CONTRIBUTORS TO HISTORICAL ADVANCES IN NATURAL GAS MEASUREMENT

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Introduction

When discussing a historic subject, controversy often arises. Like any historical subject the enormity of contributors and information is immeasurable. The authors for this paper picked the people based on their research and their interest in the given subject of natural gas measurement. It is our desire for this course to be permanent fixture at ISHM with an ever changing theme on hydrocarbon measurement.

The natural gas measurement industry was built by many individuals who devoted their time to improve the quality of measurement. The topics for ISHM 2013 are the work of Howard Bean and Edgar Buckingham on orifice meters, and Dr. Winston Lee on turbine meters.

Natural gas measurement has evolved because a number of historical developments in the industry. Over time pipelines evolved from wooden pitch covered lines to rod iron sealed by lead, and then finally to steel piping. The evolution added thicker walls and better grades of piping. As the pipe material evolved, the gas pressure increased and ever larger corrections for compressibility were required.

Meanwhile the nature of gas measurement was also changing during this time. In the early days of the industry the gas consumption was typically small, mostly for lighting purposes. Over time gas was used for heating, cooling, industrial, power generation, and the volume measurements were increasing. The industry was starting to become divided into transmission and distribution functions; and the meter choice was being divided as well. In the distribution systems the displacement meter was the traditional choice. Transmission meters measured larger volumes at considerably higher pressures. It was found that the orifice meter was better suited for these applications. Over time, the turbine meter was accepted for transmission measurements.

Much of the early testing with orifice meters was conducted with water. As the scope of the testing expanded to include the interest of the natural gas industry, attention was focused on the orifice jet contraction. It was observed that the contraction varied with density, viscosity and flowrate. These observations resulted in the fundamental relationship between Reynolds number and C_d that is still used today.

In the early days volumes were corrected using only Charles Law and Boyles Law. As meter pressure increased the industry learned that additional corrections were required. These corrections were called either compressibility or super compressibility depending on the equation being corrected.

Joint AGA – ASME Orifice Coefficient Committee

While the technical aspects of orifice metering were rapidly expanding; the commercial products were not standardized. At the time (1930) there were several companies offering different orifice designs. Litigation was of key concern; numerous lawsuits could damage the relatively new natural gas industry. Buyers having a different measurement practice than the gas seller could create difficult compromises and possible lawsuits would hamper the industry. Howard S. Bean and Thomas Weymouth had the premonition to see that a joint industry study must be organized with the objective of developing standard practices. The common goal of good measurement practice brought together AGA and ASME to collaborate. The new found partnership was made up of 3 members from each organization. As follows:

1. T. H. Kerr – Chairman - NGA
2. A.E. Young – till his retirement and replaced by C.C. Reed - NGA
3. Harry S. Bean – NGA
4. R.S. Piggot - ASME
5. R.E. Sprenkle - ASME

6. G.D. Conley - ASME

An important task of the committee was to oversee orifice correction factors based on test data. Ultimately the numerical correction values must be based on test data that could now be freely shared within the committee. Older testing consisted of 14 different tests completed over 16 years that were reviewed to make recommendations reported in AGA Report Number 1. After publication of AGA 1, the committee immediately moved on to define additional testing and data analysis that formed the basis for AGA Report Number 2. The tests are identified at the end of this paper; the present discussion will be limited to the Buttonwillow and the Columbus water testing.

1928 Buttonwillow Tests

It has been the traditions to identify a set of data where the test location was completed. Some of the older test data was taken from compressibility testing in 1928-1929 at the three locations: Daly Station – Buffalo, NY, Hastings Station, West Virginia, and Buttonwillow Gas Field in California. The ultimate responsibility for these data would rest with Howard S. Bean of the Bureau of Standards (Later NBS and NIST).

The three tests were designed to meet four objectives:

1) Study the effects on orifice C_d in the $\Delta P/P$ ratio to orifices in 4 inch pipe.
2) Study the effects on recessed and unrecessed orifice flanges
3) Deviation of Boyles law and the effects on orifice measurement
4) Effects of orifice coefficients for equal diameter ratios of changing from 8 inch to 4 inch lines.

Each test provided data at a different flowing pressure: 225 psi at Daly Station, 325 at Hastings and 600 at Buttonwillow. The Buttonwillow tests were very unique because the gas was drawn from a well at a pressure 1015 psi, with a composition of nearly 99% methane. Further, the high pressure allowed for considerable variation of $\Delta P/P$ ratio with ΔP values as large as 200 psi.

Data from all three locations were combined to quantify gas compressibility effects. Buttonwillow consisted of 14 tests (35 – 66 runs per test), Daly contributed 16 tests (13-18 runs per test) while four tests (20 – 22 runs per test) were included from Hastings. The Daly Station testing also included compressibility measurements using a specially designed instrument.

The Columbus Water Tests

The first meeting of the joint committee took place on December 1931 in Pittsburgh, PA. At this meeting a decision was reached that “determined the absolute values of orifice coefficients with testing”. Howard Bean motioned that these tests be conducted at the hydraulic laboratory at Ohio State University. Professor Sam Beitler would lead the testing of orifice plates using water.

The Columbus water tests were completed using 55 orifice plates installed in meter tubes with diameters between1.033 and 14.14 inches. The resulting range of beta ratio was 0.2 – 0.8. The 14.14 inch tube data were rejected based on accuracy, 318 tests were retained to develop the basic orifice factor.

Howard Bean of NBS

Howard Bean was a long time employee of the Bureau of Standards; he was a physicist in charge of the gas metering program with oversight from Edgar Buckingham. One of the earliest projects that Bean worked with was the Edgewood Arsenal experiments. These experiments were completed on behalf of the Department of the Interior to support royalty calculations for gas wells in the Osage Indian Nation in Northeast Oklahoma. His son Harry Bean Jr. writes, “The earliest recollection of my dad’s gas measurement work was a trip to Edgewood Arsenal, Maryland”.

Bean’s next work was to investigate the departure of natural gas from the ideal gas law as mentioned above. An interesting note is Bean’s name for the new correction factor that resulted from these tests. He called it “super” compressibility due to the fact that he wanted impress on his men in the field that this correction factor was over and beyond the pressure and volume relationship.

Bean showed great interest and vigor with his work for the natural gas industry. He served on both NGA and ASME committees on measurement. As stated in this paper, Bean was responsible for the implementation of a joint committee on the measurement of orifice plates. He also made recommendations for specific orifice correction testing procedures and locations. His efforts set the foundation for the current revisions of AGA 3 and API MPMS 14.3.

Edgar Buckingham

Edgar Buckingham was born in 1867 in Philadelphia, PA. He graduated from Harvard with a degree in physics; he received his doctorate from the University of Leipzig in Germany. Attending the University of Leipzig Buckingham had the honor to study under the famous chemist Wilhelm Ostwald. Buckingham began is his career at the NBS in 1906, he spent 31 years at NBS. His fields of expertise were soil physics, gas properties, and fluid dynamics. He was the first person in the history of NBS to achieve an independent research status, and was freed from all administrative duties. Buckingham became involved in Petroleum Engineering in 1921; he took part and analyzed the data from the Edgewood Arsenal tests that involved measurement of natural gas using orifice plates on air.

Buckingham is credited by name with the development of the Buckingham-Pi theorem that facilitates the analysis of complex interactions of multiple variables. The theorem organizes data based on dimensionless parameters; correlations between parameters are checked with test data. To this day turbine meters are corrected based on dimensionless parameters. The older “factors method” (AGA 3, 1985) is based on a number factors that are dimensionless. The current orifice equation is based on a number of dimensionless parameters: Reynolds number, beta ratio and gas expansion factor represent three examples.

Gas Turbine Meter

The turbine meter played a major role in World War Two. The machinery of war required measurements of fuels, lubricants and cooling fluids, the turbine meter well served these needs. As a result of the war effort the flow measurement community of the 1950s has access to high accuracy liquid turbine meter measurements. Potter Aeronautical, a supplier of turbine meters during the war years, employed engineers that went on to found several of the turbine meter companies in business today. Perhaps the interesting history might form the basis for a future ISHM paper.

While the turbine meter worked very well for liquids, similar operation for gas measurement would require considerable more research and testing. History shows that Dr. Winston Lee, employed by Rockwell, would make many important contributions to the development of the gas turbine meter that has been used for years. The K-Factor of a liquid meter varies primarily with viscosity while the K-Factor of a gas meter varies primarily with density. Dr. Lee provided the industry with detailed research for both meter type.

The variation of K-Factor with density and viscosity resulted in correlations based on dimensionless numbers, such as those that may be developed based on the Buckingham Pi theorem. NIST turbine meter research (Pope et al) continues to this day based on the work of Dr. Lee. The original correlations allow for proving turbine meters with liquids that are different that the flowing product, or at different temperatures. The current edition of AGA 7 allows for the calibration of gas turbine meters based on the dimensionless Reynolds number originally suggested by Dr. Lee.

One of the newest developments in hydrocarbon measurement is the availability of diagnostic parameters that can indicate the need for maintenance, gas calibration or liquid proving. These diagnostics are available as a result of the digital signal processing used in ultrasonic and coriolis meters. Over 40 year ago Dr. Lee described two diagnostic features unique to the mechanical measurements of the day. A spin test provides a quantitative value that can be monitored over time to indicate excessive bearing friction which will result in a K-Factor change and a measurement error. Spin testing remains a valuable diagnostic parameter to this day.

In order to better understand turbine meters Dr. Lee studied gas turbine technology. He published research results based on predicting how the entrance and exit velocity vectors are affected by various flow disturbances and the condition of the meter. He proposed an entirely new meter design based on a second rotor that serves to provide diagnostic information. A properly installed and well maintained meter will generate a specific pulse ratio from the two rotors; a deviation from that ratio will indicate the need for maintenance or re-calibration.

Orifice Meter Testing

1915 – Judd's Orifice Tests

1921 – Pulsation Experiments of Judd and Pheley

1919-1922 – Sptizglass Tests

1922-1925 – Edgewood Arsenal Tests

1923-1924 – Chicago Holder Tests

1924 – Cleveland Holder Tests

1926 – Buffalo Disturbance Tests

1927 – Buffalo Disturbance and Rate of Flow Tests

1928 – Buffalo Rate of Flow, Flange Form, Compressibility

1928 – Super Compressibility Tests at Hastings

1929 – Buttonwillow High Pressure Tests

1929 – Los Angeles Rate of Flow Tests

1929-1930 – Shop Tests on Effects of Orifice Installation Conditions

1929-1931 – Ohio State University Steam and Water Tests

1932 – Intercomparison of Meter Runs

1932-1933 – Columbus Tests

1932 – South Columbus Flange Form and Pressure Hole Tests

1933 – Oil Tests at Case School

Bibliography

Listed below are selected publications:

Bean, H.S., Buckingham, E. and Murphy, P. S., ”Discharge Coefficients of Square-Edged Orifices for Measuring the Flow of Air,” Bureau of Standards Journal of Research, August 22, 1928.

Bean, H.S., ”An Apparatus and Method for Determining the Compressibility of a Gas and the Correction for Supercompressibility ,” Bureau of Standards Journal of Research, November 21, 1929.

Buckingham, E., ”Notes on Contraction Coefficients of Jets of Gas,” Bureau of Standards Journal of Research, Feb. 16, 1931.

Bean, H.S., Benesh, M.E., and Buckingham, E., ”Experiments on the Metering of Large Volumes of Air,” Bureau of Standards Journal of Research, May 13, 1931.

Buckingham, E., ”Notes on the Orifice Meter: The Expansion Factor for Gases,” Bureau of Standards Journal of Research, May 23, 1932.

Lee, W. F. Z. and Karlby, H., "A Study of Viscosity Effect and its Compensation on Turbine Type Flowmeters," Trans ASME, Vol. 82, 1960.

Lee, W. F. Z., and Evans, H. J., "Density Effect and Reynolds Number Effect on Gas Turbine Flowmeters," Journal of Basic Engineering, Vol. 87, 1965.

Lee, W. F. Z., "Turbine Flowmeter," US Patent 3,301,052, Jan. 31, 1967.

Karlby, H. and Lee, W. F. Z., "Viscosity Compensated Turbine Flow Meter," US Patent 3,355,947, Dec. 5, 1967.

Lee, W. F. Z., and Evans, H. J.,"A Field Method of Determining Gas Turbine Meter Performance," ASME Paper 69-WA/FM-1, 1969.

Lee, W. F. Z., Kirik, M. J. and Bonner, J. A., "Gas Turbine Flowmeter Measurement of Pulsating Flow, "ASME Paper 74-WA/FM-1, 1974.

Oxley, R. G. and Lee, W. F. Z., "Field Test Evaluation of Auto-Adjust Turbo-Meters," AGA Operating Section Proceedings, 1982.

Lee, W. F. Z., et al, "Self-Correcting Self-Checking Turbine Meter," US Patent 4,305,281, Dec. 15 1981.

Lee, W. F. Z., Blakeslee, D. C. and White, R. V., "A Self-Correcting and Self-Checking Gas Turbine Meter," Journal of Fluid Engineering, Col 10, 1982.

Lee, W. F. Z., "Performance of a Self-Adjusting Gas Turbine Meter," ISFFM Proceedings, 1986.

Lee, W. F. Z., "Turbine Meter Accuracy in Air vs. Natural Gas," AGA Distribution/Transmission Conference, 1987.

Pope, J. G., et al, "Extended Lee Model for the Turbine Meter & Calibrations with Surrogate Fluids," Flow Measurement and Instrumentation, 2012; 24: 71 – 82.