

Comparative performance evaluation by WIB of two-wire and four-wire EMF meters of three different makes

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1 Introduction

The present comparative performance evaluation has been conducted for the following reasons.

1.1 Two-wire vs. four-wire systems

In the chemical, petrochemical and various other industries, the two-wire system is used as the standard infrastructure for field instruments (other than analysers). This means that instrument signals are transmitted and power is supplied through the same two wires.

Exceptions to this practice relate to four-wire flow meters such as the following:

- EMF meters
- Ultrasonic meters
- Coriolis mass meters

Now that fieldbus technology is gaining acceptance, the question arises in how far four-wire systems are still required and whether two-wire systems might give equally good performance. Within certain limits, the power supply for field instruments in fieldbus systems is no subject of debate. With the arrival of the Ex(e)/Ex(i) concept, this is also true for applications where instruments need to be connected and disconnected in an intrinsically safe manner.

Discussions with various manufacturers on the merits of two-wire fieldbus EMF meters indicate that such meters are able to meet or even exceed the specifications of current four-wire 4-20 mA meters.

One manufacturer wondered why two-wire 4-20 mA EMF meters have to date found so little acceptance in the industry. This particular instrument is used as a starting point for further development of the fieldbus design. No-one could come up with a direct answer to this question.

This subject has been discussed in the WIB flow expert group, and they found that two-wire 4-20 mA EMF meters are used only seldom for the following reasons:

- Meters produced by the three leading manufacturers have different specifications.
- There has been no independent investigation to accurately identify the capability limits of two-wire EMF meters in comparison with their four-wire counterparts.
- Users are not aware that such meters are available on the market, and manufacturers have done little in the way of promotion.

1.2 Cost

DSM has made a cost estimate for the power supply of four-wire instruments based on the prices quoted by contractors for projects. The result indicates that the cost of power supply of a four-wire field instrument ranges from EUR 1200 to 1800 depending on:

- the design of the power supply system
- the distance between the interconnection room and the plant
- the distance to be spanned within the plant

A major German multinational has confirmed that this estimate is correct.

Assuming an average cost of EUR 1500 per meter, for a plant using forty four-wire transmitters this amounts to an additional capital investment of EUR 60,000 for the power supply of four-wire transmitters alone.

1.3 Accuracy categories of industrial applications

Industrial flow meter applications can be broadly divided into three categories:

Category 1 are those applications that require the highest possible accuracy, where cost is not a factor. Meters may be subjected to additional calibration; the aim will be for mounting conditions to be ideal; etc.

Category 2 are applications where measurements must be $\pm 1\%$ to $\pm 2\%$ accurate. Examples include internal custody transfer billing; determination of plant efficiency; and measurement of fluids that are critical to product quality.

Category 3 are applications with an accuracy of $\pm 3\%$ to $\pm 5\%$, typically used for process control purposes. Here, reproducibility is often more important than accuracy.

The numerical distribution of these categories in the process industry is as follows.

- Category 1: 2%
- Category 2: 20%
- Category 3: 78%

The reader should keep this distribution in mind in assessing the test results. For instance, it does not really matter if the two-wire meter cannot be deployed in a Category 1 application so long as it can be deployed in, say, 80% of Category 2 and 3 applications.

1.4 Aim of project

It is the above considerations that have led to the project discussed here. The project was aimed at identifying and assessing the differences, if any, between the two meter types as well as to identify suitable applications for two-wire EMF meters.

1.5 Participating manufacturers

The following manufacturers have participated in the project:

- ABB
- Endress&Hauser
- Krohne-Altometer

The evaluation results have been reported separately to each manufacturer.

Data of meters supplied by ABB

ABB supplied the following meters from their Copa-X series:

- two-wire, serial number 000169169/002, type Copa-XT DT43
- four-wire, serial number 000169169/001, type Copa-XE DE43F
- The sensor bore of both meters is 75.8 mm.
- The liner material is PTFE and the electrodes are of titanium nitride for the two-wire meter and of Hastelloy C-4 for the four-wire meter.
- The meters have body flanges to ANSI standards.

Data of meters supplied by E&H

Endress&Hauser supplied the following meters from their Promag series:

- two-wire, serial number 410E1E91000,
- four-wire, serial number 410E1F91000,
- The sensor bore of both meters is 80 mm.
- The liner material is PFA and the electrodes are of type 1.4435 (316L) stainless steel.
- The meters have body flanges to ANSI standards.

Data of meters supplied by Krohne-Altometer

Krohne-Altometer supplied the following meters from their Altoflux series:

- two-wire, serial number A0220373, type IFM 4042K/D/H/8
- four-wire, serial number A0230380, type IFM 4080K/D/6
- The sensor bore of both meters is 75 mm.
- The liner material is PFA and the electrodes are of Hastelloy 4
- The meters have body flanges to ANSI standards.

2 Conclusions and recommendations

2.1 Conclusions

- The two-wire and four-wire meters were found to exhibit only small differences.
- Conductivity has a greater effect on the performance of the two-wire transmitter than on the performance of the four-wire EMF meter. More specifically, this applies to the meter's accuracy and the noise level of the output signal.
- The other items examined showed no significant differences.
- For Category 2 and 3 applications, where the uncertainty must be $\geq 1\%$, the two-wire EMF meter can be deployed in 90 % of cases. Here, the two-wire meter is a suitable alternative to the four-wire meter.
- A four-wire EMF meter must be used in applications requiring the highest possible accuracy.

2.2 Application guidelines

The following application guidelines relate to the two-wire EMF meter:

- Two-wire EMF meters may be used for liquids whose conductivity is less than 50 uS/cm.
- Two-wire EMF meters must not be used for liquids whose conductivity is less than 20 uS/cm.
- For liquids whose conductivity is between 20 and 50 uS/cm it should be determined whether it is acceptable for the time constant to be greater than the default value of 1 second. If this is not the case, the four-wire EMF meter should be used.

3 Evaluation

The evaluation consisted of the following elements:

Determination of the reference curve using water of 20°C and conductivity greater than 300 uS/cm.

Determination of temperature dependence using water of 45°C and 70°C and conductivity greater than 300uS/cm.

Determination of the effect of conductivity using water of 20°C and conductivities of 10, 20, 50 and 100 uS/cm.

Determination of the effect of viscosity.

These measurements were conducted with viscosities of 3.3, 8 and 20cSt at a liquid temperature of 20°C and conductivity greater than 150uS/cm

Determination of the effect of flow disturbance.

The effect was measured of a single elbow at 3D, 5D and 10D ahead of the meter.

Determination of response rate following an incremental flow rate disturbance

Determination of the effect of air bubbles

This measurement was only intended to give an indicative result and does not pretend to be highly accurate.

An additional reference curve was established on completion of all measurements.

Comparison of the first reference curve with this additional curve provides an indication of the long-term stability of the meters.

4 Selection of meter diameter and measuring range

4.1 Diameter

The diameter of the two-wire meter may affect the meter's performance. The magnetic field strength cannot be simply increased given that the power requirement needs to be supplied by the mA signal. In addition, the sampling rate must remain within realistic limits.

The two-wire meters supplied by the three manufacturers have different maximum diameters. The ABB meter is maximum 4" (DN100); the E&H meter is max. 6" (DN150) and the Krohne-Altometer is max. 8" (DN 200). All three are planning to produce meters with larger diameters.

In the (petro)chemical industry, ninety percent of flow meters are mounted in pipelines up to 6" in diameter (DN 150) and sixty percent in pipelines of 2" and 3" (DN 50 and DN 80). Therefore, it was decided to mount the meters in 3" (DN80) lines.

4.2 Measuring range

Another item is the selection of the measuring range of the meter under examination. The maximum measuring range extends from 0 to 10 m/s. Line diameters in (petro)chemical plants are selected for a liquid velocity of approx 1.5 m/s at nominal flow rate. Of course, velocities of 1 m/s and 2 m/s at nominal flow rate are also possible in practice. Assuming the nominal flow rate is approx. 70% of maximum flow rate, the maximum velocity may range from approx. 1.5 m/s to 2.8 m/s.

In some instances, for process reasons or other local compelling reasons, it is necessary to select a higher velocity at nominal flow, with the maximum being about 2.5 m/s. This corresponds with a velocity of about 3.6 m/s at the maximum flow rate. Based on these considerations it was decided to select a measuring range from 0 to 4 m/s, corresponding with approximately 0 to 72 m³/h, depending of the inside diameter.

5 Procedures

5.1 Test rig

The evaluation was conducted in DSM's test rig at Geleen. The uncertainty of the liquid system is $\pm 0.1\%$ mv.

5.2 Mounting of meters

A piping system was assembled for each manufacturer, with the two-wire meter and four-wire meter arranged in series. See photo in Annex 1 and the overall set-up in Annex 2. All 3" pipe runs have an inside diameter of 78 ± 0.3 mm. The piping system comprised an inlet pipe run of 10D upstream of the first meter and a pipe run 29D long between the first and the second meter. This system was preceded by a pipe 25D long. In this way, it was ensured that operating conditions were the same for both meters.

For determining the effect of flow disturbance the meters were removed from the piping system and tested separately. For this test, too, the meters of all three manufacturers were mounted in the same way. The flow pattern was disturbed by means of a single 90° elbow, a common source of disturbance in practice. Mounting conditions are also shown in Annex 2. The straight pipe run ahead of the elbow is 30 D long and is preceded by a concentric 6" to 3" reducer.

5.3 Output signal

All meters provide a mA output signal as well as a pulse output signal. Both were used in the evaluation. The pulse output signal was used for determining the accuracy. The data points from which the curves were constructed are the average values of three to five measurements. Each measurement lasted two minutes or 10,000 pulses, whichever took longer. Only for the lower flow rates was the limit of 10,000 pulses reduced to 5,000 or 3,000 pulses so as to avoid overly long measuring times. The number of pulses was reduced when the measuring time exceeded five minutes.

The mA output was connected to a chart recorder as well as an integrated DVM. The latter was alternately used for the two-wire and the four-wire transmitter. We checked at regular intervals whether the deviation derived from the pulse output was in good agreement with the deviation derived from the analogue output. Differences up to 0.2% were deemed to be acceptable.

The ABB meters were evaluated using the default time constant of 1 second for the analogue output. The E&H and the Krohne-Altometer meters have a time constant of three seconds.

The response rates were plotted on a Kipp recorder using the analogue outputs. The time constant of the Kipp recorder is <100 msec.

5.4 Conductivity and viscosity

The effect of conductivity was determined with demineralised water whose conductivity had been adjusted to the required value by means of a soda solution.

The viscosity tests were conducted with sugar solutions whose viscosity was adjusted to 8 and 3.3 cSt by diluting the solution used in the 20 cSt tests with demineralised water. The conductivity of this solution was greater than 150uS/cm

6 Results

Over forty curves were plotted in all, and it would be impracticable to present them each and all here. Instead, we have attempted to give a representative summary.

Readers wishing to have all details may request copies of the full report on each meter make from the WIB office at The Hague.

All deviations have been determined relative to the mean Kf. These Kf values have been derived from the data supplied by, and have been verified by, the manufacturers. The evaluation has been conducted using the default settings with which the meters are normally supplied.

The following rules were applied in constructing the curves:

- Deviations from the Kf value quoted by the manufacturer are presented on the Y axis.
- The aim has been to arrive at a standard Y axis.
- The standard Y axis ranges from -2% to +2%; a note is added where this is not the case.
- The same parameter of a two-wire and a four-wire EMF meter is shown in the same colour.
- In the curves, solid markers relate to two-wire meters and open markers relate to four-wire meters.

6.1 Effect of meter location in piping system

The two-wire and four-wire meters of each manufacturer were arranged in series. The decision to position the two-wire meter upstream of the four-wire meter was purely arbitrary. As a result, the straight pipe run upstream of the four-wire meters is almost twice as long as that upstream of the two-wire meter. Consequently, we needed to verify that the meter location in the piping system has no effect on meter performance. This is the first thing we did in the evaluation. The meters were exchanged and a curve was constructed using water at 20°C and having a conductivity in excess of 300 uS/cm.

Next, the meters were installed in their definitive positions and the reference curve was determined. The results are shown in Annex 3. Note that the scale on the Y axis differs from the standard scale.

In the case of the four-wire transmitter the differences are only a few hundredths of one percent, and the accuracy is the same for both locations. For the two-wire transmitter the differences are greater, averaging 0.15% for the three makes. Thus, the location seems to have a slight effect for the two-wire meter; the effect is only marginal for normal applications.

6.2 Reference curve

The two reference curves are provided in Annex 4. The differences are different for different makes, and range from less than 0.1% to some tenths of one percent. The spread, or difference between minimum and maximum value per flow rate, is 0.1% for the four-wire meter and 0.2% for the two-wire meter.

6.3 Effect of liquid temperature

The effect of the liquid temperature has been determined with water at 45°C and 70°C. See Annex 5.

There is no significant difference in the effect of liquid temperature between the two-wire and four-wire meters of each manufacturer.

After the temperature tests, the reference curves were again determined (Annex 6). The differences are less than 0.1% for both E&H and Krohne-Altometer whilst in the case of ABB a shift of maximum 0.3% was observed for both the two-wire and four-wire meters. Another reference curve was determined after the tests, and this showed that the shift exhibited by the ABB meters had diminished to 0.15 % . The E&H and Krohne-Altometer meters had a PFA liner whilst the ABB meter employed a PTFE liner. The shift of the ABB meter may be due to this liner material. This will be examined more closely.

6.4 Effect of conductivity

For EMF meters, the signal noise level is a function of:

- Conductivity
- Liquid velocity
- Liquid properties.

Aqueous solutions are known to add to the noise level. Also, the level increases with decreasing conductivity, and the same happens with increasing liquid velocity. Both the pulse output signal and the analogue output signal are affected by noise. The noise signal can be attenuated by means of a filter having an adjustable time constant. The time constant's default setting of ABB meters is $\tau = 1$ second, E&H and Krohne-Altometer used 3 seconds as the default setting. The default settings were used during the tests.

The evaluation reveals a number of differences between the two-wire and four-wire EMF meters in terms of the effect of conductivity. For the two-wire meters, the conductivity curves shift away from the reference curve in positive or negative direction depending on the make. At conductivities down to 50uS/cm the shift is within 0.5%, as might be expected. At 20uS/cm the curve shows wider deviations, up to about 1.5% (Annex 7).

The curves for the four-wire meter are all close together, and at conductivity values down to 20uS/cm all measured values are within a 0.2% band. The deviations will probably be greater at lower conductivity.

There is also a difference between the two wire and four wire meters in terms of repeatability. Each meter measured each flow rate three times. The difference between the minimum and maximum Kf values is a measure of repeatability.

In the case of the two-wire EMF meter, non-reproducibility is less than 0.2% at 100 uS/cm and is 0.5% at 50 uS/cm. It decreases to 1.5% at 20uS/cm and is as low as 2% at 10 uS/cm. Repeatability of the four-wire meter is within 0.25% for conductivities up to 20uS/cm. Repeatability decreases only slightly as a function of conductivity. Its repeatability at 10uS/cm is low, i.e. 0.8%.

The above figures relate to the pulse outputs. These meters are often used in 4 – 20 mA systems. The analogue output signals of both the two-wire and four-wire EMF meters carry some noise. Analysis revealed that the noise signal is made up of a more or less cyclic part with fairly narrow spurious spikes occurring at more or less regular intervals. The frequency of the cyclic part is approx. 0.1 Hz. Annex 8 provides the peak-to-peak values of the spikes as well as the values of the cyclic part as a function of flow rate and conductivity.

For the two-wire meter the noise peak-to-peak value at 50uS/cm conductivity and at maximum flow rate is 13 % and that of the cyclic portion is maximum 7%. With decreasing conductivity, the noise on the analogue signal increases to maximum 53% for the peak-to-peak value and to 26% for the cyclic part at 10 US/cm conductivity.

The noise level on the analogue output of the four-wire meter is distinctly lower. At 50uS/cm conductivity the periodic part peaks at only 3.5% and the peak-peak value is 5%. At 10uS/cm the periodic part is 12% and the peak-to-peak value is maximum 25%.

The noise level can be controlled, albeit at the expense of response rate, by increasing the time constant. Whether or not a lower response rate is acceptable depends on the meter application.

6.5 Effect of viscosity

Annex 9 presents the results of the viscosity tests for the two-wire and four-wire EMF meters, including the deviation as a function of flow rate.

The shift is only slight for both meter types, so the effect of viscosity is only small. The differences between the curves do not exceed 0.5%.

The deviations at 20cSt and at lower flow rates are due to the flow pattern changing as the Reynolds number decreases.

When the results are presented as a Reynolds' function, the curves appear to be closely in agreement especially for the two-wire and four wire meter (Annex 10). This means that a Re curve should allow accurate prediction of the Kf values for a given application.

6.6 Effect of flow disturbance

The effect of flow disturbance on performance of the two-wire and four-wire meters is shown in Annex 11. The shift resulting from the presence of the 90° elbow is small. The shift relative to the reference curve upon reducing the upstream straight pipe length from 35D to 3D is 0.6% on average for both the two-wire and the four-wire meter. Here again there is no significant difference in performance between the two types.

6.7 Response rate

The analogue output was used for testing the response rate. The following output signal levels were used (approximate values):

- 10 – 20% vice versa
- 10 – 90 % vice versa
- 40 – 90% vice versa
- 45 – 55% vice versa
- 80 – 90% vice versa

As stated above, the ABB meters were tested using the default time constant of 1 second. The ABB two-wire meter appears to have a faster response rate than the four-wire meter, averaging 1.9 seconds versus 2.3 seconds. Differences up to 0.3 second were observed depending on the increment and the output level.

E&H and Krohne-Altometer are supplied with a default time constant of 3 seconds. The time constant we measured amounted to approx. 4.2 seconds for both makes and both types.

6.8 Effect of air bubbles

The meters were tested individually for this parameter. The air connection was located at 3D upstream of the meter. Air was injected at the centre of the pipe through a stainless steel tube of 6 mm outside diameter and 4 mm inside diameter. The tests were conducted at an air flow rate of approx. 700Nl/h, at liquid flow rates of 10; 26 en 62 m³/h and at a pressure of approx. 1 to 1.5 bar.

The results indicate that the two-wire and the four-wire EMF meters respond to the presence of air bubbles in the same way.

6.9 Comparison of pulse output signal and 4-20mA output signal

The values shown in the curves relate to the pulse output signal. Since the analogue output is often used in practice, it would be interesting to know the difference between these two signals. These signals are compared in Annex 12 for the various parameters tested. The results are presented in two graphs rather than one for better clarity.

The two graphs show good agreement between the pulse output and the analogue output of both the two and four-wire meters. As expected, the outliers in the case of the two-wire meter are mainly related to the measurements conducted at lower conductivities.

Disregarding a few conductivity outliers, the differences are within $\pm 0.5\%$.

6.10 Stability of meters during tests

When all tests had been completed, the meters were remounted in the piping system and another curve, the repeated reference curve, was determined using water at 20°C. A similar curve was constructed after the temperature tests. These curves are shown in Annex 6. The differences between these curves are a measure of the stability of the meters.

In assessing these results it should be borne in mind that the meters were removed from the metering run for some tests. After these tests they were remounted as much as possible in the same way. It is not impossible that this has had some effect on the accuracy.

In the case of the two-wire meter, after all the tests it had been subjected to, the difference between the initial reference curve and the repeated reference curve was less than 0.3%. For the four-wire meter this difference is only 0.15%.

6.11 Differences in accuracy depending on application

We have derived from the evaluation results an indicator for each meter parameter that allows the uncertainty to be determined for a given application.

We have done this for both the two-wire and four-wire EMF meter for the following two applications.

Application 1

Product: aqueous salt solution

Conductivity: 300uS/cm

Viscosity: 1 cSt

Liquid temperature: 50°C

Mounting conditions: 90° elbow followed by 20 D of straight pipe length upstream of meter

Rangeability 10 : 1

In this application the meter accuracies are as follows:

- Two-wire EMF meter, pulse output: $\pm 0.89\%$
- Four-wire meter, pulse output : $\pm 0.55\%$

- Two-wire meter, analogue output: $\pm 1.01\%$
- Four-wire meter, analogue output: $\pm 0.64\%$

Application 2

Product: acid

Conductivity: 50uS/cm

Viscosity: 8 cSt

Liquid temperature: 90°C

Mounting conditions: 90° elbow followed by 5D of straight pipe length upstream of meter

Rangeability 10 : 1

In this application the meter accuracies are as follows:

- Two-wire EMF meter, pulse output: $\pm 1.49\%$
- Four-wire EMF meter, pulse output: $\pm 1.16\%$

- Two-wire EMF meter, analogue output $\pm 1.69\%$
- Four-wire EMF meter, analogue output $\pm 1.26\%$

If in this application the straight pipe length is increased to 20F from 5D, the accuracies are as follows:

- Two-wire EMF meter, pulse output: $\pm 1.30\%$
- Four-wire EMF meter, pulse output: $\pm 0.96\%$

- Two-wire EMF meter, analogue output $\pm 1.49\%$
- Four-wire EMF meter, analogue output $\pm 1.06\%$

These exemplary applications indicate that there are small differences in accuracy between the two-wire and four-wire EMF meters, ranging from 0.25% to 0.5%. In many cases the difference will be so small that it is no objection for a two-wire meter to be used. Thus, the two-wire meter can be a suitable alternative to four-wire units.

7 Industrial applications

For an existing DSM plant containing 96 EMF meters we investigated how many meters could be replaced with two-wire units. The results are as follows

- ABB 83%
- E&H 86%
- Krohne-Altometer 96%

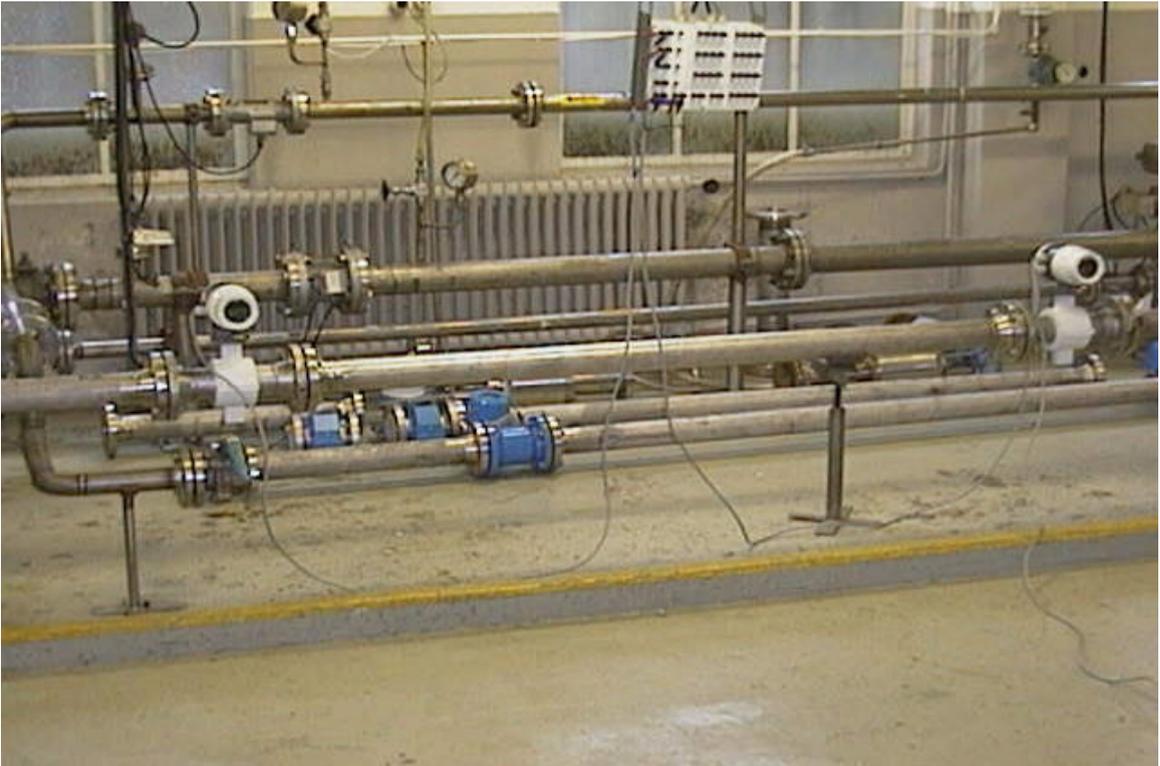
None of 96 applications imposes any restrictions in terms of conductivity. The restrictions are a consequence of the available diameters for two-wire EMF meters.

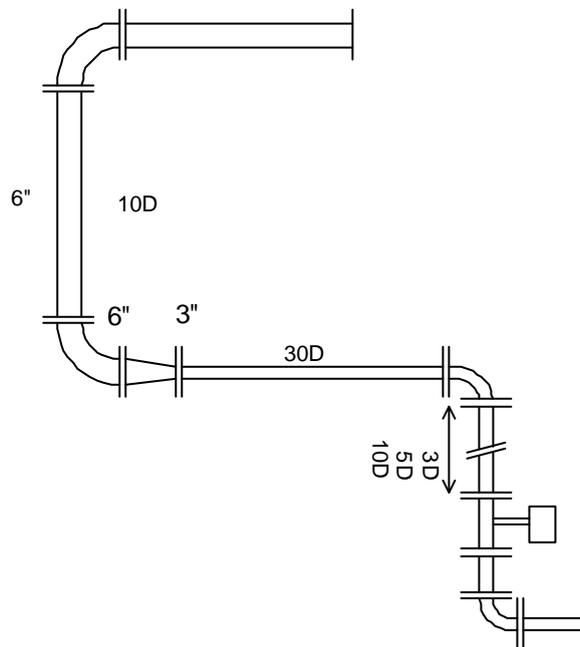
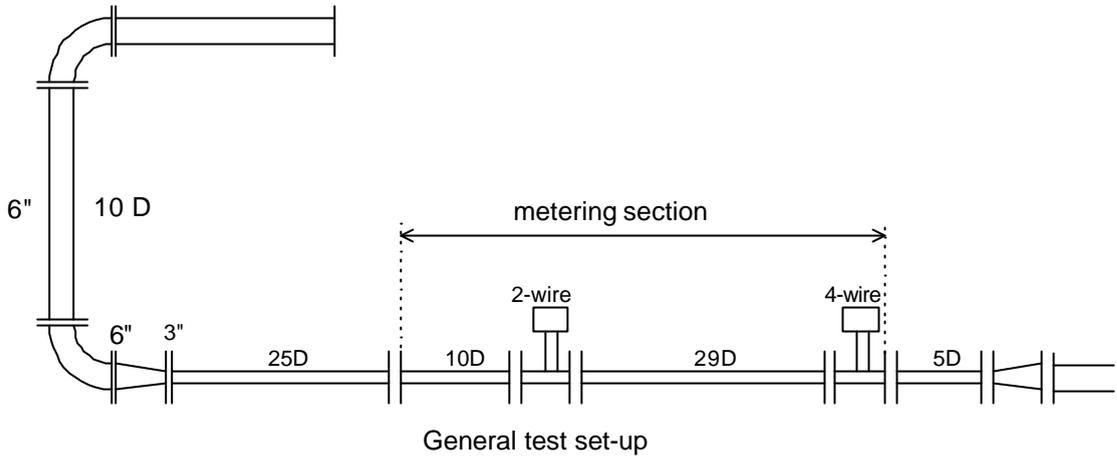
The following meter diameters can be supplied:

- ABB 4"
- E&H 6"
- Krohne-Altometer 8"

8 Operating experience

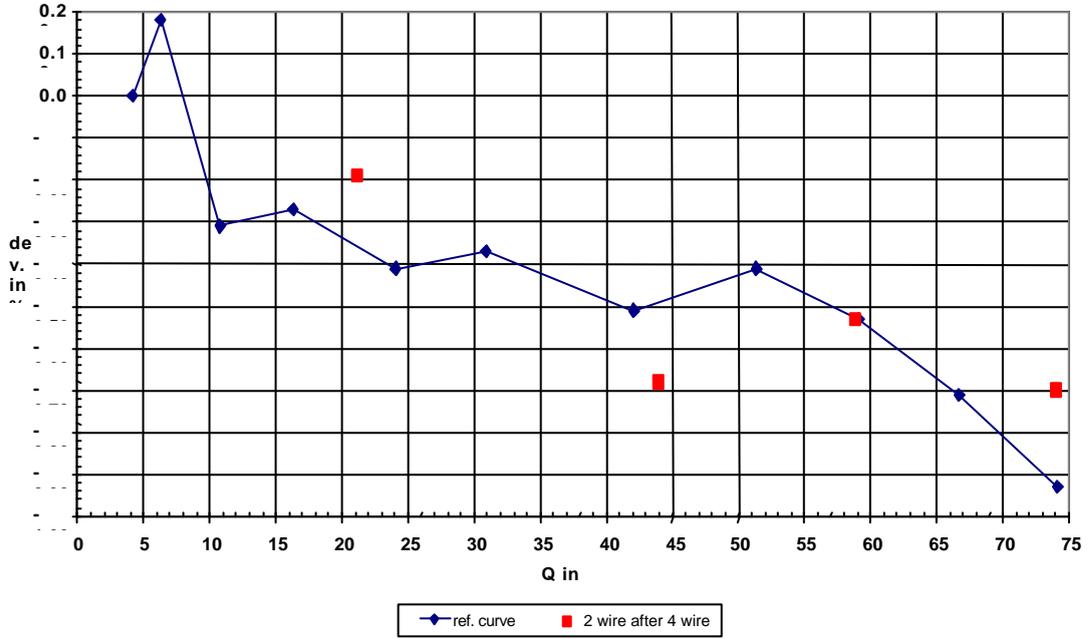
At the time of writing, operating experience with two-wire EMF meters was being collated. This programme is not yet complete but signs are that experience is highly favourable.



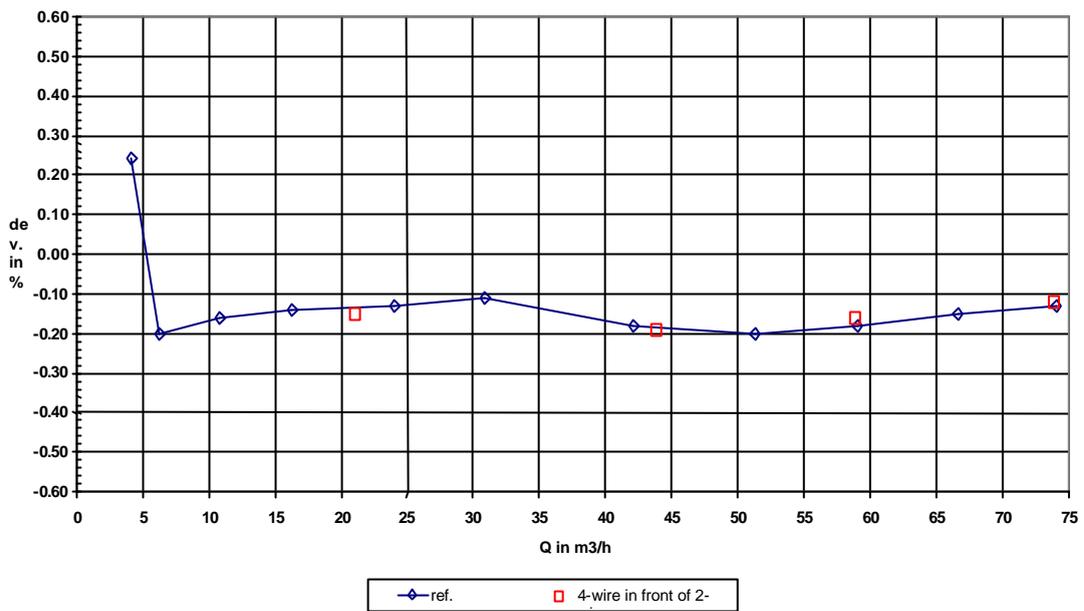


Test set-up for flow profile measurements

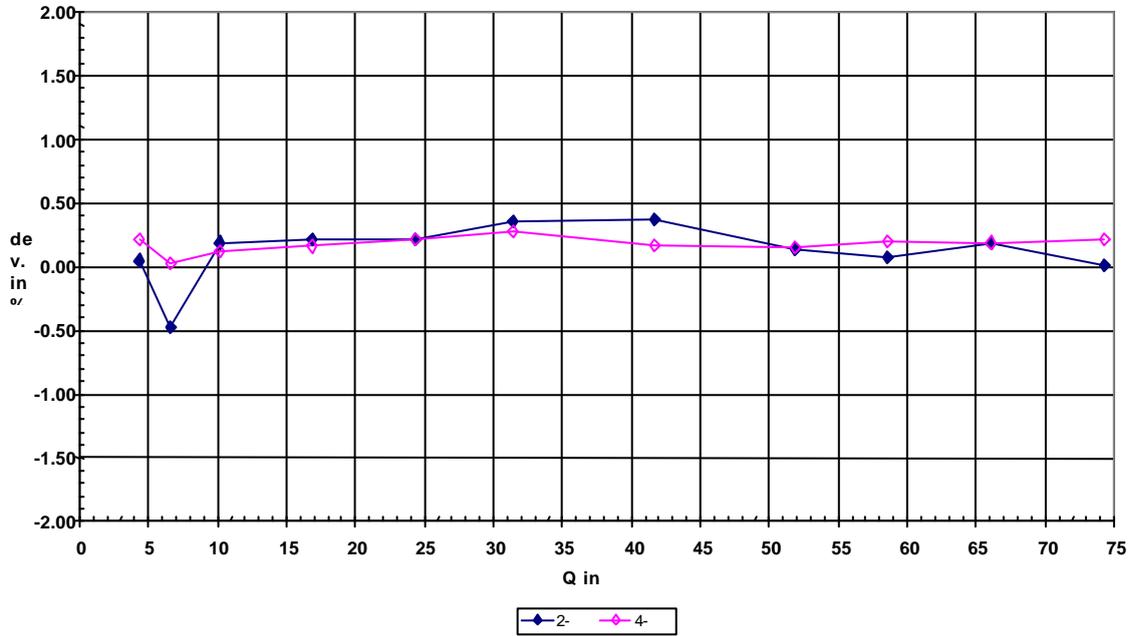
Comparison of 2-wire versus 4-wire
 Make: ABB
 Effect of position of 2-wire meter in the test set-up; water



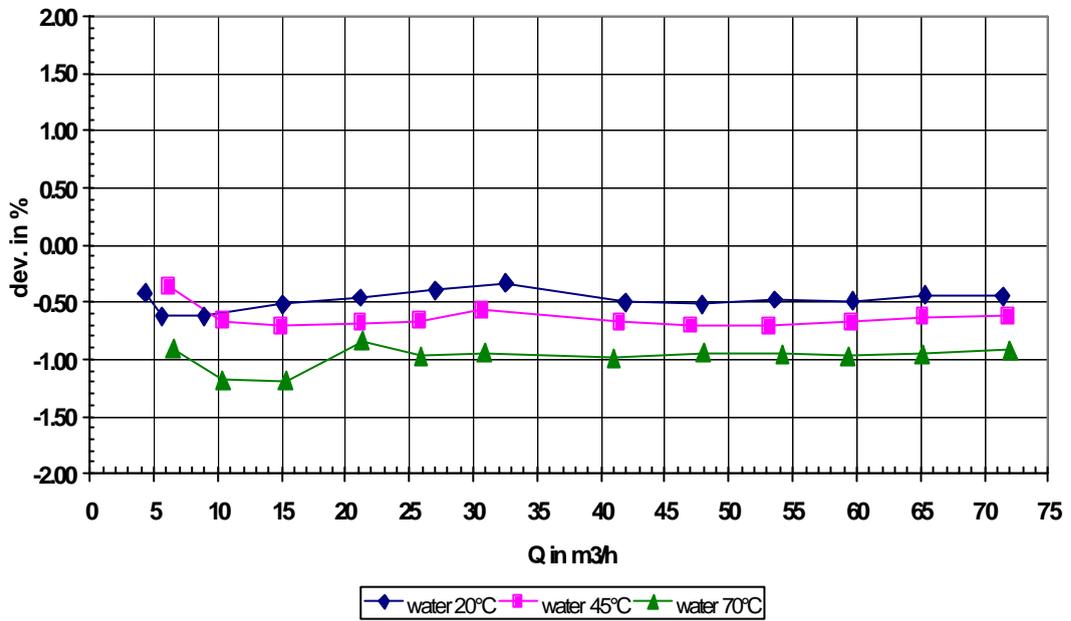
Comparison 2 wire versus 4 wire EMF
 Make: ABB
 Influence of position of the 4-wire in the test set-up; water 20°C,



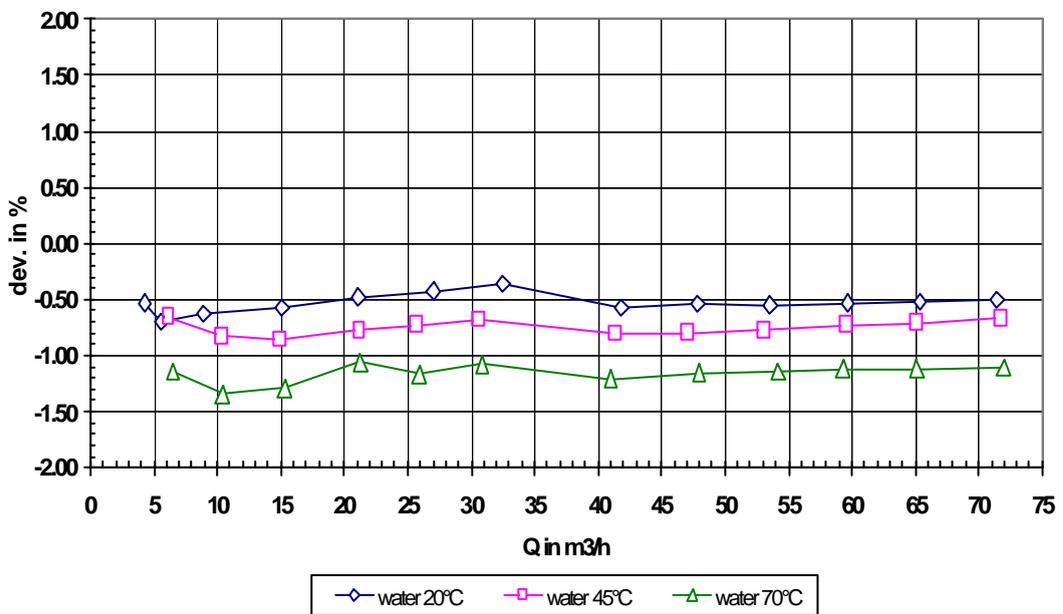
Comparison 2 wire versus 4 wire EMF
Make: E+H
Reference curve, water 20°C, 500uS/cm



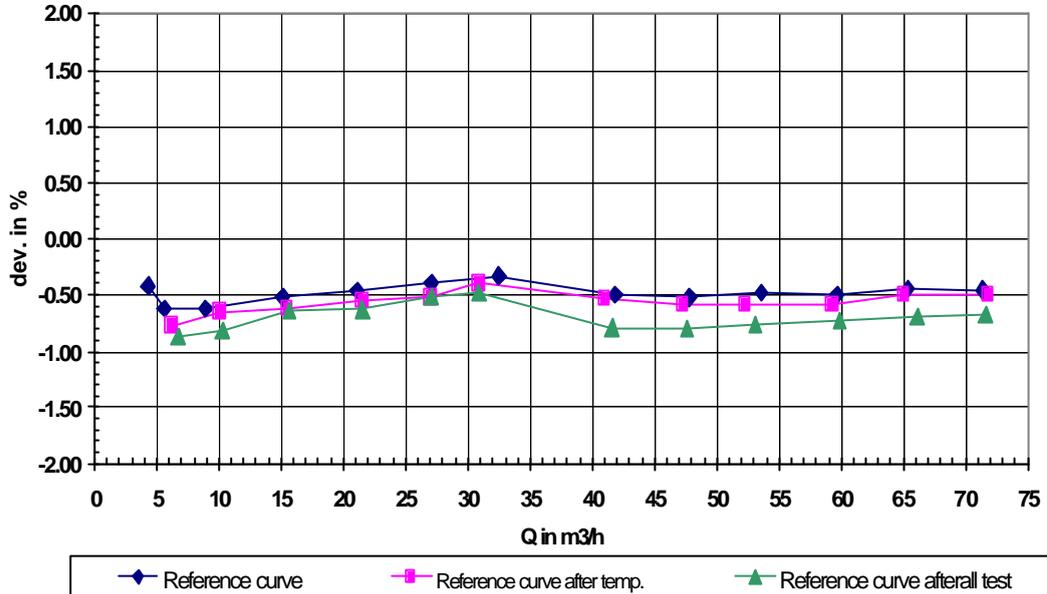
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: Krohne 2 wire
 Influence of temperature, 500uS/cm



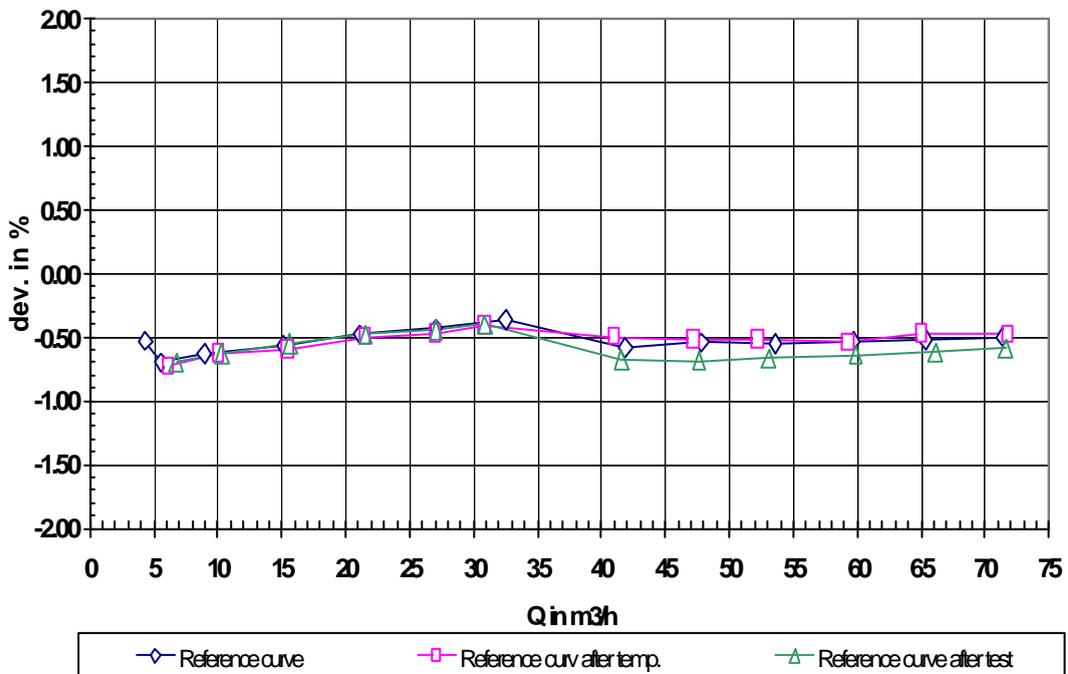
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: Krohne 4 wire
 Influence of temperature, 500uS/cm



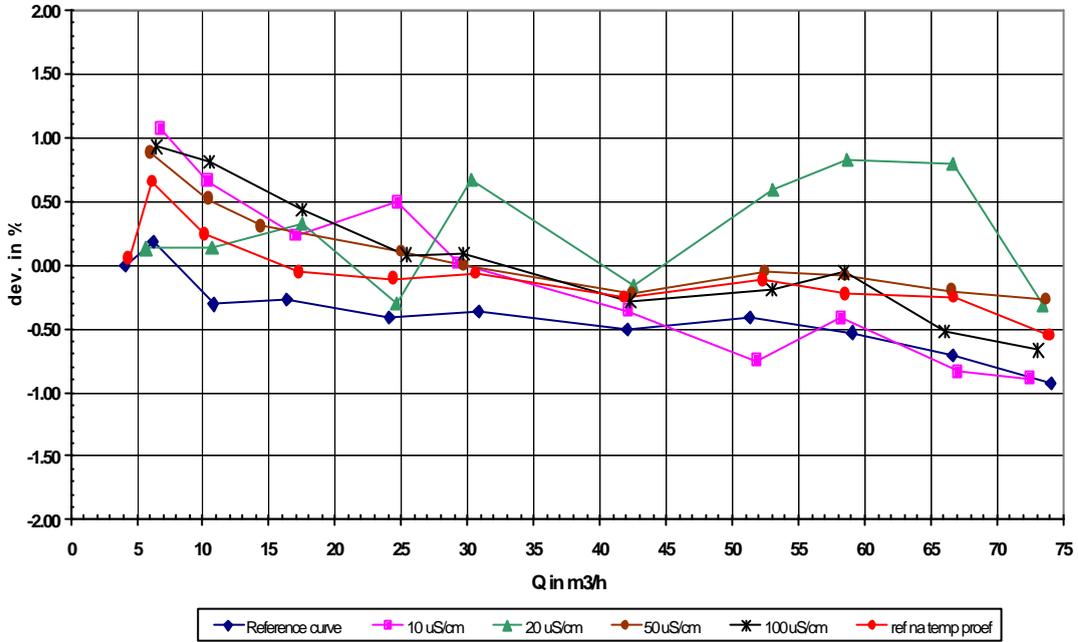
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: Krohne 2 wire
 Repeated reference curves; 500 μ S/cm; 20°C



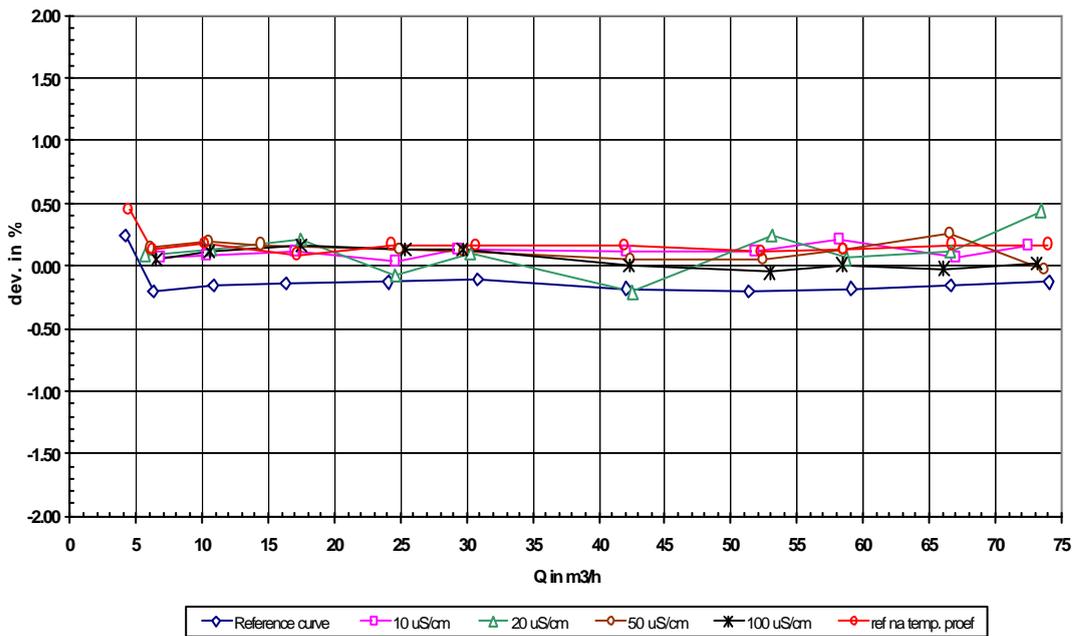
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 Manufacture: Krohne 4 wire
 repeated reference curves; 500 μ S/cm; 20°C



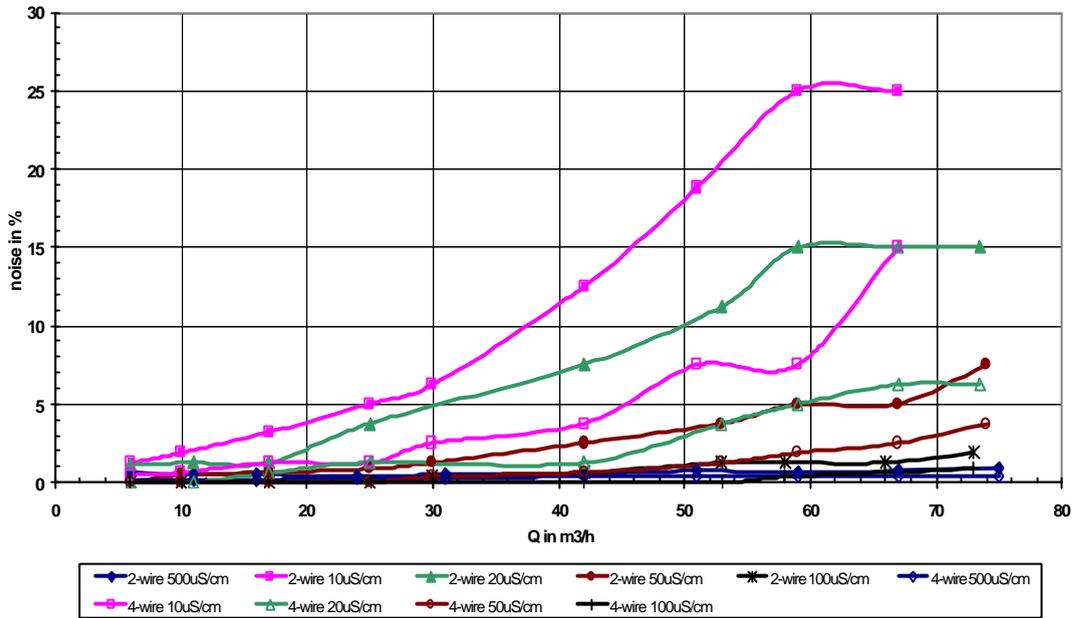
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: ABB 2 wire
 Influence of conductivity,



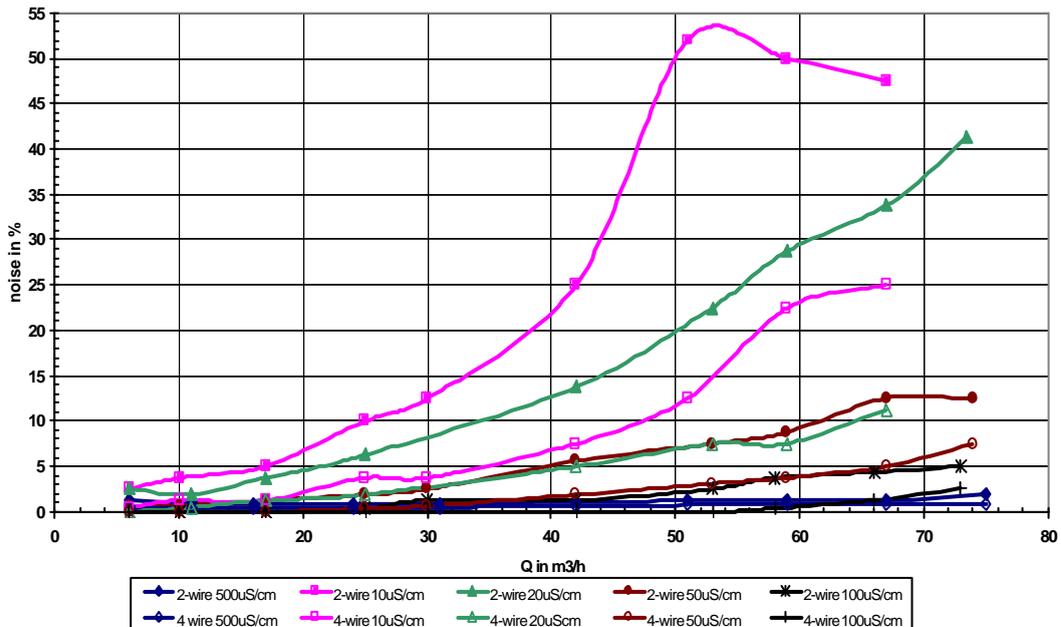
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: ABB 4 wire
 Influence of conductivity

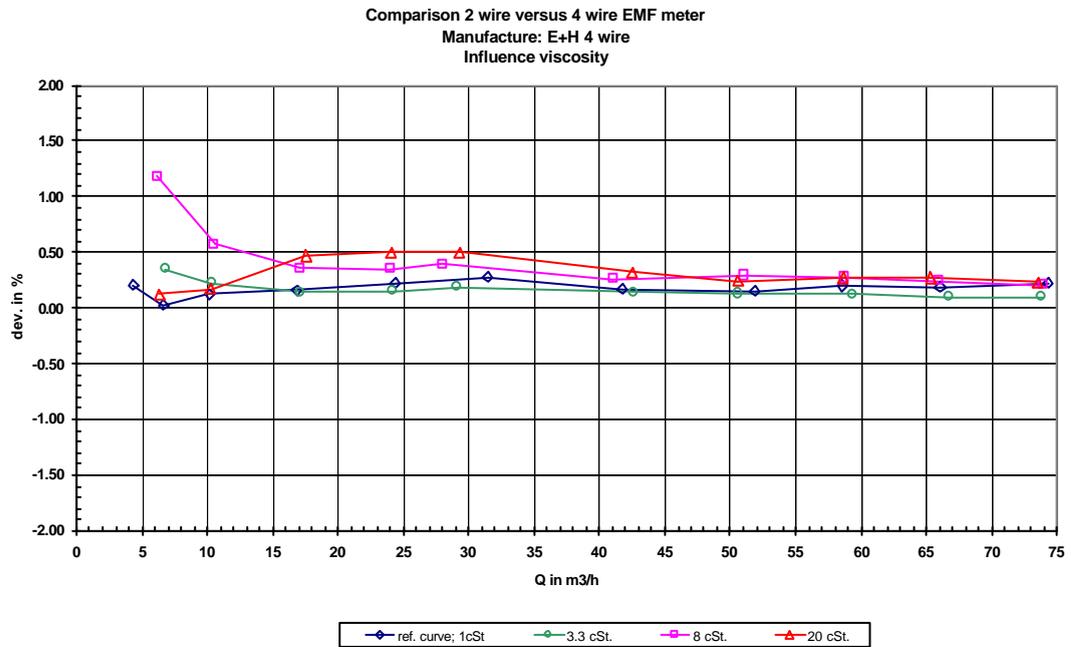
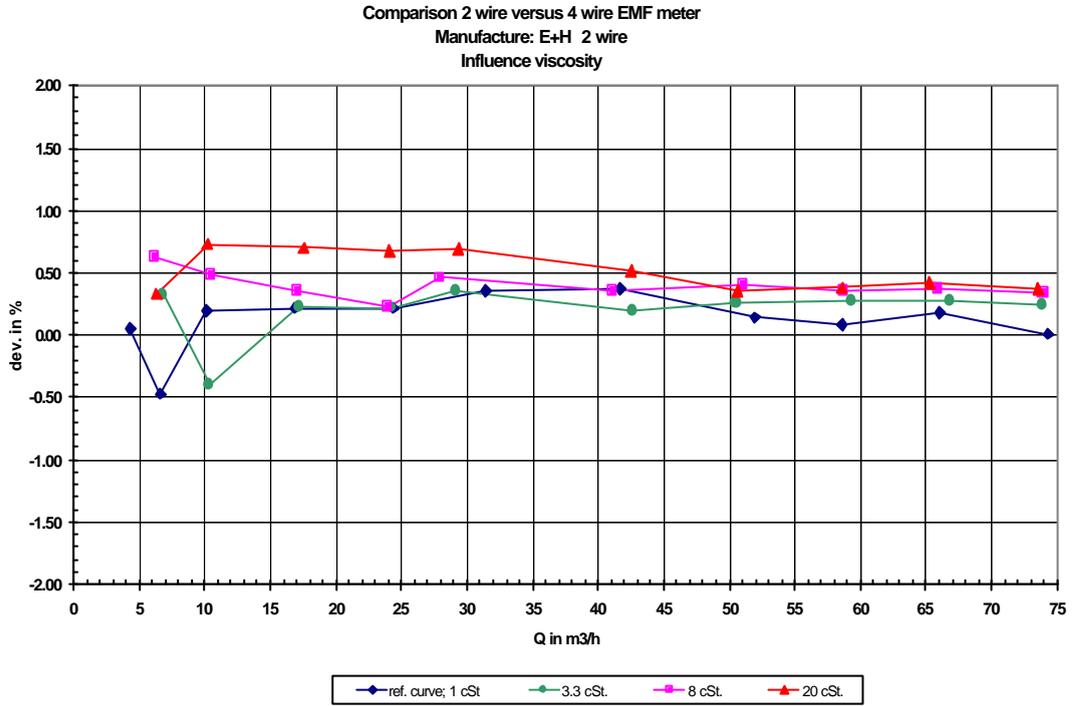


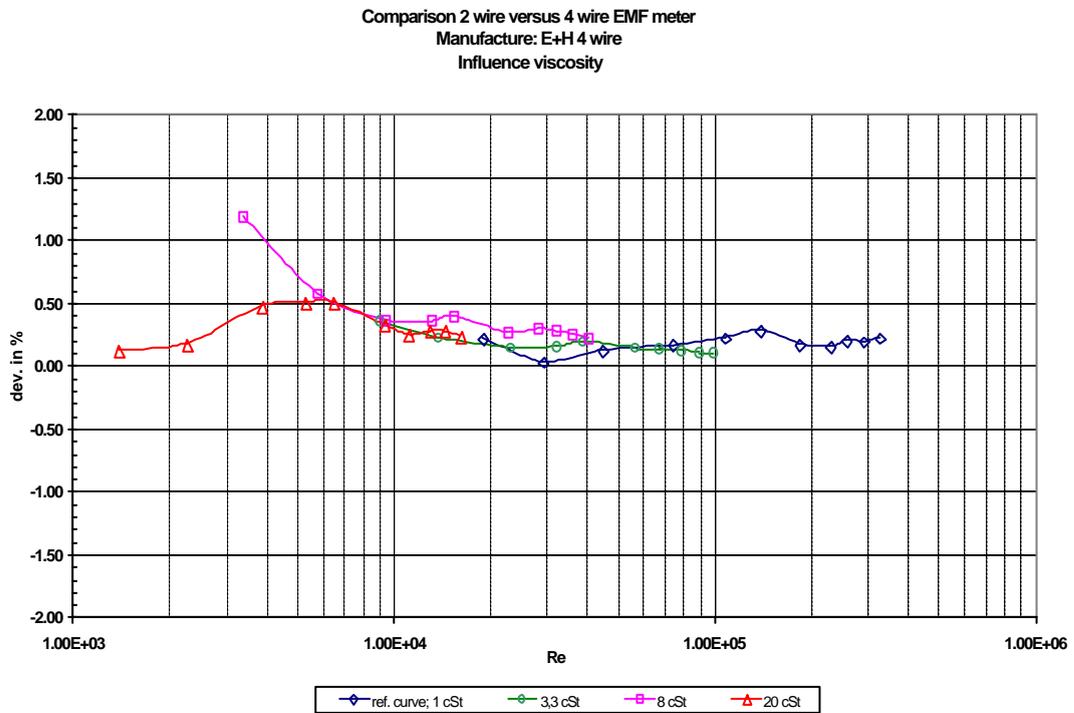
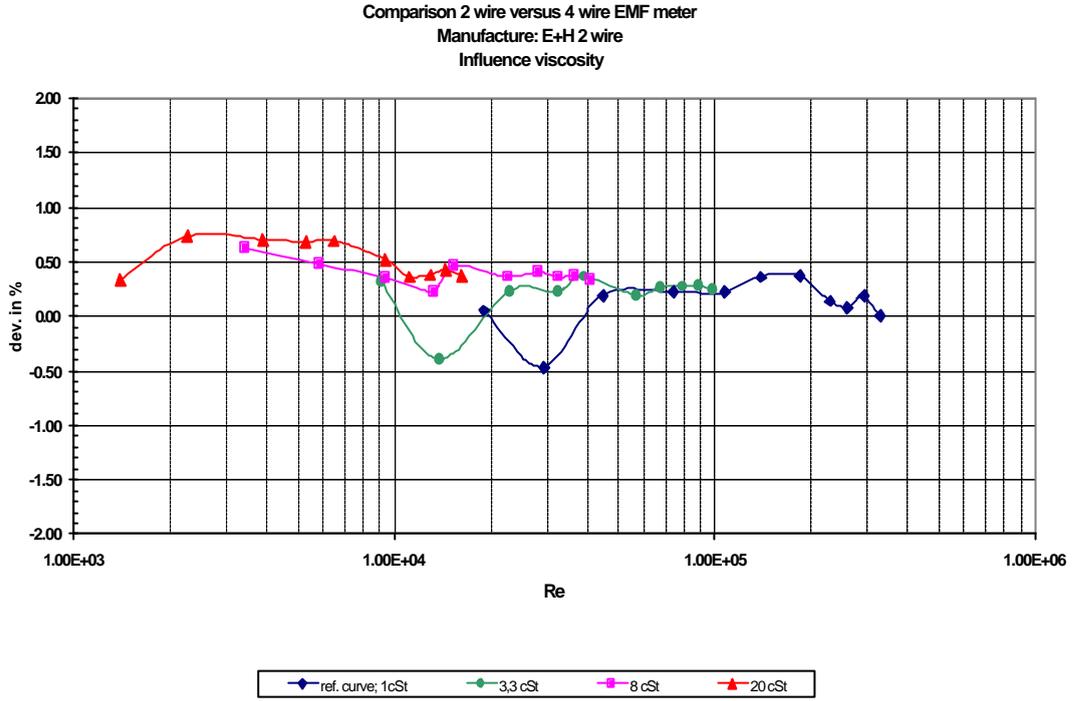
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: ABB 2 and 4 wire
 periodic part on the analog output; time constant 1 sec.



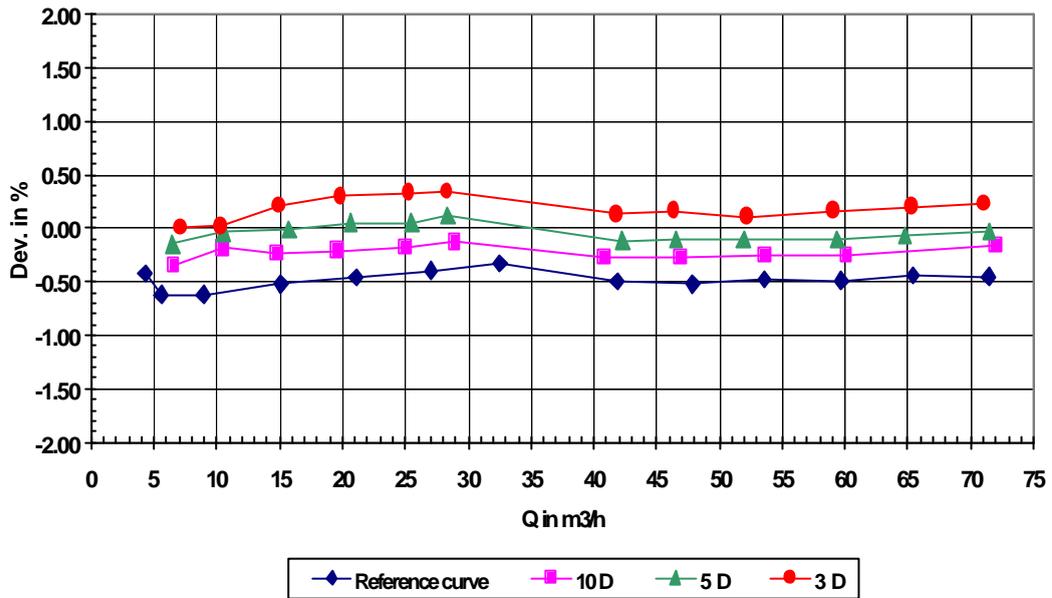
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: ABB 2 and 4 wire
 noise p-p on the analog output; time constant: 1 sec.



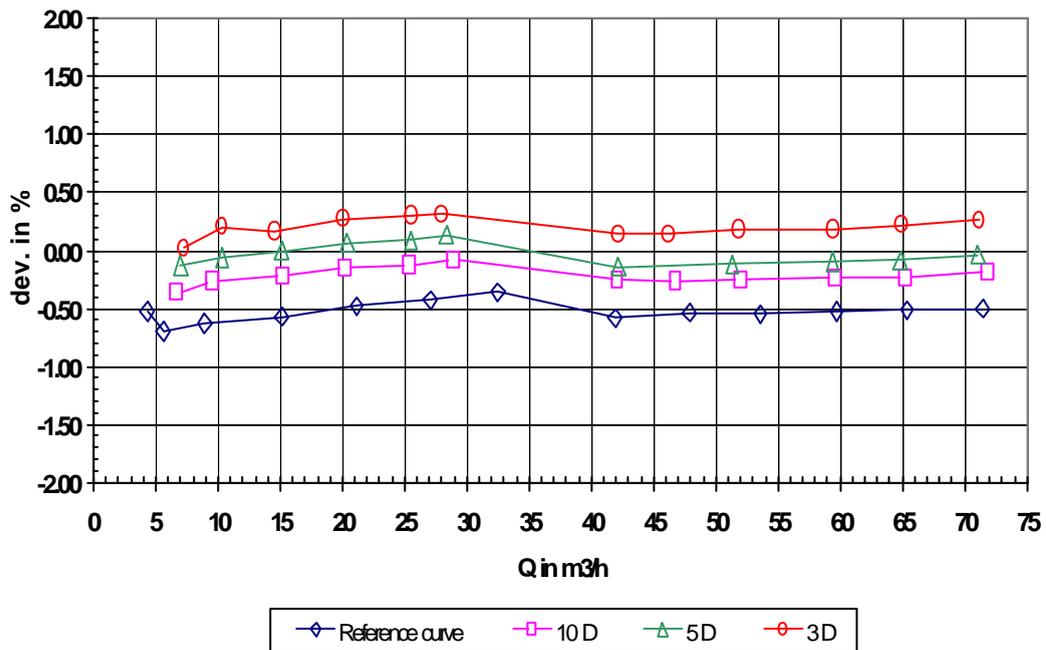




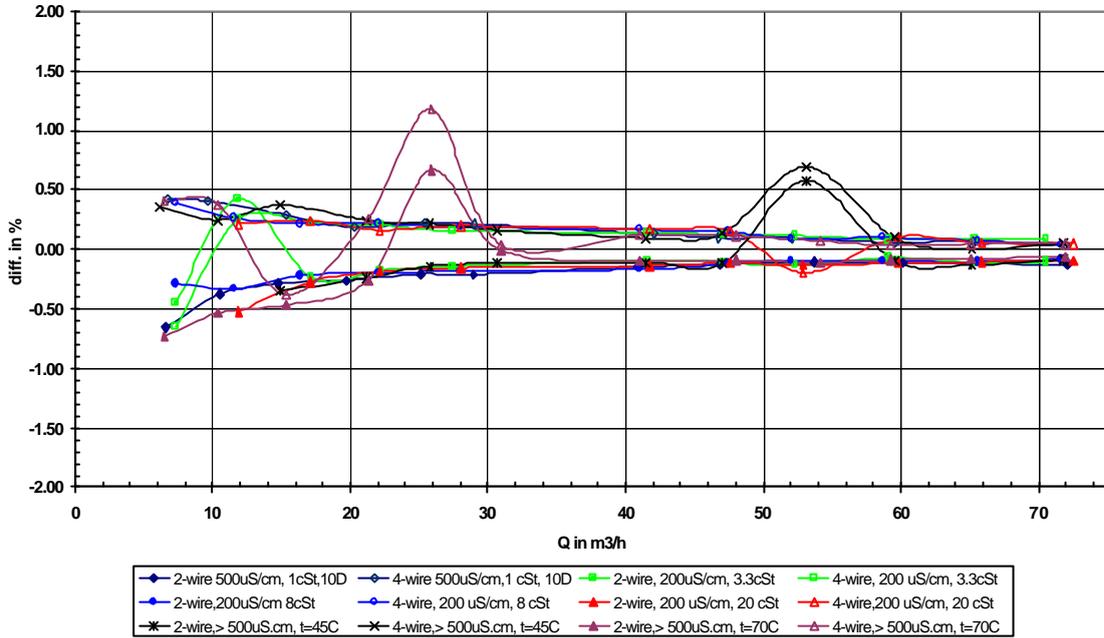
Comparison 2 wire versus 4 wire EMF meter
 Manufacture: Krohne 2 wire
 90° single bend



Comparison 2 wire versus 4 wire EMF meter
 Manufacture: Krohne 4 wire
 90° single bend



Comparison 2 wire versus 4 wire EMF meter
 Manufacture: Krohne-Altometer; 2 and 4 wire
 analog versus puls output



Comparison 2 wire versus 4 wire EMF meter
 Manufacture: ABB 2 wire
 analog versus puls output

