

Achieving Better Liquid Measurement Accuracy Using a Slightly Different Perspective

Custody Transfer Measurement in the oil and gas business has been described many ways. It has been called “An accuracy in measurement, that both the buyers and sellers can agree upon,” or “The best that can be achieved to meet the contract conditions.” But I like to call it “The Search for the Truth.”

Ever since petroleum has been bought and sold, people have searched for better ways to measure on the fly with better accuracies. A big advancement was the pipe prover. API requires an accuracy of the prover volume of 0.02% when compared to a standard such as NIST traceable Seraphin Cans. If we want to put 0.02% into perspective that is 6.45 teaspoons or a little more than 2 tablespoons of oil in one 42-gallon barrel. That is very good measurement and that is worse case. That is why we all strive to exceed the 0.02% required by API. We know and understand the value increased accuracy has to our companies.

Accuracy of measurement is important when oil is selling at \$100 per barrel and profits are good, but it is even more important when oil is at \$50 per barrel and the margins are tight. One lost barrel becomes a much larger percentage of the profit.

Different Perspective

Many times when we are trying to solve a problem we are burdened by company and industry standards and the historical, “This is how we have always done it.” But sometimes when we are faced with a problem it needs to be solved outside these conventions, “Necessity becomes the Mother of invention.” This is what is happening with Bi-Directional Pipe Provers. We found that by making the calibrated straight, tipping the horizontal launchers, sizing the launchers properly and placing the pressure and temperature transmitters correctly we are able to improve the bi-directional pipe prover.

Transmitter placement

Process conditions for both the Pressure and Temperature Transmitters

Are pressure and temperature transmitters really needed on the inlet and outlet of a prover?

We used the following fairly typical flow conditions

Flowrate (Q) = 2,000 Barrels Per Hour

Specific Gravity (S) = 0.88

Viscosity (μ) = 10cP

Process temperature 70 degrees F

Ambient temperature 90 degrees F

The Velocity through an 8 inch ID line at the above conditions is 8.9 feet per second

From a PT manufacturers data sheet we have the following

Pressure Transmitter Data

$\pm 0.15\%$ of Span

Span: 100 psi

$100 * 0.003 = 0.3$ PSI Worst Case Error per Transmitter

From a Pressure Drop calculation

It would take 25 ft. of pipe at full flow to cause a pressure drop of 0.3 psi.

Would it be advisable to use two transmitters if the distance of the pipe between the transmitters is less than 25 feet?

Temperature Transmitter Data

- 0.02% of Span

- Normal Span: -50 deg. F to 200 degF = 250 F

- Worst Case Error: 0.145 deg. C or 0.26 deg F

Worse case would be 0.52 deg F if one transmitter reads high and the other low but in this case we will split the error as above on the PT and use an error in transmitters of 0.26 deg F. There are of course other variables such as wind and radiant heat from the sun.. But under the above conditions it would take over 200 ft. of pipe to cause a temperature drop of 0.26 deg. F. Would it be advisable to use two transmitters if the distance of the pipe between the transmitters is less than say 100 ft.?



The effect of radiant heat from the sun can be minimized with the use of a sun shade over the metering equipment. Insulation works also but insulation works both ways, it can reduce the effect of radiant heat but it also traps heat as the equipment and process are trying to stabilize.

Compression during proving

If the prover is a long distance from the meter, take into account the compressibility of the fluid and the stretch of the metal in the pipe between the meter and prover due to pressure. This includes the meter run and prover piping so the volume can get quite large. In any distance but especially in the longer distances the fluid can compress as the prover sphere goes around an elbow or through a smaller flange opening, and then decompress as the sphere reaches the detector. The effect is similar to what happens if air is trapped in the meter or prover piping. We know pressure has an effect on the metal and the fluid and we correct for it.

For example if the elbow or flange causes a pressure change in (1) one psi.

5 Correction for the effect of Pressure on the Steel in the Prover

(Cpsp) Correction for the Pressure in the Steel of a prover including the piping.

$$C_{psp} = 1 + (P_p \times D) / (E \times t)$$

P_p = Rounded average pressure in prover in PSIG. 1

D = Internal diameter of the prover pipe, in inches (outside diameter minus twice the wall thickness. Average ID 8

E = Modulus of elasticity ($E = 30,000,000$ for mild steel, $E = 28,500,000$ (for stainless steel)

t = Wall thickness of the prover pipe in inches. 0.375

Length of pipe 60 ft = a volume of 157 gallons

$$(1 + ((1 \times 8) \text{ divided by } 30,000,000)) \times 60$$

$$1.0000003 \times 60 = 60.000016 \text{ or an increase in volume of } 0.000016 \text{ Gallon}$$

Correction for the effect of the Pressure on the Liquid in the Prover

Correction for the Pressure on the Liquid in the Prover = $1 / [1 - (P_p \times F)]$

P_p = Rounded average pressure in the prover in PSIG **One**

F = Compressibility factor for hydrocarbons. Actual F values should be determined for each meter installation. If actual values are unknown, refer to tables in API Chapter 11.2. = $1 / [1 - (1 \times 0.000045)]$

Length of pipe 60 ft = a volume of 157 gallons

$$1 - 0.000045 = 0.999955 \times 157 \text{ gallons} = 156.9992935$$

157 – 156.9992935 = 0.0007 gallon or .5376 teaspoon

Different fluids have a larger or less compressibility but it does have an effect. This is also on 100% stable crude. Who has that?? The shorter the distance between the meter and the prover the better.

Trivia

API recommends that during a water draw using a Seraphin Can or cans the prover must repeat in volume to within 0.02%. That is 0.0002 or a little more than two tablespoons of fluid in one 42 gallon barrel. That is very good repeatability. But new Bi Directional provers have achieved consistent water draw repeatabilities of better than 0.005%. That is 1/2 of a tablespoon of fluid in one 42-gallon barrel. In many cases repeatabilities of 0.001% have been obtained.

Economically a loss of 0.02% on a 10,000 bpd metering system is two barrels per day. At the price of oil today, \$100 per barrel, that is \$200 per day. In one year's time that is \$73,000. If that repeatability error could be cut to 0.002% the error would be \$7,300. It is obvious more accurate measurement reduces monetary losses.

If the losses are in the favor of the seller, the buyer may in the future discover and prove the overbilling and collect from the seller. If the loss above is found ten years from the date of the contract the owed amount would be \$730,000. And if the loss is in the favor of the buyer that amount could be hard to collect.

Fortunately meter technology is improving and new, more accurate meters are coming to market. It makes sense then to build a better, more accurate device to prove these meters.

To do this we need to look at all the components of a Bi-Directional Prover and how we can improve on them.

On a Bi-Directional Prover, the prover barrel, the detector switches, the prover sphere, the launching chambers, the closures, the reliability, the maintenance, the environment, and the safety can all be improved upon.

Length of Pre-run

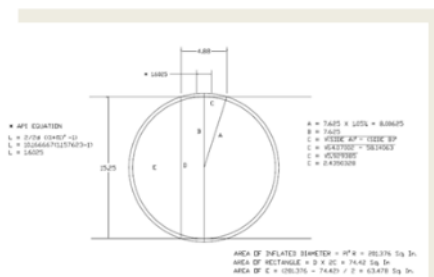
API recommends the length of the pre-run of the prover to be one half the cycle time of the 4-way valve, times the velocity of the sphere, times a safety factor of 1.25 ft. But the sphere does not have the same velocity from the beginning to the end of the 4-way cycle. The sphere comes to a complete stop when the 4-way is open and remains stopped as the valve changes direction. Therefore there is an average velocity from stop to full flow in each direction plus the time when the 4-way is full open and the sphere does not move at all. Unfortunately these flows and no flows are not published information from the 4-way manufacturer. If this information was available both money and space could be saved using a shorter pre-run.

Detector Switches

There are several manufacturers of sphere detector switches. All are very good. The API document Manual of Petroleum Standards Chapter 4-Proving Systems Section 2 – Displacement Provers Appendix A – Analysis of sphere position repeatability gives a mathematical explanation of sphere position repeatability. Naturally the rounder the ball the more precise the detector contact will be. Detector switches are normally repeatable to within 0.002 inch. However the repeatability of switch and the required volume are not the only things that affect the volume of the calibrated section.

Prover Sphere

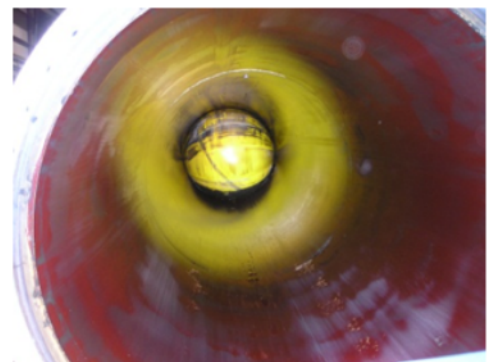
Reducing Pipe Contact



By reducing the inflation on the sphere the spheres will be rounder, last longer and the prover does not have to be opened to replace or check the sphere as often. Building the launchers so the spheres are not damaged when they enter the launchers also reduces the amount of times the prover needs to be opened to replace a damaged sphere. The internal pressure on a 30-inch sphere with 3% inflation has an internal pressure of 80 psi, 6% inflation is almost 200 psi.

There are several very good prover ball sphere manufacturers. All make spheres suitable for Provers in custody transfer service. To optimize the life and condition

of the sphere as it comes in contact and trips the detector switch it must be selected and sized properly. Different materials such as Urethane and Polyurethane with Polyurethane are the most popular. The yellow prover ball with a hardness or durometer of 55 is well suited for crude oil and many refined products such as LPG and LNG. The Green sphere with a durometer of 65 is best suited for MTBE, Benzene and solvents. The red prover ball with a durometer of 75 is best suited for chemicals such as Toluene and Propylene. The Neoprene sphere is a softer general purpose sphere with it does not have the wear capabilities of Polyurethane. Spheres are also available impregnated with Teflon and other materials to give them less resistance to drag and make them move smoother when proving non lubricating fluids.



The less the sphere has to be inflated the less chance the sphere has to distort or wear as it moves through the pipe. And of course it causes less pressure drop. It takes approximately 80 psi to inflate a 30 inch sphere to 3% oversize. If the same sphere is inflated to 1% only 30 psi is required. Less pressure in the sphere means less stress on the ball and less friction as the sphere passes through the prover pipe. Friction between the sphere and the pipe causes wear. One percent over size gives over a 4-inch wide contact area on the pipe using a thirty inch sphere. Less inflation reduces the drag on the ball, so less pressure is required to move the ball in the pipe.

A four inch sealing area is more than enough to prevent any leakage around a thirty inch sphere as it moves through a pipe. The API method of calculating the contact of the sphere to the pipe based on inflation does not match with either an Autocad drawing or the basic triangulation method of determining the contact length. Experiments are being done to determine which is correct.

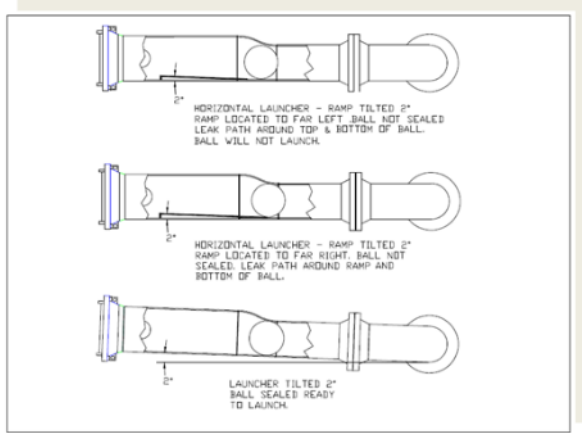
Better Reliability

Wear and tear on equipment is caused by the stress put on the equipment Less stress, less wear. Reducing the drag on the prover sphere as it moves through the prover reduces the wear on the ball and the coating inside the prover. That means longer ball life and longer prover barrel life requiring less maintenance and repair.

Sphere Storage

Store prover spheres correctly. Placing the sphere in a burlap bag and hanging it in a cool dry location is a good way to store the sphere. This prevents flat spots on the ball and damage that could occur if the spheres are stored on a warehouse shelf. The burlap distributes the weight of the sphere and keeps moisture away from the sphere. Spheres can also be placed in a bed of sand where the sand provides uniform support to the sphere.

Launching Chambers



Launching chambers can be either horizontal or vertical each has its advantages and disadvantages. A huge disadvantage of a horizontal launching chamber is the ramp in the Launchers to keep the sphere close to the prover pipe so it will launch. It also has to be perfectly horizontal so no air is trapped on one end of the launcher. And the prover has to be completely drained for sphere removal and maintenance. By tipping the entire launching chamber two degrees, the angle of a typical ramp, these disadvantages are avoided.

The launcher can be tipped where the launcher connects to the pre run or in some cases it can be tipped by rotating an elbow to any angle required. When the launcher is tipped no ramp to launch the sphere is required and the ball launches easily because both the reducer and launcher are tipped and the ball always comes to rest seated in the reducer to the calibrated



section. The vent for the blind flange side can be placed in the top of the blind where the flange opening contacts the flange. On the quick opening closure side some manufacturers can locate the vent of their closure at the tip of the closure. Where that cannot be done a vent can be placed as close as possible to where the closure is connected to the launcher and this vent can be internally piped to the highest point on the inside of the launcher.

Proper sizing of the launching chambers is critical. If the launcher is too small a diameter the sphere is carried along with the fluid as it moves rapidly in the launching chambers. The two pipe sizes larger rule of thumb works well on the smaller 6 in, 8 in and 10 inch launchers but not on larger sizes. What is interesting is at full flow on the smaller sizes where the velocity through the prover pipe is 5 ft/second the velocity of the liquid around the sphere in the launching chamber is also around 5 ft/second.

From experiments using clear pipe at WFMS we have found the sphere is not as aggressive at under 5 ft/second as it is if the velocity is over 5 ft/second. We have had no problems with sphere damage even on larger sizes following this 5 ft/sec of the liquid around the sphere rule. This can be adjusted for fluids having a higher viscosity.

Quick Opening Closures

Each different Quick Opening closure has its plusses and minuses. In any case the closure should have a safety that prevents the closure from opening when there is pressure in the launching chamber. If a closure is tipped more than five degrees there should be an equal angle at the closure connection to return the closure to a horizontal orientation. Launchers tipped over five degrees makes it difficult to replace the closure because they are designed for either vertical or horizontal applications.



Reducer on the Launchers

Installing reducers on the launchers where the piping from the 4-way is attached increases the pipe size into and out of the Launchers and lowers the pressure drop caused by the bars or other protection placed in the launchers to keep the ball from being pulled into the 4-way piping.



Straight Calibrated Section Prover

Several years ago finding good elbows to go in the calibrated section, especially in the larger sizes became difficult. To avoid this problem WMFS designed a prover with a straight calibrated section. We had no idea of how much the repeatability would improve or how it would lead to other improvements like no machined flanges, easier maintenance or being able to easily tip the launchers.

There are no alignment flanges in the calibrated Section. Alignment flanges are expensive and machining on the flange or installing pins reduce the integrity of the alignment flange and therefore

the piping system. Flanges in the pre-run are aligned using shoulder bolts that are approximately the same diameter as the flange bolt holes. Not having to cut or drill a flange is a safety improvement.

There are no elbows in the calibrated Section. Elbows cause a pressure and flow change as the ball moves through the elbow and there can be loss of fluid if the elbow is not perfectly formed in the inside diameter. Because the ball does not have to go through elbows as it passes from switch to switch less inflation of the ball is required making for better water draws and better proves with less pressure drop.

The calibrated section can be rolled out and inspected without another water draw because no flanges are broken in the calibrated section. This is a cost savings both in time and water draw cost.

It is ideal for Coriolis and ultrasonic liquid meters with manufactured pulses, because the flow before and in the calibrated section is not disrupted by the ball passing through elbows, welds or flange sets. And because the ball can be inflated less it passes smoothly between the detectors not disturbing the flow.

Since the flow through the calibrated section is smooth the pulses from conventional PD and turbines will be more evenly spaced giving better proves especially when pulse interpolation is used.

The sphere does not have to be over inflated to compensate for irregularities in elbows and flanges, The higher inflation of the sphere the higher the drag on the pipe walls increasing wear on the sphere and increasing pressure drop.

Water draw repeatabilities of 0.005% are common with the Straight Calibrated Section Prover. This of course also reduces overall uncertainty.

Proving of Manufactured pulse meters such as Coriolis and Ultrasonic

Coriolis and Ultrasonic Meters derive their measurement using either the Coriolis effect or the time to distance of an Ultrasonic signal. These measurement signals must be returned to pulses for volume proving applications. A bi-directional prover can measure using the mass output of the meter compared to the mass between the detector switches but a precise densitometer must be used to change the volume in the prover to mass. This is also complicated by the pressure and temperature change from the inlet to the outlet of the prover. These Manufactured pulse meters seem to be affected by even minute changes in flow rate. When the flow rate between the detector switches is constant much better repeatability can be achieved. Removing the elbows where the sphere must move through two different radiuses or radii with a skipping action will improve the proving repeatability on manufactured pulse meters. Eliminating welds and flanges where the IDs can be slightly different also improves the repeatability. These meters produce a reasonably uniform pulse stream as long as the flow rate is not quickly changed between the detector switches.



A comparison can be made between the cycle time of either the Coriolis or Ultrasonic and the length of the prover calibrated section. From experience we have found a minimum of ten seconds from switch to switch produces an acceptable repeatability that are in line with the API requirement of five round trips with less than 0.05% deviation between the round trips.

Electronics

Smarter meters, advanced electronics, more versatile flow computers, etc. have dramatically added to the information available to the measurement industry. We can trust these devices only if we can verify they are correct. Prove reports are seldom hand calculated anymore. They should be. The following pages outline the procedure to do this.

METER FACTOR CALCULATION SHEETS
METER FACTOR CALCULATION SHEET - 1 OF 3
 API Chapter 12, Section 2, Part 2, Second Edition, May 1995

A. GENERAL INFORMATION

Prover report number Batch

API Gravity Prover Pipe Size

Rate of Flow BBLS/Hr Prover Wall Thickness.....

Meter Number Liquid to be Proved.....

Meter Pulses per Barrel 8400 Station

Date Time

Operator Signature

B. DATA FROM PROVING RUNS

Run #	Temp. Deg. F Prover (Tp)	Meter (Tm)	Pressure PSIG Prover (Pp)	Meter (Pm)	Pulse Count Forward	Reverse	Round Trip
1	<u>90.6</u>	<u>91.3</u>	<u>36.6</u>	<u>48.1</u>	<u>12095</u>	<u>+</u> <u>12101</u>	<u>=</u> <u>24196</u>
2	<u>91.5</u>	<u>91.3</u>	<u>36.5</u>	<u>48.1</u>	<u>12092</u>	<u>+</u> <u>12101</u>	<u>=</u> <u>24193</u>
3	<u>91.6</u>	<u>91.2</u>	<u>36.6</u>	<u>48.1</u>	<u>12095</u>	<u>+</u> <u>12098</u>	<u>=</u> <u>24193</u>
4	<u>91.7</u>	<u>91.3</u>	<u>36.6</u>	<u>48.1</u>	<u>12095</u>	<u>+</u> <u>12101</u>	<u>=</u> <u>24196</u>
5	<u>91.7</u>	<u>91.3</u>	<u>36.6</u>	<u>48.1</u>	<u>12097</u>	<u>+</u> <u>12101</u>	<u>=</u> <u>24198</u>
6						<u>+</u>	<u>=</u>
7						<u>+</u>	<u>=</u>
8						<u>+</u>	<u>=</u>
9						<u>+</u>	<u>=</u>
10						<u>+</u>	<u>=</u>
AVGS.	<u>91.4</u>	<u>91.3</u>	<u>36.6</u>	<u>48.1</u>			<u>24195.2</u>

**1. AVGS
 ROUNDED**

91.4 91.3 36.6 48.1

24195.2

2. METER VOLUME = (Rounded Round Trip Pulse Count Average)
 (Meter Pulses Per Barrel)

2.= 24195.2/8400=2.88038

NOTES:

1. Average temperatures are rounded to the nearest half degree F.
2. Pressures are read to the nearest scale division.
3. Round Trip pulse count average is rounded to the nearest integer value.
4. Meter volume is reported in barrels rounded to three decimal places

