North Sea FLOW Measurement Workshop

Paper 8.3

Thermal Lagging – The Impact on Temperature Measurement

Sarah Kimpton
Advantica Ltd

Ali Niaza
Advantica Ltd

TÜV SÜD

nel
technology for life

Thermal Lagging – The Impact on Temperature Measurement

Sarah Kimpton, Advantica Ltd
Ali Niazi, Advantica Ltd

1 INTRODUCTION

Large custody transfer/fiscal metering systems in the United Kingdom are regularly audited to ensure compliance with best industry practice and British and international standards. One recurrent finding from these audits has concerned the lack of thermal lagging on both the upstream and downstream lengths as well as the impulse lines connecting the primary device to the pressure and differential pressure transmitters. Typical findings from recent audits are:

> *The orifice fittings, meter tube upstream and downstream straight lengths and temperature fittings are not thermally insulated and are open to the elements in an exposed location*
>
> *In an exposed site location, an even heat transfer throughout the metering tube lengths cannot be guaranteed and it is possible to introduce temperature gradients within a flowing stream. There may be a big difference between the flowing gas temperature and the ambient temperature depending on the time of the year*
>
> *The exposed position of the meter run and the lack of lagging on the pipe work and the temperature probe and fitting means that the temperature used to calculate gas density is unlikely to reflect the true flowing gas temperature*.

The standards and best practice documents recommend that the temperature sensor is placed in a thermowell which is then inserted into the gas stream of the flowing gas. The auditors claim that if there were no lagging, then the temperature measured in a thermowell may not be the same as the gas temperature. A temperature difference of 0.5 ºC will impact on volume measurement by as much as 0.3%.

For fiscal/custody transfer metering systems, the temperature is always measured downstream of the primary device, regardless of the type of the meter, unless it can be demonstrated that alternative techniques can provide similar performance. For orifice plates, the temperature is measured between five and fifteen diameters downstream of the orifice plate. For turbine and ultrasonic meters, the temperature is measured as close to the meter as possible, approximately five diameters downstream.
The majority of natural-gas metering-systems in the United Kingdom were built in the 1970s and 1980s with no thermal insulation to protect the temperature measurement from ambient variations. It was thought that the impact of the ambient temperature on the temperature of the flowing gas was so small that it could be neglected. Historically the belief was that if the meters were larger than 8" (200 mm), then lagging was unnecessary.

Advantica were requested as an independent organisation to investigate the impact of lagging on temperature measurement. This paper addresses the historical work carried out in this area, examines the previous experimental measurements and presents new results from a computational fluid dynamics mathematical model.

2 RECOMMENDATIONS FROM STANDARDS

The recommendations for lagging in ISO 5167 and IGE/GM/1 are given below.

There are references to the effect of ambient temperature on the gas temperature in the Institute of Gas Engineers Gas Measurement Procedure IGE/GM/1[1]. Paragraph 4.3.2.2 states:

Gas temperature variations at a meter will be affected by the proximity of gas heaters, the Joule-Thomson cooling effect caused by large pressure reductions and the exchange of heat between the gas and the environment. In the absence of heaters and large pressure reduction equipment at above-ground meter installations being fed from underground pipe, the gas temperature will tend to follow ambient at low flows and pressure, whereas at high flow and pressure it will follow ground temperature.

Paragraph 5.10.1.6 concerns meter installation pipe work. A note on thermowells states the following:

Note: In order to ensure that the measured temperature at the thermowells is the same as that of the gas passing through the meter, it may be necessary to lag the external part of the thermowell and the pipe work for a suitable distance upstream and downstream of the meter.

ISO 5167 is the standard concerned with orifice-plate metering. In both the 1991[2] and the 1997[3] versions under *Installation Requirements*, paragraph 7.1.9 states:

The pipe and the pipe flanges shall be lagged. It is however, unnecessary to lag the pipe when the temperature of the fluid, between the inlet section of the minimum straight length of the upstream pipe and the outlet of the minimum straight length of the downstream pipe, does not exceed any limiting value for the accuracy of flow measurement required.

The 2003[4] version of ISO 5167 paragraph 7.1.7 states:

Insulation of the meter may be required in the case of temperature differences between the ambient temperature and the temperature of the flowing fluid which are significant given the uncertainty of measurement required. This is particularly true in the case of fluids being metered near their critical point where small temperature changes result in major density changes. It can be important at low flow rates where small temperature changes result in major density changes. It can be important at low flow rates, where heat transfer effects may cause distorted temperature profiles, for example, stratification of temperature layers from top to bottom. There may also be a change in the mean temperature value from the upstream to the downstream side of the meter run.

3 HISTORICAL WORK

There have been a number of theoretical and experimental investigations into temperature measurement at the British Gas Engineering Research Station (later to become part of Advantica). Some significant results are listed below.

3.1 Thermowell Fatigue Failure Investigation

Pallan and Wood[5] investigated thermowell fractures due to vibration at Bacton Terminal and Alrewas Compressor Stations. As part of the work, the authors investigated the feasibility of measuring temperature on the surface of the pipe under normal and extreme conditions, both with and without thermal insulation.

Theoretical calculations were carried out to investigate the temperature profile across an unlagged 24" (600 mm) diameter pipe with a 0.5" (12.5 mm) wall thickness. Three sets of calculations were carried out:

- At typical ambient conditions of 10 ºC with a 3 m/s cross wind and with a gas flow of 8.5 mscmd at 15.56 ºC and 55 bar. The temperature of the outside of the pipe wall was 15.43 ºC and the temperature of the inside of the pipe wall was 15.45 ºC

- At severe ambient conditions of -1 ºC with a cross wind of 10.7 m/s and with a gas flow of 14 mscmd at 68 bar and 37.8 ºC. The temperature of the outside of the pipe wall was 36.19 ºC and the temperature of the inside of the pipe wall was 36.51 ºC.

- At the same severe ambient conditions with a gas flow of 14 mscmd at 68 bar and 37.8 ºC, the pipe was covered with 1“ of lagging. The temperature of the outside of the pipe wall was 37.71 ºC and the temperature of the inside of the pipe wall was 37.72 ºC.

The temperature measuring error from a thermowell may be considered to comprise several sources. The main ones are conduction error, kinetic energy error, radiation error, intrinsic dynamic error and gradient error. Theoretical analyses of the main sources of temperature measurement error of a thermowell indicated that the conduction error was the only one that could significantly affect the performance of a temperature measurement in a thermowell.

At Low Thornley test site, experiments were carried out on an 8” unlagged thermowell designed to an old ERS drawing EW 21. The thermowell was subjected to an artificial ambient temperature range by surrounding the thermowell flange with a water bath; temperatures of 39 ºC below ambient and 28 ºC above ambient were achieved. Gas velocities of up to 20 m/s were obtained. The gas temperature was measured by placing a thermocouple in the gas stream; this was compared with another thermocouple placed in the thermowell.

The results from these tests showed that the temperatures sensed in the thermowell were within ±1.7 ºC over the range of 39 ºC below ambient and 28 ºC above ambient. The tests also demonstrated that the temperature readings were within ±0.5 ºC when the gas temperature was between 39 ºC below and 11 ºC above ambient.

3.2 Gas Temperature Inferred from Pipe Wall Temperature

Following the fracture and failure of thermowells at compressor stations and elsewhere, Pallan[6] investigated the relationship between pipe-wall temperature and gas temperature. The theoretical relationship between pipe-wall temperature and gas temperature for a 24“ pipe is reproduced from Pallan’s report in figure 3.1. A number of experimental measurements were made on 6“ pipe and 24“ pipe - the surface temperatures were compared with thermowell temperatures.

For 6“ pipes, agreement of ±0.5 ºC between pipe-wall and gas temperature was measured over a temperature range of 6 to 20 ºC. For 24“ pipes, greater differences were observed, especially for low gas temperatures; between 6 and 12 ºC, differences of 0.5 to 2.5 ºC were observed whereas between 12 and 20 ºC the differences were of the order of 0 to 1 ºC. It is assumed that these measurements were for unlagged systems. The authors of this report state that under “well monitored” conditions, the difference between the wall temperature and the gas temperature was within 0.1 ºC over a seven day period.

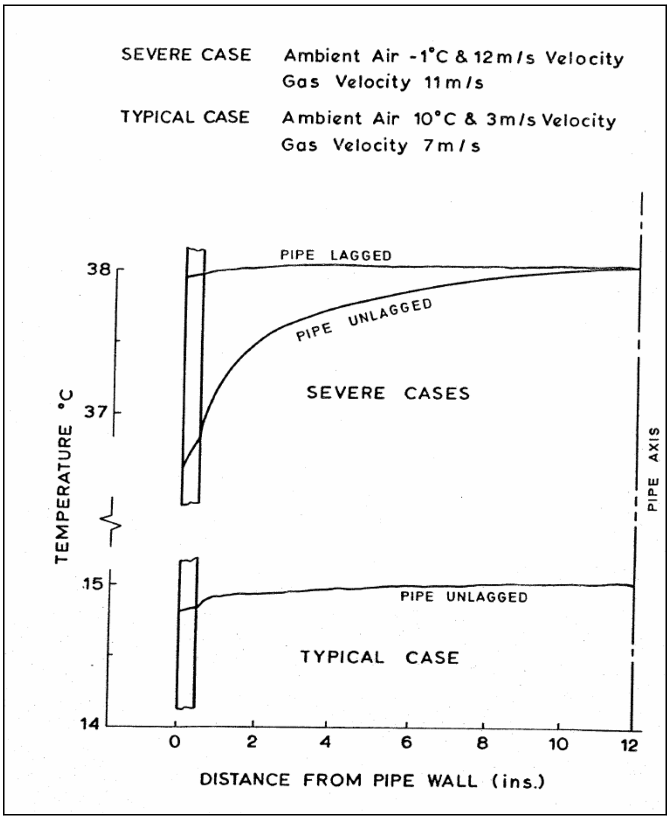

Figure 3.1 Relationship between pipe-wall temperature and gas temperature for a 24“ pipe

3.3 Surface-Temperature Measurement at Compressor Stations

Fenwick[7] carried out theoretical and experimental work to establish the principles of inferring gas temperature from the temperature of the outside pipe surface. The surface pipe-temperature is dependent on:

- Ambient temperature
- Gas temperature
- Gas density
- Gas velocity
- Speed of the wind impinging on the pipe
- Solar radiation
- Pipe wall thickness

Theoretically, for a steady gas temperature, the temperature difference between the outside wall of the pipe and the gas will not exceed 0.6 ºC if:

- gas velocity is in excess of 6.1 m/s
- gas pressure is greater than 38 bar
- ambient to gas temperature difference is less than 40 ºC
- wind speed is not greater than 1.2 m/s.

Variation in pipe wall thickness has very little effect due to the good thermal conductivity of steel. The speed of the wind blowing across a pipe has a marked effect on the accuracy of measurement. If the wind speed in the above example were 6.1 m/s, the temperature difference between the gas and the pipe surface would be 2 ºC.

The calculations above assumed that there was no lagging present. The use of lagging will extend the range within which the pipe surface temperature can be used by reducing the effects of wind and solar radiation. For example, if a surface-mounted temperature sensor were covered with a 12.5 mm thick pad of lagging that extended 0.254 m either side of the sensor, the measured temperature should be within 0.1 ºC of the true temperature even though the exposed pipe wall were 50 ºC above or below the gas temperature.

To test the theoretical calculations, experiments were carried out at two compressor stations under normal running conditions. The temperature at the surface of the pipe was compared with the temperature measured in the thermowell. At steady running conditions with no extreme gas temperature changes, the maximum measured temperature difference between the gas and the pipe surface was 0.2 ºC at a gas velocity of about 9.1 m/s.

3.4 Surface Temperature Response Times and Effects of Removing Thermal Insulation on Surface Temperature Measurement

Ingram[8] compared the response time of a surface-mounted temperature measurement with that from within a thermowell. Both thermometers were insulated. The surface-temperature sensor was surrounded with a 50 mm layer of insulation that extended round the full circumference of the pipe for a length of one pipe diameter. The thermowell was insulated over a radius of 300 mm around the flange. The tests were carried out over two flow-rate ranges – a low flow-rate change (11.7 to 8.7 mscmd) and a high flow-rate range (18.3 to 15.7 mscmd). The surface temperature measurement agreed with the thermowell temperature measurement to within ±0.1 ºC.

Ingram[9] also investigated the effectiveness of thermal insulation on surface-mounted temperature sensors. The temperature measured by three surface-mounted sensors was compared with the temperature determined by two sensors, each of which was in a lagged thermowell. Under stable thermal conditions, a set of temperature data was recorded from the lagged surface-mounted sensors and the lagged thermowell sensors. The lagging on the surface-mounted sensors was then removed and the measured temperature compared with that of the sensors in the thermowells. The ambient air temperature during the tests was 12.5 ºC with a light breeze. The gas temperature was about 6 ºC.

Before the lagging was removed from the surface-mounted sensors, the thermowell and surface-mounted sensor recorded temperatures that agreed to 0.17 ºC. When the lagging was removed, the average difference was 1.20 ºC.

The insulation used during these tests was local to the temperature measurement only. The lagging around the thermowell extended over a radius of 200 mm around the flange. The lagging on the surface-mounted sensors extended around the full circumference of the pipe and for a length of one pipe diameter either side.

Ingram stressed that it is important for thermal insulation to be waterproofed. When the gas temperature is lower than ambient temperature, airborne moisture condenses on the unprotected pipe surfaces which can be absorbed by unprotected insulation. The insulating properties of commonly used lagging materials, such as fibre glass or rock wool, are greatly reduced once water has been absorbed.

3.5 St Fergus Plant Aftercooler Temperature Measurement

Ingram[10] studied the effect of lagging on short (64 mm) thermowells at St Fergus compressor station. Due to fracture problems with long thermowells, short thermowells were fitted that did not protrude within the gas flow. The platinum-resistance-thermometer element was therefore not in the gas flow but level with the pipe wall in the neck flange. Discrepancies in the gas temperature measurement were resolved by lagging the short thermowells and agreement of better than ±1 ºC was achieved.

The 64 mm thermowell measurements, however, had very long response times of about 30 minutes which was unacceptable. Acceptable alternatives were either to install lagged surface-mounted temperature sensors or 226 mm (8.9“) thermowells.

3.5 Assessment of Gas Temperature Measurement Systems at Churchover Compressor Station

Nisbet and Robertson[11] compared surface-mounted temperature sensors with platinum resistance thermometers in direct contact with the gas and supported at varying radial depths into the gas stream.
The surface-mounted sensors were platinum resistance thermometers spirally wound in a ceramic support 25 mm long by 4 mm diameter mounted in a brass housing. The housing was bonded on to the outside of the pipe by a silicon rubber adhesive. Four sensors were located around the outside diameter of the pipe.

The sensors in the gas were also platinum resistance-thermometers comprising a spiral element wound on a cylindrical grooved ceramic support mounted in a probe. Four sensors were mounted on the probe at varying depths (see figure 3.2). The probe was inserted into the gas stream via a 2“ flanged stabbing. The insertion depths were 13, 140 and 267 mm; one further sensor was fitted 50 mm above the pipe inner wall (within the neck of the flange but outside the gas stream).

The surface sensors, and the stabbing and the flange and emergent fittings of the profile probe were comprehensively lagged. The mass flow of the gas through the system varied between 150 and 200 kg/s.

The gas temperature measurements covered only a limited range of 20.9 to 24.7 ºC. However, the maximum difference between the surface measurement and the insertion measurement was 0.15 ºC. The maximum temperature difference across the pipe profile was within the measurement uncertainty of ±0.03 ºC. The sensor located 50 mm outside the inner pipe wall was up to 0.15 ºC different to the temperature measured by the sensors within the gas stream.

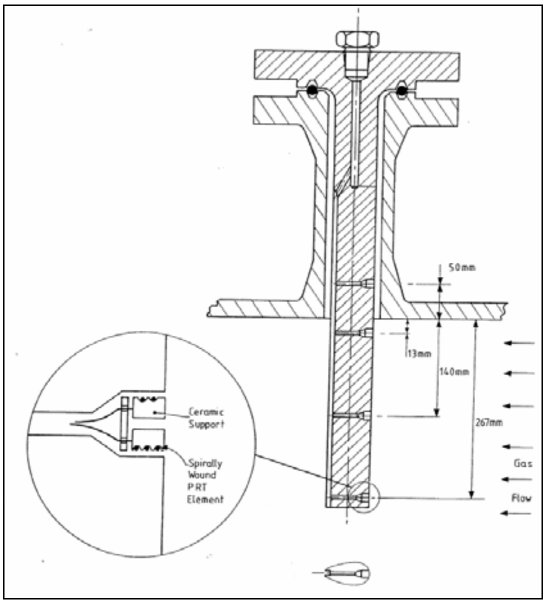

Figure 3.2 Temperature measurement insertion probe showing positions of PRTs

3.6 Thermowell Temperature sensor

It is important that a thermometer in the thermowell is at the gas temperature. Good thermal coupling between the thermometer and the thermowell is important. This can be achieved by ensuring that the bottom of the thermowell is filled with a suitable low-vapour-pressure heat-conducting fluid to optimise response times. It is also necessary to ensure that the bore of the thermowell matches the measuring element – sometimes an insert is required to ensure good thermal contact.

4 COMPUTATIONAL FLUID DYNAMICS

A study has been commissioned from Prof W Malalasekera of Loughborough University[12] to investigate heat transfer in thermowell installations using CFD. Prof Malalasekera is a recognised authority on CFD; for example, he has co-authored a textbook for advanced undergraduate and postgraduate students studying CFD and numerical methods[13].

4.1 Details of the CFD Model

Prof Malalasekera undertook a numerical study of the heat transfer characteristics of thermowells in natural gas pipelines. He modelled a thermowell that was mounted on a connecting flange attached to the pipe. The thermowell protruded into the pipe by 90 mm and it was exposed to the gas flow. A temperature sensing probe was placed inside the thermowell (but not exposed to the gas) to measure the gas temperature. The flange and the pipe line were exposed to ambient conditions which could vary considerably. There was some concern that there could be heat transfer between the ambient air and the flange and the thermowell body such that the temperature measured by the thermometer may not be the same as the gas temperature.

In this work, the temperature distribution inside the thermowell was determined using *CFD* to calculate the heat flow and conjugate transfer in the flange/thermowell arrangement. A range of ambient conditions was considered to investigate the effect on the temperature distribution inside the thermowell. The calculations were done both with and without thermal insulation.

4.2 Geometry of the Thermowell

Thermowells are typically installed in a pipe line using a flange arrangement as shown in figure 4.1. The analysis of heat transfer was considered for two gas pipe diameters, 24" (610 mm) and 8" (219.1 mm). In both cases a 90 mm length section of the thermowell was considered to be inside the pipe.

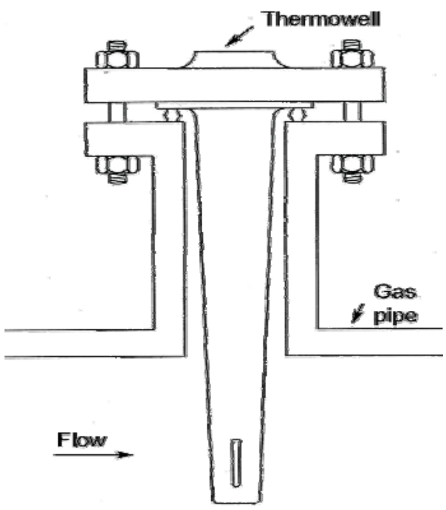

Figure 4.1 Schematic of a typical thermowell installation

4.3 Operating and Ambient Conditions

Two pipeline operating conditions were considered:

- Gas flowing at a temperature of 37.7 °C and a pressure of 60 bar.

- Gas flowing at a temperature of 15 °C and a pressure of 60 bar.
- Various winter and summer ambient conditions were also considered:
- Winter temperatures of 0, -5 and -10 °C with wind speeds of 5 m/s
- Summer temperatures of 30 and 35 °C with a wind speed of 1 m/s

For summer weather conditions, direct solar gains on the pipe surfaces were taken into account using data from the *Chartered Institute of Building Services Engineers*. A table summarising the conditions used by Prof Malalasekera is shown in table 4.1.

The *Case ID* relates to the calculation conditions:

- *HT* denotes gas temperatures of 37.7 °C
- *LT* denotes gas temperatures of 15 °C
- *24* or *08* denote 24" or 8" pipe diameters respectively
- *W1, W2 and W3* denote winter temperatures of 0, -5 and -10 °C respectively
- *S1* and *S2* denote summer temperatures of 30 and 35 °C respectively

Gas properties, such as mass density, gas velocity and viscosity, were provided by Advantica. Heat-transfer coefficients of the steel pipe work in the summer and winter ambient conditions were calculated using data from the *American Petroleum Institute.* The pipe walls were treated to be smooth and standard roughness conditions were used.

Run no.	Case ID	Pipe diameter (mm)	Flow velocity (m/s)	Gas temperature (°C)	Ambient temperature (°C)
1	HT24W1	610.0	10.035	37.7	0.0
2	HT24W2	610.0	10.035	37.7	-5.0
3	HT24W3	610.0	10.035	37.7	-10.0
4	HT24S1	610.0	10.035	37.7	30.0
5	HT24S2	610.0	10.035	37.7	35.0
6	LT24W1	610.0	8.867	15.0	0.0
7	LT24W2	610.0	8.867	15.0	-5.0
8	LT24W3	610.0	8.867	15.0	-10.0
9	LT24S2	610.0	8.867	15.0	30.0
10	LT24S2	610.0	8.867	15.0	35.0
11	HT08W1	219.1	14.278	37.7	0.0
12	HT08W2	219.1	14.278	37.7	-5.0
13	HT08W3	219.1	14.278	37.7	-10.0
14	HT08S1	219.1	14.278	37.7	30.0
15	HT08S2	219.1	14.278	37.7	35.0
16	LT08W1	219.1	13.412	15.0	0.0
17	LT08W2	219.1	13.412	15.0	-5.0
18	LT08W3	219.1	13.412	15.0	-10.0
19	LT08S1	219.1	13.412	15.0	30.0
20	LT08S2	219.1	13.412	15.0	35.0

Table 4.1 Summary of the calculation conditions

4.4 The CFD Model

The CFD model treated the investigation as a conjugate heat transfer problem; that is, the equations governing the conductive heat transfer in the solid parts were solved simultaneously with the fluid flow equations. In this way, the temperature distribution of both the natural gas and the pipe work was determined. The model considered a 700 mm length of pipe which incorporated the thermowell and its flanges.

The three-dimensional geometry had a number of complex features in the thermowell area. A tetrahedral mesh with varying grid densities was best suited for this kind of geometry. Figure 4.2 shows the cross section of a typical grid. The darker areas indicate a more concentrated grid in the flange and thermowell area to accommodate all the geometrical features as well as to obtain a refined and more resolved temperature distribution. A typical grid consisted of more than 550,000 elements. The larger models that included insulation and longer pipe lengths consisted of more than 760,000 elements.

Figure 4.2 A typical grid used for the CFD modelling of a thermowell

4.5 Results of Gas Velocity Calculations

The gas velocity around the thermowell was modelled at a number of conditions but the results were similar – an example is shown in figure 4.3 for a 24" pipe. The colour code ranges from blue (low flow) through green and yellow and finally to red (high flow). It can be seen that the flow wraps round the thermowell surface and recombines afterwards. There is a small amount of flow in the gap between the thermowell surface and the stabbing; the flow appears to be stagnant in this region as the space available is restricted.

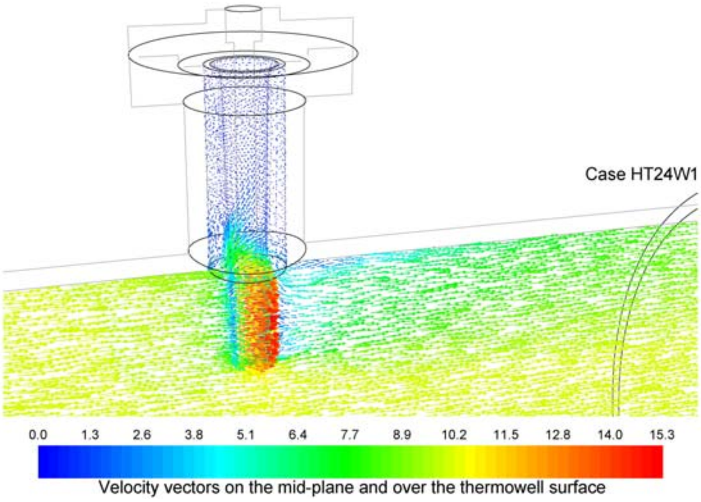

Figure 4.3 Velocity distribution in the mid-plane and gas-side surface of the thermowell.

4.6 Results of Temperature Simulations for Unlagged 24" Pipe

Prof Malalasekera provided results for all the cases listed in table 4.1. A sample of results with the most extreme difference between ambient and gas temperature is shown here – these are cases HT24W3, HT24S2, LT24W3, and LT24S2.

Figure 4.4 shows the temperature distribution when ambient temperature was -10 °C and the gas temperature was 37.7 °C. The temperature of the flange area and the top part of the thermowell stabbing was less than the gas temperature but it is clear that the bottom of the thermowell remained at the gas temperature. The temperature measurement at the bottom of the thermowell did represent the gas temperature.

Figure 4.5 shows the temperature distribution for summer conditions (ambient temperature is 35 °C). The solar gain was included in the simulations. In this case the blue colour indicated a temperature close to the gas temperature (37.7 °C) and the red indicated higher temperatures. It is interesting to note that there was an increase of temperature in the exposed part of the flanges and the thermowell. Further inspection indicated that the pipe work walls were at a slightly higher temperature (close to 40 °C) than the gas. The bottom of the thermowell was, however, still at the gas temperature and temperature measurement were unaffected by the ambient conditions.

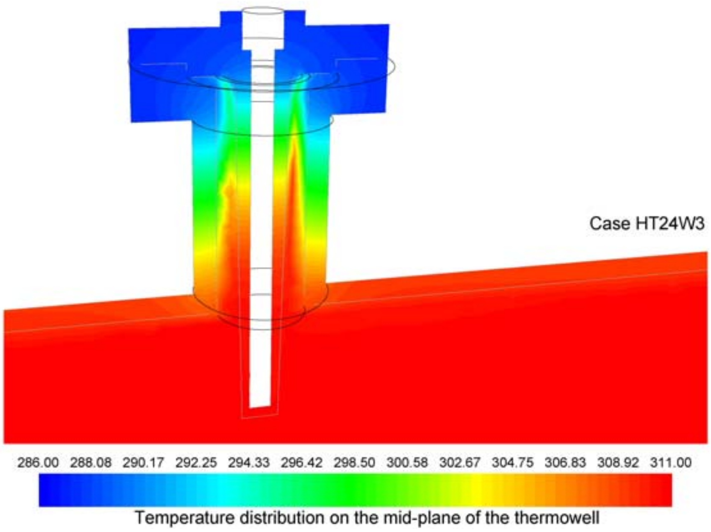

Figure 4.4. Temperature distribution in a 24" pipe for a gas temperature of 37.7 °C and ambient temperature of -10 °C. The temperature scale is in kelvin – the blue is 13 °C and the red is 38 °C.

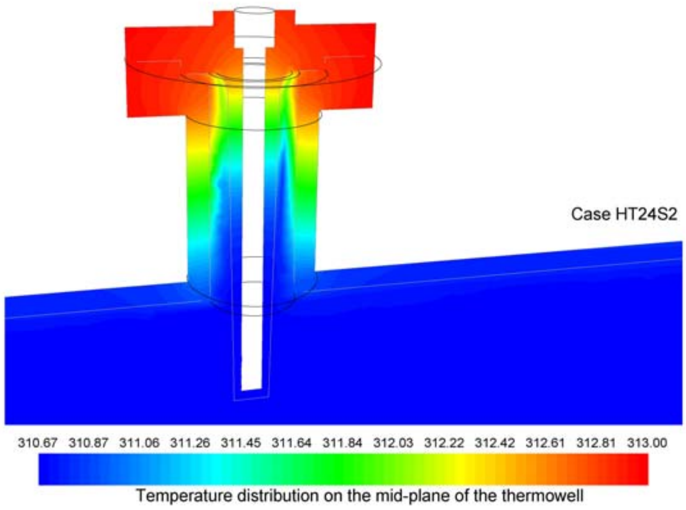

Figure 4.5. Temperature distribution in a 24" pipe for a gas temperature of 37.7 °C and ambient temperature of 35 °C. The temperature scale is in kelvin – the blue is 37.5 °C and the red is 40 °C.

Figure 4.6 shows the temperature distribution for an ambient temperature of -10 °C and a gas temperature of 15 °C. Although there was a considerable drop in the temperature of the flange, the temperature at the bottom of the thermowell remained unaffected.

Figure 4.7 shows the temperature distribution for summer conditions of 35 °C. There was a notable increase in temperature around the flange but the bottom of the thermowell remained at the gas temperature of 15 °C.

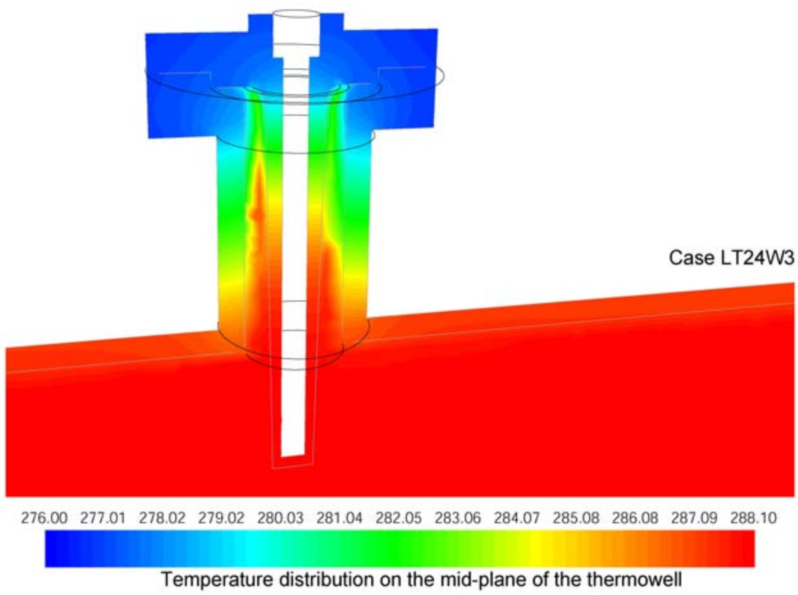

Figure 4.6 Temperature distribution in a 24" pipe for a gas temperature of 15°C and ambient temperature of -10 °C. The temperature scale is in kelvin – the dark blue corresponds to 3 °C and the red to 15 °C.

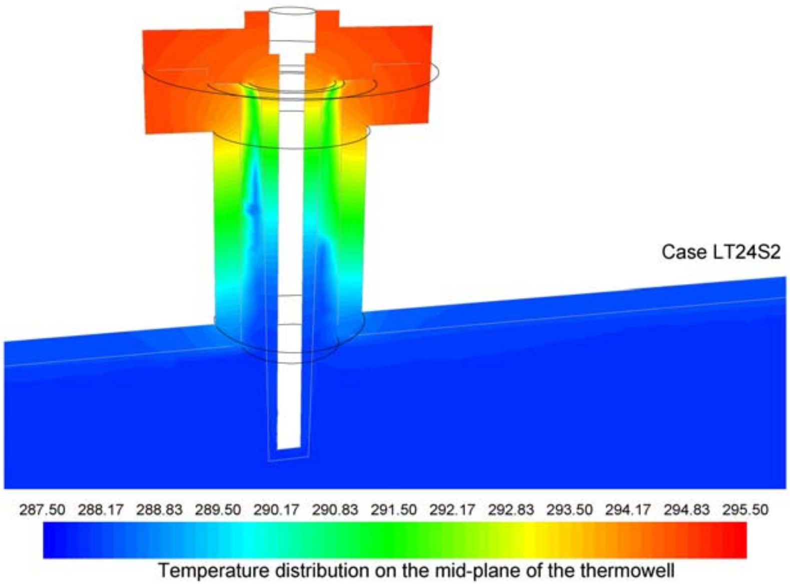

Figure 4.7. Temperature distribution in a 24" pipe for a gas temperature of 15 °C and ambient temperature of 35 °C. The temperature scale is in kelvin – the dark blue corresponds to 15 °C and the red to 23 °C.

4.7 Results of Temperature Simulations for Unlagged 8" Pipe

The general flow pattern across the thermowell was similar to that for the 24" pipe. However, for this pipe diameter, the wall was thinner and there was slightly more space between the pipe stabbing wall and the gas side of the thermowell surface. The gas velocity around the thermowell was therefore greater than that for the 24" pipe.

Figure 4.8 shows the temperature distribution for an ambient temperature of -10 °C and a gas temperature of 37.7 °C. The temperature of the flange and the top of the thermowell was much cooler than the gas as indicated by the dark blue. However, the bottom of the thermowell remained at the gas temperature.

Figure 4.9 shows the temperature predictions for summer conditions of 35 °C and a gas temperature of 37.7 °C. The ambient temperature increased the temperature in the flange area which was indicated by the red. However, the bottom of the thermowell was seen to be at gas temperature.

Figure 4.10 shows the temperature distribution when the gas temperature was 15 °C and the ambient temperature was -10 °C. Although there was a considerable decrease in the temperature of the flange area, the temperature at the bottom of the thermowell remained unaffected at 15 °C.

Figure 4.11 shows the temperature distribution for an ambient temperature of 35 °C and a gas temperature of 15 °C. The figure shows that there was a considerable increase in temperature around the flange but the bottom of the thermowell remained at 15 °C.

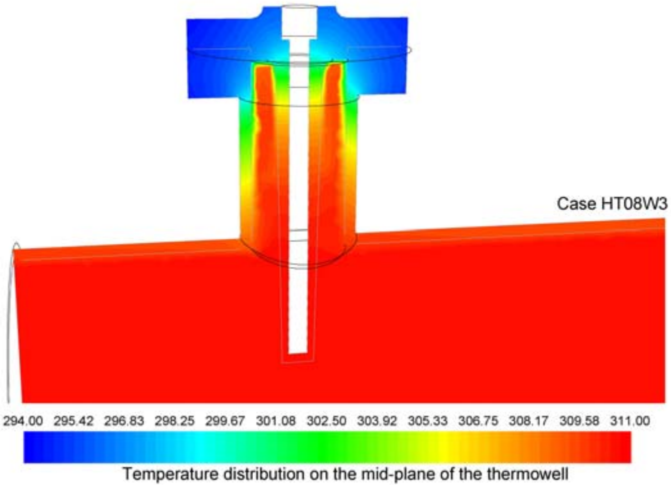

Figure 4.8 Temperature distribution in a 8" pipe for a gas temperature of 37.7 °C and ambient temperature of -10 °C. The temperature scale is in kelvin – the dark blue corresponds to 21 °C and the red to 38 °C.

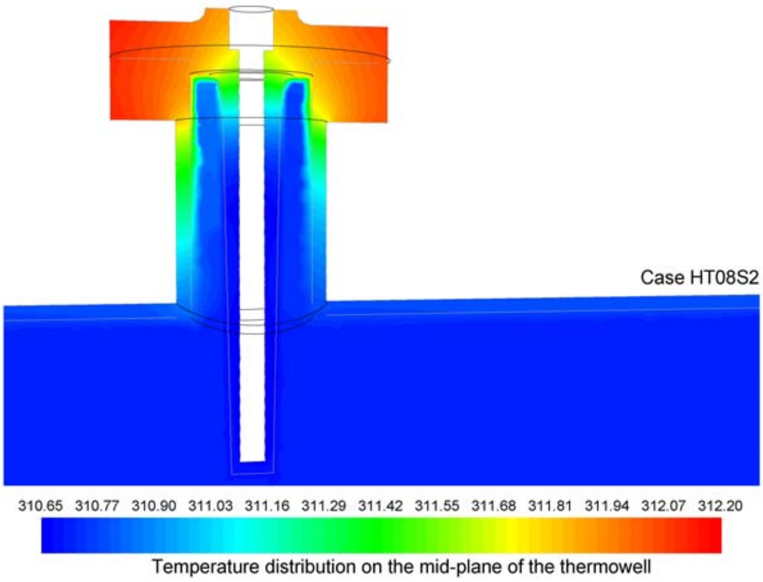

Figure 4.9 Temperature distribution in a 8" pipe for a gas temperature of 37.7 °C and ambient temperature of 35 °C. The temperature scale is in kelvin – the dark blue corresponds to 37.5 °C and the red to 39 °C

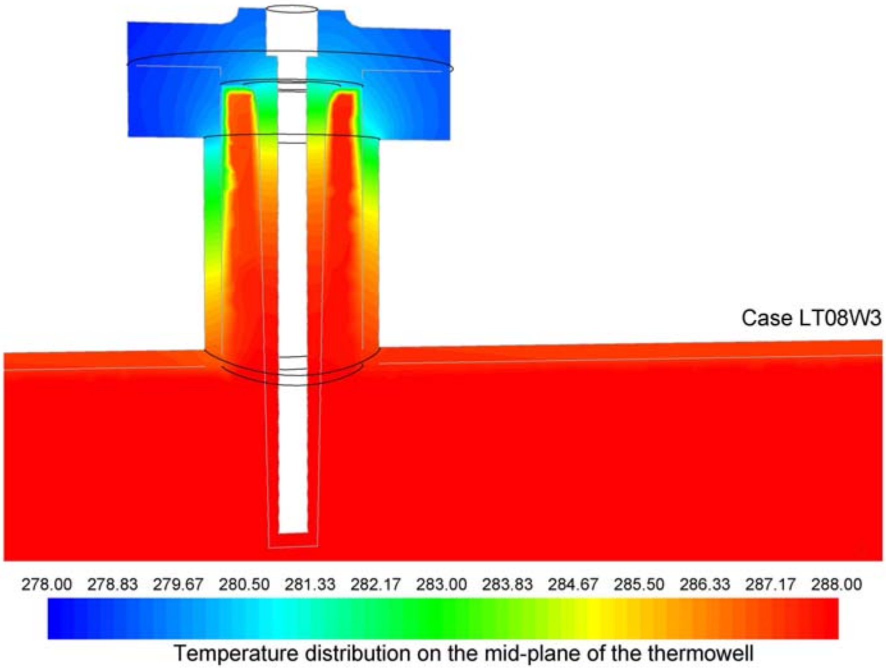

Figure 4.10 Temperature distribution in a 8" pipe for a gas temperature of 15 °C and ambient temperature of -10 °C. The temperature scale is in kelvin – the dark blue corresponds to 5 °C and the red to 15 °C

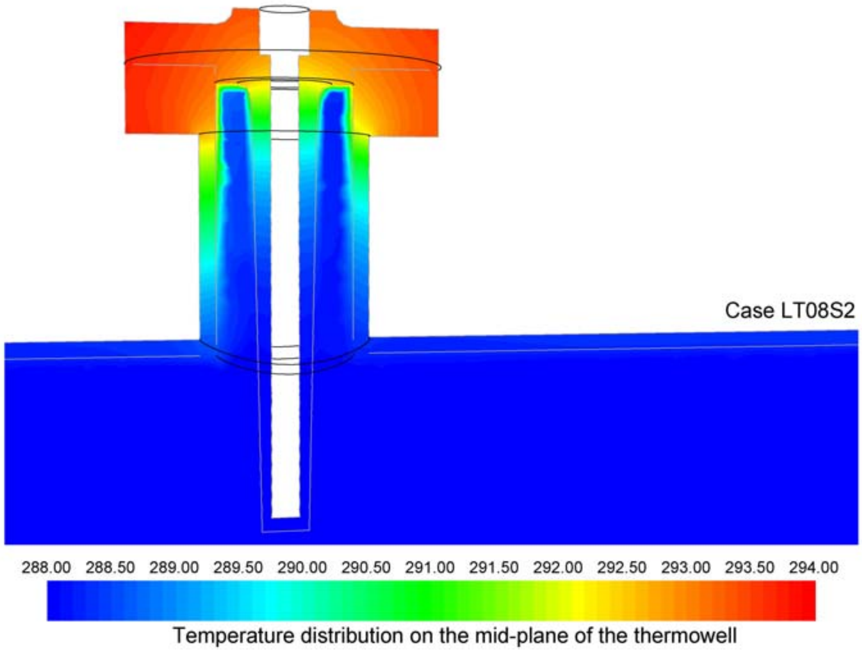

Figure 4.11 Temperature distribution in a 8" pipe for a gas temperature of 15 °C and ambient temperature of 35 °C. The temperature scale is in kelvin – the dark blue corresponds to 15 °C and the red to 21 °C

4.8 Temperature Simulation Results for Insulated Thermowells

Simulations were also presented for insulated thermowell temperature measurements in order to compare previous work carried out by Nisbert and Robertson in this area. These experiments were designed to demonstrate that if a short part of the pipe is insulated surface mounted temperature measurement is acceptable. The insulation extended around the full circumference of the pipe and for a total length of 630 mm with the thermowell positioned midway.

Figure 4.12 and figure 4.13 show the overall temperature distribution across the mid plane through the thermowell for 24" and 8" pipe respectively. Only the exposed parts of the insulation were at the ambient temperature of -10 °C; the thermowell, flange and the insulated parts of the pipe wall surfaces were well protected from ambient conditions as shown by the red colour. The temperature distribution around the top of the thermowell was explored in detail by plotting contours in a narrow temperature range; the results indicated that there was a 2 °C variation. The majority of the thermowell and the thermowell stabbing was well protected and remained at the gas temperature.

It is worth noting that only a short section of the pipe has been considered to be insulated. It appears that a 630 mm length is more than sufficient to prevent the exposure of any part of the thermowell to ambient effects. The temperature changes at the edge of the insulation were examined closely. The simulations predicted small temperature variations in the un-insulated parts of the pipe wall (about 1.5 °C for 24" pipe and 2.5 °C for 8" pipe). However, the effect does not show any significant penetration into the insulated section which indicates that the insulation is more than adequate.

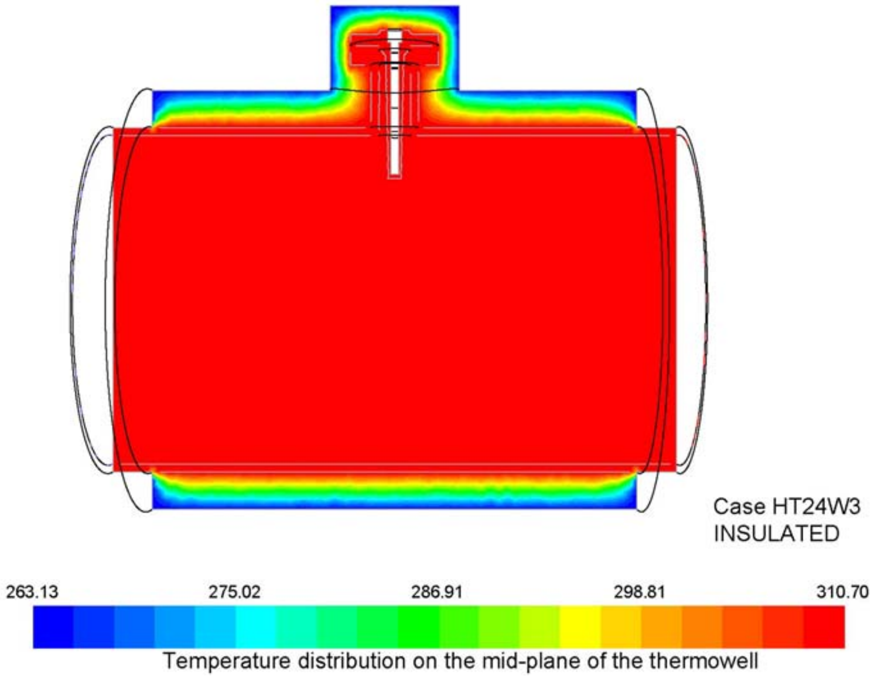

Figure 4.12. Temperature distribution for a 24" pipe insulated over a 630 mm section at the thermowell location. The gas temperature is 37 °C and ambient temperature is -10 °C. The temperature scale is in kelvin – the dark blue corresponds to -10 °C and the red to 37 °C

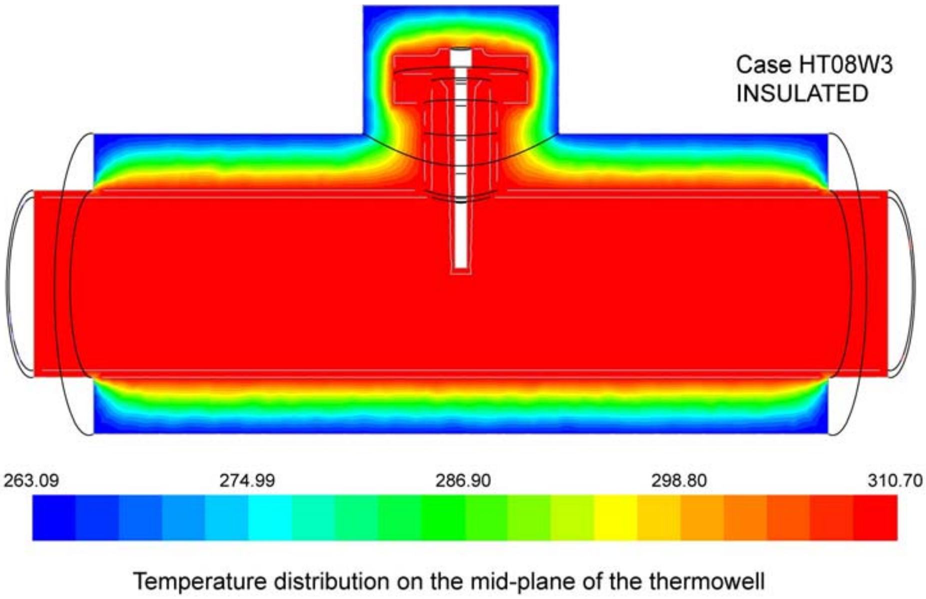

Figure 4.13 Temperature distribution for an 8" pipe insulated over a 630 mm section at the thermowell location. The gas temperature is 37 °C and ambient temperature is -10 °C. The temperature scale is in kelvin – the dark blue corresponds to -10 °C and the red to 37 °C

4.9 Results for Low Velocity Gas Flows

A simulation was carried out for an insulated 8” pipe when the velocity of the gas was very low (1.1 m/s). The gas temperature was 15 °C and the ambient temperature was -10 °C. The results are shown in figure 4.14. The thermowell remained at the gas temperature and, as in previous cases, small variations in temperature around the top area of the thermowell and at the edges of the insulation were present. The reduction in temperature in the top part of the thermowell and flange area was about 2 °C. The drop in wall temperature in the exposed part of the wall was about 3 °C. The edge effects did penetrate into the insulated part of pipe wall for a short distance. The thermowell is, however, not connected to the pipe wall directly and therefore not affected by the minor drop in cylinder wall temperature. The simulation clearly shows that even in this extreme case the bottom of the thermowell remains at the gas temperature.

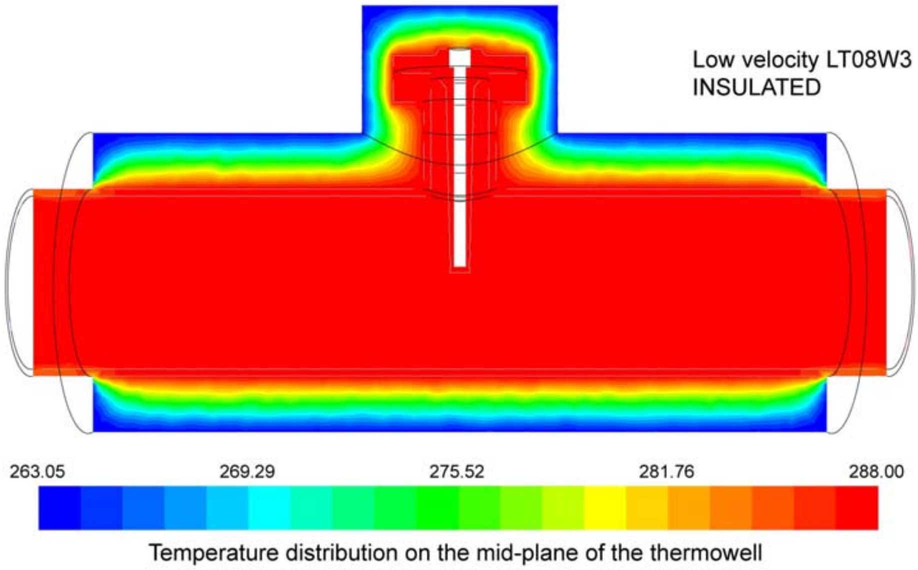

Figure 4.14. Temperature distribution for an 8" pipe insulated over a 630 mm section at the thermowell location. The gas temperature is 37 °C and ambient temperature is -10 °C. The temperature scale is in kelvin – the dark blue corresponds to -10 °C and the red to 37 °C

5 CONCLUSIONS

5.1 Experimental Measurements

The theoretical calculations of Pallan in the early 1970s indicated that the difference in the temperature of the pipe wall and the temperature of the gas were likely to be small even for unlagged pipe subjected to severe conditions. The largest source of temperature error was predicted to be from thermal conduction. Pallan's experimental measurements showed that an unlagged thermowell determined the gas temperature to within ±1.7 ºC when the ambient temperature varied between 39 ºC below and 28 ºC above the gas temperature. The tests also demonstrated that the temperature readings were within ±0.5 ºC when the gas temperature was between 39 ºC below and 11 ºC above ambient.

Theoretical calculations by Fenwick on pipe-surface temperatures show that for high gas pressures and velocities the difference between the gas temperature and the pipe surface temperature is less than 0.6 ºC. The wind speed, however, had a significant impact. Experimental measurements at two compressor stations indicated that the difference between the gas temperature measured in a thermowell and the pipe surface temperature was only 0.2 ºC. These measurements were made in an enclosed environment so the impact of wind speed was not an issue.

The experimental measurements by Ingram confirmed that the agreement between the gas temperature measured in a lagged thermowell and that measured with a lagged surface temperature sensor was within ±0.1 ºC. Ingram also looked at the effect of removing insulation from surface temperature sensors – the temperature difference between the thermowell and the surface sensor with lagging was 0.17 ºC, When the lagging was removed, the temperature difference increased to 1.2 ºC. Other points raised by Ingram were:

- The effectiveness of lagging is considerably reduced if it is not waterproofed.

- Surface-mounted temperature measurement is preferable to very short thermowells in which the sensing element is in the thermowell neck flange

Nisbert and Robertson's measurements compared surface-mounted temperature measurements with temperature measurements in a thermowell at various depths. The maximum difference between the two sets of measurements was 0.15 ºC – the greatest difference was for the sensor located within the thermowell stabbing.

5.2 Summary of CFD Calculations

The CFD study looked at temperature measurements in thermowells in 8" and 24" pipes transporting natural gas at 37.7 °C and 15 °C. Five different ambient conditions (0 °C, -5 °C, -10 °C, 30 °C and 35 °C) were considered. Under winter conditions, the simulations show that the temperatures around the top of the thermowell and the flange area were influenced by ambient temperature. The degree of influence increased with the decrease in ambient temperature. For summer conditions, the simulations show a considerable increase in temperature around the flange area and the top part of the thermowell. This increase is greater for the higher ambient temperature case.

Further simulations were carried out with insulation around the thermowell and the pipe surfaces. It was clear that the thermowell and the flange were adequately protected by the insulation and only a small temperature change can be seen around the top of the thermowell and flange. The edge effects at the end of the insulation section did not penetrate into the insulated section.

A simulation with low velocity gas flow in an insulated 8" pipe was also carried out. The results were similar to the other insulated cases. No significant drop in temperature in the thermowell is seen. However a drop in wall temperature at the end of the insulated section can be seen for the low velocity case, but it does not affect the thermowell temperature in any significant manner. Insulating a short section of the pipe would be adequate to obtain accurate measurements of the gas temperature.

In all cases the bottom of the thermowell was seen to be at the gas temperature and was not affected by the changes in ambient conditions. A temperature measurement taken at the bottom of the thermowell therefore represented the temperature of the gas inside the pipe.

The CFD modelling was based on the following conditions:

- Pipe sizes between 8" and 24"
- Five ambient temperatures from -10 to 35 °C
- Gas temperatures of 15 and 37.7 °C
- Gas velocities down to 1.1 m/s

It should be noted that outside these conditions thermal lagging around the thermowell only is advisable. Also, only one design of thermowell was used in the CFD modelling and other thermowell designs may have different thermal characteristics.

5.3 Comparison between Experimental Measurements and CFD Modelling Calculations

The experimental measurements and the *CFD* Modelling show remarkable similarities.

- The *CFD* models all indicate that the temperature at the bottom of the thermowell is the same as the gas temperature both with and without insulation. The experimental measurements of Pallan confirm that the temperature in an unlagged thermowell was relatively insensitive to the most extreme ambient conditions.

- The *CFD* model shows that the temperature within the thermowell stabbing is influenced by ambient conditions but the temperature of the gas stream within the pipe diameter is unaffected. This is confirmed by the experimental measurements of Nisbert and Robertson.

- The CFD model shows that the gas velocity within the thermowell stabbing is very low. In support of this, Ingram's temperature measurements within the thermowell stabbing showed that there was a very long response time to temperature changes.

- The *CFD* model shows that the temperature of the pipe wall is always very similar to the gas temperature. However, with insulation, the difference between the temperature of the pipe wall and the gas temperature is not detectable. Ingram confirmed that an insulated surface temperature measurement was within 0.1 ºC of the temperature in the thermowell.

- The *CFD* model shows that local insulation around a thermowell or a surface-mounted sensor is sufficient. There is no need to insulate the entire meter run. Ingram also confirmed that local insulation is sufficient for accurate measurements of gas temperature.

6 ACKNOWLEDGEMENTS

This work was sponsored by *Advantica*, *National Grid UKT*, *National Grid UKD*, *Scotia Gas Networks*, *Wales and West Utilities* and *United Utilities*. The authors would also like to thank Professor Malalasekera of *Loughborough University* for his CFD contributions.

7 REFERENCES

1 *Gas Meter Installations For Pressures Not Exceeding 100 Bar* The Institution of Gas Engineers Gas Measurement Procedures IGE/GM/1 Edition 2. **1998**

2 ISO 5167 *Measurement of fluid flow by means of pressure differential devices. Part 1. Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full.* **1991**

3 ISO 5167 *Measurement of fluid flow by means of pressure differential devices. Part 1. Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full.* **1997**

4 ISO 5167 Parts 1 and 2 *Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full*. **2003**

5 Pallan, W & Wood, KR *Thermowell Fatigue Failure Investigation* Gas Council Engineering Research Station Report ERS R247. April **1972**

6 Pallan, W Gas *Temperature Inferred from Pipe Wall Temperature* British Gas Engineering Research Station Report ERS R715 June **1974**

7 Fenwick, JS Pipe *Surface Temperature Measurement at Compressor Stations* British Gas Engineering Research Station Report ERS R1318. July **1976**

8 Ingram, R *Surface Temperature Transducer Response Time Tests on a St Fergus Gas Compressor* British Gas Engineering Research Station Report ERS R3995 July **1988**

9 Ingram, R *Effects of Removing Thermal Insulation on Surface Temperature Measurement – St Fergus* British Gas Engineering Research Station Report ERS R3996.April **1989**

10 Ingram, R *St Fergus Aftercooler Temperature Measurement* British Gas Internal Memorandum June **1986**

11 Nisbet, JR & Robertson, IC *Assessment of Gas Temperature Measurement Systems at Churchover Compressor Station* British Gas Engineering Research Station Report ERS R3670. April **1987**

12 Malalasekera, W *An Analysis of Heat Transfer in Thermowell Installations in Gas Pipelines* Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University. August **2007**

13 Versteeg, HK & Malalasekera W, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method* Second Edition. Pearson Education Ltd, **2007**