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COMPARISON OF LINEARITY, REPEATABILITY AND REPRODUCIBILITY FOR TURBINE, CORIOLIS AND ULTRASONIC METERS TESTED AT 100 BARS ON NATURAL GAS

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COMPARISON OF REPEATABILITY, REPRODUCIBILITY AND LINEARITY FOR TURBINE, CORIOLIS AND ULTRASONIC METERS TESTED AT 100 BARS ON NATURAL GAS

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ABSTRACT

The important characteristics to check in order to provide a reasonable accuracy for a gas meter are the repeatability, the reproducibility and the linearity of the deviation curves from the reference meter. This paper presents and analyses experimental calibration data obtained at K-Lab at high pressure (100 bars) with respect to these three properties for 6 turbine meters, 2 Coriolis meters and 1 ultrasonic meter. The statistical method of analysis recommended by the standards has been systematically utilised and has been compared, for calibration conditions, with other analysis methods. A more friendly use of statistical analysis for metering specialists is developed in this paper. Eventually, some meters of each type have been compared with respect to their common behaviour concerning these three metering properties by using the same method of analysis.

INTRODUCTION

Normally people are interested in the accuracy of a gas meter. But for those meters which have to be re-calibrated regularly, 3 other factors are very important. That are the repeatability, the reproducibility and the linearity of the meters. If these properties follow the calibration requirements, the meters can be expected to have a constant and reasonable accuracy over the whole range of flow conditions. Typical examples are turbine meters and

Coriolis mass meters. The idea behind the ultrasonic meters (USM) is that only the electronic transducers should be calibrated. But as long as they are linked to a flow-computer the possibility always exists to introduce an adjustment factor (Meter Factor) and to adjust their calibration curves if they are not linear and horizontal enough.

This paper presents data on repeatability, reproducibility and linearity measured for 6 turbine meters, 2 Coriolis mass meters and 1 USM. The calibrations are carried out at 100 bars absolute and approximately 37^{o}C.

It is well known that turbine meters have good repeatability both for successive identical runs and on a long term basis at identical conditions (known as reproducibility as well) and that they are reasonably linear (reference 1). But so far no systematic repeatability and linearity study and even calibration results at high pressure (100 bars) are available in the literature. Regarding Coriolis mass meters and USM some calibration curves at high pressure have already been published (see references 2 and 3), but limited information is available on repeatability, reproducibility and linearity criteria.

A great number of meters have been calibrated at K-Lab during the past few years. This paper presents data about the repeatability, reproducibility and linearity which have been observed in the tests carried out at K-Lab.

METHODS

The ISO/TC30/SC9 document "Methods of specifying flowmeter performance" has been used as guideline in this paper (reference 4).

REPEATABILITY

Repeatability is the ability of the meter to duplicate a given output or performance for test runs with an identical set of flowing conditions. In accordance with ISO/TC30/SC9 the repeatability is calculated from 30 consecutive readings of flowrate at the maximum scale value. To begin with, the standard deviation, S_r, is calculated. Having obtained an estimate of the standard deviation, repeatability at the 95% confidence level (r_{95}) is calculated using the equation:

$$r = t_{95} * \sqrt{2} * S_r$$

where

t_{95} = **Student's t at 95% confidence level.**

The described method is most likely to become the **standard method** for repeatability recommended by ISO Specifications.
But it happens often that we need information about the repeatability without performing 30 runs at the maximum flowrate which may take up to one day of calibration. Often, metering people picks up some consecutive runs as raw-data from the calibration curves and evaluates the repeatability without performing any kind of statistical analysis. The alternative method that we are presenting in this paper intends to provide metering specialists with a simplified method for analysis of the repeatability, more easy and cost-saving than the standard method and more systematic than a simple scan of some calibration results. What is easily available for analysis is the calibration curve with a certain number (3 or 5) of runs at each flowrate. In this situation, the standard deviation for the whole curve can be calculated as:

$$S_r = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(X_{ij} - \bar{x}_i)^2}{n-1}}$$

n = number of flowrates

m = number of repeatable runs on each flowrate

In the following, this method will be referred to as **Range Repeatability**. Both the standard method and the Range Repeatability are used and compared in this paper.

REPRODUCIBILITY

The **Standard reproducibility** (reference 6) is calculated as the difference in percentage between the Meter-Factors over a long term basis.

LINEARITY

The Independent Linearity is expressed in ISO/TC30/SC9 as the maximum deviation between the average deviation curve and a straight line positioned so as to minimise the deviation over the Meter range and to give a constant Meter Factor. Therefore each range may have a different **Standard Linearity**.

The definition of linearity is not representative of the whole range where the meter is to be used. It is not possible to recognise if the deviation curves are fluctuating up and down or not. This is the reason why we would prefer to use the **Range Linearity** , expressed as the 95% confidence level parameter for the deviation curve over the whole flow range, in order to take care of all the flowrates. Both methods are used and compared in this paper.

RESULTS

TURBINE METERS

Six 6 inch turbine meters from different manufacturers have been calibrated against the K-Lab sonic nozzles at 100 bars absolute and approximately 37^{o}C. The meters were installed according to AGA7 (see reference 5). The integration time have been 3 minutes in all the tests. The frequencies measured by the counters have been sampled each second.

On 2 of these meters, meter A and B, a standard repeatability test with 30 runs has been performed at maximum flowrate. On all turbine meters the Range Repeatability is calculated. The results are shown in Table 1 and Figures 1 and 2.

Two turbine meters (meter A and B) are checked for the day-to-day reproducibility. The results are shown in Table 2 and Figures 3 and 4. Reproducibility data for these two meters have been obtained at 100 bars, 37°C and flowrates from 10% of Q_{max} to Q_{max}. The K-Factor has been measured as the average on each run. For turbine meter A, 5 flow rates and 3 runs have been considered. For turbine meter B, 5 flow rates and 5 runs have been considered. The **Standard Reproducibility** is the absolute value of the difference in percentage between the two K-Factors measured at different time.

The linearity for all 6 meters and the mean value are shown in Table 3. Both the ISO/TC30/SC9 method and the confidence interval method were used. In Fig. 5 and Fig. 6 two examples of linearity for turbine meters are shown (meter A and B).

CORIOLIS MASS METERS

Two 1.5 inch Coriolis mass meters have been calibrated. They were installed in a bypass line located in the K-Lab 6" test section with good clamp supports.

Some calibrations were performed in September 1990. The difference in integration time between 3 minutes and 5 minutes was tested (see reference 2). No differences were then noticed and 3 minutes was therefore selected as integration time.

But later experiences with Coriolis mass meters have demonstrated that the integration time must be longer to obtain better reproducibility. Figure 7 and Table 4 compare the repeatability of a Coriolis mass meter with 3 minutes integration time and 15 minutes integration time. The first curve was obtained before changing the meter factor and the second curve after the meter factor was adjusted. Table 4 also shows the range of repeatability for an integration time of 3 minutes and 5 minutes for two Coriolis mass meters.

Table 5 and Fig. 8 show the reproducibility after one year for Coriolis Meter A.

In Fig. 9 the linearity for meter A is plotted. Table 6 shows the linearity and the 95% confidence interval for 2 Coriolis mass meters.

ULTRASONIC METER

For a 6" USM which has been calibrated the optimum integration time was found to be 4 minutes.

Table 7 and Fig. 10 show the results of a repeatability test. Table 7 also shows the Range Repeatability.

Table 8 shows the day to day reproducibility.

Table 9 and Fig. 11 show the Independent Linearity. Table 9 shows the Range Linearity at the 95% confidence level as well.

DISCUSSION

TURBINE METERS

6 different 6 inch turbine meters have been calibrated. Turbine meters are well known to have good properties. However, these tests have shown some variation in the characteristics of the turbine meters.

Table 1 shows the Repeatability results: The K-Lab sonic nozzles have a repeatability of about 0.04%. The standard repeatability tests with 30 consecutive runs took approximately 5 hours so it has only been performed for 2 meters. This long time might be considered as the intrinsical weakness of the standard repeatability method. It can be seen that meter A has a very good repeatability of 0.03. But turbine meter B has a higher repeatability of 0.17%. This difference can be explained by looking at Fig. 2 where the flowrate measured on meter B is slightly increasing during the repeatability test whilst the reference volume flow was stable.

The Range Repeatability is practical to calculate and to analyse for all the meters. As expected, this method for calculating the repeatability might give a higher value for the repeatability because it takes into account also the low flowrates where we noticed a large dispersion of the results as a constant trend. Moreover the same error would become larger at low flowrates because the deviation from the reference volume flow is calculated in percentage. Nevertheless the repeatability range for the turbine meters vary between 0.11% up to 0.48%. The mean value for all the turbine meters is 0.24% which compares well with the Standard Repeatability. The table shows also that the Range Repeatability has roughly the same value if 3 or 5 runs were performed at each flowrate. All these results and their comparisons may be an encouragement to use this criterion on a regular basis when calibrating turbine meter.

For these turbines, we cannot produce long time reproducibility data. However, the day-to-day reproducibility data we measured, show that the calibration curves obtained some days later had almost exactly the same shape (see Figure 2).

The independent linearity of the meters varies from 0.21% to 0.74%. The mean linearity for all turbine meters is 0.42%. This demonstrates why turbine meters of the same size are to be calibrated individually for the range to be defined. Table 3 also shows that this standard linearity compares very well with the range linearity at the 95% confidence interval. The two ways of measuring the linearity will give almost the same results if the calibration curve is horizontal which is a specific case of linearity. But, if the calibration curve is fluctuating, the range linearity will be take account of it while the standard linearity will remain the same.

CORIOLIS MASS METERS

Concerning these calibrations, we can pinpoint that the values obtained by Coriolis mass meters are fluctuating so much that a long integration time is needed to obtain a repeatability which is acceptable. To have a good repeatability of the mass meters is very important as the flow factors in the meters have to be adjusted after each calibration. The meters cannot be adjusted correctly if the results obtained are not giving a correct picture of the performance of the meters. But these calibrations also show that the repeatability of the meters is improved from 1.11 to 0.57 when the integration time is increased from 3 minutes to 15 minutes. The drawback with 15 minutes integration time is that it takes a long time to do a calibration, and especially to do a repeatability test.

On Coriolis mass meter A data from the long term reproducibility test are available. It shows that the calibration factor has changed about 0.47% in one year. But here it must be noted that the calibration curves were obtained in two different ways which might have affected the results. The first year 5 runs on each flowrate were obtained with an integration time of 3 minutes. The year after 3 runs on each flowrate with an integration time of 15 minutes was used.

The linearity of the two meters which have been tested are 0.99% and 1.29%. The 95% confidence interval is larger than the standard linearity which means that the calibration curve is not linear but is bending. This can be seen easily on Figure 9.

These meters are of the 1.5 inch type. Our experience with 3 inch Coriolis mass meters from the same manufacturer shows that the larger meters have the same properties. The difference is mainly that the maximum flow rate is larger on a 3" meter.

ULTRASONIC METERS

Only one USM had so far been tested at K-lab. The results obtained with this meter shows that the repeatability and reproducibility are good, but that the linearity, which equals about 2%, is not good at all. If this lack of horizontal calibration curve is caused by the meter itself (for instance bad O-calibration) or by an installation effect, is currently investigated.

COMPARISON OF ALL THE METERS

Fig. 12 compares some meters of each type. It can be seen that turbine meter A is very good. It shows that not all the turbine meters have the same accuracy. It shows also that the Coriolis mass meters in the test have larger repeatability, reproducibility and linearity than the turbine meter. This bar chart also shows the linearity of the USM compared with the other meters.

CONCLUSION

Standard and Range Repeatability, Reproducibility and Standard and Range Linearity have been successfully gone through and applied to 6 turbine meters, 2 Coriolis mass meters and 1 Ultrasonic flowmeter at 100 bars.

Each method has been carefully considered by taking into account the conditions of use and the so-called Range Methods are shown to be more easy to use from a metering point of view.

The results given by each method compares very well for Turbine Meters, Coriolis Meters and Ultrasonic Meter concerning linearity. The two repeatability methods compares well in order of magnitude for turbine meter and Coriolis mass meters, and USM to a less extent. The differences in repeatability observed with Turbine Meters and Ultrasonic Meter are explained by the fact that the standard method at maximum flowrate does not take into account the relatively more important effect of a constant deviation at low flowrates. The slight differences in linearity between each methods are shown as the result of a better consideration of the fluctuation in the deviation curves over the whole flow range by the alternative method.

Eventually the comparison of these properties has been fully analysed for some meters of each type. It seems from the present results that turbine meters are more repeatable, more reproducible and more linear devices than the new meters in development. On the other hand, the good results concerning repeatability and reproducibility allow to consider ultrasonic meters as promising device considering their calibration simplicity and the fact that they are non-intrusive. However the linear flow range should be improved. Experience with the use of Coriolis meters in gas has been gained through this test programme. Additional tests are however required in order to obtain a better data base for different type of meters.

ACKNOWLEDGEMENTS

This Meter Calibration and tests campaign would not have been possible without the support of the turbine meter manufacturers (Daniel, Elster, Equimeter, Faure Herman, Hydril, and Instromet) and the Coriolis mass meter user (Phillips Petroleum Company Norway) who has kindly allow us to use the calibration data.

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TURBINE METERS	STANDARD REPEATABILITY DEVIATION CURVE (%)	STANDARD REPEATABILITY SONICS NOZZLES (%)	RANGE REPEATABILITY ON THE WHOLE CURVE 5 RUNS (%)	RANGE REPEATABILITY ON THE WHOLE CURVE 3 RUNS (%)
METER A	0.03	0.05	0.13	0.14
METER B	0.17	0.03	0.22	0.17
METER C	////	////	////	0.48
METER D	////	////	////	0.39
METER E	////	////	////	0.15
METER F	////	////	////	0.11
MEAN OF THE 6 TURBINES	////	////	////	0.24

TABLE 1: REPEATABILITY TABLE FOR 6 TURBINE METERS AT 100 BARS AND 37°C FROM 10% of Q_{max} TO Q_{max}.

TURBINE METERS	DIFFERENCE BETWEEN K-FACTOR (%)
METER A	0.044
METER B	0.004

TABLE 2: REPRODUCIBILITY TABLE FOR 2 TURBINE METERS AT 100 BARS

TURBINE METERS	STANDARD LINEARITY (%)	95% CONFIDENCE LEVEL $l_{95} = t_{95}\sigma$ (%)	Qmax (acmh)
METER A	0.21	0.20	1000
METER B	0.74	0.75	1600
METER C	0.22	0.22	1000
METER D	0.49	0.51	1000
METER E	0.33	0.37	1600
METER F	0.50	0.55	1600
MEAN OF THE 6 TURBINES	0.415	0.433	////

TABLE 3: LINEARITY TABLE FOR 6 TURBINE METERS AT 100 BARS AND 37°C FROM 10% of Q_{max} TO Q_{max}.

CORIOLIS METERS	STANDARD REPEATABILITY DEVIATION CURVES 3 MINUTES (%)	15 MINUTES (%)	RANGE REPEATABILITY 3 MIN. 5 RUNS (%)	15 MIN. 3 RUNS (%)
METER A	1.11	0.57	1.90	0.85
METER B	////////////	/////////////	1.24	0.93

TABLE 4: REPEATABILITY TABLE FOR 2 CORIOLIS METERS AT 100 BARS

CORIOLIS METERS	DIFFERENCE BETWEEN METER FACTOR OVER 1 YEAR (%)
METER A	0.47

TABLE 5: REPRODUCIBILITY TABLE FOR 2 CORIOLIS METERS AT 100 BARS

CORIOLIS METERS	STANDARD LINEARITY (%)	95% CONFIDENCE LEVEL $l_{95} = t_{95}\,\sigma$ (%)	Qmax (kg/min)
METER A	1.29	1.48	300
METER B	0.99	1.85	300

TABLE 6: LINEARITY TABLE FOR 2 MASS METERS AT 100 BARS ABSOLUTE

ULTRASONIC METER	STANDARD REPEATABILITY DEVIATION CURVE (%)	RANGE REPEATABILITY ON THE WHOLE CURVE (%)
METER A	0.17	0.72

TABLE 7: REPEATABILITY TABLE FOR 1 ULTRASONIC METER AT 100 BARS

ULTRASONIC METER	DIFFERENCE BETWEEN METER FACTOR (%)
METER A	0.1

TABLE 8: REPRODUCIBILITY TABLE FOR 1 ULTRASONIC METER AT 100 BARS

ULTRASONIC METER	STANDARD LINEARITY (%)	95% CONFIDENCE LEVEL $l_{95} = t_{95}\ \sigma$ (%)	Qmax (kg/min)
METER A	1.71	2.05	1300

TABLE 9: LINEARITY TABLE FOR 1 ULTRASONIC METER AT 100 BARS

Fig 1 : REPEATABILITY TEST AT 100 BARS, Qmax AND 37 DEG C

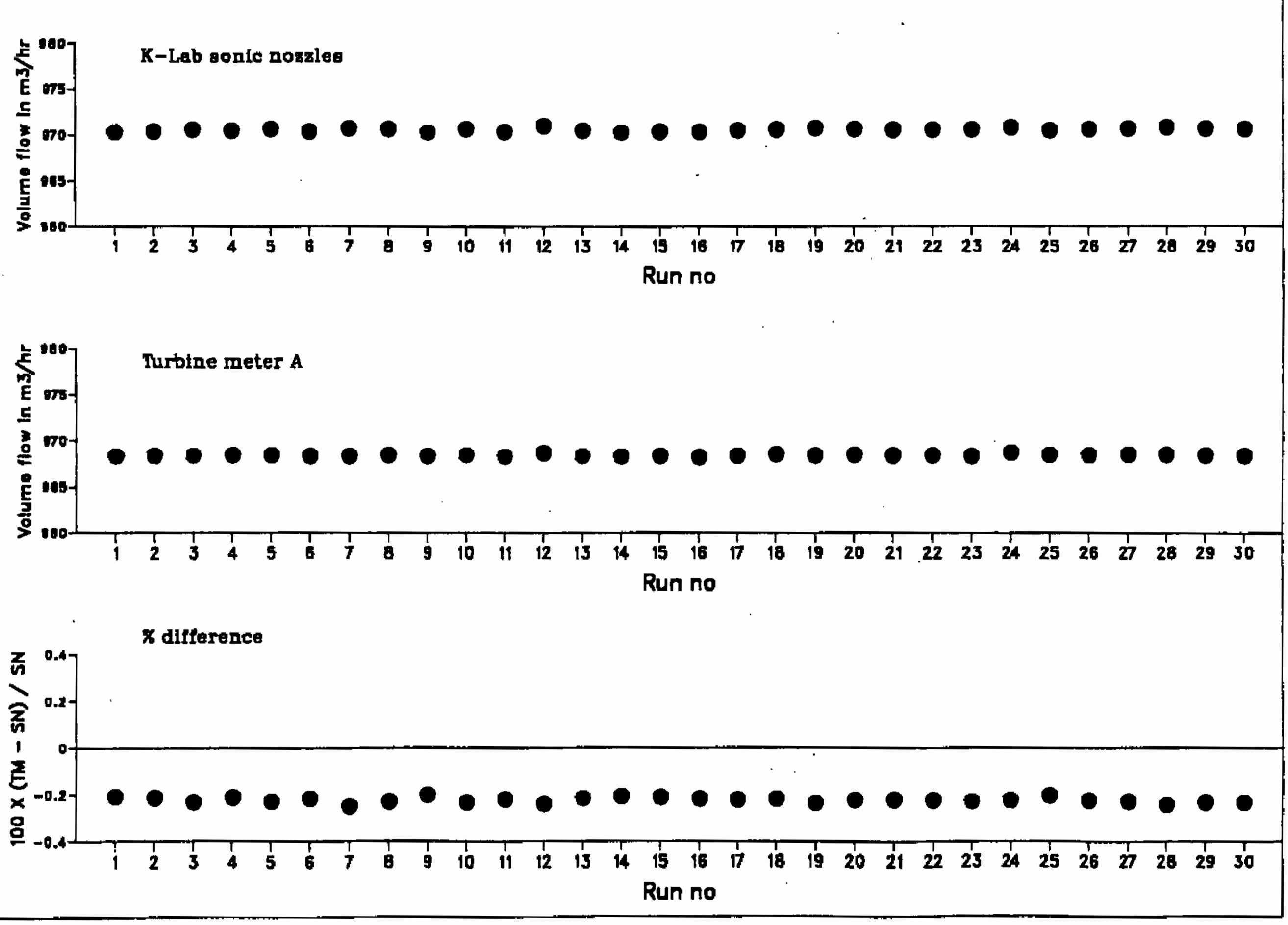
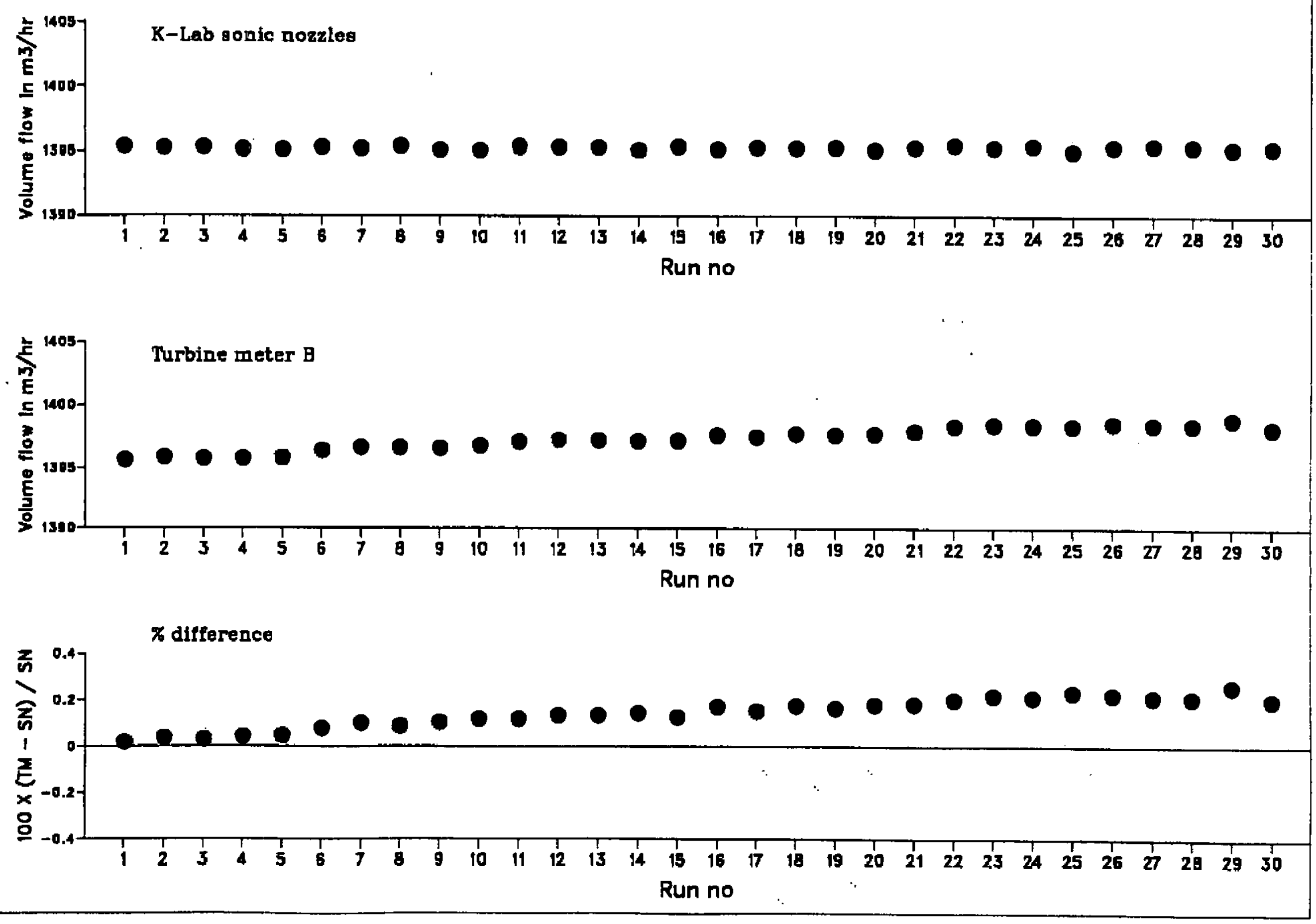
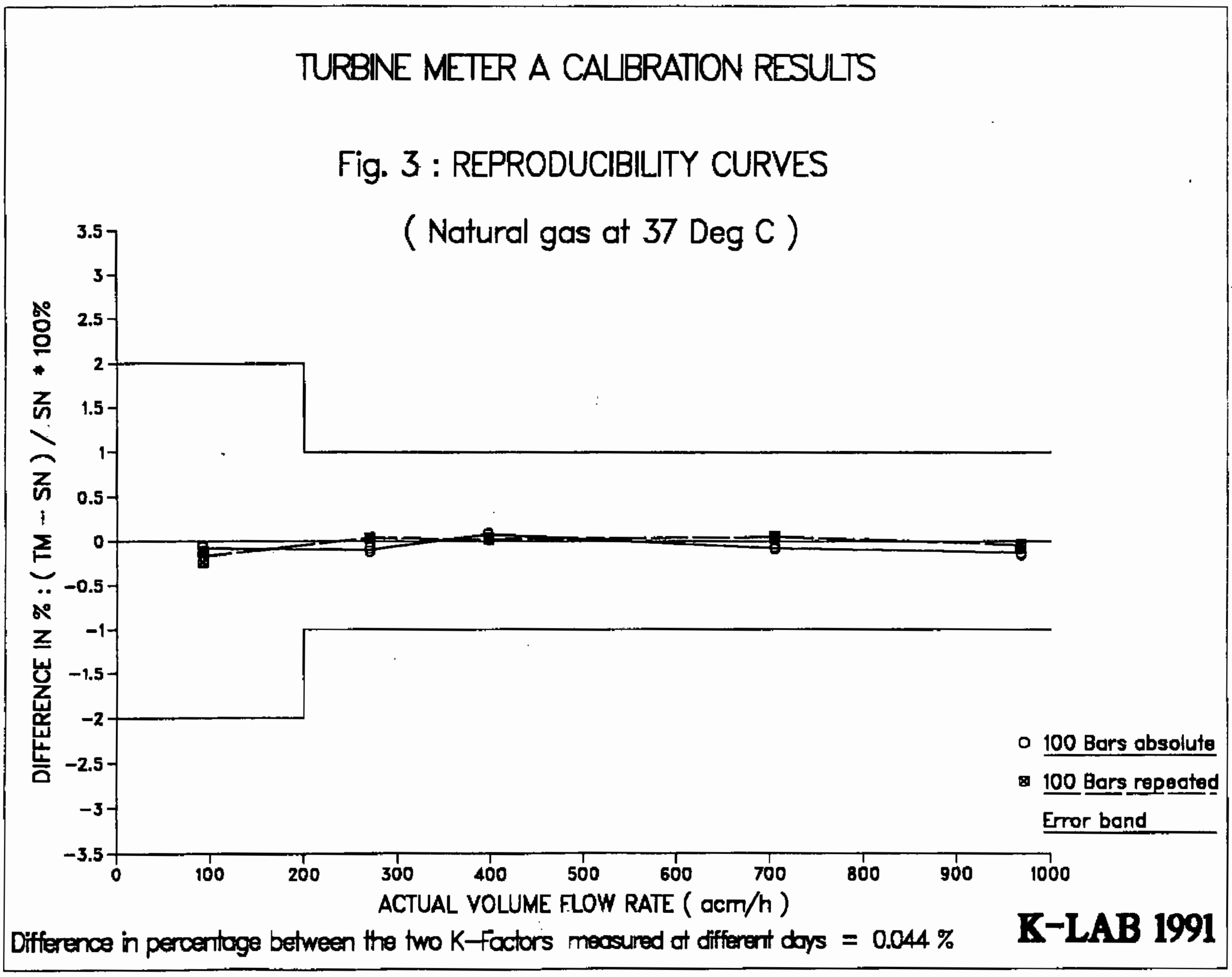


Fig 2 : REPEATABILITY TEST AT 100 BARS AND 37 DEG C



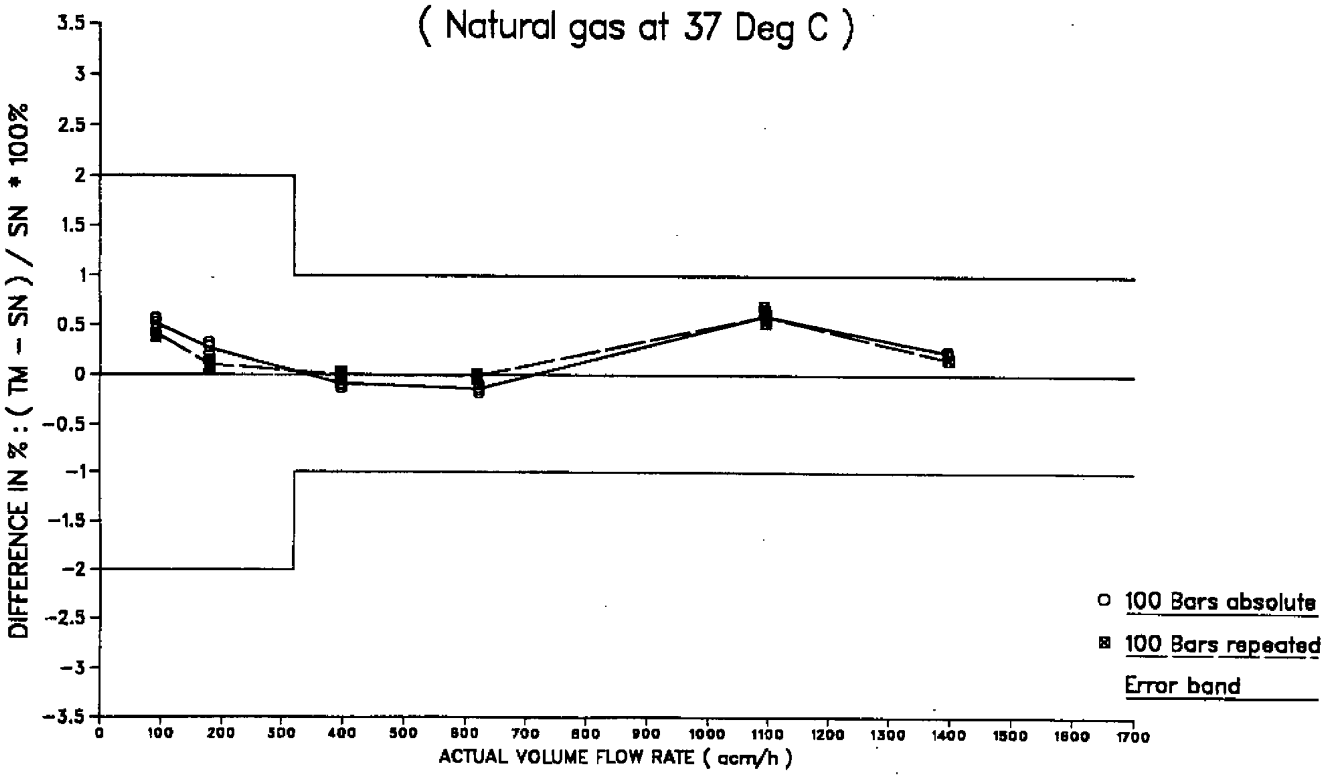


TURBINE METER A CALIBRATION RESULTS
Fig. 3 : REPRODUCIBILITY CURVES
(Natural gas at 37 Deg C)
DIFFERENCE IN % : (TM - SN) / SN * 100%
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
100
200
300
400
500
600
700
800
900
1000
ACTUAL VOLUME FLOW RATE (acm/h)
100 Bars absolute
100 Bars repeated
Error band
Difference in percentage between the two K-Factors measured at different days = 0.044 %
K-LAB 1991

TURBINE METER B CALIBRATION RESULTS

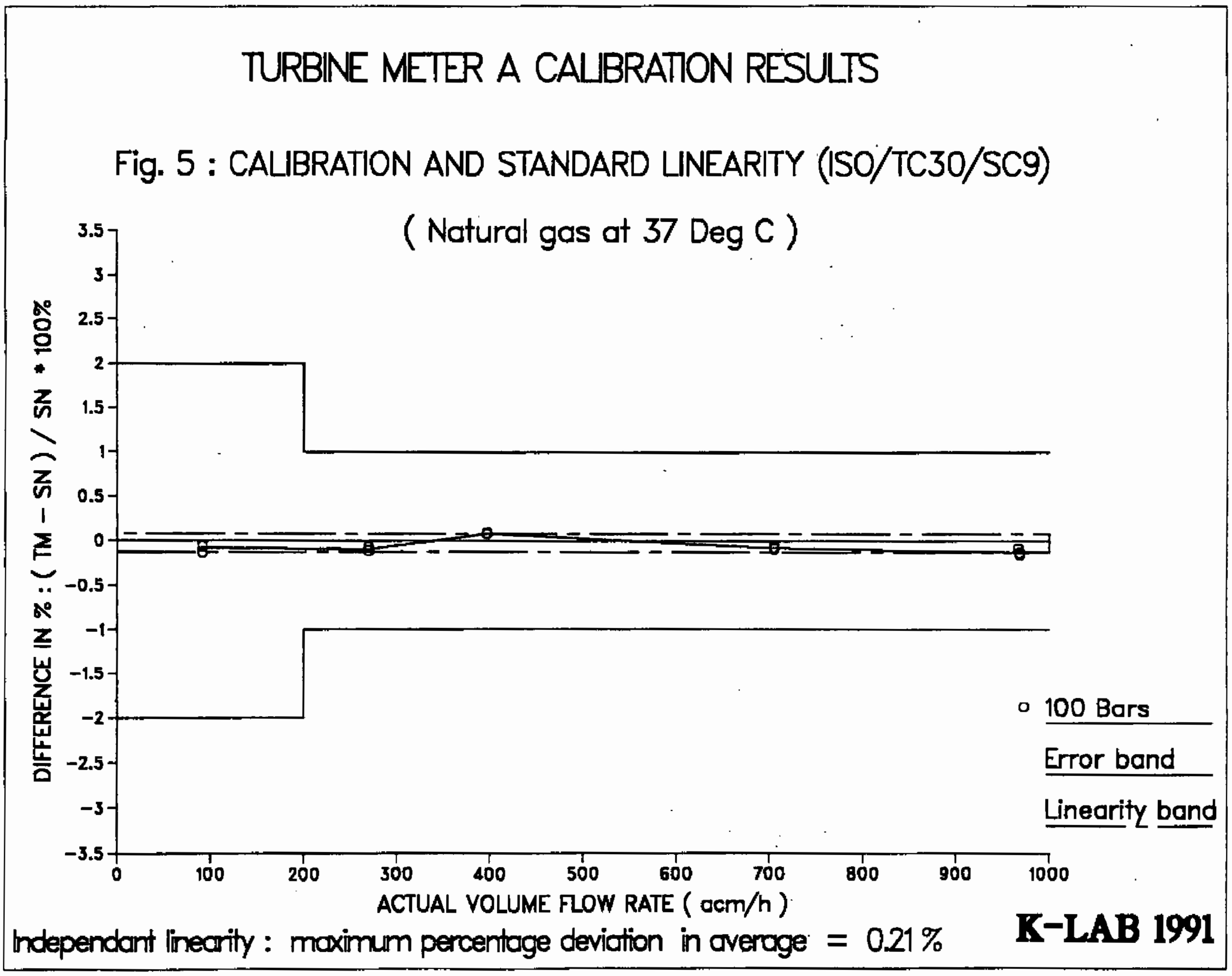
Fig. 4 : REPRODUCIBILITY CURVES

(Natural gas at 37 Deg C)



Difference in percentage between the two K-Factors measured at different days = 0.004 %

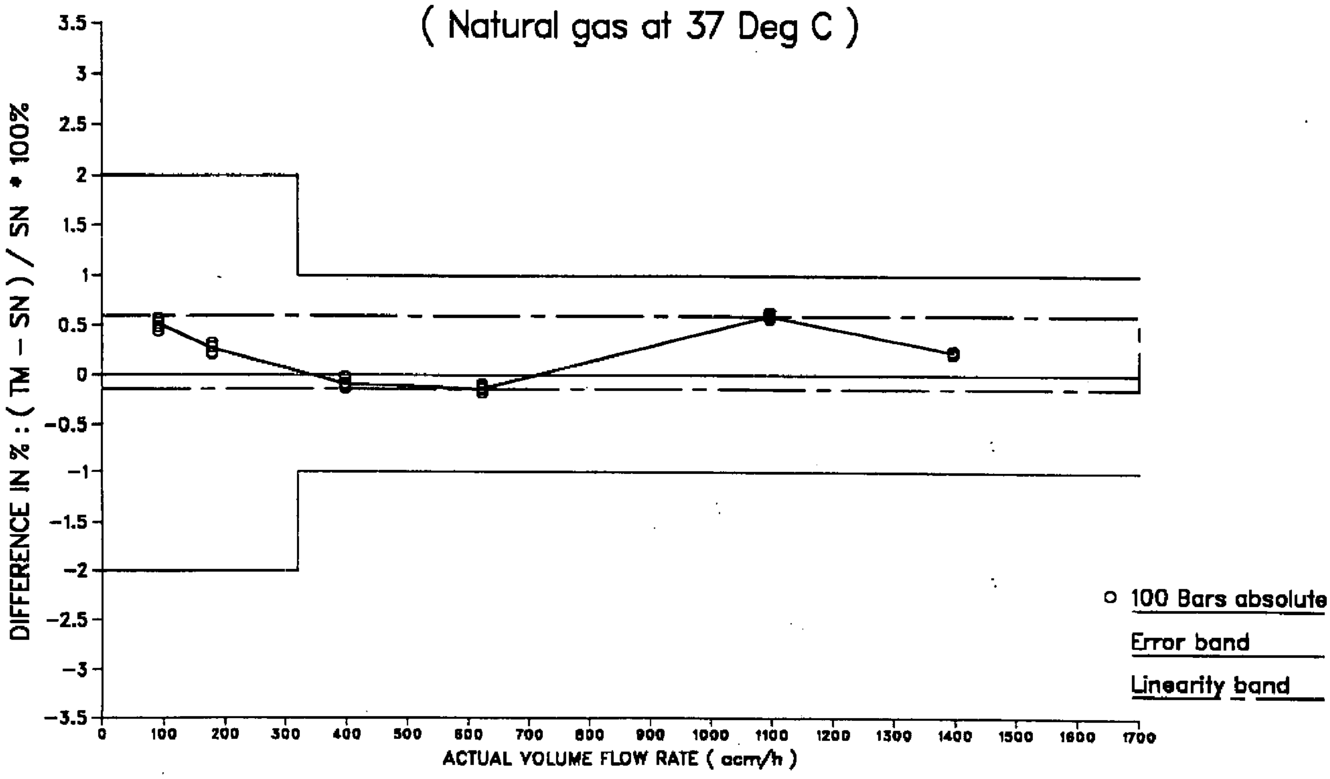
K-LAB 1991



TURBINE METER A CALIBRATION RESULTS
Fig. 5 : CALIBRATION AND STANDARD LINEARITY (ISO/TC30/SC9)
(Natural gas at 37 Deg C)
DIFFERENCE IN % : (TM - SN) / SN * 100%
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
100
200
300
400
500
600
700
800
900
1000
ACTUAL VOLUME FLOW RATE (acm/h)
100 Bars
Error band
Linearity band
Independant linearity : maximum percentage deviation in average = 0.21 %
K-LAB 1991

TURBINE METER B CALIBRATION RESULTS

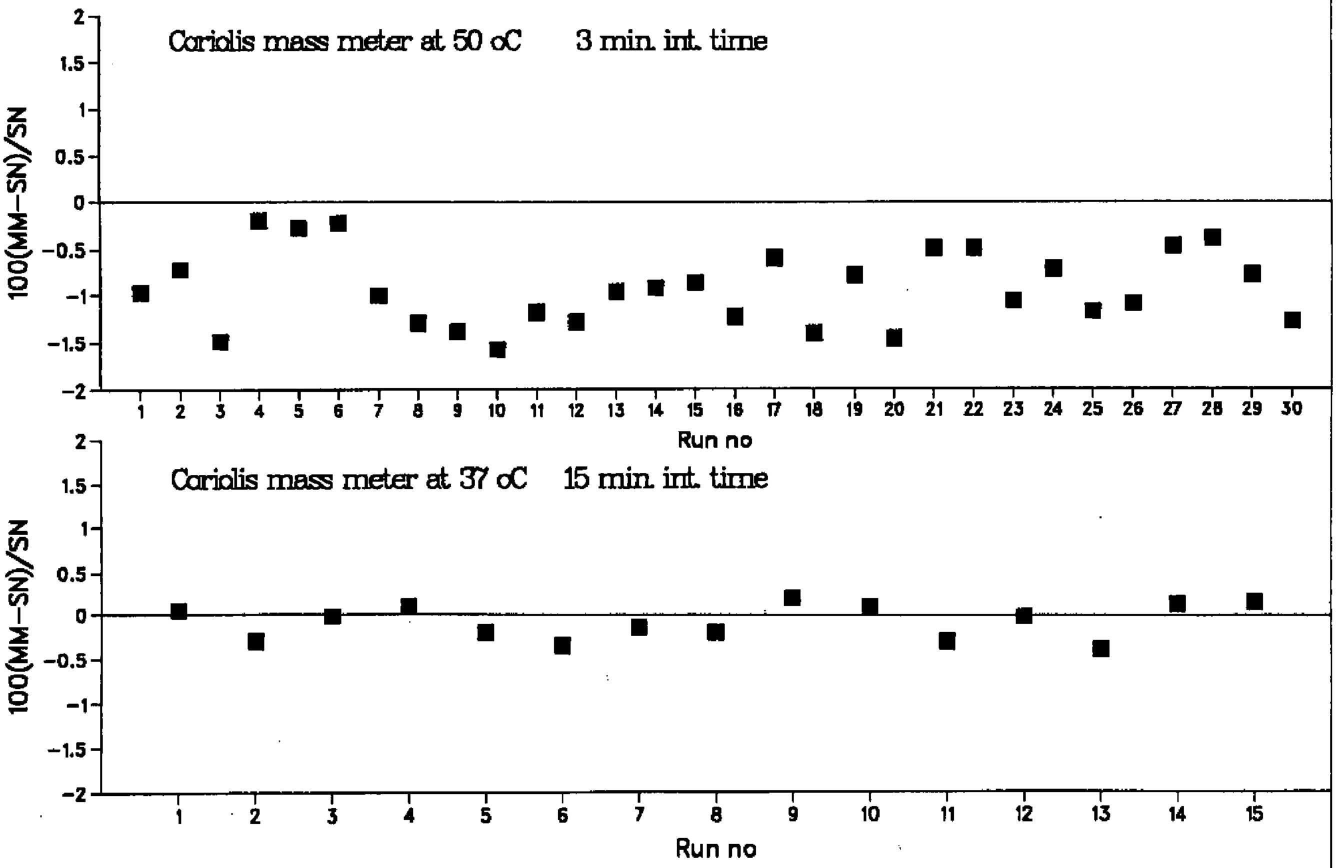
Fig. 6 : CALIBRATION AND STANDARD LINEARITY (ISO/TC30/SC9)



Independant linearity; Maximum percentage deviation in average = 0.74 %

K−LAB 1991

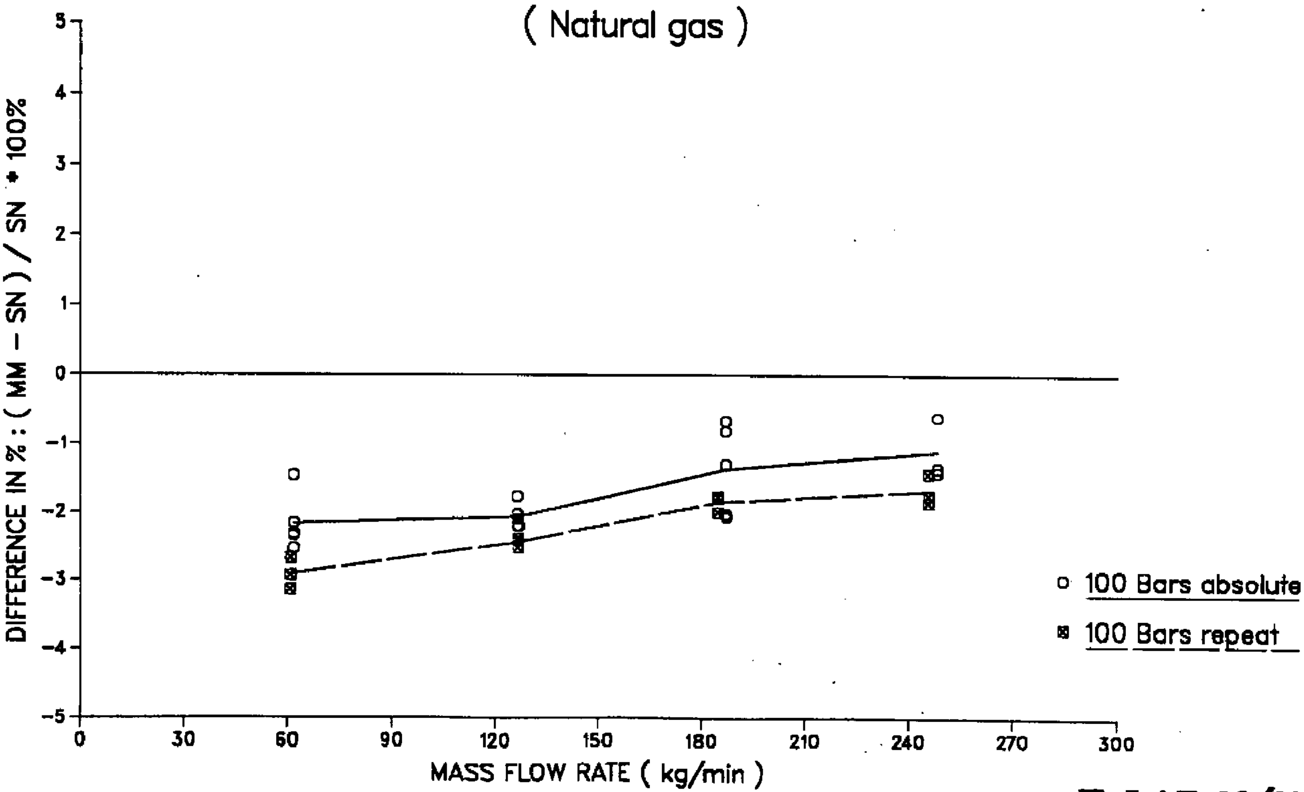
FIG 7. : REPEATABILITY TEST AT 100 BARS AND Qmax



CORIOLIS METER A CALIBRATION RESULTS

Fig. 8 : REPRODUCIBILITY CURVES

(Natural gas)



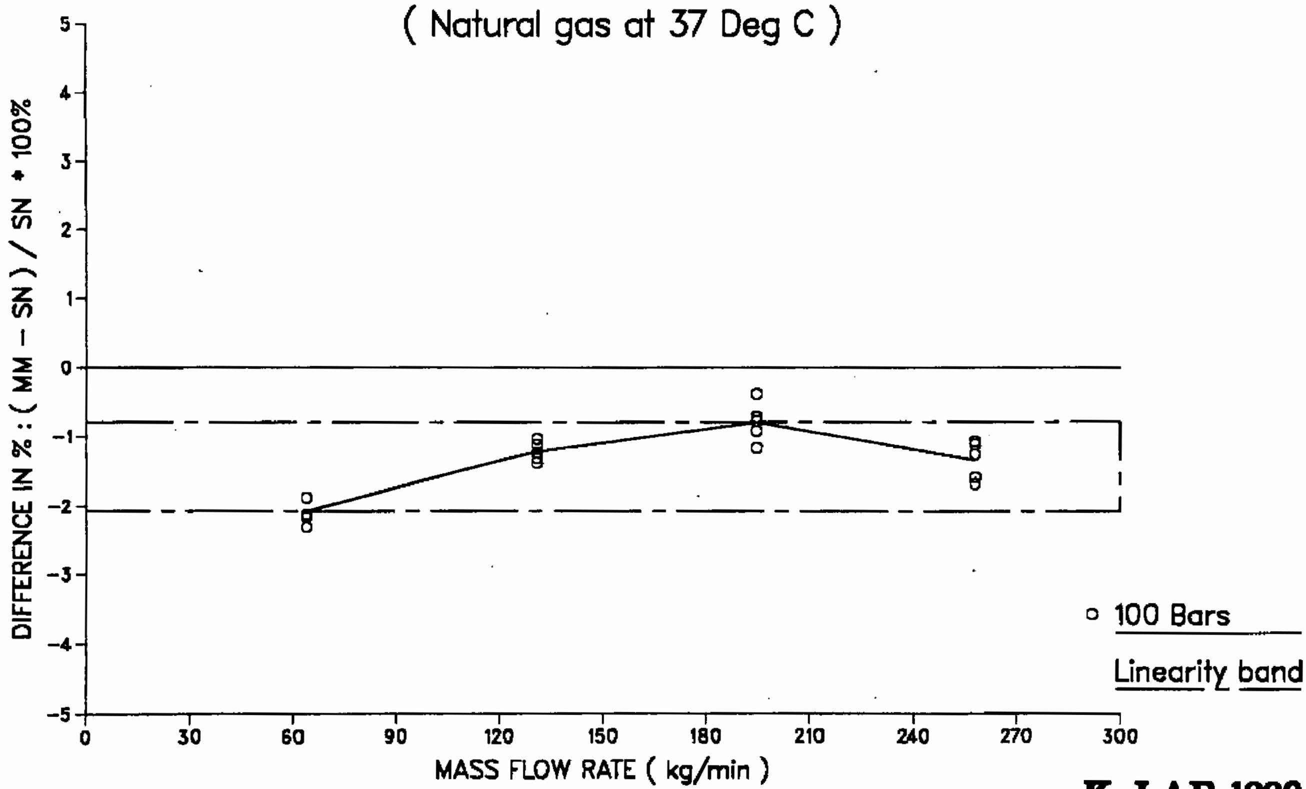
Difference in percentage between the two Meter Factors measured over 1 year = 0.47 %

K-LAB 90/91

CORIOLIS METER A CALIBRATION RESULTS

Fig. 9 : CALIBRATION AND STANDARD LINEARITY (ISO/TC30/SC9)

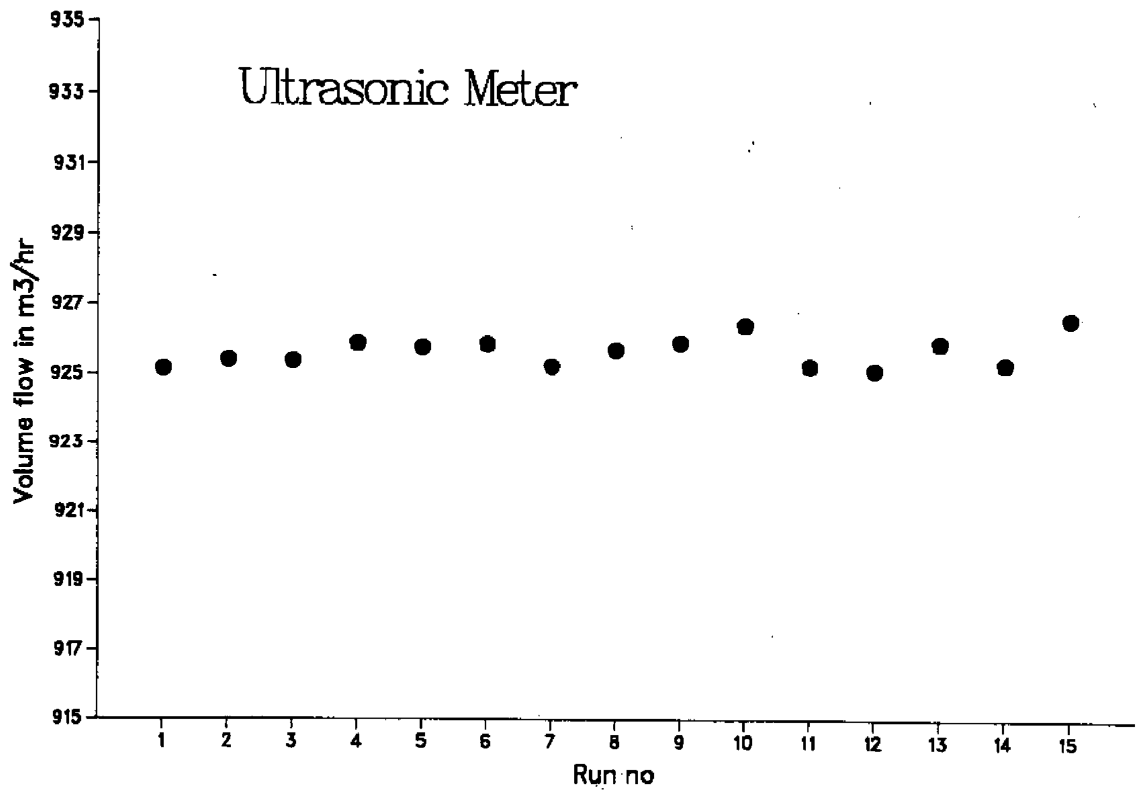
(Natural gas at 37 Deg C)



Independant linearity : maximum percentage deviation in average = 1.29 %

K-LAB 1990

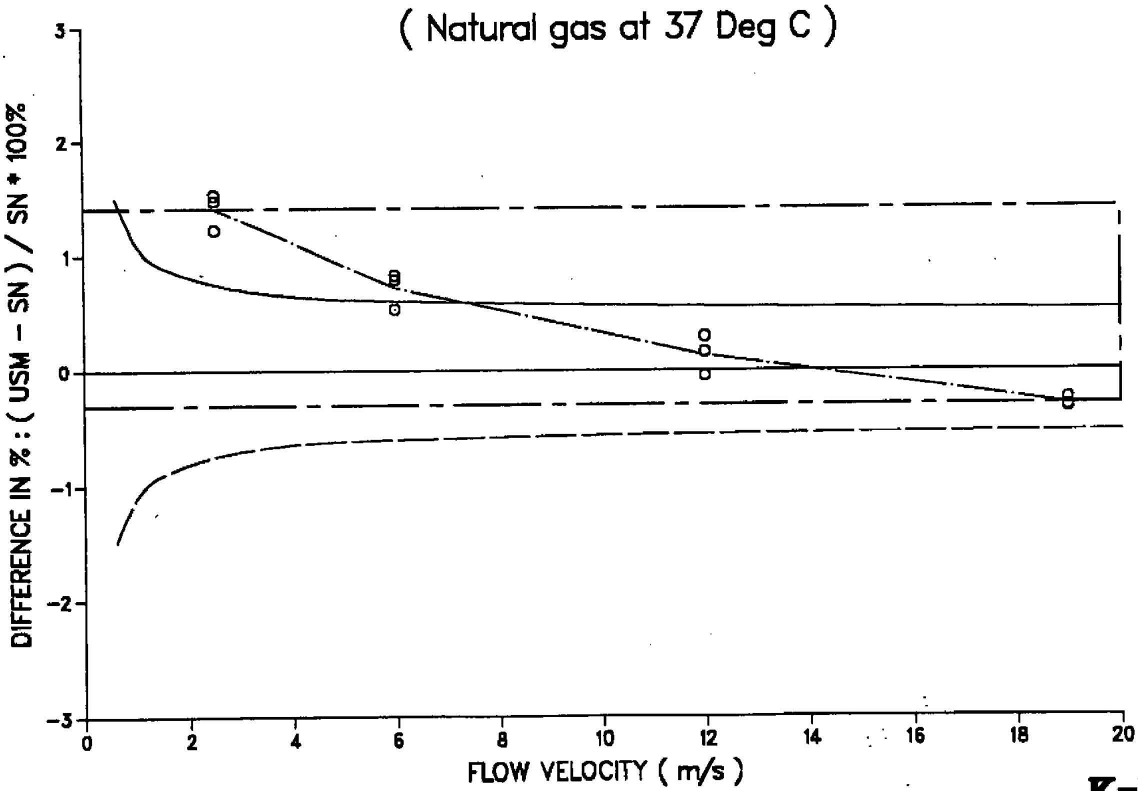
Fig 10 : REPEATABILITY TEST AT 100 BARS AND 37 DEG C



ULTRASONIC METER A CALIBRATION RESULTS

Fig. 11: CALIBRATION AND STANDARD LINEARITY (ISO/TC30/SC9)

(Natural gas at 37 Deg C)



Independant Linearity : maximum percentage deviation in average = 1.71 %

K-LAB 1990

Fig. 12 : COMPARISON OF DIFFERENT PROPERTIES FOR TURBINE, CORIOLIS AND ULTRASONIC METERS