CALCULATING THE SPEED OF SOUND IN NATURAL GAS – FROM AGA REPORT NO. 10 TO AGA REPORT NO. 8

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Introduction

The speed at which a sound wave travels in natural gas is a thermodynamic property, and varies depending on the composition of the gas, the pressure of the gas, and the temperature of the gas. The American Gas Association (AGA) Report No. 10, Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases, first published in 2003, provided an accurate method for calculating the speed of sound in natural gas or related gases. AGA 10 has now been superseded by the latest release (2017) of AGA 8 (see references 1 and 2).

Background

The original version of AGA 8 was published in 1985, and then superseded by the second edition in 1992 with new mixture equations labeled as the GROSS and DETAIL characterization models. In 1994, the second edition was republished to fix a few mistakes and add additional material that was missed when writing the 1992 version. Unless otherwise stated, all references here to just "AGA 8" refer to the 1992 edition and its update in 1994. In 2017, the third edition was released and contained two parts. Part 1 contains the original equations published in 1992, but the documentation was completely revised and new material on the ranges and uncertainties were given[3]. Part 2 of AGA 8 (2017) documents the new mixture model developed in Bochum, Germany, under research funds from the European Gas Research Group (GERG). This model was originally published by Kunz *et al.*[4] in 2004 with 18 components and later revised in 2008[5] with the same 21 components as found in AGA 8. In the sections below, any reference to "AGA 8 Part 1" (or Part 2) refers to the 2017 version (the 3rd edition).

The uncertainties in the GERG-2008 mixture model and the DETAIL characterization mixture model are nearly identical for high methane content gases and at moderate temperatures and pressures. For details, see AGA 8 Parts 1 and 2. However, for high pressures and for liquid states, the AGA 8 Part 2 (GERG-2008) model must be used. With the addition of liquid state properties, the model has the ability to calculate vapor-liquid equilibrium states, and thus the gas industry was finally given a method that could be used to obtain accurate dew points and compressibility factors from one single equation. Before, there was a plethora of cubic type equations such as Peng-Robinson that could be used, and no standard was available for consensus between different parties.

Purpose of AGA Report No. 10

The development of ultrasonic flow meters prompted the development of AGA Report No. 10 (AGA 10). An ultrasonic meter measures the speed of sound in the gas. To check the accuracy of the measurement, a method to calculate accurate thermodynamic properties, including sound speed, is needed. AGA 10 was developed specifically to do that. The information in that document is not only useful for calculating the speed of sound in natural gas, but also other thermodynamic properties of hydrocarbon fluids, such as the critical flow coefficient represented by C*. The audience for the revised 2017 AGA Report No. 8 is the same as for AGA 10, which includes measurement engineers involved with the operation and start-up of ultrasonic meters, sonic nozzles, and other meter types that are involved in applying the principles of natural gas thermodynamics in production, transmission, or distribution systems.

Why the Return to AGA Report No. 8

A long, long, long time ago in a state far, far, far away, several people met together, including both authors here, in the city of Norman, Oklahoma, with Ken Starling and a few others to finish the mixture model that would soon become the 1992 version of AGA8. The model being developed was a Helmholtz type model, the details of which are probably not of interest to anyone reading this paper, even though we'll give you the details below just to demonstrate how difficult this model is. But what is of importance to those reading this paper is the relationship between the Helmholtz energy, density, and speed of sound. The Helmholtz energy is one of four supreme properties that are unlike all others because they are built on a pyramid scheme where all other properties are beneath them. The importance of this pyramid scheme is that all properties can be calculated as simple derivatives of the one on top. For example, pressure is the first derivative of the Helmholtz energy with respect to density. The internal energy is the first derivative of the Helmholtz energy with respect to temperature. The isochoric heat capacity is the second derivative with respect to temperature. ...and, finally, there's the speed of sound, which is perhaps the most complicated of all the properties, and requires about five different derivatives of the Helmholtz energy combined in a way that results in this unique characteristic of a gas. For this reason, the introduction reports that it is a "thermodynamic" property, even though it does not seem to be related to things such as density and energy, and in many ways it seems more like a transport property.

In that state a long time ago, the small group discussed the new equation of state (not to be confused with Oklahoma) and that it should be fitted not only to density, but to all available experimental data for the components of natural gas. Unfortunately, most thermodynamic properties such as energy and entropy are not measurable, and thus they are not available to be fitted to make an equation of state better; but there are a few others that can be measured. A small handful of heat capacities were available (and fitted), but more importantly were the significant number of sound speed measurements, many made right here at NIST where the first author resides (although in 1990 the final mixture modeling was being done in Idaho where he then resided). Fitting only compressibility factors to develop an equation of state means that the first density derivative of the Helmholtz energy is the only input. By fitting heat capacities and sound speeds, multiple derivatives of the Helmholtz energy are fitted, thus resulting in a far superior equation that actually gives better compressibility factors. In fact, if highly accurate vapor phase sounds speeds (with uncertainties of about 0.01%, which is the current state of the art) are fitted by a skilled scientist, an equation of state can be developed to calculate density (without fitting it) with nearly the same uncertainty! This is a result of fitting multiple derivatives of the Helmholtz energy that are made available from within the speed of sound. The end result of fitting these data along with densities and all other properties that were then available resulted in what is now in AGA 8 Part 1 (2017).

But why the 2017 version? What happened to 1992? The decision was made back then to include only the compressibility factor equation Z (and thus the density) in the standard, even though the full Helmholtz energy model was available and from which sound speed could be calculated directly. The process to obtain the equation for Z was simple, just take the derivative of the Helmholtz energy with respect to density and report that. For you nerds reading this paper, look closely at the compressibility factor equation in either the 1992 or 2017 versions, and you'll see the pieces that came from that derivation. If the equation were integrated, those extra pieces would fall away (i.e., be reabsorbed back to their original position as exponents on the densities contributions).

Comments such as the following have been made in other documents: "The method in AGA 10 compares very favorably to the speed of sound determined by the highly accurate research that was the basis for the report." There's a reason for this: AGA 8 was indeed fitted to the speed of sound data, and, even though the original work gave absolutely no hints to this fact, it was already setup to be a full-fledged high-order equation of state that could later be used in that form, as finally reported in the 2017 version of AGA 8 Part 1.

Finally, to re-cap this in less than four paragraphs, even though the 2017 version seems to have new capabilities beyond those reported in 1992, the work done during the development of the mixture model exceeded what was needed for the 1992 equation by fitting speed of sound data as well, thus allowing a treasure to be revealed more than two decades later.

The methods for calculating the speed of sound in AGA 10 were based on the integration hint given above, but done on a numerical basis rather than an analytical basis (by integrating the compressibility factor equation to obtain the original Helmholtz model). The numerical methods used in that standard resulted in nearly the same values as those in the 2017 version of AGA 8, with the small differences coming from numerical integration. AGA 10 was thus an extension of the information contained in AGA Report No. 8 (1992), *Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases*, and contains excerpts from that report. With the new 2017 version of AGA 8, AGA Report No. 10 could finally be retired.

Applicable Gas Compositions

The calculations described in AGA 8 Part 1 are only for the gas phase with characteristics within the ranges outlined in Table 1 (taken directly from that document), and which have changed from the original 1992 version. For the liquid phase, mixed phase, and saturation properties including dew points, see AGA 8 Part 2. The DETAIL equation of state can be applied, as shown in Figure 1, for temperatures above −200 °F and pressures up to 40,000 psia. The upper temperature limit is approximately 350 °F or the onset of decomposition of the gas components. For applications outside of these ranges, refer to AGA Report No. 8 Part 2.

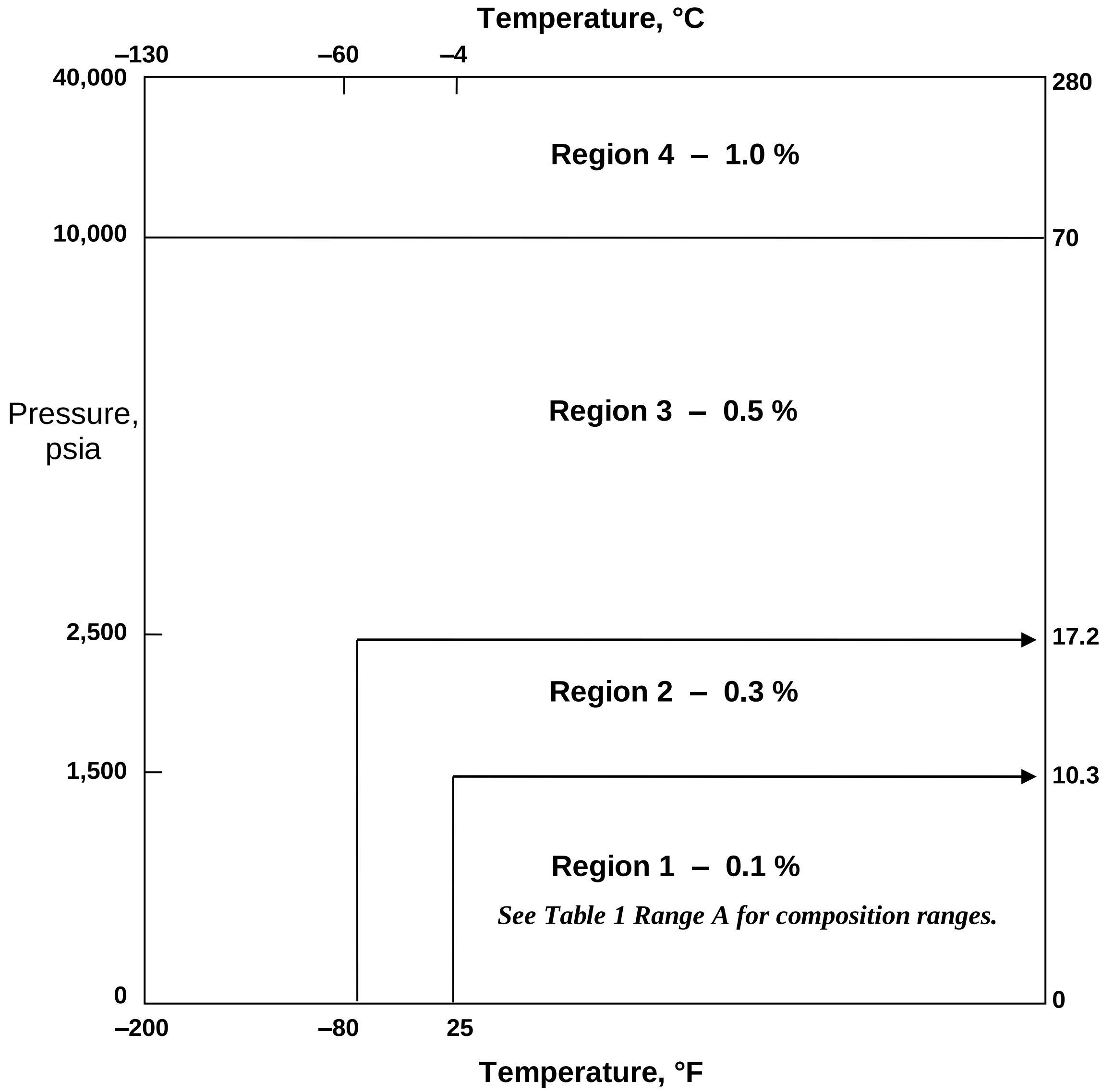

Figure 1. Overview of uncertainties for natural gas compressibility factors with the DETAIL equation of state (not to scale). The upper temperature limit is the onset of decomposition of the components in the gas. (This figure is taken directly from AGA 8 Part 1.)

Calculation Method

The equations used for calculating the speed of sound are shown below and are extremely difficult to solve without the use of a computer. They are best solved with programs that are available from various sources. They make the job of calculating the speed of sound a rather simple task, once you have accurate input data. The reliability of the calculation results depends on the accuracy of the measurements of the composition, the flowing temperature, and the flowing pressure of the natural gas under consideration. AGA 8 Parts 1 and 2 come with an Excel spreadsheet the makes the calculations rather simple, with the source code written in VBA and embedded as a module in the spreadsheet. The code was translated into both Fortran and C, and all three codes are made freely available from AGA or NIST[6]. This work was done at NIST on the condition that the material would not be copyrighted and would be made available to all without charge so that others could use and/or modify the code as necessary for any application.

	Range A	Range B	Range C
Lower temperature limit	**25 °F**	25 °F	17 °F
	–4 °C	–4 °C	–8 °C
Upper pressure limit	**1500 psia**	300 psia	3000 psia
	10.3 MPa	2.1 MPa	21 MPa
Gross heating value†			
Btu/scf	**630 to 1200**	680 to 1500	960 to 1090
MJ/m^3	**23.5 to 44.7**	25.3 to 56	35.8 to 40.6
Relative density†	**0.554 to 0.91**	0.47 to 0.91	0.554 to 0.64
Upper composition limits (mole percent)			
Methane	**100.0**	100.0	100.0
Nitrogen	**50.0**	50.0	3.0
Carbon dioxide	**30.0**‡	80.0	3.0
Ethane	**10.0**	25.0	4.0
Propane	**4.0**	6.0	2.0
Isobutane	**0.4**	1.5	0.1
n-Butane	**0.6**	6.0	0.4
Isopentane	**0.3**	2.0	0.1
n-Pentane	**0.3**	2.0	0.1
Total pentanes	***0.3***	*2.0*	
n-Hexane	**0.12**	0.2	0.03
n-Heptane	**0.04**	0.2	0.01
n-Octane	**0.03**	0.2	0.003
n-Nonane	**0.03**	0.2	0.003
n-Decane	**0.03**	0.2	0.003
Total hexanes plus	***0.15***		
Total heptanes plus	***0.04***		
Hydrogen	**5.0**	100.0	1.0
Oxygen	**0.2**	1.0	0.2
Carbon monoxide	**1.0**	10.0	1.0
Water	**0.05**	1.4	0.005
Hydrogen sulfide	**0.1**	4.0	0.1
Helium	**0.4**	5.0	0.4
Argon	**0.2**	3.0	0.2

Note: The above table provides component mole percent limits under the specified ranges of pressure, temperature, Btu value, and relative density for states with an uncertainty in density generally less than 0.1 %. The composition limits for different pressures, temperatures, Btu values, and relative densities outside of these ranges can be determined from the Excel spreadsheet provided in the supplementary material.

†Values are based on a methane lower limit composition of 60 mole percent. Reference conditions in U.S. customary units are (60 °F, 14.73 psia; density at 60 °F, 14.73 psia) and in SI units are (15 °C, 0.101325 MPa; density at 0 °C, 0.101325 MPa).

‡**The upper limit for the mole percent of CO_2 is reduced under the following conditions:**

$x_{CO2,max} = 20$ % when $x_{N2} > 7$ % | **$x_{CO2,max} = 5$ % when $x_{C3} > 2$ %**
$x_{CO2,max} = 10$ % when $x_{N2} > 15$ % | **$x_{CO2,max} = 10$ % when $x_{iC4} > 0.1$ %**
$x_{CO2,max} = 7$ % when $x_{C3} > 1$ % | **$x_{CO2,max} = 10$ % when $x_{nC4} > 0.3$ %**

Table 1. Ranges for Temperature, Pressure, Heating Value, and Relative Density with Uncertainties Less than 0.1 % in Compressibility Factors of Natural Gas Calculated with the DETAIL Equation of State (This table is taken directly from AGA 8 Part 1.)

Formulas for the Calculation of the Speed of Sound

As shown in the formulas below, these calculations are for people that enjoy difficult mathematical challenges. The equations are taken directly from AGA 8 Part 1. Most of us would shy away from attempting to implement the equations, and certainly it would take an incredible amount of work to do the calculations without the use of a computer. There are a number of commercially available programs that can be purchased and used for these calculations, making calculations quite simple for the end user. The inputs required are a complete gas analysis at least through C6+ or higher, the flowing pressure, and the flowing temperature.

Nomenclature used in the equations

a = Helmholtz energy
c_p = constant pressure heat capacity (real gas)
c_v = constant volume heat capacity (real gas)
d = density
M = molar mass
P = absolute gas pressure
R = universal gas constant
T = absolute gas temperature
w = gas speed of sound
Z = compressibility factor

The following nomenclature is used to simplify the appearance of the derivative equations. The variables that are not defined above are coefficients and terms in the equation of state.

$$\zeta_n = C_n^* T^{-u_n}$$
$$\psi_n = C_n^* T^{-u_n} D^{b_n} \exp\left(-c_n D^{k_n}\right)$$
$$\omega_n = c_n k_n D^{k_n}$$
$$\beta_n = b_n - \omega_n$$
$$\xi_{i,k} = \vartheta_{i,k}^{\mathrm{o}} / T$$

Properties and the derivatives of the Helmholtz energy required in the equations are given below.

$$Z = \frac{P}{dRT} = 1 + \frac{d}{RT}\left(\frac{\partial a^{\mathrm{r}}}{\partial d}\right)_T$$

$$\left(\frac{\partial P}{\partial d}\right)_T = RT + 2d\left(\frac{\partial a^{\mathrm{r}}}{\partial d}\right)_T + d^2\left(\frac{\partial^2 a^{\mathrm{r}}}{\partial d^2}\right)_T$$

$$c_v = \left(\frac{\partial u}{\partial T}\right)_d = T\left(\frac{\partial s}{\partial T}\right)_d = -T\left(\frac{\partial^2 a}{\partial T^2}\right)_d = -T\left[\left(\frac{\partial^2 a^0}{\partial T^2}\right)_d + \left(\frac{\partial^2 a^{\mathrm{r}}}{\partial T^2}\right)_d\right]$$

$$c_p = c_v + \frac{T}{d^2}\left(\frac{\partial P}{\partial T}\right)_d^2 \left(\frac{\partial P}{\partial d}\right)_T^{-1} = c_v + T\frac{\left[R + d\left(\frac{\partial^2 a^{\mathrm{r}}}{\partial d \partial T}\right)\right]^2}{\left[RT + 2d\left(\frac{\partial a^{\mathrm{r}}}{\partial d}\right)_T + d^2\left(\frac{\partial^2 a^{\mathrm{r}}}{\partial d^2}\right)_T\right]}$$

$$w^2 = \frac{1000c_p}{Mc_v}\left(\frac{\partial P}{\partial d}\right)_T = \frac{1000c_p}{Mc_v}\left[RT + 2d\left(\frac{\partial a^{\mathrm{r}}}{\partial d}\right)_T + d^2\left(\frac{\partial^2 a^{\mathrm{r}}}{\partial d^2}\right)_T\right]$$

$$\frac{a^r}{RT} = Bd - D\sum_{n=13}^{18}\zeta_n + \sum_{n=13}^{58}\psi_n$$

$$\frac{d}{RT}\frac{\partial a^{\mathrm{r}}}{\partial d} = Bd - D\sum_{n=13}^{18}\zeta_n + \sum_{n=13}^{58}\beta_n\psi_n$$

$$\frac{d^2}{RT}\frac{\partial^2 a^{\mathrm{r}}}{\partial d^2} = \sum_{n=13}^{58}\left[\beta_n(\beta_n - 1) - k_n\omega_n\right]\psi_n$$

$$\frac{d^3}{RT}\frac{\partial^3 a^{\mathrm{r}}}{\partial d^3} = \sum_{n=13}^{58}\left\{(\beta_n - 2)\left[\beta_n(\beta_n - 1) - k_n\omega_n\right] + k_n\omega_n(1 - k_n - 2\beta_n)\right\}\psi_n$$

…and so on and on and on…

Ultrasonic Meter Operation

An ultrasonic meter uses transducers to create sound pulses that travel across the flowing gas stream both with the flow and against the flow of gas. The difference in the transit times can be used to calculate the sound speed of the gas in the pipe, which is simply the ratio of the distance between the transducer faces, known as path length, and the time required for a pulse to travel that distance. The path lengths are measured very accurately in the manufacture of the meters. For meter diagnostics, the measured speed of sound determined by the meter can be compared to the theoretical speed of sound in the gas as calculated by AGA 8.

Table 2 shows that, for the speed of sound, a small pressure change has less effect than a small temperature change. For example, a one pound change in pressure from 200 psi to 201 psi only changes the speed of sound by 0.1 ft/s, if at all; whereas a temperature change of one degree Fahrenheit can change the speed of sound at 200 psi from 1.5 ft/s to as much as 2.1 ft/s at 1,000 psi. At pressures in the 1,000-psi range, it can require more than a 10 psi change in pressure to cause the speed of sound to change by 0.1 ft/s. The gas composition used for these calculations is the Gulf Coast Gas shown in Table 3.

This shows that calculated values used to verify the accuracy in speed of sound determined by a meter requires very accurate temperature measurements. The pressure is also very important in calculating the standard volumes but a small change in the pressure does not affect the speed of sound calculation nearly as much as does a corresponding change in the temperature. Stated another way, a 1 psi change in pressure does not affect the speed of sound calculation nearly as much as a 1 degree change in the temperature. The speed of sound determined by the meter should agree with the speed of sound calculated with the use of AGA 8 to within 0.2%.

Figure 2 shows the speed of sound for the Gulf Coast gas mixture plotted for four different temperatures and for pressures from near 0 psia to 1,500 psia. This figure clearly shows how the speed of sound varies with changes in temperature and pressure. This covers a large span of the normal operating pressures and temperatures except for most gas storage operations.

Temperature (K) →	30 °F	31 °F	35 °F	40 °F	60 °F	70 °F	90 °F	100 °F	120 °F
Pressure (psig) ↓									
200	1351.1	1352.6	1358.5	1365.9	1394.4	1408.3	1435.1	1448.1	1473.4
201	1351.0	1352.5	1358.4	1365.8	1394.3	1408.2	1435.0	1448.0	1473.4
202	1350.9	1352.4	1358.3	1365.7	1394.3	1408.1	1434.9	1448.0	1473.3
205	1350.5	1352.0	1358.0	1365.4	1394.0	1407.9	1434.8	1447.8	1473.2
210	1350.0	1351.5	1357.5	1364.9	1393.6	1407.5	1434.4	1447.5	1472.9
500	1321.6	1323.4	1330.4	1339.1	1372.4	1388.4	1418.9	1433.6	1461.9
501	1321.5	1323.3	1330.3	1339.0	1372.4	1388.3	1418.9	1433.6	1461.9
502	1321.4	1323.2	1330.3	1338.9	1372.3	1388.3	1418.8	1433.5	1461.9
505	1320.7	1323.0	1330.0	1338.7	1372.1	1388.1	1418.7	1433.4	1461.8
510	1320.7	1322.5	1329.6	1338.3	1371.8	1387.8	1418.5	1433.3	1461.7
1000	1296.3	1298.4	1306.8	1317.1	1356.2	1374.6	1409.7	1426.4	1458.3
1001	1296.3	1298.4	1306.8	1317.0	1356.2	1374.6	1409.7	1426.4	1458.3
1005	1296.2	1298.4	1306.7	1317.0	1356.2	1374.7	1409.7	1426.4	1458.4
1010	1296.2	1298.3	1306.7	1317.0	1356.2	1374.7	1409.7	1426.5	1458.5

TABLE 2. Speed of Sound (in ft/s) Variation as a Function of Gas Pressure and Temperature for the Gulf Coast Gas (the Composition is Given in Table 4)

The composition of the gas used to calculate the speed of sound in Table 2 is the Gulf Coast Gas composition from AGA 8. This composition was determined by averaging a large number of gas samples collected by various companies that operate facilities both onshore along the Gulf of Mexico Coast and offshore in the Gulf of Mexico. The Gas Research Institute (GRI) reference compositions of the Gulf Coast Gas, the Ekofisk Gas, the Amarillo Gas, and air are included in Table 3. Comparisons of how the composition of a gas affects the speed of sound are shown in Table 4. The comparisons are made at several pressures and temperatures. The composition of the Ekofisk gas has a high ethane content, nearly 8.5 mole percent, as compared to the ethane content of 1.8 mole percent in the Gulf Coast gas. The Ekofisk gas has no hexanes and heavier hydrocarbon components, whereas the composition of the Gulf Coast gas contains a small amount of *n*-hexane. The Ekofisk gas also has five times the amount of propane, and the other components are also greater except for the hexanes and that of methane, which is only 85.9063 mole percent compared to 96.5222 mole percent in the Gulf Coast gas. Table 4 shows that there can be a significant difference in the speed of sound calculated for the same conditions when the gas composition is changed.

Components	Gulf Coast Gas	Ekofisk Gas	Amarillo Gas	Air
Speed of Sound (ft/s) @ 14.73 psia and 60 °F	1412.4	1325.6	1377.8	1118.1
Relative density	0.5811	0.6495	0.6087	1.00
Heating value (Btu/ft^3)	1036.05	1108.11	1034.85	
Methane	96.5222	85.9063	90.6724	
Nitrogen	0.2595	1.0068	3.1284	78.12
Carbon dioxide	0.5956	1.4954	0.4676	0.04
Ethane	1.8186	8.4919	4.5279	
Propane	0.4596	2.3015	0.8280	
i-Butane	0.0977	0.3486	0.1037	
n-Butane	0.1007	0.3506	0.1563	
i-Pentane	0.0473	0.0509	0.0321	
n-Pentane	0.0324	0.0480	0.0443	
n-Hexane	0.0664	0.0000	0.0393	

TABLE 3. Reference Gas Compositions (mole percent)

Temperature →	30 °F Gulf Coast	30 °F Ekofisk	60 °F Gulf Coast	60 °F Ekofisk	120 °F Gulf Coast	120 °F Ekofisk
Pressure (psig) ↓						
200	1351.1	1260.3	1394.4	1301.8	1473.4	1377.1
201	1351.0	1260.2	1394.3	1301.7	1473.4	1377.1
205	1350.5	1259.6	1394.0	1301.2	1473.2	1376.8
210	1350.0	1258.9	1393.6	1300.6	1472.9	1376.4
500	1321.6	1220.0	1372.4	1270.6	1461.9	1358.7
501	1321.5	1219.9	1372.4	1270.5	1461.9	1358.7
505	1320.7	1219.4	1372.1	1270.2	1461.8	1358.5
510	1320.7	1218.8	1371.8	1269.7	1461.7	1358.2
1000	1296.3	1180.0	1356.2	1241.7	1458.3	1345.5
1001	1296.3	1179.9	1356.2	1241.7	1458.3	1345.5
1005	1296.2	1179.8	1356.2	1241.7	1458.4	1345.5
1010	1296.2	1179.8	1356.2	1241.6	1458.5	1345.5

TABLE 4. Comparison of Speed of Sound (in ft/s) in Gulf Coast Gas and Ekofisk Gas at the Same Conditions

Figure 3 shows the speed of sound in four different gases, including air from near 0 psia to 1,500 psia at 60 °F. This demonstrates how the speed of sound varies for gases with different compositional mixtures at various pressures. Air, being composed primarily of nitrogen, oxygen, argon, and carbon dioxide, is included as a reference. One of the diagnostics available in the ultrasonic meter is the speed of sound calculated by the meter. Some meters have the ability to connect to pressure and temperature transmitters, as well as a gas chromatograph, and bring those inputs into the meter electronics. The meter software then uses the AGA 8 or AGA 10 calculation method, along with pressure, temperature, and gas composition, to compute the speed of sound. The calculated value is then compared to the speed of sound measured by the ultrasonic meter. With this diagnostic (along with the other available diagnostics), an ultrasonic meter user can then determine its overall health and functionality. Watching the trend in the output data over time helps observe any potential drifts in the ultrasonic meter. A drift in the speed of sound calculation can point to a number of potential problems, including deposit buildup on the wall of the meter or face of the transducers, liquid inside the meter, or, possibly, a transducer that may be failing.

We eluded to the GERG-2008 model at the beginning, and it would be appropriate to add a small discussion about the differences between the two models. Although AGA 8 is well suited for the calculation of the speed of sound in the gases discussed here, it is interesting to see the differences between the two, and, more importantly, to know about the second model and its more accurate nature. This model is quite complex and built with far more modern techniques available between the time when the DETAIL model was developed on 25 MHz machines and 15 years later when the GERG-2008 model was developed on 1 GHz machines, with a 50 to 100 increase in computing power, along with additional methods and fitting techniques. Figures 4 and 5 show differences between the two models for the Gulf Coast and Amarillo gases. For the Golf Coast gas, the maximum deviation is about –0.06% at 140 °F and 1500 psia, which is within the uncertainty of the measurements in the speed of sound data. For the Amarillo gas, the maximum difference increases to nearly +0.2 % at the lowest temperature shown on the plot (20 °F) and for a pressure at about 1350 psia. As the ethane, propane, and heavier components increase, so does the uncertainty in the DETAIL equation of state (given the assumption that the GERG-2008 model is the more accurate of the two). The software in reference 7 has the ability to plot these comparisons for any gas and for any temperature and/or pressure (an option in the preferences has to be set in order for the plotting options to be visible). The plots here were made with that software. The publication in reference 3 gives addition details about the differences between the two models.

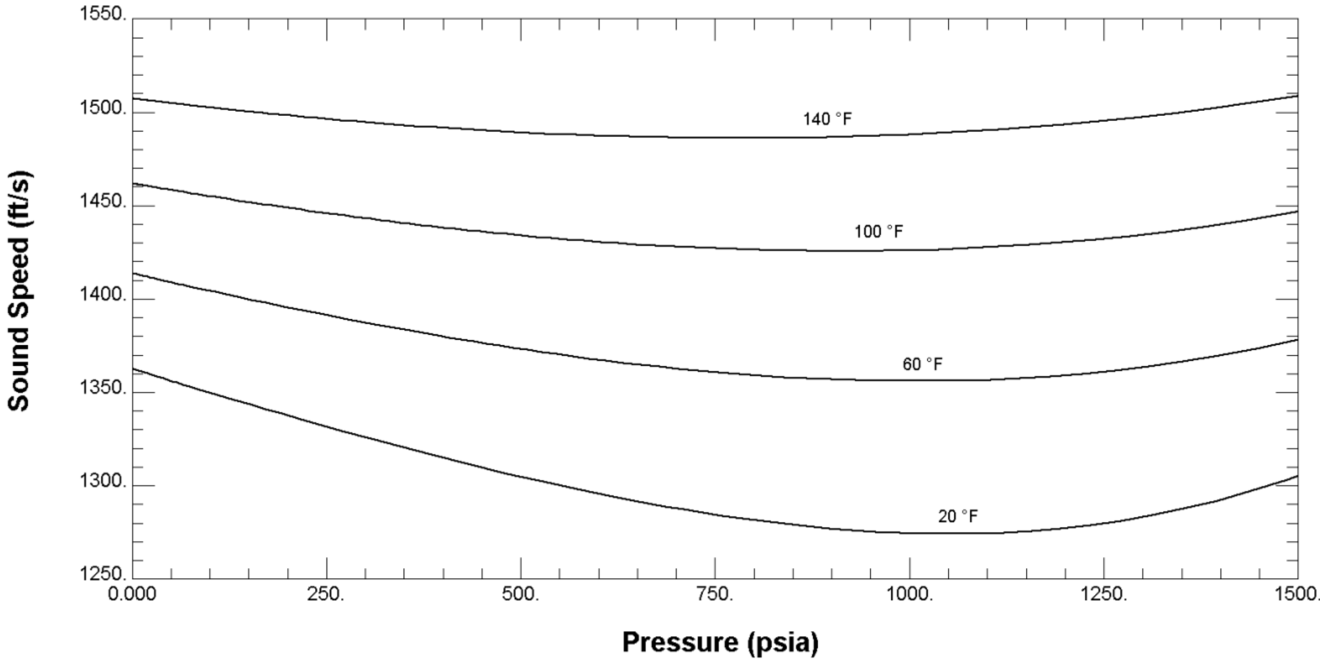

FIGURE 2. Speed of Sound in the Gulf Coast Gas Below 1,500 psia

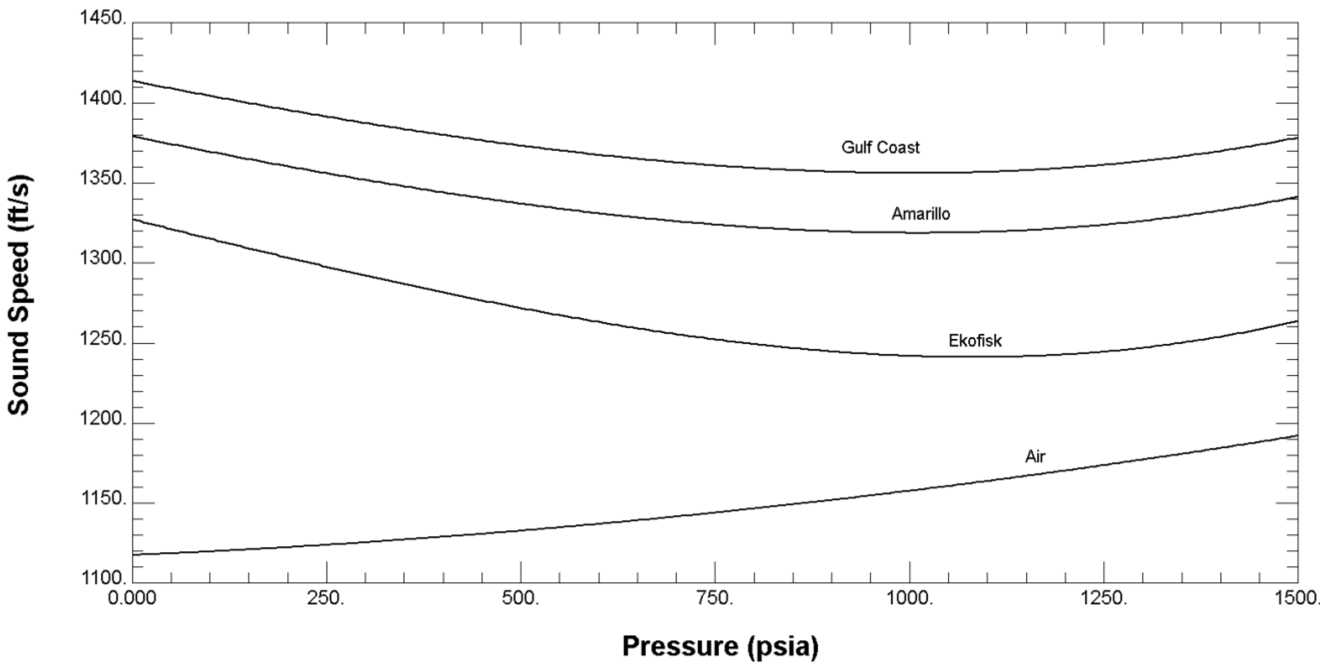

FIGURE 3. Speed of Sound in Various Gases at 60 °F

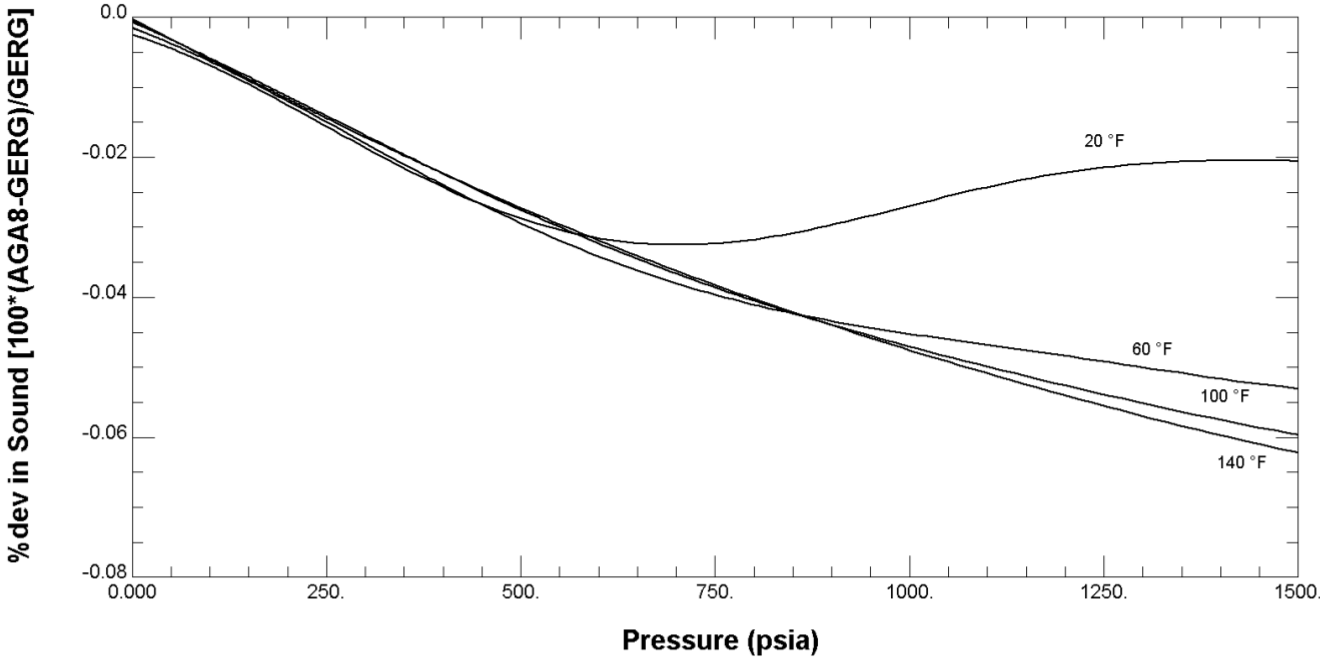

FIGURE 4. Percent Differences Between the Speed of Sound Calculated by AGA 8 and that by the GERG-2008 (i.e., Parts 1 and 2 of AGA 8) for the Gulf Coast Gas

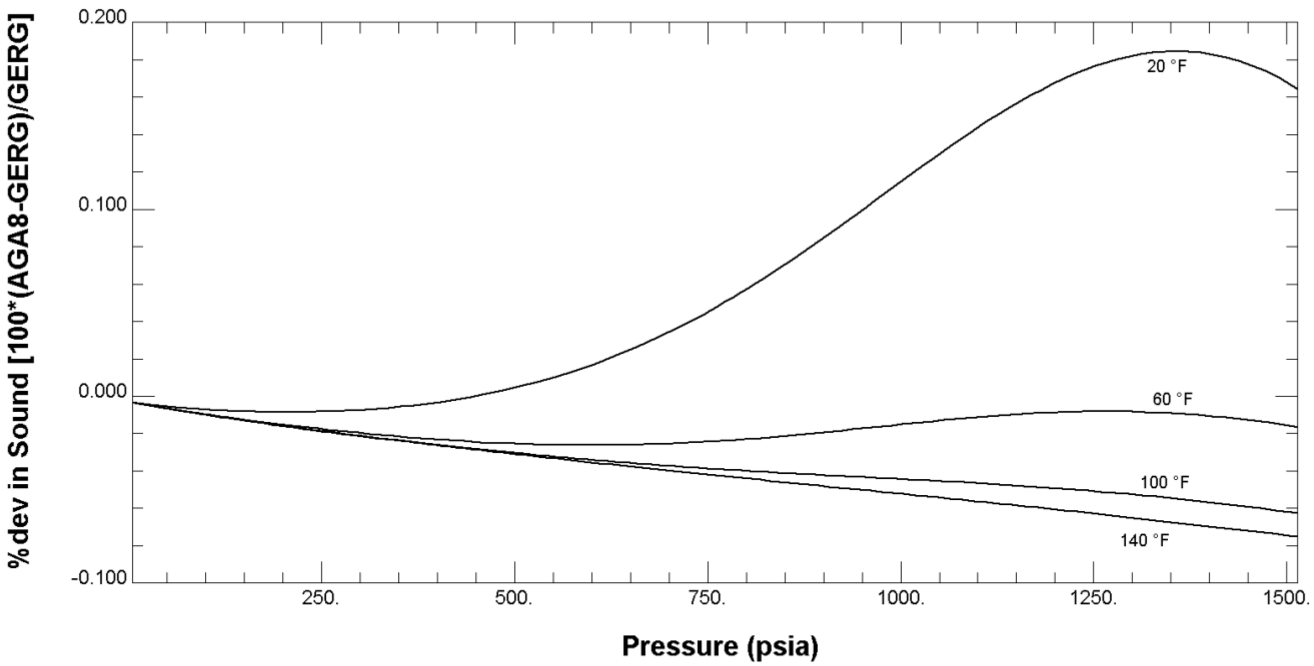

FIGURE 5. Percent Differences Between the Speed of Sound Calculated by AGA 8 and that by the GERG-2008 for the Amarillo Gas

Reverse Calculations

The methods discussed above about the use of an ultrasonic meter to verify a meter's condition can also be turned into new ways of obtaining information. In the above material, four properties were available: temperature, pressure, composition (assumed to be just "one property"), and speed of sound. Only three are necessary for the calculation of density. The common thinking is that T, P, and $\boldsymbol{x}$ are used to calculate density d, and then with an equation of state, T, d, and $\boldsymbol{x}$ are used to calculate the speed of sound w. Then, with a measured speed of sound, this value can be compared against the calculated value as a verification of the meter's operation.

This method could be inverted if one of the four properties is unknown. For example, if the pressure is unknown, the temperature, speed of sound, and composition could be used to calculate the pressure. Or, if one of the compositions in the gas is unknown, T, P, w, and the remaining compositions could be used to determine the unknown composition. However, for this to be possible, the change in speed of sound with respect to the missing composition must be sufficient enough for the procedure to produce a meaningful number.

As an example, assume a simple mixture of 80/10/10 methane/ethane/nitrogen. At 60 °F and 1500 psia, the speed of sound is 1310.49 ft/s. If the composition is changed to 79.9/10.1/10 (a 0.1% change in ethane), the speed of sound changes to 1309.64 ft/s; for a 0.1% change in nitrogen (79.9/10/10.1), the calculated value is 1310.31 ft/s. The percent changes in speed of sound for these two perturbations are 0.065% and 0.01%. Thus the sensitivity to speed of sound 6.5 times more for ethane than for nitrogen at these conditions.

Summary

AGA-10 was conceived following the development and wide use of ultrasonic flow meters for custody transfer measurement. The revision of AGA Report No 8 in 2017 brought in all the necessary details from AGA Report No 10, which was then retired. Without its inclusion, AGA 10 would have required revision since it was based on AGA equations. With the new AGA Report No 8 revision, the equations and calculation methods necessary to compute the speed of sound in natural gas and other hydrocarbon gases are all available. With software that uses the equations laid out in the AGA 8 document, users can accurately calculate speed of sound and, in turn, compare the calculated values to that of measurement devices, such as ultrasonic meters, for diagnostic purposes.

References

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