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AN INVESTIGATION INTO THE VELOCITY OF SOUND CORRECTION APPLIED TO GAS DENSITY MEASUREMENT

1.4

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SUMMARY

This paper gives the results up to and including October 1985 of the joint experimental research effort into the velocity of sound correction associated with Solartron density meters. The whole of the experimental work has been carried out in the laboratory at Dantest.

The aim of the project is to measure the densities of various gases as accurately as possible, and then compare the results obtained with those measured using a Solartron density meter with various velocity of sound corrections applied to the results.

Gases tested were Methane, a synthetic natural gas, and Argon as a check on the original Solartron Argon calibration. The pressure range was varied from 50 bar abs up to 150 bar abs with the temperature at 35 °C. Results are reported on Solartron 7811 transducers.

1 INTRODUCTION

This paper gives the results up to October 1985 of our joint research effort into the Velocity of sound correction associated with Solartron density meters. The whole of the experimental work has been carried out at Dantest. The gases tested were Argon, Methane and a synthetic natural gas (93.7% Methane) over a range of pressures 50 bar to 150 bara and a temperature of 35 °C. Solartron 7811 transducers were used.

The aim of the project is to measure the density of a gas as accurately as possible using the real gas equation

$$\rho = \frac{p}{ZRT}$$

and compare the result obtained with that measured using a Solartron density meter with various corrections applied to the results.

Section 2 describes the equipment used in the Dantest laboratory, the procedures used for obtaining measurements of density using the Solartron density meter, the determination of the compressibility factor Z, and the gas constant R.

Sections 3, 4, and 5 give details of the results obtained using Argon, the synthetic natural gas and Methane.

Section 6 gives the conclusions and recommendations arising from the study, whilst section 7 gives the aims of the project for the next series of tests.

2 EQUIPMENT USED IN THE DANTEST LABORATORY

Dantest has 2 alternative methods for determining the "true" density of a gas, ie

I - By direct mass and volume determination:

$$\rho = \frac{\text{mass}}{\text{volume}}$$

II - By using the real gas equation:

$$\rho = \frac{p}{Z \times R \times T}$$

where ρ - gas density

p - absolute static pressure

Z - compressibility factor

R - gas constant for the gas in use

T - temperature K

Figure 1 shows a sketch of the laboratory.

The laboratory can be divided into 5 sections:

a) Gas supply section.

b) Compressibility factor measurement.

c) Density measurement using method I.

d) Density meter calibration.

e) Deadweight tester.

The gas supply section comprises a gas bottle together with a pressure regulator and associated pipework. With the aid of a quick connection system at A, the gas supply can be directed to the three sections b, c and d as required.

In the compressibility factor section are two meters for determining Z, and these are items numbered 4 and 5 in Figure 1. Item 4 is a Desgranges and Huot Z-meter, Type 60000, with which a Heto thermal bath is used to stabilise the temperature. This Z-meter is calibrated using 99.9952% purity Nitrogen and the NBS nitrogen tables, and has a working range of 3 to 80 bars abs.

Item 5 is a Dantest designed Z-meter using the same principle of the Desgranges and Huot Z-meter but has a working range from 50 to 150 bars abs. The Dantest Z-meter enables us to determine Z without reference to the NBS tables. Results show agreement with NBS nitrogen and methane tables within 0.1%. The temperature in the Dantest Z meter is also stabilised by means of the Heto thermal bath.

The section for determining the density according to method I comprises a pressure vessel (item 2 in Figure 1) specially designed by Dantest. This vessel can be used over the range 10 to 80 bars abs, and can be used for most types of gases. The accuracy when determining density by this method is between 0.05% and 0.1% depending on the pressure and gas type. Pressure and temperature can be accurately measured in the vessel, which has a nominal volume of 12 litres. This method cannot be used to make a calibration curve for a density meter. The method is used to determine a single point of density at room temperature.

Density meters to be calibrated are enclosed in a thermal cabinet (item 3 in Figure 1). Each density meter in the cabinet has a PT100 thermometer attached near the measuring cylinder. The uncertainty of the temperature measurement is within 0.1°C. The temperature in the thermal cabinet is adjustable over the range 0 to 40 °C.

The deadweight tester is used to stabilise and set the working pressure in sections b, c and d. It is a Desgranges and Huot Type 5201S and has been previously calibrated by the Laboratoire National d'Essais, France. This instrument has a measurement range of 0.4 bar abs to 200 bar abs, and an uncertainty of 0.01%.

Having described the general layout for the Dantest laboratory, I shall now concentrate on the means of obtaining the results given in this paper. The "true" value of density for Methane was obtained by using NBS tables on the measured temperature and pressure. The "true" value of density for Argon was obtained from Solartron who, with Dantest measured temperature and pressure, computed the density values using multiple degree interpolation in the F. Din tables. The true value of density for the synthetic natural gas was obtained using the real gas equation (method II) :

$$\rho = \frac{p}{ZRT}$$

in which

1. R - the gas constant was determined by measuring ρ (p,T) using method I (ρ = m/v) then measuring Z (p,T) and hence R can be obtained from:

$$R = \frac{p}{\rho Z T}$$

2. Z - the compressibility factor was measured using the Dantest Z - meter.

Three Solartron 7811 density meters were placed in series in the thermal cabinet and were stabilised at 35°C. After having purged the system with the gas under calibration the density meters were calibrated step wise with increasing pressure (and hence increasing density).

3. RESULTS USING ARGON

The aim of the Argon tests was to ensure that nothing peculiar had happened to the density meters since leaving Solartron and that both Dantest and Solartron were measuring without any significant systematic deviations. Figure 2 shows a comparison between the calibration obtained on Argon at Solartron and the corresponding calibration at Dantest over the range of pressures 40 to 150 bar abs at a nominal temperature of 20 °C. It can be seen that the overall differences are acceptable, but the Dantest results are consistently higher than Solartron's results over the range 40 to 150 bar abs.

4. RESULTS USING SYNTHETIC NATURAL GAS

Figs 3, 4 and 5 show the results obtained for calibrations on synthetic natural gas with 3 different corrections applied to the raw data. The details of the 3 methods of correction used are given in Appendix 1.

Fig 3. is Total Oil Marine's method of interpreting the velocity of sound correction using the Solartron user gas offset formula from the original certificate applied to Argon constants.

Fig 4. uses the Argon user gas calibration certificate at 20°C which has been supplied by Solartron from gas composition provided by the partners in the project. This user data at 20°C has been corrected to 35°C using the Solartron temperature correction formula supplied by Solartron.

Fig 5. uses the Argon user gas calibration certificate at 35°C which has been supplied by Solartron from gas composition provided by the partners in the project.

At offshore operating conditions with pressures approximately 120 bar abs. to 150 bar abs. it can be seen that the TOM velocity of sound correction is worse than the user data at 20°C which in turn is worse than the user data at 35°C.

It would thus appear that from these results, with the various corrections offered by Solartron, the Argon user data formula at the temperature corresponding to the field density measurements gives the best accuracy although still not within + 0.2%.

5. RESULTS USING METHANE

Fig 6 shows the results obtained in Methane with Total Oil Marine's method of interpreting the velocity of sound correction using the Solartron user gas offset formula applied to Argon constants. The detail of the correction is given in Appendix 1.

It can be seen that at no test pressure is the difference between true density and measured density better than 0.2%.

Fig 7. shows the effect of calibrating a density meter on Methane at 35°C and then attempting to use the constants obtained to measure the density of synthetic natural gas which contains 93.7% Methane. The deviation is within 0.2%.

6. CONCLUSIONS AND RECOMMENDATIONS

Before going into a discussion of these results it must be stressed that the measurements concerned are the first of their kind to be published. For this paper measurements have been made on two gases with a high methane content: pure methane and a synthetic natural gas with approximately 94% methane. This material basis is not large enough to draw general conclusions.

So the conclusions that follow should be treated with this in mind.

6.1 The argon calibration at Dantest shows that the density meters do not show a major drift from the Solartron calibration.

The results also prove that the two laboratories reproduce each others results within 0.15% (the British Calibration Service accuracy limits in Solartrons authorisation).

6.2 When regarding the results for the synthetic natural gas and methane they show poor agreement with the velocity of sound correction. The maximum deviations being about 0.4% to 0.5%. An explanation for part of this could be the tables used for the argon calibration. The FDIN tables show systematic differences from both NBS and IUPAC tables of approximately 0.2%. Using NBS or IUPAC and the same constants for the velocity of sound correction the deviation from 'true' density would fall to 0.2% - 0.3%. Further documentation is needed for further analysis of contributions to the deviation.

6.3 Comparison of the methane and the synthetic gas calibration, Fig. 7, shows that methane used as a calibration gas would bring deviations down to under 0.2% in the pressure range 50 to 150 bar.

Recommendations based on our limited results is that at offshore metering conditions the uncertainty in density measurement can be lessened if one of the following calibrations procedures is used:

1. Calibration with methane at the operating temperature providing the natural gas has a high methane content.

2. Calibration with argon using IUPAC tables and using the user gas calibration certificate derived at the operating temperature. This second recommendation requires more work doing to substantiate it.

A final conclusion is that more data is necessary in this high pressure range.

7. FUTURE WORK

The one obvious shortcoming of the foregoing tests is that the gas measured in the density meters is locked in, ie the measurement is "static". However, in the field it is, without exception, the case that density is measured "dynamically" with a small flow of gas always taking place through the density meter. It is our intention to investigate whether or not the difference between "static" or "dynamic" measurement is negligible. Our inclination from limited tests is to say that there is no difference, but it needs to be investigated thoroughly once and for all.

A second area to be explored is to compare the performance of density meters on various "dry" natural gases which are at conditions above their dewpoint.

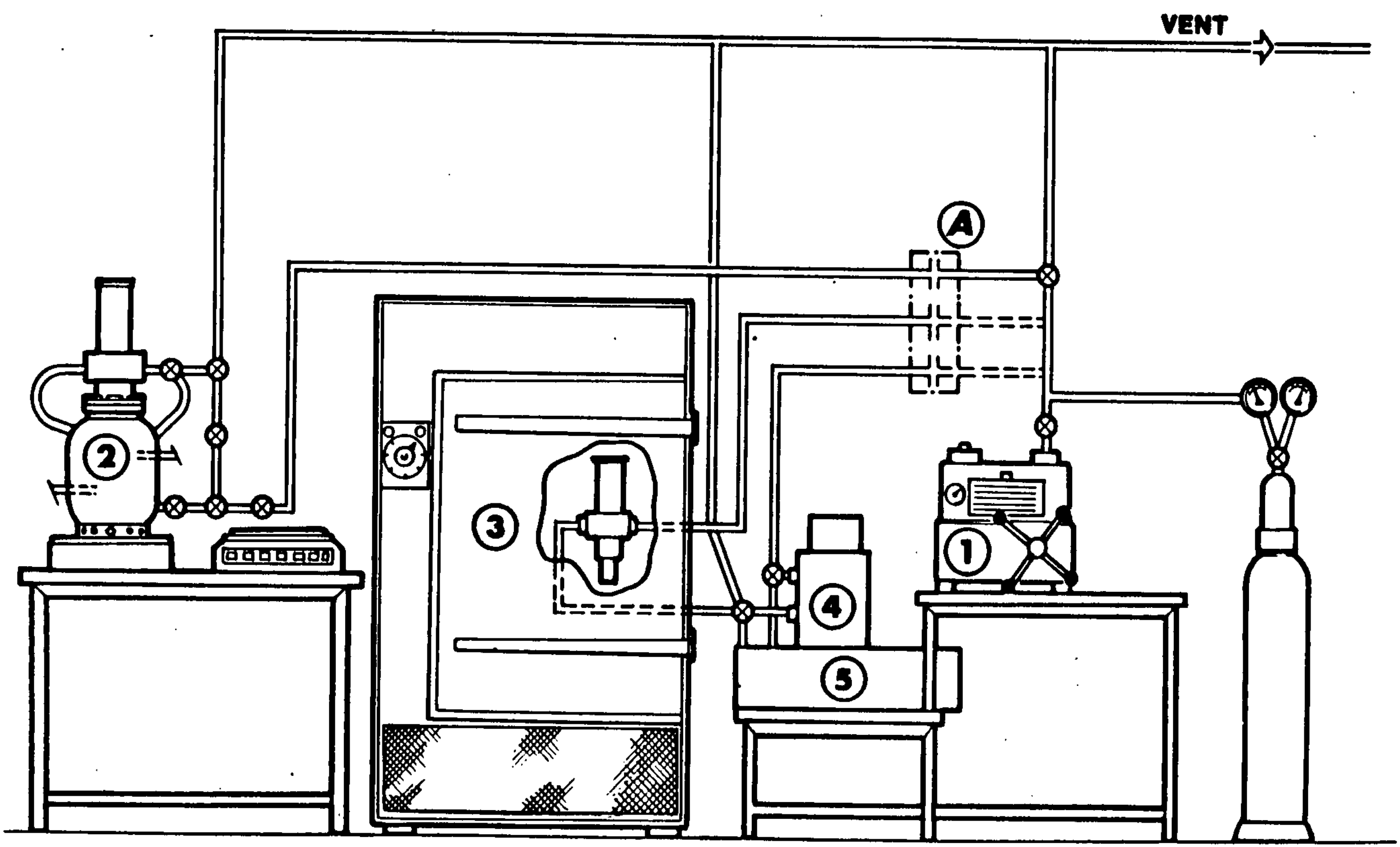

FIGURE 1 - SKETCH OF THE DANTEST LABORATORY

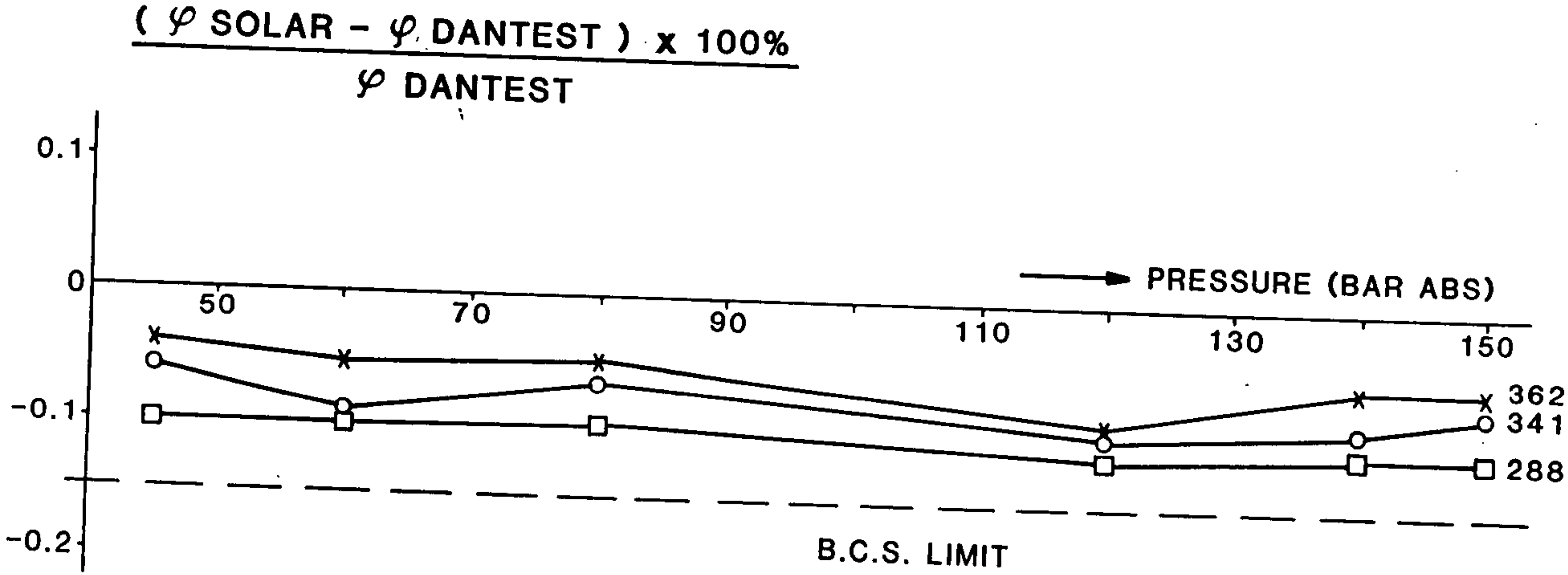

FIGURE 2 – COMPARISON BETWEEN DENSITYMETERS USING SOLARTRONS ARGON CONSTANTS AND DENSITY DETERMINED AT DANTEST

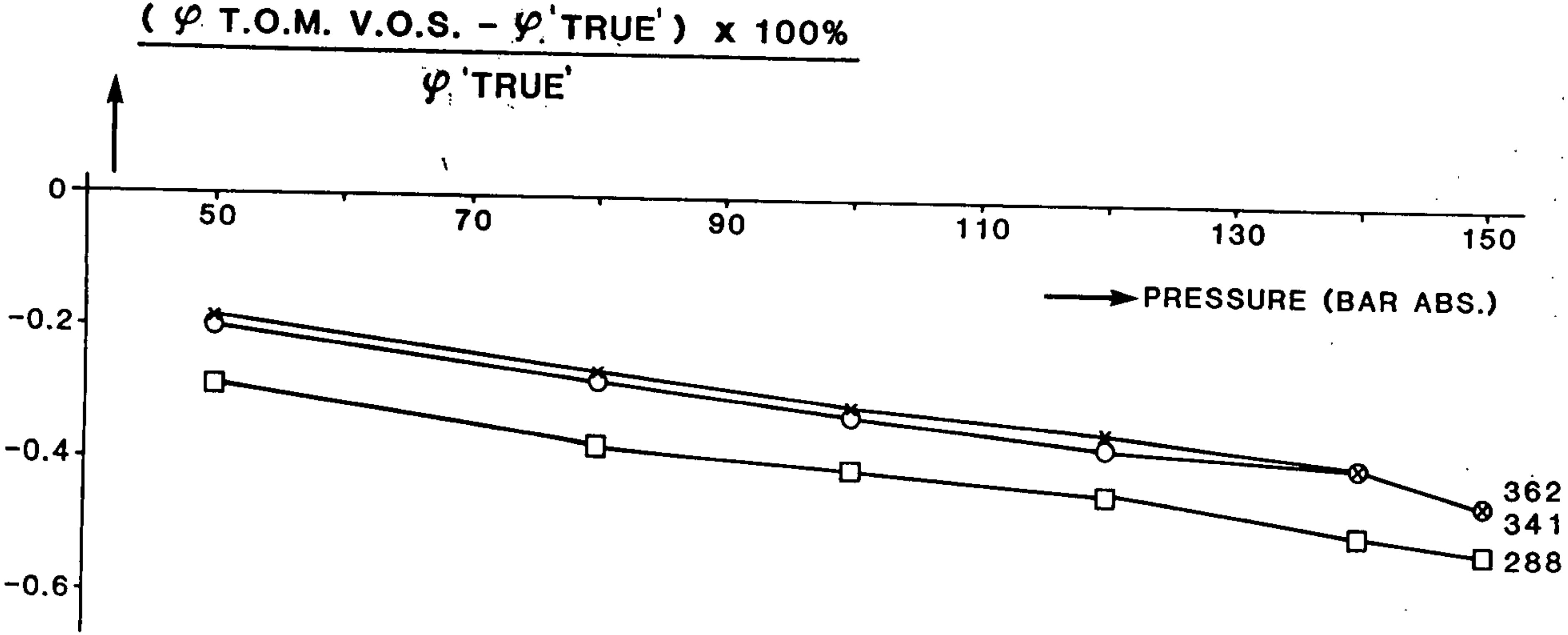

FIGURE 3 - COMPARISON BETWEEN SYNTHETIC NATURAL GAS WITH T.O.M. VELOCITY OF SOUND CORRECTION (USER GAS OFFSET DATA) AND 'TRUE' DENSITY OF THE SYNTHETIC NATURAL GAS

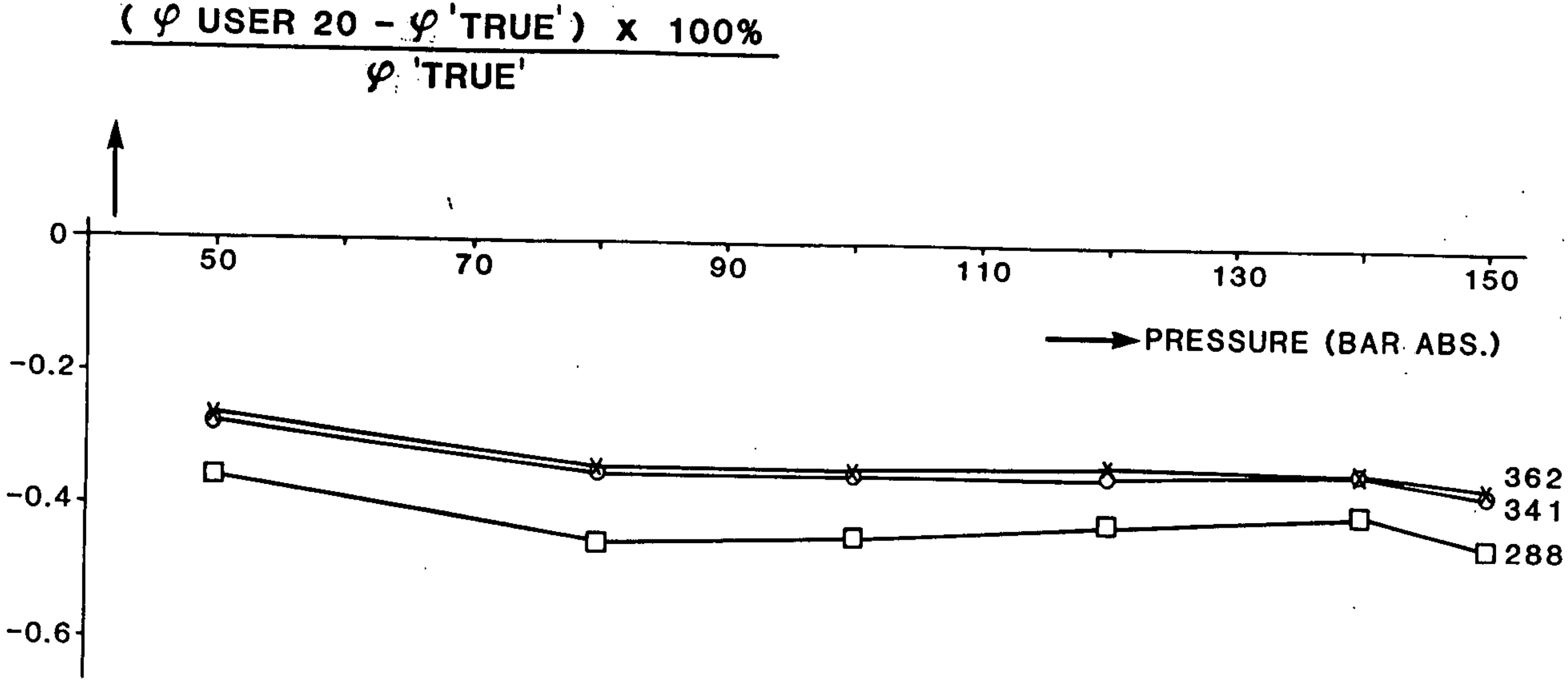

FIGURE 4 - COMPARISON BETWEEN SYNTHETIC NATURAL GAS USER DATA AT 20°C TEMPERATURE CORRECTED TO 35°C AND 'TRUE' DENSITY OF THE SYNTHETIC NATURAL GAS

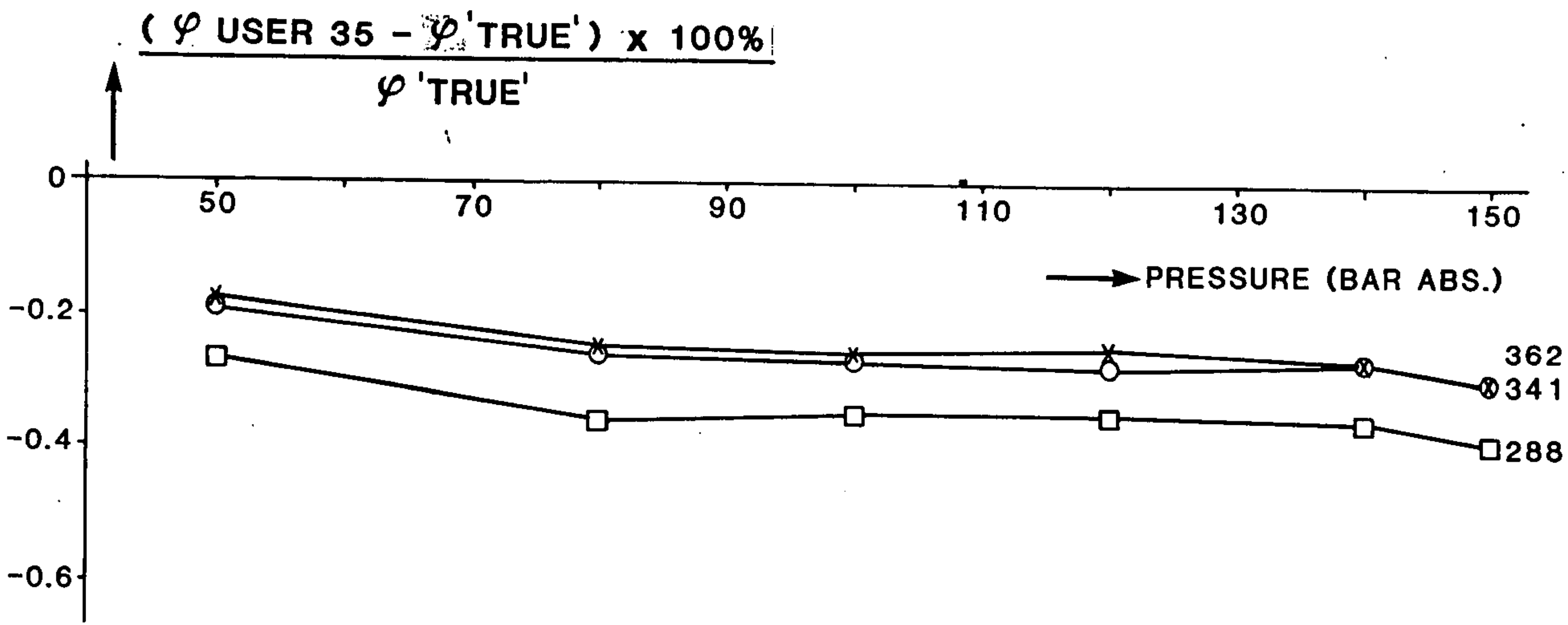

FIGURE 5 – COMPARISON BETWEEN SYNTHETIC NATURAL GAS USER DATA AT 35°C AND 'TRUE' DENSITY OF THE SYNTHETIC NATURAL GAS

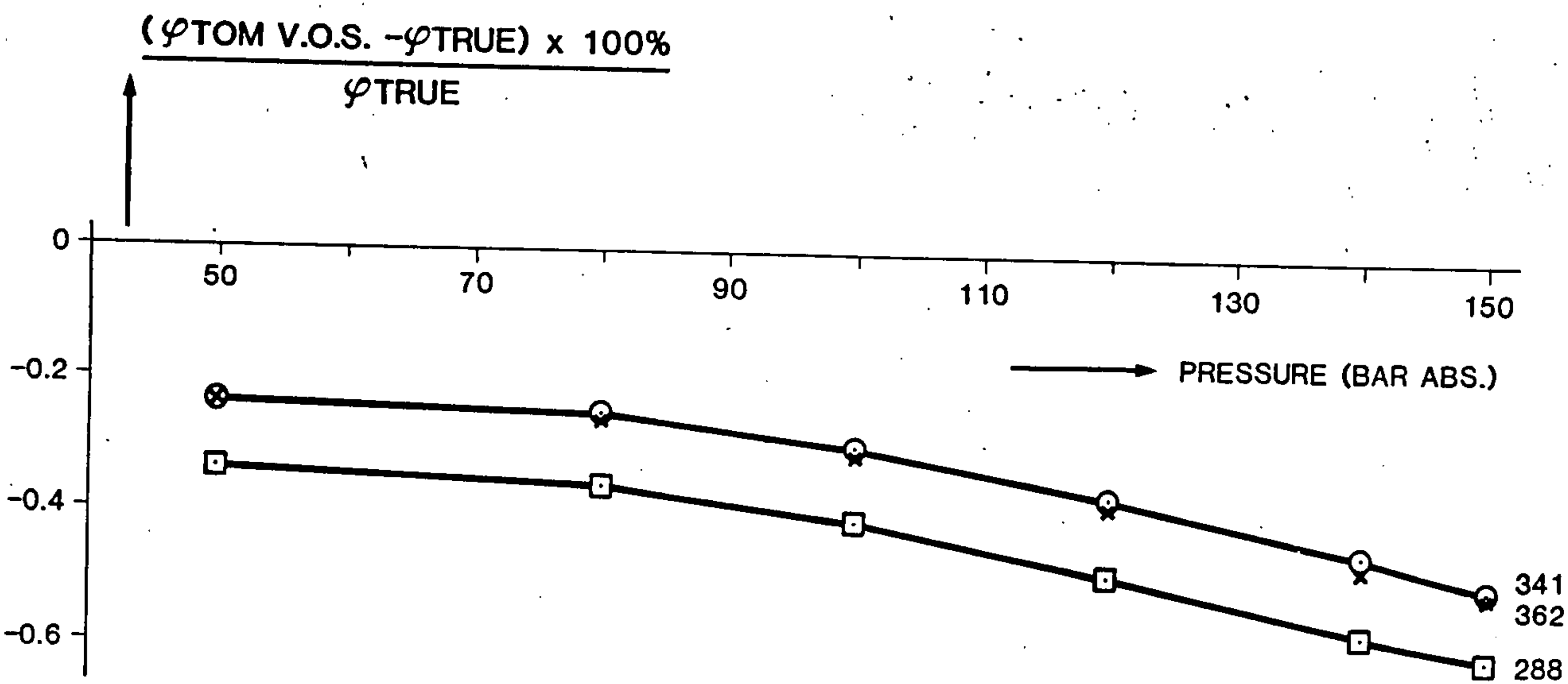

FIGURE 6 - COMPARISON BETWEEN METHANE WITH TOM VELOCITY OF SOUND CORRECTION (USING GAS OFFSET DATA) AND TRUE DENSITY OF METHANE

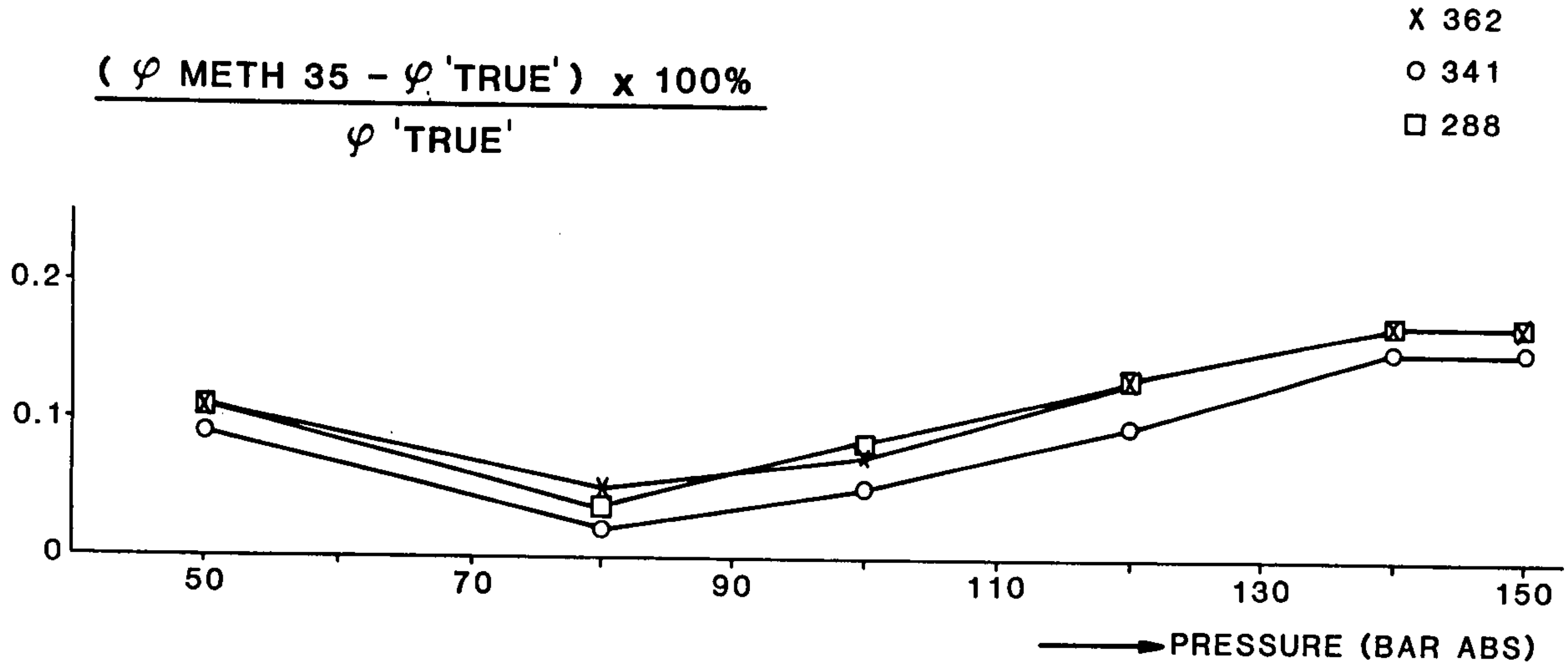

FIGURE 7 – COMPARISON BETWEEN DENSITYMETERS CALIBRATED ON METHANE AT 35°C AND THEN USED IN THE SYNTHETIC NATURAL GAS

APPENDIX 1

A1. TOM CONSTANTS FOR USER GAS OFFSET DATA ON THE SYNTHETIC NATURAL GAS

S.G. = 0.591, K = 1.3, hence G = 0.4546

$$D_A = D_T \left(1 + \frac{K3}{(DT+K4)} \quad 0.00282 - \frac{0.4546}{(T + 273)}\right.$$

A2. TOM CONSTANTS FOR USER GAS OFFSET DATA ON METHANE

S.G. = 0.555, K = 1.3, hence G = 0.555/1.3 = 0.4269

$$D_A = D_T \left(1 + \frac{K3}{(DT+K4)} \quad 0.00282 - \frac{0.4269}{(T + 273)}\right.$$

CALIBRATION CERTIFICATE

7811N GAS DENSITY METER SERIAL NO: 200288

CYLINDER NO: 200681 AMPLIFIER NO: 000621

UNIT PRESSURE TESTED TO 375 BARS (5440 PSI)

DENSITY CALIBRATION FOR ARGON AT 20 DEGREES C

DENSITY [KG/M3]	PERIODIC TIME [uS]
0	453.475
25	514.825
50	569.027
100	663.708
150	746.016
200	819.805
250	887.304
300	949.856
350	1008.411
400	1063.682

DENSITY=K0 + K1.T + K2.T**2 where K0=-80.9998
K1=-.025139
K2= 4.4876E-04

TEMPERATURE COEFFICIENT DATA

DT=DI(1+K18(T-20))+K19(T-20)

where DT=ACTUAL DENSITY (KG/M3)
T=TEMPERATURE (DEG.C)
DI=INDICATED DENSITY (KG/M3)
K18=-2E-05
K19= 1.14E-04

USER GAS OFFSET DATA

$$DA = DT\left(1 + \frac{K3}{(DT+K4)}\left(0.00282 - \frac{G}{T+273}\right)\right)$$

where DA=ACTUAL DENSITY (KG/M3)
DT=TEMPERATURE-CORRECTED DENSITY (KG/M3)
K3= 741
K4= 63.5
T=TEMPERATURE (DEG.C)

$$G = \frac{\text{GAS SPECIFIC GRAVITY}}{\text{RATIO OF SPECIFIC HEATS}}$$

FINAL TEST

TESTER.....A6.........DATE. 21 SEP 1984 ....QC..........

S.E.G. 21 SEP 1984 35

SOLARTRON TRANSDUCERS

LT000126

1GD7

SOLARTRON
Schlumberger

USER GAS CALIBRATION CERTIFICATE

7811N GAS DENSITY METER

SERIAL No:200288

Cyl No:200681

ARGON CALIBRATION DATA AT 20°C

K0 = -80.9998

K1 = -.025139 K18 = -2E-05

K2 = 4.4876E-04 K19 = 1.14E-04

USER GAS DATA AT 35°C

COMPOSITION BY % VOLUME :-

HYDROGEN	.0000
HELIUM	.1000
NITROGEN	.5600
CARBON MONOXIDE	.0000
CARBON DIOXIDE	.3100
OXYGEN	.0000
ARGON	.0000
METHANE	93.6900
ETHANE	4.3200
ETHYLENE	.1000
PROPANE	.4800
PROPYLENE	.0000
BUTANE	.2190
PENTANE	.2210
HEXANE +	.0000
TOTAL	100.0000

MAXIMUM TOTAL SENSOR ERRORS USING NEW COEFFICIENTS :-

DENSITY [kg/m³]	V.o.S. [m/s]	PERIODIC TIME [µs]	MAX. ERROR [%density]
40	430	547.218	0.199
60	432	588.292	0.185
80	441	626.556	0.175
100	456	662.517	0.171
120	476	696.548	0.166
140	502	728.930	0.167

FOR DENSITIES 40 TO 140 kg/m³:-

K0 = -81.338

K1 = -.024939

K2 = 4.5078E-04

N.B. SINGLE PHASE GAS IS ASSUMED

ESTED BY:-
FINAL TEST 87
6. /85

QUALITY CONTROL
8 AUG 1985
DLW
35

2005

SOLARTRON Transducers

SOLARTRON
Schlumberger

USER GAS CALIBRATION CERTIFICATE

7811N GAS DENSITY METER

SERIAL No:200362

Cyl No:200810

ARGON CALIBRATION DATA AT 20°C

K0 = -83.8641

K1 = -.026795

K2 = 4.8134E-04

K18 = -6.5E-06

K19 = 1.634E-03

USER GAS DATA AT 20°C

COMPOSITION BY % VOLUME :-

HYDROGEN	.0000
HELIUM	.1000
NITROGEN	.5600
CARBON MONOXIDE	.0000
CARBON DIOXIDE	.3100
OXYGEN	.0000
ARGON	.0000
METHANE	93.6900
ETHANE	4.3200
ETHYLENE	.1000
PROPANE	.4800
PROPYLENE	.0000
BUTANE	.2190
PENTANE	.2210
HEXANE +	.0000
TOTAL	100.0000

MAXIMUM TOTAL SENSOR ERRORS USING NEW COEFFICIENTS :-

DENSITY [kg/m³]	V.o.S. [m/s]	PERIODIC TIME [μs]	MAX. ERROR [%density]
40	414	535.127	0.197
60	415	574.366	0.184
80	422	610.961	0.173
100	435	645.383	0.171
120	454	677.978	0.166
140	478	709.011	0.169

FOR DENSITIES 40 TO 140 kg/m³:-

K0 = -83.4582

K1 = -.029219

K2 = 4.8573E-04

TESTED BY:-
FINAL TEST
87
6/8/85

QUALITY CONTROL
S. EYG.
- 8 AUG 1985
35

N.B. SINGLE PHASE GAS IS ASSUMED

2005

SOLARTRON Transducers

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.