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DEVELOPMENT AND DEPLOYMENT OF AN ACOUSTIC RESONANCE TECHNOLOGY FOR ENERGY CONTENT MEASUREMENT

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ABSTRACT

Current issues relating to the interchangeability of different sources of natural gas have resulted in cost effective natural gas energy content (BTU) measurement becoming a top gas industry priority. Heating value of gas is measured currently at gas custody transfer locations only. Industry needs a low cost device to accurately measure heating value of pipeline gas at the distribution networks due to large travel distance of gas from the custody transfer point. It is beneficial if BTU measurement is done on a daily basis in real time and reported back to SCADA system. Historically, BTU measurements have been performed for a specific gas sample either through volumetric flow or the calorific heating value. GTI/GRI surveys among the gas industry indicated that currently available commercial BTU measurement devices (Gas Chromatography, Calorimeter, NMR, Inferential devices and Absorption Spectroscopy) are either bulky or too expensive for multiple field deployment.

Gas Technology Institute in USA is in process of developing a safe, cost effective, field deployable, real time BTU measurement device integrated with automated daily reporting to SCADA system without compromising the accuracy of measurement. It will be accomplished with support of the Sustained Membership Program (SMP) and Operations Technology Program (OTD).

GTI has developed a state-of-the-art device which exploits spherical acoustic resonance techniques integrating sonic speed, specific gravity, wobbe index and heating value, which is fast, accurate, and cost efficient, so that many units can be deployed in the field. Specific gravity for pipeline gas is measured by GTI's acoustic resonance device against a reference gas mixture by measuring their respective radial resonance frequencies (in two identical 2" diameter stainless steel spherical resonators). By measuring specific gravity, sonically calorific value can be calculated since heating value vs. specific gravity shows a linear relationship. A user friendly software has been developed at GTI for real time automated BTU measurements. The results are communicated to SCADA system instantly. Such a device would eliminate, or substantially reduce, the need for the field use of expensive gas chromatographs and gas sampling. The prototype device is being tested at different natural gas distribution sites in the USA. The device performance results at different test sites will be presented and compared with simultaneous GC data collected at the respective sites.

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DEVELOPMENT AND DEPLOYMENT OF AN ACOUSTIC RESONANCE TECHNOLOGY FOR ENERGY CONTENT MEASUREMENT

1. INTRODUCTION

For the past several years energy content measurements are done on volumetric flow basis and not on the calorific heating value. It is beneficial for large individual customers if the heating value or BTU measurements are done on a daily basis in real time. Although there are several methods available for heating value measurements (Gas chromatography, NMR, Inferential devices and Absorption Spectroscopy), they are either bulky or expensive and not economical for multiple field deployments. There is a need for a device consistent, accurate (0.1%), reliable and cost effective. Large individual customers and distribution networks need a device that can measure the heating value in-situ accurately and report it or telemeter it back to a SCADA system in real time.

2. AIM OF THE STUDY

Currently the energy content or heating value is measured only at the gas custody transfer area. Since pipelines run several hundred miles after the custody transfer point the energy content could be different at the distribution net works. So it is necessary to measure the energy content at these locations. It will be beneficial for large individual customers in cost savings. The device must be cost efficient so that many units can be deployed in the field. Hence the main objective is to build a cost effective field deployable prototype device that will be useful for large individual customers to know the energy use on a daily or monthly basis. The unit will be useful for distribution network applications with highly accurate real time heating value measurements. This unit is safe, viable, inexpensive and reliable for field applications.

3. METHOD

GTI has many years of experience in the development of state-of-the-art acoustic resonators for various applications. Acoustic resonance technology approach has been exploited in the current development of a viable low cost, highly accurate BTU measurement device that can measure energy use in real time and telemeter back to SCADA system along with other data. A novel approach would be to utilize two identical spherical acoustic resonators in parallel to measure the respective radial frequencies in pipeline gas and a reference gas mixture; exploit the relationship, between sonic speed, specific gravity, wobbe index and heating value. Since there is a linear relationship between heating value and the specific gravity, by measuring specific gravity sonically, heating value can be determined in real time.

GTI REALTIME BTU MEASUREMENT DEVICE

The BTU device under development at GTI consists of two small identical (2'' dia) stainless steel spherical resonators constructed on the same block (Figure 1).

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Figure 1. GTI Prototype BTU Device

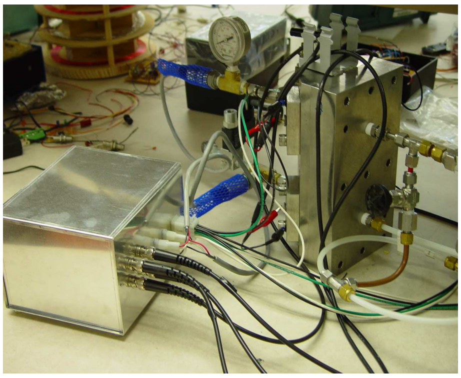

Figure 2. BTU System Control Unit

One sphere is filled with the pipeline gas and the second one is filled with a reference gas mixture. Temperature and pressure of the device are maintained constant. Each sphere is provided with a transducer to propagate low frequency acoustic waves (< 50 KHz) in the gas mixtures contained in the spheres and another transducer to receive the acoustic signal after it's propagation through the mixtures. The transmitters are excited by a sine wave of 5V peak to peak and acoustic waves are generated in the two spheres, one filled with pipeline gas and the other with a reference gas. The received signals at the receiver transducers of both spheres are amplified after sending through a noise filter. In the acoustic spectrum, a dominant radial mode resonance frequency is measured for both spheres.

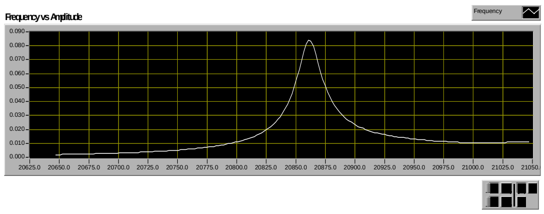

Figure 3. Radial Frequency of a Natural Gas Mixture

Sonic speed for a fluid confined in a sphere can be related to its acoustic resonance frequency by Ferris's equation (1-3).

$$V = 2\,\pi\, a\, f_{30} / v_{30} \quad \ldots\ldots \quad (1)$$

where V is the sonic speed in m/sec, a is the radius of the sphere (25mm), f_{30} is the frequency of the radial mode and v_{30} is the respective eigen value (7.72525184) for the sphere.

Sonic speed is related to specific gravity and hence the radial frequency. V_1 is the velocity, f^1 is radial resonance frequency, ρ_1 is the density for sample gas mixture, V_r is the velocity, f^r is the frequency, ρ_r is the density for reference standard gas mixture at the same pressure and temperature respectively.

$$V_1 = 2\,\pi\, a\, f^1{}_{30} / v_{30} \ldots\ldots (2)$$

$$V_r = 2\,\pi\, a\, f^r{}_{30} / v_{30} \ldots\ldots (3)$$

$$(V_1^2 / V_r^2) = (f^1 / f^r)^2 \ldots\ldots (4)$$

$$(V_1^2 / V_r^2) = (\rho_r / \rho_1) \ldots\ldots (5)$$

$$(\rho_1 / \rho_r) = (f^r / f^1)^2 \ldots\ldots (6)$$

Knowing ρ_r, f^1 and f^r in equation (6), ρ_1 can be calculated.

$$\text{Specific gravity of gas mixture} = \rho_1 / \rho_{air} \ldots\ldots (7)$$

$$\text{Wobbe Index} = (\text{Gross Calorific Value for gas mixture}) / \sqrt{\text{Specific gravity of mixture}} \ldots\ldots (8)$$

Heating value Vs Specific gravity plot was generated for mixtures of known compositions that cover the required range of specific gravity for pipeline applications. The specific gravity and heating value shows a linear relationship for pipeline gas mixtures. By measuring the radial frequencies of reference standard mixture and sample mixture (Fig. 3) that directly correlates to specific gravity sonically from equations (6) and (7) and heating value can be determined from the following relation

$$(\text{Sp.Gravity}) = (0.000878)\,(\text{Heating Value}) - 0.32185 \ldots\ldots (9)$$

Radial Resonance frequency for Standard Reference gas mixture: 20988.8 Hz

Specific gravity of reference mixture: 0.5767

Figure 4 represents 407 natural gas pipeline sample analyses by GC at different locations and at different cities (New York, New Jersey, Connecticut, Rhode Island and Pennsylvania) by formerly IGT and AGA Laboratories (4).

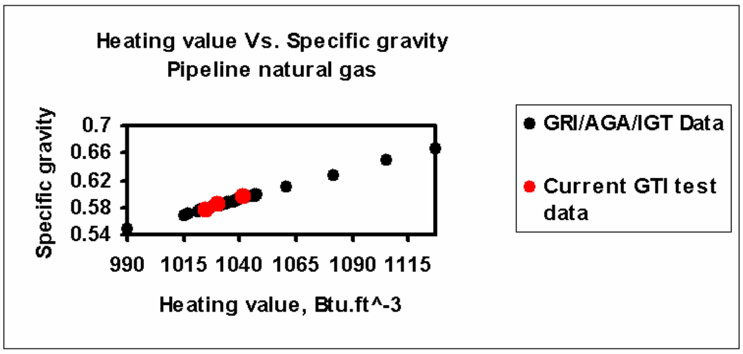

Figure 4. Heating Value Vs. Specific Gravity of Pipeline Gas

This device will cover the specific gravity range from 0.54 to 0.7 (can be extended to 0.95) and the respective heating value range from 36.85MJ/m^3 (990 BTU) to 41.91MJ/m^3 (1126 BTU) (can be extended to 46.53 MJ/m^3 (1250 BTU)). The system is fast (covers the required BTU range for pipeline gas in North America, highly accurate, repeatable, stable and low cost

4. RESULTS

GTI REALTIME BTU MEASUREMENT DEVICE

The unit was tested with two different simulated mixtures of distribution gas. The synthetic mixtures were prepared by Scott Specialty Gases. Their heating values determined from gas analysis using a Gas Chromatograph are listed in the following table. The heating values determined from our (GTI) BTU prototype device at the laboratory are compared with the GC data. The reported deviations are 0.19%.

Radial Resonance Frequency, Hz	Specific gravity	Calorific Value MJ/m^3 (BTU) (GTI/ AR method)	Calorific Value MJ/m^3 (BTU) (from gas analysis by GC)	Deviation (%)
20860.8	0.5838	38.38 (1031)	38.30 (1029)	0.19
20634.2	0.5967	38.93 (1046)	39.01 (1048)	0.19

Table 1 : BTU Test Data Comparison

The device was taken to various gas distribution locations at Chicago, IL., Peoria, Il., Streator, IL., and Trenton, New Jersey and tested with BTU measurements. The preliminary test data indicated that the system is working well. The deviations in the field data are within 0.3%. It was fast and easy to operate at field conditions. It was able to collect BTU data at the set intervals automatically. However the device is undergoing further development. GTI is in the process of identifying a commercial partner to work with to take the system into commercial ready.

Figure 5. Field Test at a Gas Distribution Station

5. CONCLUSION

The prototype device performed well at the laboratory. The limited field tests at selected gas distribution sites in Illinois and New Jersey were successful. The unit was easy for deployment at test sites and operation. The device has great market potential for the following reasons:

- The prototype device is a safe, easily deployable small unit ideal for field applications
- Accurate (+/- 0.1%) in real time BTU measurement
- Fast response in measurement.
- It can record the data on a daily basis and telemeter back to SCADA system.
- An ideal heating value control tool for LNG blending operations
- A low cost device with a good market potential (among large individual customers, distribution network system and LNG blending control support)

6. REFERENCES

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7. LEGENDS FIGURES

Figure 1. GTI Prototype BTU Device

Figure 2. BTU System Control Unit

Figure 3. Radial Frequency of a Natural Gas Mixture

Figure 4. Heating Value Vs. Specific Gravity of Pipeline Gas

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8. LEGENDS TABLE

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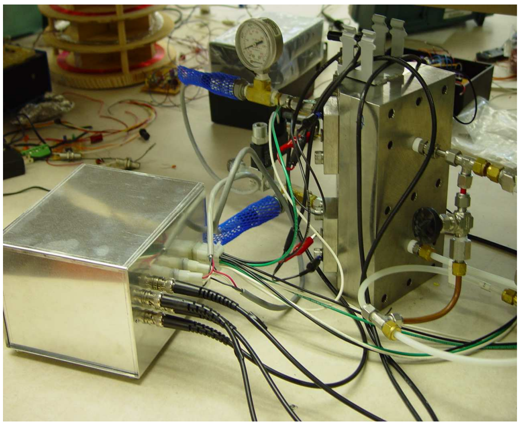
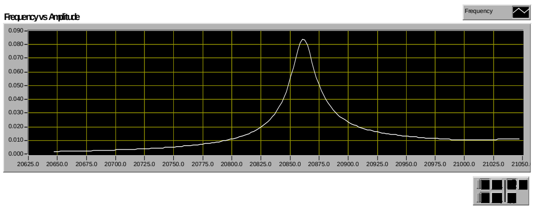
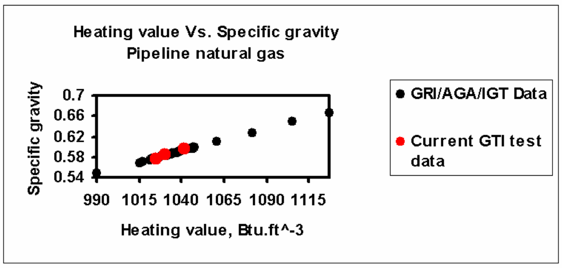
10. FIGURES




Frequency vs Amplitude
Frequency


Heating value Vs. Specific gravity
Pipeline natural gas
Specific gravity
0.7
0.66
0.62
0.58
0.54
990 1015 1040 1065 1090 1115
Heating value, Btu.ft^-3
GRI/AGA/IGT Data
Current GTI test data