8192	7.95089
19	19.9	11785.860	1005.48	11.722	0.791866	1.52	99954	178700	15.1622	7.16760	198229	16.8193	7.95092
20	19.912	11786.473	1005.58	11.721	0.791857	1.52	99970	178707	15.1621	7.16751	198240	16.8193	7.95095

Table C.4: NEL 1

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	20.098	1413.660	141.13	10.017	0.793878	1.71	75857	21569	15.2576	7.21273	23781	16.8223	7.95242
2	20.096	1414.111	141.17	10.017	0.793880	1.71	75856	21577	15.2583	7.21310	23790	16.8233	7.95288
3	20.151	1811.457	120.08	15.086	0.793839	1.71	114358	27544	15.2054	7.18811	30473	16.8224	7.95246
4	20.155	1798.548	119.18	15.091	0.793837	1.71	114399	27348	15.2056	7.18818	30256	16.8225	7.95251
5	20.188	1806.866	91.11	19.831	0.793813	1.71	150420	27427	15.1793	7.17578	30390	16.8192	7.95097
6	20.203	1805.933	91.05	19.835	0.793802	1.71	150498	27413	15.1794	7.17582	30374	16.8190	7.95089
7	20.288	1810.317	72.50	24.968	0.793740	1.71	189730	27448	15.1620	7.16761	30441	16.8153	7.94915
8	20.29	1805.730	72.24	24.996	0.793739	1.71	189945	27378	15.1617	7.16750	30363	16.8148	7.94893
9	20.34	1822.872	60.73	30.015	0.793703	1.71	228289	27625	15.1547	7.16417	30645	16.8114	7.94732
10	20.341	1806.753	60.21	30.009	0.793702	1.71	228247	27381	15.1548	7.16424	30375	16.8119	7.94758
11	20.33	1810.534	65.64	27.585	0.793710	1.71	209766	27442	15.1569	7.16520	30441	16.8133	7.94821
12	20.303	1808.800	65.55	27.593	0.793730	1.71	209733	27417	15.1576	7.16553	30411	16.8128	7.94798
13	20.201	1793.796	80.52	22.277	0.793803	1.71	169015	27212	15.1701	7.17140	30166	16.8169	7.94987
14	20.156	1789.283	80.34	22.270	0.793836	1.71	168830	27143	15.1698	7.17125	30091	16.8174	7.95009
15	20.147	1805.935	103.20	17.500	0.793842	1.71	132648	27434	15.1910	7.18129	30378	16.8212	7.95191
16	20.135	1801.979	102.98	17.498	0.793851	1.71	132606	27373	15.1905	7.18105	30312	16.8215	7.95205
17	20.152	1809.674	145.49	12.439	0.793839	1.71	94292	27557	15.2276	7.19859	30444	16.8229	7.95272
18	20.139	1800.522	144.74	12.440	0.793848	1.71	94279	27419	15.2284	7.19894	30291	16.8235	7.95297
19	20.124	1420.412	190.69	7.449	0.793859	1.71	56436	21727	15.2963	7.23104	23888	16.8177	7.95023
20	20.108	1417.364	190.28	7.449	0.793871	1.71	56421	21681	15.2967	7.23124	23835	16.8164	7.94964
21	20.134	929.742	183.65	5.062	0.793852	1.71	38364	14277	15.3559	7.25921	15634	16.8154	7.94917
22	20.112	933.634	184.47	5.061	0.793868	1.71	38338	14336	15.3551	7.25882	15700	16.8160	7.94945
23	20.147	1800.738	143.36	12.561	0.793843	1.71	95212	27420	15.2271	7.19834	30293	16.8226	7.95255
24	20.156	1796.895	139.95	12.839	0.793836	1.71	97334	27356	15.2240	7.19690	30229	16.8229	7.95272
25	20.167	1795.327	136.61	13.142	0.793828	1.71	99652	27328	15.2217	7.19582	30203	16.8231	7.95282
26	20.163	1800.746	133.75	13.464	0.793831	1.71	102083	27404	15.2181	7.19411	30293	16.8225	7.95252
27	20.152	1811.173	131.78	13.744	0.793839	1.71	104187	27559	15.2161	7.19315	30469	16.8228	7.95267
28	20.159	1802.735	129.60	13.910	0.793834	1.71	105456	27426	15.2136	7.19195	30326	16.8222	7.95240

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	20.093	1423.171	138.86	10.249	0.793882	1.71	77612	21657	15.2174	7.19375	23945	16.8251	7.95374
2	20.171	1416.386	137.95	10.267	0.793825	1.71	77857	21550	15.2148	7.19253	23831	16.8252	7.95381
3	20.232	1802.327	120.70	14.933	0.793781	1.71	113358	27331	15.1643	7.16868	30323	16.8244	7.95343
4	20.232	1796.273	120.33	14.928	0.793781	1.71	113322	27238	15.1636	7.16837	30221	16.8243	7.95339
5	20.243	1813.272	89.52	20.256	0.793773	1.71	153802	27446	15.1362	7.15540	30499	16.8199	7.95131
6	20.253	1805.343	89.05	20.273	0.793766	1.71	153953	27328	15.1373	7.15593	30366	16.8201	7.95140
7	20.298	1805.117	72.50	24.897	0.793733	1.71	189223	27304	15.1259	7.15056	30355	16.8161	7.94953
8	20.328	1791.920	72.06	24.867	0.793712	1.71	189095	27099	15.1229	7.14914	30135	16.8172	7.95005
9	20.365	1810.484	60.79	29.784	0.793685	1.70	226633	27369	15.1170	7.14636	30441	16.8137	7.94844
10	20.382	1808.089	61.04	29.622	0.793672	1.70	225470	27329	15.1149	7.14537	30401	16.8139	7.94851
11	20.402	1815.988	66.29	27.393	0.793658	1.70	208580	23680	13.0397	6.16439	30536	16.8151	7.94909
12	20.404	1809.077	66.44	27.231	0.793657	1.70	207344	27347	15.1166	7.14618	30420	16.8152	7.94915
13	20.356	1811.321	80.49	22.505	0.793691	1.71	171218	27406	15.1304	7.15271	30464	16.8187	7.95077
14	20.237	1801.184	79.95	22.528	0.793778	1.71	171032	27242	15.1245	7.14987	30295	16.8195	7.95113
15	20.14	1801.725	104.20	17.291	0.793848	1.71	131042	27298	15.1510	7.16239	30311	16.8233	7.95291
16	20.073	1809.711	104.74	17.278	0.793896	1.71	130790	27417	15.1499	7.16184	30446	16.8237	7.95306
17	20.088	1801.770	144.95	12.430	0.793885	1.71	94117	27366	15.1884	7.18003	30316	16.8257	7.95401
18	20.178	1798.463	144.70	12.429	0.793820	1.71	94260	27316	15.1885	7.18012	30260	16.8255	7.95394
19	20.18	1421.703	191.47	7.425	0.793818	1.71	56315	21709	15.2697	7.21850	23913	16.8200	7.95134
20	20.179	1415.824	190.71	7.424	0.793820	1.71	56305	21622	15.2717	7.21943	23817	16.8220	7.95230
21	20.17	929.860	182.45	5.097	0.793826	1.71	38647	14271	15.3475	7.25526	15637	16.8165	7.94970
22	20.168	929.454	182.13	5.103	0.793828	1.71	38696	14265	15.3477	7.25537	15630	16.8163	7.94961
23	20.19	1809.207	139.31	12.987	0.793811	1.71	98513	27466	15.1812	7.17668	30440	16.8251	7.95374
24	20.202	1808.798	136.95	13.208	0.793803	1.71	100208	27461	15.1819	7.17700	30434	16.8255	7.95398
25	20.198	1811.820	135.19	13.402	0.793806	1.71	101677	27507	15.1820	7.17703	30483	16.8245	7.95349
26	20.184	1799.967	132.88	13.546	0.793816	1.71	102743	27317	15.1764	7.17439	30284	16.8248	7.95360
27	20.18	1805.651	130.07	13.883	0.793819	1.71	105289	27396	15.1724	7.17248	30379	16.8244	7.95343
28	20.198	1805.052	128.24	14.075	0.793806	1.71	106784	27388	15.1730	7.17278	30369	16.8244	7.95346

Table C.5: NMi

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp C	Volume l	Time s	Flow l/s	Density kg/l	Visc. mPas	Reynolds	Pulses	K factor p/l	Strouhal	Pulses	K factor p/l	Strouhal
1	19.76	4947.890	198.63	24.909	0.830926	3.45	98161	75243	15.2071	7.18875	83228	16.8209	7.95167
2	19.84	4959.685	199.57	24.851	0.830869	3.44	98129	75420	15.2066	7.18855	83422	16.8200	7.95127
3	19.94	4984.638	200.58	24.851	0.830799	3.43	98373	75798	15.2063	7.18845	83843	16.8203	7.95142
4	20.06	4963.126	199.71	24.852	0.830714	3.42	98674	75466	15.2053	7.18803	83477	16.8194	7.95105
5	20.24	4958.804	199.55	24.850	0.830587	3.40	99109	75404	15.2061	7.18845	83412	16.8210	7.95184
6	20.33	4954.845	199.61	24.822	0.830524	3.40	99221	75337	15.2047	7.18783	83338	16.8195	7.95115
7	17.89	1991.692	394.89	5.044	0.832244	3.62	18956	31006	15.5677	7.35851	33487	16.8133	7.94760
8	18.1	1990.595	394.44	5.047	0.832096	3.60	19069	30982	15.5642	7.35695	33468	16.8131	7.94752
9	18.18	1990.870	199.03	10.003	0.832040	3.59	37875	30591	15.3656	7.26312	33496	16.8248	7.95309
10	18.21	1993.075	199.00	10.015	0.832019	3.59	37950	30623	15.3647	7.26269	33532	16.8243	7.95284
11	18.28	1984.628	131.84	15.053	0.831969	3.58	57142	30343	15.2890	7.22694	33395	16.8268	7.95408
12	18.46	1984.770	131.97	15.040	0.831842	3.57	57353	30345	15.2889	7.22696	33401	16.8286	7.95498
13	18.61	4960.352	247.48	20.044	0.831737	3.55	76727	75591	15.2390	7.20344	83449	16.8232	7.95245
14	18.84	4957.638	247.66	20.018	0.831574	3.53	77077	75551	15.2393	7.20365	83411	16.8247	7.95324
15	19.15	4988.361	198.59	25.119	0.831356	3.50	97479	75844	15.2042	7.18716	83904	16.8200	7.95106
16	19.3	4964.643	197.66	25.117	0.831250	3.49	97839	75488	15.2051	7.18765	83513	16.8216	7.95185
17	19.75	4962.096	167.62	29.604	0.830933	3.45	116631	75335	15.1821	7.17693	83440	16.8155	7.94910
18	19.88	5123.749	173.05	29.609	0.830841	3.44	117031	77772	15.1787	7.17538	86144	16.8127	7.94782
19	20.18	4964.823	180.13	27.562	0.830630	3.41	109762	75412	15.1893	7.18047	83491	16.8165	7.94970
20	20.28	4953.197	179.71	27.563	0.830559	3.40	110038	75231	15.1884	7.18009	83294	16.8162	7.94959
21	20.46	4963.265	220.25	22.534	0.830432	3.38	90367	75507	15.2132	7.19187	83476	16.8188	7.95084
22	20.56	4957.536	220.00	22.534	0.830362	3.38	90592	75418	15.2128	7.19174	83380	16.8188	7.95090
23	20.65	1986.703	112.60	17.643	0.830298	3.37	71087	30299	15.2509	7.20978	33421	16.8223	7.95258
24	20.7	1986.904	112.62	17.643	0.830263	3.36	71174	30302	15.2509	7.20978	33425	16.8227	7.95274
25	20.73	1986.554	158.77	12.512	0.830242	3.36	50512	30411	15.3084	7.23700	33422	16.8241	7.95344
26	20.68	1979.347	158.33	12.501	0.830277	3.37	50407	30300	15.3081	7.23682	33297	16.8222	7.95253
27	20.67	1985.724	265.19	7.488	0.830284	3.37	30185	30619	15.4196	7.28952	33388	16.8140	7.94865
28	20.68	1983.949	264.56	7.499	0.830277	3.37	30237	30593	15.4203	7.28985	33361	16.8154	7.94933

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp C	Volume l	Time s	Flow l/s	Density kg/l	Visc. mPas	Reynolds	Pulses	K factor p/l	Strouhal	Pulses	K factor p/l	Strouhal
1	21.13	4930.127	199.81	24.674	0.829960	3.33	100602	74854	15.1830	7.17784	82921	16.8192	7.95125
2	21.16	4951.784	201.65	24.556	0.829939	3.32	100195	75178	15.1820	7.17739	83282	16.8186	7.95094
3	21.2	4930.664	202.24	24.380	0.829911	3.32	99573	74850	15.1805	7.17670	82920	16.8172	7.95030
4	21.22	4941.310	202.70	24.378	0.829897	3.32	99615	75021	15.1824	7.17761	83105	16.8184	7.95088
5	21.24	4939.360	202.60	24.379	0.829882	3.32	99669	74986	15.1813	7.17710	83068	16.8176	7.95048
6	21.26	4934.974	202.91	24.320	0.829868	3.32	99478	74915	15.1804	7.17668	82992	16.8171	7.95027
7	20.16	1988.841	395.74	5.026	0.830644	3.41	20004	30918	15.5457	7.34898	33440	16.8138	7.94842
8	20.25	1988.764	393.88	5.049	0.830580	3.40	20143	30911	15.5428	7.34764	33440	16.8145	7.94875
9	20.19	1982.018	196.57	10.083	0.830623	3.41	40163	30418	15.3470	7.25503	33339	16.8207	7.95170
10	20.18	1998.751	198.24	10.082	0.830630	3.41	40151	30678	15.3486	7.25579	33622	16.8215	7.95206
11	20.21	1992.157	133.00	14.978	0.830609	3.41	59693	30410	15.2649	7.21622	33517	16.8245	7.95348
12	20.21	2006.201	133.94	14.978	0.830609	3.41	59693	30624	15.2647	7.21613	33753	16.8243	7.95341
13	20.29	4933.636	246.96	19.977	0.830552	3.40	79775	75056	15.2131	7.19179	82979	16.8190	7.95093
14	20.35	4964.021	245.56	20.215	0.830510	3.39	80846	75510	15.2115	7.19103	83490	16.8190	7.95094
15	20.48	4981.354	199.45	24.976	0.830418	3.38	100208	75618	15.1802	7.17630	83768	16.8163	7.94969
16	20.53	4964.089	198.77	24.974	0.830383	3.38	100327	75358	15.1806	7.17652	83482	16.8172	7.95011
17	20.75	4964.301	166.60	29.798	0.830228	3.36	120359	75249	15.1580	7.16591	83466	16.8132	7.94831
18	20.82	4965.052	166.62	29.799	0.830179	3.35	120571	75260	15.1579	7.16590	83476	16.8127	7.94808
19	21.04	4962.996	181.40	27.359	0.830023	3.33	111301	75273	15.1668	7.17018	83446	16.8136	7.94857
20	21.11	4953.376	181.05	27.359	0.829974	3.33	111492	75124	15.1662	7.16991	83285	16.8138	7.94866
21	21.22	4970.161	222.88	22.300	0.829897	3.32	91123	75505	15.1917	7.18198	83580	16.8164	7.94990
22	21.23	4968.640	223.40	22.241	0.829890	3.32	90905	75482	15.1917	7.18199	83552	16.8159	7.94968
23	21.25	2030.014	115.34	17.600	0.829875	3.32	71972	30913	15.2280	7.19916	34141	16.8181	7.95074
24	21.24	2017.314	115.43	17.477	0.829882	3.32	71450	30725	15.2306	7.20042	33936	16.8224	7.95275
25	21.27	2020.853	161.40	12.521	0.829861	3.32	51226	30901	15.2911	7.22899	33991	16.8201	7.95170
26	21.2	2009.900	160.62	12.514	0.829911	3.32	51109	30734	15.2913	7.22908	33810	16.8217	7.95244
27	21.18	2016.559	270.19	7.463	0.829925	3.32	30468	31084	15.4144	7.28726	33909	16.8153	7.94939
28	21.11	2006.875	269.30	7.452	0.829974	3.33	30370	30934	15.4140	7.28706	33743	16.8137	7.94862

Table C.6: FORCE 2

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	17.17	1297.492	258.19	5.025	0.833915	3.21	21328	20101	15.4922	7.32257	21834	16.8279	7.95426
2	17.17	1299.067	258.52	5.025	0.833915	3.21	21326	20131	15.4965	7.32461	21858	16.8259	7.95335
3	17.17	1324.963	132.20	10.022	0.833915	3.21	42535	20306	15.3257	7.24388	22294	16.8261	7.95345
4	17.17	1315.867	131.26	10.025	0.833915	3.21	42546	20169	15.3275	7.24474	22144	16.8284	7.95455
5	17.17	1811.808	120.63	15.020	0.833915	3.21	63743	27649	15.2605	7.21304	30482	16.8241	7.95248
6	17.27	1810.388	120.55	15.018	0.833843	3.20	63881	27631	15.2625	7.21403	30455	16.8224	7.95169
7	17.37	2406.283	120.39	19.987	0.833771	3.20	85215	36618	15.2177	7.19289	40471	16.8189	7.95008
8	17.37	2434.491	121.87	19.976	0.833771	3.20	85167	37051	15.2192	7.19361	40951	16.8212	7.95116
9	17.77	3015.563	120.38	25.050	0.833484	3.17	107785	45806	15.1899	7.17989	50713	16.8171	7.94934
10	17.87	3017.495	120.56	25.029	0.833412	3.16	107942	45835	15.1898	7.17987	50747	16.8176	7.94960
11	18.57	3593.554	120.42	29.842	0.832909	3.11	130807	54502	15.1666	7.16918	60408	16.8101	7.94624
12	18.87	3560.612	120.39	29.576	0.832694	3.08	130553	54000	15.1659	7.16897	59853	16.8097	7.94616
13	19.67	3321.425	120.51	27.561	0.832119	3.02	123968	50402	15.1748	7.17346	55849	16.8148	7.94874
14	19.97	3318.977	120.37	27.573	0.831904	3.00	124898	50360	15.1734	7.17287	55804	16.8136	7.94828
15	20.17	2968.814	131.98	22.494	0.831760	2.99	102372	45120	15.1980	7.18459	49933	16.8192	7.95096
16	20.37	2713.446	120.49	22.520	0.831616	2.97	102971	41231	15.1951	7.18329	45635	16.8181	7.95050
17	20.47	2106.311	120.44	17.488	0.831544	2.97	80152	32068	15.2247	7.19734	35422	16.8171	7.95005
18	20.47	2109.252	120.53	17.500	0.831544	2.97	80204	32115	15.2258	7.19784	35470	16.8164	7.94972
19	20.47	1509.125	120.64	12.509	0.831544	2.97	57332	23052	15.2751	7.22114	25387	16.8223	7.95253
20	20.47	1521.612	121.50	12.524	0.831544	2.97	57397	23242	15.2746	7.22091	25596	16.8216	7.95220
21	20.47	1311.288	174.70	7.506	0.831544	2.97	34401	20155	15.3704	7.26620	22062	16.8247	7.95364
22	20.47	1307.719	173.96	7.517	0.831544	2.97	34453	20099	15.3695	7.26579	22010	16.8308	7.95655
23	20.47	2534.222	120.58	21.017	0.831544	2.97	96324	38531	15.2043	7.18767	42622	16.8186	7.95075
24	20.57	2576.531	120.65	21.355	0.831473	2.96	98104	39171	15.2030	7.18711	43334	16.8187	7.95086
25	20.67	2601.994	120.38	21.615	0.831401	2.95	99529	39553	15.2010	7.18621	43762	16.8186	7.95084
26	20.77	2641.059	120.55	21.908	0.831329	2.94	101116	40142	15.1992	7.18538	44420	16.8190	7.95104
27	20.97	2702.604	120.70	22.391	0.831185	2.93	103827	41076	15.1987	7.18521	45459	16.8204	7.95177
28	21.07	2734.809	120.67	22.664	0.831113	2.92	105335	41555	15.1948	7.18343	45996	16.8187	7.95098

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	16.87	1320.830	262.32	5.035	0.834131	3.23	21225	20310	15.3767	7.26787	22217	16.8205	7.95070
2	16.87	1315.332	261.24	5.035	0.834131	3.23	21224	20225	15.3763	7.26771	22124	16.8201	7.95052
3	16.97	1360.582	135.14	10.068	0.834059	3.23	42535	20610	15.1479	7.15978	22893	16.8259	7.95328
4	16.97	1335.821	131.79	10.136	0.834059	3.23	42823	20236	15.1487	7.16016	22476	16.8256	7.95315
5	16.97	2073.559	138.41	14.981	0.834059	3.23	63293	31199	15.0461	7.11166	34881	16.8218	7.95135
6	17.07	1829.499	122.19	14.973	0.833987	3.22	63400	27525	15.0451	7.11121	30775	16.8215	7.95126
7	17.17	2445.171	122.36	19.983	0.833915	3.21	84810	36665	14.9949	7.08750	41127	16.8197	7.95040
8	17.17	2485.146	124.44	19.971	0.833915	3.21	84756	37266	14.9955	7.08780	41802	16.8207	7.95090
9	17.67	3026.846	121.19	24.976	0.833556	3.17	107218	45302	14.9667	7.07439	50881	16.8099	7.94591
10	17.77	3011.074	120.62	24.963	0.833484	3.17	107410	45072	14.9687	7.07537	50619	16.8109	7.94643
11	18.27	3627.338	120.99	29.980	0.833125	3.13	130500	54240	14.9531	7.06816	60978	16.8107	7.94644
12	18.57	3610.969	120.64	29.932	0.832909	3.11	131201	53990	14.9517	7.06758	60699	16.8096	7.94602
13	18.67	2651.390	124.26	21.337	0.832837	3.10	93748	39748	14.9914	7.08639	44588	16.8168	7.94946
14	18.77	2744.270	127.11	21.590	0.832766	3.09	95079	41134	14.9890	7.08532	46149	16.8165	7.94932
15	18.87	2641.360	120.80	21.866	0.832694	3.08	96519	39582	14.9855	7.08366	44414	16.8148	7.94856
16	19.07	2677.080	120.44	22.227	0.832550	3.07	98578	40103	14.9801	7.08121	45007	16.8120	7.94726
17	19.17	2718.680	120.57	22.549	0.832478	3.06	100236	40723	14.9790	7.08070	45707	16.8122	7.94740
18	19.27	2762.640	120.56	22.915	0.832406	3.05	102105	41373	14.9759	7.07928	46445	16.8118	7.94724
19	19.37	2803.330	120.54	23.256	0.832335	3.05	103870	41981	14.9754	7.07909	47130	16.8121	7.94743

Table C.7: SP

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	20.019	3506.438	691.14	5.073	0.820587	4.31	15770	54616	15.5760	7.36322	58944	16.8102	7.94669
2	20.093	3506.444	691.46	5.071	0.820535	4.31	15796	54586	15.5673	7.35915	58945	16.8106	7.94688
3	20.109	3506.371	344.98	10.164	0.820524	4.30	31675	53948	15.3858	7.27336	58970	16.8179	7.95036
4	20.025	3506.354	345.18	10.158	0.820583	4.31	31580	53948	15.3857	7.27329	58964	16.8163	7.94956
5	20.154	3506.266	233.24	15.033	0.820493	4.30	46908	53680	15.3096	7.23737	58967	16.8175	7.95016
6	20.157	3506.266	233.00	15.049	0.820491	4.30	46962	53677	15.3090	7.23706	58965	16.8171	7.94996
7	20.284	3506.127	174.83	20.055	0.820403	4.28	62813	53501	15.2592	7.21359	58952	16.8141	7.94857
8	20.305	3506.129	174.84	20.054	0.820388	4.28	62848	53503	15.2599	7.21393	58952	16.8141	7.94858
9	20.426	3506.003	139.71	25.095	0.820304	4.26	78922	53381	15.2255	7.19767	58946	16.8129	7.94804
10	20.385	3505.999	139.75	25.088	0.820332	4.27	78808	53382	15.2259	7.19785	58947	16.8131	7.94816
11	20.401	3505.788	116.87	29.996	0.820321	4.27	94266	53272	15.1956	7.18353	58930	16.8094	7.94639
12	20.449	3505.793	116.86	30.000	0.820288	4.26	94411	53292	15.2011	7.18618	58943	16.8130	7.94810
13	20.441	3505.900	127.18	27.565	0.820293	4.26	86729	53336	15.2131	7.19185	58945	16.8132	7.94821
14	20.498	3505.907	127.13	27.578	0.820254	4.25	86909	53330	15.2113	7.19102	58936	16.8104	7.94688
15	20.489	3506.064	155.69	22.519	0.820260	4.26	70947	53443	15.2431	7.20602	58949	16.8134	7.94831
16	20.518	3506.067	155.99	22.477	0.820240	4.25	70873	53446	15.2439	7.20642	58951	16.8139	7.94856
17	20.516	3506.241	199.97	17.533	0.820242	4.25	55282	53581	15.2817	7.22431	58956	16.8146	7.94889
18	20.492	3506.237	199.96	17.535	0.820258	4.25	55249	53581	15.2816	7.22423	58958	16.8151	7.94914
19	20.433	3506.367	279.71	12.536	0.820299	4.26	39431	53774	15.3361	7.24998	58966	16.8168	7.94989
20	20.386	3506.362	279.97	12.524	0.820332	4.27	39342	53778	15.3373	7.25053	58967	16.8171	7.95006
21	20.248	3506.431	463.86	7.559	0.820428	4.29	23651	54245	15.4702	7.31333	58964	16.8160	7.94949
22	20.176	3506.422	463.50	7.565	0.820477	4.29	23621	54248	15.4710	7.31367	58966	16.8166	7.94975
23	20.294	3505.687	110.31	31.782	0.820395	4.28	99573	53260	15.1926	7.18207	58937	16.8118	7.94750
24	20.285	3505.686	110.33	31.773	0.820402	4.28	99520	53263	15.1934	7.18249	58937	16.8118	7.94749
25	20.287	3505.689	110.45	31.740	0.820400	4.28	99423	53257	15.1916	7.18162	58937	16.8118	7.94753
26	20.269	3505.687	110.48	31.733	0.820413	4.28	99348	53263	15.1934	7.18244	58937	16.8118	7.94748
27	20.284	3505.687	110.38	31.762	0.820402	4.28	99481	53270	15.1952	7.18332	58936	16.8117	7.94745
28	20.27	3505.688	110.55	31.711	0.820412	4.28	99281	53265	15.1938	7.18265	58937	16.8119	7.94756
29	20.28	3505.689	110.68	31.675	0.820405	4.28	99200	53263	15.1934	7.18245	58937	16.8119	7.94753
30	20.3	3505.689	110.49	31.729	0.820392	4.28	99424	53259	15.1921	7.181838	58937	16.8117	7.94748
31	20.33	3505.692	110.52	31.719	0.820371	4.28	99477	53263	15.1932	7.182373	58938	16.812	7.94761
32	20.35	3505.696	110.53	31.716	0.820357	4.27	99526	53265	15.1937	7.182639	58937	16.8119	7.94755
33	20.381	3505.699	110.55	31.711	0.820335	4.27	99599	53261	15.1926	7.182123	58937	16.8117	7.94748
34	20.387	3505.700	110.6	31.698	0.820331	4.27	99575	53260	15.1925	7.18209	58936	16.8116	7.94744

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	19.691	3506.376	700.99	5.002	0.820815	4.36	15401	54587	15.5679	7.35927	58938	16.8087	7.94589
2	19.775	3506.398	701.61	4.998	0.820757	4.35	15425	54581	15.5662	7.35850	58941	16.8094	7.94625
3	19.643	3506.314	349.21	10.041	0.820848	4.36	30873	53884	15.3677	7.26461	58969	16.8179	7.95020
4	19.758	3506.323	349.98	10.019	0.820768	4.35	30908	53881	15.3669	7.26430	58969	16.8179	7.95025
5	19.922	3506.227	231.83	15.124	0.820655	4.33	46879	53521	15.2646	7.21598	58970	16.8188	7.95070
6	19.99	3506.237	231.66	15.135	0.820607	4.32	47006	53519	15.2640	7.21575	58970	16.8187	7.95066
7	20.193	3506.122	174.74	20.065	0.820466	4.29	62681	53308	15.2043	7.18760	58960	16.8162	7.94958
8	20.159	3506.121	174.71	20.068	0.820489	4.30	62632	53306	15.2036	7.18723	58957	16.8154	7.94917
9	20.24	3505.947	139.96	25.049	0.820433	4.29	78357	53178	15.1680	7.17042	58948	16.8137	7.94839
10	20.243	3505.948	140.00	25.043	0.820431	4.29	78346	53190	15.1715	7.17209	58949	16.8139	7.94848
11	20.131	3505.763	116.71	30.039	0.820509	4.30	93672	53080	15.1408	7.15756	58940	16.8124	7.94773
12	20.166	3505.769	116.68	30.045	0.820485	4.30	93787	53080	15.1408	7.15754	58935	16.8109	7.94707
13	20.111	3505.676	109.88	31.905	0.820523	4.30	99433	53066	15.1371	7.15581	58941	16.8130	7.94800
14	20.117	3505.676	109.88	31.904	0.820519	4.30	99445	53065	15.1369	7.15568	58940	16.8128	7.94792
15	20.112	3505.676	109.89	31.903	0.820522	4.30	99429	53065	15.1370	7.15573	58935	16.8114	7.94726
16	20.118	3505.675	109.82	31.922	0.820518	4.30	99508	53073	15.1392	7.15677	58937	16.8118	7.94746
17	20.115	3505.676	109.80	31.929	0.820520	4.30	99520	53073	15.1391	7.15673	58937	16.8120	7.94754
18	20.123	3505.677	109.82	31.921	0.820514	4.30	99517	53076	15.1399	7.15714	58937	16.8118	7.94747

Table C.8: NEL 2

Configuration 1

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	20.18	986.528	195.15	5.055	0.794828	1.82	36065	15168	15.3751	7.26834	16586	16.8125	7.94780
2	20.313	983.951	194.14	5.068	0.794732	1.82	36247	15129	15.3758	7.26868	16548	16.8179	7.95040
3	20.103	1414.116	140.08	10.095	0.794884	1.82	71924	21588	15.2661	7.21675	23795	16.8268	7.95453
4	20.119	1414.615	139.68	10.127	0.794872	1.82	72171	21593	15.2642	7.21589	23802	16.8258	7.95407
5	20.206	1803.219	120.25	14.996	0.794809	1.82	107039	27429	15.2111	7.19082	30338	16.8244	7.95342
6	20.212	1803.556	119.95	15.035	0.794805	1.82	107331	27434	15.2111	7.19079	30344	16.8245	7.95351
7	20.252	1805.813	88.60	20.382	0.794776	1.82	145603	27410	15.1788	7.17553	30373	16.8196	7.95117
8	20.271	1809.270	88.72	20.392	0.794762	1.82	145727	27462	15.1785	7.17541	30432	16.8200	7.95140
9	20.304	1855.023	74.13	25.025	0.794738	1.82	178944	28128	15.1632	7.16817	31192	16.8149	7.94897
10	20.322	1838.701	73.35	25.067	0.794726	1.82	179298	27880	15.1629	7.16805	30919	16.8157	7.94934
11	20.365	1829.872	61.10	29.949	0.794694	1.81	214390	27731	15.1546	7.16416	30764	16.8121	7.94767
12	20.392	1819.156	60.85	29.895	0.794675	1.81	214109	27568	15.1543	7.16401	30584	16.8122	7.94772
13	20.371	1868.741	68.74	27.187	0.794690	1.81	194642	28326	15.1578	7.16566	31421	16.8140	7.94856
14	20.366	1863.489	68.92	27.039	0.794694	1.81	193561	28247	15.1581	7.16582	31333	16.8142	7.94864
15	20.336	1804.868	80.57	22.401	0.794716	1.82	160269	27382	15.1712	7.17199	30354	16.8179	7.95038
16	20.321	1789.777	79.93	22.392	0.794726	1.82	160161	27154	15.1717	7.17223	30101	16.8183	7.95058
17	20.288	1796.526	99.68	18.024	0.794750	1.82	128841	27291	15.1910	7.18133	30220	16.8214	7.95202
18	20.272	1798.339	99.74	18.030	0.794762	1.82	128850	27319	15.1912	7.18144	30251	16.8216	7.95215
19	20.257	1414.346	114.89	12.311	0.794772	1.82	87952	21551	15.2374	7.20327	23797	16.8254	7.95394
20	20.244	1412.667	114.75	12.311	0.794782	1.82	87935	21526	15.2378	7.20346	23770	16.8263	7.95436
21	20.231	930.833	130.18	7.150	0.794791	1.82	51060	14253	15.3121	7.23855	15655	16.8183	7.95054
22	20.227	929.218	129.97	7.150	0.794794	1.82	51051	14230	15.3140	7.23944	15633	16.8238	7.95318
23	20.249	1818.754	137.59	13.218	0.794778	1.82	94423	27694	15.2269	7.19829	30599	16.8242	7.95334
24	20.248	1808.801	134.46	13.452	0.794779	1.82	96092	27539	15.2250	7.19739	30431	16.8239	7.95319
25	20.262	1819.636	132.15	13.770	0.794769	1.82	98385	27697	15.2212	7.19559	30612	16.8231	7.95286
26	20.257	1817.387	129.22	14.064	0.794772	1.82	100478	27658	15.2186	7.19434	30575	16.8236	7.95307
27	20.245	1816.891	126.52	14.360	0.794781	1.82	102571	27645	15.2156	7.19293	30565	16.8227	7.95264
28	20.263	1822.491	124.65	14.621	0.794768	1.82	104472	27728	15.2143	7.19236	30659	16.8226	7.95259

Configuration 2

								Turbine Meter			Kral Meter		
Pt no	Temp	Volume	Time	Flow	Density	Visc.	Reynolds	Pulses	K factor	Strouhal	Pulses	K factor	Strouhal
	C	l	s	l/s	kg/l	mPas			p/l			p/l	
1	20.198	932.179	192.80	4.835	0.794815	1.82	34506	14342	15.3855	7.27322	15676	16.8165	7.94971
2	20.171	932.611	192.90	4.835	0.794835	1.82	34487	14348	15.3848	7.27289	15684	16.8173	7.95008
3	20.156	931.398	91.15	10.218	0.794846	1.82	72868	14188	15.2330	7.20115	15668	16.8220	7.95230
4	20.162	928.430	90.80	10.225	0.794841	1.82	72926	14140	15.2300	7.19973	15619	16.8230	7.95277
5	20.062	1425.522	94.46	15.092	0.794914	1.83	107437	21637	15.1783	7.17525	23980	16.8219	7.95222
6	19.683	1417.326	93.83	15.105	0.795187	1.84	106790	21509	15.1758	7.17391	23846	16.8246	7.95341
7	19.526	1790.684	89.38	20.035	0.795301	1.84	141234	27132	15.1517	7.16250	30108	16.8137	7.94819
8	19.721	1796.995	89.69	20.035	0.795160	1.84	141743	27220	15.1475	7.16057	30218	16.8158	7.94927
9	19.79	1799.857	71.82	25.062	0.795110	1.83	177534	27240	15.1345	7.15446	30259	16.8119	7.94741
10	19.807	1810.487	72.24	25.064	0.795098	1.83	177598	27400	15.1340	7.15424	30438	16.8121	7.94750
11	19.831	1840.756	61.19	30.082	0.795081	1.83	213251	27856	15.1329	7.15371	30940	16.8083	7.94573
12	19.845	1842.415	61.60	29.910	0.795070	1.83	212087	27860	15.1215	7.14830	30967	16.8078	7.94551
13	20.134	1840.913	66.22	27.798	0.794861	1.82	198156	27858	15.1327	7.15372	30942	16.8080	7.94565
14	20.308	1801.018	65.22	27.613	0.794736	1.82	197458	27245	15.1276	7.15135	30273	16.8088	7.94610
15	20.304	1801.481	80.59	22.354	0.794738	1.82	159841	27268	15.1364	7.15554	30290	16.8139	7.94852
16	20.277	1792.139	80.19	22.349	0.794758	1.82	159725	27134	15.1406	7.15749	30134	16.8145	7.94880
17	20.254	1423.168	81.13	17.541	0.794775	1.82	125311	21578	15.1619	7.16759	23935	16.8181	7.95048
18	20.256	1417.906	80.83	17.541	0.794773	1.82	125320	21503	15.1653	7.16918	23848	16.8192	7.95098
20	20.219	1419.210	109.08	13.011	0.794800	1.82	92889	21571	15.1993	7.18523	23875	16.8227	7.95266
21	20.211	929.592	124.18	7.486	0.794806	1.82	53436	14212	15.2884	7.22736	15633	16.8170	7.94996
22	20.208	935.384	124.97	7.485	0.794808	1.82	53425	14300	15.2878	7.22708	15732	16.8188	7.95077
23	20.196	1426.324	110.95	12.855	0.794817	1.82	91741	21676	15.1971	7.18419	23992	16.8209	7.95177
24	20.202	1805.793	136.36	13.243	0.794812	1.82	94518	27440	15.1955	7.18345	30376	16.8214	7.95203
25	20.204	1799.538	132.88	13.542	0.794811	1.82	96659	27332	15.1883	7.18004	30271	16.8215	7.95209
26	20.224	1800.266	130.86	13.757	0.794796	1.82	98230	27340	15.1866	7.17925	30283	16.8214	7.95203
27	20.223	1799.914	127.39	14.130	0.794797	1.82	100886	27332	15.1852	7.17855	30278	16.8219	7.95227
28	20.231	1809.553	125.76	14.389	0.794791	1.82	102755	27478	15.1850	7.17846	30439	16.8213	7.95197
29	20.23	1808.595	123.41	14.655	0.794792	1.82	104652	27457	15.1814	7.17677	30423	16.8213	7.95200