Bi-lateral intercomparison on hydrocarbon flow meter (500 - 5000 l/min) Trapil - SP

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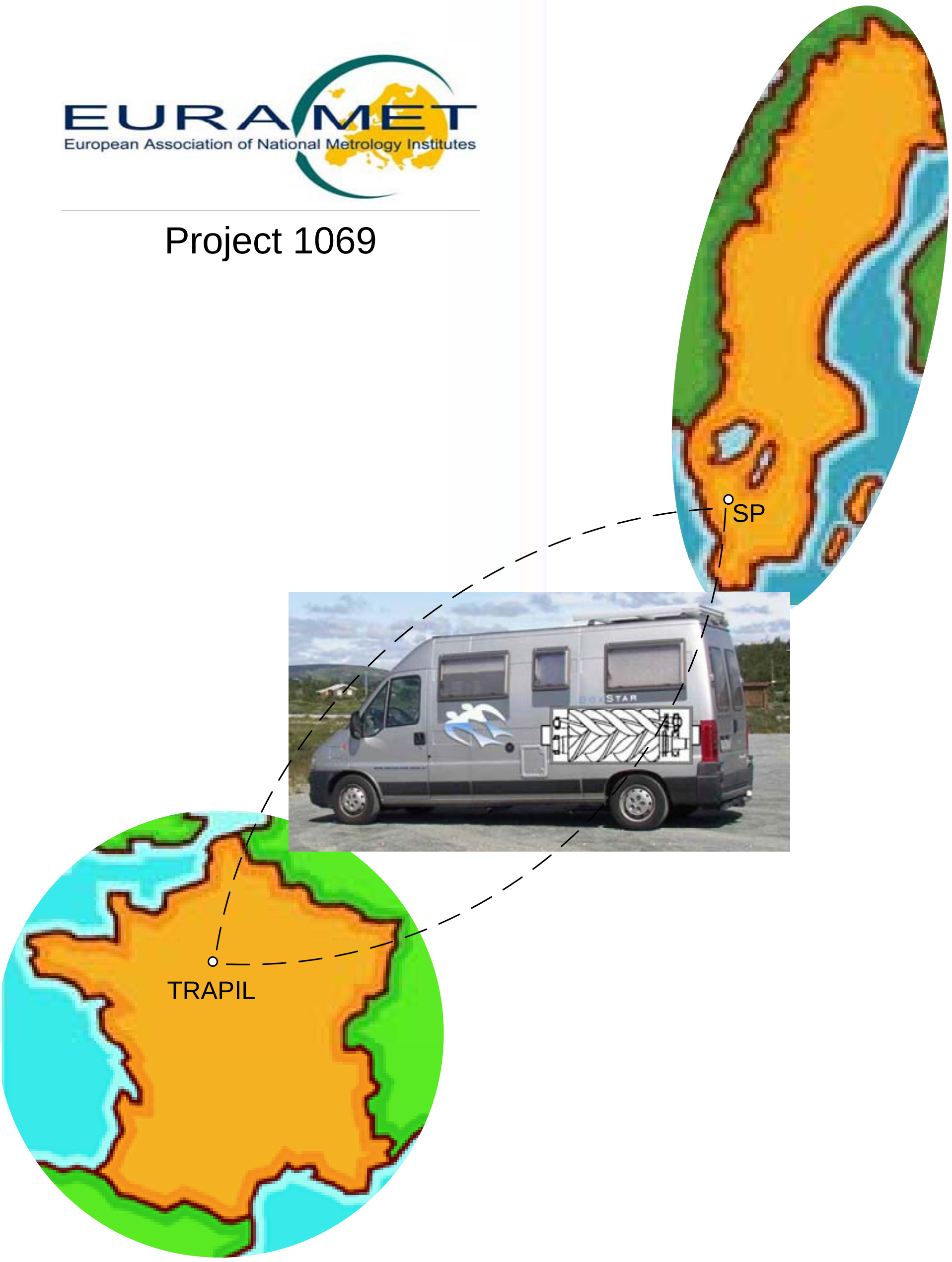
Project 1069



Mätteknik

SP Rapport 2009:2009:44

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Abstract

A bilateral calibration inter-comparison was performed between Trapil (France) and SP (Sweden) as pilot. The flow meter calibration concerned a well examined DN-150 screw meter (producer KRAL) as transfer standard and the used medium was kerosene of very similar viscosity. The difference in the measured meter K-factor between the laboratories over the flow range of 500 to 5000 L/min was 0,02 % at maximum. For the first time in the flow measurement area a linkage between two comparisons is performed with the aim to refer Trapils measurement results to a key comparison reference value for this type of fluid. As a result Trapil is given a degree of equivalence amounting to 0,018 %. This can be considered to prove Trapils claim of a calibration measurement capability of 0,038 %.

Key words: Flow meter, intercomparison, hydrocarbon, linking to KCRV.

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Sammanfattning

Rapporten presenterar en bilateral kalibreringsjämförelse mellan Trapil (Frankrike) och SP (Sverige). Jämförelsen är mellan två flödesriggar av samma typ (ball prover) och avser bestämningen av en flödesmätares K-faktor för fotogen nära rumstemperatur. Som transferstandard valdes en volymetrisk mätare (skruvmätare av fabrikat KRAL) med en DN 150 anslutning och jämförelsen gjordes över ett flödesområde mellan 500 och 5000 L/min. Trapils önskan med denna jämförelse är att kunna ansluta sig till en tidigare genomfört nyckeljämförelse och via en ”Degree of Equivalence” till dess ”Key Comparison Reference Value” kunna få sin kompetens att kalibrera mätare för oljeprodukter bekräftat. Detta jämförelseprojekt utgör det första försöket inom flödesmättekniken att länka en sekundär jämförelse till nyckeljämförelsens referensvärde. Med en största skillnad mellan Trapil och SP över flödesområdet på 0,02 % och en DoE till KCRV på 0,018 % kan ett CMC-värde (Calibration Measurement Capability) av 0,038 % anses rimligt. Osäkerheten att bestämma graden av ekvivalens är signifikant större.

1 Introduction

With perpetually rising fuel prices the measurement of oil is of increasing importance. Traditionally for trading of oil products a measurement uncertainty of 0,5 % is mandatory. However, refineries have higher aims pressing uncertainties in volume/flow measurement to at least 0,3 %. Internally this demands for a flow calibration uncertainty of 0,1 % at maximum. This leaves very smal margins for calibration laboratories that have to prove their measurement capability. An early attempt to study the degree of agreement between European national flow laboratories was performed by SP in the mid 90's showing that all of 10 participants were within ±0,07 % of each others result[1]. This result however, was valid for kerosene after adjustment to a common temperature and viscosity of 20 °C and 2 cSt respectively.

1.1 Background MRA

Since the signing of the mutual recognition agreement (MRA) in 1999 all national metrology institutes (NMI's) are forced to declare their calibration measurement capability (CMC). The CMC-tables declare the lowest measurement uncertainty available from a calibration laboratory to a customer. With the help of calibration inter-comparisons the laboratories have to prove these claims.

1.2 Key-comparison

On the highest level those comparisons embrace five to ten laboratories in what is termed a key-comparison for each metrological quantity, leading to a best possible representative of this quantity, called a key-comparison-reference-value (KCRV). For the area of flow of hydrocarbons only one such key-comparison and KCRV does exist. It was piloted by NEL in the UK and finished in 2008 [2]. For this comparison a cloned meter package from an earlier European inter-comparison [1] was used with one meter being a Kral screw meter, but the variation in liquid temperature and viscosity was wider than in the preceding exercise. An important difference was that the comparison focused at one specific "cardinal point" characterized by a Reynolds number of 100 000. The result was further stated in terms of a Strouhal number, which is the product of the calibrated K-factor and the pipe diameter leading to a dimensionless number. This calculations were thought to solve the problem with differences in fluid viscosities and temperature between laboratories. There is, however, no consensus within the flow community that a KCRV should be defined with such a construction and limited conditions.

1.3 Scope of inter-comparison

Flow is a dynamic quantity, hence a traceability cannot be built just on the measurement of mass/volume and time. And there are no stable dynamic mass/volume standards that can be distributed. Traceability is rather achieved by flow inter-comparisons using transfer standards. The purpose of this comparison is to connect Trapil to the result of the key-comparison and the defined KCRV. SP as one of the participants in the key-comparison can supply a suitable meter for and link Trapils calibration result to the key-comparison. This process is described in the following report.

2 Comparison arrangement

2.1 Calibration object

The object for the inter-comparison was a volumetric flow meter specified in table 1. This meter is of the same model as the one used in the comparisons mentioned before, but it is of larger size allowing higher flow rates to be measured. It has been used by SP as a master meter since many years and has shown very good repeatability and long time stability. Compared to many other meters it also possesses a very good linearity.

Table 1. Transfer standard

Typ	OMG 140
Producer	Kral
Measurement principle	Screw meter with pulse output
Flow range	200 to 5000 L/min
Out put	pulses
K-factor	8,84 p/L
Connection	Flanges DN 150
Material	Housing and screws in carbon steel

2.2 Calibration method

At both laboratories a volumetric calibration was performed with a ball prover as reference. From the pulses counted by the meter and the reference volume determined by the prover the meter- or K-factor at different flow rates was calculated. Each value was the average of mostly ten repeated runs.

2.3 Comparison details

Totally four calibrations were performed, the first at SP, the second at Trapil, both in September 2008. The third and forth were run during the first days in January 2009 when these measurements did not interfere with other commissioned work.

2.3.1 Measurement conditions

Table 2 contains the suggested and agreed terms of measurement and conditions.

Table 2. Data for the measurement

Total time for calibration	4 working days / laboratory and calibration curve
Fluid	Kerosene
Nominal temperature	Room-temperature (20 °C)
Pressure	> 300 kPa
Flow rates and order of calibration	1000, 5000, 4000, 3000, 2000, 1000, 500 L/min
Number of repetitions	≥ 8 at each flow rate

2.3.2 Transportation

The meter was delivered to and fetched at Trapil by the project leader himself. After leaving some instructions concerning the electrical installation he then left the laboratory until the calibration was finished.

2.4 Laboratories and resources

At both laboratories the used measurement equipment makes up the primary flow standard.

Trapil uses kerosene (nominal viscosity 5,34 cSt at 20 °C) and a ball prover of 2,5 m^3 size. It is built outdoor below ground with only the end chambers above. It does not have a cooling device or temperature control to stabilize the fluid temperature. Thus the fluid temperature increased from 23 °C after the first runs to over 30 °C at the end of the measurement series.

The ball prover at SP is installed inside a building and the pipe work is insulated. It has a volume of 3,5 m^3 and can be run with both water (up to 95 °C) and kerosene (nominal viscosity 5,26 cSt at 20 °C). The kerosene temperature can be stabilized to ±0,2 °C in the temperature range from 15 to 35 °C The prover can be run in both directions utilizing two calibrated volumes of slightly different size. The SP results always make up the average of an equal number of runs in respective direction.

At SP both pressure and temperature are measured at the meter under test and at the in- and outlet of the prover. Corrections are applied for possible temperature changes at low flow rates and/or pressure drops at high flow rates. The corrections are applied assuming a linear expansion/contraction with temperature and pressure changes.

3 Results

3.1 Aspects of parameters for comparison

The first calibration at SP, SP/1 was conducted at the stipulated 20 °C. The measurement conditions at Trapil however varied between 23 and 31 °C (see table 3). Thus the K-factor belonging to different flow rates actually corresponds to different viscosities too. Volumetric or displacement meters are known to be sensitive to changes in viscosity. In an industrial scale these effects can be considered negligible, especially when compared to turbines. However, as the sensitivity is systematic it means the calibration results would not be directly comparable. Depending on this circumstances two calibration series were run at SP after the Trapil calibration. SP/2 was a repetition at 20 °C to verify the meter stability. In SP/3 the same sequence as stated in table 3 was followed adjusting the kerosene temperatures to those reported by Trapil for the various flow rates.

Later on Trapil also delivered an update of the experimental data including a correction of the K-factor for the deviation from 20 °C for each single run before the averages for each flow rate were calculated. This renders possible a twofold comparison between SP and Trapil at a variable temperature base and at an assumed nominal temperature of 20 °C.

The most relevant comparison data concern values referring to the same conditions (variable temperature). They are given in table 3 and figure 1. The other comparisons with reference to a common temperature are of secondary importance and therefore only given graphically in figure 2. Further Trapil has made an own diagram of the comparison, while they had only access to the first calibration SP/1, which refers to results at 20 °C. This is shown and commented in the appendix.

Table 3. Measurement results - left Trapil – right SP/3 (varying fluid temperature)

q [L/min]	K-factor [p/L]	stdav [p/L]	Temp [°C]	q [L/min]	K-factor [p/L]	stdav [p/L]	Temp [°C]
986,6	8,84406	0,00056	23,5	1001,3	8,84404	0,00013	23,12
5004,0	8,84240	0,00038	25,4	5001,9	8,84068	0,00067	25,45
3994,3	8,84260	0,00035	27,3	3995,9	8,84060	0,00026	27,09
2978,9	8,84325	0,00027	28,8	3015,8	8,84147	0,00029	28,37
1968,9	8,84360	0,00038	29,2	2034,1	8,84256	0,00024	29,55
1017,4	8,84237	0,00017	30,0	1016,7	8,84242	0,00029	29,86
502,5	8,84104	0,00041	30,7	522,2	8,84078	0,00028	30,76

As table 3 shows the temperature adjustment in SP/3 to the Trapil conditions was quite good with a maximum difference in temperature of 0,4 °C at the first tested flow rate at 23 °C, were it is most difficult to control temperature. The tabled K-factors are stated with an uncertainty of 0,07 % (SP) and 0,05 % (Trapil).

3.2 Graphical presentation

In figure 1 the K-factors and the repeatability (standard deviation) from table 3 referring to different fluid temperatures are presented by coloured symbols. The actual temperatures and thus the varying viscosities are also indicated. For comparison the data at constant temperature (SP/1) are shown as well.

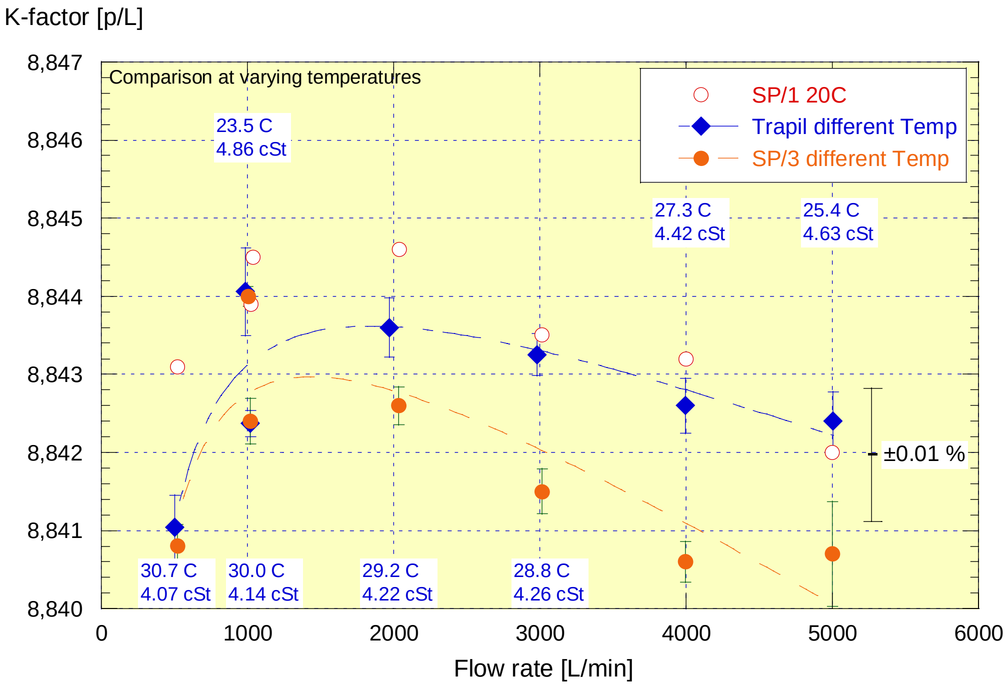


Fig. 1. K-factor of OMG 140 in kerosene with standard deviations valid for varying temperature and viscosity conditions. The calibration SP/1 was performed at 20 °C. The calibrations at Trapil and SP/3 refer to the same indicated temperatures.

The difference between Trapil and SP is always below 0,02 %, which can be considered very close, especially with respect to the stated measurement uncertainties. When comparing SP and Trapil data measured at the same temperature the difference is some what larger. Comparing the open circles (SP/1 at 20 °C) and the red circles (SP/3 at different temperatures) clearly indicates the influence due to temperature expansion of the meter housing, which leads to almost a parallel shift. Looking to the difference in the repeated measurement at 1000 L/min for Trapil (blue diamonds) again one can se that it is strongly influenced by a temperature shift of 6,5 °C.

With the resolution given in figure 1 the SP/3 result seems to fall slightly faster to decreasing flow rates. This could be a possible effect of the somewhat lower viscosity as there is a risk for a lower viscous fluid to leak between screw and housing and therefore not been measured properly, which can lead to a lower K-factor.

If the meter is stable the comparison between the open circles (SP/1 at 20 °C) and the red circles (SP/3 at different temperatures) directly indicates the influence due to temperature, which leads to almost a parallel shift.

Figure 2 shows the K-factors for the various flow rates referring to a temperature of 20 °C. The red diamonds represent the corrected measurements at Trapil and the circles measurements at SP before and after the calibration at Trapil. The white circles SP/1 are without a correction for a pressure drop (at higher flow rates) and are the same in figure 1 and 2. The relation between the temperature corrected Trapil data and SP/2 is now the opposite compared to figure 1. The performed corrections at Trapil apply a linear expansion of the housing having the largest effect at the two lowest flow rates. This indicates that the temperature correction to some extent can alter the characteristic of the meter behavior.

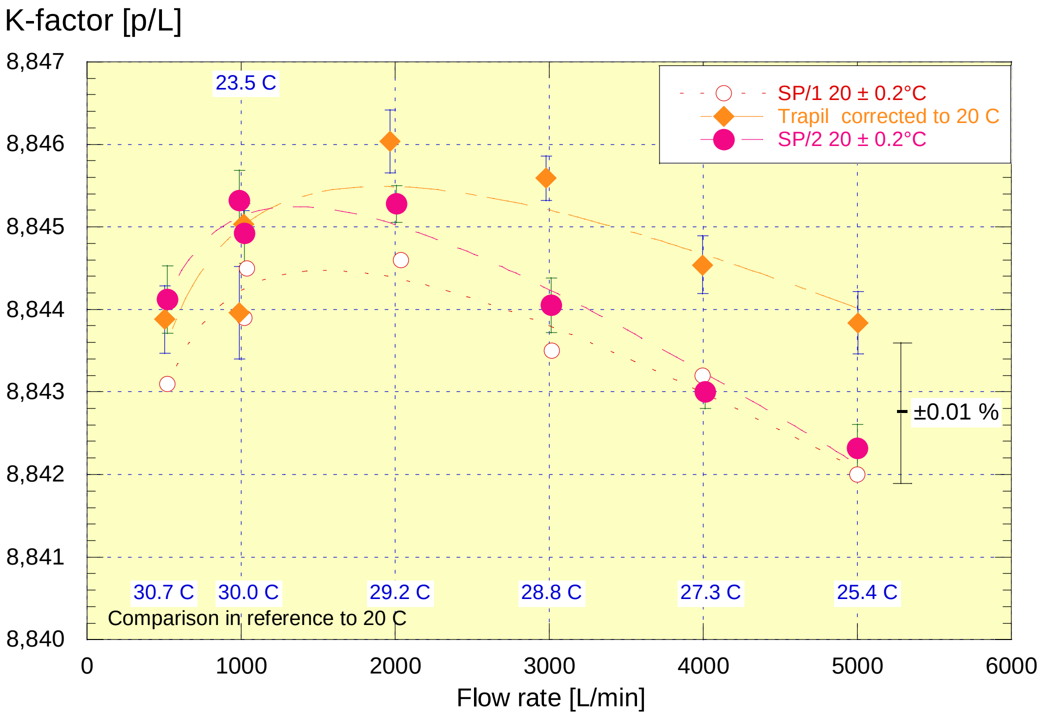


Fig. 2. Comparison of calibration curves for kerosene valid at 20 °C. The SP-calibrations were performed before and after the Trapil measurements both at 20 °C. The Trapil values were recorded at the indicated temperatures but corrected for a deviation from 20 °C.

3.3 Meter stability

The two curves SP/1 and SP/2 in figure 2 can be used as a measure of the stability of the meter over time. With a maximum difference of less than 0,02 % again the agreement between Trapil and SP must be considered very good.

3.4 Temperature effects

As mentioned some of the presented K-factor values include temperature corrections. They are of two kinds.

In the SP/3-data (at variable temperature) the corrections assume that the liquid volume passing the screw meter is shrinking on the way from the meter to the prover due to a measurable temperature drop. And assuming thermal stability, i.e. at any section of the pipe work the temperature is constant over time, the counted pulses refer to a measured reference volume, which had to be larger when passing the meter. Thus the number of pulses correspond to a larger volume and represent a lower K-factor.

The temperature correction applied at Trapil refers to the temperature deviation from 20 °C varying in the range from 3 to 11 °C. That means the housing of he screw meter was expanded compared to 20 °C, thus referring to a larger volume. Disregarding possible viscosity effects a liquid at 20 °C would have passed a smaller housing volume. The counted pulses should refer to this minor volume and the meter should be characterized by a higher K-factor. The expansion factor used by Trapil was dependent on the deviation from 20 °C assuming a expansion coefficient of 30 ppm per °C, which is close to carbon steel in the meter housing.

3.5 Pressure effects

In the calibration rig there is a permanent pressure drop along the piping system. At SP the meter is situated upstream of the prover and at higher flow rates there is a measurable pressure drop from the meter to the prover entrance. Like many other liquids kerosene is considered incompressible. In flow metering a 12 bar pressure increase generally is assumed to lead to a volume compression of about 0,1 %. Depending on the amount of entrapped air, which depends on the pumping conditions and can neither be prevented or completely removed, higher compressibility can occur. A typical pressure drop at 5000 L/min is 140 kPa (1,4 bar) corresponding to an increase in K-factor of roughly 0,012 %.

3.6 Degree of equivalence to KCRV

The measurements SP/1 and SP/2 were performed in the same rig and at exactly the same conditions as those in the key-comparison project CCM-FF-K2 [2]. The only difference was a somewhat bigger screw meter with a higher flow range. But there is reasonable overlap in the flow range containing the cardinal point to which the KCRV refers. The same Reynolds number of 100000 as used before is considered to guarantee equivalent flow conditions. The kerosene used at the different laboratories had different viscosity (1,51 to 4,32 cP) and thus the flow rates corresponding to the cardinal point also varied. For SP with the highest viscosity in the key-comparison this flow rate was 32 L/s or 1920 L/min.

3.6.1 Linking Euramet 1069 to the relevant KCRV

Following the intention of the key-comparison project, the comparison between SP and Trapil should, however not be performed at this flow rate. The comparison should in stead involve the flow rates corresponding to a Reynolds number of 100000 in the pipe preceding the flow meter. The larger pipe diameter now has to be compensated by a higher flow rate, which is calculated below for comparison purposes.

The fact that the comparison previously was built on the Strouhal number and now directly on the K-factor is not critical, nor is the fact that the viscosity at Trapil is somewhat higher than at SP. The circumstance that the temperature defining the cardinal point in this project was 28 °C rather than 20 °C earlier, is not bothering. But it means the viscosity has to be considered for the linking as well.

3.6.2 Equivalence of flow conditions by Reynolds number

Table 4 collects the data that are needed to relate the flow rate q, diameter D and viscosity ν to a common Reynolds number, which is determined by the following equation.

$$\mathrm{Re} = \frac{q}{\nu(T) \cdot D(T)} \cdot \frac{4 \cdot 1000}{60 \cdot \pi} \qquad (1)$$

The kinematic viscosity ν and the inner pipe diameter D are dependent on fluid temperature as indicated in equation (1). The constants at the right just make a scaling factor; the number 60 transforms the flow rate from L/s used in the key-comparison to L/min used here. Starting from a given cardinal point of Re=100000 the corresponding flow rates for Trapil and SP/3 are then calculated backwards with equation (2).

$$q = \mathrm{Re} \cdot D(T) \cdot \nu(T) \cdot \frac{\pi \cdot 60}{1000 \cdot 4} \qquad (2)$$

Table 4. Equivalence in flow conditions

	CCM-FF-K2	Euramet 1069		Difference
	SP	Trapil	SP(3)	
Pipe diameter [m]	0,0799	0,150016	0,150016	
Temperature [°C]	20,3	28,8	28,37	
Viscosity [cSt]	5,20	4,26	4,18	
Flow rate [L/s] measured [L/min]	32 (1920)	**50,19** **3012**	**49,25** **2955**	
Nearest mea- q [L/min] sured points K [p/L]		2978,9 8,84325	3015,8 8,84147	 0,02 %
Compared K-factors		**8,83313**	**8,84149**	**0,018 %**

The calculated flow rates used for comparison are marked in bold style. The belonging K-factors are calculated from the fitted curves. They are also shown in bold letters in the bottom row. They indicate a difference of 0,018 % between Trapil and SP. For comparison the nearest experimental values are given as well. Due to the similarity in the kerosene between the two laboratories the flow rates are very close and represent the middle part of the flow range in figure 1. If another laboratory had made a bilateral comparison with Trapil, like for example NEL having considerable lower viscosity, different parts of the two flow curves had to be compared.

3.6.3 Result of the linking procedure

Figure 3 shows the result of the linking. It is a reproduction of tables 4A and 5A of the key comparison report [2] in the form of a Youden plot. This plot shows the simultaneous degree of equivalence (DoE) with respect to two meters in a package. The important one is the screw meter, a Kral OMG 100, on the y-axis, which is scaled in percent deviation from the KCRV. For SP this DoE is -0,001 % with an uncertainty of 0,032 %. With a difference in K-factor of 0,018 % to the SP-value this means a DoE of +0,0179 % for Trapil. This is indicated by a dashed line as there is no simultaneous value for the second meter. The uncertainty U(DoE) is about 0,07 %. This value is the combination of the uncertainties in SP's DoE, the reproducibility of the meter in SP's rig, the uncertainty from Trapils calibration data and of course contributions from the linking as described above with the construction of K-factors at comparable flow rates referring to the Reynolds number of the cardinal point.

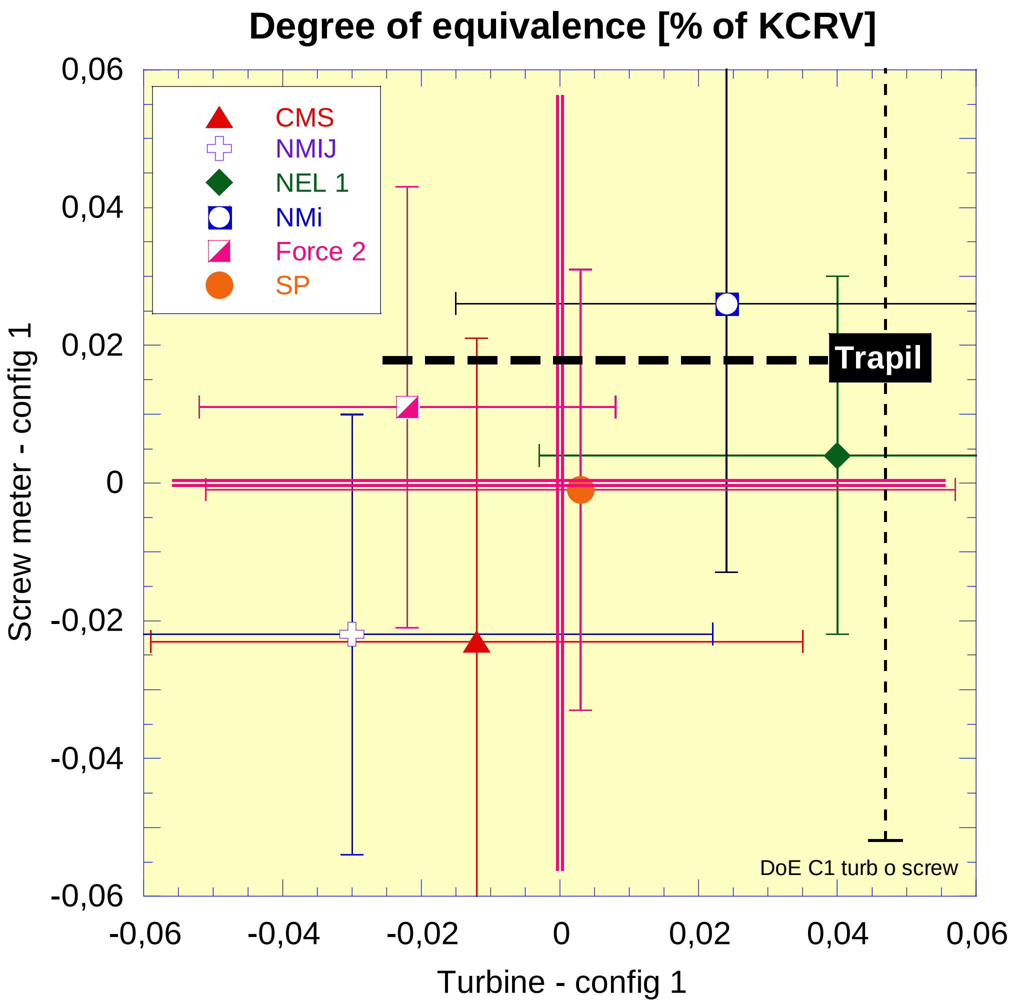


Fig 3. Youden plot showing the result of the key-comparison in relation to two reference values, which make up the centre of the graph (one for each meter in one axis). Trapils calibration result is linked into the plot with a black line (with respect to only one KCRV for the screw meter and corresponding uncertainty).

4 Discussion and conclusions

This bilateral comparison presents the first attempt in the fluid flow area to link a laboratory result to a preceding flow key comparison.

4.1 Alternative linking approach

The linking procedure described in 3.6.2 is based on the central assumption that given the same Reynolds number in the preceding pipe, then the screw meter experiences the same conditions and the measured K-factors corresponding to this situation are the once to be compared.

One can raise an alternative perspective. What comparisons of this kind are aimed to show is how well different laboratories with their different primary flow standards can manage to reproduce a certain calibration result. As such the comparison should not be restricted to one flow rate or one particular Reynolds number. Further the used instrument is just a transfer meter. The construction above is quite academic. A comparison should of course embrace a flow range that is representative for the flow rig. Thus it should rather concentrate at a number of flow rates and certain temperatures.

The key comparison [2] and also the earlier European comparisons [1] have shown that the screw meter does not exhibit a clear sensitivity to viscosity above a certain flow rate. In the flow rage above the maximum K-factor the measured curves at different viscosities are more or less parallel to each other.

This means it should be possible to fit an almost straight line to the different results and to determine the DoE from the fitted average line making up a KCR-line. Such an attempt is indicated in the appendix. A later bi-lateral comparison like the one reported here could then be performed by fitting the same model equation to the new data and then determine the distance to the reference line at various flow rates. Eventual temperature and viscosity effects could then be handled by proper corrections. In the current case comparing the temperature corrected Trapil data with the results of SP/1 and SP/2 would just by optical judgement without any calculation render the same difference. At a flow rate of 1920 L/min, which was relevant in the key comparison the closeness to SP is even better than 0,018 %.

4.2 Qualification of Trapils measurement capability

The comparison with SP was performed on a different screw meter and at temperatures deviating from room temperature as in the relevant key comparison. There the smaller temperature variations between laboratories were taken care of by building a Strouhal number. As the screw meter in this project had a very different K-factor this is not a suitable method for linking. Due to the closeness between Trapil and SP and the even better closeness between SP and the KCRV a DoE for Trapil is not a critical matter. The calculated DoE of 0,018 % is half of the CMC-value of 0,038 % claimed by Trapil. The DoE is also much less than the uncertainty in its determination which is about 0,08 %. Thus, until proven different the Trapil claim should be acceptable to the flow community.

5 References

[1] Lau, P. and Stolt, K. Calibration Intercomparison on Flow Meters for Kerosene - Synthesis Report, 3476/1/0/203/92/9-BCR-S(30), SP-Report 1995:77 Borås, Sweden: Swedish National Testing and Research Institute, ISBN 91-7848-606-8, ISSN 0284-5172

[2] Paton, R. International Key Comparison of Liquid Hydrocarbon Flow Facilities CCM-FF-K2 Draft B (Final), Project No: FFIN56, Report No: 2008/84 (Rev.3), October 2008

Appendix An alternative evaluation and linking procedure

With the help of figure A1 below another way to compare the outcome of laboratory inter-comparisons is shown. Different from the actual key comparison [2] for kerosene the measured quantity, the K-factor, may be represented not by one but several values over a certain flow range. To go a step further the results then could rather be represented by a fitted curve, describing the K-factor as a function of the flow rate. This is done with the data in figure A1 coming from a corresponding European comparison using a screw meter [1]. The data shown describes the situation before any attempts were made to correct for deviations from a standardised temperature and/or viscosity. It also leaves all data including obvious outliers.

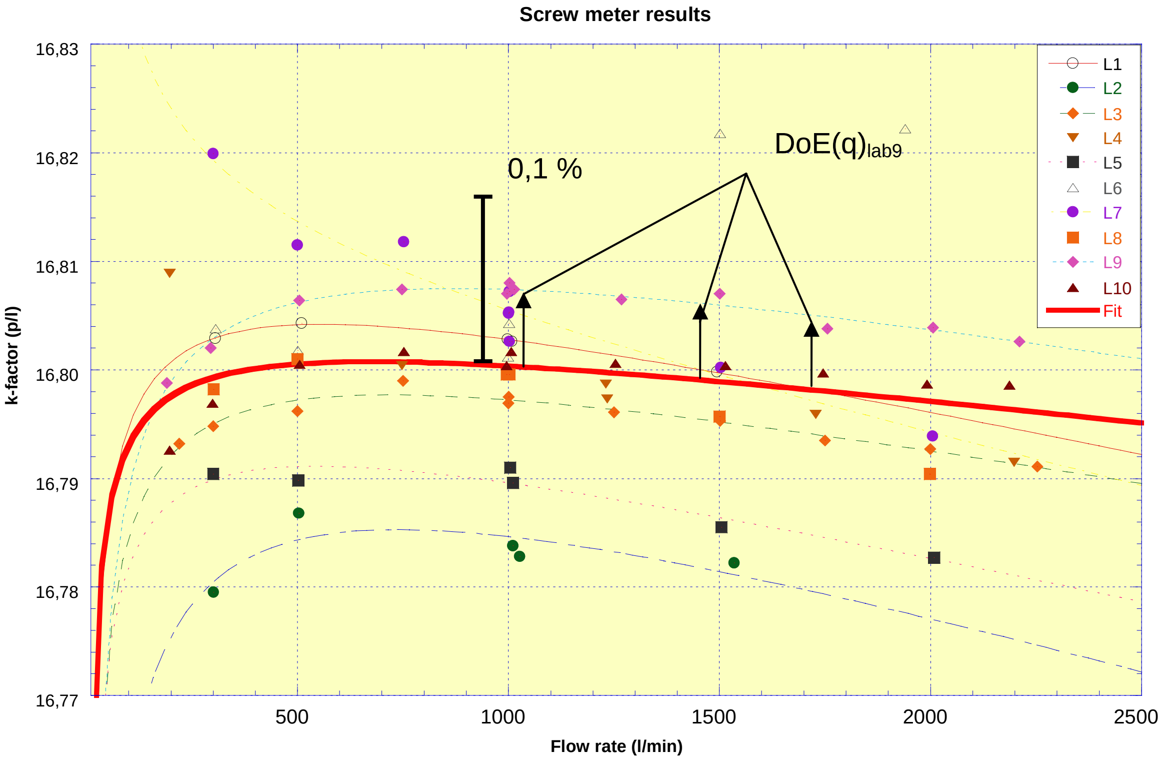


Figure A1. Construction of a comparison reference curve (thick line) by fitting all values.

Viscosity matters, but most distinctly in the low flow range of he meter. The two curves at the bottom represent significant lower viscosities than the rest. Above 1000 L/min all results indicate no clear tendency to different behaviour with flow rate despite an offset that partly may be caused by different viscosities. Generally all 10 laboratories show more or less parallel curves in the high flow range. These are fitted with a simple model:

$$k = k_0 + a \cdot q + b \cdot \frac{1}{\sqrt{q}}$$ (1/√q determines the left part, q the right part of the curve).

The thick curve represents the fit to all points including outliers, which is the reason for a somewhat different slope. But despite the choice of reference points for the comparison reference line a DoE could be defined as the difference between any laboratory curve and the reference curve.

A different way to present the comparison data is suggested by Trapil. Figure A2 displays the measured K-factors as a function of a quantity, which is the logarithm of the ratio between actual flow rate and belonging kinematic viscosity. This is an attempt to account for differences in viscosity caused by varying temperature. The curve is adjusted to data from SP/1 using a polynomial fit. The Trapil results (original data and after temperature correction) for each run are shown with the estimated uncertainties.

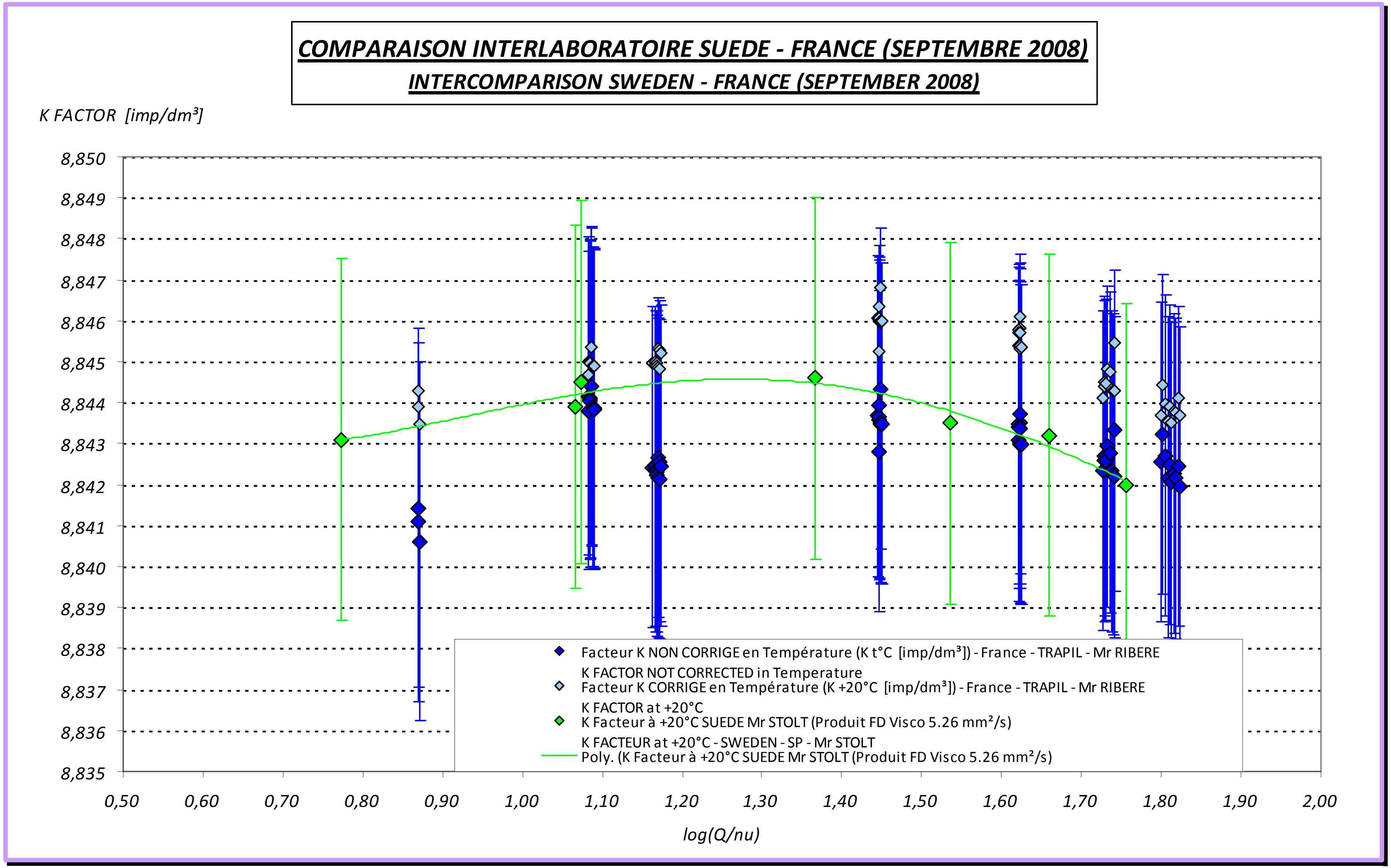
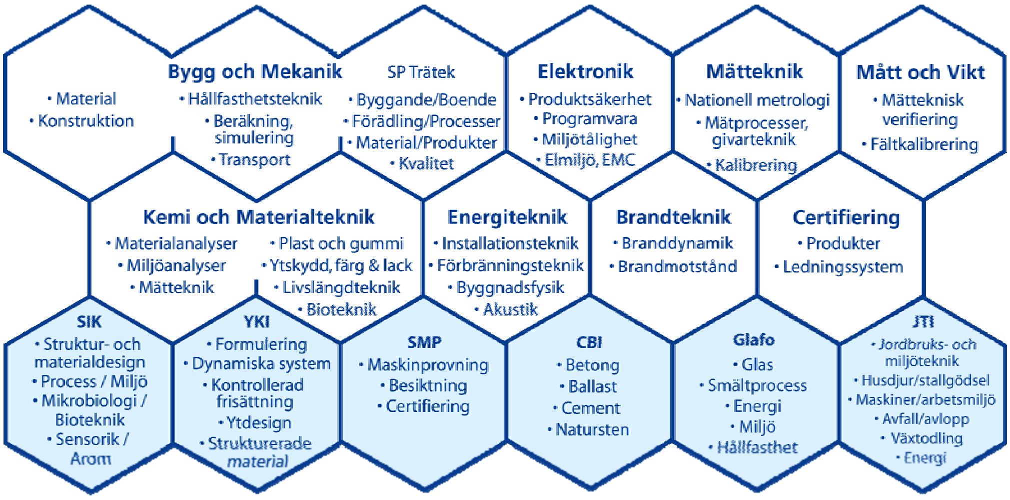


Figure A2: Comparison plot constructed by Trapil with the data of SP/1 at 20 °C and Trapils original data at various temperatures and corrected to 20 °C.

SP Sveriges Tekniska Forskningsinstitut utvecklar och förmedlar teknik för näringslivets utveckling och konkurrenskraft och för säkerhet, hållbar tillväxt och god miljö i samhället. Vi har Sveriges bredaste och mest kvalificerade resurser för teknisk utvärdering, mätteknik, forskning och utveckling. Vår forskning sker i nära samverkan med högskola, universitet och internationella kolleger. Vi är ca 870 medarbetare som bygger våra tjänster på kompetens, effektivitet, opartiskhet och internationell acceptans.



SP är organiserat i åtta tekniska enheter och sex dotterbolag varav CBI, Glafo och JTI ägs till 60 % av SP och 40 % av industrin.

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