Introduction:
The American Petroleum Institute (API) Manual of Petroleum Measurement Standards (MPMS), Chapter 14.3 is a living document, constantly reviewed and reconsidered for revision as new information and research data become available relative to the design and operation of orifice metering systems. In spite of this scrutiny within the API, the American Gas Association (AGA), and the International Standards organization (ISO), the latest recommendations and revisions are not well known in many areas of our industry. Many companies are still designing to AGA 3 1985 standards.

In the broadest sense, the most recent major revisions were made in 1992 and 2000. In 1992, in API Chapter 14.3, Part 1, the Reader-Harris Gallaher (RHG) equation replaced the Buckingham equation. The newer equation produces more accurate discharge coefficients (and volumes) relative to the old Buckingham equation, since it is based on a greatly extended research database. The impact of the new equation is small at typical interstate pipeline operating conditions, typically less than 0.25%, but for rich gases at low pressure and high differentials, the differences may exceed 1%. The RHG equation is an iterative equation, requiring more microprocessor capability than the simple algebraic solution of the original Buckingham equation which had been in use since the 1930s. This required many microprocessors to be upgraded, at considerable expense, once the new equation was introduced. In my opinion, it is unfortunate that the Buckingham equation was not modified to give improved discharge coefficients in its more user-friendly format, but that is water under the bridge. Note that the simple factored approach, so popular with operating personnel, is no longer the standard, but it is still available for closely estimating volumes (see API MPMS, Chapter 14.3, Part 1, Appendix 1-B).

The second fundamental change, in the 2000 revision, was the general recommendation in API Chapter 14.3 Part 2 that flow conditioning should be provided in all upstream sections of orifice metering systems used in custody transfer applications. Besides this general recommendation, Part 2 now includes tables showing a dramatic increase in the recommended upstream run lengths when no flow conditioner is utilized (contrary to the basic recommendation) or when the 19 tube, concentric tube bundle is used. As examples, in the catch-all category for runs without flow conditioning, the old standard (prior to 2000) recommended maximum upstream run lengths of 44D (where D is the measured internal diameter of the run). The new recommended length would be 145D (see Table 2-7), more than three times as long as the old recommended length. Such excessive lengths are not practical or cost effective, particularly in offshore applications where deck space is so expensive and especially when newer types of flow conditioners meeting API recommendations may require only 13D of upstream length. Most of the new designs incorporate a perforated plate flow conditioner, but not all.

Discussion of Flow Conditioning:
It is critical to understand the importance of good flow conditioning to accurate orifice measurement. Recent research re-emphasizes that swirling flow or poorly developed flow profiles have major impacts on orifice metering system performance. The wealth of new data allows reasonably good estimates of errors expected in systems with varying piping configurations if they do not have adequate flow conditioning. If an orifice metering system is
installed downstream of a header, for example, it is likely that the flow exiting the header on the way to the meter run inlet is swirling at angles greater than 2 degrees (the maximum acceptable swirl angle). In this case, without adequate flow conditioning, the indicated volume from the metering system will be too low. As swirl angles increase, the errors increase, and may exceed 7% of the actual flow. Two elbows, out of plane with one another and in close proximity to one another, are another source of severe swirl.

In the presence of a poor flow profile (when flowing velocities are not uniformly distributed across the cross-section of the inlet run), the indicated flow rates will exceed the actual. Depending on the severity of the poor profile, errors may exceed 2% of flow.

Note that many metering systems have both poor flow profiles and high swirl angles in the flowing stream. In these instances, it takes a great deal of experience to estimate the net impact on the indicated volumes.

**New Flow Conditioning Technology:**

Some manufacturers have developed and adequately tested new flow conditioner designs. This means they have compared the performance of their flow conditioning system to the performance of the 19 tube concentric bundle conditioner defined in API Chapter 14.3 part 2 using the API Test Protocol, and their system performed as well as, or better than, the tube bundle over a range of specified test conditions. Beware that some manufacturers are selling new designs or different models in their product line that have not been fully evaluated, so ask to see the data and make the comparisons yourself. Note that the tests must be performed at an independent, NIST or equivalent traceable facility.

Many other less dramatic changes have been implemented in Part 2, and others are under consideration at this time.

**Other Significant Changes in Part 2:**

The internal roughness criterion for meter tubes has been modified. For runs 12” and below, the criteria is more demanding than for 14” and larger diameter runs. This reflects the fact that as the distance between the interior wall of the meter run and the nearest edge of the orifice plate bore increases, the relative roughness of the pipe becomes less critical. In the field, during internal meter run inspections, the internal run must be free of significant rust, scale, pitting, unfinished welds, unnecessary gaps and contaminant build-ups, but, on the other hand, most commercial grade pipe in good condition will meet industry standards, which are defined in micro-inches of roughness. Comparators and profilometers are available if exact determinations of roughness are required. Remember that the most severe requirements are for small runs, such as 2 or 3 inch runs with high beta ratios, where even small imperfections in the internal run may produce detectible errors in measurement.

Another change involves orifice plate thickness for 8” meter runs. Prior to 2000, the recommended plate thickness for 8” orifice meter runs was 1/8”. This caused a restriction of the operating differential pressure range for 8” runs since the thin plate could not withstand high differentials without bending and producing an unpredictable shift in the discharge coefficient. Now that the recommended thickness is ¼”, the 150” differential restriction has been eliminated for 8” runs.

In the latest revision, higher differentials are allowed than ever before. In the latest revision of part 2, up to 1000 inches of differential is allowed. In the past, most companies allowed 250” or less. Many continue that policy today. Actually operating at differentials up to 1000” is not necessarily a smart thing to do, and the standard cautions that very high differential pressures may cause operating problems due to the Joule-Thompson cooling of the stream as the pressure is suddenly reduced as it passes thru the orifice bore (creating an increased potential for liquid, hydrate or ice formation in unprocessed and/or wet gas streams). Also, a significant percentage of the differential pressure thru the orifice meter will be a permanent pressure loss in the line. If a compressor station is required to boost line pressures, it’s counter-productive to immediately give up high pressure losses thru the metering system. It’s a waste of horsepower and fuel.
The latest version of the standard better defines the maximum allowable pulsation levels that may be present in custody transfer measurement systems. It also allows estimates of metering errors in the presence of higher levels of pulsation.

**Changes Being Considered for Part 2:**

It is too early to define pending changes very well, but one that has created a great deal of concern for me is a recommendation that single point verifications for static, differential and temperature transducers are adequate for verifying the overall performance of the transducers. While it may be arguable that this is true for state of the art transducers, many transducers in the field are over 20 years old and/or not state of the art technology – and single point verifications are certainly not adequate.

**Conclusions:**

In order to produce accurate measurement using an orifice metering system, flow conditioning must be adequate to reduce swirl angles and non-uniform flow profiles to acceptable levels. In addition, the internal condition of the system must meet standard requirements and be relatively free of rust, scale, pitting, hydrates, ice, gaps, protrusions, and contaminants in the run or on the orifice plate itself. Compliance with the latest revision of API Chapter 14.3 will insure very good measurement performance which meets custody transfer recommendations.

Finally, even though the standard continues to improve, the design and operation of systems in the field continue to have many deficiencies. I have listed some of the most common deficiencies I find during facility reviews below.

**Common Orifice Metering Deficiencies:**

1. No flow conditioner – may produce positive or negative bias, depending on whether the flowing stream exhibits a poor flow profile or swirl angles greater than 2 degrees.

2. Upstream run lengths that are too short – may produce poorly conditioned flow and either a positive or a negative bias, depending on the relative impact of the poor flow profile vs. swirl.

3. Sampling systems that are not equipped with a sample probe – tend to increase the indicated Btu content whenever the stream's actual Btu content exceeds about 1,045 Btu/cubic foot.

4. Sampling systems that are not flow proportional tend to reduce the accuracy of physical property determinations and measurement accuracy. The error may be positive or negative, depending on the direction of the error (increase in uncertainty, not bias).

5. Liquids in the meter run – relatively small amounts of liquids in a natural gas orifice metering system will tend to dam up against the orifice plate and modify the flow pattern thru the plate enough to produce a distinctive negative bias. If large quantities of liquids are available, this may be reversed and the gas meter will over-estimate the throughput.

6. Rich or wet gas sampling systems that are not heat traced or insulated show a very strong seasonal pattern of over-stating Btu contents, especially during cold months. Cold ambient conditions produce condensation from the gas stream to occur in the sample lines and exposed equipment. These liquids will saturate the sampling system and carry over into spot or composite samples.

7. Poor audit trails due to missing data, unavailable configuration information and/or the ability to make changes to critical measurement inputs without the audit trail clearly identifying that a change was made, time and date stamping it, and recording of both the new and old values for the parameter.

8. Pulsation thru orifice meter runs tends to cause chart recorders to over-indicate flow rates dramatically. For systems equipped with flow computers, heavy pulsation will just insure that the indicated quantity is wrong, but not necessarily high or low. Uncertainty increases dramatically, but not necessarily the bias.

9. Incorrect verification or calibration procedures or equipment – or using test equipment that is not properly certified.