INSTRUMENTS FOR THE DETERMINATION OF SPECIFIC GRAVITY / RELATIVE DENSITY OF GAS

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HISTORY

The terms Specific Gravity and Relative Density have been used for a number of years. Yet there seems to be some confusion over what exactly they mean.

Specific Gravity is formally defined as the ratio of gas density to air density when both are at standard conditions of 0 Degree C and 760 mm. Over the years the definition evolved to become the ratio of gas density to air density at the same temperature and pressure, “Relative” to each other. Hence, the term “Relative Density.” This is the most commonly used definition today. The fixed or “Specific” requirement of temperature and pressure, (0 degree C and 760 mm), had been removed over the years.

The American Gas Association in 1985 officially replaced the term Specific Gravity with Relative Density. However, both terms are still used synonymously.

TERMINOLOGY

Relative Density = \( \frac{\text{Density of gas sample}}{\text{Density of Air}} \)
(Both at same temperature and pressure)

Specific Gravity = \( \frac{\text{Density of gas sample}}{\text{Density of Air}} \)
(Both at Standard Conditions)

Density = weight per unit volume
Units: lbs./ft.³, grams/cubic centimeter, etc.
Example: Pure water has a density of 62.4 lbs/ft³

Notice that both the Specific Gravity and Relative Density terms are unit less. Also, it should be noted that both are temperature and pressure dependent. Therefore, if the gases are not at identical conditions, some type of compensation would have to be applied.

APPLICATION OF SPECIFIC GRAVITY IN FLOW MEASUREMENT

Specific gravity values are primarily used in the orifice meter flow correction calculations and for custody transfer. The fundamental orifice flow equation is a mass flow calculation based upon the physical laws of conservation of energy and mass. Differential pressure and density are the two main variables in the equation once the orifice meter is installed. Both variables are under the square root meaning that flows varies by the square root of the differential pressure and density. In practice density is not directly measured but calculated from the temperature, pressure, compressibility and specific gravity values. Specific gravity is also used in determining the super-compressibility multipliers for displacement meters when correcting volume.

METHODS FOR DETERMINING SPECIFIC GRAVITY

Many different types of instruments are used in the oil and gas industry for determining specific gravity. Including:

- Effusion and weighing methods (Gravity Balance)
- Direct weighting
- Kinetic energy
- Vibrating element
- Gas chromatography

EFFUSION AND WEIGHING TECHNOLOGY

The best known effusion and weighing instrument is the gravity balance. Gravity balances operate on the principle of measuring the pressure exerted by a gas of a given density and the pressure exerted by air of the same density, the specific gravity being determined from the ratio of these pressure measurements.

In this instrument, the means for measuring the buoyant force exerted upon a body suspended in gas or air are provided by a balance beam having a sealed float on one end and a balance weight and a graduated scale on the other end. When the buoyant force of the gas sample and air taken on successive tests is equal, the densities are equal. The pressures at which this equality occurs are measured by a mercury manometer, and the pressure ratio is used in calculating specific gravity.

This instrument calculated specific gravity by the following equation:

\[
\text{Specific Gravity} = \frac{P_{\text{ar}}}{P_{\text{gas}}} \times \frac{T_{\text{gas}}}{T_{\text{ar}}}
\]

Where

- \( P_{\text{ar}} \) is air absolute pressure (barometric + manometer)
- \( P_{\text{gas}} \) is gas absolute pressure (barometric + manometer)
- \( T_{\text{gas}} \) is air absolute temperature (temperature \( F + 460 \))
- \( T_{\text{ar}} \) is gas absolute temperature (temperature \( F + 460 \))
The gravity balance is a primary measurement device. The accuracy obtained is dependent upon the care used in construction of the gravity balance and the care used in its operation.

The gravity balance is a very accurate device, however it does require a fair amount of time to obtain a reading.

As the gas industry was making its initial movement towards an on-line continuous specific gravity measurement two other devices appeared. The direct weighing and the kinetic energy devices.

**DIRECT WEIGHING TECHNOLOGY**

One of the more popularly used direct weighing instruments is the UGC Gravitometer. This gravitometer uses a simple balance beam system to measure specific gravity. Identical tanks, referred to as reference and sample, are hung on each end of the balance beam at equal distance from the pivotal axis.

Pressure, temperature and other ambient changes are experienced equally by both tanks and thus nullify these changes. For example the effects of ambient temperature fluctuations are eliminated by having the reference tank gas pressure regulate the sample tank gas pressure through the use of an especially adapted pressure regulator. The pressure in the sample tank is not kept constant but is maintained equal to the reference tank pressure which in turn is a function of the ambient temperature as predicted by the perfect gas law for a confined gas. The ambient temperature which governs the pressure in the sealed referenced tank is allowed to control the pressure in the sample tank. Only the genuine specific gravity changes are recorded and not the apparent changes due to a variation in the ambient temperature.

Calibration is performed by the use of calibration discs that are equal to the weight difference of “full scale” gravity and “minimum scale” gravity.

**KINETIC ENERGY TECHNOLOGY**

The most popular kinetic energy type gravitometer is the Ranarex gravitometer. This device became very popular and is still widely used, especially the portable version, by field technicians. This instrument's popularity grew because for the first time an operator could take a spot (field) specific gravity measurement in a matter of minutes. There are no additional readings to record or mathematical equations to remember. The field technician simply connected the portable gravitometer to a pipeline probe and within a few minutes had the required reading for the spot sample.

This gravitometer consists of two cylindrical gas-tight measuring chambers, each having separate inlet and outlet connections. Each chamber contains an impeller and an impulse wheel, both with axial vanes. These wheels are mounted on separate shafts facing each other but not touching. An electric motor and drive belt rotate the impellers at the same speed and in the same direction.

The impellers draw continuous flows of the gas sample into the upper chamber and dry reference air into the lower chamber, and spin the gas and air against the vanes of their corresponding impulse wheels which are proportional to the density of the gas and of the air. The other variables of pressure, temperature and speed are equal for both the air and gas sample and therefore cancel each other. These torques are transmitted from the chambers by the impulse wheel pivot shafts to two external measuring wheels. These external measuring wheels are shaped differently for the gas and air samples. A flexible tape is wrapped over the measuring wheels rims in the crossed direction so that the torque creates two opposing forces. The measuring wheels are thus restrained from continuous rotation, but a difference between the torques permits limited motion of the entire system.

Calibration involves using either calibration pulleys or reference gases of known specific gravity. The calibration is performed by adjusting the effective distance between the impulse wheel and the front of the cylindrical chamber making the pointer indicate the appropriate specific gravity. The zero adjustment is re-aligned after each change.

**VIBRATING ELEMENT TECHNOLOGY**

The vibrating element technology has been employed since the 1960's. This type of gas gravitometer is usually electronic and produces a frequency signal that is proportional to the specific gravity of the gas.

The principle of resonant frequency measurement is simply that if a very stable element is maintained in resonance, only two factors have any major effect on the natural frequency, these being a change in mass of the fluid surrounding the element or the stressing of the element. The element is made to vibrate at its natural resonant frequency by means of electromagnetic induction. A solid state amplifier is used to maintain the conditions of vibration and to provide the output signal for measurement. This signal is linearized using the quadratic equation shown below:

\[
\text{Specific gravity} = K_0 + K_2 T^2
\]

where, \( K_0 \) and \( K_2 \) are calibration coefficients unique to each gravitometer. \( T^2 \) is the output time period (the inverse of frequency)

The gravitometer consists of a vibrating cylinder gas density transducer surrounded by a constant volume reference chamber. This gas reference chamber has a fixed volume which is initially pressurized with the sample gas. It is then sealed by closing the reference chamber valve, thus retaining a fixed quantity of gas now known as the reference gas.

The sample gas enters the instrument at the base plate and passes through a filter, followed by a pressure
reducing orifice. The sample gas is then fed through a spiral heat exchanger (wound around the reference chamber) so that it enters the gas density transducer at the equilibrium temperature. The output of the gravitometer is generated from the frequency of vibration of a thin-walled metal cylinder contained within this gas density transducer.

Following the gas density transducer, the gas flows down to a pressure control valve chamber. The reference gas pressure acts through a separator diaphragm on the pressure control valve chamber so that the gas pressures on both sides of the diaphragm are equal, i.e., the gas pressures within the gas density transducer and the reference chamber are equal.

With a fixed quantity of pipeline gas contained in the reference chamber and with pressure and temperature equalization established, the density changes being measured by the density transducer will be caused entirely by changes in the molecular weight of the flowing gas. As the ambient temperature changes, the pressure of the fixed volume of reference gas will change as defined by the gas laws. This change in pressure will affect the sample gas pressure within the gas density transducer such that the temperature and pressure changes are self-compensatory.

Calibration involves charging the reference chamber with the pipeline gas to a defined pressure in the range of 30 to 90 psig and then calibrating the output signal using two gas samples of known specific gravity. Typically pure gases such as methane and nitrogen.

GAS CHROMATOGRAPHY TECHNOLOGY

Gas chromatography is a technique by which a gas mixture is physically separated into its individual components and quantified. Gas chromatographs include the following major components:

- Sampler
- Column Oven
- Packed or Capillary Columns
- Sample Loop
- Column Switching Valve(s)
- Detector and Associated Electronics
- Carrier Gas
- Computer used for Data Acquisition, Calibration and Communications

In the natural gas application, the gas chromatograph separates the gas sample into its individual components by injecting a precisely measured volume of the mixture into the separation columns.

The carrier gas, usually helium, transports the sample through the columns and is also used to actuate the valve(s) in the system. The columns are packed with a material that selectively retards (adsorption) the passage of the hydrocarbon molecules based on the number of carbon atoms (molecular weight) in the molecule. The molecules with fewer carbon atoms (light components) will exit (elude) the columns first. The molecules with more carbon atoms (heavy components) will elude later. Therefore, the components are carried through the columns at different rates and elude separately.

A detector usually Thermal Conductivity Detector (TCD) is used to sense the elution of the components from the column. The time at which the component appears at the detector identifies the component. The detector also is utilized to determine the concentration of the components. The detector’s output is a DC voltage that changes when any gas other than helium is present at the detector. When this output is taken to a recorder, each component forms a separate “peak” which can be identified and quantified. The physical recording of these peaks is a “chromatogram.” After all the peaks have been identified and quantified, the BTU (heating value), specific gravity, etc. are computed.

The specific gravity of the gas is calculated by the following equation.

\[
\text{Specific Gravity} = \frac{\text{Theoretical specific gravity}}{\text{Compressibility of the sample}}
\]

where, Theoretical specific gravity = sum of the specific gravity of each component multiplied by the mole % of that component.

MAJOR COMPONENTS OF A GAS CHROMATOGRAPH

Sampler

The sampling system must extract a representative gaseous sample from the pipeline, reduce the pressure, filter the sample, prevent sample condensation and efficiently deliver the sample to the chromatograph. More measurement inaccuracies occur due to improper sampling systems than any other reason.

Column Oven

The chromatograph oven usually contains the columns, the switching valve(s), the sample loop, and the detector. The temperature of the oven must be precisely controlled since the performance of the columns and detector is affected by changes in temperature.

Packed or Capillary Columns

The columns separates the sample into its individual components. They consists of a length of \( \frac{1}{16} \) diameter stainless steel tubing which is micropacked with a granular liquid coated porous support material. This packing is termed the “stationary phase” of the analysis. A tiny mesh screen is installed at the tip of the columns to hold the packing in place. The column length varies depending on the components to be separated.
Sample Loop

Fixed gas sample volume that is injected into the columns to be analyzed.

Valve(s)

The sample valve(s) seizes and injects the gas sample into the carrier gas ahead of the column.

Detector and Associated Electronics

The detector is used to identify the individual components of the gas sample. The TCD is the most commonly used detector for natural gas chromatographs. The TCD consists of a reference side and a measurement side of a Wheatstone Bridge circuit. As the components elude from the columns, they flow across a thermistor (measurement side) where heat is removed in direct proportion to the thermal conductivity of the component. This produces an imbalance in the circuit which is amplified and sent to the computer for calculation. This signal is represented in the chromatogram as a separate peak.

Carrier Gas

A carrier gas usually helium, is used to transport the gas sample through the columns. This carrier gas must be pure (99.995%) or a reduction in the sensitivity of the detector will occur.

Computer

An internal computer provides all of the instrument control and the integration of the chromatogram peak areas. Once the compositional analysis of the sample is completed the computer calculates the heating value, specific gravity an compressibility of the gas using ASTM, GPA, AGA, and ISO methods. The computer is also used to automatically transfer data to a central computer system using a data acquisition network known as a SCADA system.

The computer may also be used to perform automatic functions such as daily calibrations and calculate daily averages of stored analyses.

SUMMARY

Specific gravity is an important physical measurement. Even as the instruments for measuring gas composition become more accurate, reliable and rugged for field use the usefulness of the specific gravity value will remain. It is an important variable in correcting the flow measurement. Experience has shown accounting for the gas by mass is more accurate than accounting by volume.