In-Situ Testing of Gas Orifice Meters

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Overview

- Why do we do *in-situ* testing
- Test Equipment
- Design Considerations
- Summary

Elements of a *Differential Producer*

- Primary Element--mostly steel; subjected to pressure, temperature, and flow velocity, but no electronics
- Sensing Element--electronics and exotic metals; subjected to pressure and temperature, but not flow; generates electronic signals or pen movements.
- Recording Element--Electronics or pen & ink; only sees electronic signals or pen movements
- Differential Producers are *Inferential Devices*
  - Assuming **all conditions match reference conditions** you can use *Bernoulli's Equation* to infer a flow rate from a differential pressure across a known restriction

Assumptions in Calculations

- Constant density at each snapshot
- No friction
- Tube is straight and level
- Gas does no work
- Flow profile matches power law
- Single phase flow
- Atmospheric pressure known precisely
- Fluid properties known and constant for each snapshot
- Enough friction to dampen swirl
- Press and Temp known
- Tube roughness in narrow range
- Plate condition meets specs
- Plate bore concentric to tube bore

Measurement *System Accuracy*

- Each element of a measurement system is:
  - manufactured to close tolerances
  - inspected by the manufacturer and purchaser
  - installed to precise specifications
- After all that, what can still be wrong?

What can be wrong with a new installation?

- Flow profile
- Backwards plate
- Beta Ratio
- Incorrect station parameters
- Non-rigid mounting

Flow Profile

- Problem
  - 25% of flow not in center 20% of pipe
  - Error can be low by 5% or more
- How to prevent it
  - Upstream piping
  - Flow Conditioners and/or Straightening vanes
- How to detect it
  - *In Situ* Testing

Backwards Plate

- Problem
  - Leading edge shaped like a venturi
  - Reading can be as much as 26% low
- How to prevent it
  - Attention to details
- How to detect it
  - *In Situ* testing

Beta Ratio

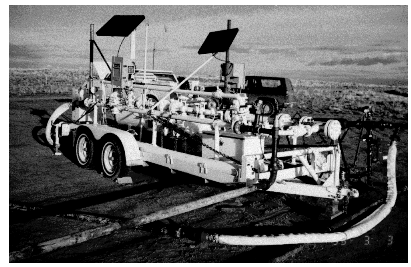
- Problem:
  - Uncertainty in gas measurement is controlled to a large extent by beta ratio
    - » Less than 0.3, uncertainty is a function of edge sharpness and concentricity
    - » Greater than about 0.62, it increases very quickly
  - Combined error can be 7%
- How do you prevent it
  - Proper station design
- How do you detect how “uncertainty” equates to “error”
  - *In Situ* Testing

Incorrect station parameters

- Problem
  - Any of the parameters from gas analysis to Tube ID will affect the conversion of dP, P, and T to flow rate
  - Combined error can be over 10%
- What can you do to prevent errors
  - Double check original input (two people)
- What can you do to detect errors
  - Verify all parameters each calibration
  - *In Situ* Testing

Non-Rigid Mounting

- Problem
  - The gas does work (reducing dP)
  - up to 15% error
- How to prevent
  - Independent braces
  - Use hold-down bolts
- How to detect
  - Inspection after installation
  - *In-Situ* testing



Installation Verification

- To insure that a new station meets its potential:
  - Install all the parts at their final location
  - Use “normal” gas at “normal” temperature and pressure
  - Design a test manifold that ensures that all gas goes through the test skid after the new station
  - Use a certified test skid

When to Test

- As part of station commissioning process
- Regularly on very large volume stations
- Regularly on particularly erosive/corrosive or dirty applications
- When routine plate inspections point to a problem

Test Equipment

- Uncertainty
- Calibrated Differential Producer
- Proportional devices with provers
  - Turbine meters
  - Vortex-shedding meters
- Inferential vs. Proportional devices
- Calibration methods

Uncertainty

- Uncertainty means “you don’t know”
- No conclusions can be drawn from data beyond the uncertainty range, for example:
  - If a calibration device is stated to be ±0.5%
  - Your tested device is off by 0.6%
  - Actual results are 0.1-1.1% and the meter has a bias high
- Consequently:
  - a calibration device can only certify a calibrated device to within twice its uncertainty (i.e., a 0.25% device must be used to calibrate a 0.5% device)
  - Midpoint of a confidence range must fall within the dead-zone around zero (i.e., the center of a 90% confidence range from a 0.5% skid must be in the range -0.5-0.5%)

Calibrated Differential Producer Skid

- As long as:
  - The test manifold has positive isolation between inlet and outlet
  - Sensing elements on test skid are calibrated before every test
  - Orifice plates on test skid are inspected before and after every test
  - Tube on test skid is inspected quarterly
  - Recording elements are verified against a calculation standard frequently
  - The skid is certified against a primary standard annually to be within ±0.5%
- A properly designed Differential Producer Skid can be used to certify a station is ±1.0%

Proportional Devices

- All have some moving part that is proportional to mass flow rate (motion can be gross like a turbine rotor or microscopic like the vibration frequency of a vortex)
- They are all prone to:
  - Foul in dirty fluid (20 mils of paraffin on a turbine blade caused the reading to be 2% low in one test against a primary standard)
  - Have bearing or vibration-sensor wear that is not obvious on recording element
- A Proportional Skid must be calibrated against a primary standard before and after each station test

Inferential vs. Proportional

Inferential

- Pros
  - No moving parts
  - Well understood in field
  - Very rugged
  - Useable in dirtier fluids
- Cons
  - Narrow rangability
  - “Flow” measurement unrelated to fluid density

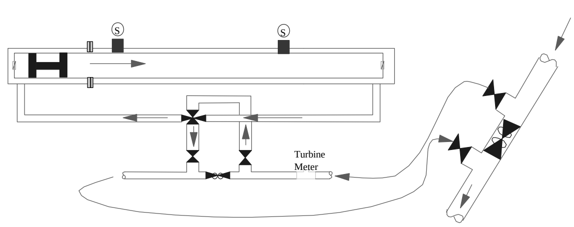
Proportional

- Pros
  - Good rangability
  - Flow measurement is directly related to mass flow rate
- Cons
  - Moving parts prone to fouling and wear
  - Must be recalibrated before and after each use
  - Should not be used with dirty fluids

Calibration Methods

- Piston Prover
- Sonic nozzle
- Primary standards not discussed in this paper:
  - Weigh tanks
  - High pressure Bell Prover

Piston Prover



- Piston used to quickly develop “k-factor” for turbine meter
- Turbine meter is used to prove station being tested
- After test, turbine can be re-proven

Piston Prover Design Considerations

- Piston run times related to flow by:
  - Precise displacement volume
  - Exact duration of travel between detector switches
  - Exact count of piston round trips
- Obstacles to use in gas
  - No U.S. standards exist for piston provers in compressible flow (some European countries have adopted procedures and ISO is evaluating)
  - Gas pressure must increase to overcome piston inertia
  - Fairly small volume capacity
- Techniques to overcome obstacles
  - New correlations based on equations of state
  - Bi-directional pistons
  - Fast-acting, electronically operated diverter valves
  - Acceleration/deceleration regions before/after measured volume
  - Use Piston to prove turbine and turbine to prove installed station

Sonic Nozzle

- Under most conditions, a compressible fluid is limited to speeds less than or equal to the speed of sound
- Sonic (or Critical Flow) nozzles use a substantial pressure drop to force the gas to the speed of sound
  - With an open-ended pipe sonic velocity is reached when downstream pressure (psia) is less than 1/2 upstream pressure
  - Properly designed convergent/divergent nozzles can reduce this to about 20% pressure drop
- With careful measurement of upstream pressure, temperature, and gas composition; very accurate (about ±0.25%) mass flow measurement is possible so volumes can be accurately determined

Sonic Nozzle Limitations

- They require a large differential pressure, so:
  - It can be difficult to get the gas back into the line
  - If hydrocarbon gas is discharged to atmosphere, care must be taken to avoid an explosive atmosphere
  - Liquids can drop out of gas
  - Temperature drop can cause hydrates to freeze
- They are not effective in multi-phase flow
- Calculations require careful evaluation of:
  - Atmospheric pressure
  - Upstream temperature and pressure
  - Density
  - Compressibility

Sonic Nozzle Use in *In-Situ* Testing

- Considerations
  - Use dry air or non-flammable gas as test fluid
  - Ensure that operating personnel are careful, competent, and observant
  - Verify that atmospheric pressure and gas composition are the same in EFM unit as in test-facility computer
  - Verify that EFM unit uses the same Temp and Pressure base as the test facility
  - Verify that EFM unit uses the same compressibility calculation as test facility
- With proper diligence, a sonic nozzle can be used to certify that the differential producers on a test skid are accurate to ±0.5% of volumetric flow rate

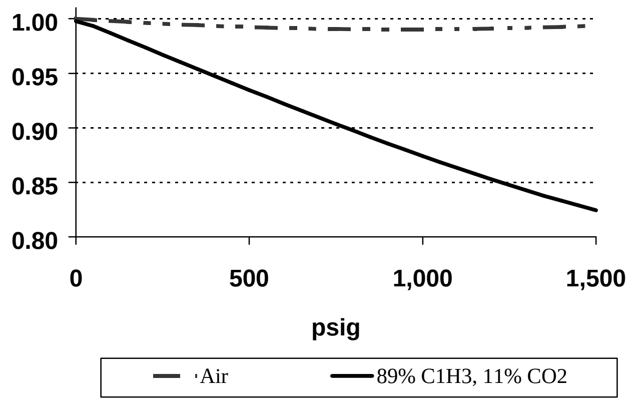
Test Skid Design Considerations

- Flow conditioning
- Capacity and Rangeability
- Operating pressures and temperatures
- Flexibility
- Data Capture
- Transportability

Why do we need Flow Conditioning?

- Any device used on a test skid will be sensitive to flow profile problems
- Confined-space piping on test skid will contribute to poor flow profiles
- Swirl and asymmetry cause flow-rate errors that are related to compressibility and density
- Flow conditioners with straightening vanes are required to get repeatable results that can be transferred from one type of gas to another

Changes in Compressibility



Capacity and Rangeability

- Skid capacity should be
  - Large enough to handle max expected volume
  - Small enough to be within design conditions for min volume
  - Appropriate to keep sensing elements within 10-90% of calibrated range
- Example
  - A differential producer has a range of about 6:1 (assuming arbitrary limitations on beta-ratio of 0.3-0.6 and dP of 45-105")
  - A skid with one 3-inch and one 6-inch tube (and the piping to run them in parallel) has a range of almost 39:1 (with the same limitations)

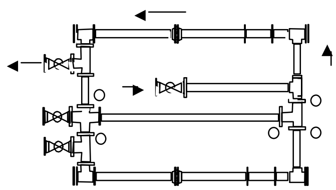
Operating Pressures & Temperatures

- The test skid (excluding hoses) should be designed to handle 150% of design pressure on highest design-pressure station in the operation
- Increase hydrostatic test pressure to compensate for the lowest ambient temperature expected
- Hoses should be:
  - Designed for most-likely pressures and temperatures
  - Labeled with MAOP
  - Tested to 150% of MAOP annually (hold test for 24 hours)

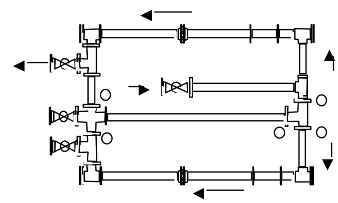
Flexibility

- The test skid should be able to:
  - Use one meter to evaluate one stream
  - Use some combination of skid meters in parallel for larger streams
  - Simultaneously evaluate multiple flow streams
  - Re-measure a given stream multiple times
- Possible reasons to re-measure
  - Compare one meter to another to quickly evaluate “calibration”
  - Evaluate impact of damaged plates
- Streams must be positively isolated from each other
  - Double-Block-and-Bleed valves
  - Spectacle blinds

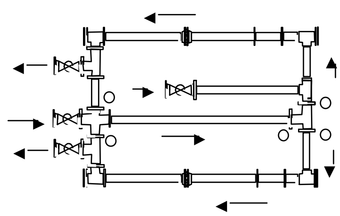
Flexible Flow



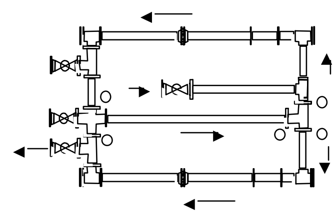
Normal Flow



Parallel Flow



2-Stream



Serial Flow

Data Capture

- Types of data
  - Prover reports
  - Flow Parameter reports
  - Volume reports
- Data should be available on both paper and ASCII files
- Data should be able to accumulate/summarize data over flexible time frames
- For each time frame, capture at least:
  - Cumulative volume for period
  - Average flow rate during period
  - Instantaneous flow rate at end of period
  - Average and snapshot temperature, dP, and static pressure for each calc

Data Analysis

- At least 30 time periods must be used, any number greater than 30 is acceptable
- It is better to use cumulative gas for each time period than to use flow rates
- Calculate:

$$\text{Error} = \frac{\sum \text{Skid Volume} - \sum \text{Station Volume}}{\sum \text{Skid Volume}} \times 100$$

  - Total error should be less than 1%
  - Error for individual time periods should be computed and checked for:
    - » Standard deviation of errors
    - » Mean error
    - » Count of periods above and below zero (worse than 60-40% distribution indicates a bias when n>30)

$$90\%\text{Confidence} = \frac{1.65 \times \text{Standard Deviation}}{\sqrt{\text{Sample Count}}} = \text{CONFIDENCE}(0.10, \text{Std Dev}, n)$$

Data Analysis Example

	Acceptable Range	Meter 1	Meter 2
Total Error	-1% to 1%	-0.88%	-0.32%
Mean Error		-0.99%	-0.07%
Std Deviation		0.58%	0.42%
90% confidence	-1% to 1%	-1.10% to -0.88%	-0.15% to 0.0%
Count < 0	32-48	75	44
Count > 0	32-48	5	36
Conclusion		Bias low	Accurate Meas

- Notes:
  - Total error and mean error values -0.5 to 0.5% mean “accurate values” no conclusions can be drawn about where a number falls in that range
  - Midpoint of 90% confidence range must fall between -0.5 to 0.5% on passing tests
  - Rule of thumb count range
    - » 30 <n<100 ==> acceptable range = 0.4n to 0.6n
    - » n>100 ==> acceptable range =0.45n to 0.55 n

Transportability

- Considerations
  - Weight
  - Width (limited to about 8-feet)
  - Fitting all piping/equipment onto skid
- Non-negotiable items
  - Isolation between streams must be positive (either block and bleed or spectacle blinds)
  - Differential producers must have dual-chamber fittings
  - Flow profile-isolating conditioner must be installed upstream of each station

Transportability Options

- Truck Mounting
  - Larger weight-carrying capacity
  - Considerable flexibility in skid size
  - Leveling can be tricky
  - Transportation for driver can be a problem after hook-up
  - Bed height can be a problem with operations personnel
- Trailer mounting
  - Many weight/size compromises needed
  - Axles and tongue (or 5th wheel) need to be matched to weight
  - Less expensive than truck-mounted
- Cargo
  - Least expensive
  - Least convenient for moving

Summary

- *In-Situ* testing is both necessary and practical
- It ensures
  - The measurement system works together
  - Large stations continue to work
  - Stations in dirty/corrosive/erosive streams continue to work
- Skid certification:
  - Proportional skids should have a built-in prover
  - Differential-producer skids should be calibrated periodically
- The skid must be designed to
  - be transported, leveled, and connected to the process gas
  - allow a wide variety of flows
  - work with expected fluid pressures, temperatures, and fluid qualities
  - capture data consistent with installed equipment