

Title: Status of AGA Report No. 3 by E.L. Upp

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Introduction

For measurement of high pressure, high volume natural gas, the orifice meter remains the predominant choice for flow measurement. AGA-3, which is the standard upon which the orifice measurement is based, makes this statement in its foreward: "This is not a final report, but is made with the understanding that the committee will continue its analytical studies of data already developed. The committee also fully expects that it will be necessary for it to conduct further experimental work of its own. This will make necessary one or more supplemental reports, in which data will be summarized and the mathematical principles announced, which are the basis for the present report, and such modifications and extensions will be made as additional data and further study may require."

History

AGA Report No. 3, currently defined as ANSI/API 2530, is based on tests conducted at Ohio State University in 1932/1933 and upon equations developed by Buckingham and Beitler from that test data during that time frame. The document states an accuracy or precision of plus or minus 0.5%. The historical utilization of the equipment has indicated that the stated tolerance is viable in terms of statistically acquired samples from many meters or from systems with multiple meters on the input and multiple meters on the output. Students of the device have, however, questioned the capability of a single device to produce an accuracy within that tolerance.

In recent times a great deal of interest has been generated relative to improving the level of precision of orifice measurement. Modern technology should be able to improve the accuracy level to plus or minus 0.2%, compared with the stated accuracy of plus or minus 0.5% of the present approach. The industry must develop a new orifice measurement equation suitable for computer manipulation that will stand the test of today's technology.

Flow coefficient tests conducted by various parties subsequent to 1935 have raised additional questions on the validity of the basic equations. There have also been technical questions raised relative to the super-compressibility curves relating to a zero pressure gauge base instead of a zero pressure absolute base. Further questions relate to the high Reynolds number application that was extrapolated from the low Reynolds number test data. This was an item of necessity, since high Reynolds number data was not available on a laboratory basis in the 1930's. The coefficients themselves were derived by manual cross plotting and determining best fit curves for those plots, which is not consistent with modern computer capability.

There have also been questions raised on the impact of upstream disturbances on orifice flow coefficients and whether or not the straightening vanes and/or the piping configurations set forth in AGA No. 3 really reflect the data originally derived and are all applicable when best accuracy is desired. The bootstrap

method of expanding the scope of orifice measurement is also questioned. The original tests were run with water on relatively small diameter lines and through subsequent tests extrapolated for gas up to lines as large as 48" in diameter. All of the equations in use today are based on a few hundred data points in the 1932/1933 tests. The changing gas composition is also presenting problems. The gases being measured today have far broader chemical composition than those even conceived of at the time of the original derivation.

All of these and other various ramifications have been running through the heads of measurement men for many years. While the theoretical concerns were valid, with gas selling at 20¢ a thousand cubic feet and unaccounted for running consistently at less than 0.5% (closer to 0.2%), the industry and those in responsible charge did not have a financial basis for additional basic research in this area.

In the early 1970's three new elements entered into this.

1. The value of gas began to climb. It moved off its 20¢ plateau to figures of \$1.00 and projections of \$2.00, \$3.00, \$4.00 or more per thousand cubic feet. The cost of unaccounted for, which previously had been a minor element of the operating income sheet began to take on new and more important proportions. Pressures began to be exerted for higher measurement precision than plus or minus 0.5%.

2. The availability of natural gas declined. In the late 50's the Reserve Life Index stood at some 40 years and, while that had been decreasing for many years, it wasn't until the early 70's that the amount of gas sold was actually more than the amount of gas found in the United States. Pipeline curtailment became commonplace and the gas control offices began to demand contemporary information on gas volumes. They had to know today what was being sold today—they could no longer wait until next month to find out what happened. Computers were hooked up to provide gas supply with this information. While the information level could be improved, it could only be improved to a point.

3. The gas industry found itself in the world market. Europe—with the North Sea discoveries and imported LNG from Algeria found itself in the natural gas business. Governmental entities throughout Europe began to study gas measurement and began to raise questions through the International Standards Organization. Other tests were not able to confirm the data in AGA No. 3.

The time was ripe for measurement men to implement some of their concern. In 1975 the Transmission Measurement Committee of the American Gas Association and the Committee on Gas Measurement of the American Petroleum Institute jointly proposed going back to the beginning and reestablishing the basic orifice coefficient. This was only after several abortive attempts had been made to study other ramifications.

All these, however, relied on basic 1933 O.S.U. analysis as the base data and this in itself was being questioned. The committees determined that the first phase of any evaluation had to be a reestablishment of basic flow coefficient data, but this is only the first phase. It must, however, be placed in the perspective of the project or problem as a whole. The other elements as defined today include:

1. The extension of this basic flow coefficient work to gases to test expansion factors and the influence of high Reynolds numbers. Three avenues appear to be available for utilizing current technology in such work.

- a. Sonic flow nozzle testing; which appear to have high precision but are in

themselves theoretical applications and not truly basic standards for gas measurement.

b. Bell prover tests; using large volume bell provers against which sonic flow nozzles were originally tested.

c. Mass flow testing; utilizing the cryogenic facilities that the National Bureau of Standards has in Boulder, Colorado.

2. Restatement and expansion of the super-compressibility data included in Pipeline Research Project NX 19. This should be restated to an absolute zero pressure base and should be extended to include other fuel gas components (such as are being encountered in SYN fuels), acid gases and water vapor; remove limits on the range of pressure and temperature.

3. Interference tests, to determine the impact of upstream disturbances on the primary metering element. Emphasis has to be placed here on the influence of tap location.

Our purpose today will be to look at the work being done on orifices as a result of the questions asked and to look at how this work might affect the use of the orifice and the revision of Report No. 3.

Orifice Measurement Developments in Answer to the Problems Listed Above

The major developments in the orifice meter can be broken down into five areas of interest: 1) Basic Test Work, 2) Mathematical Evaluation of Basic Tests, 3) Data Handling on Line, 4) Manufacturing, and 5) Special Application Requirements. These areas will be examined so that an awareness of things that may come will be known to you.

Basic Test Work

For those of you who attended last year's Gulf Coast Measurement School, a portion of what will be covered here is a repeat. There has been an American Petroleum Institute study completed on the effects of upstream piping on the basic flow coefficient. This work is still being analyzed by a subcommittee task force of the A.P.I. Petroleum Measurement Committee, and results have not been published. The purpose of the work was to determine if the original AGA-3 configurations could still be allowed and/or if additional tolerances on the coefficients would have to be added for any of them. The test work was done on 4" and 8" meter tubes with approximately a .7 beta plate installed. The five pictured configurations in AGA-3 both with and without straightening vanes were studied. As was stated last year, the results in essence indicated further study was needed before any changes could be made. They also indicate that the coefficient tests (covered below) should be made with a single definitive upstream configurations. Then, if the effects of configuration were studied, they would be made at a later date on the same basis.

The AGA-API coefficient tests are just now under way even though at last year's conference I stated that they would begin in the summer of 1978. It is of no value to wash the dirty linen of the two industry organizations in public, but it is sufficient to say that the paper work has apparently been worked out so that the tests can now proceed.

The AGA/API Orifice Data Project was established in 1976 to review the basic orifice coefficient in terms of base data and equation. The scope of the group includes:

1. The primary objective is to develop a new orifice coefficient equation capable of producing improved coefficient accuracy to meet the industrial needs for accurate measurement of valuable products bought and sold throughout the North American continent and the rest of the world.

2. The secondary objective is to effectively endorse the use of the new orifice coefficient equation to update AGA Report No. 3 and make it a more accurate and acceptable universal method of fluid flow measurement for custody transfer.

In reviewing the work of this group, it is important that it be put in the context of the original proposal. The project was conceived as the first element of a multi-phase project to prove and improve orifice measurement.

The original purpose of the flow coefficient tests was to restudy, under controlled and known conditions and with carefully measured equipment the basic coefficients on 2", 3", 4", 6" and 10" meter runs with .200, .375, .500, .570, .660 and .750 beta plates installed. The desired Reynolds number range is 20 to 1 minimum with the possibility of several test mediums being used to cover this range. From this data and the data of the original tests, a study would be made to confirm the present coefficients or to arrive at new ones, and this would then be promoted for use by the standards organization. Since the tests have just begun, there is no data to discuss.

A prior part of the AGA-API program was to restudy the original orifice data and determine if a better equation could be derived with the use of modern computer analysis. This work has basically been completed by Mr. John Stolz of France (who incidentally did his work on a hand-held calculator) and confirmed by Mr. Wayne Fling of Cities Service on their full blown computer. This work has resulted in a new, more logical equation, which covers all tap locations and is being printed in the new International Standards Organization's Standard 5167. The usefulness of this type of equation has been recognized by the U. S. standardizing groups including AGA, but at the present time no work is being done to revise AGA-3 to this equation or a similar one.

The reasons for the delay in acceptance are multiple. The first is a desire to wait until the AGA-API coefficient tests are completed. These may result in another database on which the equation will be built. It has been recognized that this equation approach is an improvement in relation to the old basic data, but that the basic data may change. The desire to change is moderated by the fact that commercial measurement is dependent on these standards, and if a change is made it should be done a minimum number of times because of the resulting effects on the custody transfer of gas. Standards should simplify the commercial aspects of the business, and we hope that any change made will be a lasting change. If the new equation changes the calculated volume of an orifice meter and reflects itself in an unbalance in a company's lost and unaccounted for report, then a prudent company will want to be aware of such a change before it occurs and contractual agreements studied accordingly. This, plus the necessary time to reprogram to a new equation, influences the American Standard Writing Organizations to move slowly on any change. It is my feeling that the AGA-3 report will not be revised until more tests are run, and this will be a matter of several years before it is completed.

If the industry needs an incentive to approach this, they only have to look into the data currently available. The 1977 "Gas Facts" indicates that some 19.5 Tcf of natural gas passed in custody transfer in the United States. The value of that gas in orifice measurement ranges the full gamut between old production contracts and industrial rates, but a figure of \$2.00 per Mcf does not appear

inappropriate as a general average at this time. It certainly isn't low as a marginal value. If the precision of orifice metering can be increased by 0.3%, as proposed herein, then with one measurement we are dealing with (19.5 Tcf) (\$2.00/Mcf) (0.3%) or \$117,000,000.

Conservative estimates state that all natural gas passes through orifice meters in custody transfers a minimum of three times. This includes at the well head, between the producer and the pipeline and between the pipeline and the distribution company. This does not take into account inter-pipeline transfers, field ownership's, plant operation or even distribution customer (industrial) utilization. If we can accept the 3 times figure, then the magnitude of potential error suitable for correction as proposed herein is about one-third of billion dollars per year. Or, phrasing this slightly differently, about a million dollars a day.

Quite frankly, if we don't do it, Europe will do it for us. The following quotations are taken directly from a report of ISO TC 30's report to the ISO Central Secretariat:

1. "In the opinion of TC 20, it so appears that the present position of ACA-3 is not technically defensible in the 1980's (as regards the association of the AGA-3 tolerance with the AGA-3 installation requirements), and must not be endorsed by an ISO labeled document, even if at the start (1935) of AGA-3 recommendation there was no suspicion of the technical honesty of the AGA-3 authors."
2. "Publication of ISO TC 28/5 N6 (note this is ANSI/API 2530 - AGA-3) as an ISO standard would be deadly to ISO, since this document would be judged to be published knowing it to contain false information."
3. "If 70% of the meters in use conform to AGA-3 it is unfortunately quite certain that many gas measurements are just wrong. Many wrong practices do not turn the practice into a correct one ..."
4. "... more seriously it is a kid game that demonstrates that the accuracy claimed by AGA-3 is not attained. There are already mountains of documents to show this fact."

With that kind of adverse publicity on an international level, it is time we got going with the job that must be done.

Beyond these the problem is not so much research, as it is manipulation. All of these data must be put together to define a revised orifice measurement equation, supported by qualified laboratory tests that will provide a higher level of precision and, hopefully, will employ a simpler form of calculations suitable to computer technology.

Until all of this is done we won't solve the basic problem. The Europeans point out the American system involves many meters feeding in and many meters feeding out. Statistically this provides a reasonably high level of overall precision. The pluses and minuses tend to counteract each other. This was pointed out in the paper by Jim Kemp presented at the AGA Transmission Conference in 1968. In Europe, however, the gas passes from country to country through succeeding single meter stations measuring the same gas volume at slightly different pressure and temperature conditions. These do not reflect the same degree of precision that we obtain in the United States. As we enter the world market, we are faced with this same problem. LNG in must equal LNG out. The Alaskan gas

will pass into custody transfer at the Alaska/Canadian border and then again at the Canadian/Continental U.S. border. Will these measurements match? Similar problems on a lesser degree could be experienced with Mexican imports. From a practical standpoint, we are faced with these problems today.

From a theoretical standpoint, we are also faced with the possibility of an international standard being different from our own AGA No. 3. In itself this could have a serious impact on our measurement practices.

Mathematical Evaluation of Basic Tests

Mr. Stolz's evaluation of the original test data is not the only work being done on a new equation. Work by Mr. Dick Miller of Foxboro and Dr. Ray Teyssandier of Daniel on this test and other tests run by Foxboro and Daniel indicate that their approach (which is similar to Mr. Stolz's equation) may have advantages. A report on their study is to be made at the ASME Winter Annual Meeting. It covers more data and makes an approximate equal fit to the data, as does the Stolz study.

What all this means to a user of orifices is that there is considerable restudy of the basic theory and data of the device to improve our ability to use them. The drive for these studies is economic in nature; with the ever-increasing cost of fuel there is a desire to reduce the tolerances on the meters used in measuring the gas flow.

Data Handling on Line

Probably the greatest change that has taken place in the orifice metering business is the rapid expansion in the availability of computers to arrive at volumes and approach an on line real time control of a pipeline operation. The cost of these devices is continuing to come down closer to the price range of the conventional recording chart approach. The latest entries into the field of measurement are the micro-processing units that have programmable capacities to allow a single unit to measure and collect the variables from multiple meter tubes, calculate flow, control the station and send the data back to the central office for billing. The basic drive to the use of this equipment is the desire to automate or modernize. However, because of the data treatment, it also is capable of making the calculations more correctly since it can treat all variables as real time variables and make the corrections on an instantaneous basis. The attraction if this feature is minimal if the pipelines are operating at relatively stable conditions, and the composition of the gas is not changing, in which case the use of averages introduces only small errors. With the beginning of the end of the single standard natural gas source and the anticipated increase in use of LNG, SNG, LPG and coal gasification, the stability of composition may become a luxury of our past. With these changes, we find more and more companies changing from a cubic foot or cubic meter custody transfer base to a total heating value base. This adds yet another variable to our calculations that will truly be a significant variable with multiple supply sources, and the use of average heating values will introduce errors. Computers for handling these problems are being sold today, and will increase, as the pipelines become less stable in the gases they handle. It is only fair to state that the universal acceptance of these units has been slow to come because of their online reliability record; but with the new generations of computers coming onto the market, this record is improving, and hence their acceptance.

Another area of interest, although not directly natural gas measurement, has to do with plant gases such as ethane, ethylene and propylene. These and other

similar fluids have such rapidly changing densities in their range of measurement that the standard approach of using average transport properties such as pressure, temperature, specific gravity and compressibility to predict density becomes inaccurate. In these cases, the variations in properties must be measured and continuously used to calculate flow. An alternative would be to use a densitometer, which measures the density directly and integrates it into the flow reading to make the corrections as they occur. The use of these methods will become more attractive as we either desire more accuracy or have special problems to solve. You are referenced to other talks that will be given at this school for details of these units.

Manufacturing

In the making of orifice metering equipment to AGA-3 requirements, we find the problems of the past being complicated by the sizes and pressure ratings that are now being required. In the past the majority of meter tubes for custody transfer were in the 16" and smaller sizes. For 10" and smaller meter runs special tubing was available with close control on the internal diameter and the finish of the tubing. This made it possible to obtain good pipe for the manufacture of meter tubes. A number of companies have increased the pressure rating requirements on their meter stations to meet more stringent safety and governmental requirements. Likewise, higher-pressure pipelines are planned, with the Alaskan Gas Project as a case in point, which will operate at over 1600 psig. These requirements create problems of getting good meter run piping, since in both cases the tubing cannot be used. Similarly, it is more difficult to get good plate from which orifice plates can be made in the thicker dimensions required in the larger plates. All of this is occurring as customers are tightening their requirements, sometimes below the requirements of AGA-3. We recently shipped our first 48" 600 lb. ANSI Senior orifice fitting, which is another example of the requirement for larger orifice devices, but this took considerable time to deliver and was not inexpensive.

Because of the high cost of labor, we are also noting an upswing in the orders for fabricated stations that are skid mounted and shipped complete with instrumentation and controls. These only require the adjacent piping to be attached in the field before operations begin. This trend will continue as we see more use of complex electronic equipment and controls as part of the meter station. This is also being prompted by customer demands to purchase measurement from a single vendor who will take sole responsibility for the fabrication, installation and initial operation of the metering system.

Special Application Requirements

The AGA-3 report is in English units and will remain so for the next few years by my estimation. In the United States, we do not have the requirement as they have in Canada to go to metric, or, more correctly, International System of Units (SI). There is still an argument in the United States of which units will be adopted and what their correct values are. It is the feeling of the combined AGA-API committee responsible for this conversion that considerable work will be involved and an outside contractor will be required, since the conversion will not be simply substituting one unit for another. There are basic redefinition's that will have to be made. The recommendation in the meantime is to make the measurements and calculations in customary English units and convert the final answer to the desired units. A related part of AGA work will be the redefining of the NX-19 (super-compressibility factors) to reflect an Fpv factor of 1.0000 at absolute pressure of zero rather than at zero gauge pressure and to extend the range of the tables. This work is in the process of being funded and begun.

It is the intention to publish the results of this work in a report as an alternate to the present table. This work will be coordinated with AGA-3 revision since super-compressibility gets into the definition of base conditions and of specific gravity as presently used in AGA-3.

AGA-3 has become an American National Standards Institute standard ANSI/API 2530 with its publication in 1978. The basic document is the same, but it has been reprinted with the introductory paragraph change to reflect that it is now a standard and not just a committee report as it was in the past. This gives the report additional legal standing.

In passing, it may be of interest to those of you that are familiar with another publication of the AGA Transmission Measurement Committee, The Gas Measurement Manual, that this is progressing and shortly Chapters 1 through 11A will be available. The original intention was to put this out as a complete reference, but because of the problems of getting all of the chapters ready at once the decision was made to publish each chapter as a separate entity. These can be added to a loose leaf binder so that eventually you could purchase all chapters and have a complete book. This also eases the job of updating the work. For those of you who are not familiar with this manual, it is a detailed write-up of all aspects of gas measurement (i.e., primary elements, secondary elements, station design, auxiliary equipment, testing procedures, etc.) that are not covered in the basic standard and yet are required to obtain proper measurement. The new book is being written by a combined committee of the Transmission and Distribution Measurement Committees of the AGA and will cover both areas of measurement—transmission and distribution.

There is one special application of an orifice meter that may be of interest in that it represents a blending of the technology of the liquid and gas measurement people. Tests are being run on orifice and turbine meters tested in place with a mechanical displacement prover. The particular purpose is to try to improve the accuracy of a meter system to a few tenths of a percent in a critical measurement application on ethylene, which is roughly five times as expensive as natural gas. The philosophy is that there is enough money involved so that an in-place throughput test against a known standard (the volume of the prover) is justifiable. The meter, then, would have a factor applied as indicated by the test. The significance of the test is that it breaks away from the philosophy that, if mechanical requirements are met, then the orifice meter is accurate. It gets into factoring a meter to a standard that has been used for years by the liquid measurement people. The facility is by no means inexpensive, but it will be interesting to watch the results since it would afford an in-place throughput test that could define errors that might not be known otherwise. It bears watching, and within the next year or so there should be test results published in industry publications and papers presented at meter schools on the subject. Whether it affects AGA-3 or not, it may affect testing procedures for gas meters.

Conclusion

In summary, there is continued work being done to further improve the ability to get accurate measurement in the following areas: basic test work, data handling, manufacturing and special applications. The overall goal is to develop an orifice meter installation that will provide for measurement within a precision limit of plus or minus 0.2%. suitable for computer application. The milestones or objectives that must be achieved in attainment of this goal include:

1. Re-derivation of the basic coefficient (present work).

2. Redefining super-compressibility, including both basic structures add general expansion.
3. Redefinition of expansion factor.
4. Interference studies to determine tube configuration and the impact of both interference and correcting devices.
5. Mathematical interpretation.
6. Industry acceptance and revision of AGA-3.

This work is in various degrees of completion and will be affecting the manner in which the standards are revised and the way we apply orifice meters. We should stay aware of the work as it is completed to be able to plan on its implementation to our use of orifice meters.