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GAS DENSITY INVESTIGATION ON AN OFFSHORE FISCAL GAS METERING STATION

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GAS DENSITY INVESTIGATION ON AN OFFSHORE FISCAL GAS METERING STATION

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SUMMARY

An investigation was initiated to determine the reason for differences in gas density measured by parallel on-line densitometers. Density differences of 0.5% or more had been observed. This paper details an extensive series of tests to resolve the problem, conducted on one meter run during the annual preventive maintenance check. Gas density measurements were made under static and dynamic conditions with pure methane, nitrogen and sales gas. The time delay from point of gas sampling to the point of density measurement was established. The time required for the densitometer to come to temperature equilibrium with the gas stream was investigated. The conditions necessary for the densitometers to produce essentially identical values were determined.

INTRODUCTION

Vibrating element densitometers are commonly used on high pressure North Sea metering systems to measure the gas density for custody transfer. The instruments are installed in accordance with general industry guidelines (Institute of Petroleum or American Petroleum Institute). Often, two densitometers are used to minimize the possibility of shut down if one instrument should malfunction.

During an annual preventive maintenance check of the offshore Tyra East gas metering station operated by Mærsk Oil & Gas, it was observed that the two densitometers on the same gas line would register values that gradually drifted apart. The difference would become large enough to be of concern. There was no evidence of any malfunction of either instrument. It was noted that after performing the vacuum point check on the densitometers the registered values would be in very good agreement.

At a later date a series of tests were conducted on the offshore operating system to determine the source of this problem and the best solution to eliminate it. This paper reports on the results of those tests.

METERING STATION

The gas metering station on Tyra East is equipped with four meter runs. Each meter run is a nominal 273 mm ID and is equipped with an orifice plate fitting. A pressure measuring cell, three differential pressure cells, two in-line densitometers and a platinum resistance thermometer (PRT) are installed on each meter run. Information from all of the installed instrumentation is transmitted to the central control room. In the control room, the information is recorded and displayed. The appropriate information is processed by the flow computer to calculate at 20 second intervals the mass flowrate, the standard volume flowrate and the energy flowrate.

The two densitometers are in a parallel flow arrangement. In normal operation, the gas stream from the sample point after passing through a 9 micron filter is split into two streams, one for each densitometer. There is a 2 micron filter in each line before the gas enters the densitometer. On exiting from the densitometers the gas streams are recombined and the gas is returned to the downstream side of the orifice plate.

The piping arrangement for each densitometer in addition to the filters contains a vacuum connection, a vent connection and numerous block valves. The two parallel piping arrangements are identical except that 1 meter more of tubing was required to connect the second densitometer. All of the components of the piping system are covered with 1 inch of foam rubber insulation.

With this equipment arrangement the density values measured by the two densitometers were generally quite close, but it was noticed that a difference would develop between the two sets of values. On one occasion this difference developed immediately after a meter run was put back into service after a maintenance check as shown in Figure 1. The meter run was cold at the start

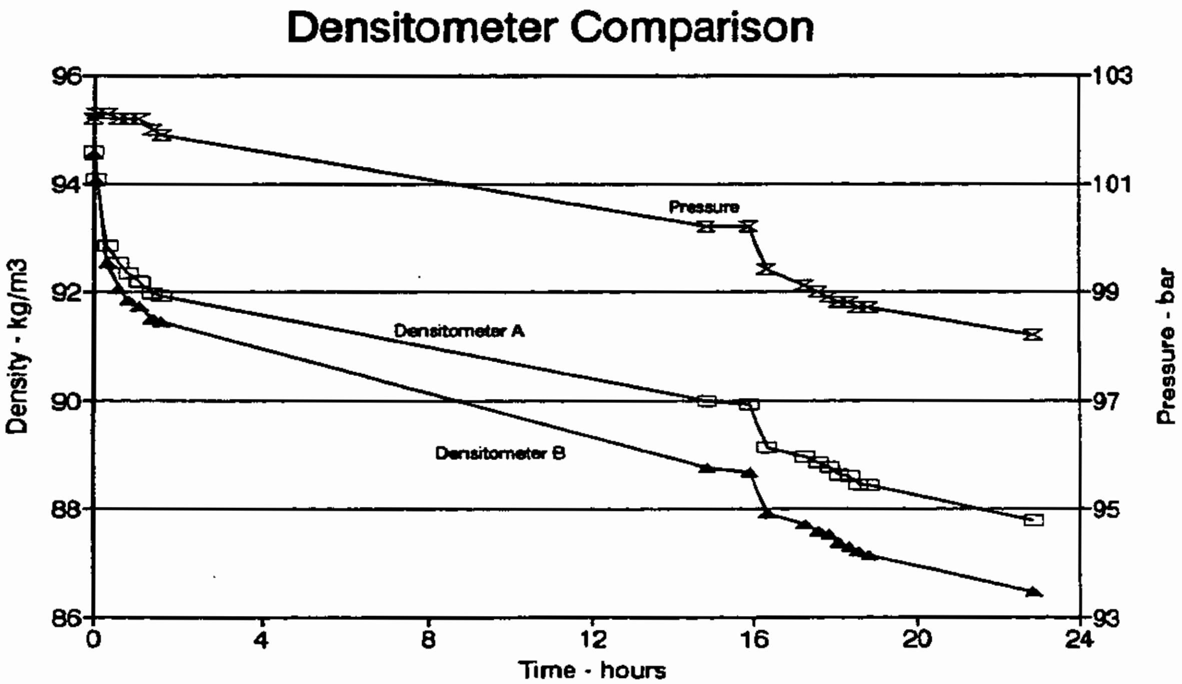


Figure 1

and the change in density over the first hour was thought to be the result of temperature stabilization. The densitometer temperature was not measured but the gas stream temperature was in the range of 30 to 32 degrees Celsius (°C). The discharge pressure from the metering station decreased over the next 24 hours with a corresponding decrease in measured density of each of the densitometers. The difference of about 1 kg/m^3 in the measured density was disturbing as well as the fact that it was increasing with time. Flow through the meter run was discontinued and the vacuum point of each densitometer was rechecked and found to be within range.

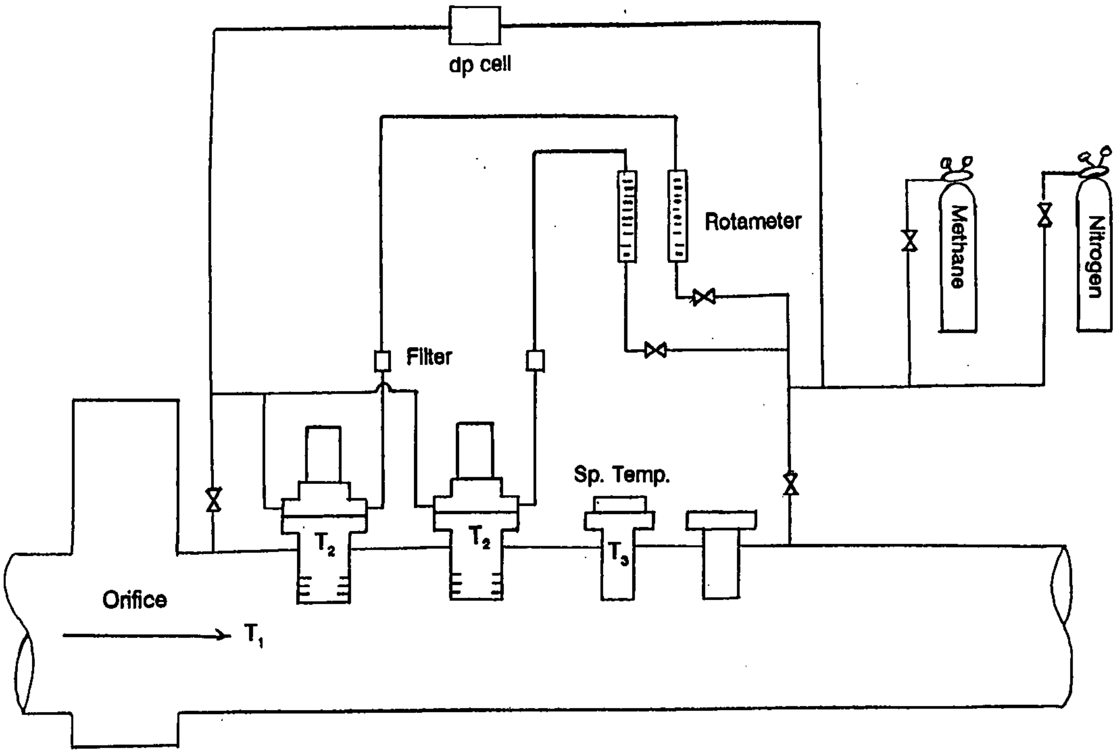
Some rudimentary tests showed that the gas entering the densitometers was essentially at ambient temperature. The gas leaving the densitometers was several degrees warmer. One obvious question was, "What is the gas temperature in the density measurement chamber?" Could the density difference be the result of temperature variation?

TEST PROGRAM

A series of tests were devised to check the operation of the densitometers with nitrogen, methane and sales gas under a variety of static and dynamic conditions. The sample gas system was modified as shown in Figure 2 for these tests. A connection was installed in the gas sample line so that nitrogen or methane could be introduced into the system in addition to normal sales gas. A high pressure rotameter and needle valve was installed to control and balance the flow to each densitometer. A 100 bar test gauge and a differential pressure cell were connected to the sample system for use during some of the tests.

Temperature probes were installed through T fittings into the gas line entering and leaving each densitometer. Initially a single thermocouple was installed in the oil filled well containing the densitometer. After discovering that one of the thermocouples was shorted to the pipeline two thermocouples were attached to each densitometer, one to the bottom of the measuring chamber and one in a cavity on the side of the densitometer.

During the course of the tests, a special insulated enclosure was built around the two densitometers and a portion of the meter run pipeline. A thermocouple was also used to measure the ambient air temperature in the enclosure surrounding the densitometers. The PRT for the flow computer was used as the reference temperature for these tests.



Test Meter Run

Figure 2

TEST RESULTS AND DISCUSSION

A short period of density history was collected on the test meter run before the test equipment was installed. This data shown in Figure 3 would serve as a baseline for comparison with the test

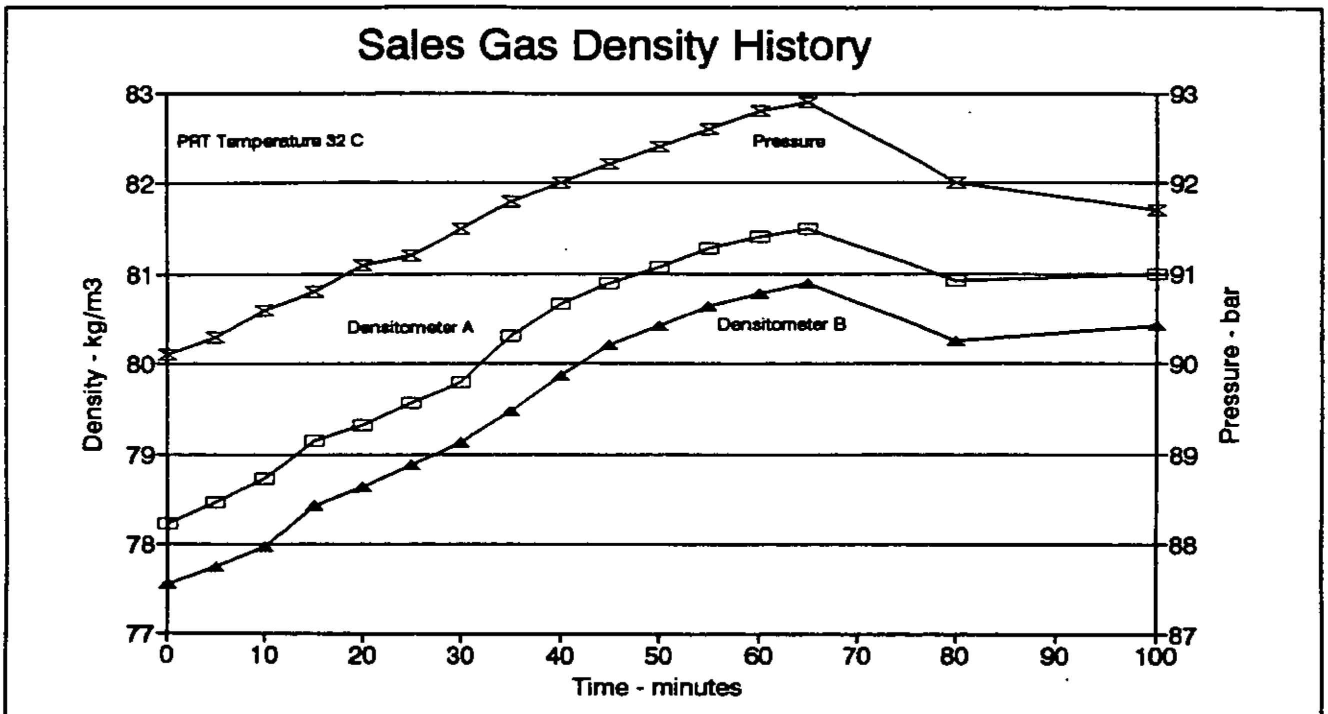


Figure 3

results. There was a reasonably consistent difference of about 0.6 kg/m^3 between densitometer A and B. Densitometer A was the first instrument downstream of the orifice plate. These results were consistent with the previous observations.

To assure that the densitometers were measuring correctly and that the installation in the pipeline was not contributing to the measurement difference, several tests with pure nitrogen and methane were carried out with the sample system isolated from the main pipeline. The measured density values for methane as a function of pressure for densitometers A and B are plotted in Figure 4. The two agreed within about 0.02% of full scale. The methane density measured at 50 and 100 bar and 17.4°C were 37.25 and 80.31 kg/m^3 respectively. Values interpolated from the National Bureau of Standards[1] (NBS) data for these conditions are 36.56 and 79.72 kg/m^3. Considering that these tests were done on an operating offshore platform and the possibility of error in the pressure and temperature measurements, the deviation from the NBS data is considered very reasonable.

The measured density for methane also agreed quite well with the value calculated for each pressure and temperature condition using a gas density calculation program from AGA 8[2].

Methane Density vs Pressure

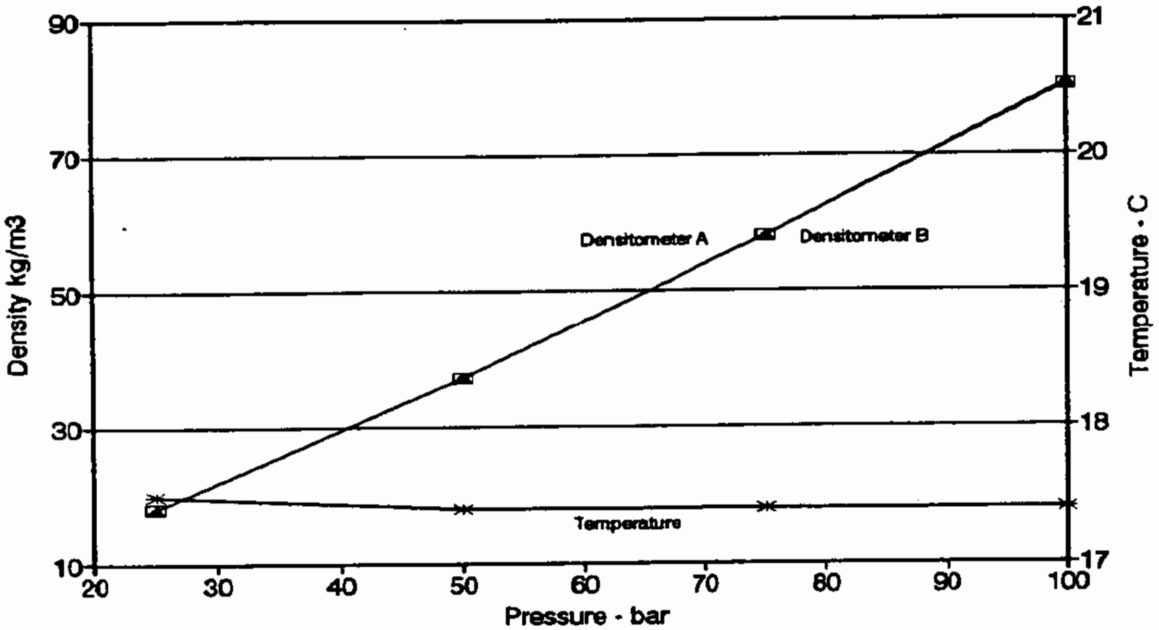


Figure 4

A similar test was performed with nitrogen and the results are shown in Figure 5. Again, there was good agreement of the measured values with values calculated from AGA 8.

Nitrogen Density vs Pressure

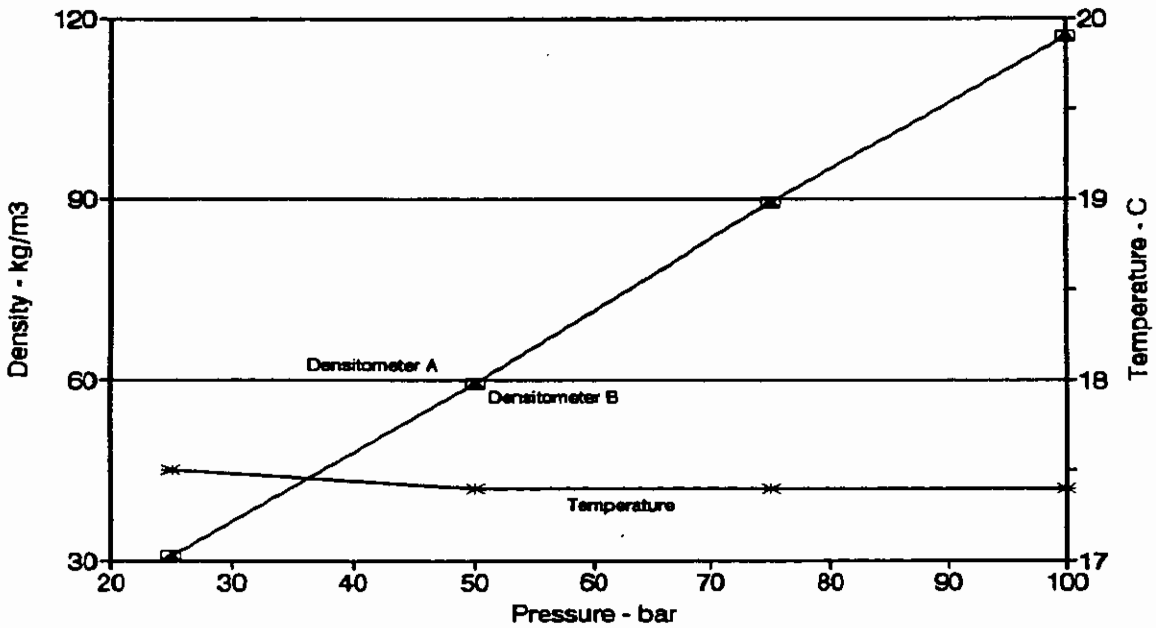


Figure 5

The experimentally measured nitrogen density at 50 and 100 bar and 17.4°C were 59.47 and 117.04 kg/m³ respectively. These values are in line with values interpolated from NBS[3] data of 58.35 and 116.04 kg/m³ taking into account the possibility of error in the temperature and pressure measurements. While this was not an attempt to calibrate the densitometers, the field installed densitometers were judged to be fairly accurate.

The stability of the densitometers with time was tested by pressurizing and isolating the sample system. When the nitrogen supply valve was closed completely isolating the sample system, the density decreased indicating that a small leak existed in the sample system. The small volume of the sample system made the leak very noticeable. Attempts to locate the leak were unsuccessful. Therefore, to negate the effect of the leak, the sample line discharge valve was opened to the meter run to provide a large reasonably constant pressure reservoir. The densitometer stability with time is shown in Figure 6. The first four data points show the effect

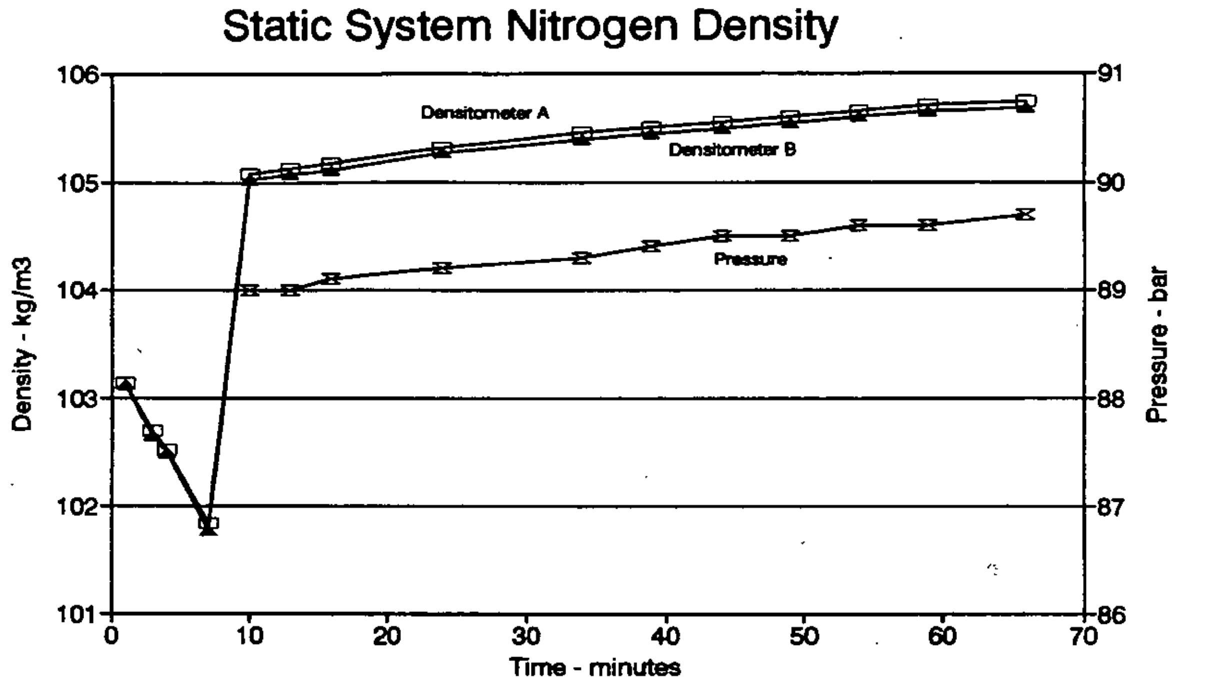


Figure 6

of the leak. The sample system was open to the meter run for the remaining points. The meter run was isolated by block valves, but the observed pressure increase indicates that some minor leakage was occurring through the block valves. The PRT temperature increased during the test from 17.1°C to 17.4°C. This increase in temperature would not account for the pressure change observed in the meter run.

The two densitometers track very well and have a small constant difference in measured density of about 0.05 kg/m³. The increase in density with time is as expected with the increase in the pressure. The 0.3°C temperature increase would alter the nitrogen density in the order of 0.12%.

A stability test with methane was also conducted with the sample system open to the mainline pressure. The pressure and density data are shown in Figure 7. The densitometers tracked very

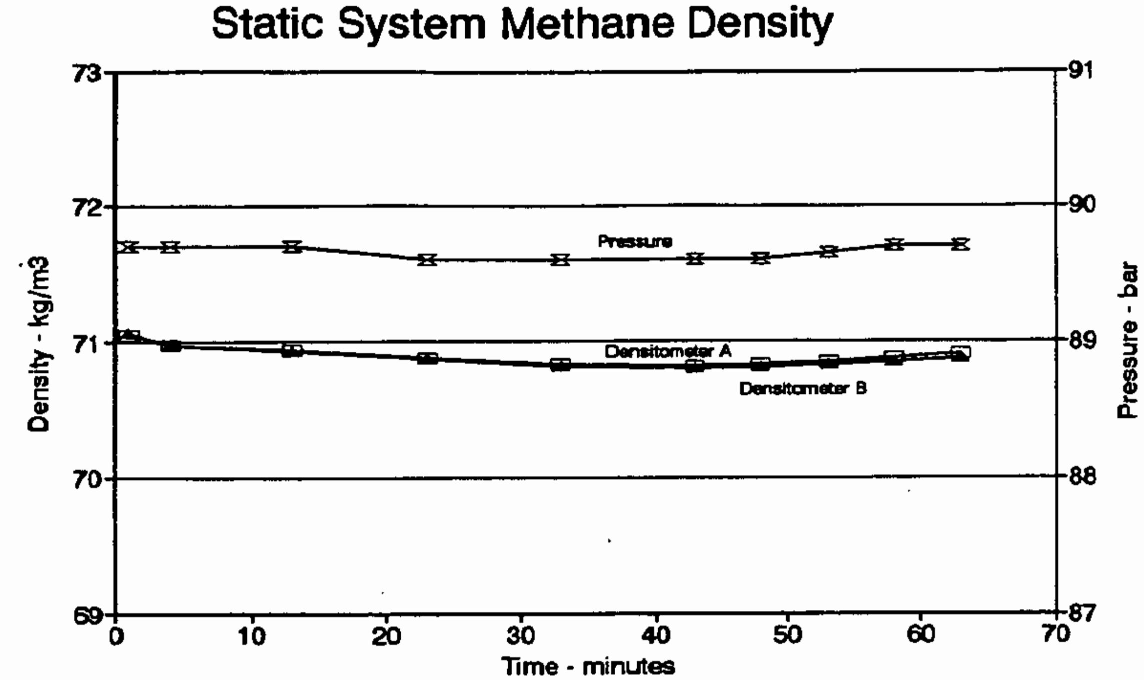


Figure 7

well over the time period with a very small difference of about 0.02 kg/m³. The pressure decreased by 0.1 bar during the first part of the test and then increased by that amount towards the end. The temperature increased from 17.5°C to 17.9°C during the test. The change in temperature and pressure will account for the density history. The static tests with nitrogen and methane show that the two densitometers are accurate within the limits of the field check and measure essentially identical values under identical conditions.

Two tests were conducted (one each with nitrogen and methane) to observe the effect of gas flow rate on the densitometers. The rotameters and needle valves were used to adjust for equal flow through each densitometer, but the total flow through the sample system was controlled by the differential pressure across the system. The test were conducted at a pressure of approximately 100 bar on the system.

The results of the test with nitrogen are shown in Figure 8. The two densitometers had a constant difference in the density value for nitrogen of about 0.1 kg/m³. The density values increased with increasing gas flow through the densitometer, consistent with information supplied by the manufacturer. The nitrogen gas entering the densitometers was below ambient temperature because of expansion from the high pressure cylinder. The gas exiting the densitometers was warmer, but not at the temperature registered by the PRT sensor. It is postulated that the densitometers were unequally cooled by the extensive nitrogen flushing of the

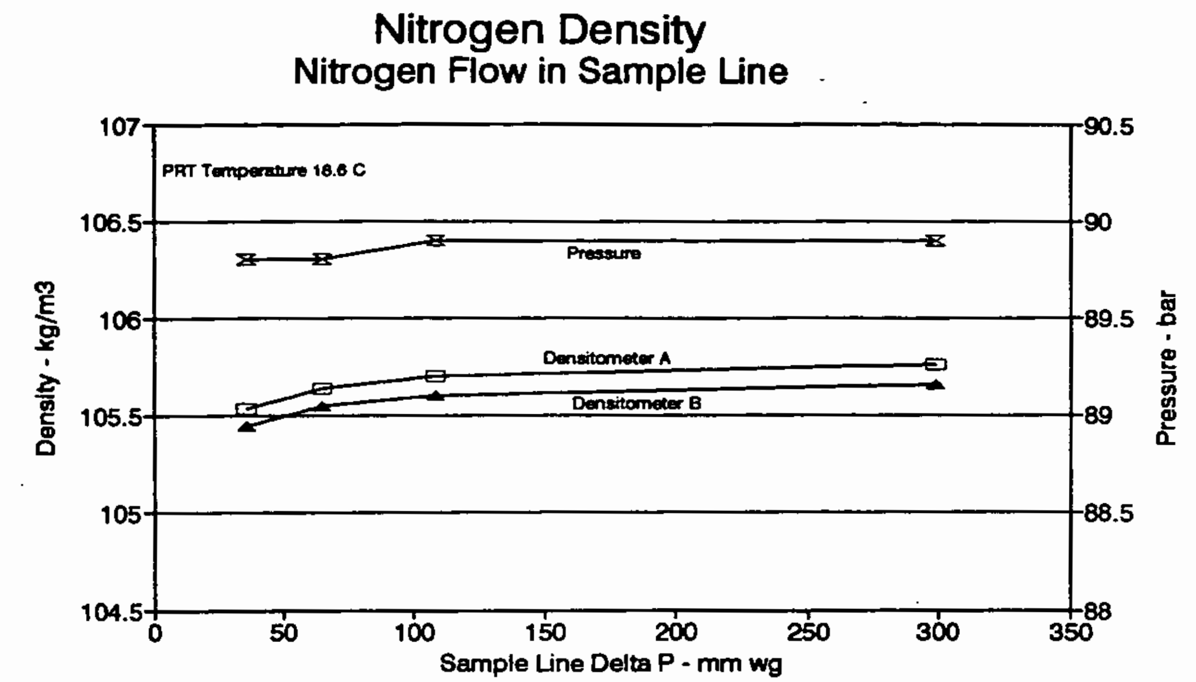


Figure 8

system prior to the flow test. A difference in densitometer temperature would result in a difference in the measured density.

Flow tests with methane were carried out and the results are shown in Figure 9. The

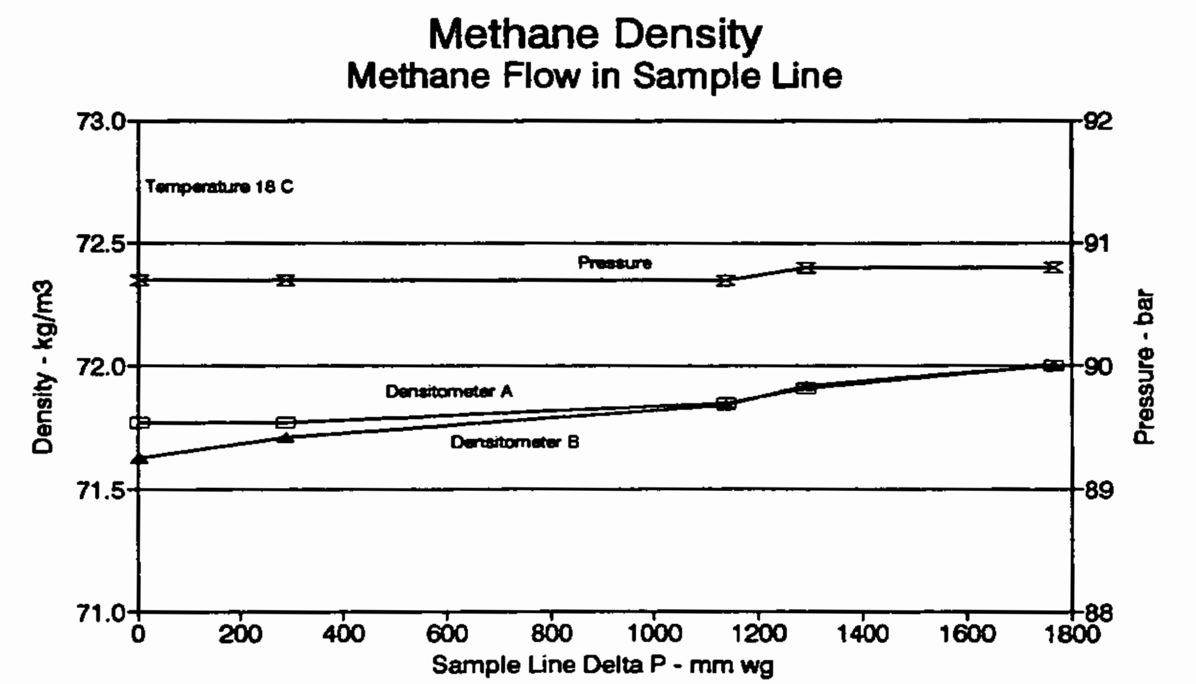


Figure 9

temperatures of the densitometers were unequal and lower than the PRT sensor temperature. This temperature difference is probably responsible for the initial gas density difference of about 0.15 kg/m³. As the flow rate increased the density difference decreased presumably as the measurement conditions became comparable. A slight increase in density is observed with increased flow rate. The results of these tests were not as precise as the nitrogen tests, but it is confirmed that the densitometers produce essentially identical results with gas flow and as expected the density increases with increased flow rate.

The response of the densitometer to temperature change, as a result of flow in the meter run, was the objective of the next test. The densitometers were purged with methane, isolated from the meter run and allowed to stabilize. Sales gas flow was started in the meter run and the results are shown in Figure 10. The temperature of the PRT sensor rose very quickly and stabilized at

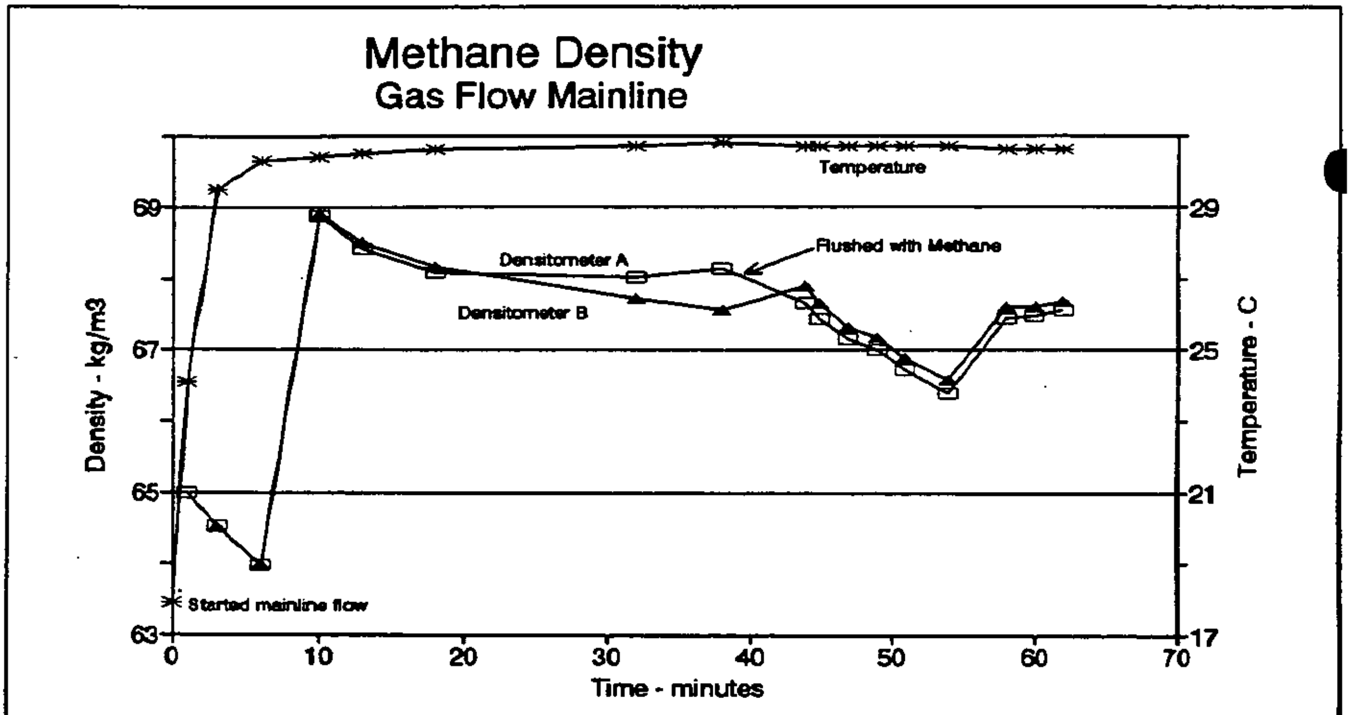


Figure 10

about 31°C. The two densitometers measured nearly identical but decreasing values for the first six minutes. The decrease in density is the result of the densitometers warming and the persistent leak in the sample system.

Prior to the 10 minute mark, the sample system discharge valve to the meter run was opened to maintain a more constant pressure thereby, producing an offset in the measured density. Densitometer B showed decreasing values up to the 40 minute mark as the densitometer temperature equalized with the meter run. Densitometer A also showed a decrease in density as it became warmer, but then the measured density increased slightly as a result of the leak permitting sales gas with its higher density to mix with the methane. Just after the 40 minute mark, the sample system was purged with methane and isolated once again. The measured values were within 0.2

kg/m³ or less and decreasing as the pressure dropped because of the leak. The discharge valve to the meter run was opened again at about the 55 minute mark. These results illustrate the sensitivity of the densitometers to changes in pressure, gas composition and temperature.

Inlet and outlet gas stream measurements on the densitometers indicated that the one inch of foam rubber was not adequate insulation as the temperature of the densitometers were not the same as the temperature measured by the PRT sensor. Therefore, a special insulated enclosure was assembled around the two densitometers and a portion of the meter run to provide a more uniform temperature environment. After stabilizing for over 12 hours, the pressure, density and temperature for the meter run are plotted in Figure 11 for a twenty five hour period. This figure

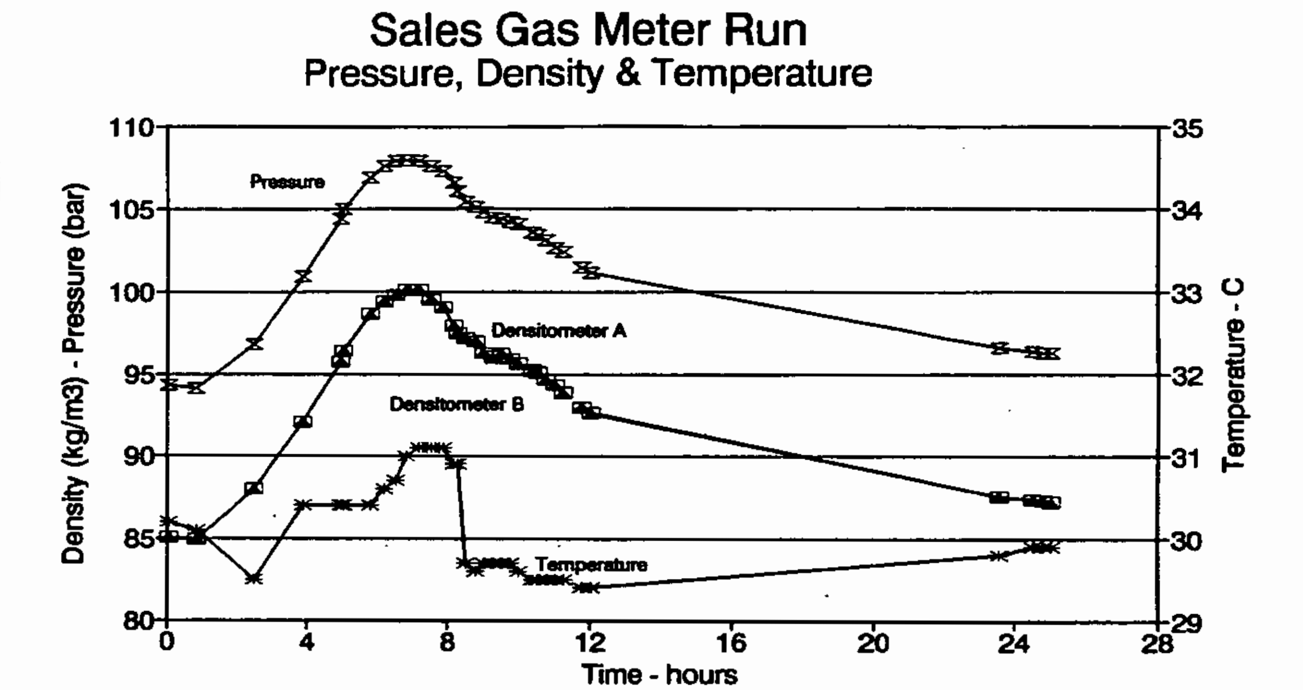


Figure 11

demonstrates that very often in field operations changes in pipeline delivery pressure will have a greater overall effect on the measured density than temperature variations. The density difference during this time period averaged 0.02 kg/m³. It is evident from this figure that the two densitometers track very well in this dynamic situation. This figure illustrates the importance of maintaining the instruments at the same flow and temperature condition.

The sales gas composition is measured at 20 minute intervals by a chromatograph. Using the chromatograph analyses, sales gas densities were calculated by AGA 8 over a six hour period for the temperature and pressure conditions recorded in Figure 11. The calculated and measured densities are compared in Figure 12. The calculated densities compare very favorably with the measured density. The measured density would be expected to be slightly greater since the calculated densities are based on a maximum molecular weight of hexane whereas the measured sample actually has a small fraction of higher molecular weight components.

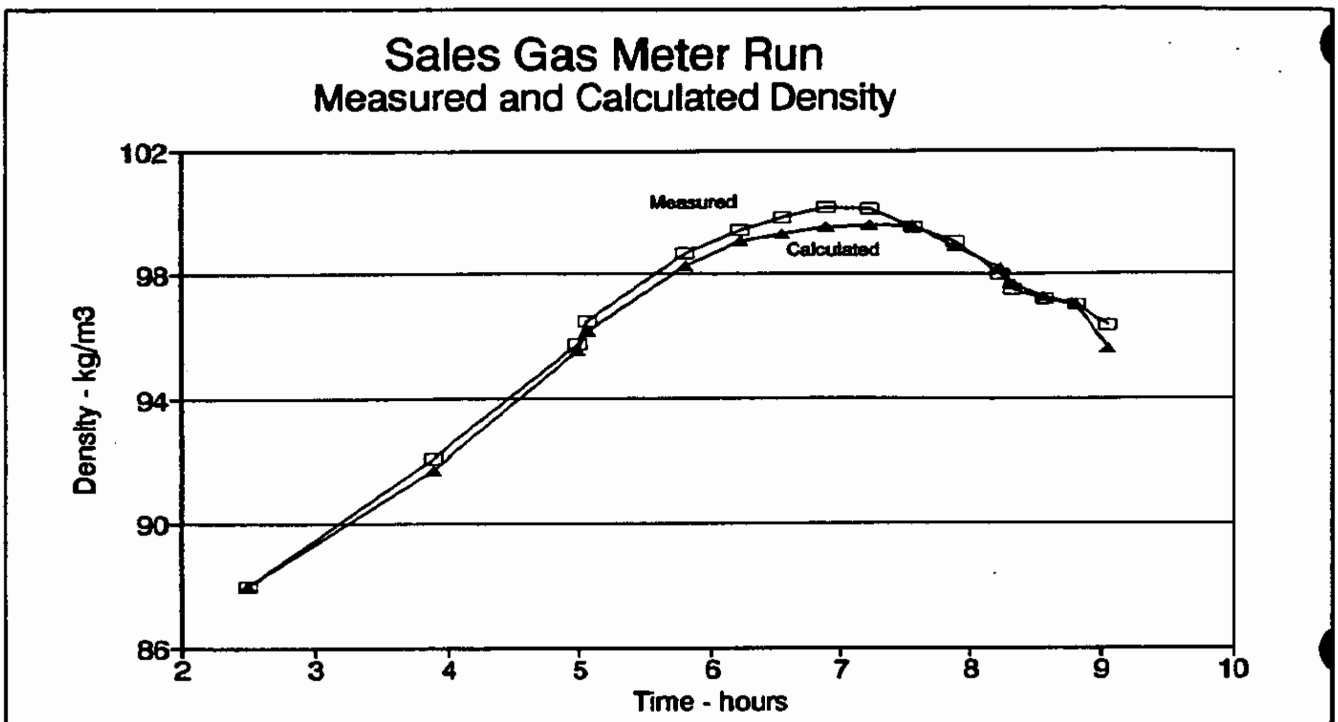


Figure 12

There are always slight changes in the chromatograph composition of the sales gas from one analysis to the next. A series of data points were calculated to determine the effect of using a constant gas composition for the density calculation. The gas density was calculated for each pressure and temperature condition using the first gas composition and these are compared with the densitometer measurements in Figure 13. There is no doubt that even small variations in gas composition has a noticeable effect on the measured density.

The length of the lines from the sample point to the densitometers and the relatively low flow rate in the sample lines will result in a lag between the volume measurement of the sales gas and the density measurement of that gas. This lag time is not a constant since the flow rate in the sample system is dependent upon the differential pressure across the orifice plate which varies from about 1000 mm water gauge (wg) to over 3000 mm wg.

The lag time was determined by measuring the time required for sales gas to displace methane from the sample system. One test is shown in Figure 14. The displacement was started at the 10 minute mark and was completed at about the 70 minute mark. The lag time is about 60 minutes. The hump in the first part of the displacement curve was completely unexpected and was considered to be the result of contamination by sales gas left in a dead end connection on the sample system.

The displacement of the two curves in Figure 14 suggests that either the flow rate was different into the two densitometers or the volume of the lines differed. This test was performed before

Comparison of Densities
Constant Comp. Calculated & Measured

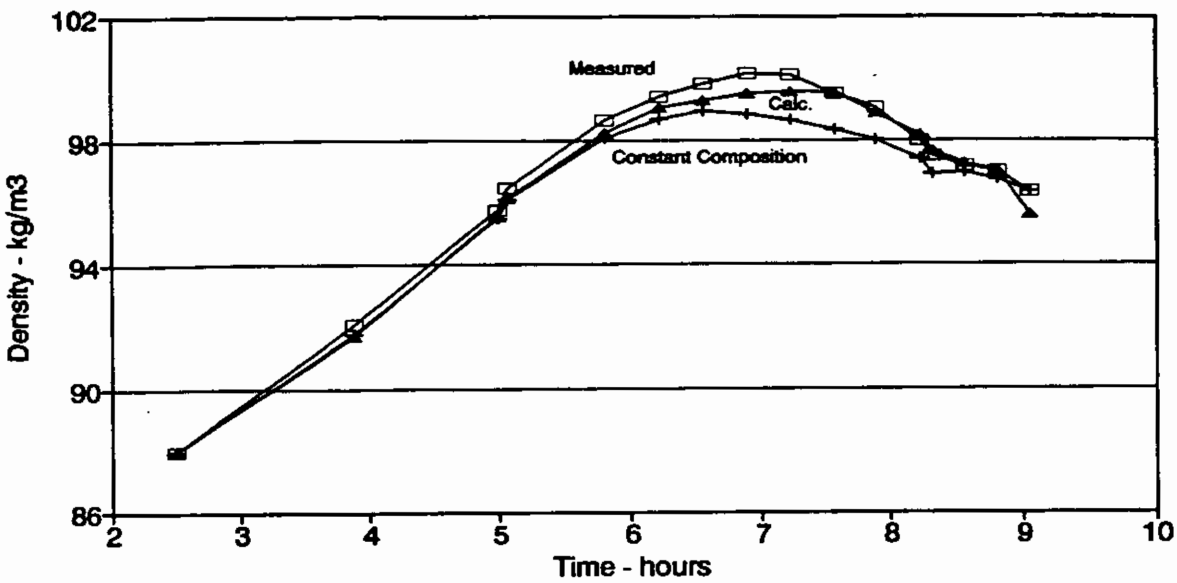


Figure 13

the special enclosure was built around the densitometers. A difference in densitometer temperatures could have contributed to this result. The displacement of the curves probably is a combination of all these factors.

Methane Displacement by Sales Gas

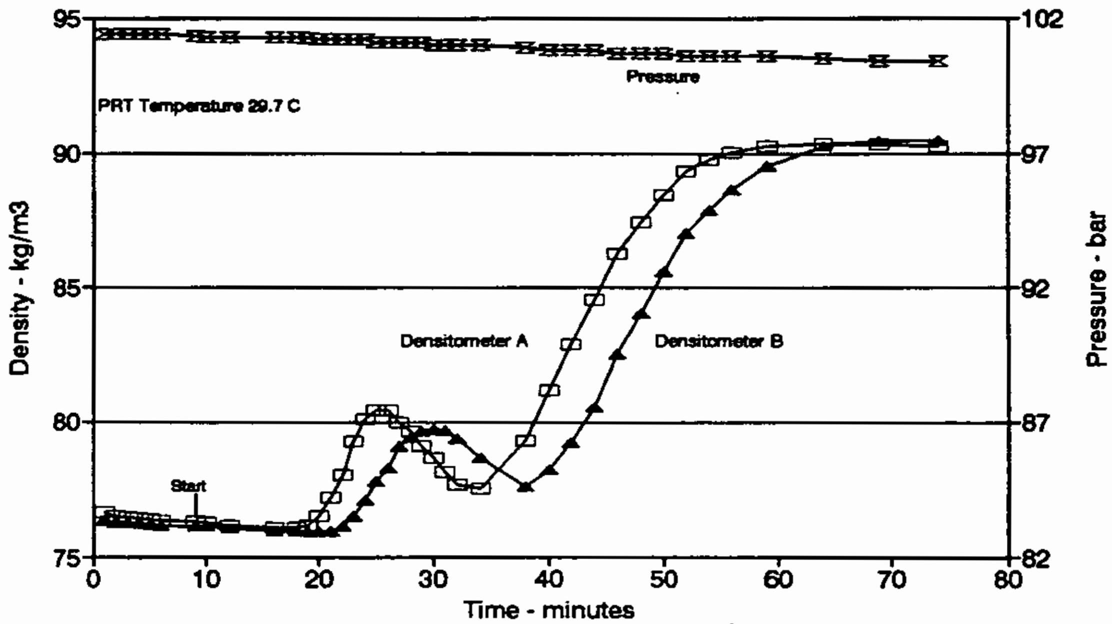


Figure 14

The methane displacement by sales gas test was repeated several times after the densitometers were in the special enclosure. More attention was paid to details of the displacement in an

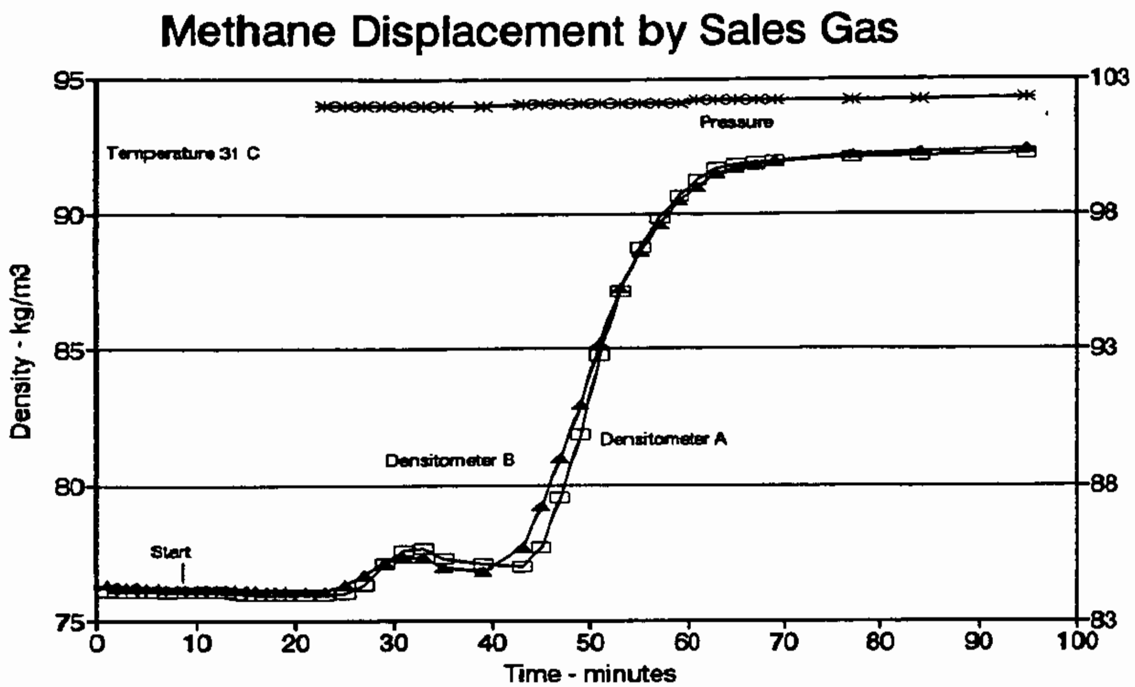


Figure 15

attempt to determine the cause of the hump in the first part of the displacement curve. Two results are shown in Figures 15 and 16. There is agreement between the values of the two

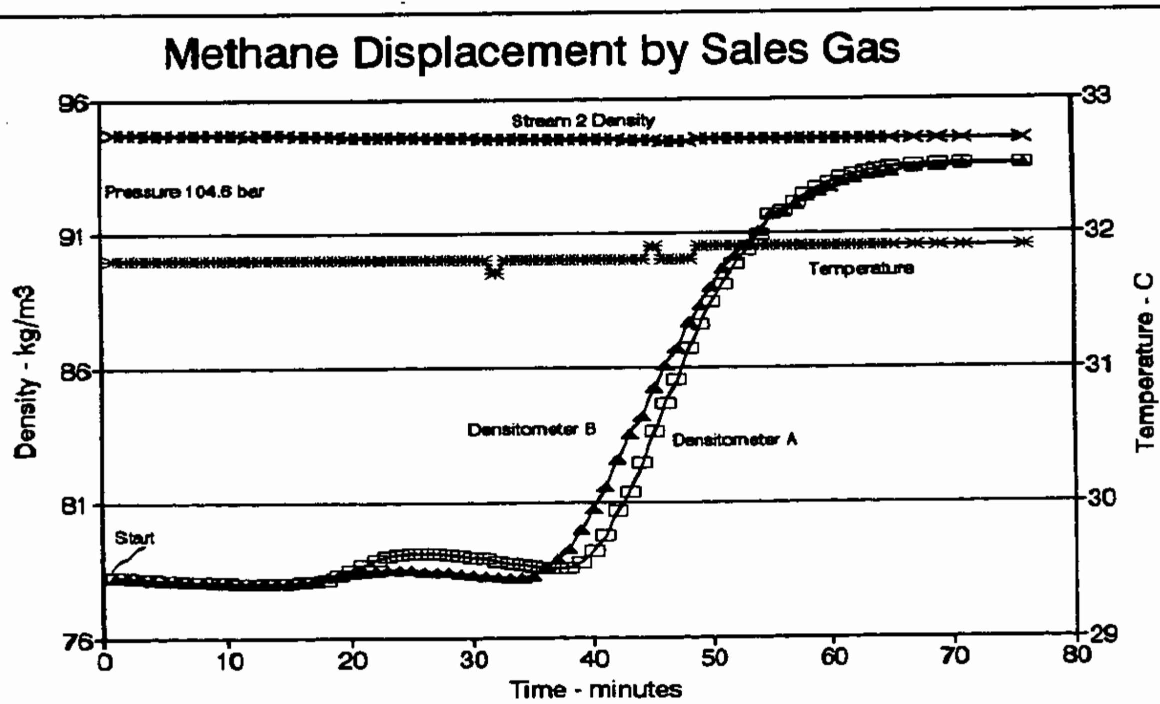


Figure 16

densitometers prior to the start and upon completion of the displacement, but there is a shift in the curves during the transition portion of the displacement. Extensive purging of all parts of the sample system decreased, but did not remove the hump from the displacement curve. One possible explanation for this phenomenon is that some material was absorbed onto the metal filters from the sales gas during normal operation of the sample system and was desorbed into the methane when the pure methane was introduced into the sample system.

In Figure 16 (the last displacement test) the density of an adjoining meter run is recorded and plotted. Two factors were responsible for the difference between the test meter run density and stream 2 meter run density at the end of the test. First there was a small difference in the differential pressure across the orifice plates and secondly , the densitometers on the stream 2 meter run were not as well insulated and therefore at a slightly lower temperature.

It is assumed in the gas flow calculation that the temperature measured by the PRT sensor is the temperature of the gas in the densitometer. In some of the previous tests, it has been shown that apparently the temperature in the densitometer measuring chamber is not the PRT temperature.

To get a more accurate measure of the densitometer temperature, two thermocouples were fixed to the outside of the instrument as shown in Figure 17. The thermocouple on the bottom was

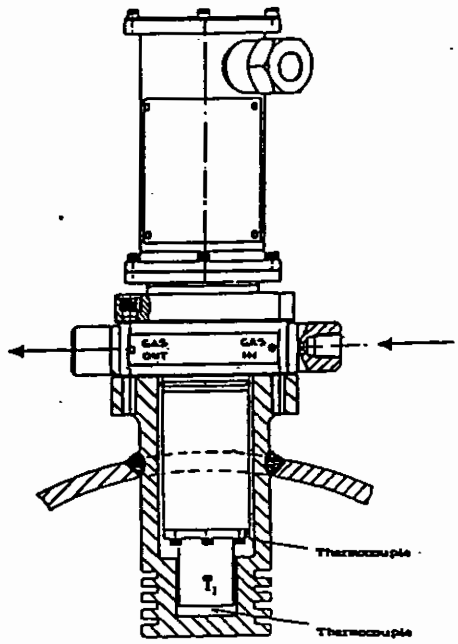


Figure 17

Gas Density Transducer

held in place with tape. The side thermocouple was inserted in a small hole on the body of the densitometer and taped in place. The instruments were reassembled inside of the insulated enclosure. The meter run was completely isolated and allowed to stabilize at ambient temperature which was about 13°C.

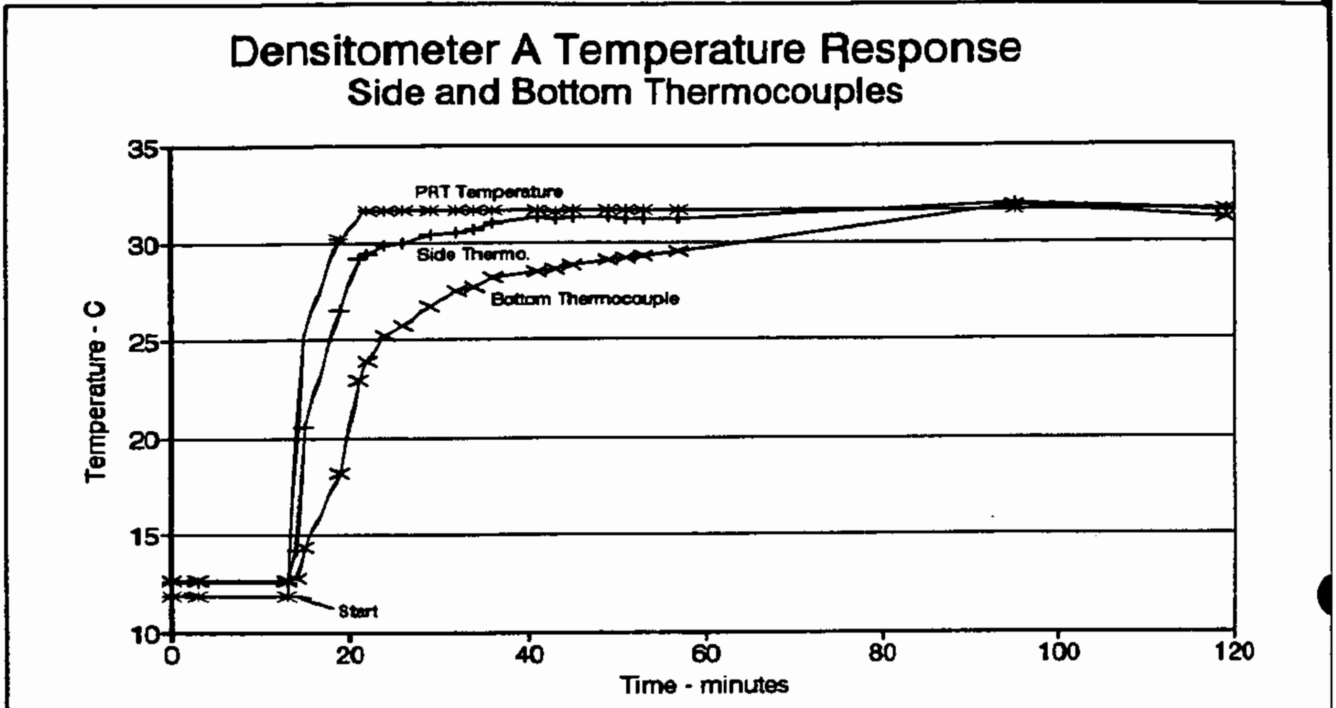


Figure 18

After about 18 hours, flow was started in the sample system and through the mainline. The PRT sensor temperature very quickly stabilized at about 32°C as shown in Figure 18 and Figure 19

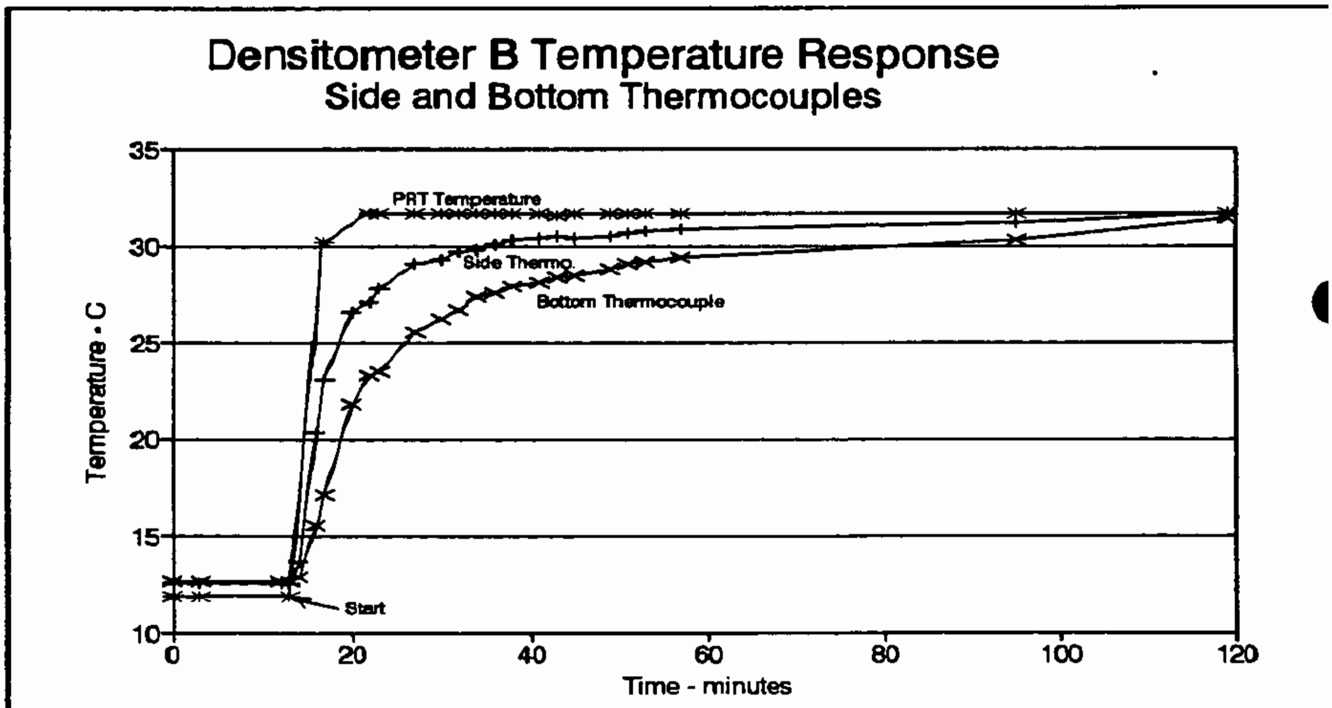


Figure 19

for densitometer A and B respectively. The side and bottom thermocouples took considerably longer to reach the same temperature as the PRT sensor. Since the side and bottom measurements are on the outside of the density measurement chamber, the chamber temperature could not be any higher. The well in which the densitometer is mounted is filled with oil and the heat transfer must be through that medium. The fact that for the side mounted thermocouple, the heat transfer is taking place across a much shorter distance, may explain why that thermocouple warms up faster than the bottom thermocouple. In addition to a less efficient heat transfer the bottom of the densitometer, which is the measuring chamber, may be cooled (heat is being removed) by the flow of gas through the densitometer. It can be concluded that the measuring chamber of the densitometer may take at least two hours to come to temperature equilibrium with the gas stream even in a well insulated system.

A plot of sales gas density history is shown in Figure 20 for the test meter run after the stream

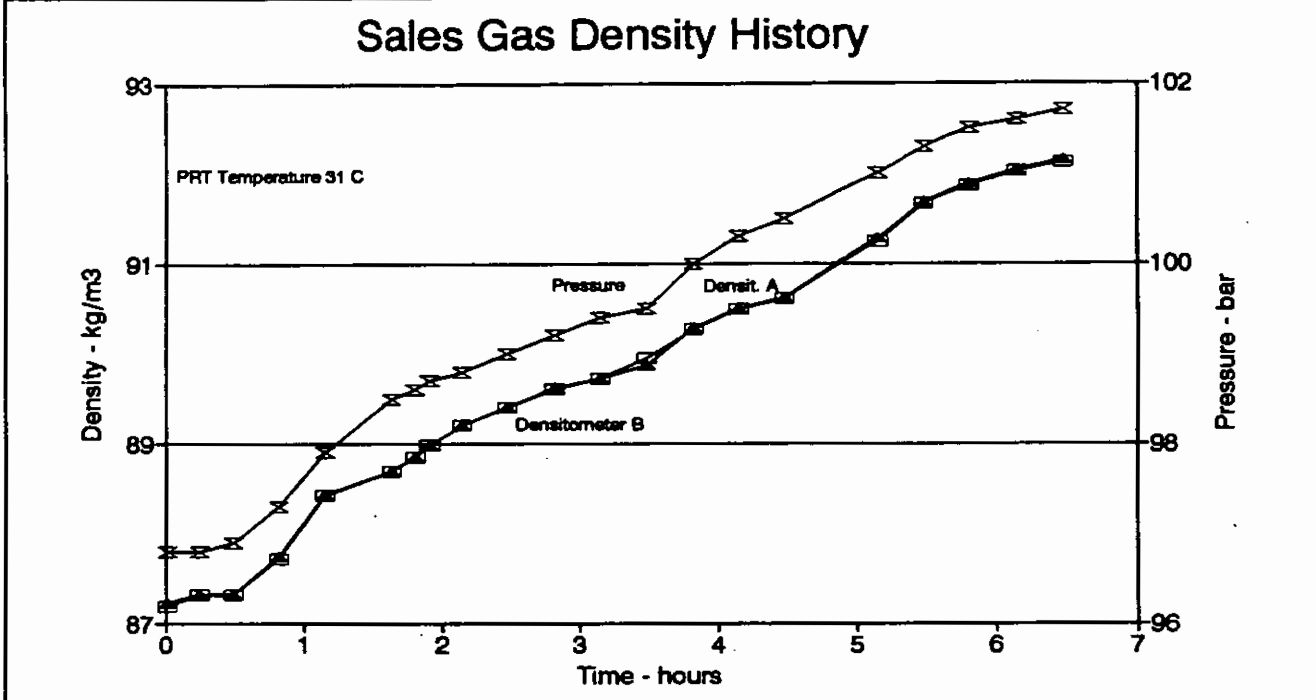


Figure 20

had been in operation for about a week. The two densitometers were measuring on average within 0.01% of full scale. This demonstrates that with similar flow rates and in a temperature stable environment the two densitometers will measure essentially the same value.

CONCLUSIONS

Based on the preceding tests it can be concluded that:

1. Calibrated densitometers on the same meter run will measure the same density under similar conditions of pressure, temperature and sample flow rate.

2. The PRT temperature sensors respond very quickly to temperature changes of the sales gas in the meter run.

3. Starting from ambient temperature, the temperature in the densitometer measuring chamber may take at least two hours or more to stabilize to the line temperature.

4. The density measurement lags behind the volume measurement by about one hour in this system.

5. There is a slight increase in measured density with increased gas flow through the densitometers in this system.

6. The measured density will vary between meter runs because of small differences in differential pressure across the orifice plates.

7. Differences in measured density on the same stream are the result of temperature and flow rate differences in the densitometers.

8. With an enclosure surrounding the densitometers and pipeline to provide good temperature equilibrium, densitometer accuracy of 0.2% should be possible.

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