

TEMPERATURE AND INSTALLATION EFFECTS ON SMALL COMMERCIAL ULTRASONIC FLOW METERS

Carl Carlander and Jerker Delsing

Division of Electronic Engineering
Luleå University of Technology, Luleå, Sweden

Abstract: Experimental work has been performed on a selection of small ultrasonic flow meters for water. This work was accomplished in order to investigate the influence of temperature and flow profile disturbances on the performance of flow meters in district heating applications.

The flow meters tested were all ultrasonic flow meters of sing-around type. The selection of flow meters contains in total seven meters of three different brands. All meters have a flow range from $0.015 \text{ m}^3/\text{h}$ to $1.5 \text{ m}^3/\text{h}$. These meters are commonly used in heat meters in small district heating subscriber stations. The flow meters are presented without identification.

All tests were performed in a flow meter calibration facility and in a flow range including the minimum and maximum flow of each flow meter. In the tests three different water temperatures and three different installations were investigated. Water temperatures of 20°C , 50°C and 70°C were used. These temperatures are representative for district heating applications. The installations tested involved flow meters mounted with long straight pipes both up- and down-stream representing ideal conditions, a single elbow and a double elbow out of plane both generating disturbed flow profiles. All set-ups are in accordance with the flow meter specifications.

The results demonstrate that both the change in temperature and the disturbed flow profiles introduce errors in the flow measurements. The change from 20°C to 50°C and 70°C can cause a shift in meter performance larger than the specified maximum permissible error. Compared with the ideal installation the installations generating disturbed flow profiles cause errors up to more than 2 %. The errors due to temperature and installation effects have a bias to add when combined. This might lead to even larger errors.

Keywords: ultrasonic flow meter temperature installation effects district heating

1 INTRODUCTION

A project concerning measurement quality assurance in district heating systems is in progress at Luleå University of Technology. The district heating industry desires accurate heat measurements. The flow measurement involved can be affected by different installation effects. Both temperature and flow profile disturbances might influence the flow measurement. In order to investigate the magnitude of this influence on the flow meter performance experimental work concerning temperature and flow profile disturbances has been performed on a selection of seven ultrasonic flow meters for water. The flow range of these meters stretches from $0.015 \text{ m}^3/\text{h}$ to $1.5 \text{ m}^3/\text{h}$. This meter type is commonly used in heat metering in small district heating subscriber stations. The flow meters are presented without identification.

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There is a large amount of literature about ultrasonic flow meters. However, most of the literature deals with other aspects than the performance of commercial flow meters under realistic conditions. In 1986 Højholt [1] and in 1989 Heritage [2] reported work on larger single- and double-beam flow meters with internal diameters of 159 mm and 100 mm. Large errors up to more than 10 % were reported due to different installation effects. The meters tested here are more up to date and much smaller than the meters tested by Højholt and Heritage.

2 FLOW METERS

The seven tested flow meters are all small ultrasonic flow meters designed for district heating applications. The tests were performed in a test facility at Luleå University of Technology. Prior to these tests five of the flow meters were tested in another test facility at an accredited laboratory. This makes it possible to make conclusions about the absolute performance of the flow meters and the test facility in Luleå.

2.1 Flow meter specifications

Seven ultrasonic flow meters of three different brands have been tested. They are denoted meter 1 to 7 without any further identification.

Meter 1, 2 and 3 are of the same model and brand. Meter 1 and 2 have 3/4 inch connections while meter 3 have 1 inch connections. Except for the inlets the three meters are the same. In the European Heat meter standard EN 1434 [3] flow meters are divided into three different accuracy classes, class 1, class 2 and class 3, where class 1 meters have the highest accuracy. Meter 1, 2 and 3 are class 2 flow meters.

Meter 4, 5 and 6 are of the same model and brand. All three meters are identical and belongs in class 2. Meter 7 is the only class 3 meter in the test.

The maximum permissible error (MPE) of a class 2 flow meter is according to the European Heat meter standard EN 1434 [3] expressed as in equation 1.

$$E_2 = \pm \left(2 + \frac{0.02 q_p}{q} \right) , \text{ but not more than } \pm 5\% \quad (1)$$

E_2 is the class 2 MPE as a function of the flow rate q . The permanent flow rate of the flow meter is termed q_p . For a class 3 meter the MPE, E_3 in equation 2, is extended to:

$$E_3 = \pm \left(3 + \frac{0.05 q_p}{q} \right) , \text{ but not more than } \pm 5\% \quad (2)$$

All meters deliver pulsed outputs where each pulse represents a specified fixed volume passing through the meter. This volume differs between the three brands.

The specified fluid temperature range of the flow meters varies with brand but the temperatures tested are all covered by these different temperature ranges.

All flow meters have the same specified limits of the flow rate. The different limits are specified in EN 1434 [3]. The upper limit q_s is the highest flow rate at which the flow meter shall function for short periods without the maximum permissible error being exceeded. The permanent flow rate range q_p is the highest flow rate at which the meter shall function continuously without the MPE being exceeded. The lower limit q_i is the lowest flow rate above which the meter shall function without the MPE being exceeded. These limits are the same for all tested flow meters.

- q_s , 3 m³/h or 0.83 l/s
- q_p , 1.5 m³/h or 0.42 l/s
- q_i , 0.015 m³/h or 0.0042 l/s

The different manufacturers have chosen different geometric designs and placement of the transducers. All geometric designs are rather complex and restrict the fluid flow through the meters. Meter 4, 5, 6, and 7 are also equipped with simple flow conditioners at the inlet and outlet, probably to reduce the influence of swirling flows and perhaps also to generate turbulence.

No straight piping up- or down-stream were required in the mounting specifications of any of the flow meters.

2.2 Previous calibrations

Meter 1, 2, 4, 5, and 6, were together with a meter identical to meter 1 and 2, simultaneously tested at an accredited laboratory three months before the tests presented here were performed. The temperature during those tests varied between 45 °C and 49 °C. These tests were performed at seven different flow rates between q_i and q_p . The measurements were repeated three times. The total pressure drop over the six meters was also measured.

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3 EXPERIMENTS

The tests performed in the flow meter test facility at Luleå University of Technology included different fluid temperatures and installation effects. A study of the pressure drop over the meters was also performed.

3.1 Flow meter test facility

All tests were performed in a flow meter test/calibration facility at Luleå University of Technology. The test facility is based on continuous weighing. This facility is outlined in [4] and [5].

In this facility the flow is generated by a head tank and controlled by control valves. In one of three test runs the tested flow meter is set up. Finally the water is collected in one of three scales and weighed. The use of three scales with different capacities increases the flow range of the test facility. This range is from $0.0007 \text{ m}^3/\text{h}$ or 0.0002 l/s to $40 \text{ m}^3/\text{h}$ or 11 l/s .

The estimated total uncertainty of the test facility with a 95 % confidence is $\pm 0.1 \%$ between q_i and q_s [4]. The facility is not accredited but the agreement with the measurements performed at an accredited lab, described in section 2.2, indicate that the estimated uncertainty is of a proper order. More of this in section 4.1.

3.2 Experimental set-up

All meters were exposed to seven different tests.

- 20 °C, 100 pipe diameters straight piping, 6 repetitions + 2 finishing off repetitions
- 20 °C, single elbow 10 pipe diameters up-stream the flow meter, 6 repetitions
- 20 °C, single elbow closely mounted to flow meter, 6 repetitions
- 20 °C, double elbow 10 pipe diameters up-stream the flow meter, 6 repetitions
- 20 °C, double elbow closely mounted to flow meter, 6 repetitions
- 50 °C, 100 pipe diameters straight piping, 6 repetitions + 2 finishing off repetitions
- 70 °C, 100 pipe diameters straight piping, 2 repetitions

In addition to the tests above meter 1, 4 and 7 were also to exposed one more tests.

- 50 °C, double elbow closely mounted to flow meter, 2 repetitions

All tests were performed at 20 different flow rates from q_i to q_s . Most of the tests were repeated six times but some only two times. The tests were repeated in the manner that all 20 flow rates were measured starting with the lowest. After measuring the highest flow rate the test was repeated again starting with the lowest flow. Each test consists of 120 or 40 measurements.

Each measurement was performed during about 120 s. During this measurement time the pulses from the flow meters were counted. The start and stop of a measurement was triggered by the pulses sent by the flow meter. This way the correct number of pulses was counted. The measurement time was measured by a 1 MHz counter. During the measurement time the test facility also measured the flow rate. Due to meter 7 delivering fewer pulses per litre than the other meters the measurement time had to be longer for this meter during the three smallest flow rates.

The temperature was continuously measured both up- and down-stream the flow meter. At the tests at 20 °C and 50 °C the pressure drop over the flow meters was also measured.

The internal diameter of the piping in front and after the meters was 25.6 mm. Down-stream the meters 50 pipe diameters straight piping was mounted in all tests. The pipe bends used all had a bending radius and pipe diameter ratio $r/D = 1$. The bends of the double elbow were mounted out of plane. The two elbows were spaced 1 pipe diameter. Up-stream both the single elbow and the double elbow 100 pipe diameters of straight piping was mounted to insure a fully developed flow profile before the elbows.

All of the experimental set-ups were in accordance with the flow meter specifications.

4 RESULTS

The results for meter 1, 4 and 7 are presented below. Meter 1 well represents also meter 2 and 3. Meter 4 represents also meter 5 and 6.

Outliers in the readings from the flow meters are removed in the results below. About 0.5 % of the measurements are obvious outliers. These outliers might be caused by the flow meters reading the wrong flow rate or by errors in the pulse detecting system. By using a high speed counter to examine the appearance of the pulse train from the flow meters the reason for the outliers could probably be determined. This has not yet been done but will be the scope for future research.

The results are described as the mean percentage error or the mean relative error. The mean percentage error, err , is calculated as shown in equation 3.

$$err = \frac{100}{N} \left(\sum_{i=1}^N \frac{V_{meas,i} - V_{true,i}}{V_{true,i}} \right), \text{ err in \%} \quad (3)$$

The number of repetitions, N , is 6 or 2. The flow rate measured by the flow meter is denoted V_{meas} and the same flow rate measured by the test facility V_{true} . The calculation of the mean relative error is described in equation 4.

$$relative\ err = \frac{100}{N} \left(\sum_{i=1}^N \frac{V_{meas,i} - V_{ref,i}}{V_{ref,i}} \right), \text{ relative err in \%} \quad (4)$$

The *relative err* is the mean percentage difference between a present test, V_{meas} , and a test performed earlier chosen to be the reference test, V_{ref} . Here this reference test is either the test at 20 °C or at 50 °C with straight piping.

The x-axis of the following plots is the flow rate determined by the test facility. The curved solid lines in the following figures indicate the class 2 MPE or class 3 MPE as stated in equation 1 and 2. The three vertical lines marks the flow limits q_i , q_p and q_s .

4.1 Comparison with previous tests

Meter 1, 2, 4, 5 and 6 were previous to the tests in Luleå also tested at an accredited laboratory. Figure 1 display the mean percentage error with 95 % confidence error bars for the test at 50 °C with straight piping and the previous test results at the accredited laboratory for meter 1. The mean percentage error, err , is calculated as in equation 3 with the six repetitions performed in Luleå and the three repetitions at the accredited laboratory. The error bars include both the repeatability of the meter in each test and the uncertainty of both facilities respectively.

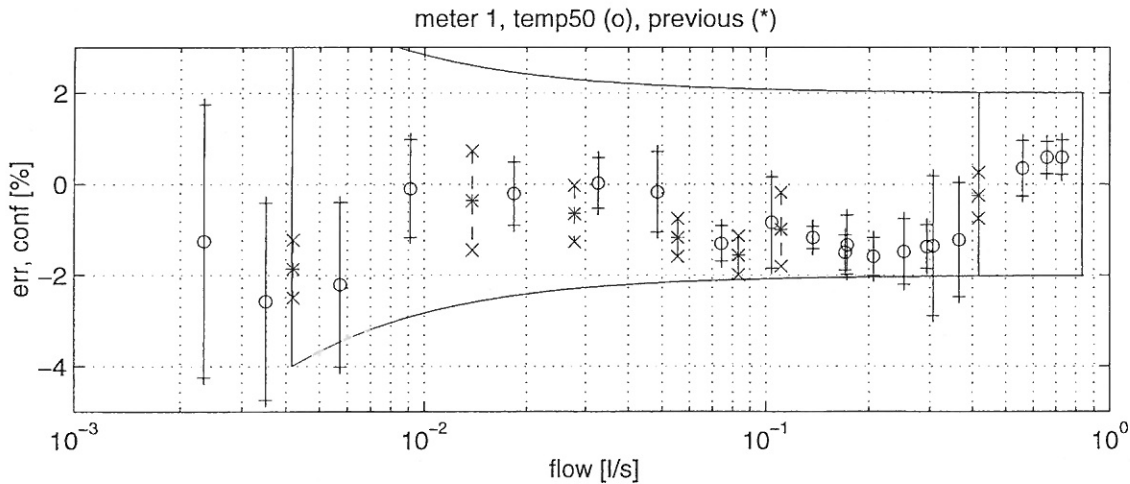


Figure 1: The mean percentage error with 95 % confidence error bars for the 50 °C test and previous test results for meter 1

There is no larger disagreement between the results from the two facilities than what could be expected considering the uncertainties given by the error bars. The results for the other four meters that were tested

in both facilities are similar to that in figure 1. Meter 4 however show a difference between the two facilities at low flow rates. During the tests meter 4 generated reproduceable results. The performance of the meter might have changed slightly after the tests at the accredited laboratory.

The 95 % confidence error bars for meter 1 are representative for all meters and describes the repeatability of the flow meters.

The results from the comparison on the two test facilities show that the absolute errors presented at least can not be proven all wrong. The focus of this paper is however more on the relative change in meter performance due to temperature and installation effects than on the absolute error.

About two months after the start of the first test the second experiment with straight piping at 20 °C and 50 °C finished off the test series for all meters. These results were compared with the same but initializing results to check that the performance of the meters were not changed during the test. The agreement between initializing and finishing off results turned out to be good for all meters.

4.2 Temperature experiments

All meters were tested at 20 °C, 50 °C and 70 °C with straight piping up- and down-stream the meters. In the figures 2, 3 and 4 the mean percentage error is displayed for all temperatures for the tests with meter 1, 4 and 7 with straight piping.

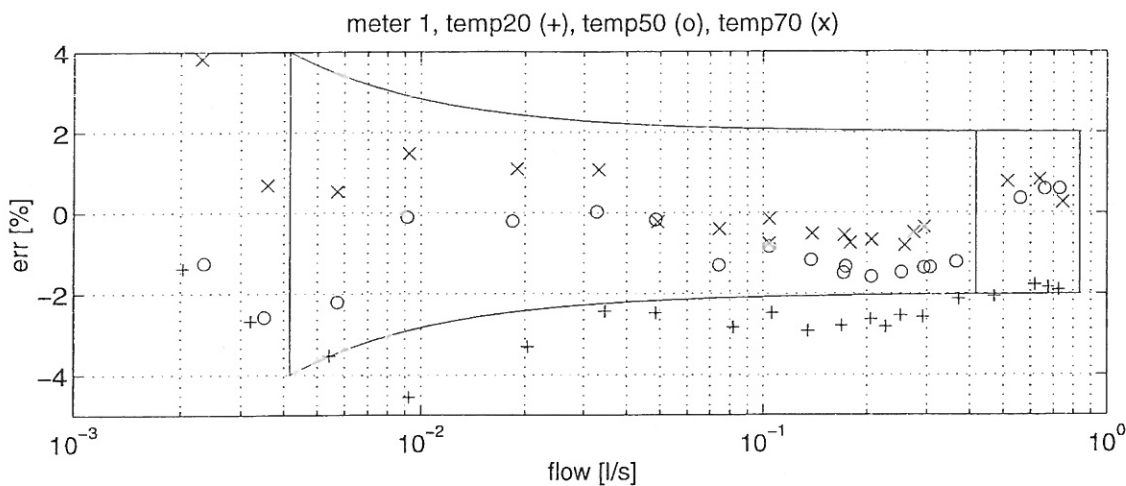


Figure 2: The mean percentage error in the 20 °C, 50 °C and 70 °C tests with the straight piping for meter 1

The errors for meter 1 are organized with negative errors for the 20 °C test, positive errors for the 70 °C test and the errors at 50 °C in between. The magnitude of the difference in the mean error due to the change in temperature corresponds to the MPE of the meter. But since the mean error is plotted many errors of single measurements would be larger than the MPE even if the mean error curves were lifted 1 % to better fit the MPE. The performance of meter 2 and 3 are close to identical with meter 1.

Also the mean errors for meter 4 are organized but in the opposite order compared to meter 1. The difference in the mean error for the three temperatures is now larger than for meter 1 and in the lower flow range the mean errors do not fit the MPE. At q_i the difference between 20 °C and 70 °C is about 20 %. Meter 5 and 6 performs a little better than meter 4 and the differences of the mean errors are just outside the MPE limits at low flow rates.

The errors for meter 7 are more random. The mean errors are not lined up for the different temperatures as in the case with meter 1 and 4. All mean errors are well inside the class 3 MAP limits.

4.3 Installation effect experiments

All meters were also tested with straight piping, the single elbow and the double elbow at 20 °C. In the figures 5, 6 and 7 the mean relative percentage error, *relative err*, is displayed for all installations for the tests with meter 1, 4 and 7 at 20 °C. The mean relative error is calculated as in equation 4 with the test at 20 °C with straight piping for each meter as the reference. The relative error for the straight piping test in the following figures will equal zero as a result of those tests being compared with themselves.

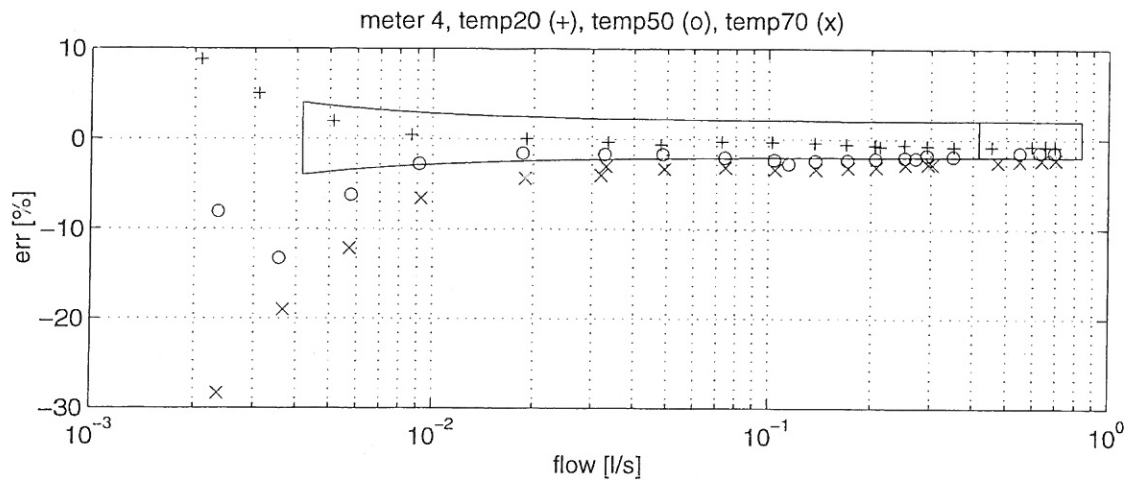


Figure 3: The mean percentage error in the 20 °C, 50 °C and 70 °C tests with the straight piping for meter 4

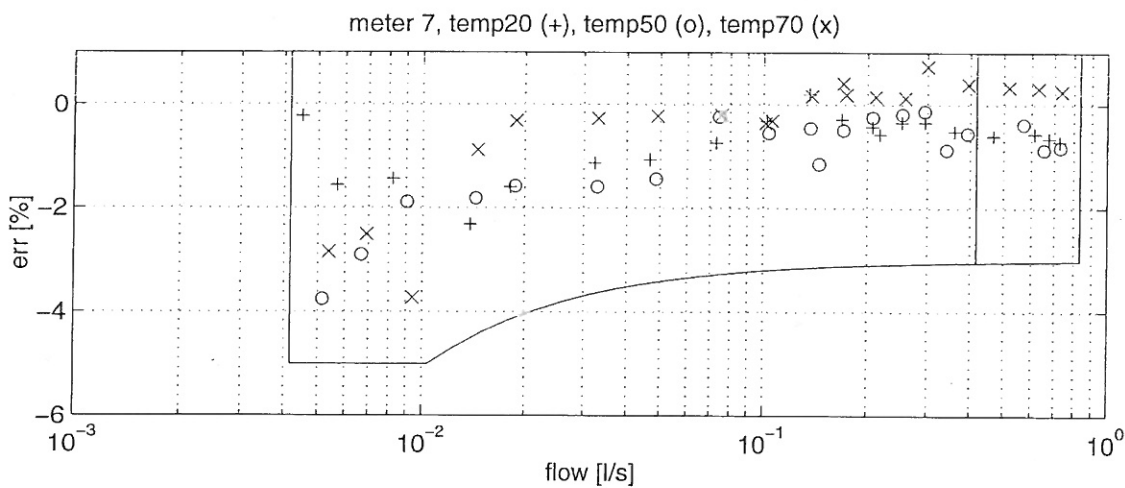


Figure 4: The mean percentage error in the 20 °C, 50 °C and 70 °C tests with the straight piping for meter 7

Since no straight piping up- or down-stream the meters were required in the mounting specifications of the meters the effects presented below originates from the experiment where the elbows were closely mounted to the meters.

The errors due to the single elbow mounted up-stream meter 1 are all positive with a magnitude up to more than 1 %. The double elbow causes both positive and negative errors with a magnitude of more than 2 %.

The installation of the elbows in front of meter 4 generated mostly positive errors but also negative errors at low flow rates. The magnitude of these errors were as most 2 %.

In the tests with meter 7 the elbow caused only negative errors with a maximum magnitude of 2 %.

When the elbows are mounted 10 pipe diameters up-stream instead of close to the flow meter the effect decrease slightly as could be expected.

4.4 Combined experiments

In order to investigate the result of a combination of both temperature and installation effects the double elbow test was performed at both 20 °C and 50 °C.

If studying the relative error between the test with the straight piping and the test with the double elbow at both 20 °C and 50 °C the effect of the double elbow can be isolated for both temperatures. In figure 8 these two relative errors are displayed for meter 1. The '+'s in figure 8 are identical with the 'x's in figure 5.

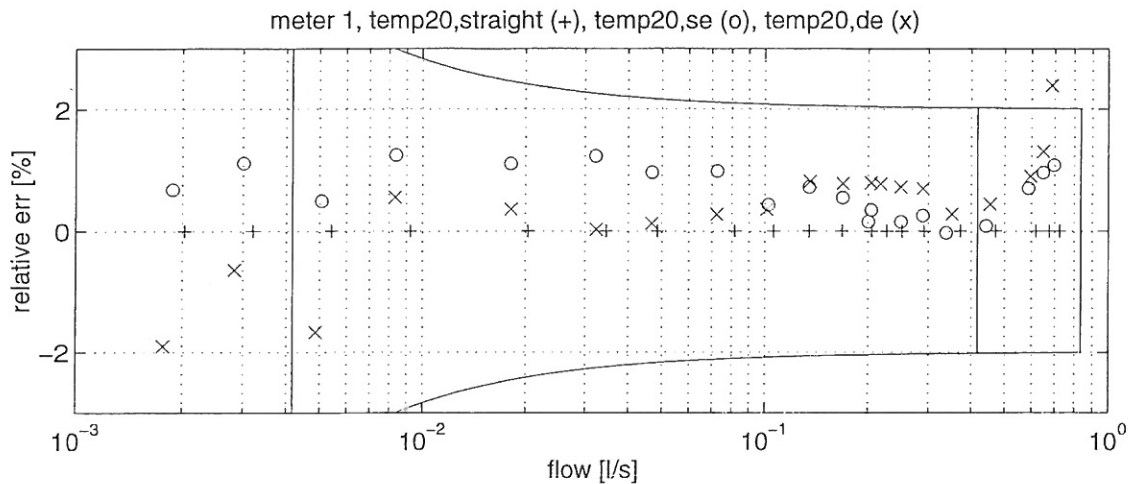


Figure 5: The relative mean percentage error in the tests with the straight piping, the single elbow and the double elbow at 20 °C for meter 1. The errors are relative to the errors in the test with straight piping at 20 °C.

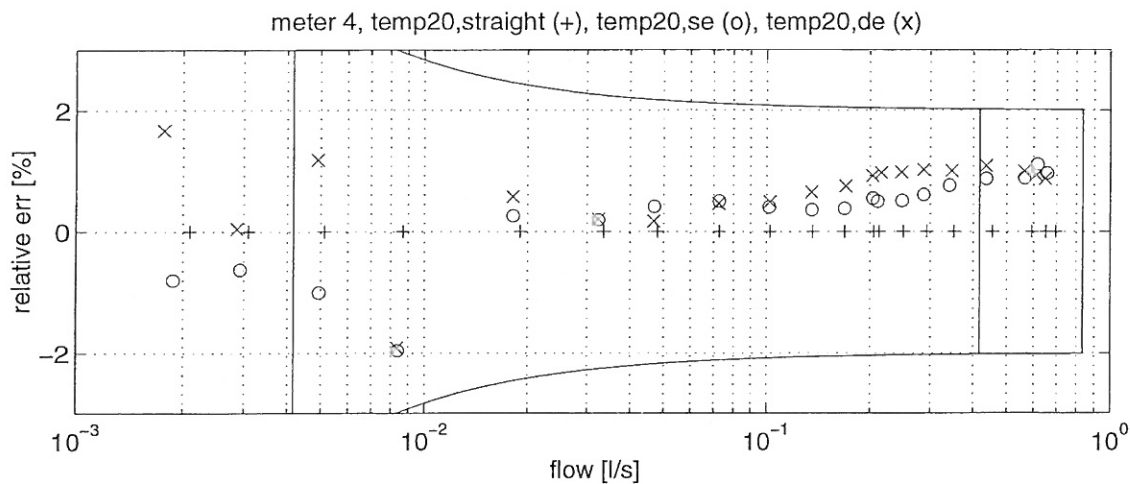


Figure 6: The relative mean percentage error in the tests with the straight piping, the single elbow and the double elbow at 20 °C for meter 4. The errors are relative to the errors in the test with straight piping at 20 °C.

If the error due to the temperature change and the error resulting from the double elbow were not correlated one would expect the '+'s and the 'o's in figure 8 to agree. However, they do not.

The temperature of the fluid influence both the viscosity and the density as well as the speed of sound. This might be the reason for the disagreement in figure 8.

In figure 9 the relative errors are plotted with Reynolds number. The influence of temperature on both the viscosity and the density have been compensated for when calculating Reynolds number.

The agreement is now better. The differences are small compared to the repeatability of meter 1. The effects of the installation appear to be additive to the effects of the change in temperature. The results for the other meters are similar to the results for meter 1. The results for meter 7 presented in figure 10 are thus not similar to the results for meter 1 and 4. The double elbow at 20 °C generates negative errors compared to the straight piping while the double elbow at 50 °C causes mainly positive errors. For Reynolds numbers higher than 20 000 the agreement is however comparable to the results for meter 1 and 4.

The internal diameter of the flow meters could not be measured due to the complex geometric design. For all meters the diameter is estimated to 10 mm. Reynolds number might, because of the uncertainty in the diameters, be affected with large errors. For each meter this error is however always the same.

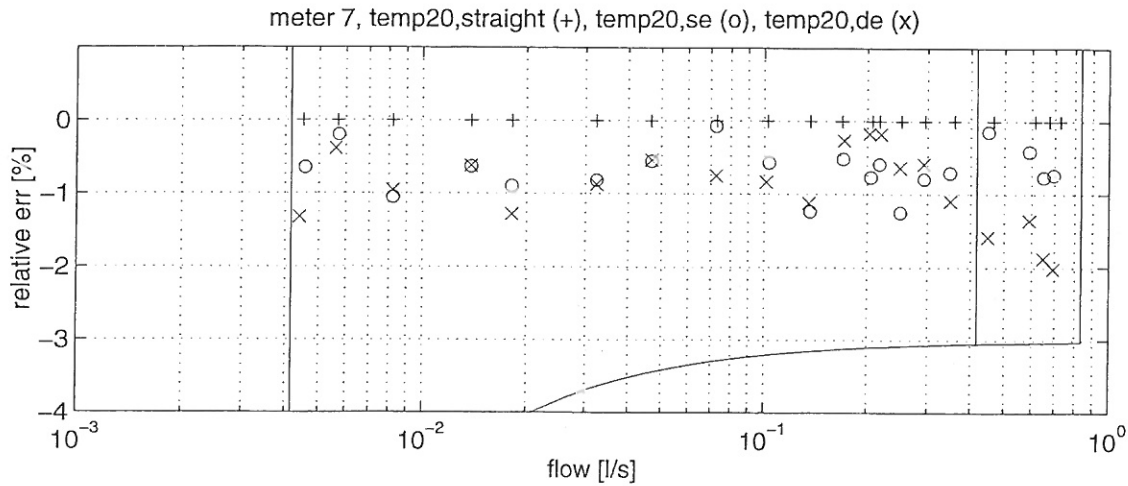


Figure 7: The relative mean percentage error in the tests with the straight piping, the single elbow and the double elbow at 20 °C for meter 7. The errors are relative to the errors in the test with straight piping at 20 °C.

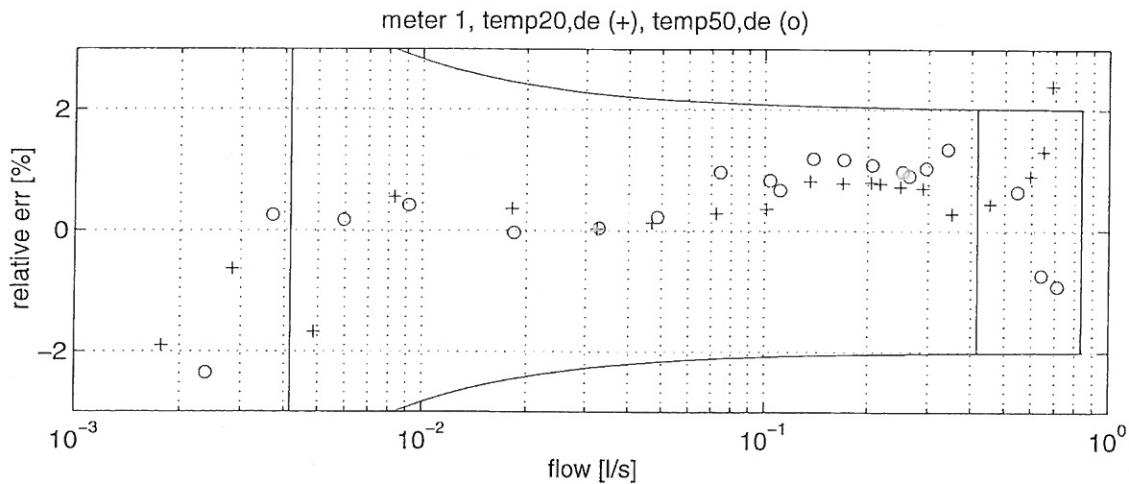


Figure 8: The mean percentage error in the tests with the double elbow at 20 °C, relative to the test with straight piping at 20 °C, and the mean percentage error in the tests with the double elbow at 50 °C, relative to the test with straight piping at 50 °C for meter 1.

4.5 Pressure drop

The maximum allowed pressure drop is specified in EN 1434 [3]. At q_p the pressure drop shall not exceed 0.25 bar.

The pressure drop was measured for all meters at 20 °C and 50 °C. In figure 11 the pressure drop at 20 °C for meter 1, 4 and 7 is shown.

The solid vertical lines indicate q_i , q_p and q_s . The solid horizontal line marks the maximum allowed pressure drop at 0.25 bar.

At q_p the pressure drop is just under the 0.25 bar limit. For meter 4 the pressure drop might be just over that limit. The pressure drop at 50 °C is slightly smaller than at 20 °C and agrees well with the measurements at the accredited laboratory.

5 DISCUSSION

The agreement between the two test facilities described in section 2.2 show that the absolute errors presented are relevant. Nevertheless the relative error as a result of changes in temperature and installation effects is

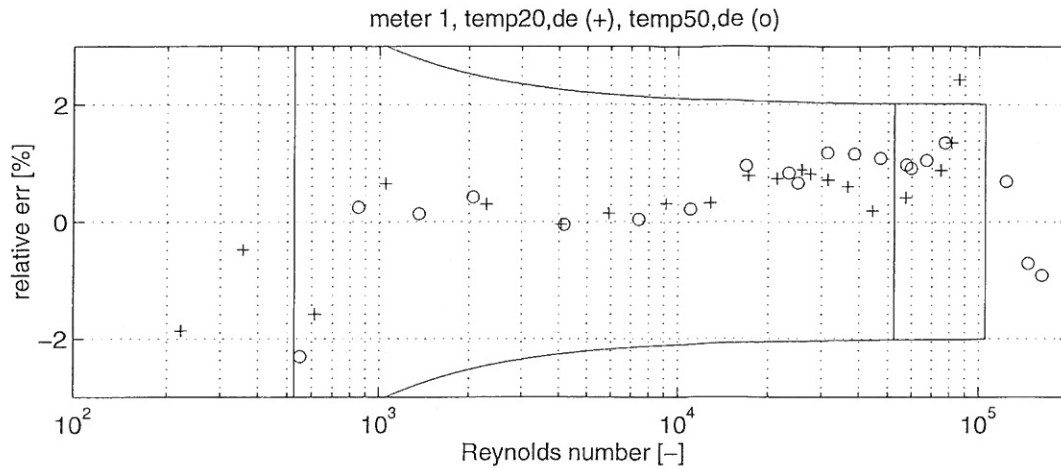


Figure 9: The mean percentage error in the tests with the double elbow at 20 °C, relative to the test with straight piping at 20 °C, and the mean percentage error in the tests with the double elbow at 50 °C, relative to the test with straight piping at 50 °C for meter 1.

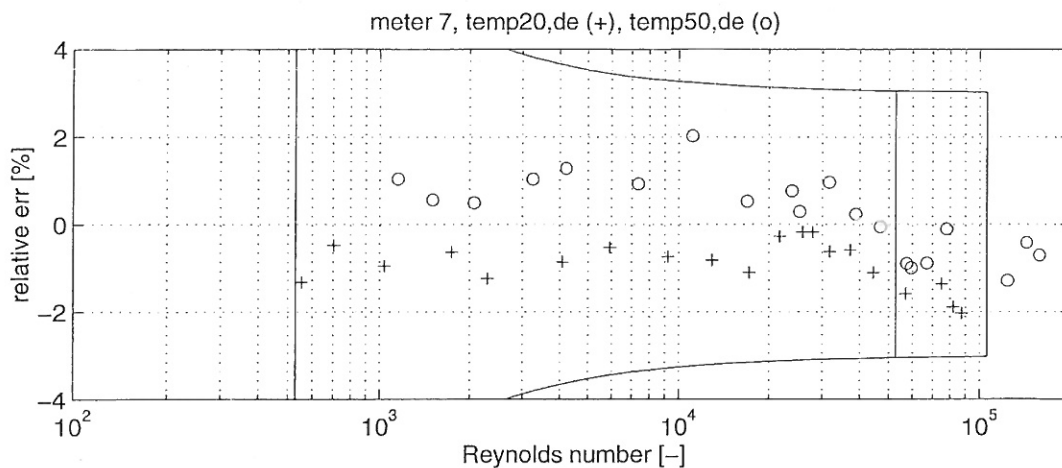


Figure 10: The mean percentage error in the tests with the double elbow at 20 °C, relative to the test with straight piping at 20 °C, and the mean percentage error in the tests with the double elbow at 50 °C, relative to the test with straight piping at 50 °C for meter 7.

the main focus.

The change in meter performance caused by switching the water temperature from 20 °C to 50 °C and 70 °C was for all meters, except meter 7, larger than the maximum permissible error. Meter 7 is the only class 3 meter in the test. It appears as the temperature is the main difficulty for the meters in the test. The way the meters compensates for different temperature effects is not known.

Also the installation effects affect the accuracy of the meters. Compared to the tests with straight piping up-stream the meters the single and double elbow generates both positive and negative errors with a magnitude up to more than 2 %. The errors decreased some when 10 pipe diameters of straight piping was mounted between the elbows and the meters. The errors due to installation effects are smaller in the tests presented in this paper than for example in Højholt's [1] and Heritage's [2] results. The main explanation for the smaller errors is probably the larger sound beam to pipe diameter of the small flow meters tested here compared to the large meters tested by Højholt and Heritage. Also the more complex geometric design of the smaller meters described in this paper together with the flow conditioners could have helped to reduce the errors.

If correcting for the change in viscosity and density as in section 4.4 when the water temperature is changed the errors resulting from temperature changes and installation effects seem to add when combined. This could lead to even larger errors.

As can be seen in section 4.5 the pressure drops measured over the flow meters are all rather high. At q_p

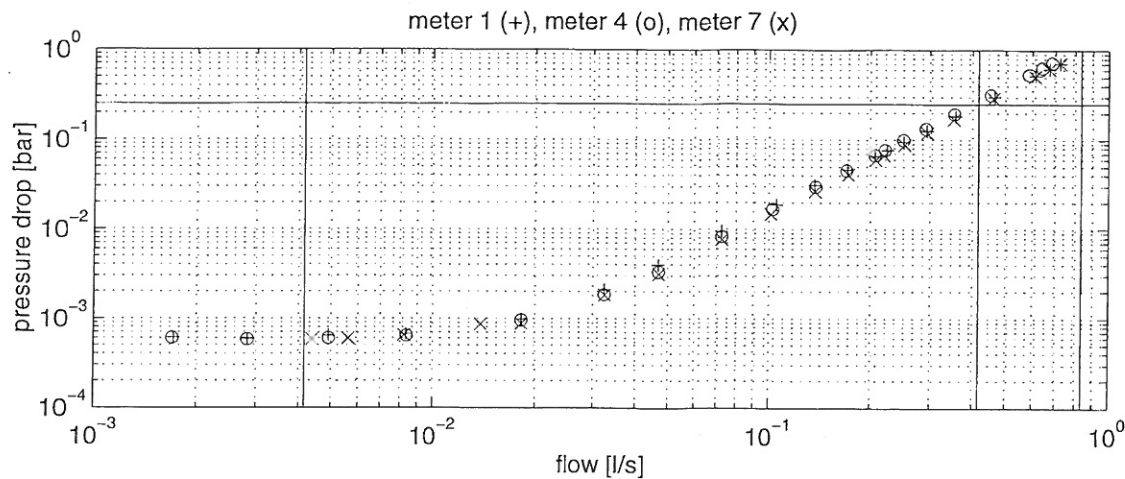


Figure 11: The mean pressure drop at the 20 °C test for meter 1, 4 and 7

all meters are close to or just over the 0.25 bar limit.

Meter 7 was the only class 3 meter in the test. It was also the only meter which performance matched the specifications. The performance of the six class 2 meters is more in the order of class 3 meters. Perhaps some restrictions would be appropriate in the meter specifications about up-stream disturbances.

Acknowledgement

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Authors

Carl Carlander and Prof. Jerker Delsing,
 Division of Industrial Electronics, Luleå University of Technology, SE-971 87 Luleå, Sweden,
 phone: +46 920 917 29, +46 920 918 98
 E-mail: carl.carlander@sm.luth.se, jerker.delsing@sm.luth.se