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An Investigation into Heat Meter Measurement Errors
Final Report

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An Investigation into Heat Meter Measurement Errors

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Executive Summary

A series of inspections of Non-Domestic Renewable Heat Incentive (RHI) application sites, carried out prior to Ofgem accreditation, revealed that heat meters were not installed according to manufacturer's guidance in a significant number of cases. This finding raised concerns about the effect such installation errors may have on RHI payments. AECOM and BSRIA[1] were therefore appointed to investigate this issue.

This report covers the work carried out by AECOM and BSRIA, together with input from DECC and Ofgem and aims to:

- Bring together information on heat meter installation issues.
- Identify the magnitude of the subsequent measurement errors.
- Identify actions that could be taken to reduce the occurrence of these errors.

The report covers installation errors relating to water based heating systems and does not attempt to address steam systems. Testing has also been carried out on glycol/water mixes to gauge the potential errors associated with using a meter calibrated for the wrong heat transfer fluid.

Although the report was originally commissioned to cover non-domestic installations, a section has been included considering the implications for domestic installations.

The project consisted of three work areas:

- Gathering existing information on potential causes of heat meter errors. This was undertaken through a literature review and a workshop with representatives from DECC, AECOM and members of the metering industry.
- Carry out laboratory tests. These have been limited in scope due to time and budget but provide additional information where existing knowledge is limited.
- Develop recommendations of actions for DECC/Ofgem that could reduce the occurrence of installation errors.

It is important to recognise the limitations of the current project to provide definitive answers to questions on the magnitude and frequency of heat meter errors. Rather the report aims to provide an indication as to whether there are reasons for concern or not and to identify actions that can be taken to mitigate the impact of meter installation errors.

Meter Installation Errors

Through the literature review and consultation with industry, a reasonably comprehensive list of meter installation issues has been developed. This includes a number of general system design issues as well as direct meter installation issues. There was less evidence available on the magnitude of errors. These vary with meter type, the details of a particular installation and the condition of the system into which the meter is installed.

A series of laboratory tests have been undertaken on three types of heat meters. The initial test rig design generated unexpected results that led to a review of the design. Pressure losses were considered to be

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[1] Building Services Research and Information Association

too high in this initial rig and therefore the rig was redesigned and the tests rerun. The results discussed in this report are for the redesigned test rig. Another issue that arose from the testing was an apparent drift in the turbine meter between the initial tests and those run in the redesigned rig. Checks were carried out at various times during the testing to see whether the turbine meter offset remained consistent, which it did. The evidence therefore points to the meter drifting from its original calibration rather than being damaged.

It is recognised that limitations on the time and resources available have constrained the tests carried out, with only one meter of each type being tested and the tests only covering single errors, not combined errors that could also occur in real installations.

A subsequent further test (the results of which are not set out in *Table 1*) on the installation of temperature probes showed that large negative errors of -15% to -40% were likely to occur if a probe was strapped to the outside of a pipe instead of being inserted into a pocket.

Table 1[2] summarises the magnitude and frequency of flow meter installation errors found. The error magnitudes need to be compared with the Measuring Instrument Directive (MID) accuracy Class 2[3] Maximum Permissible Error (MPE) limits when determining their significance.

Conclusions and Recommendations

The laboratory testing has generally supported the literature data regarding the magnitude of installation errors. In many cases these are relatively small and are unlikely to lead to significant under or over payments.

The problems leading to the largest errors appear to be free gases (bubbles), dirt, and low system pressures in the heating system. Of the other potential problems investigated only using a heat meter calibrated for the wrong heat transfer fluid (up to 10% error) and installing a temperature probe on the outside of a pipe (only encountered in domestic installations to date, but up to 40% under reading) showed evidence that the error magnitude may be significant.

Many of the installation and setup errors identified could increase the risk of gas bubble formation at the meter and while system static pressures can be set, local cavitation can occur where meters are inappropriately located, such as near pumps. Standard system design, installation and maintenance good practice will help to reduce the risks with gases and dirt for non-domestic heating systems.

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[2] Positive errors indicate an overestimation while negative errors indicate an underestimation. Therefore an error of +2 has the same magnitude as an error of -2, but one is an over and the other an under estimate.

[3] Required under the 2011 RHI Regulations for non-domestic installations.

	Error Magnitude by meter type			Comment	Frequency of Error[4]
	Turbine	Ultrasonic	Vortex		
Gas entrainment	Within MID limits	Can stop reading	Within MID limits	Ultrasonic meter can identify there is a problem and report an error.	No data available
Wrong fluid [5]					4%
Meter calibrated for water used with glycol/water mix	Up to +5%	Within MID limits	Within MID limits	Calculator error will lead to an over estimation of energy.	
Meter calibrated for glycol/water mix used with water	No measurements have been made			Calculator error will lead to an under estimation of energy.	
Meter in wrong orientation	Within MID limits	Within MID limits	Up to -3%	After further test vortex meter error considered calibration drift rather than actual error. Removing air from the system was a problem with ultrasonic meter. While a function of the test, it could be problem in real systems.	11%
Meter downstream of fitting					5%
Reducer	Within MID limits	Within MID limits	Within MID limits		
Valve	Within MID limits	Within MID limits	Within MID limits		
Double bend	Up to +3%	Within MID limits	Within MID limits	Turbine meter show error of less than 1% over the upper MID limit	
Meter in wrong branch				Error magnitude depends on temperature difference	7%
Flow instead of return	Up to +5%				
Return instead of flow	Up to -5%				

Table 1: Summary of Flow Meter Error Magnitudes and Frequencies

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[4] Error frequencies are those found in the site visits carried out by AECOM to early applicants to Phase 1 of the RHI.

[5] The calculator error of at least 5% needs to be added to the flow meter error to give a total error, which could be 10% for the turbine meter.

While much of the standard good practice for non-domestic installations also applies to domestic systems, there remain greater challenges from limited budgets and space for the installation. Recommendations for domestic installations are:

- Consider developing a series of standard designs for meter installations that can be installed into a domestic heating system together with a guidance document. A pre-fabricated meter assembly could include filters, correct straight lengths of pipe and the necessary isolation valves.
- Annual maintenance is carried out, including checking that static pressure is being maintained and that air has been bled from system.
- Where dwellings are connected to a district heating system, the heat meter should be installed on the primary side of a heat exchanger which would normally be at a higher pressure and with better maintained water than the secondary dwelling circuit (which is usual practice).

A number of recommendations are made to improve the availability of information to installers that could help to reduce the occurrence of installation errors. These recommendations are:

1. Consider developing a general good practice guide on installing heat meters that could be included with other RHI guidance. This should include heating system design and operational factors that affect heat meters.

   And/or
2. Consider including checks within the application approval process regarding system design and commissioning that will at least draw the installer's attention to key issues.
3. Consider developing a guide with a body such as BSRIA or CIBSE[6] and making this available for RHI applicants. Work is already underway to improve industry knowledge through CPD[7] offers/training from CIBSE and other trade bodies such as ESTA[8].
4. Work with manufacturers to ensure their guidance is clear and that it is readily available. There was some evidence at the metering industry workshop held at DECC on 9th January 2013, which included representatives from both meter manufacturers and installers, that this would be something manufacturers were willing to do. This was highlighted as a potentially important area during the laboratory tests, where it was found no guidance was available on placement of meters in relation to pumps.
5. Consider identifying the potential benefits of good practice installation and maintenance within RHI documents to help incentivise the take up of good practice, i.e. incorrect heat measurement could lead to under payment and hence loss of revenue for RHI participants.

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[6] Chartered Institution of Building Services Engineers

[7] Continuing professional development

[8] Energy Services and Technology Association

Introduction

1 Introduction

1.1 Background

In January 2012 AECOM was appointed by Ofgem to carry out 57 site inspections of non-domestic installations which had made applications to the Renewable Heat Incentive (RHI). For most sites the inspections were undertaken before RHI accreditation had been awarded by Ofgem. The objective of these site inspections was to:

- Determine whether installations conformed to RHI requirements;
- Identify common problems;
- Identify how the RHI application process may be improved; and,
- Assist in developing a formal audit programme.

One of the problems identified during the inspections was the incorrect installation of heat meters used to determine useful heat generation against which the RHI would be paid. Overall, 28% of the meter installations were found not to be in accordance with manufacturer’s guidance. This has led to concerns within DECC and Ofgem regarding the effect these installation errors could have on RHI payments.

DECC has therefore appointed AECOM to investigate the potential RHI payment error as a result of measurement inaccuracies caused by heat meter installation errors. AECOM has appointed BSRIA as their sub-consultants. The objectives of this work are to quantify the effects of errors in metering arrangements on meter readings.

1.2 Scope of Report

This report covers the work carried out by AECOM and BSRIA, together with input from DECC and Ofgem, setting out:

- Information gathered on heat meter installation issues.
- The magnitude of the subsequent measurement errors.
- Actions that could be taken to reduce the occurrence of these errors.

The report covers installation errors relating to water based heating systems and does not attempt to address steam systems. Additional testing has also been carried out on glycol/water mixes to gauge the potential errors associated with using a meter calibrated for the wrong heat transfer fluid.

Although the report was originally commissioned to cover non-domestic installations, a section has been included considering the implications for domestic installations.

1.3 Project Approach

The approach has been to:

1. Gather information on meter installation issues and, where available, the magnitude of the resultant measurement error. This has involved:
    - Reviewing existing literature and published documentation.

   - Carrying out a workshop with representatives from DECC, AECOM and members of the metering industry.

2. Carry out a series of laboratory tests to supplement / extend knowledge on error magnitude.
3. Develop recommendations for actions that DECC and Ofgem can undertake or initiate that could reduce the occurrence of installation errors.

1.4 Limitations

It is important to recognise that the current work has limitations that are likely to prevent definitive answers to all questions. Rather the work can indicate whether there is reason for concern over the issue of heat meter installation errors and identify actions that can be taken to reduce the impact of these on the RHI scheme.

While laboratory tests have been carried out on three different types of heat meter, there were limitations to the data that could be obtained within the timescales and budget of the work. Results from the testing therefore need to be interpreted with care so as not to draw false conclusions. The constraints on testing were:

- Only one meter of each type has been tested, therefore should the test meter be faulty due to manufacture errors then this could result in spurious error data. To offset this risk, the meters installed claim Measuring Instruments Directive (MID) status that should ensure a level of quality.
- Only relatively simple tests have been carried out that do not necessarily mimic combined installation problems.
- Testing procedures by their nature cause the meters to be handled in ways that they would not expect to be in a correctly installed system; specifically the meters are removed and reinstalled more often than would normally be the case and the nature of the tests are to incorrectly install the meters which could lead to changes in meter behaviour.

1.5 Terminology

It is useful to ensure that some specific terms used with heat meters and their components are understood. Key terms used in this report are defined here for convenience:

Flow meters are designed to operate at a nominal flowrate, and should be operated at or just below this flow for most of the time. This is referred to as **qp** which is defined as the highest flowrate that is permitted permanently for the heat meter to function correctly.

Flow meters will typically be capable of operating at twice qp for short periods of time. This is referred to as **qs** the highest flowrate that is permitted for short periods of time for the meter to function correctly.

Flow meters can operate at lower flows than the nominal flow. The lowest flowrate that is permitted for the meter to function correctly is referred to as **qi**. Some meters will operate at flowrates below qi but will be outside their calibration range.

The ratio between qp and qi, referred to as the turn down ratio, can be as high as 100:1 but may be as low as 30:1.

A further commonly used term is **qt** which is defined in ISO 4064-1: 2005 as the flowrate between qp and qi that divides the flowrate range into two zones, each characterised by its own Maximum Permissible Errors (MPE). For a class 2 meter (required under the 2011 RHI Regulations) these MPEs are given as:

$qi \le q \le qt$	MPE = ±5%	
$qt < q \le qs$	MPE = ± 2%	Where the flow temperature is between 0.1 and 30°C
$qt < q \le qs$	MPE = ± 3%	Where the flow temperature is greater than 30°C

Types of Meter

2 Types of Meter

This section is intended to give a brief overview of the main types of meter used, particularly in RHI installations, with the intention of providing a knowledge base for further discussions. It is not a complete listing of all meter types.

2.1 Heat Meters

A heat meter has three components, a flow measuring device, a pair of temperature sensors (to measure the temperatures in the flow and return pipes) and a calculation or integrator unit.

Meters can be sold as combined units where all three components have been matched by the manufacturer or as semi-combined where the components are separate but sold as a kit. Alternatively individual components are sold that are matched and integrated on-site by the installer. The first two options offer the better solutions and RHI guidance documents state that these are the preferred approach for RHI metering where possible.

2.2 Flow Measurement[9]

There are a wide variety of flow measurement devices available. The following paragraph outlines the more common types of heat meter and is intended as a brief overview rather than a detailed description of each technology.

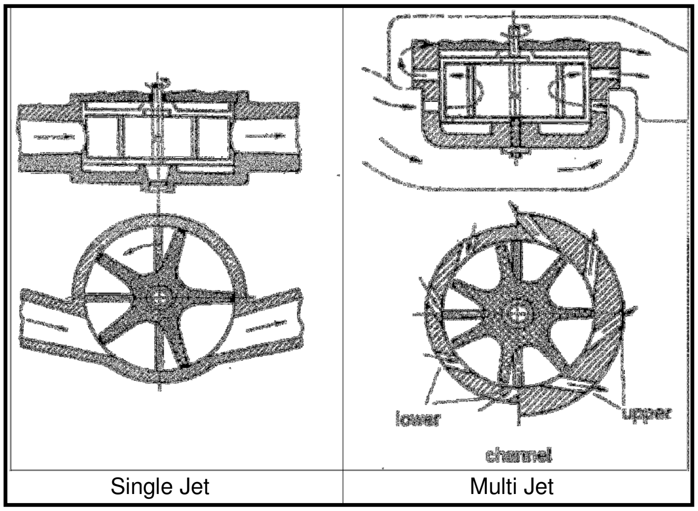
Turbine Meters

Turbine meters use the working fluid to drive a turbine and measure the rate of rotation. As the volume displaced by the turbine is known the volumetric flow rate can therefore be determined.

Typically the turbine axis is set at 90° to the flow and is of either single or multi jet design (see *Figure 1*). Single jet meters are typically used for smaller installations such as water supply for dwellings.

Woltmann meters have their axis orientated in line with the flow.

While mechanical measurement of turbine rotation can be made, heat meters more typically use electronic measurement. Magnetic or ultrasonic measurement of rotation avoids mechanical linkages with the turbine.



Single Jet

Multi Jet

Figure 1: Turbine Meters

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[9] Much of the information in this section of the report has been drawn from Omega and Euroheat and Power working group TF Customer Connections (see Appendix A for full references)

This reduces maintenance and enables the turbine section of the meter to be sealed from the rest of the meter.

Ultrasonic Meters

Ultrasonic meters use the changing frequency or travel time of sound in a moving fluid to determine the velocity of the fluid.

Doppler meters bounce sound off discontinuities within the working fluid (particles, air bubbles or even vortices) and measure the change in frequency from which the velocity of the discontinuities can be determined. This type of meter requires some form of acoustic discontinuity that is evenly spread through the fluid. However, if the concentration of discontinuity is too high the sound wave will be attenuated and the meter will not be able to measure the flow.

Alternatively meters can use the difference in time taken for sound to pass through the working fluid depending on whether the sound wave is moving with or against the flow to determine the fluid velocity. Piezo-electric crystals function as both transmitters and receivers. Typically one or more pairs of transmitter / receivers are placed at an angle through the flow, but other designs exist as shown in *Figure 2*.

The average fluid velocity needs to be measured in order for accurate measurements of heat flow are to be made. As the velocity will vary across the pipe depending on whether the flow is laminar or turbulent or due to disturbances up stream of the meter, meters with more than one transmitter / receiver pairs tend to provide more robust measurements. Setting sensors at an angle across the flow is one way of improving the robustness of meters with single sensor pairs.

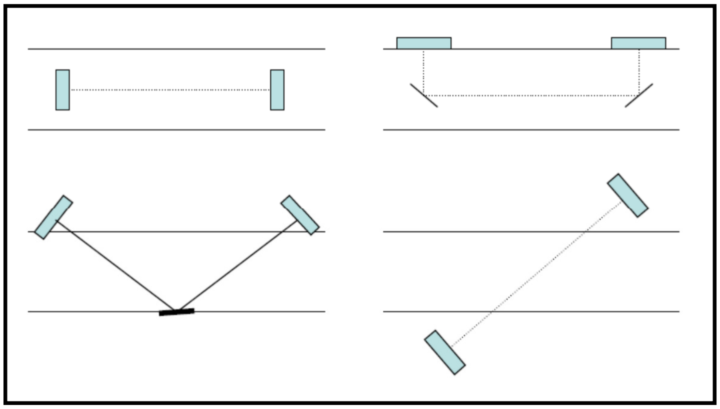

Figure 2: Ultrasonic Sensor Pair Arrangements

Vortex Meters

Vortex flow meters, also known as vortex shedding flow meters or oscillatory flow meters, measure the vibrations of the downstream vortexes caused by a non-streamline barrier (referred to as a bluff body) in the moving fluid. Flow velocity is proportional to the frequency of the vortices. The majority of vortex meters use piezoelectric or capacitance-type sensors to detect the pressure oscillation around the bluff body. These detectors respond to the pressure oscillation with a low voltage output signal which has the same frequency as the oscillation.

In some cases, vortex meters require the use of straightening vanes or straight upstream piping to eliminate distorted flow patterns and swirl. Low flow rates present a problem for vortex meters, because they generate vortices irregularly under low flow conditions.

Vortex flow meters are well suited for measuring steam flow, and they are widely used for this purpose.

Electromagnetic Meters

Electromagnetic meters use Faraday's law of electromagnetic induction that states that a voltage will be induced when a conductor moves through a magnetic field. The working liquid serves as the conductor and the magnetic field is created by energized coils outside the flow tube. The voltage produced is directly proportional to the flow rate. Two electrodes mounted in the pipe wall detect the voltage which is measured by a secondary element.

Electromagnetic flow meters can measure difficult and corrosive liquids and slurries, but can only be used for electrically conductive fluids.

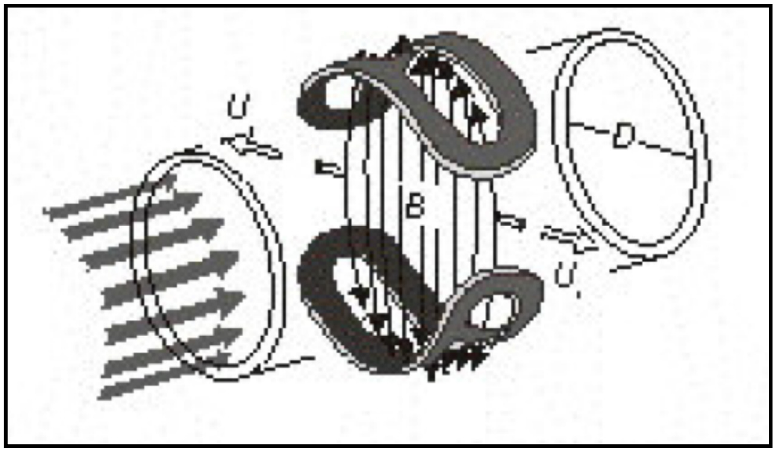

Figure 3: Electromagnetic Meter

2.3 Temperature Sensors

Heat meters use a measure of the temperature difference between the flow and return water in order to calculate heat consumption. Temperature sensors are therefore supplied as matched pairs of platinum resistance thermometers (Pt 100 or Pt 500[10] are the most common) fitted into the water flows in pockets.

The measurement of temperature difference has the advantage of overcoming difficulties in measuring absolute temperature. However, due to the low voltage differences produced by the thermocouples, connections to calculator units must be limited in length. 4-wire[11] connections offer better connection lengths if required.

Positioning the thermocouples into the correct part of the fluid flow, ensuring good conductivity between fluid and thermocouple and avoiding local temperature distortions through heating or cooling are the main challenges with temperature measurement. Temperature gradients can develop within large pipes downstream of branch fittings and in these cases several temperature sensors need to be installed around the circumference of the pipe to determine the average temperature.

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[10] Platinum temperature sensors use the change in resistance with temperature to measure temperature. Pt 100 and Pt 500 sensors have resistances of 100 and 500 ohms respectively at 0°C. The higher the resistance the greater the sensitivity as the change in resistance with temperature is larger.

[11] With a 4-wire connection the error due to the resistance of the connection leads can be removed, thus improving accuracy with longer leads.

2.4 Calculation Units

The calculation unit will convert the quantities measured by the temperature sensor pair and the flow meter into heat measurements. This requires conversion of volume flow and velocity into mass flowrates as well as corrections for physical properties and conditions within the metering system.

Calculation units will also typically provide some data storage and a data display, reporting accumulated energy flow, instantaneous fluid flowrate and temperature difference, as well as being able to export the data to a more permanent data storage system.

A number of techniques exist for retrieving data automatically including: direct connections using m-bus or other data transfer protocols, wireless data transmission to a base station or remote read facility for wireless pick up of data on an intermittent basis.

2.5 Meter Standards

Measuring Instruments Directive (MID)

Meters used to measure heat for Phase 1 RHI payments must comply with the European MID accuracy class 2. This sets the Maximum Permissible Error (MPE) for the meter as the sum of the MPEs of each component, which are also set out in the MID.

The maximum permissible relative error applicable to a complete heat meter, expressed in percent of the true value, for an accuracy class 2 meter, is:

$E = Ef + Et + Ec$

Where

Flow error,	$Ef = (2 + 0.02\ qp/q)$	but not more than 5 %,
Temperature error	$Et = (0.5 + 3 \times \Delta\theta_{min}/\Delta\theta)$,	
Calculation error,	$Ec = (0.5 + \Delta\theta_{min}/\Delta\theta)$,	

And

q = flow rate

qp = highest value of q permitted continuously for the heat meter to function correctly

$\Delta\theta$ = temperature difference between flow and return

$\Delta\theta_{min}$ = the lower limit of $\Delta\theta$ for the heat meter to function correctly within the MPEs.

Limits of Error

The MPE of a meter varies, depending on the variables above, but the worst case could be ±10% (where a meter is operating at qi and minimum $\Delta\theta$, with a turndown ratio of 150:1 and a $\Delta\theta_{min}=3^{o}C$)

Figure 4 illustrates the magnitude of the total maximum error for a meter with a turn down of 150:1 with varying Δθ at qi and qp. The MPE rapidly drops with increasing Δθ. The MPE also drops at qp relative to that at qi. *Figure 5* shows that the MPE reduced as flow increases above qi but rapidly becomes relatively constant.

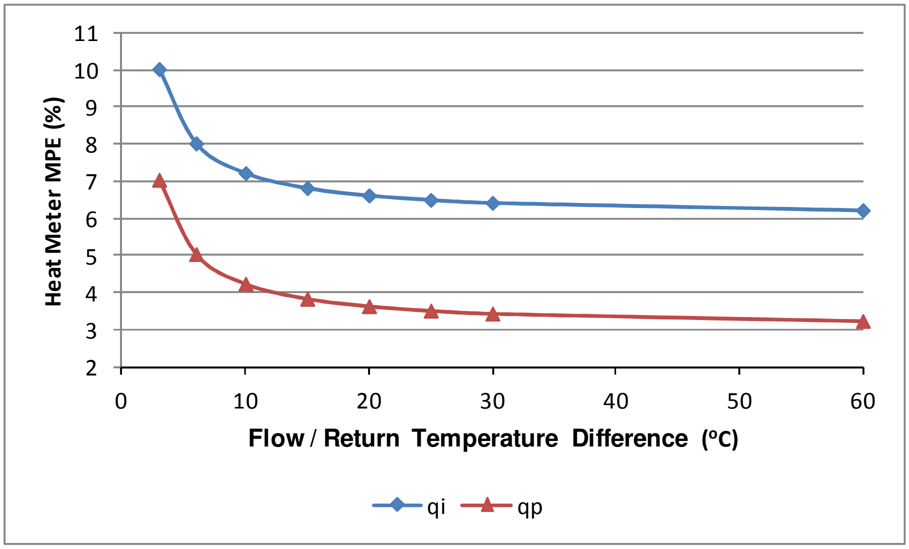

Figure 4: Heat Meter MPE vs Flow/Return Temperature Difference at qi and qp

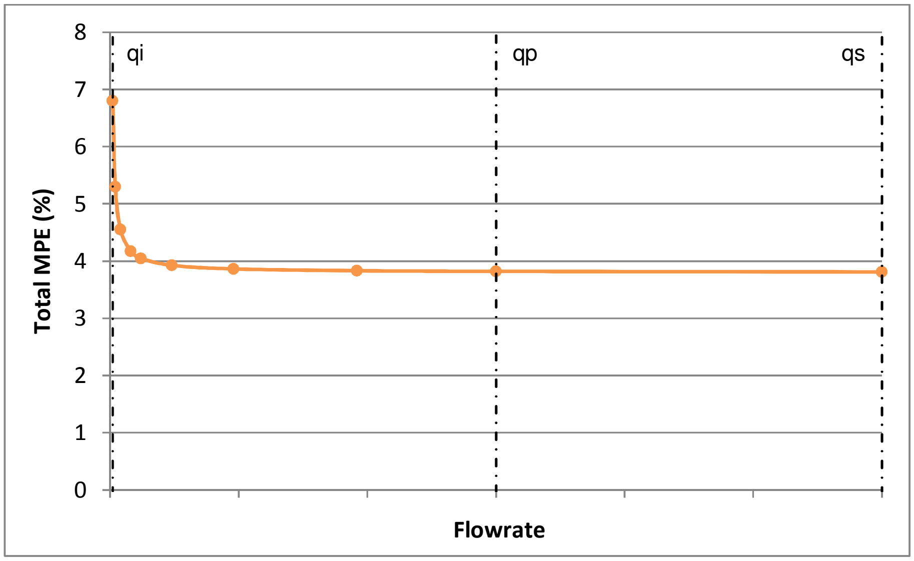

Figure 5: Heat Meter MPE for Flow / Return Temperature Difference of 15°C Between qi and qs

Typical Accuracy Curves for Flow Meters

Typically flow meters are more accurate at higher flowrates than their minimum flowrate (qi). At qi meter accuracy often approaches or reaches the MPE set by the MID. *Figure 6* and *Figure 7* provide examples of accuracy curves of meters currently on the market.

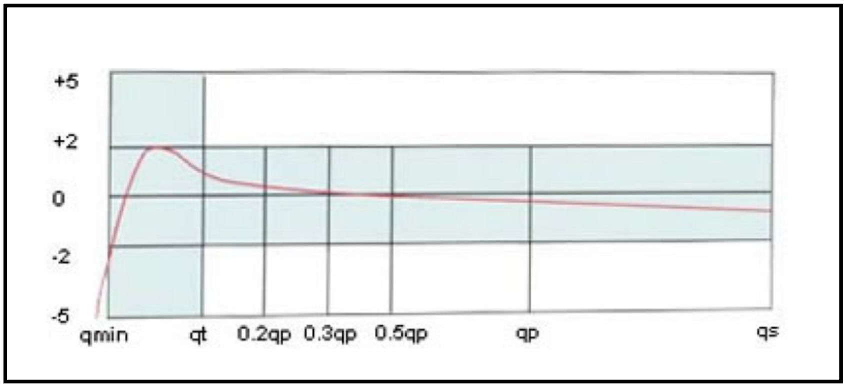

Figure 6: Typical Flow Meter Accuracy Curve for Turbine Meter[12]

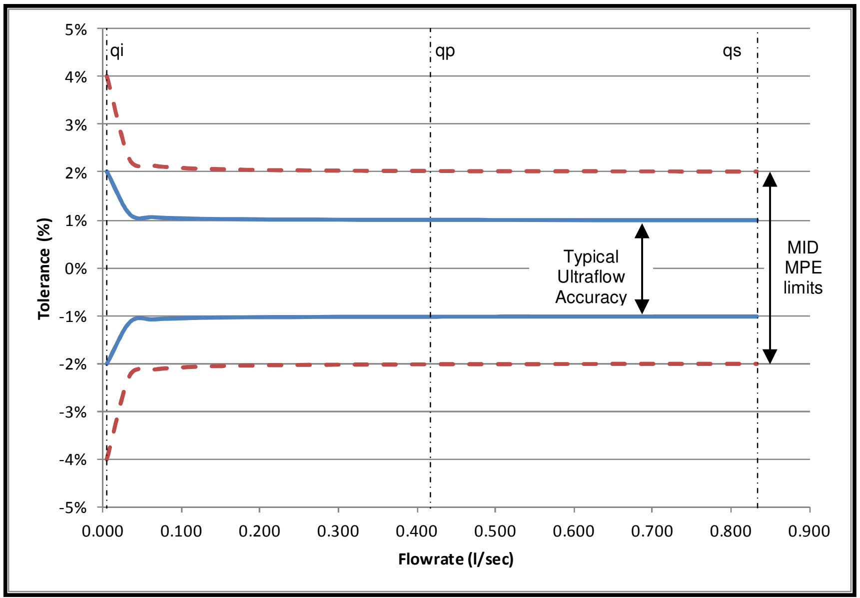

Figure 7: Example Flow Meter Accuracy for Ultrasonic Meter[13]

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[12] UK Meters Ltd – TOMi and MAXi ranges of water meters

[13] Typical accuracy curve derived from Kamstrup Multical 401 data, qp = 1.5m^3/hour

BS EN 1434

BS EN 1434-1:2007 specifies the general requirements that apply to heat meters, as stated in the MID. As well as setting the accuracy classes the standard also sets environmental classes that indicate the type of environment a particular meter is designed to operate in. Environmental classifications are:

- Class A (Domestic use, indoor installations)
  Ambient temperature +5^{o}C to +55^{o}C
  Low level of humidity
  Normal electrical and electromagnetic conditions
  Low level of mechanical conditions (vibration etc)
- Class B (domestic use, outdoor installations)
  Ambient temperature -25^{o}C to +55^{o}C
  Normal level of humidity
  Normal electrical and electromagnetic conditions
  Low level of mechanical conditions (vibration etc)
- Class C (Industrial installations)
  Ambient temperature +5^{o}C to +55^{o}C
  Normal level of humidity
  High electrical and electromagnetic conditions
  Low level of mechanical conditions (vibration etc)

Installation Errors

3 Installation Errors

This section sets out the range of installation errors that can be encountered that can lead to heat measurement errors. The inaccuracy as a result of different installation errors depends on the type of meter installed; what may be a significant problem with one type may have no or little impact on another. Commentary on the magnitude of the errors is made in Section 4.

Information in this section has been gathered from literature, a workshop with meter manufacturers and with follow up one-to-one conversations with manufacturers.

Most of the installation problems discussed here relate to the flow meters, but some specific points are covered regarding temperature sensors and calculator units.

3.1 Water Quality

Maintaining good water quality is important for all components of a heating system. Where water quality is poor, accelerated wear and corrosion are likely to lead to increased maintenance and reduced component life. In the case of heat meters, poor water quality can also affect measurement accuracy.

Dirt in the system can lead to increased wear or deposits on meter components leading to flow restriction or failure of the meter. Indications are that dirt or other deposits can cause very large measurement errors of over 10%. It is always recommended that heat meters are installed after the system has been flushed to remove residual dirt or objects before the system is set to work. It is also good practice to install a strainer upstream of a meter.

Other contaminants that could form deposits or alter water properties include Magnetite, a product of corrosion and therefore an indication of poor water quality; limescale in hard water areas, and; bacterial growth in low temperature systems. Correct water treatment can reduce these.

3.2 Gas Entrainment

Gaseous corrosion products and to some extent air can become entrained in any heating system, even if sealed and pressurised, and is a major cause of measurement error for all types of heat meter.

Gas bubbles within the heating fluid can adversely affect most common types of flow meter. Ultrasonic flow meters are affected as the speed of sound will differ in gas to that in water, thus leading to measurement errors. Mechanical displacement meters will also be affected as the average density of the fluid will differ from that expected. Vortex meters are sensitive to changes in viscosity and density (and thus Reynolds number[14] (Re)), both of which can be affected by gas entrainment. Electromagnetic meters can overcome gas entrainment provided the gases are well mixed and large bubbles or slugs of gas are not present.

Unfortunately gas entrainment occurs in most heating systems, even when these are sealed and pressurised. De-aerators can be installed, but these are uncommon, especially in smaller commercial or domestic systems.

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[14] Reynolds Number (Re) is a dimensionless ratio between viscous and inertial forces used to characterise fluid flow. For fluid flow in pipes: $Re = \rho v d / \mu$, Where ρ = fluid density, v = fluid velocity, d = pipe diameter and μ = fluid dynamic viscosity. Laminar flow occurs for values of $Re < 2300$, while for values of $Re > 4000$ flow is turbulent.

Bends, fittings and pumps can cause local reductions in pressure leading to gas bubbles forming in the area of the fitting (cavitation). Problems with gas are increased where system pressures are low (relative to vapour pressure) as there is less resistance to the formation of bubbles within the heating fluid.

System operating temperature can also affect levels of free gases. High system temperatures will drive gases out of solution, which if not removed will lead to bubbles.

In summary, installation and system design issues that can lead to gas entrainment include:

- Flow meter downstream and close to bends, valves or other fittings.
- Change in pipe diameter close to and upstream of flow meter (possibly due to the flow meter being of a smaller size than the heating pipework.
- Incorrectly fitted gasket at flow meter flange joint.
- Flow meter downstream and close to a pump.
- Flow meter installed at a high point.
- Low system pressure.
- High operating temperatures

Manufacturers state that when gas can be heard within a heating system that this will be at a level to cause inaccuracies in heat meter readings.

Water droplets in steam cause similar problems in steam meters and meter manufacturers have stated that any mixed phase flow causes flow meter reading errors.

3.3 Flow Profile

Bends, valves, restrictions, expansions and other fittings can change the flow profile so that it differs from that anticipated by the flow meter. Double bends can be particularly troublesome as these cause a swirling pattern in the flow that can persist for long distances (50 pipe diameters or more) downstream of the bend.

Placing disturbances downstream of a meter can also influence the flow profile, but to a much more limited extent than upstream disturbances.

The standard approach to avoiding this type of error is to place the meter a reasonable distance from bends and fittings (see section 4.4).

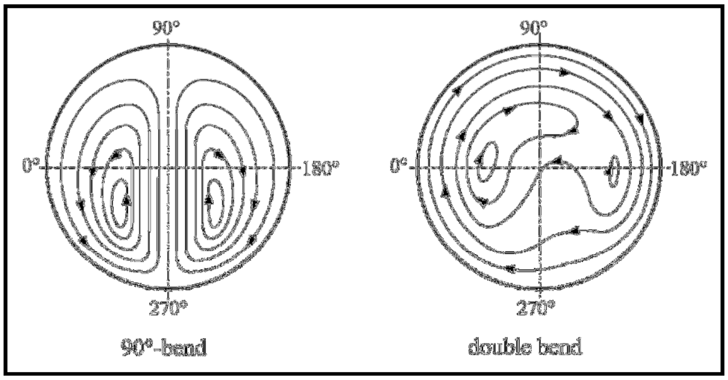

Figure 8: Example of Vortex Formation Downstream of Bends[15]

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[15] C.Ruppel, F.Peters / Flow Measurement and Instrumentation 15 (2004) 167-177
Note that the double bend is two 90° bends in two planes (one vertical one horizontal)

Single jet turbine meters can suffer from inconsistent readings where the flow pattern is not uniform. Multi jet meters are better at dealing with these flow disturbances as they effectively measure the fluid flow at a number of points in the pipe simultaneously thus providing more accuracy.

Installation and system design issues that can disturb the flow pattern causing meter reading errors include:

- Flow meter downstream and close to bends, valves or other fittings.
- Change in pipe diameter close to and upstream of flow meter (possibly due to the flow meter being of a smaller size than the heating pipework).
- Incorrectly fitted gasket at flow meter flange joint.
- Flow meter downstream and close to a pump.

3.4 Flow Meter Orientation

Installation errors relating to meter orientation are:

- Not installing a meter the right way up. This is particularly important for mechanical flow measurement where this could change the loadings on bearings leading to measurement errors from increased internal friction and increased wear over time. Some manufacturers have stated that they would consider their meters to no longer be MID compliant when incorrectly installed in this way, see *Figure 9*.
- Other types of meter such as ultrasonic meters may suffer from problems with air when the flow meter is installed at the top of the pipe as this is where air is likely to collect.
- Installing a meter with flow in the wrong direction. Many meters will register a flow, however, some will register this as a negative flow, others may ignore negative readings. In each case there could be errors in the heat flows reported. Some meters will be damaged by reverse flow, typically mechanical meters.

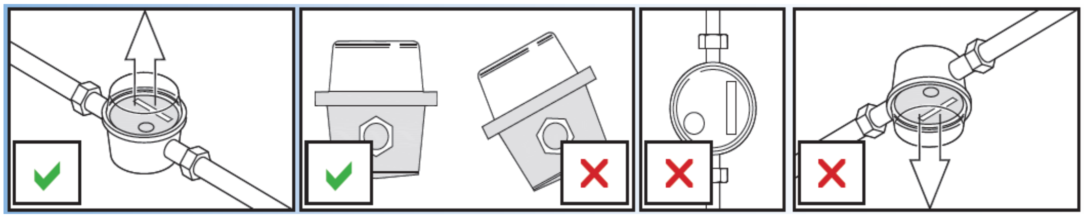

Figure 9: Extract from Manufacturer's Installation Instructions[16]

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[16] Delta Flowtech Multi Jet and Woltmann Water Meter Installation Guidelines 2010

3.5 Heating Fluid Properties

The physical properties of the heating fluid are important for accurate measurement as they can affect flow meter measurements directly and also the conversion of the measured quantity to heat consumption.

Heat meters require the mass flowrate of the heating fluid to be determined in order to calculate heat consumption. As stated in section 2, flow meters measure fluid velocity and volumetric flow. It is therefore necessary to convert these to mass flow, which requires the fluid density to be known. This is an issue for most common types of heat meter likely to be used in the RHI scheme.

Viscosity can affect turbine and vortex meters. In turbine meters the measurement of volumetric flow is directly affected while vortex meters suffer from a reduction in the turndown ratio with increased viscosity.

Problems occur where system temperatures or the system working fluid differs from what is expected. The system design or installation errors that can lead to measurement errors include:

- The flow meter being installed in the flow path when it is calibrated for the return (or vice-versa). The influence of this installation error is usually small unless the heating system has been designed for a large temperature difference.
- The heating system being operated at temperatures that differ from those originally anticipated. This might occur where a heating system is modified over time to reduce the operating temperatures, say to change the system from a medium temperature (110-120^{o}C) system to a low temperature system (60-80^{o}C).
- The heating fluid being different from that assumed in the meter setup. Typically this would be a heat meter set up for a water system being installed in a system with a glycol / water mix (or vice-versa), which would have different properties.

Some meters can adjust for fluid temperature by holding the thermal properties of the heating fluid within the calculator over a range of temperatures and using the measurement of the fluid temperature local to the flow meter to determine the properties.

3.6 Environmental Conditions

Environmental temperature, humidity, vibration and electromagnetic interference can all affect heat meter operation and indicated readings.

Heat meters are designed to operate in a range of environmental conditions. BS EN 1434-1:2007 sets three classes of conditions into which heat meters must be categorised and the MID requires manufacturers to state environmental limits for meters. As well as the external limits mentioned above, heating fluid temperature and pressure are also included within the MID requirements.

As all meters include some electronic circuits they can be adversely affected by moisture, dirt and temperature. If the electronic components are placed such that they experience levels of humidity or temperature for which they are not designed, then damage can occur leading to errors in readings and possible failure of the unit.

Installation errors that can lead to measurement errors include:

- Placing a meter designed for indoor use outside. Low temperatures or high humidity can lead to the failure of electronic components.

- Using a combined meter, where electronics are mounted directly on the flow meter, on very high temperature pipes. This can reduce the life of the electronic components.
- Placing power cables near meter components or running power cables alongside meter communication cables. This can cause electromagnetic interference leading to distortion of meter readings. The MID states that class 2 meters should not be adversely affected by conventional power cables, but does not specify what these are. In plant rooms electrical power circuits can be single or three phase, at a number of voltages and carrying a range of currents.
- Vibration or noise can also adversely affect flow meter readings.

3.7 Temperature Sensors

Good practice recommendations for installation of temperature sensors are:

- Always use a matching pair of temperature sensors. This avoids errors in differences between the two sensors.
- Ensure good thermal contact between the sensor and working fluid. Sensor pockets should be packed with thermal grease. Poor contact will reduce the measured temperature relative to the actual fluid temperature.
- Ensure the sensor is not near the pipe wall where the heating fluid temperature could be reduced through heat loss. If the temperature probe is placed in a horizontal pipe then it could be too short or too long and may not be in the central flow region.
- Avoid heat losses or heat at the top of the temperature probe(s). Incorrect probe/pocket lengths could expose the top of the probe to ambient conditions. Equally, removing large areas of pipe lagging around the temperature probe pocket will increase local heat loss.
- Avoid electro-magnetic fields (EMF), typically from power cables running adjacent to the heat meter communication cables, which will cause interference with the temperature signal back to the integrator. EMF can distort the temperature measurement recorded.
- Ensure communication cables are kept within the maximum permissible length and are the same length for both temperature probes. Signals from the temperature sensors are weak and will be influenced by losses in the communication cable. Too long a cable could lead to incorrect or no reading while different length cables mean that the signal from one sensor will have different influences to the other.

3.8 Meter Sizing

Correctly sizing a heat meter is not necessarily a simple task. The flow meter component is designed to operate at or around qp for most of the time. Heating systems however, increasingly operate with variable flow to reduce pumping energy consumption. The choice and location of heat meters therefore needs to consider the overall system operating regime.

One benefit, from a metering point of view, with variable flow systems is the fact that temperature differences remain higher than in constant volume systems, hence increasing the accuracy of the temperature difference measurement.

Incorrect meter sizing can be due to a poor knowledge of a heating systems operating regime, but also a lack of knowledge regarding the effect over or under sizing could have on meter readings.

Oversizing

Heat meter oversizing could occur where:

- A meter is installed early in the development of a large system (such as district heating) when flowrates are well below those anticipated when the system is fully developed.
- The flow range of a system is large, such that a meter sized for the peak flow may be too large for the average or typical flow.

Where the meter is oversized, the flow meter will tend to operate at the lower end of its range. While this may not stop the meters working properly, provided the flowrate is at or higher than the minimum flow for which the meter meets the MID Class 2 requirements (qi), meter accuracy in this area is typically lower than at the nominal design flow (qp). Thus, meters that are constantly operating at the lower end of their range will have higher errors than those operating around qp, even though they may still be within in the MID limits. See Section 2.5 for typical meter error curves.

Where a flow meter operates below qi it will no longer be MID compliant and flow sensor errors could be higher than the 5% maximum limit within the Directive. Some meters will not operate at very low flows, eg vortex meters have a minimum operating flow to initiate vortex formation and some mechanical meters need a specific flow to drive the meter. In this case no heat consumption will be recorded even though there may be some occurring.

If a system is operating at or close to qi then the effect of other installation errors is likely to be greater than if the meter is operating near qp.

Undersizing

Heat meter undersizing could occur where:

- A meter is chosen on the basis of the maximum permissible flowrate (qs) rather than qp.
- A heating system is extended or enlarged, leading to increased flowrates at the point where the heat meter is installed.

Undersized meters are likely to operate above qp for extended periods and may even exceed qs. Meters are only designed to operate at qs for very short periods of time. Continuous operation at or above qs will lead to increased wear, which could increase measurement errors over time or lead to failure of the meter. Mechanical flow meters are particularly prone to wear in this case due to the moving parts. Ultrasonic and magnetic meters are least affected.

Operation above qs means that the meter will no longer be MID compliant, however, the magnitude of errors may not increase unless the meter is operated above qp for some time when excess wear may affect the meter.

3.9 Incompatible Meter Components

Where meter sub-components are installed separately, rather than as a combined meter, there is a risk that the components used may not be compatible. This can obviously lead to errors which are very difficult to quantify. Larger installations are most at risk as it is not always possible to buy combined meters for very large pipe sizes: typically the flow components of combined or semi-combined meters are limited to nominal diameters of 300mm or less.

3.10 Poor Installation

Incorrectly connected components or poorly sealed joints are another potential source of error, which can vary depending on the errors made. Error magnitudes arising from poor workmanship are difficult to quantify and suitable training and supervision are likely to be the only solutions available for improving standards and reducing the risk of errors.

3.11 Meter Life

General age and wear will cause meters to become less accurate. While manufacturers recognise that meters require replacement over time there appears to be a reluctance to set hard rules for replacement cycles. This appears to be related to the variability in system use that makes it hard to specify when meters should be replaced.

A number of the issues mentioned above can cause accelerated wear, reducing meter life.

System use may also reduce meter life. District heating systems typically operate 24/7, while an office heating system may only operate for two thousand hours per year. Systems installed into well insulated buildings may have a shorter stop-start cycle than those fitted to older buildings with a more consistent heating demand. Clearly the rates of wear are likely to differ and hence the recommended replacement frequency will vary with application.

Quantification of Errors

4 Quantification of Errors

This section reports on the quantification of measurement errors resulting from the installation issues identified in the previous section. Information is limited to that found in literature (referenced in Appendix A) and provided by meter manufacturers, with additional data provided from the laboratory tests undertaken by BSRIA (as set out in Appendix B). The effect of some errors can be estimated through calculation and comment has been made in this section on the potential effect when using water / glycol mixes.

4.1 Laboratory Experiments

An initial set of experiments were undertaken by BSRIA to measure the response of three types of heat meter to a number of incorrect installations. These initial experiments were unable to achieve the full flow range, even after introducing a second pump, of the heat meters and also showed unexpected results, particularly with the vortex meter. A review of the test rig revealed that the design of the rig led to higher than expected pressure losses through heat exchangers and control valves designed to maintain the desired temperature. System temperature over the range being tested (30° to 80°C) was considered to be less important than the pressure loss through the system and therefore the test rig was redesigned to reduce pressure losses. This resulted in a compromise in temperatures achievable, which were limited to 50°C in the new rig. A series of retests were then carried out using the redesigned test rig and the results reported here are from the retests with the exception of gas entrainment and temperature probe installation (not affected by system pressures).

Before running the tests in the redesigned test rig for incorrect meter installations, a test with each meter correctly installed was undertaken at two temperatures (30°C and 50°C).

The results for the Turbine meter did not fall within the MID error band, as shown in *Figure 10*. However, the error was considered to be reasonably consistent and suggested that the meter had "drifted" since the first set of tests by around 4%. *Figure 11* shows that the results fall within the error band width if the upper and lower limits are displaced by +4%. To confirm this view, retests of the correct installation were carried out after running the glycol / water mix tests and after running the meter orientation tests (the last set of tests carried out). The results for all the correct installation tests are shown in *Figure 12* and can be seen to be consistent throughout. The results for the Ultrasonic (*Figure 13*) and Vortex meters (*Figure 14*) lay within the MID error band.

The limitations of the laboratory experiments, and the data that could be obtained within the timescales and budget of the work, need to be recognised. Results from the testing therefore need to be interpreted with care so as not to draw false conclusions. The constraints on testing were:

- Only one meter of each type has been tested, therefore should the test meter be faulty due to manufacture errors then this could result in spurious error data. To offset this risk, the meters installed claim Measuring Instruments Directive (MID) status that should ensure a level of quality.
- Only relatively simple tests have been carried out that do not necessarily mimic combined installation problems.
- Testing procedures by their nature cause the meters to be handled in ways that they would not expect to be in a correctly installed system; specifically the meters are removed and reinstalled more often

than would normally be the case and the nature of the tests are to incorrectly install the meters which could lead to changes in meter behaviour.

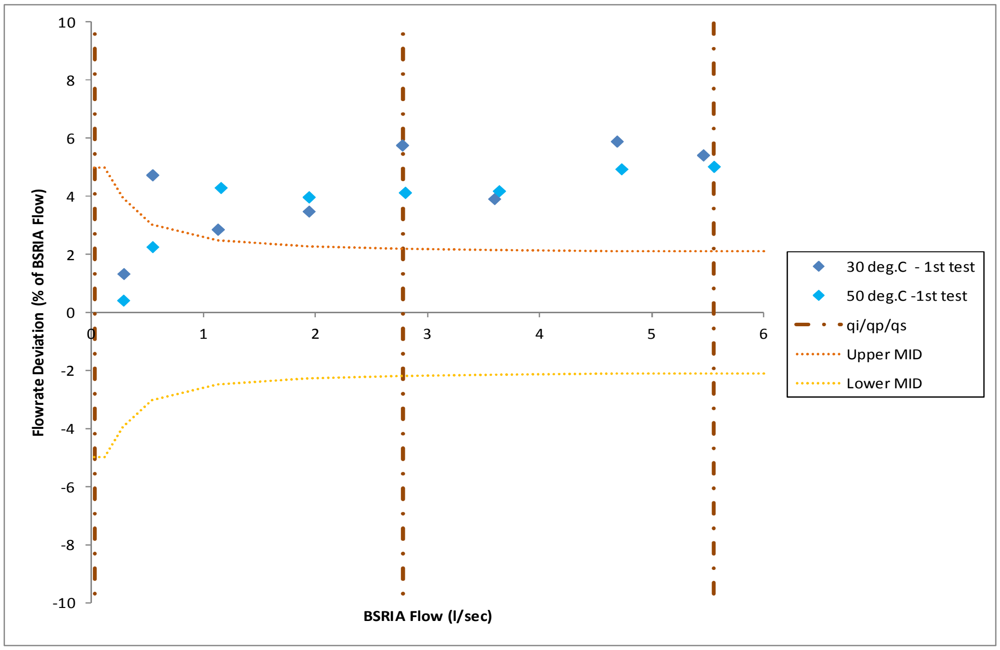

Figure 10: Laboratory Test for Correctly Installed Turbine Meter

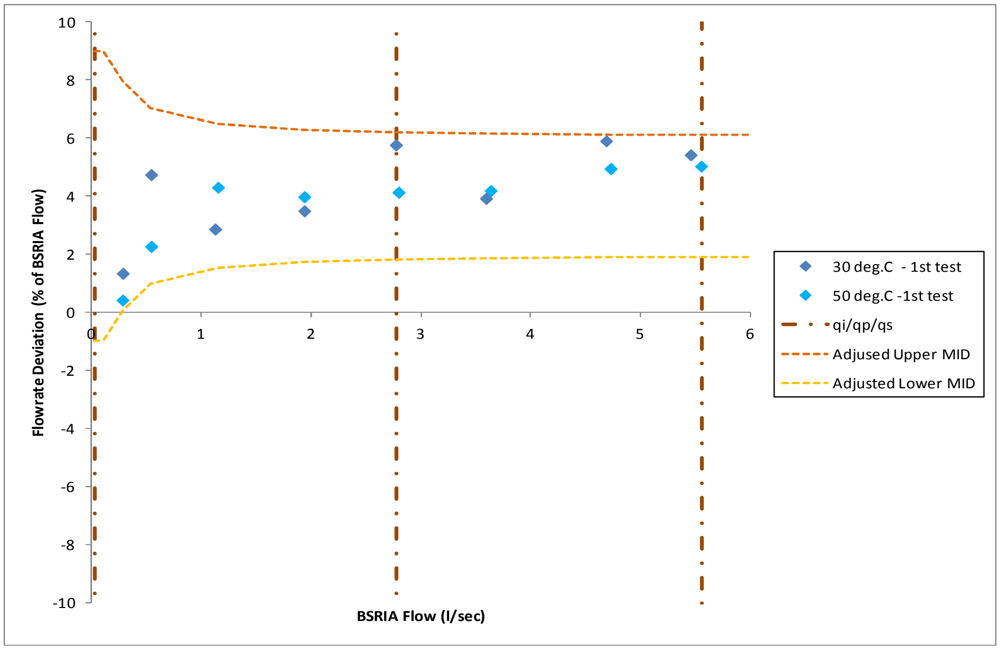

Figure 11: Laboratory Test for Correctly Installed Turbine Meter – Adjusted Error Bands

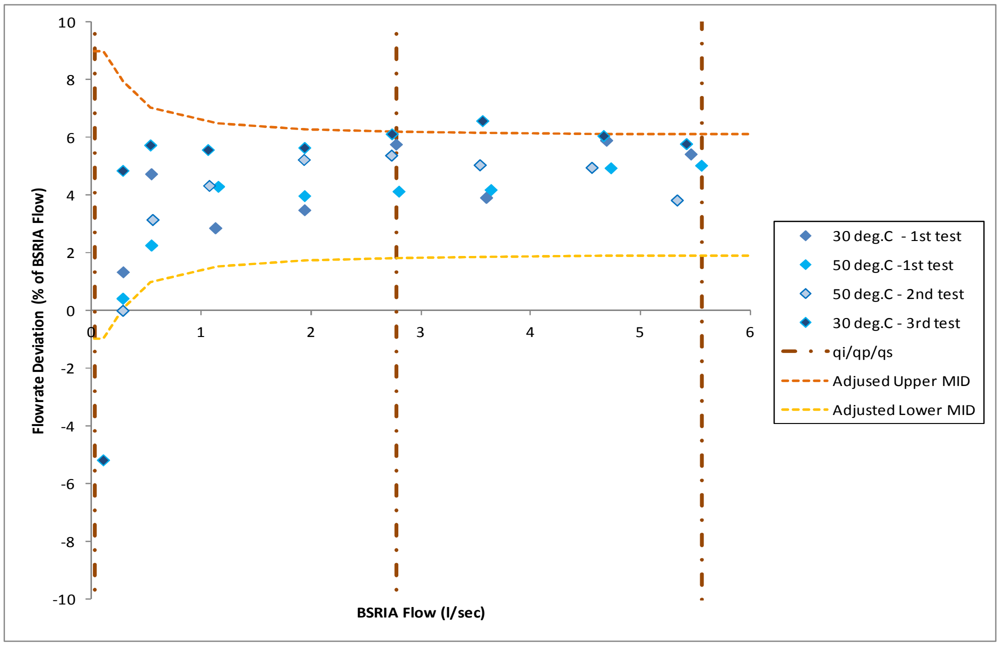

Figure 12: Laboratory Test for Correctly Installed Turbine Meter – Including Periodic Retests

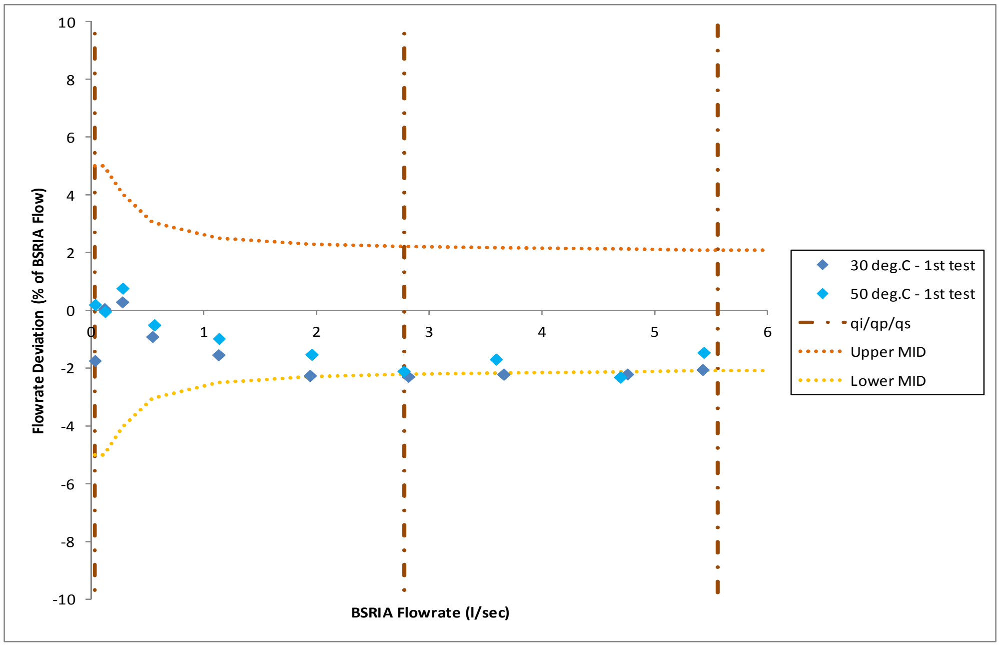

Figure 13: Laboratory Test for Correctly Installed Ultrasonic Meter

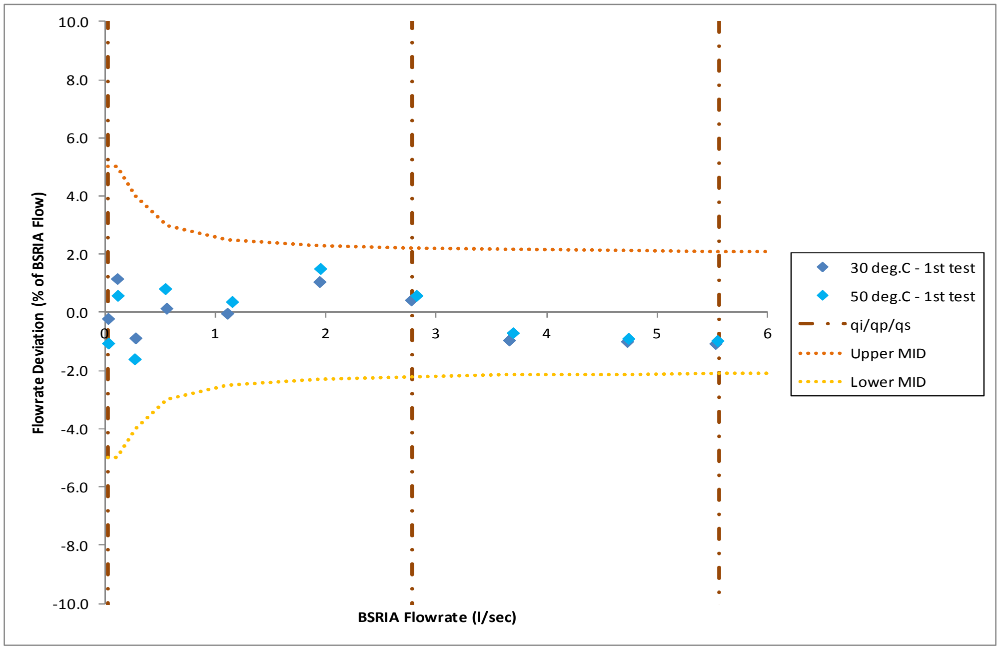

Figure 14: Laboratory Test for Correctly Installed Vortex Meter

4.2 Dirt

Anecdotal evidence from the manufacturer's workshop held on 9th January 2013 indicated that dirt can cause measurement errors in the order of 15%. This comment was not specific to any type of meter or installation.

Francisco Arregui et al (Key Factors Affecting Water Meter Accuracy) discusses the effect of dirt deposition on single and multi-jet turbine meters, stating that dirt is likely to cause over estimation at medium to high flowrates and under reading at low flowrates and that error magnitude can be considerable. An example is given of a single jet turbine meter suffering from lime scale build up giving measurement errors of +25% across the whole flow range.

4.3 Gas Entrainment

Anecdotal evidence from the manufacturer's workshop held on 9th January 2013 indicated that free gas bubbles can cause measurement errors in the order of +/-30% to 50%. However, no further evidence was provided to back up this statement, nor was the statement made with reference to any particular type of meter.

Laboratory Tests

To provide an indication of the effect of free gases on the test meters, air was deliberately introduced into the test rig and the reaction of the meter noted.

Little effect was observed with the turbine meter, but more significant effects were seen with the ultrasonic and vortex meters.

The ultrasonic meter stopped reading and showed an error code. The error code is a standard feature of the meter and is intended to alert the user to a problem rather than attempt to give spurious readings.

The vortex meter showed a relatively small error at low air volumes, increasing as the volume of air increased, eventually causing the reading error to exceed the MPE for a Class 2 meter.

4.4 Flow Profile

Francisco Arregui et al (Key Factors Affecting Water Meter Accuracy) reports that a gate valve placed three pipe diameters upstream of three different meters (80mm Vertical Woltmann, 80mm Horizontal Woltmann and single jet meter) had no noticeable effect on their accuracy.

Francisco Arregui et al also report the results of a further experiment undertaken to determine the effect of an incorrectly sized gasket and a partially blocked filter on domestic single jet water meters. A number of meters of the same specification and type were tested and the results are given in *Table 2* as errors compared to the results of meters without any obstruction. The results suggest there is a risk of a high over estimation of flow with a gasket that restricts flow (-1 to +16%), while a blocked filter will have a relatively small (<1%) effect.

Test	Flowrate (l/h)	Meter						
		A	B	C	D	E	F	G
Gasket too small	400	-1.4	16.2	4.0	-0.1	-	-	-0.9
	1500	-1.2	16.2	4.8	4.6	-	-	-0.4
Blocked filter	400	-	0.3	0.4	-	-0.7	-0.2	-
	1500	-	0.2	1.7	-	0.2	-0.8	-

Table 2: Effect of Blockages Adjacent to Single Jet Water Meter

Experimental results reported in Sira, on behalf of the Department of Trade and Industry (DTI) (Final Report on Clamp-on Transit Time Ultrasonic Flowmeter, Performance Evaluation) for a range of obstructions at varying distance upstream of a clamp-on ultrasonic meter are provided in *Table 3*. These results are averages for velocities of 1 to 5.5m/s.

These suggest that the errors due to most types of obstruction are likely to have reduced to less than 1% with the meter 20 pipe diameters downstream of the obstruction. The exceptions indicated are for a double bend where significant errors still remain at 20 pipe diameters and a single bend with a 50mm pipe which appears to have similar errors to the double bend.

		Upstream Disturbance			Downstream Disturbance	
		5D	10D	20D	5D	10D
25mm pipe	Gate Valve	-1.8	-0.9	0.1	0.7	0.8
	Single bend in plane	-2.9	-1.6	-0.9	0.9	0.14
	Double bend	-4.9	-3.1	-3.5		
	Reducer	-3.3	0.4	0.2		
	Expander	-2.7	-1.7	0.2		
50mm pipe	Gate Valve	-1.4	-2.1	-0.2	0.3	0.8
	Single bend in plane	-7.9	-5.5	-3.9	0.1	0.0
	Double bend	-6.3	-4.3	-5.0		
	Reducer	-0.6	-1.5	-0.3		
	Expander	-3.1	-2.6	0.4		

Table 3: Average Percentage Shift from Baseline at Flows Greater than 1m/s for Water

C Ruppel and F Peters (Effects of upstream installations on the reading of an ultrasonic flow meter) report on the effect of a single and double bend upstream of an ultrasonic meter. The results, illustrated in *Figure 16* and *Figure 17*, support those from Sira but show smaller errors. This may reflect the greater inaccuracy of clamp-on meters compared to meters installed directly into the pipework.

Meter readings were taken at various angles around the pipe (illustrated in *Figure 15*) for each distance between the disturbance and the meter, measured in terms of pipe diameters D. This accounts for the range of errors reported in the graphs illustrated here.

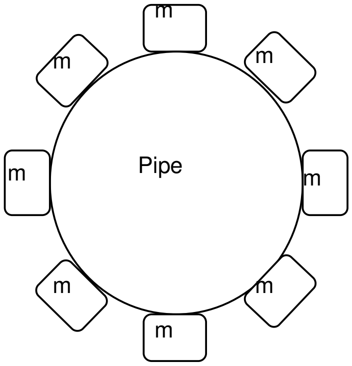

Figure 15: Meter positions around pipe

While the tests were repeated at different Reynolds number (150000 to 25000), the scatter is so small that the influence of the Reynolds number can be considered insignificant. This is to be expected because the flow/meter interaction is a question of flow structure and path arrangement, both of which are invariant in the investigated range of Reynolds numbers.

For the single 90° bend the three curves (maximum, minimum and mean error) merge at about 20 D which means that the dependence of the error magnitude and sign with angle of the meter vanishes at this point, leaving profile distortions that stop at 50 D.

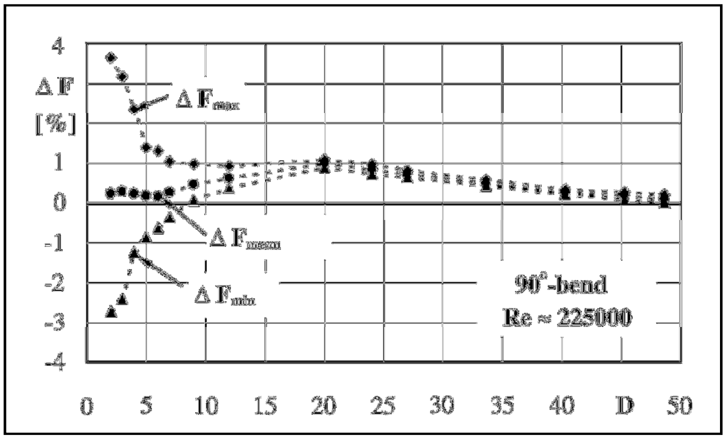

Figure 16: Flow measurement errors (ΔF) resulting from 90^o bend against distance upstream of ultrasonic meter as ratio of pipe diameter D

For the double bend the extreme values do not converge with the mean within the observation range confirming that the angular dependence in the double bend case exists well downstream of the disturbance. The mean error shift also shows a moderate upward trend and is likely to reach a maximum value more that 50D from the disturbance.

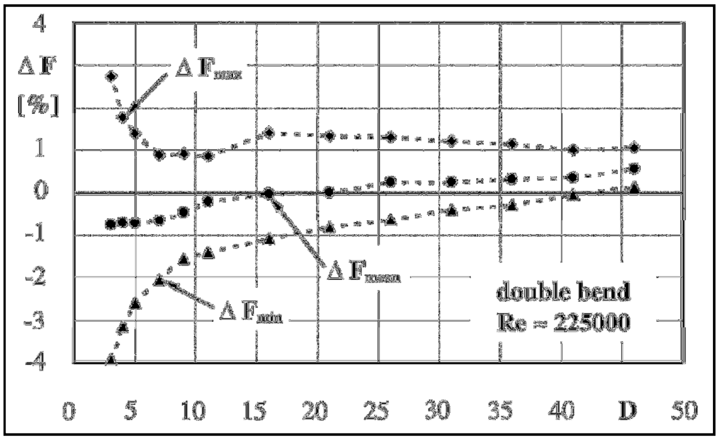

Figure 17: Flow measurement error (ΔF) resulting from a double bend against distance upstream of ultrasonic meter as ratio of pipe diameter D

These results show that errors due to bends can vary depending not only on the distance between the disturbance and the meter, but also on the position of the meter around the circumference. Errors are however low (below 2%) after around 7 pipe diameters

Carl Carlander and Jerker Delsing (Installation effects on an ultrasonic flow meter with implications for self diagnostics) report further experimental results of the effect of upstream obstructions on an ultrasonic heat meter. The experiments carried out placed the obstructions tested between 11D and 13D away from the meter.

Figure 18 through to Figure 21 show the results for 4 different upstream disturbances against Reynolds number[17]. The solid lines represent limits of reference measurements (unobstructed) with a 95% confidence level. The results suggest that the greatest error occurs around Re=4000, but that above this (when flow is turbulent) the error remains plus or minus 0.5% until Re=100,000.

The single bend shows a maximum error of around 2% compared to straight pipe at lower flowrates (Re 3000 – 5000), while the double bend shows a larger maximum error of up to 4% at lower flow.

The reducer shows little significant error until Re>100,000.

Pulsating flow causes errors up to 3% at lower flows but the results show little significant error for Re > 5000.

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[17] Reynolds Number (Re) is a dimensionless ratio between viscous and inertial forces used to characterise fluid flow. For fluid flow in pipes: $Re = \rho v d / \mu$, Where ρ = fluid density, v = fluid velocity, d = pipe diameter and μ = fluid dynamic viscosity. Laminar flow occurs for values of Re < 2300, while for values of Re > 4000 flow is turbulent.

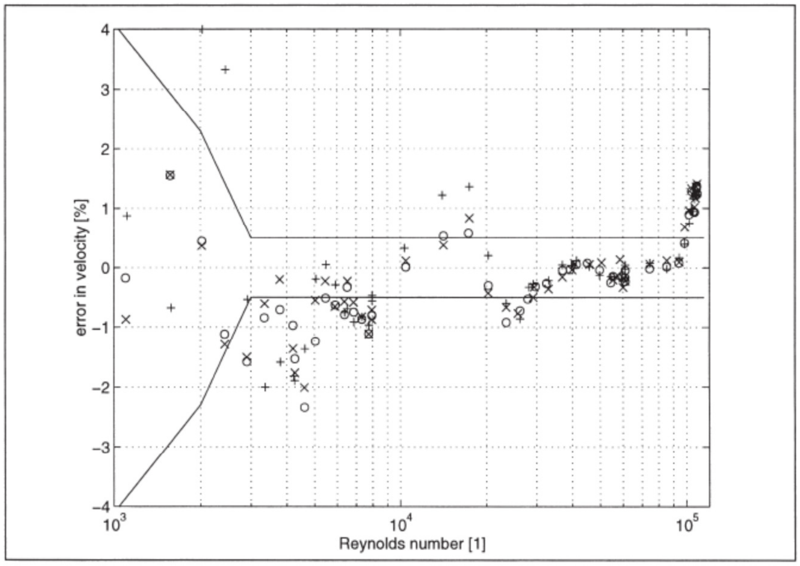

Figure 18: Percentage error due to single elbow[18]

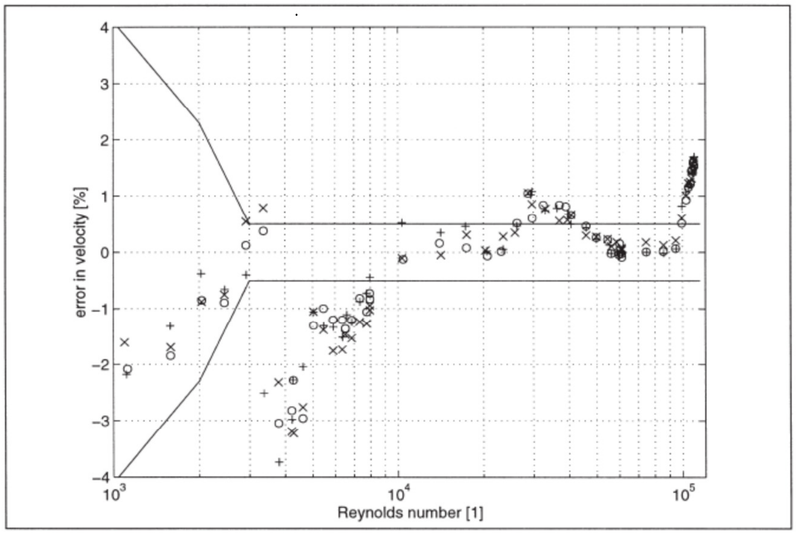

Figure 19: Percentage error due to double elbow[17]

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[18] The experiment was repeated 3 times and the different symbols represent the results from each of these 3 tests.

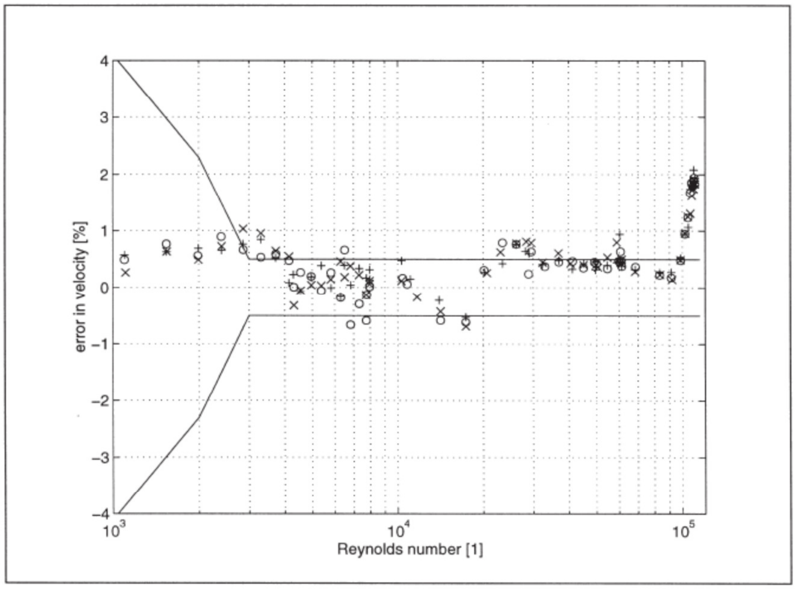

Figure 20: Percentage error due to reducer[17]

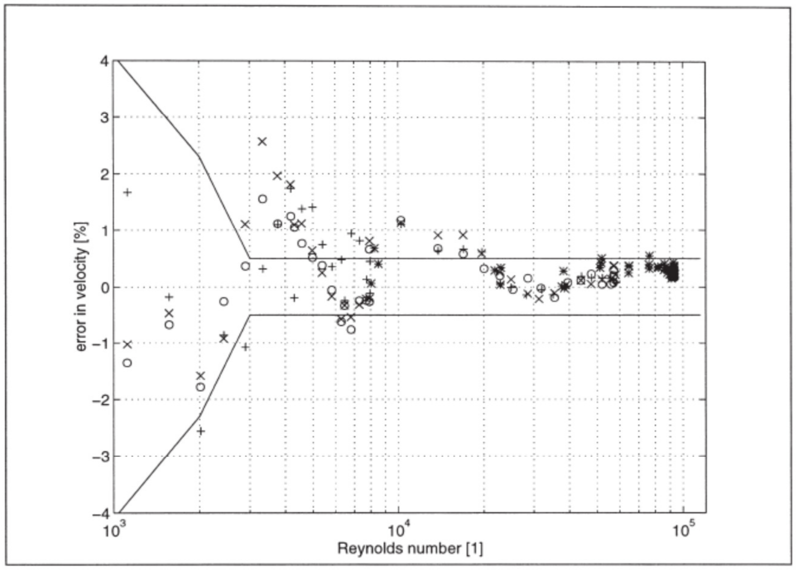

Figure 21: Percentage error due to 4.4 Hz pulsation[17,19]

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[19] Measurements are not shown for Re > 95000. There is no reference to this in the paper quoted here, but it is noted that vibration was set up at high Reynolds numbers and this may be the reason for the lower cut off point.

Laboratory Test - Reducer

Figure 22 to *Figure 24* show the results for the laboratory tests carried out with flow meters placed at varying distances (measured in pipe diameters D) from a reducer. Each figure shows the error in water flowrate measurement for different distances from the reducer together with the results with no reducer present. The values of qi, qp and qs and the upper and lower MPE for a MID Class 2 meter are also drawn to provide a reference framework.

The results for the ultrasonic and vortex meter lie within the MID error band and hence show that the presence of a reducer is unlikely to cause a serious measurement error with these types of meter.

The turbine meter results lie outside the MID error band, but the results with the reducer are similar to those without. Given the assumed displacement of the calibration of the turbine meter, the results suggest that the presence of a reducer is unlikely to cause a serious measurement error with this type of meter.

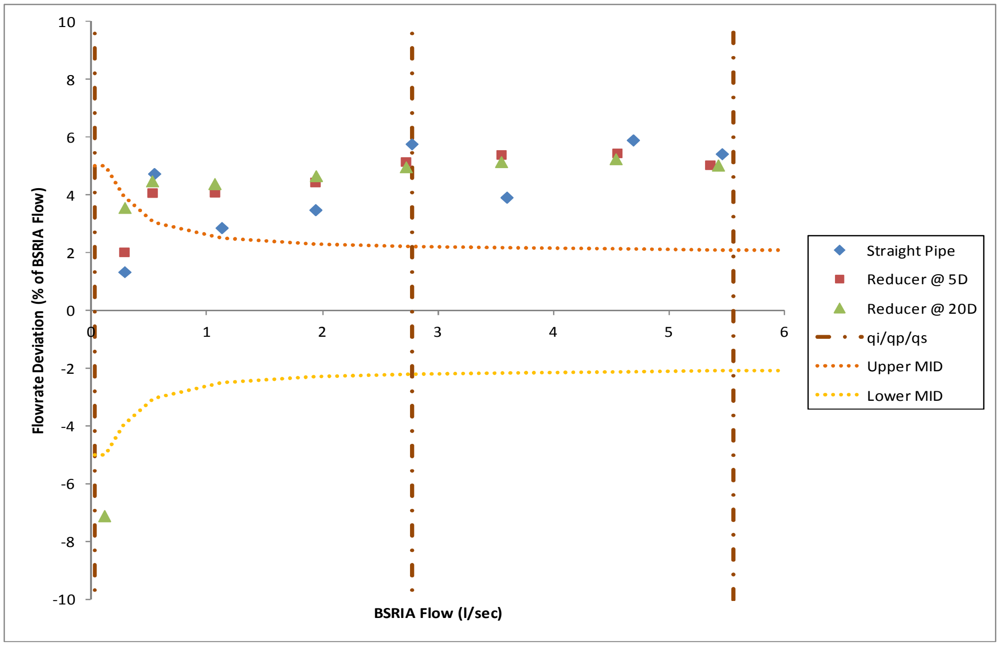


Figure 22: Laboratory Test for Reducer with Turbine Meter

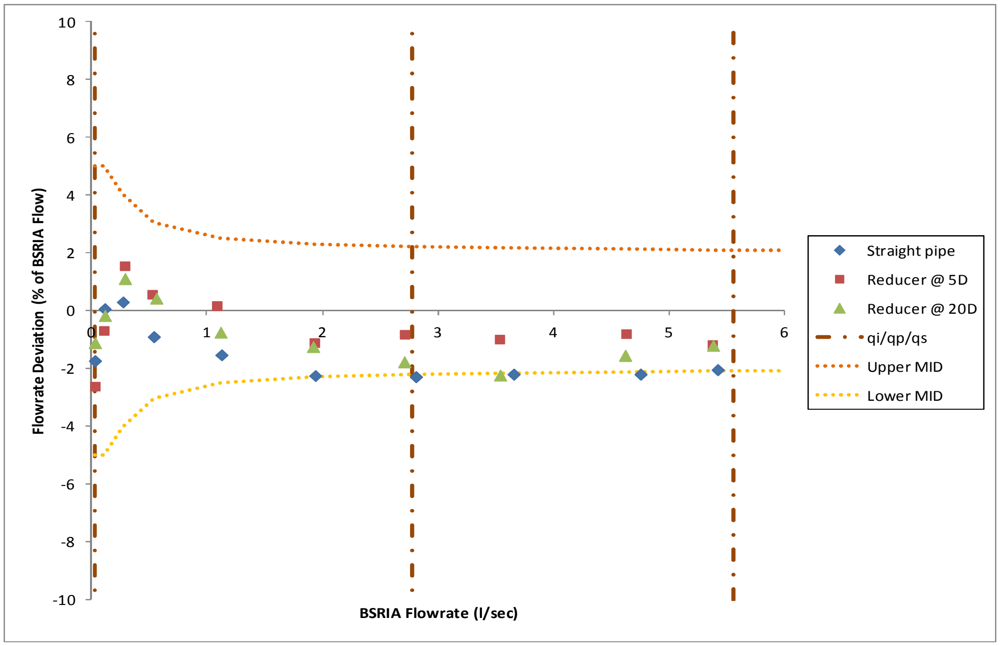


Figure 23: Laboratory Test for Reducer with Ultrasonic meter

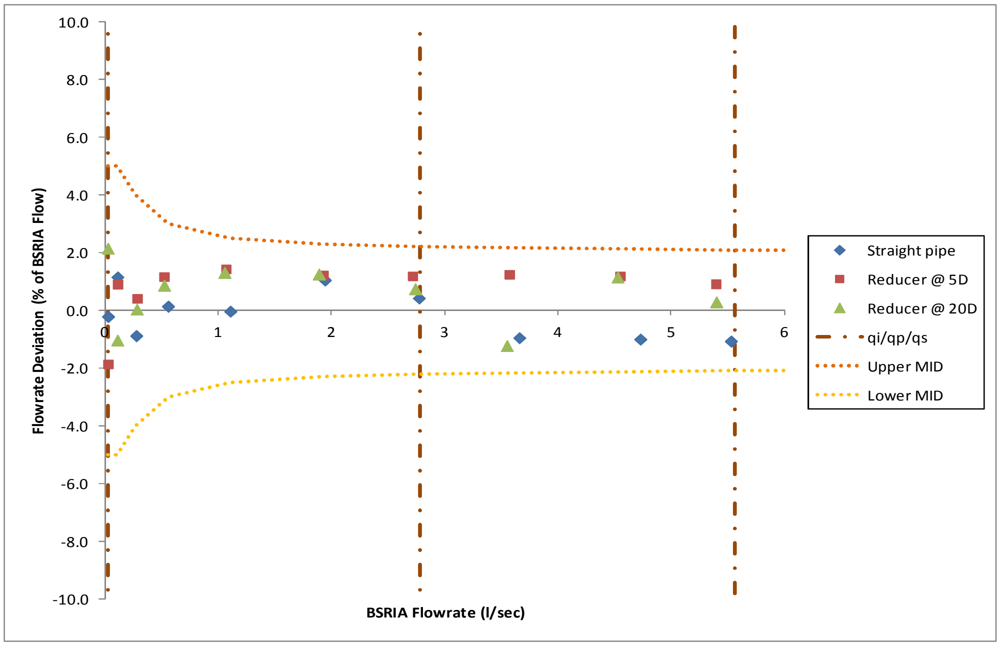


Figure 24: Laboratory Test for Reducer with Vortex Meter

Laboratory Test - Valve

Figure 25 to *Figure 27* show the results for the laboratory tests carried out with the flow meters placed at varying distances (measured in pipe diameters D) from a gate valve.

The results are very similar to those see for the reducer. The overall conclusion is that a gate valve is unlikely to cause a measurement error that exceeds the MID error band.

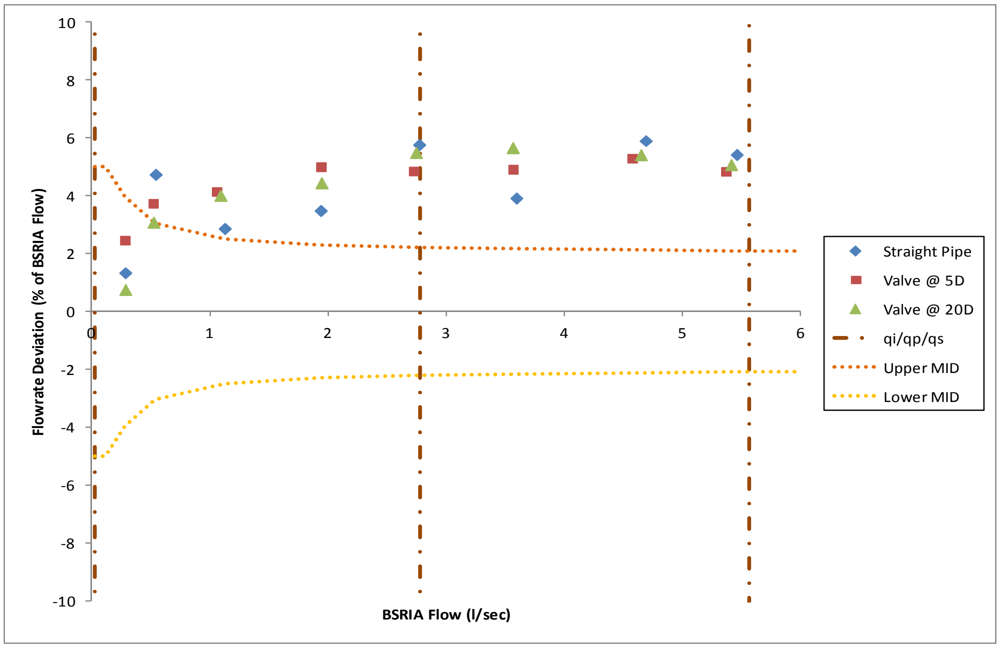


Figure 25: Laboratory Test for Valve with Turbine Meter

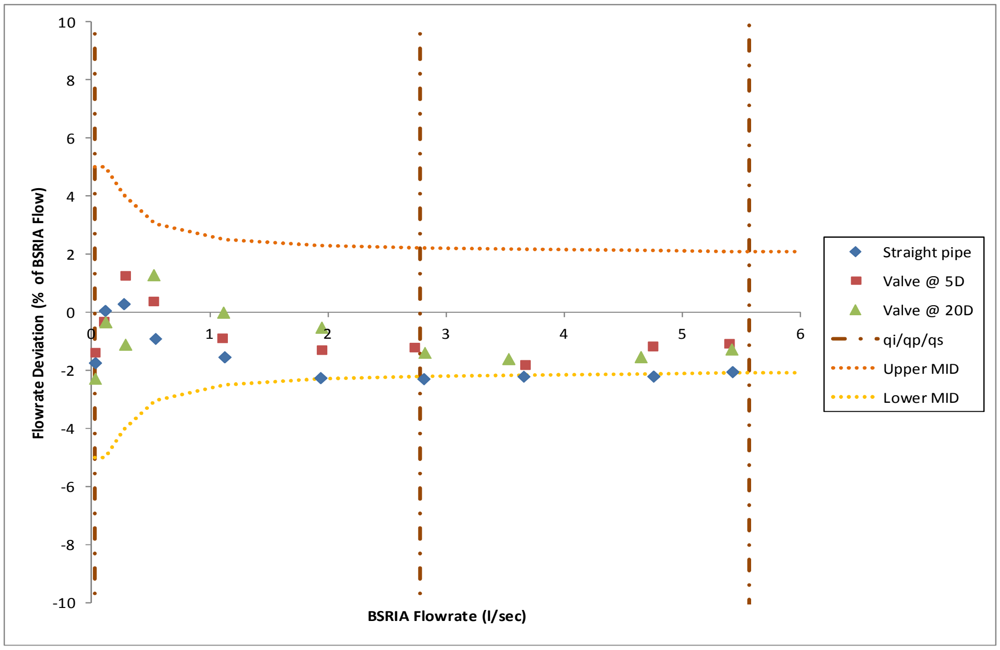


Figure 26: Laboratory Test for Valve with Ultrasonic Meter

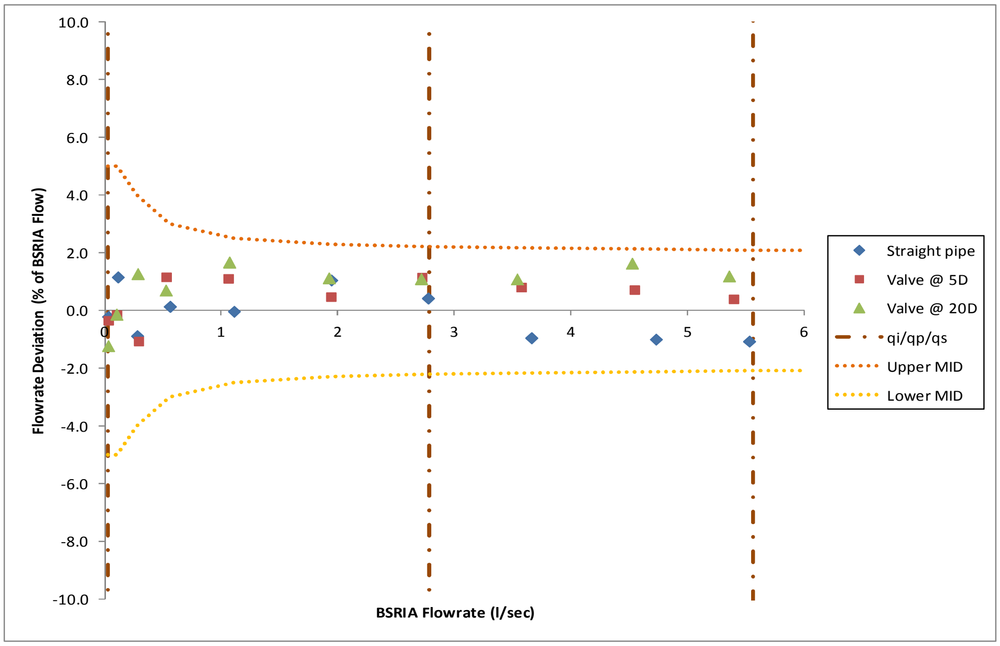


Figure 27: Laboratory Test for Valve with Vortex Meter

Laboratory Test – Double Bend

Figure 28 to *Figure 30* show the results for the laboratory tests carried out with a flow meters placed at varying distanced (measured in pipe diameters D) from a double bend.

The results for the ultrasonic and vortex meter lie within the MID error band, indicating that even placing these types of meter 5 pipe diameters downstream from a double bend is unlikely to cause a serious measurement error.

The results for the turbine meter suggest that the error may be slightly outside the MID error band. Given the displacement of the meter, error bands have been drawn at MID +4%. The results show that the readings with the meter 5 pipe diameters downstream from the double bend are slightly higher than the upper error band for flow velocities between qp and qs. However, the additional error is very small (less than 1%) and this is unlikely to lead to significant measurement error.

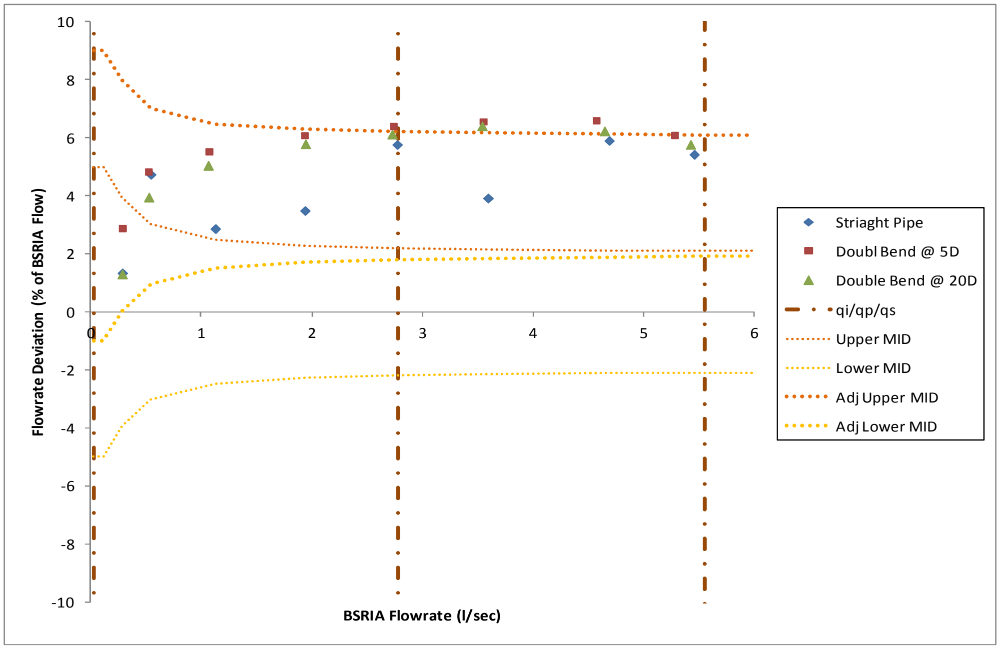


Figure 28: Laboratory Test for Double Bend with Turbine Meter

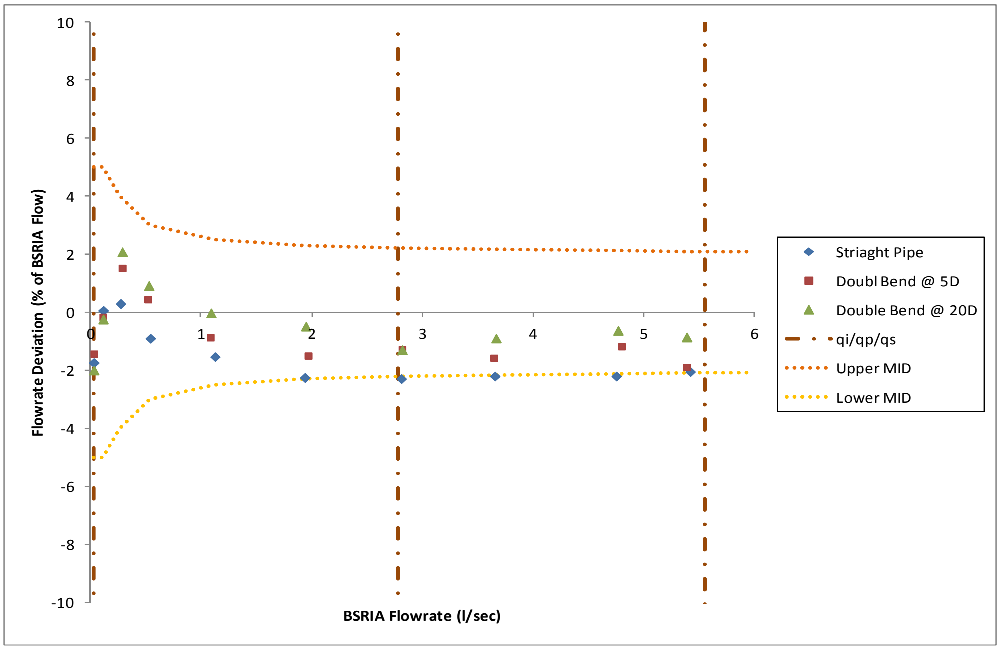


Figure 29: Laboratory Test for Double Bend with Ultrasonic Meter

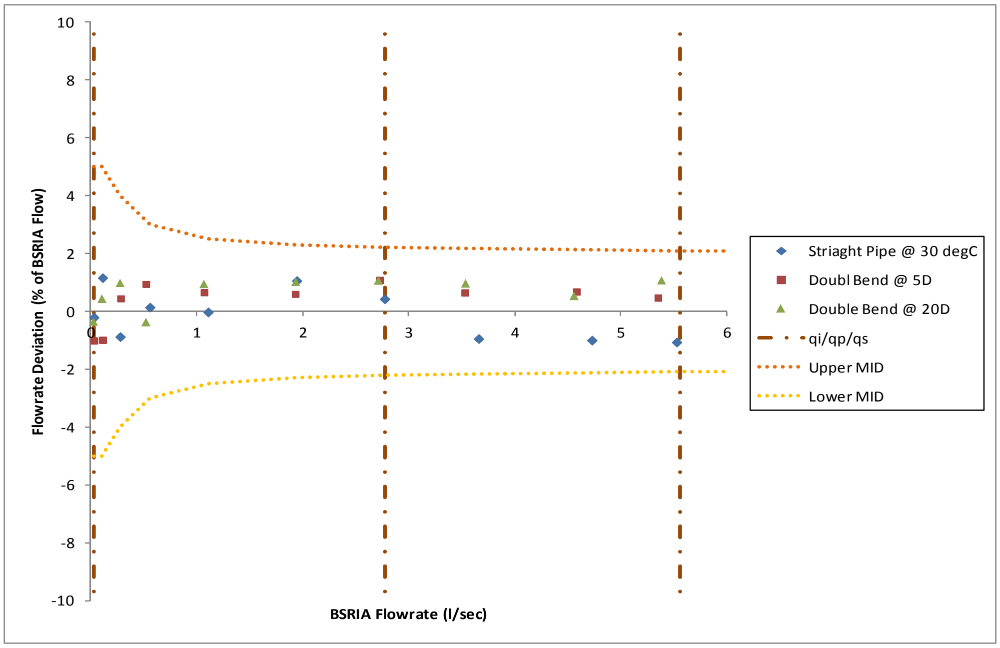


Figure 30: Laboratory Test for Double Bend with Vortex Meter

4.5 Meter Orientation

Francisco Arregui et al report on experimental results for placing a domestic scale single jet turbine water meter at 45° and 90° to the correct horizontal orientation. *Figure 31* shows the results for various water flow rates. The report states that qp for the meter is 1.5m^3/hr but does not state qi. Typically this would be between 15 and 30 litres/hr for turn down ratios of 100:1 and 50:1 respectively. At low flows there is obviously a significant discrepancy in reading when the meter is installed in the wrong orientation. This is not a time dependent factor as no specific long term wear tests were carried out with the meter in the wrong orientation, therefore some error can be anticipated from the initial installation at low flowrates.

The report concludes that the overall effect of incorrect orientation of this type of meter is likely to be an under estimate of water volumes by 1-4%.

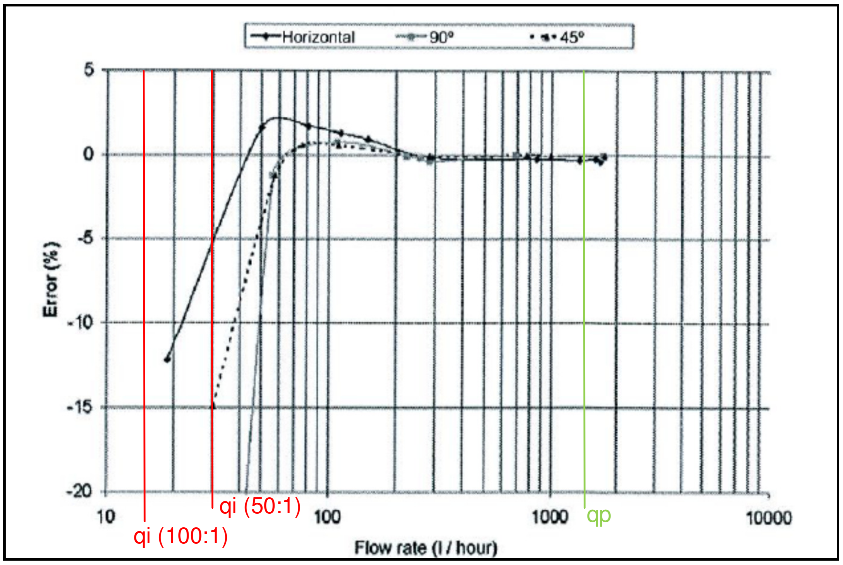
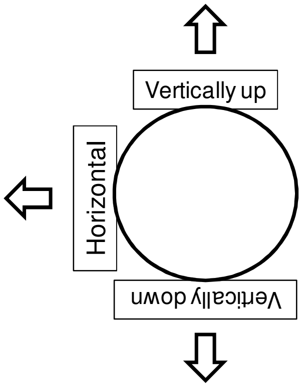


Figure 31: Affect of Incorrect Orientation of 15mm Single Jet Water Meter

Laboratory Test

Figure 32 to *Figure 34* show the results for the laboratory tests carried out with the flow meters placed at varying orientations around the circumference of the pipe.

An orientation of "vertically up" refers to the meter placed horizontally at the top of the pipe with the face upwards, "horizontal" refers to the meter placed at the side of the pipe and "vertically down" refers to the meter placed at the bottom of the pipe facing down.



The correct orientation varies from meter to meter. For the turbine meter the correct orientation is vertically up with neither horizontal or vertically down being approved by the manufacturer. For the ultrasonic and vortex meters horizontal is correct, with vertically down being considered acceptable, but vertically up not being acceptable.

The results for the turbine and ultrasonic meters are within the MID error bands (assuming a 4% displacement for the turbine meter) showing that meter orientation is unlikely to cause a significant measurement error in the short term. In the longer term wear may become an issue for the turbine meter but this cannot be tested in this set of experiments.

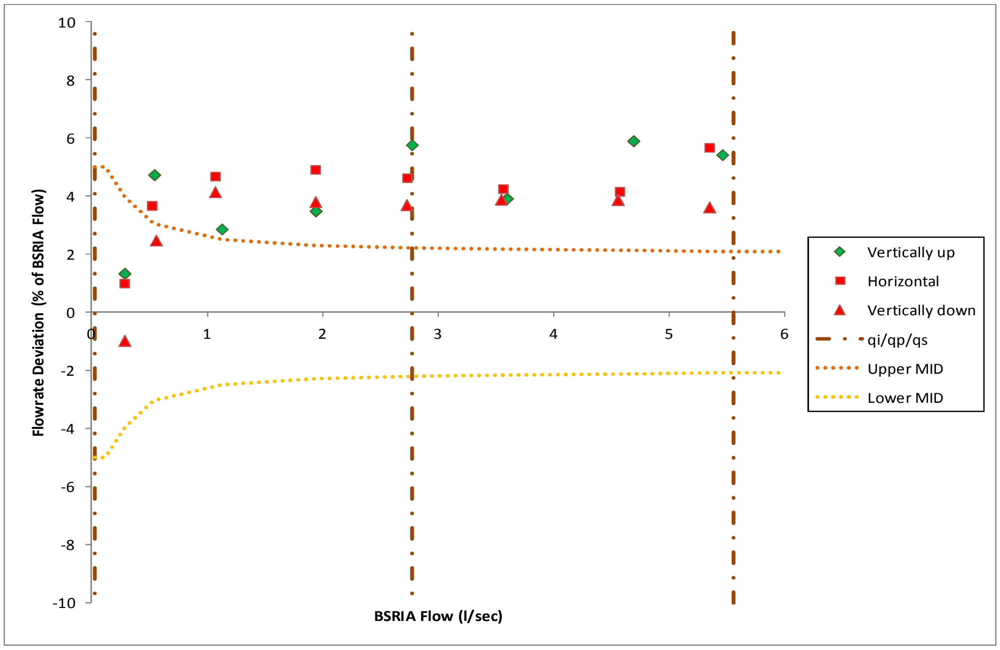


Figure 32: Laboratory Test for Flowmeter Orientation with Turbine Meter

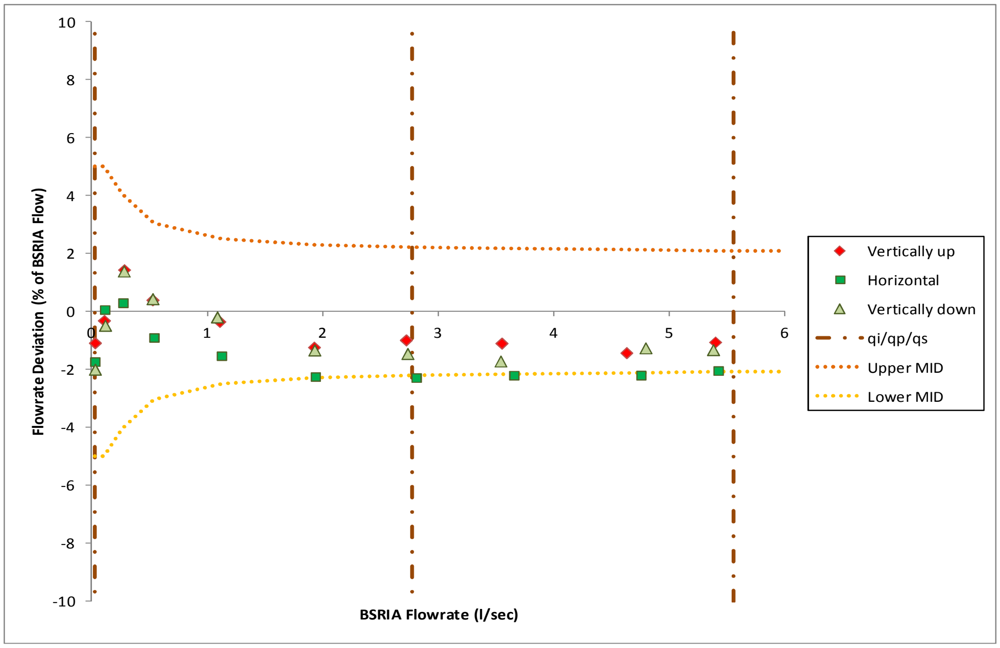


Figure 33: Laboratory Test for Flowmeter Orientation with Ultrasonic Meter

The vortex meter results fall within the MID error band for the test with the meter at straight up, but drop below the lower MID error limit for flows greater than the qp for the test with the meter straight down. This is unexpected as this is considered acceptable, if not ideal, by the meter manufacturer.

The tests with the meter facing straight down was carried out after the test with the meter facing straight up, which is not recommended by the manufacturer. A retest with the meter installed as per the manufacturer's instructions was therefore undertaken and the results (*Figure 35*) showed that the meter now appeared to be out of calibration. The shift is relatively small with the error lying at worst 1% below the MID lower limit. A check had previously been carried out during the test programme with the meter correctly installed which indicated the meter was still in calibration. This shift is therefore thought to have occurred when the meter was installed in the incorrect orientation.

The meter orientation tests were the last tests undertaken. The results for the tests before the orientation test are therefore still considered valid.

The nature of testing the meters by incorrect installation appears to be capable of causing problems with the meters and therefore any future testing should take this into account when designing the experiment.

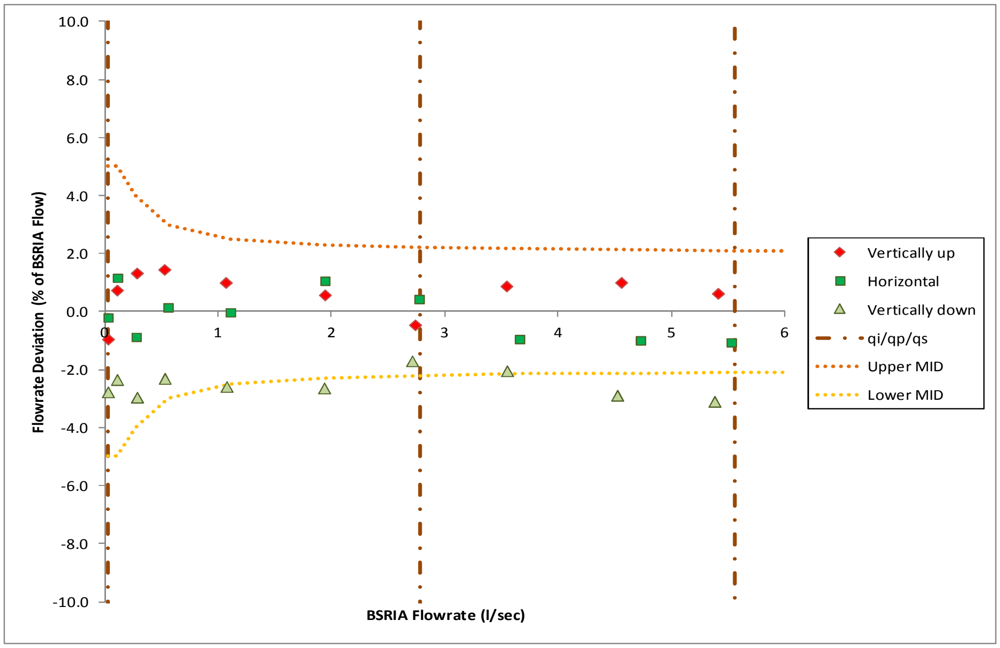


Figure 34: Laboratory Test for Flowmeter Orientation with Vortex Meter

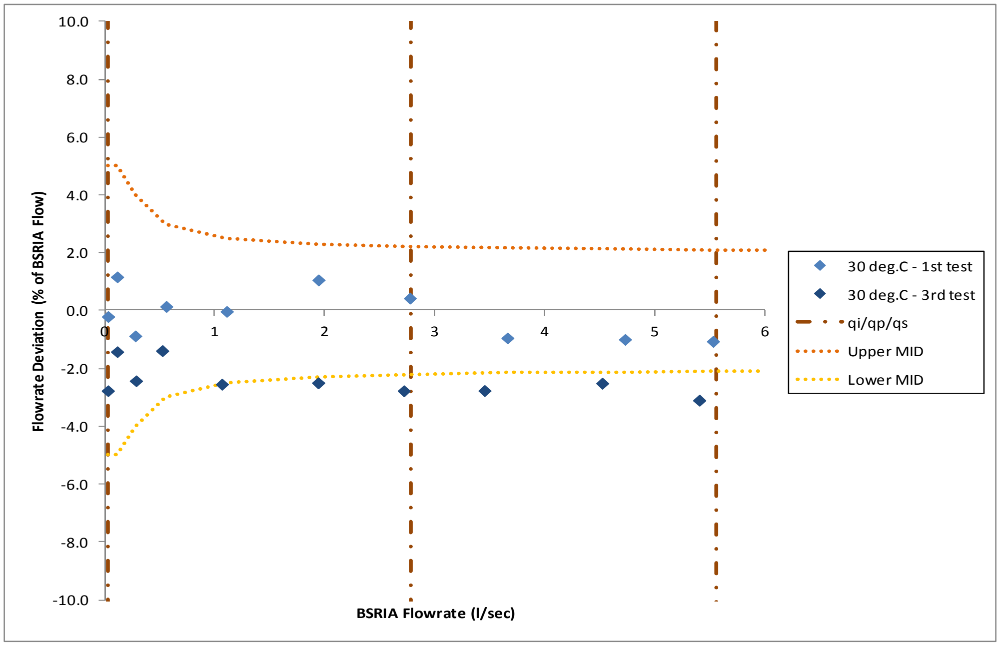


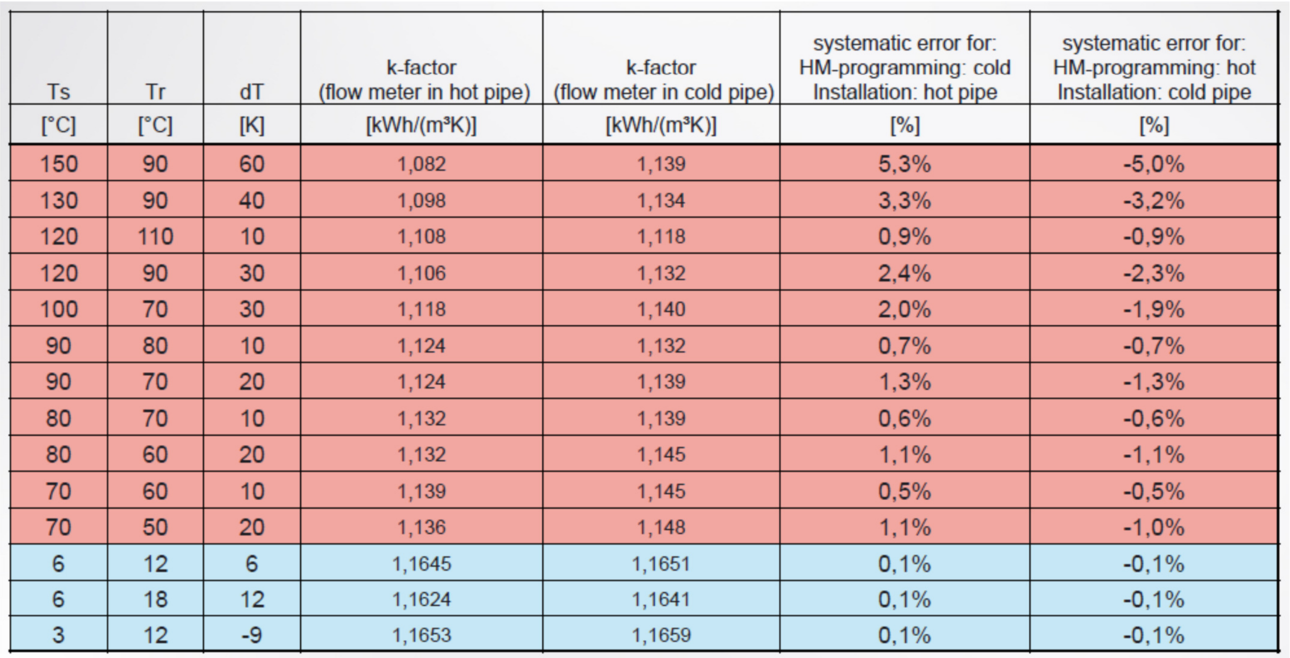
Figure 35: Vortex Meter Correctly Installed Before and After Orientation Tests

4.6 Heating Fluid Properties

4.6.1 Meter Placed in Wrong Branch

Kamstrup have provided an estimate of the error caused by placing their ultrasonic flow meters in the wrong branch (ie return instead of flow or vice versa) as being some 2.5% higher than the standard error of 2%, i.e. an absolute error of 4.5%. It was not specified whether the error was an under or over estimate.

Itron has also provided data resulting from the same installation error for their ultrasonic meters. This information indicates that for a 10°C temperature error resulting from the incorrect location of the meter the measurement error will be less than 1%, with a difference of 60°C giving an error of around 5%. The errors are positive where the fluid is hotter than expected and negative when lower than expected. *Table 4* provides the full set of results.



Ts	Tr	dT	k-factor (flow meter in hot pipe)	k-factor (flow meter in cold pipe)	systematic error for: HM-programming: cold Installation: hot pipe	systematic error for: HM-programming: hot Installation: cold pipe
[°C]	[°C]	[K]	[kWh/(m³K)]	[kWh/(m³K)]	[%]	[%]
150	90	60	1,082	1,139	5,3%	-5,0%
130	90	40	1,098	1,134	3,3%	-3,2%
120	110	10	1,108	1,118	0,9%	-0,9%
120	90	30	1,106	1,132	2,4%	-2,3%
100	70	30	1,118	1,140	2,0%	-1,9%
90	80	10	1,124	1,132	0,7%	-0,7%
90	70	20	1,124	1,139	1,3%	-1,3%
80	70	10	1,132	1,139	0,6%	-0,6%
80	60	20	1,132	1,145	1,1%	-1,1%
70	60	10	1,139	1,145	0,5%	-0,5%
70	50	20	1,136	1,148	1,1%	-1,0%
6	12	6	1,1645	1,1651	0,1%	-0,1%
6	18	12	1,1624	1,1641	0,1%	-0,1%
3	12	-9	1,1653	1,1659	0,1%	-0,1%

Table 4: Measurement Errors from Placing Ultrasonic Meter in Wrong Branch

Note

Ts = Supply (or flow) water temperature

Tr = Return water temperature

K-factor is the meter coefficient and is characteristic of a meter operating under specific conditions. The definition depends on the type of meter and the value depends on the operating conditions of the meter,

4.6.2 Water Glycol Mixes

The addition of glycol will affect the physical properties of the heating fluid, including the specific heat capacity, density and viscosity. Theoretically, specific heat capacity and density will affect all types of meter, with viscosity affecting vortex and turbine meters. Optical and magnetic properties could also change affecting other types of meter.

Calculated Theoretical Error

An estimate of the effect of heat transfer fluid properties on the measurement of heat can be made based on standard heat transfer equations and the known properties of typical heat transfer fluids. The following example illustrates the theoretical error in measured heat transfer resulting from measuring pure water with a meter set up to measure a 30% glycol/water mix.

Table 5 gives the properties of pure water and an (unspecified) ethylene glycol / water mix at two different concentrations[20]. Properties for propylene glycol were not available for a range of temperatures.

	Pure Water			Percentage Glycol					
				30%			45%		
Temperature (°C)	Density (kg/m^3)	Specific heat (kJ/kg.K)	Viscosity (centiPoise)	Density (kg/m^3)	Specific heat (kJ/kg.K)	Viscosity (centiPoise)	Density (kg/m^3)	Specific heat (kJ/kg.K)	Viscosity (centiPoise)
4.4	1000	4.205	1.546	1057	3.726	3.500	1079	3.402	5.650
25	997	4.181	0.890	1045	3.776	1.700	1065	3.475	2.500
50	988	4.182	0.547	1026	3.831	1000	1044	3.573	1.400
70	978	4.191	0.404	1002	3.873	0.700	1021	3.642	0.875
90	965	4.208	0.314	978	3.919	0.500	996	3.705	0.650

Table 5: Properties of Glycol / Water Mixes

The effect of measuring pure water with a meter set up to measure a 30% glycol / water mix can be estimated based on the equation for heat:

$$Q = V \rho \, Cp \, \Delta T \quad \text{kWh}$$

Where:

Q = heat energy (kWh)
V = volumetric flowrate of heat transfer fluid (m^3/s)
ρ = density of heat transfer fluid (kg/m^3)
Cp = specific heat capacity of heat transfer fluid (kJ/kg.K)
ΔT = the temperature difference between the flow and return (K)

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[20] Properties taken from The Engineering Toolbox (www.EngineeringToolBox.com).

Strictly this is not the correct equation to use as meters use the specific enthalpy to calculate the energy transfer over time. However, this formula represents an acceptable estimate given available information.

Assuming:

Heat flow measured for 1 hour
$V = 0.1\ m^3/s$
$\Delta T = 10^oC$ at an average temperature of 50^oC

From *Table 5*

$\rho.Cp$ pure water = 988 x 4.182 = 4132 $kJ/m^3.K$
$\rho.Cp$ 30% glycol = 1026 x 3.831 = 3929 $kJ/m^3.K$

The meter is set up for 30% glycol and therefore calculates the heat consumption to be 3929 kWh. However, the actual consumption is 4,132 kWh, some 5% higher than that reported.

A similar calculation carried out for a meter set up for a 45% glycol mix shows a potential under read of 10%.

If the meter were set up for pure water and installed with a glycol mix the error would be an over estimate of heat consumption.

Laboratory Tests

Laboratory tests have been carried out on the flow meters of each of the three types of heat meter with three concentrations of mono-ethylene and mono-propylene glycol.

The results for the turbine meter (*Figure 36* and *Figure 37*) are outside the MID error limits even adjusting for the estimated +4% meter offset. The results show an error that is relatively small with the worst case over reporting the flowrate by around 3%. Concentration of glycol does not appear to make a substantial difference in the results, nor does the type of glycol.

The results for the ultrasonic meter (*Figure 38* and *Figure 39*) show one or two points that lie outside the MID error band, but the error is very small being less than 1% below the MID band. There is no trend of over or under reading as most points lie within the MID error band. Neither glycol concentration nor type appears to affect the results. Overall the results suggest that using an ultrasonic flow meter calibrated for water with a glycol / water mix will not lead to a significant flow measurement error.

The results for the vortex meter (*Figure 40* and *Figure 41*) all lie within the MID error band, suggesting that using a vortex meter calibrated for water with a glycol / water mix will not lead to a flow measurement error.

While the use of a flow meter calibrated for water with a glycol / water mix does not appear to lead to a large error in flow measurement, the overall heat meter will still read incorrectly due to errors resulting from the wrong physical properties being used in the calculator units.

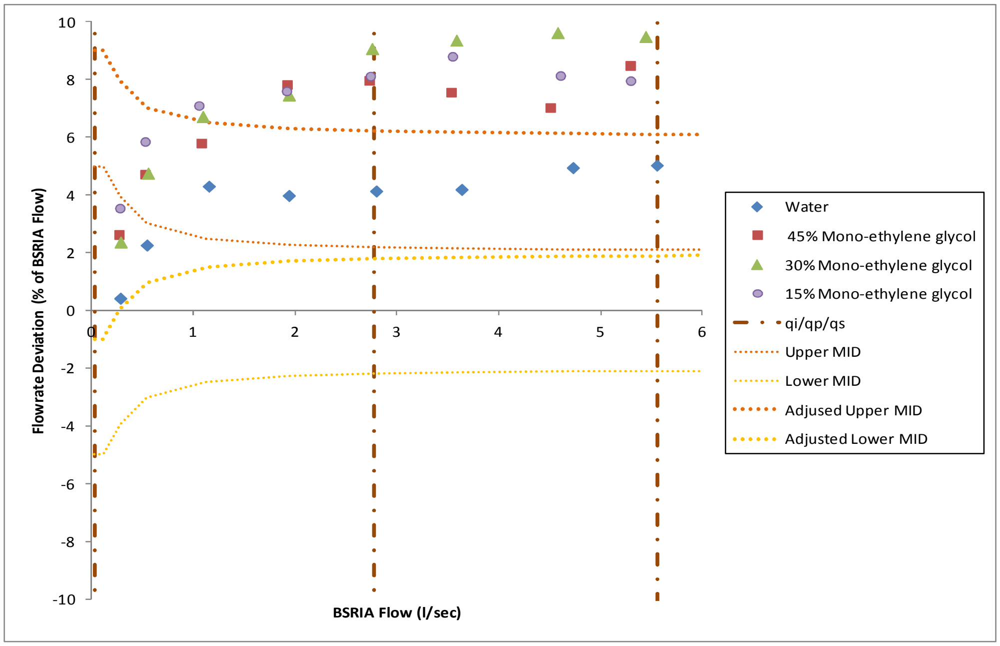

Figure 36: Laboratory Test for Mono-ethylene Glycol with Turbine Meter

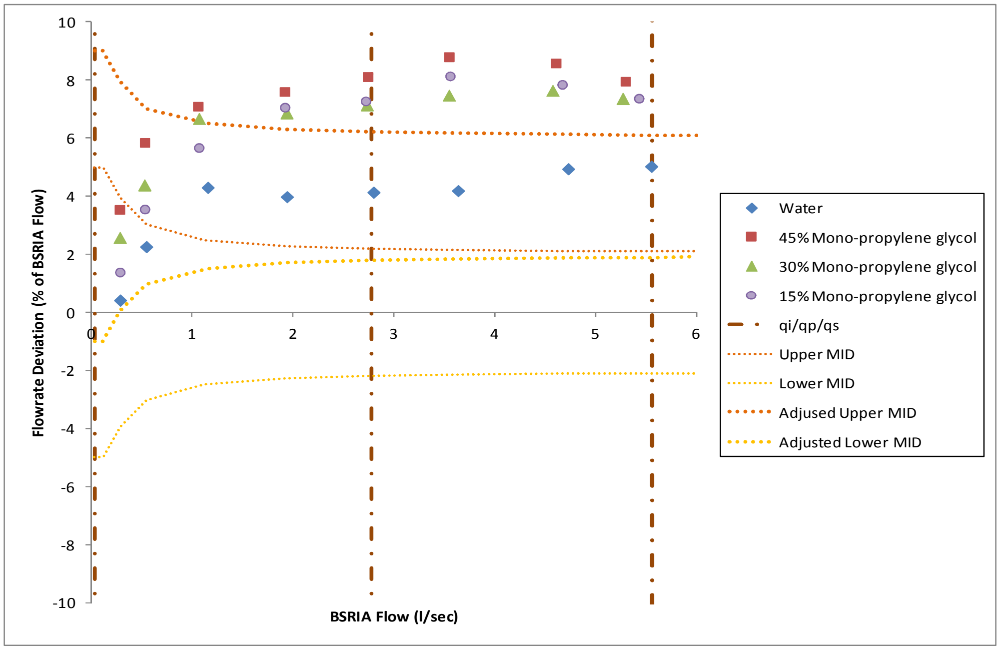

Figure 37: Laboratory Test for Mono-propylene Glycol with Turbine Meter

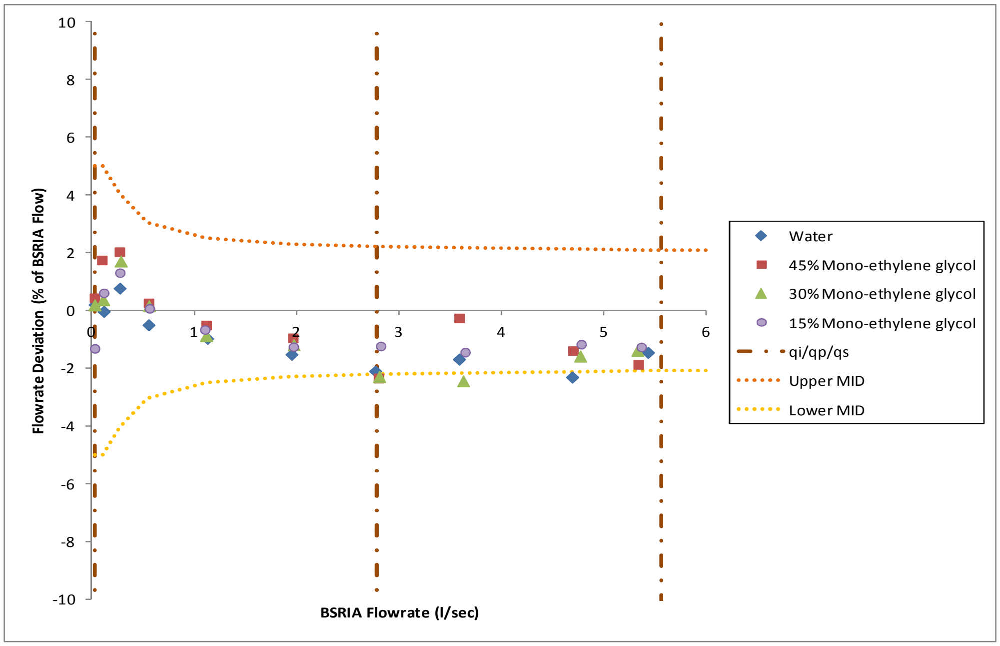

Figure 38: Laboratory Test for Mono-ethylene Glycol with Ultrasonic Meter

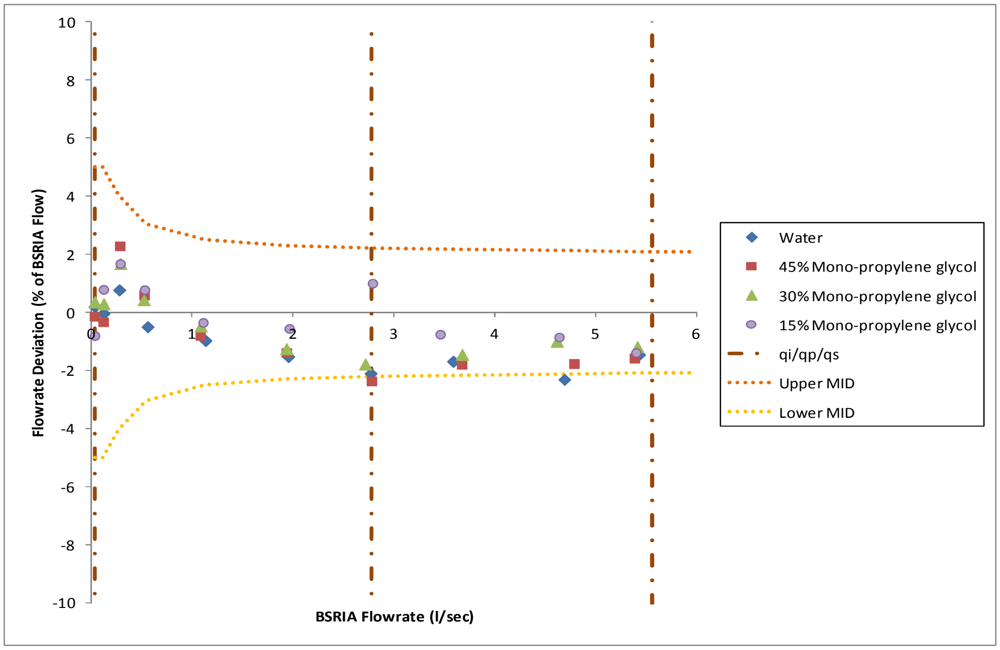

Figure 39: Laboratory Test for Mono-propylene Glycol with Ultrasonic Meter

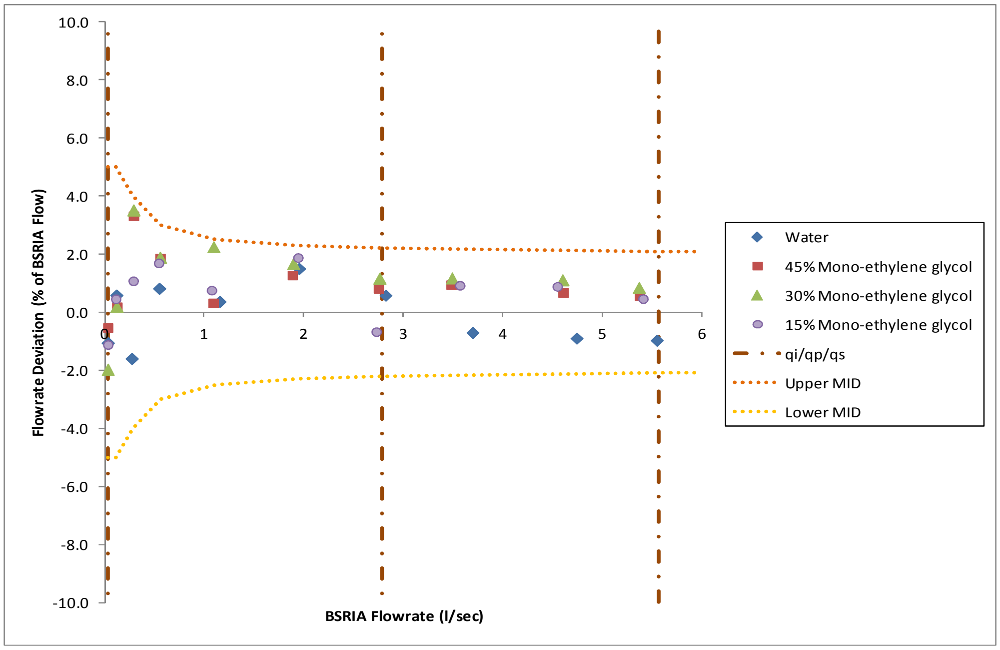

Figure 40: Laboratory Test for Mono-ethylene Glycol with Vortex Meter

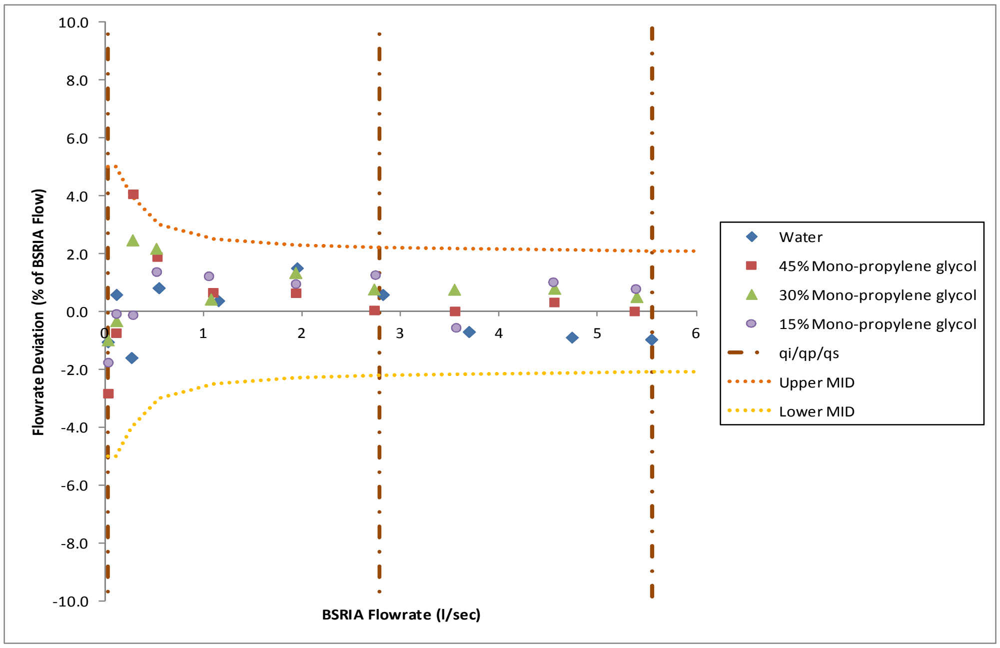

Figure 41: Laboratory Test for Mono-propylene Glycol with Vortex Meter

4.7 Temperature Probe Installation

Figure 42 illustrates the errors in temperature difference recorded in laboratory tests for three different temperature probe installations. The correct installation is with the probes in pockets with thermal grease. The results for this installation are within the MID MPE band. When the thermal grease is missing then the results are slightly worse but still very close to the MPE band and at higher temperature differences do not appear to be a cause for concern. The installation of the temperature probes on the outside surface of the pipe[21] however, shows a high level of error well outside the MPE band and indicating under-reading of temperature difference.

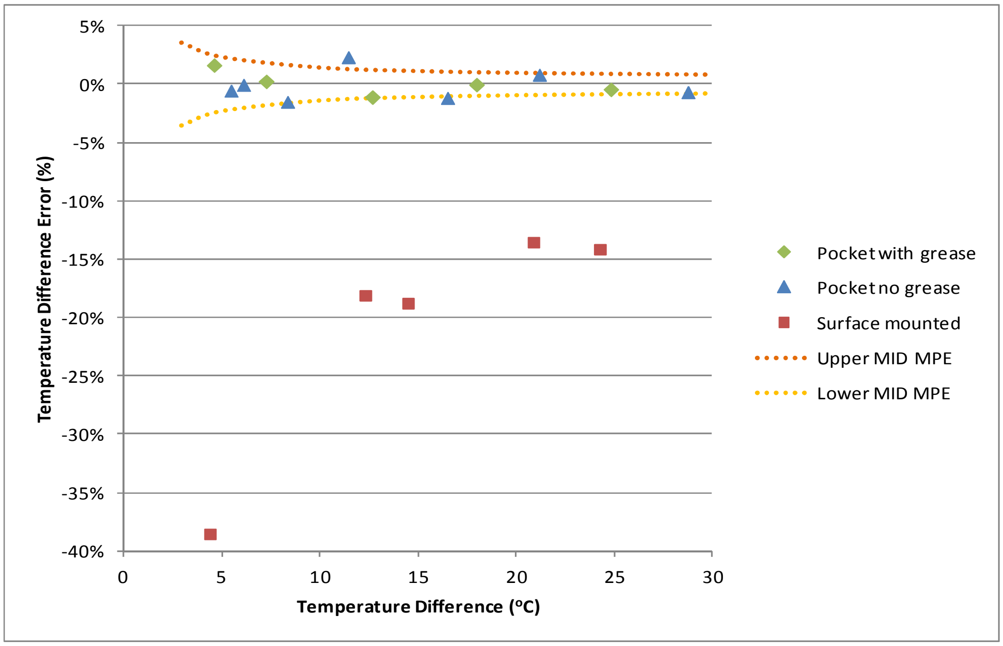

Figure 42: Errors Due to Incorrectly Installed Temperature Probes

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[21] The probe has been strapped horizontally in line with the pipe with insulation over the top.

Installation Good Practice

5 Installation Good Practice

A complete manual on how to install a heat meter would be a substantial document as each type of meter has different requirements. The following is intended to form a set of general principles that work for most meters and cover some of the items not covered by the meter manufacturer's guide as they are to do with the heating system design.

System Design

- Reduce the risk of gas entrainment through:
    - Install a de-aerator and ensure that the system can be vented at all high points.
    - Ensure the static pressure at the meter for the system operating temperature is above the minimum pressure recommended by the manufacturer. This should be the static pressure at the highest anticipated flowrate within the meters measurement range.
- Reduce the risk of dirt in the system affecting meters through:
    - Install a side stream filter within the heating circuit.
    - Install a fine mesh strainer 20 pipe diameters before the flow meter.
- Ensure the meter is calibrated for the correct working fluid, i.e. water or water / glycol mix. There is also an ongoing need to monitor water / glycol mixes to ensure they remain close to the intended concentration,
- Install meters in accordance with manufacturer's guidance, but in general:
    - Ensure the flow meter is installed 20 pipe diameters downstream, and 10 pipe diameters up stream, of bends, valves or other fittings. Where a meter is installed downstream of a double bend then it should be at least 50 pipe diameters downstream.
    - Do not install meters downstream of pumps or fast acting valves that could set up pulsating flow.
    - Do not install meters at high points in pipework.
    - Do not install meters on vertical pipework with upward flow.
    - Ensure the meter has the same diameter as the pipework. If a reducer or expander is required these should be at least 20 pipe diameters up stream and 10 pipe diameters downstream of the meter.
    - Ensure gaskets are correctly fitted where meters are connected with flange joints. The gasket should not protrude into the water flow.
- Ensure temperature sensors are installed correctly:
    - In the correctly sized pocket so that the sensor is in the main flow.
    - Use a suitable thermal grease to pack temperature sensor pockets.
    - Avoid exposed lengths of temperature probe or un-insulated areas of pipe around the probe.

  - Ensure that both temperature sensors have the same length of communication cable and that these are within the length limits stated by the manufacturer/supplier.
- Ensure power cables are not routed near meter components or communication cables other than the necessary power connection for the meters.

System Commissioning

Two of the worst problems reported by manufacturers are air and dirt in the heating system. Correct design, commissioning and maintenance of the system can help to minimise these two items.

- Ensure system has been chemically cleaned before flushing.
- Ensure system is flushed in accordance with BSRIA BG 29/2012. Heat meters should have flushing loops to avoid debris damaging or getting stuck in the meter.
- Ensure air has been removed from the system before setting to work.
- Vent air from high point after operation has commenced and system is up to temperature.
- Ensure the system water has been appropriately chemically treated.

RHI Phase 2 – Domestic Installations

6 RHI Phase 2 – Domestic Installations

The focus of this report has been on non-domestic installations for Phase 1 of the RHI. However, in this section of the report some consideration is given to domestic installations.

6.1 Meter Standards

In the Domestic RHI, installations which \re required to meter eligible heat must use meters to MID accuracy Class 3. This is a more relaxed standard than the Class 2 meters required for non-domestic installations.

Figure 4 and *Figure 5* (in Section 2) show how the MPE will vary for a Class 2 meter. *Figure 43* shows that if the meter were constructed to Class 3 rather than Class 2 that the MPE at the design flowrate would be around 1% higher, with the MPE converging towards a maximum at qi regardless of the class. The highest MPE, which occurs when the temperature difference and flow are at their minimum values, is 10% regardless of the accuracy class. The generally higher error for a Class 3 meter is due to more relaxed MPE for flow measurement.

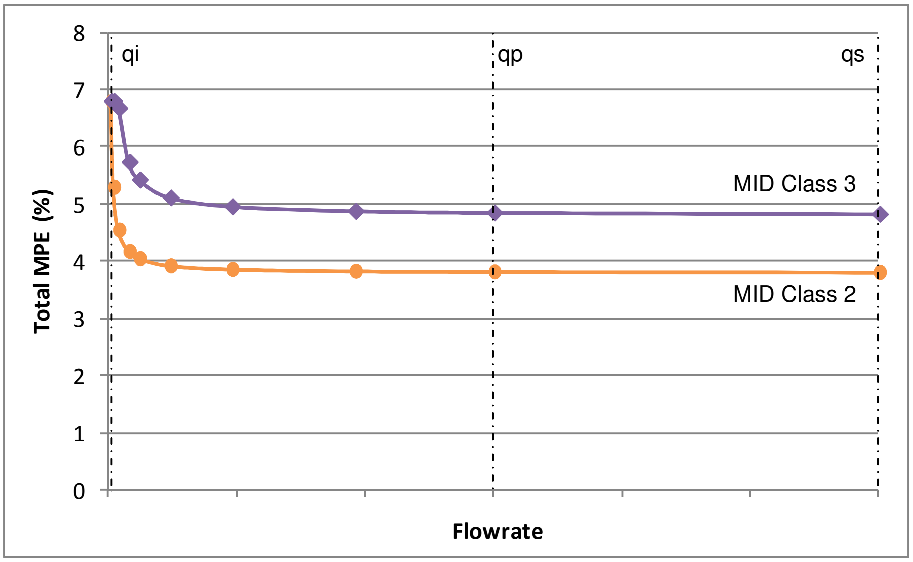

Figure 43: MID MPE for Class 2 v Class 3 Meters

Assuming all meters are installed correctly then the inference from this reduced meter accuracy is that there would be roughly 1% greater average error for the domestic than non-domestic installations.

It is not clear whether the relaxed meter standards would lead to different behaviour with regard to meter installation errors. Some of the references quoted in Section 4 of this report deal with domestic scale meters and therefore it is inferred that there would be little change in meter behaviour. If this is the case then the additional error would in fact be lower for domestic installations as the error band for a correct installation would be higher.

6.2 Potential Installation Issues

Specific meter types have been seen to have particular issues with specific installation problems. It is therefore worth considering how installing meters in a domestic environment might influence the different meter types.

Space

The relatively confined spaces, typically available for heating equipment in dwellings, are likely to make installing meters according to manufacturer's guidance challenging. In district heating installations, most heat meters are installed as part of a hydraulic interface unit pre-fabricated package where the aim is to reduce the size of this unit as far as possible. Hence providing a straight length of pipe of 20 diameters upstream of the meter is hardly ever possible

The meter tests suggest that a number of installation errors have a relatively minor influence, but four specific issues are worth more attention and may be worth concentrating on in any guidance provided as part of RHI supporting documentation.

- Meter downstream of double bends:
  Can lead to increased errors for all types of meter.
- Meter close to pumps, either upstream or downstream:
  Can lead to cavitation / local pressure reduction which can cause large errors, particularly in ultrasonic and vortex meters.
- Meters installed vertically with flow upward:
  Can lead to gas entrainment in meter leading to large errors or stopping the meter working.
- Meter installed in incorrect orientation:
  Can cause ultrasonic meters to stop working due to gas entrainment and can cause long term wear in mechanical meters leading to large errors or meter failure.

System Operation

Domestic installations can operate for relatively short periods of time depending on time of year and occupancy. This should not affect long term quarterly reporting, but would influence meter choice if short reporting periods are required as those meters using a pulse output may not have the definition needed.

Domestic systems also tend to switch on and off during the day leading to relatively long operating periods where the system is in warm up or cool down mode. It is possible that temperature differences may be reduced during these periods leading to slightly raised average errors, although this will affect all types of meter.

The need to match the heat meter type with the frequency of readings required has already been noted in the premium payment scheme where a specific meter type is used. However, this may be considered restrictive if this is required for all domestic installations.

Water Quality

As seen in these investigations, entrained gases and other water quality issues can cause considerable meter errors, and in some cases lead to meters failing to read. Some key points to consider are:

- Entrained gases are present in most domestic systems:
  Ultrasonic meters seem to be particularly prone to problems with gas (potentially recording no flow) and may therefore not offer the best solution for individual dwelling installations. Turbine meters appear to be the most robust meter when gases are present (showing little or no additional error) with vortex meters showing errors of up to 14%.

  It is unlikely that a de-aerator would solve the problem unless the system is very well sealed, nor is the cost likely to be justifiable.

  Good quality construction with well sealed joints will reduce air ingress and sealed pressurised systems are likely to suffer less than atmospheric systems (systems that are open vented to header tanks). However, a sealed system should have a pressure gauge installed and a system available for the occupant to easily re-pressurise the system
- Commissioning may not be carried out to a high standard:
  At the very least the system should be flushed and inhibitor added.
- A fine mesh strainer should be installed 20 pipe diameters or more upstream of the flow meter.
- Maintenance tasks need to be carried out at least annually to keep the system in good working order including:
  - Check to ensure that the concentration of inhibitor is maintained when makeup water is added to the system.
  - Clean filter upstream of meter.
  - For sealed systems check and re-pressurise the system if required.

6.3 Options for Improving Meter Installations

While much of the good practice set out in Section 6 also applies to domestic systems, there remain greater challenges from limited budgets and space for the installation. Recommendations for domestic installations are:

- Consider developing a series of template designs for meter assemblies that can be installed into a domestic heating system, together with a guidance document. A pre-fabricated meter assembly could include filters, correct straight lengths of pipe and the necessary isolation valves.
- Annual maintenance is carried out which includes checks that static pressure is being maintained and that air has been bled from system.
- Where dwellings are connected to a district heating system, the heat meter should be installed on the primary side of a heat exchanger which would normally be at a higher pressure and with better maintained water than the secondary dwelling circuit (which is usual practice).

Conclusions and Recommendations

7 Conclusions and Recommendations

An initial review of meter installation errors identified a substantial range of potential problems. There is relatively little information readily available on the magnitude of errors. The range of responses to the different types of meter also complicates the determination of error magnitude. A limited set of laboratory experiments have been undertaken to supplement the existing literature. The limited experimental work carried out by this study means that the results should be treated with some caution as it has not been possible to prove repeatability of results.

Table 6 summarises the results of the investigations into error magnitudes. Actual meter behaviour is complex and therefore a degree of simplification has been used with the aim of drawing out the main trends.

It should be noted that all meters are MID Class 2 and therefore the flow meters could have an error of ±2% across most of their measurement range. The errors given in *Table 6* therefore need to be compared to the MID limit when considering their potential importance.

A further test, not reported in *Table 6*, was carried out on the installation of temperature probes. This showed that large negative errors of -15% to -40% were likely to occur if a probe was strapped to the outside of a pipe instead of being inserted into a pocket.

One clear message from meter manufacturers is that free gases and dirt can be sources of substantial error. Of the other potential problems investigated only using a heat meter calibrated for the wrong heat transfer fluid (up to 10% error) and installing a temperature probe on the outside of a pipe (only encountered in domestic installations to date, but up to 40% under reading) showed evidence that the error magnitude may be significant.

Laboratory tests have indicated that ultrasonic meters are very sensitive to gas bubbles while turbine and vortex meters are less so. While many of the installation problems can increase the risk of gas bubbles forming and getting into meters, affecting the measurements, predicting when this may happen is difficult. There are a number of system design issues that can increase the risk of problems with gas bubbles that good practice could design out and hence reduce the risk of measurement errors.

One system design problem highlighted by the laboratory tests was the issue of low system pressures, which may occur locally due to specific circumstances, such as placing the meter near a pump. This is believed to have caused some unexpected errors with the vortex meter and may have been responsible for not being able to achieve the full flow range in the original test rig.

It has also been seen that the carrying out of tests on the heat meters can affect the meter as the turbine meter showed errors outside the MID error band after carrying out the original tests, even when installed as per manufacturer's instructions in the second test rig. Similarly after carrying out the orientation tests in the second test rig the vortex meter also showed errors outside the MID error band with correct installation. Some of the reasons for this could be:

- Install the meters in ways that go against manufacturer's instructions.
- The action of frequently changing the meters over in the test rig, which would not normally be expected in a real installation.
- The way the meters were stored between the initial tests and the retests, with the meters being disconnected from the rig.

Future tests therefore need to take into account these factors when designing the test rig, so that the influence of the tests themselves is reduced as much as possible.

	Error Magnitude by meter type			Comment	Frequency of Error[22]
	Turbine	Ultrasonic	Vortex		
Gas entrainment	Within MID limits	Can stop reading	Within MID limits	Ultrasonic meter can identify there is a problem and report an error.	No data available
Wrong fluid [23]					4%
Meter calibrated for water used with glycol/water mix	Up to +5%	Within MID limits	Within MID limits	Calculator error will lead to an over estimation of energy.	
Meter calibrated for glycol/water mix used with water	No measurements have been made			Calculator error will lead to an under estimation of energy.	
Meter in wrong orientation	Within MID limits	Within MID limits	Up to -3%	After further test vortex meter error considered calibration drift rather than actual error. Removing air from the system was a problem with ultrasonic meter. While a function of the test, it could be problem in real systems	11%
Meter downstream of fitting					5%
Reducer	Within MID limits	Within MID limits	Within MID limits		
Valve	Within MID limits	Within MID limits	Within MID limits		
Double bend	Up to +3%	Within MID limits	Within MID limits	Turbine meter show error of less than 1% over the upper MID limit	
Meter in wrong branch				Error magnitude depends on temperature difference	7%
Flow instead of return	Up to +5%				
Return instead of flow	Up to -5%				

Table 6: Summary of Flow Meter Error Magnitude and Frequencies

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[22] Error frequencies are those found in the site visits carried out by AECOM to early applicants to Phase 1 of the RHI.

[23] The calculator error of at least 5% needs to be added to the flow meter error to give a total error, which could be 10% for the turbine meter.

A further conclusion, supported by the laboratory tests, is that meter errors tend to be larger at flows close to the minimum flow rate for the meter. A recommendation from the workshop held with manufacturers that meters are operated around qp as much as possible is therefore supported. This can be challenging for heating systems where variable flow is used to minimise energy consumption at times of low demand.

Section 7 gives some recommendations regarding meter installation good practice. A number of actions by DECC/Ofgem may help to improve good practice in RHI installations:

1. Consider developing a general good practice guide on installing heat meters that could be included with other RHI guidance. This should include heating system design and operational factors that affect heat meters.

   And/or
2. Consider including checks within the application approval process regarding system design and commissioning that will at least draw the installer's attention to key issues.
3. Consider developing a guide with a body such as BSRIA or CIBSE[24] and making this available for RHI applicants. Work is already underway to improve industry knowledge through CPD[25] from CIBSE and other trade bodies such as ESTA[26].
4. Work with manufacturers to ensure their guidance is clear and that it is readily available. There was some evidence at the Metering Industry workshop held at DECC on 9th January 2013, with representatives from both meter manufacturers and installers that this would be something manufacturers were willing to do. This has been highlighted as a potentially important area from experiences with the laboratory tests where no guidance was available on placement of meters in relation to pumps.
5. Consider identifying the potential benefits of good practice installation and maintenance within RHI documents to help incentivise the take up of good practice, i.e. incorrect heat measurement could lead to under payment and hence loss of revenue for RHI participants.

The report has not made any attempt at making recommendations around meter sizing. However, it is known that at least one manufacturer is developing an application (APP) for mobile devices for meter sizing.

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[24] Chartered Institution of Building Services Engineers
[25] Continuing professional development
[26] Energy Services and Technology Association

Appendix A – Information Gathering

Appendix A – Information Gathering

Papers & Literature

1. Directive 2004/22/EC of The European Parliament and of the Council of 31 March 2004 on measuring instruments (Measuring Instruments Directive (MID))
2. British Standards Institute, Heat meters – Part 1: General requirements, BS EN1431-1 2007
3. Comité Européen De Normalisation (CEN), Heat meter installation – Some guidelines for selecting, installation and operation of heat meters, CR 13582 July 1999
4. Francisco Arregui[*], Enrique Cabrera Jr[*], Ricardo Cobacho, Jorge Garcia-Serra, "Key Factors Affecting Water Meter Accuracy" www.ita.upv.es/idi/descargaarticulo.php?id=54

   * Institute for water technology, Universidad Politecnica de Valencia, Span
5. Sira on behalf of Department of Trade and Industry," Final Report on Clamp-on Transit Time Ultrasonic Flowmeter, Performance Evaluation", DTI NMSD Programme for Flow Measurement Project FEUS05, Reference GBBK/C/03/18 Oct 2005
6. C Ruppel, F Peters[*], "Effects of upstream installations on the reading of an ultrasonic flow meter", Flow Measurement and Instrumentation 15 (2004) 167-177 (www.sciencedirect.com) **z** 2004 Elsevier Ltd

   * Strömungslehre, Universität Essen, D-45127 Essen , Germany
7. Carl Carlander[*], Jerker Delsing, "Installation effects on an ultrasonic flow meter with implications for self diagnostics", Flow Measurement and Instrumentation 11 (2000) 109-122 (www.sciencedirect.com) **z** 2004 Elsevier Ltd

   * Division of Industrial Electonics, Luleå University of Technology, S-971 87 Luleå, Sweden
8. Omega[*], "Flow and Level Measurement", Transactions in measurement and control Volume 4 (www.omega.com/literature/transactions/volume4)

   * Omega is a manufacturer and supplier of a range of measuring instruments.
9. Members of the Euroheat and Power[*] working group TF Customer Connections, "Types of Heat Meter", edited by Bo Frank, 2007, (www.bofcon.se/doc/types_of_heatmeters.pdf)

   * Euroheat & Power is an association of national district heating associations; utilities operating DHC systems; industrial associations and companies; manufacturers; research institutes; consultants and other organisations involved in the CHP/DHC business across the EU.

Appendix B – Laboratory Testing

Appendix B – Laboratory Testing

Objectives

There are gaps in existing knowledge about the magnitude of measurement errors resulting from some installation errors. Given the timescales and budget for the current project it is not possible to carry out laboratory tests to fill all the gaps. However, some additional data can be generated that will aim to quantify some of the effects of the most common errors and perhaps help identify where further work may usefully be directed.

The Test Rig

BSRIA's test rig at Bracknell has been used to carry out a range of laboratory tests. Initially the rig was able to simulate a heating system of 100-150kW demand. Flow and return temperatures could be varied using the heating and cooling heat exchangers.

A calibrated flow meter and temperature sensors are included in the rig, but the meter accuracy was also compared to that with no obstruction, i.e. as near as perfect an installation as possible. The second comparison recognises that all meters will have some level of inaccuracy and that it is the additional errors that are of interest in the current work rather than the absolute error.

This initial test rig was found not to have a pump capable of delivering the full range of flowrates required. Therefore a second pump was introduced after the test piece that was brought on at flowrates between 2.8 and 3.0 l/sec. Even with this second pump it has not been possible to achieve flowrates greater than 4.5 l/sec, well within the declared maximum permissible maximum flowrate of 5.56 l/sec.

As tests were carried out results for the vortex meter showed unexpected behaviour at higher flowrates (above qp) with the error points transitioning from within to well outside the MID error band at a flowrate of 4.3 l/sec.

This inability to operate the rig over the full flow range of the meters under test and the unexpected results for the vortex meter led to a review of the test rig. This revealed that the design of the rig led to higher than expected pressure losses through heat exchangers and control valves designed to maintain the desired temperature.

System temperature over the range being tested (30^{o} to 80^{o}C) was considered to be less important than the pressure loss through the system and therefore the test rig was redesigned to reduce pressure losses. This resulted in a compromise in temperatures achievable, which were limited to 50^{o}C in the new rig. Most of the tests were then carried out using the redesigned test rig and the results reported in this report are from the retests with the exception of gas entrainment.

Before running the tests for incorrect meter installation or fluid type, a test with correct meter installation and water was undertaken for each meter type at two temperatures (30^{o}C and 50^{o}C).

Meters to be Tested

Three different types of heat meters were tested, an ultrasonic meter, a turbine meter and a vortex meter. The ultrasonic and vortex meters both claim MID Class 2 accuracy. It is not clear from information provided with the meters whether the turbine meter meets this standard, although the manufacture has claimed MID Class 2 when their meters have been used in RHI installations. It is recognised that with only one meter of each type to test there is a risk that any of the meters could be faulty and thus give unexpected results.

The initial test rig produced results for the turbine meter that were within the MID error band, marked as “Original Test” in *Figure 44*. However, when a retest was carried out following the initial set of tests and rebuild of the test rig the meter readings fell outside the MID error band for most of the meter range. However, the results show a level of consistency and suggest that the meter calibration has “drifted” rather then that the meter has developed a fundamental error. If the MID error band is shifted up by 4% then the results with a correctly installed meter all fall within the new error band as illustrated in *Figure 45*. Further checks with the correctly installed meter were carried out after the glycol tests and after the meter orientation tests. These additional tests showed consistent behaviour with the meter calibration being displaced by +4% as illustrated in *Figure 46*.

While it is not clear why the meter readings had changed in this way it is considered possible that the testing process itself was one possible cause. The flow meter was found to have a deposit of magnetite in it that could not be removed without dismantling the meter. This was not undertaken as it was considered more likely to cause damage than leaving the magnetite in place. The deposit was thought to have resulted from the cycle of changing the meters within the rig together with the down time once the initial set of tests had been carried out. Other problems could be tests such as the orientation tests where the meters are deliberately installed incorrectly, which could cause unknown damage.

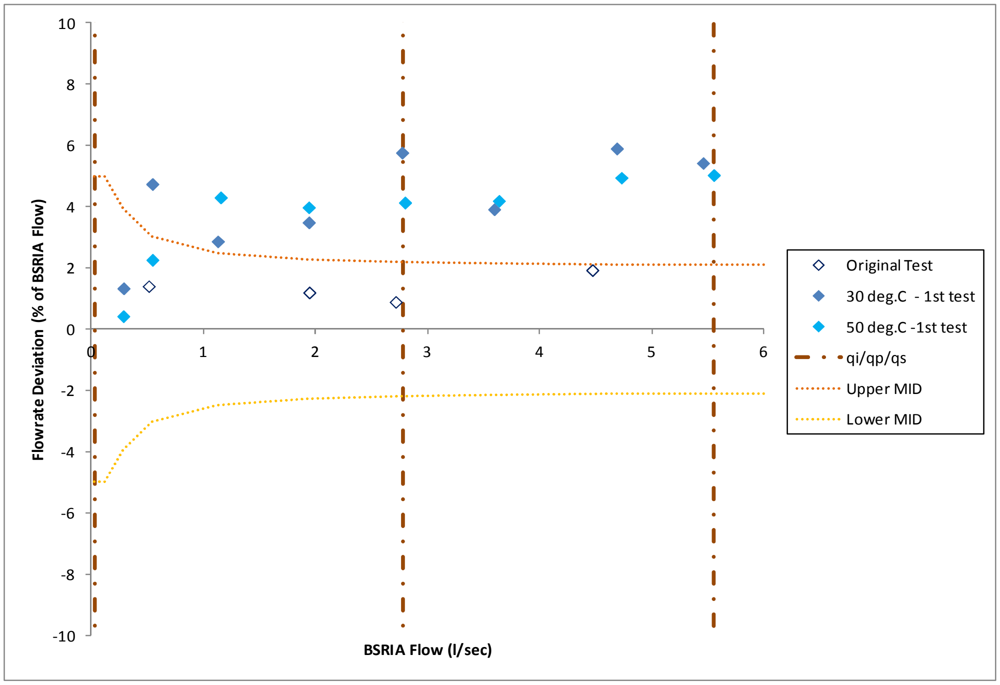

Figure 44: Correct Installation – Turbine Meter

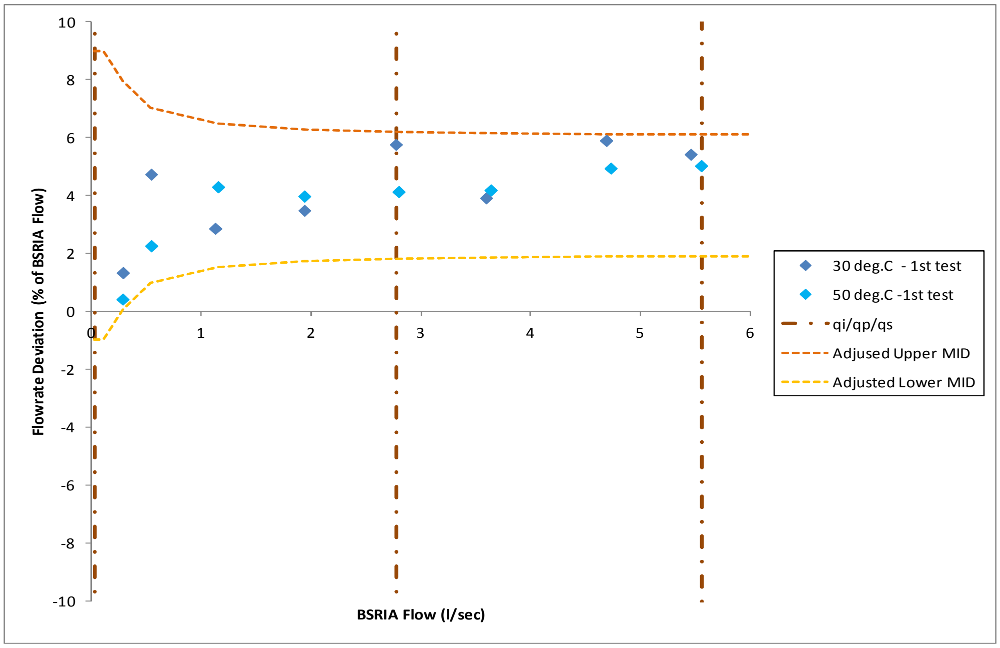

Figure 45: Meter Drift - Turbine Meter

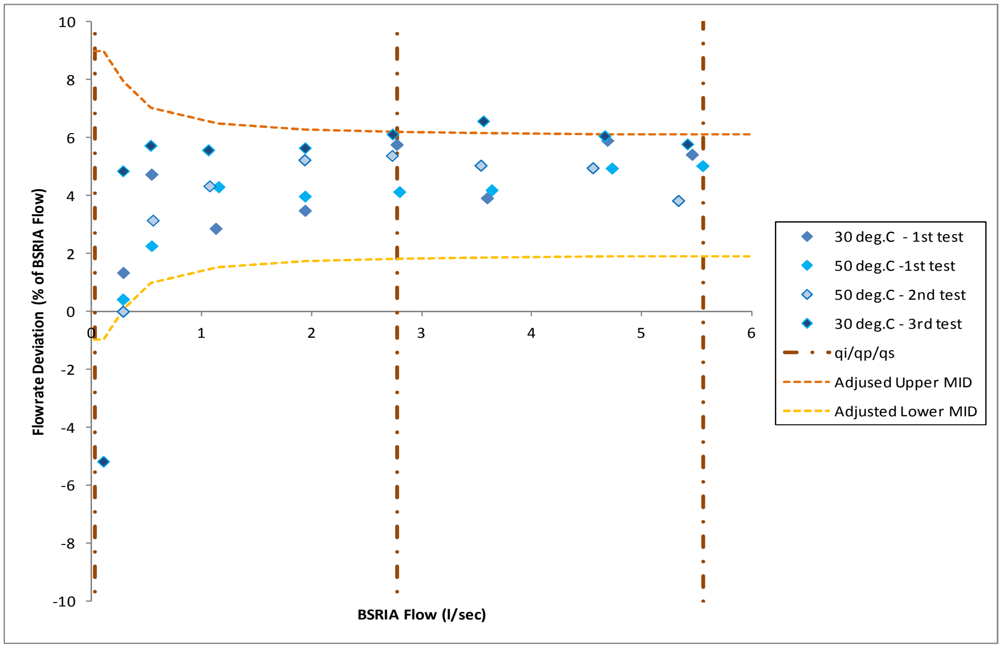

Figure 46: Retests - Turbine Meter

The ultrasonic meter showed consistent behaviour when correctly installed between the original set of tests and the retests with the rebuilt test rig. In each case the results with a correctly installed meter were within the MID error band, although some of the points are on the lower limit (*Figure 47*).

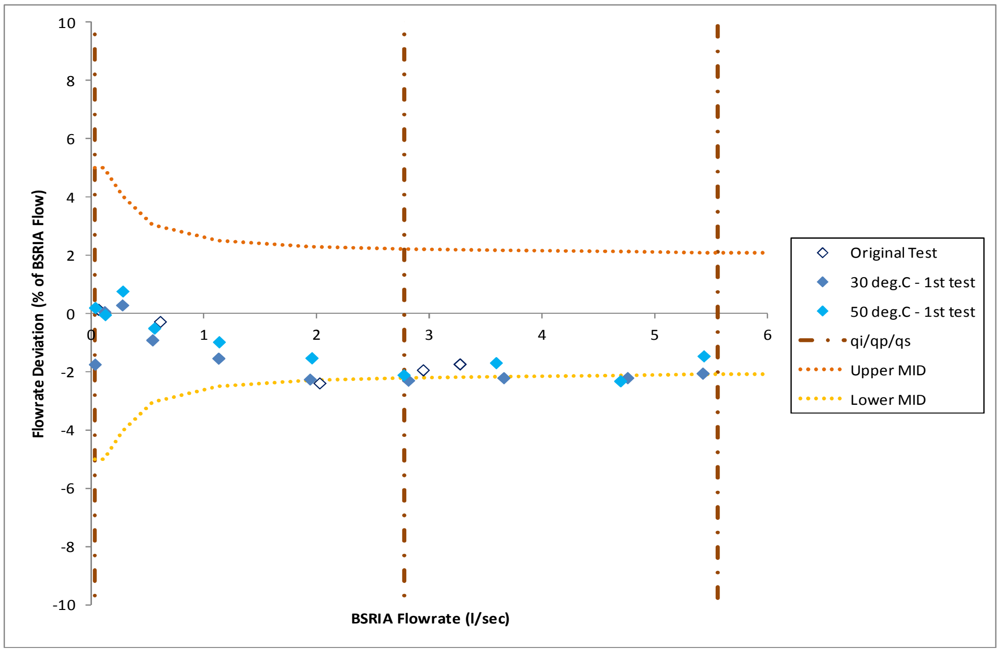

Figure 47: Correct Installation - Ultrasonic Meter

As has already been stated the original tests with the vortex meter had shown unexpected behaviour at higher flowrates (above qp). The retests with the redesigned test rig showed behaviour consistent with expectations with the results all lying within the MID error band (*Figure 48*).

As with the turbine meter, a check carried out after the glycol tests was consistent with these results. However, following the orientation test the meter appeared to have drifted with the results for a correctly installed meter lying up to 1% below the lower MID error across much of the meter flow range (*Figure 49*).

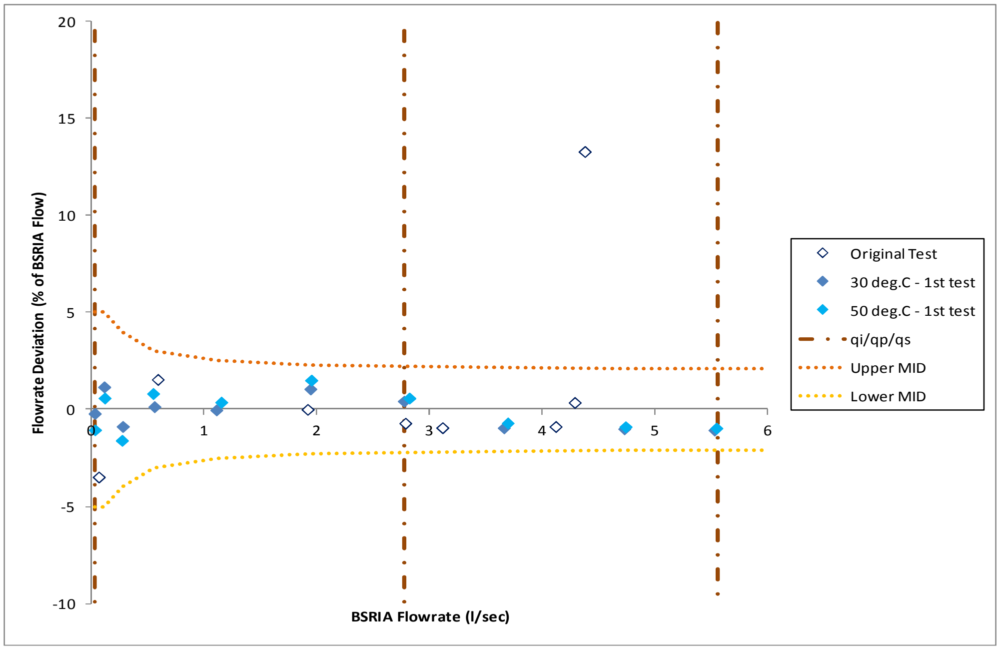

Figure 48: Correct Installation -Vortex Meter

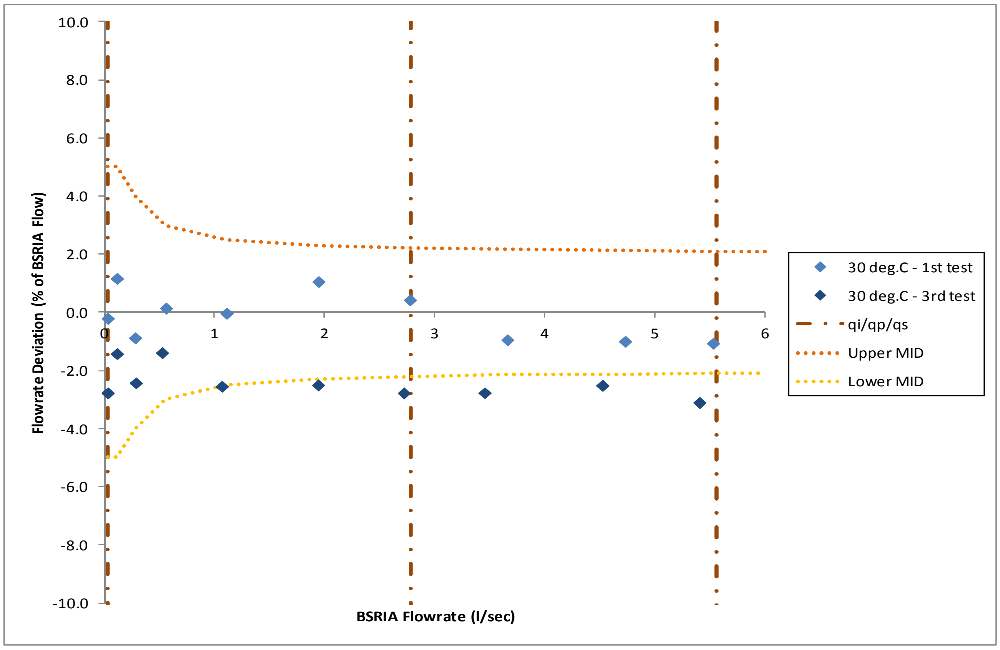

Figure 49: Meter Drift - Vortex Meter

Tests Carried Out

Tests have been developed based on data gathered from literature and manufacturers.

A) Influence of upstream disturbances on meter accuracy at varying distances from the disturbance.

The tests reported have been carried out in the redesigned rig.

Fittings and bends will cause a disturbance in the flow pattern of the heating fluid, which may propagate for some distance downstream of the fitting. A series of tests have been carried out on a range of fittings and with the flow meter at various distances from the disturbance. Based on existing information, variations of flowrate and temperature have been limited to keep the number of tests to a reasonable number.

Obstructions to be tested:

- Double bend. This type of disturbance can have severe effects on meter accuracy and these effects can persist a considerable distance downstream.
- Reducer upstream with expansion downstream. This simulates the use of a meter that has a smaller bore than the heating pipework. Smaller meters may have a cost benefit, but may also end up operating above qp for much of the time.
- Gate Valve. Installing valves upstream and downstream of a meter will enable the meter to be removed for cleaning and repair. It is therefore good practice, but the valves need to be far enough away from the meter such that they do not significantly affect meter accuracy.

Flowrates to be tested:

- Minimum flow qi. Below this flow the meter will no longer be MID compliant. Oversized meters or meters in systems with high turndown ratios may end up operating near qi for substantial periods. It is known that meter accuracy is not as good at these lower flows and so it is important to understand the influence of obstructions at this point. The turbine meter has not been tested at qi as the test would take a considerable length of time.
- Nominal flow for the meter qp. The meter should operate at or around this flow for most of the time and so this is an important point at which to understand meter accuracy. All meters have been tested around this point. However, the ultrasonic meter did not record results for flowrates over 3.2 l/sec (around 15% higher than qp).
- Maximum permissible flow for short periods qs. Above this flow the meter will no longer be MID compliant and damage may occur. No meters have been tested at this point as the test rig is unable to deliver the necessary flowrate.

Temperatures to be tested:

- Initially tests were to be carried out at 80°C and 30°C. The retests could not be carried out at these temperatures due to the limited heat input available. The retests were only carried out at 30°C.

Distances to be tested:

- Initially the tests were to be carried out at four distances between the fitting and flow meter. Measured in pipe diameters (D) these were 5D, 10D, 20D and 50D.
- The retests were carried out at 2 distances, 5D and 20D. These are the minimum anticipated as practical on site and the distance recommended by guidance.

B) Gas bubbles in the System

The tests reported have been carried out in the original test rig.

Free gases in the form of bubbles have been mentioned as a potential problem by several manufacturers. There are also a wide range of circumstances that can increase the risk of bubbles being present in the system even if only locally to the meter. Air has been introduced into the system to see the response of the meters.

Water flowrates to be tested:

- Three flowrates have been tested for each meter between qi and qp.

Temperature to be tested:

- All tests were carried out at 80°C.

C) Meter orientation

The tests reported have been carried out in the redesigned tests rig.

Most manufacturers provide guidance on the orientation their meter should be installed in, i.e. facing upwards or to the side. However, as site inspections showed, incorrectly orientated meters was one of the most common installation errors. Tests have therefore been carried out to determine whether meter orientation has an immediate influence on meter accuracy. Time does not allow for wear testing to be carried out.

Meter orientations tested:

- Vertically up.
- 90° to the side
- Vertically down.

Flowrates to be tested:

- Minimum flow qi. Below this flow the meter will no longer be MID compliant. Oversized meters or meters in systems with high turndown ratios may end up operating near qi for substantial periods. It is known that meter accuracy is not as good at these lower flows and so it is important to understand the influence of obstructions at this point. The turbine meter has not been tested at qi as the test would take a considerable length of time.

- Nominal flow for the meter qp. The meter should operate at or around this flow for most of the time and so this is an important point at which to understand meter accuracy. All meters have been tested around this point. However, the ultrasonic meter did not record results for flowrates over 3.2 l/sec (around 15% higher than qp).
- Maximum permissible flow for short periods qs. Above this flow the meter will no longer be MID compliant and damage may occur. No meters have been tested at this point as the test rig is unable to deliver the necessary flowrate.

Temperature to be tested:

- All tests were carried out at 30°C.

D) Temperature Probe Installation

The tests reported have been carried out in the original test rig.

The degree to which the temperature probes are in contact with the average heating fluid will determine the accuracy with which they measure temperature and the speed of response to changes in temperature. As each of the three heat meters are supplied with the same type of temperature probe (2-wire Pt500s) this set of tests were only carried out for one meter, the Sontex. The probes were installed with varying degrees of thermal contact with the heating fluid.

Temperature Probe Configuration:

- Installed in pocket with thermal grease, the correct installation.
- Installed in pocket without thermal grease, a potentially common error to save time and money.
- Strapped to the outside of pipe, witnessed on site inspections of some domestic installations.

Temperature differences to be tested:

Temperature probes are supplied as matched pairs and temperature difference measured as this reduces the errors inherent in measuring absolute temperatures. Therefore the test will be carried out with a range of temperature differences.

- 5°C: Lower than normal but indicative of low system demands at minimum flowrates.
- 10°C: Typical for many heating systems
- 15°C
- 20°C: Would be considered a reasonable temperature difference for communal or district heating where increased temperature differences reduce pipe sizes and pumping energy.
- 25-30°C:

Flowrate to be tested:

- A flowrate of 0.5 l/sec was used for all tests.

E) Glycol Water Mixes

The tests reported have been carried out in the redesigned test rig.

Meters are normally calibrated for water. Should such meters be installed in situations where a water / glycol mix is used as the heat transfer fluid, inaccuracies in heat measurement are likely to occur as the physical properties of the heat transfer fluid differ from those expected by the meter.

Two commonly used glycols have been tested:

- Mono-ethylene glycol
- Mono-propylene glycol

Each glycol has been tested at three concentrations:

- 15% - more likely to be used in below ground applications where pipework is protected from low temperatures
- 30% - common for typical UK external temperatures
- 45% - used in areas where lower than average temperatures might be expected

The tests have all been carried out at a single temperature:

- 50°C

Results

Table 7 to *Table 14* give the numerical results. These have been represented graphically in Section 4 within the main report.

				Turbine Meter			Ultrasonic Meter			Vortex Meter		
			Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Straight pipe	Water	30°C	0.028				0.029	0.028	-1.7	0.028	0.028	-0.2
			0.111				0.113	0.113	0.1	0.111	0.113	1.2
			0.278	0.285	0.289	1.3	0.271	0.272	0.3	0.276	0.274	-0.9
			0.556	0.542	0.568	4.7	0.539	0.534	-0.9	0.558	0.558	0.1
			1.11	1.13	1.16	2.9	1.12	1.11	-1.5	1.11	1.11	0.0
			1.94	1.94	2.01	3.5	1.94	1.89	-2.3	1.94	1.96	1.1
			2.78	2.77	2.93	5.8	2.81	2.74	-2.3	2.77	2.78	0.4
			3.61	3.59	3.73	3.9	3.65	3.57	-2.2	3.66	3.62	-0.9
			4.72	4.69	4.96	5.9	4.75	4.65	-2.2	4.73	4.68	-1.0
			5.56	5.46	5.75	5.4	5.42	5.31	-2.0	5.53	5.47	-1.1
	Water	50°C	0.028				0.031	0.031	0.2	0.030	0.03	-1.0
			0.111				0.118	0.118	0.0	0.115	0.12	0.6
			0.278	0.282	0.28	0.4	0.275	0.277	0.8	0.269	0.26	-1.6
			0.556	0.543	0.55	2.3	0.556	0.553	-0.5	0.546	0.55	0.8
			1.11	1.15	1.20	4.3	1.13	1.12	-1.0	1.15	1.16	0.4
			1.94	1.94	2.01	4.0	1.95	1.92	-1.5	1.95	1.98	1.5
			2.78	2.80	2.91	4.1	2.77	2.71	-2.1	2.82	2.84	0.6
			3.61	3.64	3.79	4.2	3.59	3.53	-1.7	3.69	3.67	-0.7
			4.72	4.73	4.96	4.9	4.69	4.58	-2.3	4.74	4.69	-0.9
			5.56	5.55	5.83	5.0	5.43	5.35	-1.5	5.54	5.49	-1.0
	After Glycol Tests											
	Water	50°C	0.028							0.031	0.030	-2.4
			0.111							0.120	0.118	-1.2
			0.278	0.282	0.282	0.0				0.279	0.276	-0.9
			0.556	0.555	0.573	3.2				0.527	0.533	1.1
			1.11	1.07	1.12	4.3				1.07	1.08	1.5
			1.94	1.93	2.03	5.2				1.94	1.96	1.0
			2.78	2.73	2.88	5.4				2.73	2.77	1.5
			3.61	3.54	3.71	5.1				3.55	3.58	1.1
			4.72	4.55	4.78	5.0				4.55	4.60	1.0
			5.56	5.33	5.54	3.8				5.39	5.43	0.7
	After Orientation Tests											
	Water	30°C	0.028							0.027	0.027	-2.8
			0.111							0.112	0.110	-1.4
			0.278	0.283	0.296	4.9				0.283	0.276	-2.4
			0.556	0.534	0.564	5.7				0.521	0.514	-1.4
			1.11	1.06	1.12	5.6				1.06	1.04	-2.5
			1.94	1.94	2.05	5.7				1.94	1.89	-2.5
			2.78	2.73	2.90	6.1				2.72	2.64	-2.8
			3.61	3.56	3.79	6.6				3.45	3.35	-2.8
			4.72	4.66	4.94	6.1				4.52	4.41	-2.5
			5.56	5.42	5.73	5.8				5.40	5.23	-3.1

Table 7: Flow meter data with correct installation

			Turbine Meter			Ultrasonic Meter			Vortex Meter		
		Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Reducer	5D	0.028				0.029	0.028	-2.6	0.028	0.028	-1.9
		0.111				0.105	0.104	-0.7	0.112	0.113	0.9
		0.278	0.281	0.286	2.0	0.286	0.290	1.6	0.285	0.286	0.4
		0.556	0.525	0.547	4.1	0.524	0.527	0.6	0.522	0.528	1.2
		1.11	1.07	1.11	4.1	1.08	1.09	0.2	1.07	1.08	1.4
		1.94	1.94	2.02	4.5	1.93	1.91	-1.1	1.93	1.95	1.2
		2.78	2.72	2.86	5.2	2.71	2.69	-0.8	2.71	2.75	1.2
		3.61	3.55	3.74	5.4	3.53	3.50	-1.0	3.57	3.61	1.3
		4.72	4.55	4.80	5.5	4.63	4.59	-0.8	4.55	4.60	1.2
		5.56	5.35	5.62	5.0	5.37	5.31	-1.2	5.39	5.44	0.9
	20D	0.028				0.029	0.029	-1.1	0.027	0.027	2.2
		0.111				0.116	0.116	-0.2	0.110	0.109	-1.0
		0.278	0.286	0.296	3.6	0.289	0.292	1.1	0.282	0.282	0.0
		0.556	0.524	0.547	4.5	0.560	0.563	0.4	0.523	0.528	0.9
		1.11	1.07	1.11	4.4	1.12	1.11	-0.7	1.06	1.07	1.3
		1.94	1.94	2.03	4.7	1.92	1.89	-1.2	1.89	1.91	1.3
		2.78	2.72	2.86	5.0	2.71	2.66	-1.8	2.74	2.76	0.8
		3.61	3.55	3.73	5.2	3.54	3.46	-2.2	3.55	3.50	-1.2
		4.72	4.54	4.78	5.3	4.62	4.55	-1.5	4.53	4.58	1.2
		5.56	5.42	5.70	5.0	5.38	5.32	-1.2	5.40	5.41	0.3

Table 8: Obstructions Upstream of Meter - Reducer

			Turbine Meter			Ultrasonic Meter			Vortex Meter		
		Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Double Bend	5D	0.028				0.028	0.028	-1.4	0.029	0.028	-1.0
		0.111				0.111	0.111	-0.2	0.111	0.110	-1.0
		0.278	0.285	0.293	2.9	0.285	0.290	1.5	0.281	0.282	0.4
		0.556	0.521	0.546	4.8	0.517	0.520	0.5	0.519	0.524	0.9
		1.11	1.07	1.13	5.5	1.08	1.07	-0.9	1.07	1.08	0.7
		1.94	1.93	2.05	6.1	1.97	1.94	-1.5	1.93	1.94	0.6
		2.78	2.74	2.91	6.4	2.81	2.78	-1.3	2.72	2.75	1.1
		3.61	3.55	3.78	6.6	3.64	3.59	-1.6	3.53	3.55	0.7
		4.72	4.57	4.87	6.6	4.80	4.74	-1.2	4.58	4.61	0.7
		5.56	5.28	5.60	6.1	5.39	5.29	-1.9	5.35	5.38	0.5
	20D	0.028				0.029	0.028	-2.0	0.028	0.028	-0.4
		0.111				0.113	0.112	-0.2	0.107	0.108	0.4
		0.278	0.284	0.288	1.3	0.286	0.292	2.1	0.278	0.280	1.0
		0.556	0.525	0.546	4.0	0.526	0.530	0.9	0.521	0.519	-0.4
		1.11	1.06	1.12	5.0	1.09	1.09	0.0	1.07	1.08	0.9
		1.94	1.94	2.05	5.8	1.95	1.94	-0.5	1.93	1.95	1.0
		2.78	2.73	2.89	6.1	2.82	2.78	-1.3	2.71	2.74	1.1
		3.61	3.54	3.77	6.4	3.66	3.63	-0.9	3.54	3.57	1.0
		4.72	4.65	4.94	6.2	4.77	4.74	-0.6	4.56	4.59	0.5
		5.56	5.42	5.74	5.8	5.39	5.34	-0.9	5.39	5.44	1.1

Table 9: Obstructions Upstream of Meter – Double Bend

			Turbine Meter			Ultrasonic Meter			Vortex Meter		
		Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Valve	5D	0.028				0.028	0.028	-1.4	0.029	0.029	-0.3
		0.111				0.104	0.103	-0.3	0.101	0.101	-0.1
		0.278	0.282	0.289	2.5	0.284	0.288	1.3	0.288	0.285	-1.1
		0.556	0.521	0.541	3.7	0.522	0.524	0.4	0.525	0.531	1.2
		1.11	1.06	1.10	4.1	1.10	1.09	-0.9	1.06	1.07	1.1
		1.94	1.94	2.04	5.0	1.95	1.92	-1.3	1.94	1.95	0.5
		2.78	2.72	2.86	4.9	2.73	2.70	-1.2	2.72	2.75	1.2
		3.61	3.56	3.74	4.9	3.67	3.60	-1.8	3.57	3.60	0.8
		4.72	4.57	4.82	5.3	4.75	4.69	-1.2	4.54	4.58	0.7
		5.56	5.36	5.62	4.8	5.39	5.34	-1.1	5.39	5.41	0.4
	20D	0.028				0.029	0.028	-2.3	0.028	0.028	-1.2
		0.111				0.116	0.116	-0.3	0.099	0.099	-0.1
		0.278	0.286	0.288	0.8	0.285	0.281	-1.1	0.281	0.285	1.3
		0.556	0.523	0.539	3.1	0.524	0.531	1.3	0.522	0.526	0.7
		1.11	1.09	1.13	4.0	1.11	1.11	0.0	1.07	1.08	1.7
		1.94	1.94	2.03	4.4	1.94	1.93	-0.5	1.92	1.94	1.1
		2.78	2.74	2.90	5.5	2.82	2.78	-1.4	2.71	2.74	1.1
		3.61	3.56	3.76	5.7	3.53	3.47	-1.6	3.53	3.57	1.1
		4.72	4.65	4.90	5.4	4.65	4.57	-1.5	4.52	4.59	1.6
		5.56	5.41	5.68	5.1	5.41	5.35	-1.3	5.35	5.42	1.2

Table 10: Obstructions Upstream of Meter – Valve

			Turbine Meter			Ultrasonic Meter			Vortex Meter		
		Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Orientation	**Vertically up**	0.028	Correct Orientation			0.029	0.028	-1.1	0.028	0.028	-0.9
		0.111				0.107	0.107	-0.3	0.107	0.108	0.7
		0.278				0.281	0.285	1.4	0.282	0.286	1.3
		0.556				0.527	0.529	0.4	0.524	0.532	1.5
		1.11				1.11	1.10	-0.3	1.07	1.08	1.0
		1.94				1.92	1.90	-1.2	1.94	1.95	0.6
		2.78				2.72	2.69	-1.0	2.74	2.72	-0.5
		3.61				3.55	3.51	-1.1	3.54	3.57	0.9
		4.72				4.63	4.56	-1.4	4.55	4.60	1.0
		5.56				5.40	5.34	-1.1	5.41	5.44	0.6
	Horizontal	0.028				Correct Orientation			Correct Orientation		
		0.111									
		0.278	0.281	0.284	1.0						
		0.556	0.520	0.539	3.7						
		1.11	1.07	1.12	4.7						
		1.94	1.93	2.03	4.9						
		2.78	2.73	2.85	4.6						
		3.61	3.56	3.71	4.3						
		4.72	4.57	4.76	4.2						
		5.56	5.34	5.65	5.7						
	Vertically Down	0.028				0.029	0.028	-2.0	0.027	0.026	-2.8
		0.111				0.116	0.116	-0.5	0.107	0.105	-2.3
		0.278	0.283	0.281	-1.0	0.279	0.283	1.4	0.284	0.276	-3.0
		0.556	0.557	0.570	2.5	0.528	0.530	0.4	0.528	0.516	-2.3
		1.11	1.07	1.11	4.2	1.09	1.08	-0.2	1.07	1.05	-2.6
		1.94	1.94	2.01	3.8	1.93	1.90	-1.3	1.93	1.88	-2.6
		2.78	2.72	2.83	3.7	2.73	2.69	-1.5	2.71	2.66	-1.7
		3.61	3.54	3.68	3.9	3.54	3.48	-1.7	3.55	3.48	-2.0
		4.72	4.55	4.73	3.9	4.79	4.73	-1.3	4.52	4.39	-2.9
		5.56	5.34	5.54	3.6	5.38	5.31	-1.3	5.38	5.21	-3.1

Table 11: Flowmeter Orientation

			Turbine Meter			Ultrasonic Meter			Vortex Meter		
		Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Mono-Ethylene Glycol	15%	0.028				0.030	0.030	-1.3	0.029	0.029	-1.1
		0.111				0.119	0.119	0.6	0.109	0.109	0.5
		0.278	0.278	0.287	3.5	0.276	0.279	1.3	0.284	0.288	1.1
		0.556	0.526	0.556	5.9	0.564	0.565	0.1	0.540	0.549	1.7
		1.11	1.05	1.13	7.1	1.11	1.10	-0.7	1.07	1.08	0.8
		1.94	1.92	2.06	7.6	1.97	1.95	-1.3	1.94	1.98	1.9
		2.78	2.74	2.96	8.1	2.82	2.79	-1.2	2.73	2.71	-0.7
		3.61	3.55	3.86	8.8	3.65	3.59	-1.4	3.56	3.60	0.9
		4.72	4.61	4.98	8.1	4.78	4.72	-1.2	4.54	4.58	0.9
		5.56	5.29	5.72	8.0	5.36	5.30	-1.3	5.40	5.43	0.5
	30%	0.028				0.029	0.029	0.2	0.029	0.028	-2.0
		0.111				0.112	0.113	0.4	0.117	0.118	0.2
		0.278	0.286	0.292	2.4	0.285	0.290	1.7	0.287	0.297	3.5
		0.556	0.554	0.581	4.8	0.559	0.560	0.2	0.553	0.564	1.9
		1.11	1.09	1.17	6.7	1.12	1.11	-0.9	1.09	1.12	2.3
		1.94	1.94	2.08	7.5	1.97	1.95	-1.2	1.89	1.92	1.7
		2.78	2.76	3.01	9.1	2.81	2.74	-2.3	2.76	2.79	1.2
		3.61	3.58	3.92	9.4	3.63	3.54	-2.4	3.49	3.53	1.2
		4.72	4.58	5.02	9.6	4.77	4.69	-1.6	4.59	4.65	1.1
		5.56	5.44	5.96	9.5	5.33	5.25	-1.4	5.36	5.41	0.9
	45%	0.028				0.029	0.029	0.4	0.029	0.029	-0.5
		0.111				0.100	0.101	1.8	0.120	0.120	0.2
		0.278	0.269	0.276	2.6	0.272	0.278	2.0	0.289	0.298	3.3
		0.556	0.526	0.551	4.7	0.556	0.557	0.3	0.555	0.566	1.9
		1.11	1.08	1.14	5.8	1.12	1.11	-0.5	1.09	1.09	0.3
		1.94	1.92	2.07	7.8	1.96	1.95	-0.9	1.88	1.91	1.3
		2.78	2.73	2.95	8.0	2.80	2.73	-2.3	2.75	2.77	0.8
		3.61	3.53	3.80	7.6	3.59	3.58	-0.3	3.48	3.51	1.0
		4.72	4.51	4.82	7.0	4.70	4.63	-1.4	4.60	4.63	0.7
		5.56	5.29	5.74	8.5	5.34	5.24	-1.9	5.37	5.40	0.6

Table 12: Mono-ethylene Glycol Water Mixes

			Turbine Meter			Ultrasonic Meter			Vortex Meter		
		Target flowrate (l/s)	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %	BSRIA measured flowrate (l/s)	Recorded from test meter (l/s)	Error %
Mono-Propylene Glycol	15%	0.028				0.030	0.030	-0.8	0.031	0.030	-1.8
		0.111				0.117	0.118	0.8	0.113	0.113	-0.1
		0.278	0.280	0.284	1.4	0.284	0.288	1.7	0.282	0.282	-0.1
		0.556	0.526	0.545	3.6	0.524	0.529	0.8	0.522	0.529	1.4
		1.11	1.06	1.12	5.7	1.11	1.10	-0.3	1.05	1.06	1.2
		1.94	1.92	2.05	7.1	1.96	1.95	-0.6	1.93	1.95	1.0
		2.78	2.72	2.92	7.3	2.79	2.81	1.0	2.74	2.78	1.3
		3.61	3.56	3.85	8.1	3.46	3.43	-0.8	3.56	3.54	-0.5
		4.72	4.67	5.03	7.9	4.64	4.60	-0.8	4.54	4.59	1.0
		5.56	5.43	5.83	7.4	5.40	5.33	-1.4	5.38	5.43	0.8
	30%	0.028				0.031	0.031	0.4	0.029	0.029	-1.0
		0.111				0.119	0.119	0.3	0.116	0.115	-0.3
		0.278	0.280	0.287	2.6	0.285	0.290	1.7	0.280	0.287	2.5
		0.556	0.524	0.547	4.4	0.518	0.520	0.4	0.520	0.531	2.2
		1.11	1.07	1.14	6.7	1.08	1.08	-0.5	1.07	1.08	0.4
		1.94	1.93	2.07	6.9	1.93	1.91	-1.2	1.93	1.96	1.3
		2.78	2.73	2.93	7.2	2.71	2.67	-1.8	2.73	2.75	0.8
		3.61	3.54	3.81	7.5	3.68	3.62	-1.4	3.54	3.57	0.8
		4.72	4.57	4.92	7.6	4.62	4.57	-1.0	4.56	4.60	0.8
		5.56	5.27	5.66	7.4	5.41	5.35	-1.2	5.39	5.42	0.5
	45%	0.028				0.029	0.029	-0.1	0.030	0.029	-2.8
		0.111				0.116	0.115	-0.3	0.111	0.110	-0.7
		0.278	0.278	0.287	3.5	0.280	0.287	2.3	0.284	0.295	4.1
		0.556	0.526	0.556	5.9	0.519	0.523	0.6	0.529	0.539	1.9
		1.11	1.05	1.13	7.1	1.08	1.07	-0.8	1.10	1.10	0.7
		1.94	1.92	2.06	7.6	1.93	1.91	-1.4	1.94	1.95	0.6
		2.78	2.74	2.96	8.1	2.78	2.71	-2.4	2.73	2.73	0.1
		3.61	3.55	3.86	8.8	3.67	3.61	-1.8	3.55	3.55	0.0
		4.72	4.61	5.00	8.6	4.79	4.70	-1.8	4.56	4.57	0.3
		5.56	5.29	5.72	8.0	5.38	5.30	-1.6	5.37	5.37	0.0

Table 13: Mono-propylene Glycol Water Mixes

		BSRIA PRT 1 (^oC)	BSRIA PRT 2 (^oC)	BSRIA difference (^oC)	Test meter probe 1 (^oC)	Test meter probe 2 (^oC)	Test meter difference (^oC)	Error in Temp Difference	Ambient temp. (^oC)
TEMPERATURE DIFFERENCE	Pocket no grease	74.3	68.9	5.5	74.4	69.0	5.4	-1%	18.3
		73.5	67.4	6.1	73.7	67.6	6.1	0%	21.0
		76.1	67.7	8.3	76.0	67.7	8.2	-2%	20.7
		76.0	64.6	11.4	76.5	64.8	11.7	2%	20.9
		74.8	58.3	16.5	74.8	58.5	16.3	-1%	20.8
		73.9	52.7	21.2	74.3	52.9	21.3	1%	21.0
		80.2	51.5	28.7	80.2	51.6	28.5	-1%	21.1
	Surface mounted	74.6	70.2	4.4	68.5	65.8	2.7	-39%	18.8
		75.1	62.7	12.3	68.0	58.0	10.1	-18%	20.6
		73.0	58.5	14.5	66.7	55.0	11.8	-19%	20.9
		77.7	56.8	20.9	68.2	50.2	18.0	-14%	21.0
		78.6	54.4	24.2	70.9	50.1	20.8	-14%	21.0
	Pocket with grease	74.9	70.3	4.6	75.2	70.5	4.7	2%	19.7
		73.1	65.8	7.3	73.2	66.0	7.3	0%	20.4
		74.0	61.3	12.7	74.0	61.5	12.5	-1%	20.0
		76.8	58.8	18.0	76.9	59.0	18.0	0%	21.0
		79.6	54.8	24.8	79.7	55.0	24.7	0%	21.0

Table 14: Installation of Temperature Probes