Temperature distribution in a pipeline

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DRAFT – Preliminary results

Experimental setup

Low temperature test

Two different VoS based temperature measuring devices have been tested. One Clamp-on (called Clamp-on meter) and one "wetted" VoS device (called Wet-meter). The test section started with a flow conditioner followed by an injector section to which the VoS device was connected followed by a "T-array sensor". Two DN 100 pipes of different length followed before the water was directed back into the test rig.

To generate water flow with different temperature patterns, warm and cold water was mixed using two different configurations as the injector section. The configurations are shown in Figure 1. A normal Tee-conduit (right image, called T-cross) together with a self-made flow injector/mixer (left image, called mixer) were used.

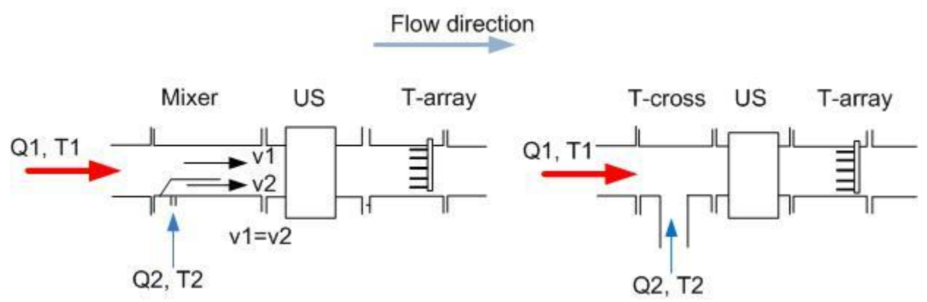

Figure 1. Two injector configurations were used in this study, mixer/injector (left image) and T-cross (right image). The flow rates (Q_1 & Q_2), temperatures (T_1 & T_2) and liquid speed (v_1, v_2) is marked in the figure.

The distance between the wet VoS device and the injector section was varied at 1D, 5D, 11D and 49D. The Clamp-On meter was kept at a fixed distance of 5D. The flow rates Q1 and Q2 were selected so that the cold and warm water had the same liquid speed out of the mixer. The same flow rates were used for the T-cross configuration. Experiments were done with the two configurations at water temperature below 40 ^{o}C. As temperature reference (T_{ref}) for those measurements the following equation was used:

$$\frac{\quad}{\quad} \qquad (1)$$

$Q_{1,2}$ denotes the two measured flow rates, $T_{1,2}$ are the corresponding measured temperatures, $\rho_{1,2}$ is the density and $C_{p1,2,Tref}$ the heat capacity respectively. This weighting as reference temperature was chosen since it is the expected final temperature when mixing two flows with different temperatures and volume. The temperature dependent density and heat capacity were calculated using the equations from IAPWS-IF97. Iteration was used to reach a final reference temperature since C_{pTref} is the heat capacity at the final temperature. Only 3 iteration step was necessary to reach a stable temperature.

High temperature test

Tests were also performed at temperatures up to 120-140 ^{o}C. In these measurements the T-array was the temperature reference and the test configuration is shown in Figure 2. The T-array was placed downstream and as close as possible to the VoS-meters. The measurement started with the clamp-on meter and four different measurements were performed.

Table 1 Measurement parameter during the high temperature evaluation of the VoS-temperature meter.

Measurement number	Name	Boric acid [ppm]	Ammonia [ppm]	Comment
1	Water I	0	0	Only water
2	Boric acid	10	0	
3	Boric + Ammonia	10	5	
4	Water II	0	0	Only water

Figure 2. Experimental setup during the high temperature investigations. The VoS-meter was connected to the high temperature test rig via two metal hoses. Two reference sensors were mounted in the setup, one single Pt-100 placed closed to the pump and the Tarray placed down streamed the VoS-meter.

Results

High temperature tests

In Figure 3 the deviation of the temperature measured by the VoS- meter is compared to the average temperature measured by the Tarray in degrees Celsius as a function of water temperature. It is observed in that the two measurements with boric acid and boric acid mixed with ammonia is within the range of the two measurements with pore water. However at around 110 °C it seems like there is an increase in deviation of the boric acid and ammonia measurement. No clear difference between the measurements with water and the measurements with water and extra chemicals is observed.

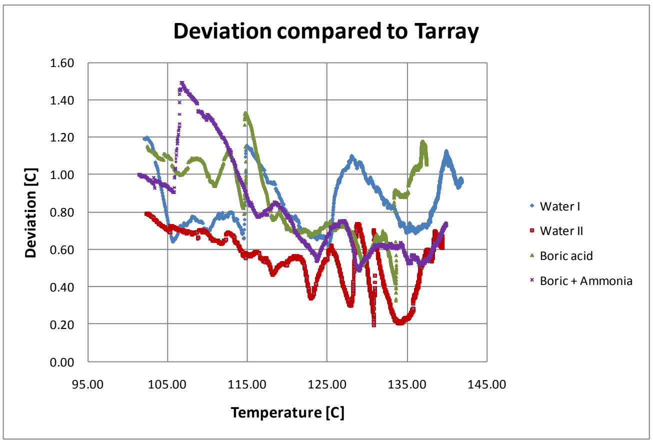

Figure 3. The deviation between the VoS-meter and the average Tarray temperature as a function of the temperature for all the four different measurement.

Figure 4 shows the deviation to the Tarray average temperature for three high temperature measurement with the wet VoS-meter. As seen in the figure all three runs are within 0.2 K from each other in the range from 95-120 °C. At around 120 °C the deviation increase rapidly for some unknown reason. This is also observed for the Clamp-On meter. The deviation for the wet VoS-meter do not fluctuate as much as the deviation for the Clamp-On meter. It is worth the mention that for the wet meter channel 3 gave -25 °C during the high temperature test. This indication could be due to an air bubble blocked the VoS sensor. All presented in Figure 4 is with only channel 1 and 2.

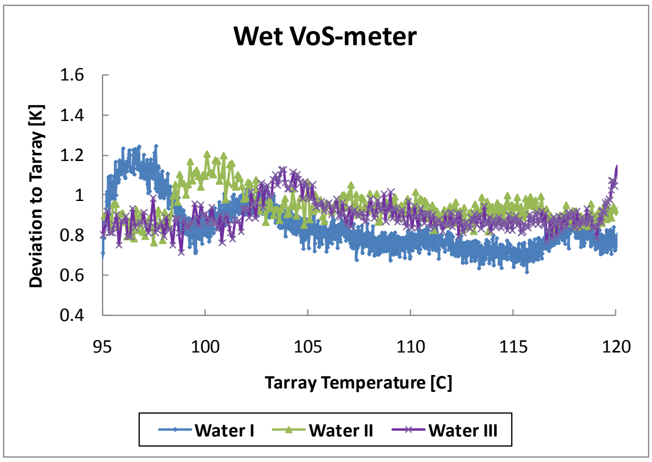

Figure 4. The deviation between the wet VoS-meter and the average Tarray temperature as a function of temperature. All measurement is with water.

Low temperature tests

The measured deviation as a function of temperature difference at inlet is shown in Figure 5 (mixer configuration) and Figure 6 (T-cross configuration). As observed in both figures is that both VoS temperature meters displays much smaller deviation to the temperature reference than the normal Pt-100 sensor. The Pt-100 sensor shows a deviation up to 3K at large temperature difference between the cold and warm water flow. Surprisingly is the even the normal T-cross configuration the Pt-100 shows a deviation up to 2K.

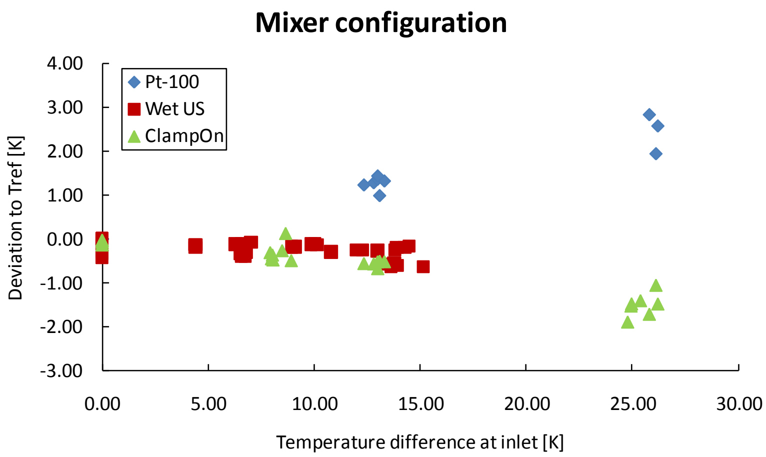

Figure 5. The measured deviation to Tref as a function as temperature difference at inlet for the two US devices and a single Pt-100. The reported data is from the mixer configuration.

The deviation showed a decrease with increased distance from the injector region, as expected. In addition no clear trend with respect to liquid speed out from the injector was observed as long as the liquid speed of the two flows were the same. Furthermore, neither of the VoS-meter showed any significant pressure dependence on the deviation. The main observation in Figure 5 and Figure 6 is that the VoS-temperature meter could lower the deviation several times compared to the single Pt-100 sensor.

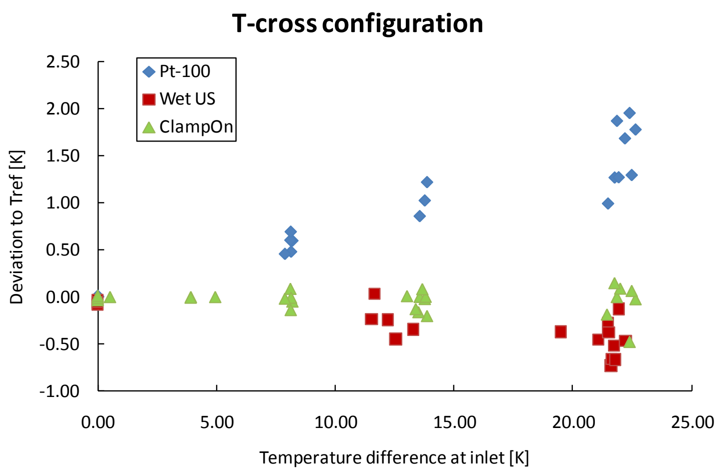

Figure 6. The measured deviation to Tref as a function as temperature difference at inlet for the two US devices and a single Pt-100. The reported data is from the T-cross configuration.

Since the Tarray have 9 Pt-100 sensors it is possible to obtain a view of the temperature distribution during the experiments. Two measured temperature distributions is shown in Figure 7 (T-cross) and Figure 8 (mixer).

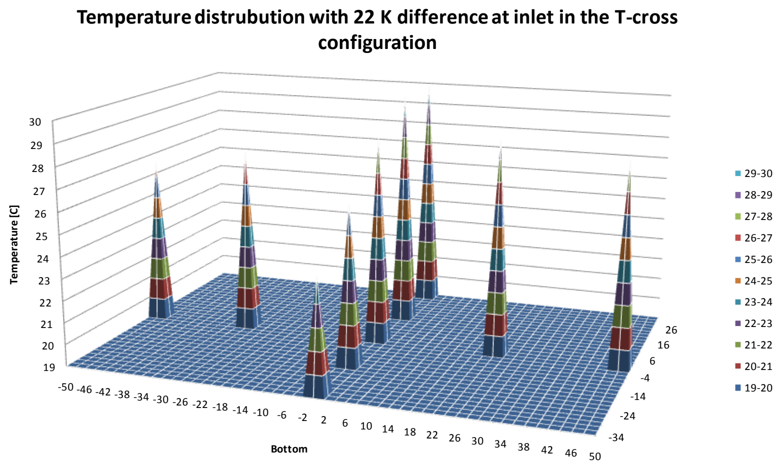

Figure 7. Temperature pattern in the T-cross configuration when the temperature difference at the inlet was 22 K. The flow is flowing inwards the figure.

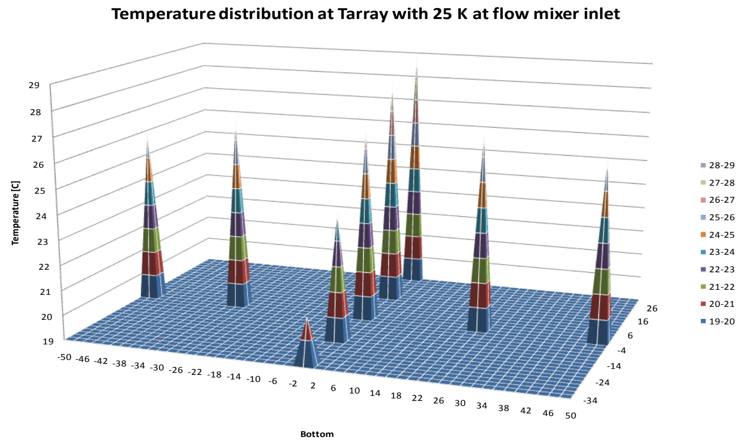

Figure 8. Temperature pattern in the mixer configuration when the temperature difference at the inlet was 25 K. The flow is flowing inwards the figure.

Summary

Two different VoS-temperature meter have been tested to see if a temperature measuring device based on the speed of sound could be used instead of a normal Pt-100. Based on the performed measurements a VoS-temperature meter could lower the deviation almost one order of magnitude compared to a normal Pt-100.