18th NORTH SEA FLOW MEASUREMENT WORKSHOP 2000

DETERMINATION OF GAS DENSITY AT OPERATING CONDITIONS

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1 INTRODUCTION

ISO DIS 15970 "Natural gas - Measurement of properties - Volumetric properties: density, pressure, temperature and compression factor" [3] was submitted March 2000.

One part of this standard covers the use of density transducer for operating density. The author of this paper is member of the working group 1 (WG 1) in ISO/TC193/SC2 developing this draft standard.

This paper describes the experience related to the "Sampling and installation guidelines", "Verification methods" and "Quality control" given in this ISO/DIS.

The experience will include field data from orifice meter system and ultrasonic meter system using different installation methods. Further, experience from systems using on-line chromatographs as well as velocity of sound for density determination and checks in addition to densitometer is given.

More specifically, the temperature problems related to on-line installation will be discussed in more detail. Field observations will be described and explained.

2 SAMPLING AND INSTALLATION GUIDELINES

2.1 General

The purpose of a proper installation of densitometer is to have representative and conditioned samples of gas into the densitometer and to obtain the density at the same condition of the location in the pipe where density is to be determined.

There are two methods of installation, in-line and on-line.

In-line installation has some advantages over on-line installation: no requirement for external loop and no requirements for differential pressure to drive gas through the transducer [1].

Nevertheless, on-line installation has become the more common installation in fiscal measurement station. This is partly due to better access for control and partly because of better protection of the measuring device.

One of the main problems with on-line installations, unlike in-line installation, is to control the condition within measuring element relative to pipeline conditions, both in terms of pressure but not least in terms of temperature.

This paper will therefor concentrate on on-line installations of densitometer, and the temperature matter.

The paper will however also touch upon another way of determining density, namely by utilizing the information from velocity of sound (VOS) from an ultrasonic meter. In terms of installation effects, this could be regarded as an ideal installation.

2.2 On-line installation

By this method, gas is extracted from the pipe and introduced into the densitometer via a by-pass loop. A sampling probe is recommended at the sampling point in accordance with ISO 10715.

A drive is needed to set up flow through the densitometer. This is normally differential pressure along the by-pass loop. Figures 1, 2 and 4 show different ways of setting up such a differential pressure.

In Figure 1 the differential pressure is set up by the flow meter element itself, on this case the orifice plate. This principle is called the pressure-recovery method. It utilizes the recovery of the pressure drop downstream the orifice plate to drive the sample through the densitometer. The sample is returned into the line at the downstream tapping point.

In Figure 2 the differential pressure is set up across the sampling probe. Figure 3 shows a real installation of this kind. In this case, the restrictions in the sampling tube shall be symmetrically on both sides of the densitometer to obtain correct pressure in the densitometer.

In Figure 4 the differential pressure is set up as the difference between the pipeline pressure and a system at much lower pressure, for example a vent or flaring system. Note that the example here don't use a sampling probe because it would have had an impact on the flow pattern into the orifice plate.

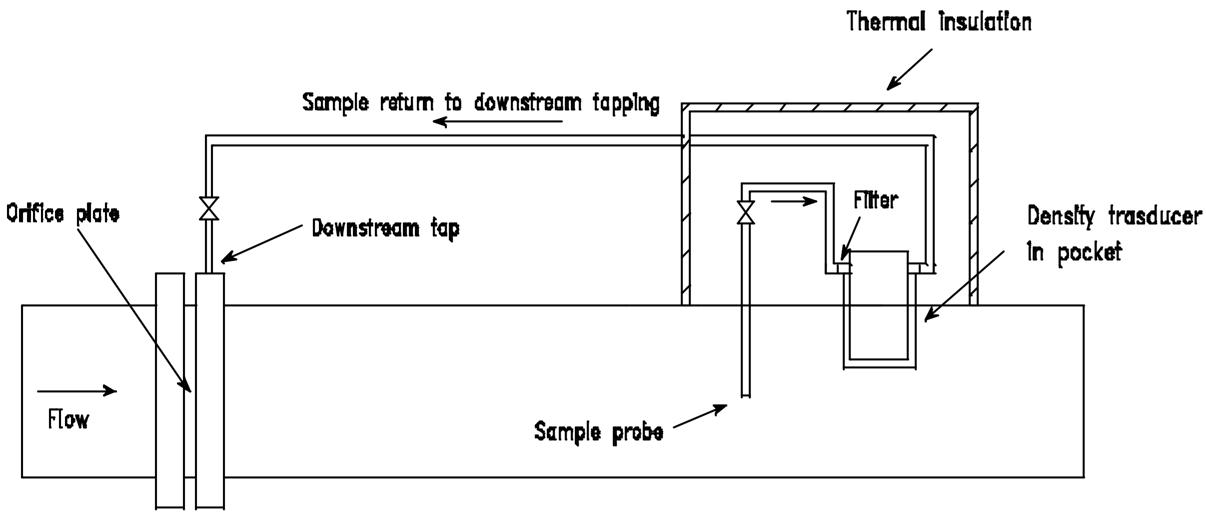

Figure 1 - Installation of gas density meter on an orifice plate system using pressure recovery method

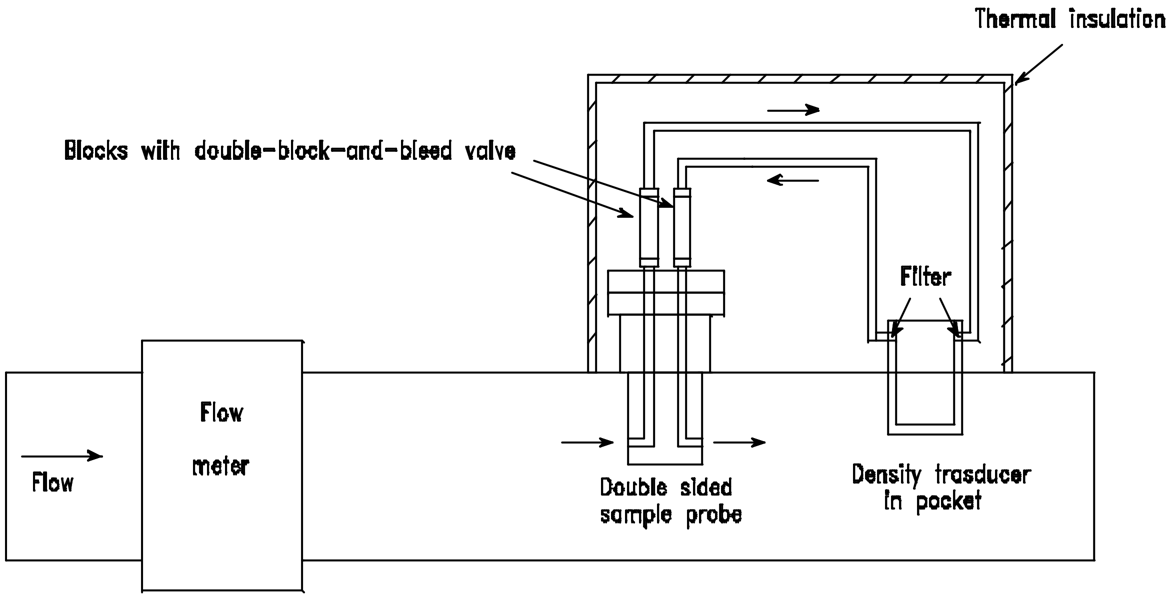

Figure 2 - Principle for on-line installation when the flow meter causes no pressure drop (e.g. ultrasonic meter).

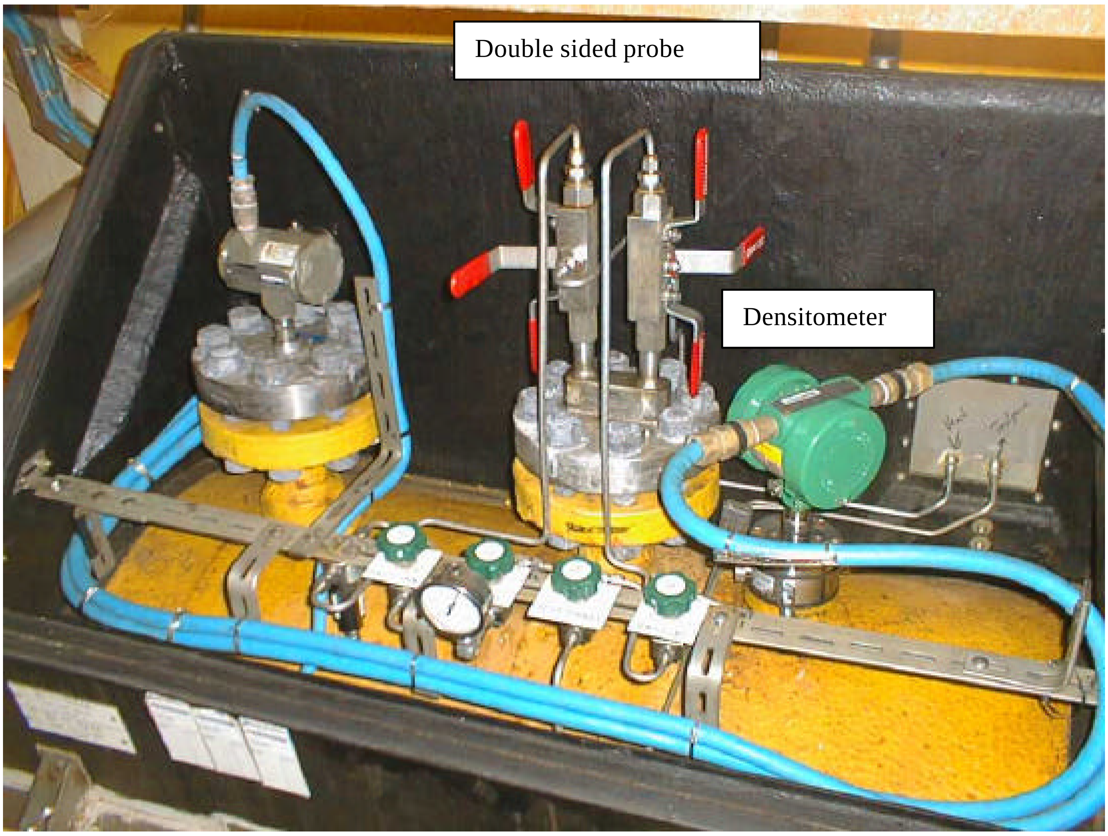

Figure 3 - Real installation of the principle in Figure 2

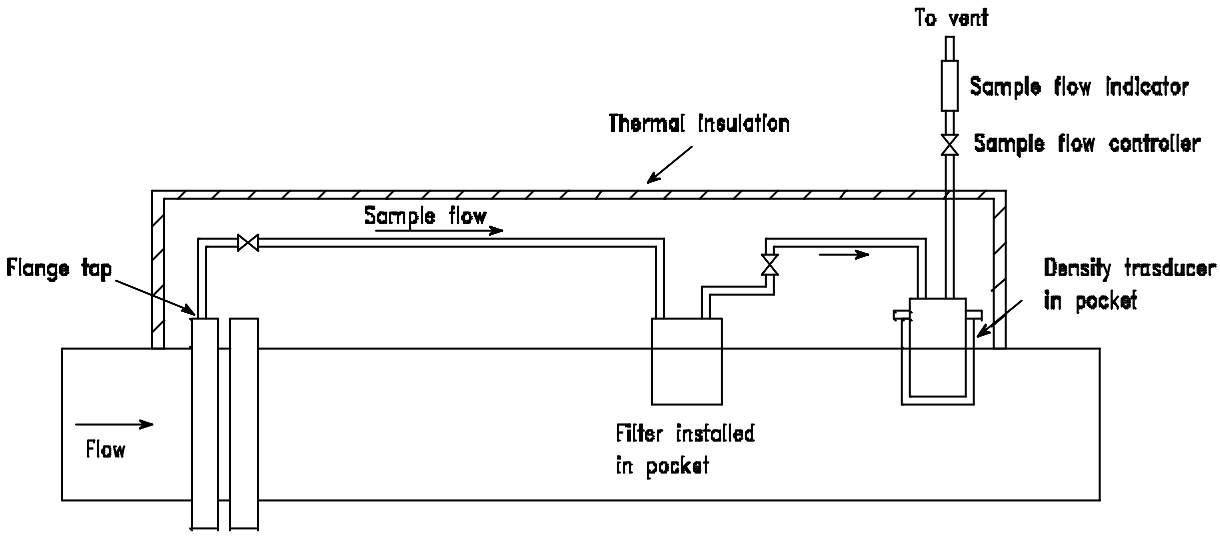

Figure 4 - Principle of an on-line installation with sample gas to vent. In this case with sampling from the upstream tapping of an orifice plate, no sampling probe is used

All these installation methods have some characteristics in common:

There is a possibility of pressure and temperature differences between the densitometer and the line. There are two ways around this potential problem: Either to make effort to minimize the temperature and pressure differences or monitor the difference and compensate for it. In order to minimize the temperature difference, the densitometer shall be installed in a pocket in the main pipe and the whole density transducer installation including the sampling lines shall be thermally insulated from the ambient. To further reduce temperature differences, filters upstream of the densitometers may be installed in pockets into the line, as indicated in Figure 4, in order to increase the heat exchange with the pipeline gas.

In order to minimize the pressure difference between the point of interest for density in the pipe and the densitometer, location of any restriction in the sample line, such as filters, flow control valve(s) etc. should be carefully chosen.

In the case of the method in Figure 1, where the density at the downstream tapping point shall be used in flow calculations in accordance with ISO 5167-1, most of the restrictions should be upstream of the densitometer. This is of course the best place to put a filter in order to clean the gas and at the same time a more open tubing downstream of the densitometer allows good pressure equilibrium between the densitometer and point of interest.

In the case of the method in Figure 2 the restrictions should be symmetrical on both sides of the densitometer.

In case of the method in Figure 4, it is necessary to install filters upstream of the densitometer in order to clean the gas. Since flow is needed, there is in this case a risk of pressure drop between the sampling point and the densitometer.

2.3 Pressure and Temperature Correction

ISO DIS 15970 allows correction for pressure and temperature differences between the densitometer and pipe to be calculated using the following equation:

$$\rho_l = \rho_c \left(\frac{T_d}{T_l}\right)\left(\frac{p_l}{p_d}\right)\left(\frac{Z_d}{Z_l}\right) \qquad (1)$$

where r_l is the density at line condition

r_c is the density in the densitometer at the densitometer condition

T_d is the temperature in density transducer

T_l is the temperature in pipe

p_d is the pressure in the densitometer (can often be set equal to p_l)

p_l is the pressure at the required location in the pipe

Z_d is the compression factor in the densitometer

Z_l is the compression factor in the pipe at the required location

Z_d and Z_l are calculated from the available knowledge of the gas composition in the pipe.

The temperature element used for determination of the temperature in the densitometer should be a calibrated Pt-100 element installed directly into the chamber in the densitometer where the vibrating element is. The densitometer shall be calibrated with this temperature element installed.

2.4 Temperature Differences

It is normally assumed that even if the temperature changes along the tube from sampling point to the densitometer, pipeline temperature is recovered in the densitometer placed in the pocket in the main line. This is however not necessary true.

If the flow is low it is true that the temperature is better recovered in the densitometer pocket. However, the low flow also results in a temperature at inlet to the densitometer which is closer to the ambient compared to the situation with higher flow rate.

The dependence of temperature condition in the densitometer tubing could be illustrated by Figure 5.

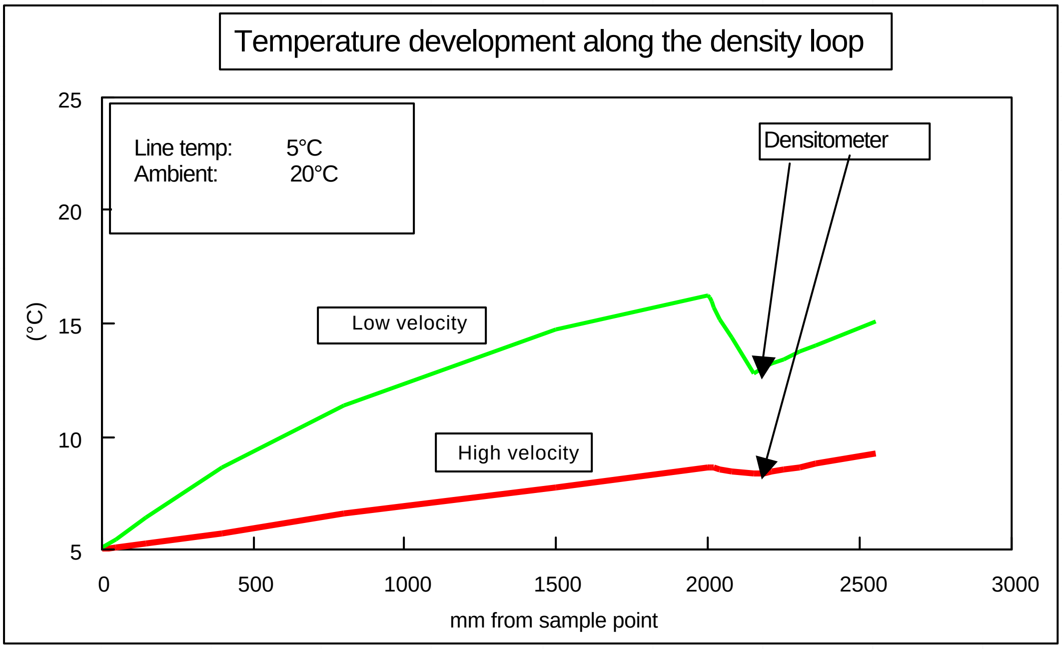

Figure 5 - Illustration of temperature development along the density loop

The shape of the curves in Figure 5 will depend on how well the densitometer installation is insulated.

Different curves like in Figure 5 are not relevant for an installation like Figure 4. In this case the flow rate is kept constant, independent of the flowrate in the main pipe.

For the installation methods like in Figure 1 and Figure 2, the flowrate in the densitometer tubing are close to proportional to the flow velocity in the main pipe. This is the reason why the temperature in the densitometer varies relative to the main pipe with flowrate even though all temperatures are constant. Such a dependence of flow velocity is illustrated in Figure 6.

Another way of illustrating the densitometer dependence is shown in Figure 7. For a given flowrate, the difference between densitometer temperature and line temperature is very close to being proportional to the difference between ambient temperature and line temperature.

It should be noted that all, which has been explained about the densitometer temperature for a given flowrate, is relevant also for the method in Figure 4.

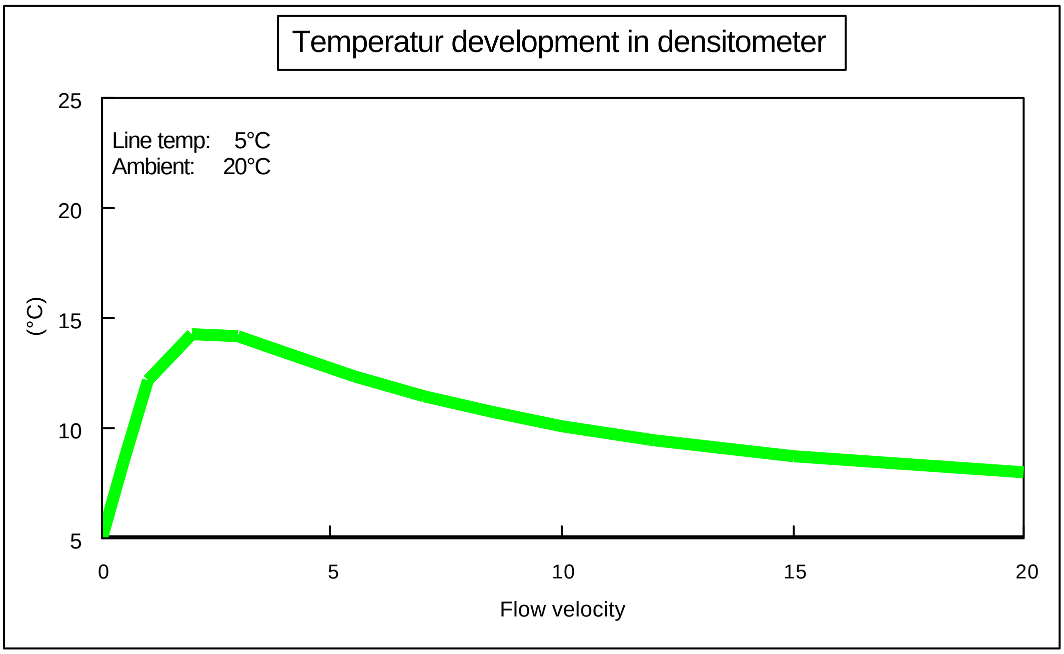

Figure 6 - Illustration of density temperature for a given ambient and line temperature as a function of flow velocity

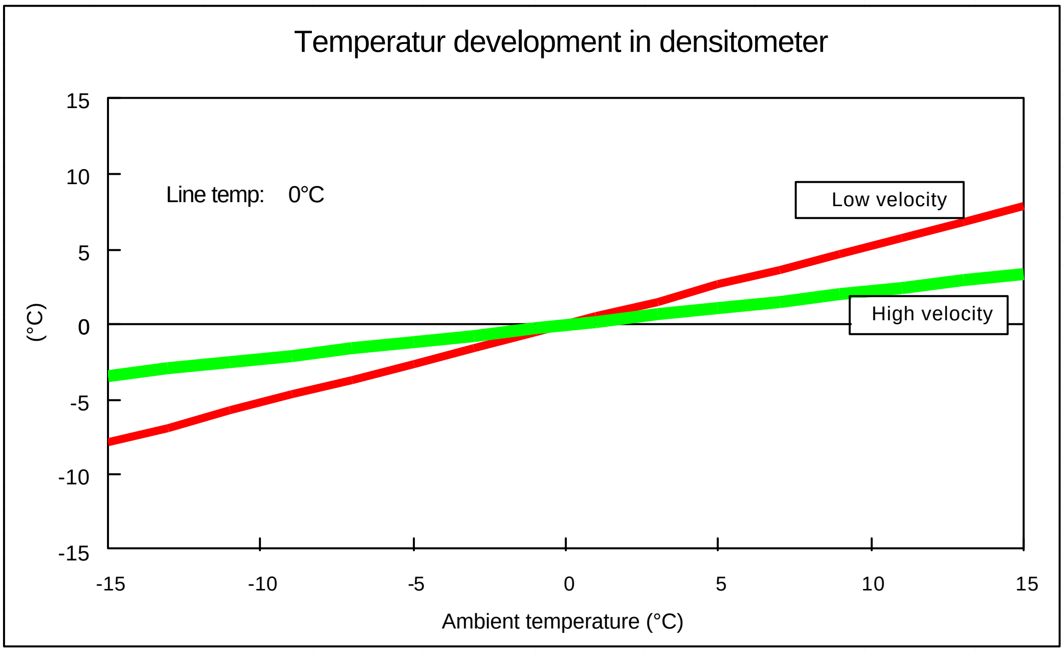

Figure 7 - Illustration of density temperature relative to line temperature as a function of ambient temperature at two different flowrates.

3 FIELD OBSERVATIONS

In this section a few examples from field for the different installation methods will be given

3.1 Installation method like figure 1

The experience reported here is from an installation where the pressure is in the order of 120 bar and line temperature around 22°C, The ambient temperature was in the order of 5°C when this test was carried out.

ISO/DIS 15970 recommends as an on-line verification test of the installation effect to carry out a pressure shift test for this type of installation.

This test is carried out to verify that the pressure inside the densitometer is equal to the desirable line pressure under flowing conditions.

With established flow through the sampling system, close the valve in the sampling line at the side of the densitometer not facing the tapping point where the desirable pressure exists in the pipe. If no sudden change in density is observed, then it is likely that the pressure inside the densitometer is correct under flowing conditions.

If a change in density is observed, then it is most likely that an undesired pressure drop exists in the sampling line under flowing conditions. It should then be checked for any blockage in the sampling line.

The sudden effect on density due to the sudden change in pressure should not be mixed with the possible slower change in density due to slow temperature change caused by the stop of flow through the densitometer.

This pressure shift test was carried out at a given installation. The result of the test in terns of density development is shown in Figure 8.

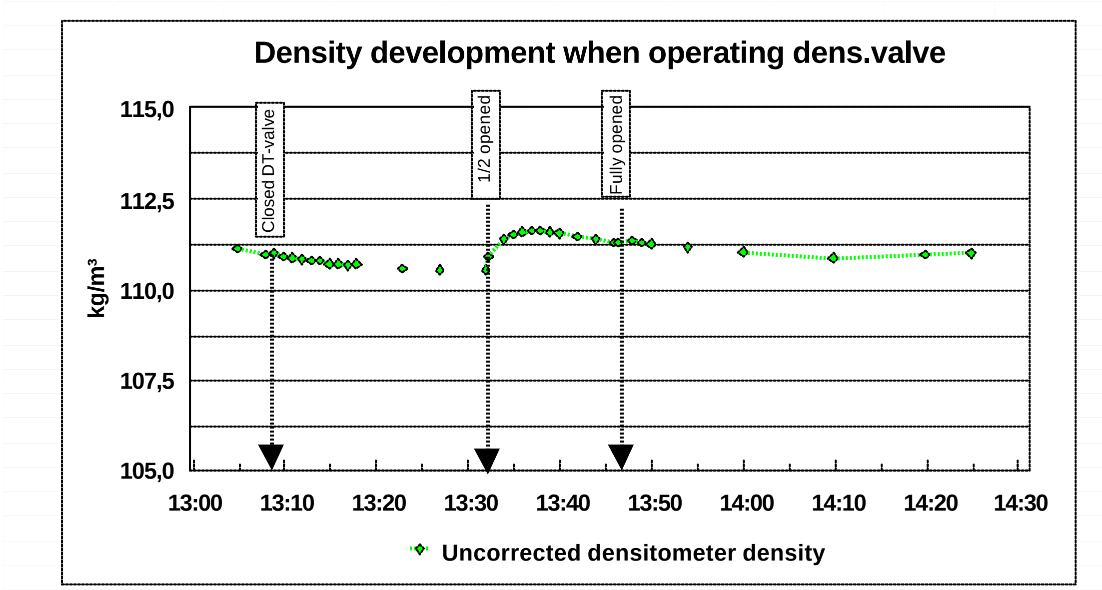

Figure 8 - Development of density during a pressure shift test

The first interpretation of the results in Figure 8 would be in accordance with the assumption in ISO/DIS 15970 that an undesired pressure drop exists in the sampling line.

Since this was an installation with temperature element in the densitometer itself it was possible to follow the temperature development during this test. The temperature development is shown in Figure 9.

Three temperatures are recorded: Line temperature (Tline), the temperature in the densitometer itself (TD7812) and the temperature in the densitometer tube immediately upstream the densitometer (TDTube). During the test the flowrate in the main pipe and hence also in the densitometer tube was close to constant.

Prior to closing the valve it can be seen that the densitometer temperature is closer to the line temperature than the tube temperature. This is in accordance with the principle as shown in Figure 5. After the valve is closed, the temperature in the densitometer approaches line temperature while the tube temperature is slightly approaching ambient temperature but the still gas is warmed up a bit by the warmer pipeline.

The valve was then opened ½-way. A temperature drop was the observed both in the tube temperature as well as in the densitometer temperature. This can be explained by a move from zero flow to low flow in the diagrams in Figures 5 to 7. Note that in this example the ambient temperature is lower than the line temperature. A further opening of the valve to fully open is equivalent to moving from low flow to high flow in Figures 5 to 7. All conditions are returned to the original conditions which can be seen also from the temperatures readings. Figure 9 also indicates that the tubing temperature is not representative for the densitometer temperature. Reference is also made to [2].

By correcting the density for the differences between densitometer temperature and line temperature a density representative for the line conditions is obtained . It can then be seen this corrected density stayed very constant during the pressure shift test, Figure 10. So the density variation first observed during the pressure recovery test as shown in Figure 8 was not due to pressure shift but temperature shift which unavoidably is generated by these actions.

The conclusion from the test is that the installation effect on the density is negligible provided the density is corrected to line conditions.

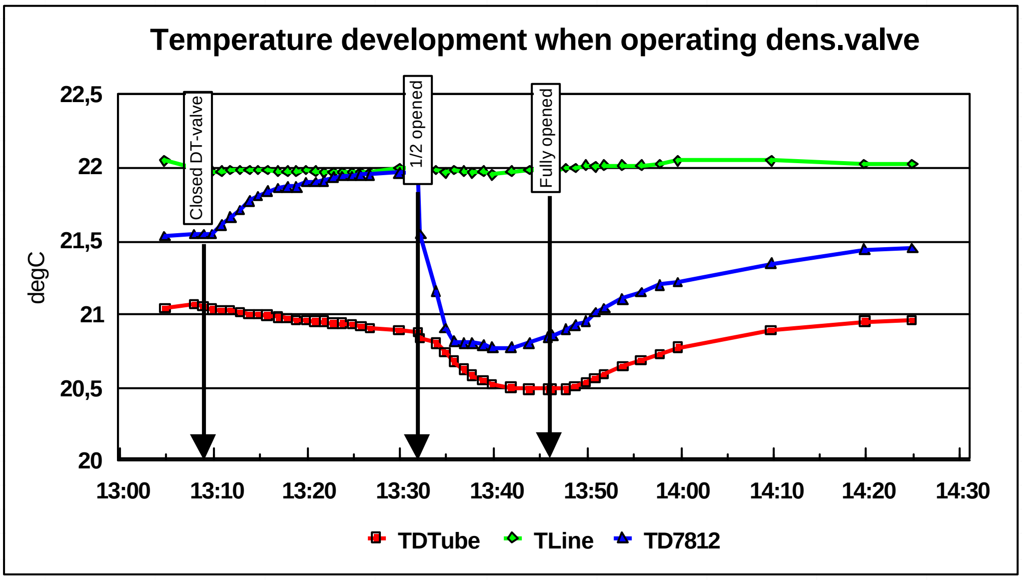

Figure 9 - Temperature development during the pressure shift test

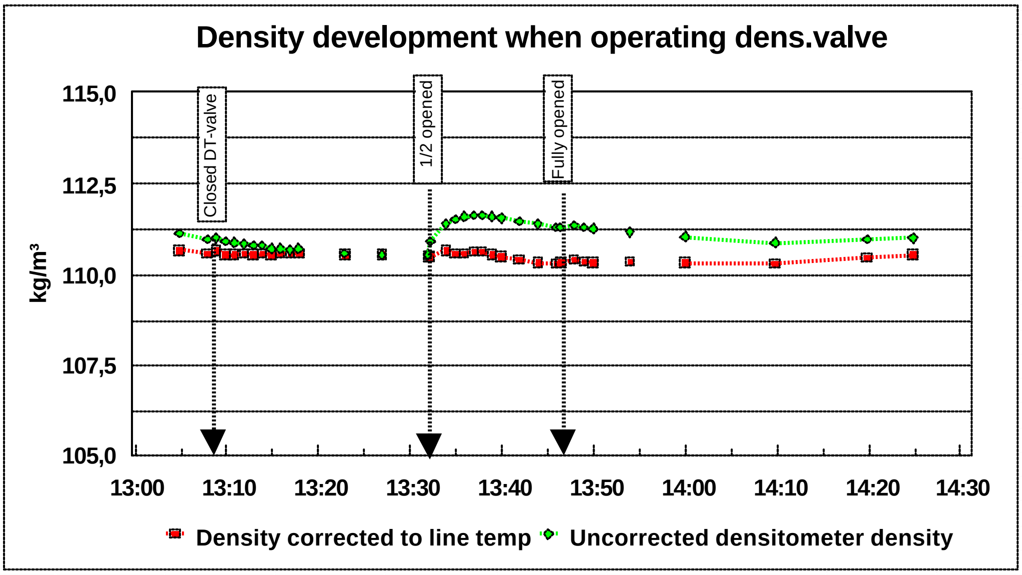

Figure 10 - Uncorrected and corrected density development during a pressure shift test

3.2 Installation Method Like Figure 2

The installation with densitometer installation like the one in Figure 2, which is reported here, is installed in connection with an ultrasonic flow meter. This installation has been studied for a long period of time by collecting a spot sample of data every day. This is partly the reason for some scattering in the results.

Flowing conditions in this installation is pressure in the order of 100 bar and line temperature in the order 5°C.

Figure 11 sums up the experience.

In this case the density has been calculated from VOS in addition to measured density not corrected to line conditions and measured density corrected to line conditions

The difference between densitometer temperature and line temperature is approximately 1/10 of the difference between ambient temperature and line temperature.

The uncorrected measured density varies relative to the VOS density such that an increase in density temperature by 1°C relative to line temperature results in a decrease of uncorrected measured density by 1% relative to the VOS density.

Comparison between corrected density results in a difference against VOS density, which does not depend on density temperature or ambient temperature.

The conclusion in this case is also that a temperature correction of the density to line condition was necessary.

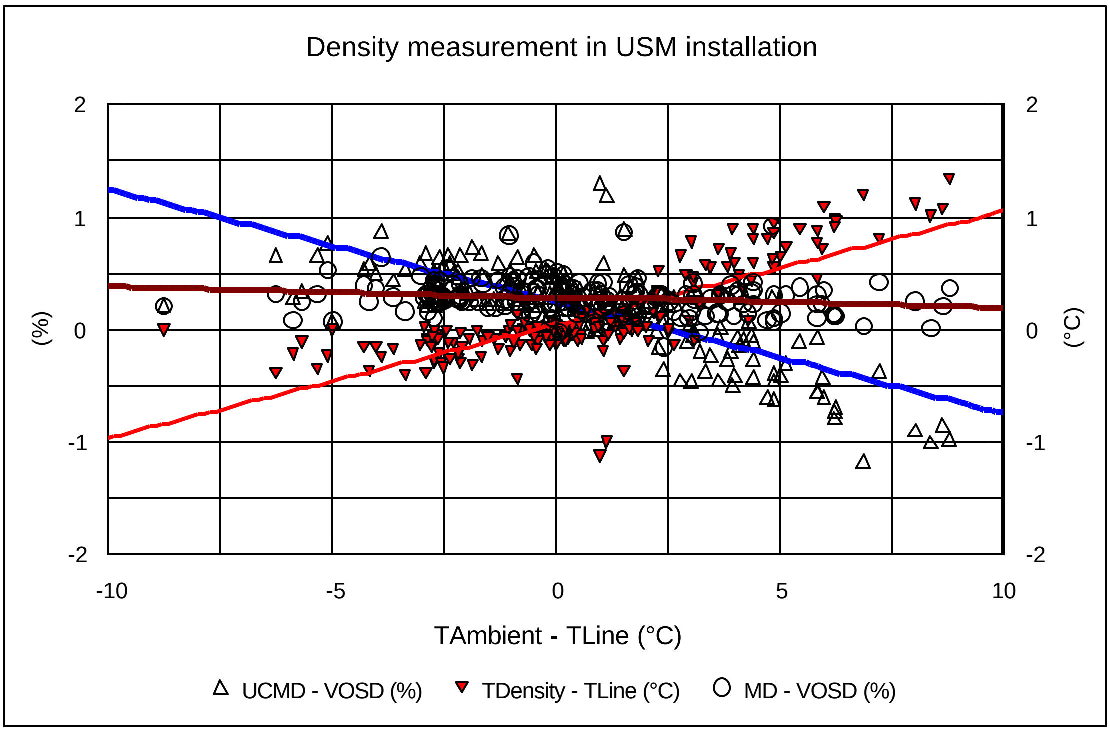

Figure 11 - Temperature and density relation in an installation like Figure 2

3.3 Installation Method Like Figure 4

The example of this installation is from a system with orifice plate. In addition there is an ultrasonic flow meter in the vicinity and an on-line gas chromatograph system (OGC). This system gives the possibility for a check of measured density against the density calculated from VOS and a check of measured density against density calculated from the gas analysis. Line temperature is in this case in the range of 2 – 10°C, and pressure in the range of 55 – 65 bar.

The data presented here are collected over a period of one year, representing daily average values.

Figure 12 shows clearly that even with this installation the density temperature depends on the difference between ambient temperature and line temperature. The difference between density temperature and line temperature is approximately 1/100 of the difference between ambient temperature and line temperature which is approximately 1/10 of the ratio when using installation method in accordance with Figure 2.

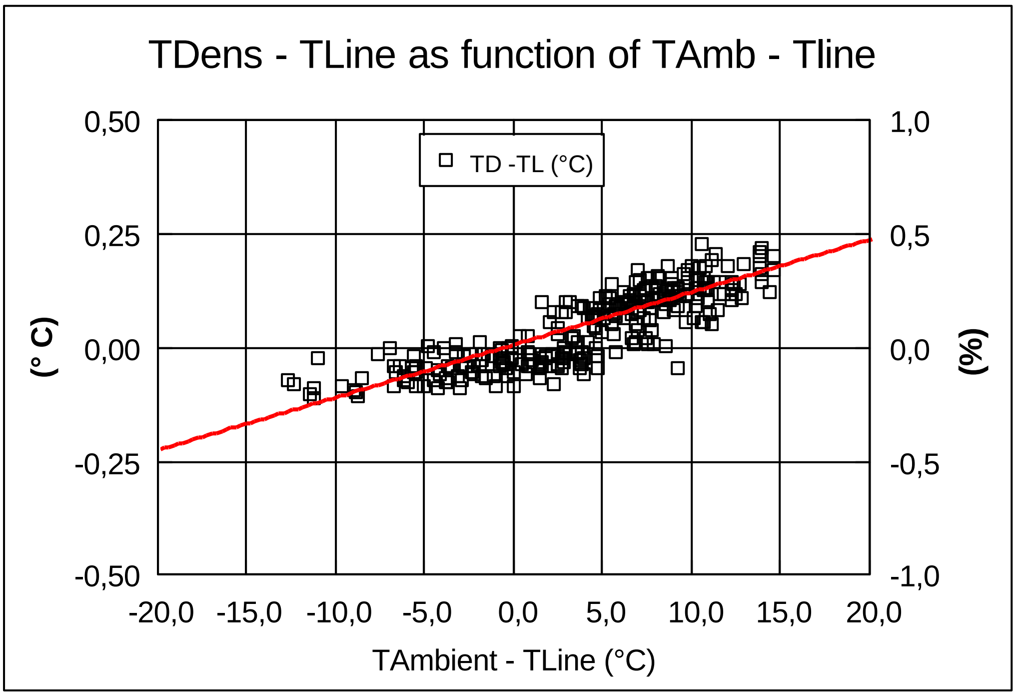

Figure 12 - Temperature relation in an installation in accordance with Figure 4

The measured density is then compared with calculated density, both from VOS and from gas composition. As mentioned in Section 2.1, the densities calculated from VOS and from gas analysis have no installation effects built in.

The result of such a comparison when not correcting measured density to line conditions (MUCD) is shown in Figure 13.

Even though the absolute uncertainty of the calculated densities is uncertain, a very clear trend is seen in terms of temperature dependent difference between the densities. The measured density not corrected to line conditions increases relative to both VOSDensity and GCDensity when density temperature decreases relative to line temperature by a factor which is very close to - 1% pr. degree change in density temperature.

The result of the comparison after correction of measured density to line conditions (MCD) is shown in Figure 14. As can be seen, the difference between measured density and the two calculated densities is no longer dependent on the difference between ambient temperature and line temperature.

The conclusion from these data is that even in the case of relative small temperature differences it is still better to correct for the temperature differences than not.

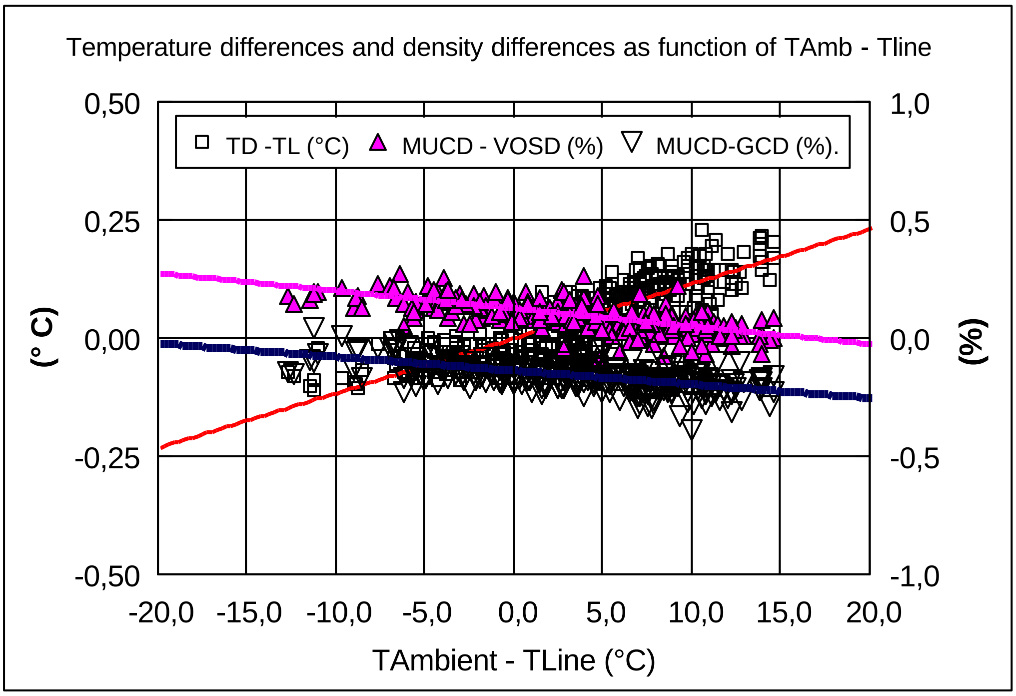

Figure 13 - Differences in density temperature, TD, and line temperature, TL, and between density not corrected to line conditions, MUCD, and calculated density from VOS, VOSD, and calculated density from gas chromatograph analysis, GCD, as a function of Tambient and Tline

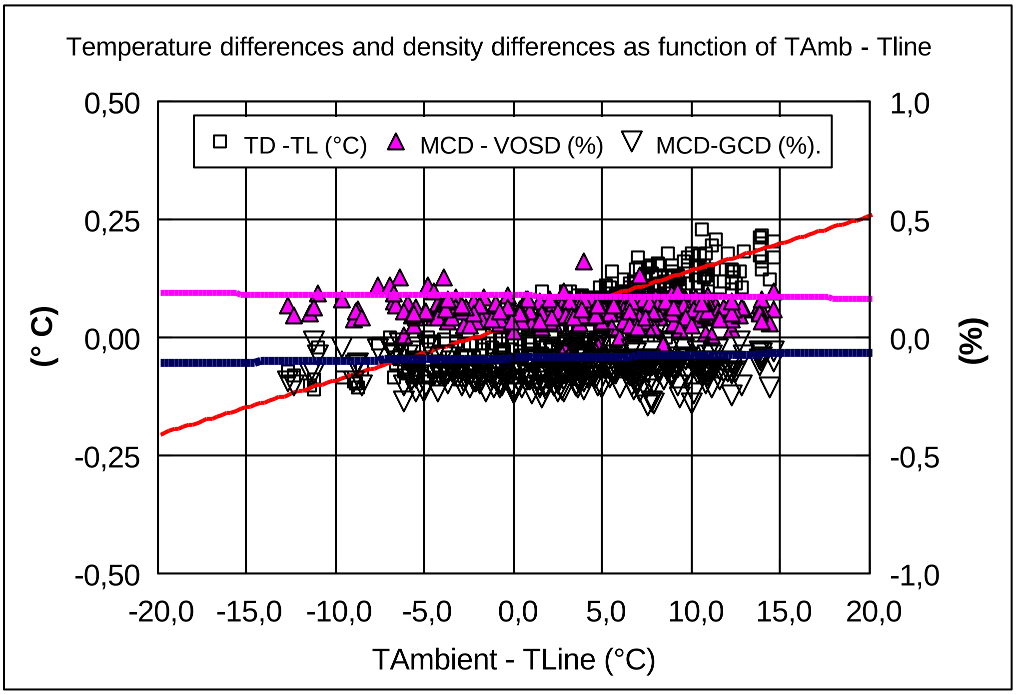

Figure 14 - Differences in density temperature, TD, and line temperature, TL, and between density corrected to line conditions, MCD, and calculated density from VOS, VOSD, and calculated density from gas chromatograph analysis, GCD, as a function of Tambient and Tline

4 CHECK OF CONSISTENCY

ISO/DIS recommends as a quality control of measured density a comparison, manually or automatically, with the expected value. The expected value can be based on knowledge of composition, pressure and temperature or on other consistent measurements such as velocity of sound.

The analysis may be from a gas chromatograph or an assumed composition. Alternatively, gas with known quality may be introduced into the densitometer and the reading from the densitometer can be compared with the density calculated from the gas properties, pressure and temperature.

As can be seen from the data presented in this paper it seems to be necessary to keep control of the temperatures and carefully evaluate what possible effects the temperatures may have on the final results. In many cases it is worthwhile to consider correcting for temperature differences.

5 ACCURACY

It might be argued that adding temperature and compressibility terms to the determination of density will add additional uncertainty to uncertainty of density compared to not adding these terms.

That is only partly true. Adding these terms to the determination of density might increase the uncertainty from typical 0.20% to 0.25% provided the temperature elements are calibrated and temperature transmitters adjusted accordingly.

However, not adding these terms and leave the density uncorrected for difference in conditions between densitometer and line might result in another additional uncertainty of as much as 1% or more. The author this paper have seen examples of differences in densitometer temperatures and line temperatures of close to 10°C. The effects of even such high temperature differences which can be as high as 10% on density have been cancelled out by applying (1). In such cases, applying (1) can reduce the uncertainty from close to 10% to 0.3%.

6 CONCLUSION

The brief conclusions to be drawn from the examples presented here are:

- Even though great care is taken to avoid temperature differences between the temperature in the densitometer and in the line, it is extremely difficult to avoid temperature differences completely.
- The correction method given in ISO/DIS 15970 is a good alternative provided all components in the temperature loops are calibrated.

7 REFERENCES

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