Executive Summary
Flow meter accuracy is right at the heart of the custody transfer process, which makes selection of the proving solution vital. Problems with some older solutions such as master meters and cans are well recognized. Others, particularly pipe provers, continue to be widely used.

While pipe provers are used in many applications without incident, contractors and systems integrators often ignore the potential for longer-term issues around maintenance, safety and repeatability. Over time these can make the provers an inefficient solution, and poorly adapted for changing process requirements.

At the same time, modern alternatives in the shape of small volume provers are field proven, being already widely used in offshore environments where a much smaller footprint and resistance to corrosion makes them an attractive solution.

However, the benefits of the solution are more broadly applicable, and across applications they may offer a safer, more flexible and efficient solution.

With contractors focused on up front costs, it is up to owners and operators to evaluate the benefits and weaknesses of each proving solution. If they do, they must question if pipe provers continue to be the most suitable answer for their plant, both now and for the future.
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Introduction
Flow meter accuracy is a central concern in the custody transfer process. As the cash register in fiscal accounting, ensuring and maintaining accurate measurements is essential for profitable, efficient operations, as well as fair transactions. The choice of proving solution to establish a meter’s accuracy is therefore important, and the global meter proving market may be worth as much as $180 to 200 million a year. Not all of that money is necessarily well spent.

Companies have a range of options – of varying quality. The weaknesses of some of these are increasingly recognized. Low costs for master meters, for example, are offset by recurrent uncertainty due to meter drift and errors that go undetected, as well as the need to calibrate with an approved technology. Likewise, cans, another low-cost solution and one offering good levels of accuracy, rely on a slow, labor-intensive process. The disadvantages of other methods, however, are less immediately obvious.

Ball or pipe provers, in particular, remain a popular choice, despite more modern, flexible and sophisticated alternatives. In part, that can be put down to habit on the part of both EPC contractors and the consultants drafting specifications or FEED studies for the end users. More significantly, contractors tend to focus on upfront costs, where ball provers can be competitive. Other costs may only become apparent in the long-term.

However, their use also reflects that ball provers are a field-proven and often successful solution. With suppliers globally, they are able to deal with high flow rates (over 20,000 BPH), can prove manufactured pulses produced by microprocessor-based flow meters such as coriolis and ultrasonic equipment, and – at least initially – offer a rugged and reliable solution. There is little argument that ball provers work.

Against this, however, they are bulky and demonstrate higher life cycle and maintenance costs compared to small volume provers (SVPs). They are also potentially less accurate and stable than alternatives, as well as being less versatile. Again, this last point will not bother contractors not focused on lifecycle costs. As long as the prover is suitable for its current application, they are happy. But owners and operators may need to think longer term when it comes to a key asset that may be used for 20 years.

The demands over that period cannot be known. Just as fuels over time have become more dirty and corrosive – think not only of crude oil but ethanol in gasoline, which has caused significant compatibility problems in the last decade – the demands on the prover will continue to evolve. While a ball prover is static, its lining cannot be changed and the solution has a limited turndown ratio, SVPs are designed for flexibility: firmware can be upgraded; its size means it can be moved, and seal materials can be switched.

At the same time SVPs are now a mature technology themselves, tested and approved by both regulators and oil companies for proving all types of meters, including coriolis and ultrasonic meters. Much smaller (Table 1), they can offer greater versatility and more reliable operation – particularly in certain applications.

<table>
<thead>
<tr>
<th>Reference Volume (L/gallon)</th>
<th>Flow rate Range (m3h/BPH)</th>
<th>Approximate Dimensions L x W x H (m/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 / 52.8</td>
<td>15<del>40 / 94</del>251</td>
<td>8 x 1.8 x 3 / 26 x 6 x 10</td>
</tr>
<tr>
<td>500 / 132.1</td>
<td>5.5<del>160 / 34</del>1003</td>
<td>12 x 2 x 3.2 / 39 x 7 x 10</td>
</tr>
<tr>
<td>1000 / 264.2</td>
<td>12<del>360 / 75</del>2258</td>
<td>14 x 2.6 x 3.5 / 46 x 9 x 11</td>
</tr>
<tr>
<td>1500 / 396.3</td>
<td>22<del>650 / 138</del>4076</td>
<td>19 x 3 x 4 / 62 x 10 x 13</td>
</tr>
<tr>
<td>5000 / 1321</td>
<td>47<del>1,400 / 295</del>8780</td>
<td>24 x 3.5 x 4.5 / 79 x 11 x 15</td>
</tr>
<tr>
<td>10000 / 2642</td>
<td>74<del>2,200 / 464</del>13796</td>
<td>27 x 4.5 x 5 / 89 x 15 x 16</td>
</tr>
</tbody>
</table>

Table 1: Typical prover size comparison
A false economy

It is true that most contractors remain committed to pipe provers. However, they do not have to deal with the majority of challenges that result from specifying the technology. While they must contend with the bulk and resulting installation costs up front, more significant and longer-term costs are largely hidden.

Challenges arise over the lifecycle in three principal areas:

- Safety hazards
- Maintenance costs and
- Uncertainty and repeatability vulnerabilities

It is worth considering each.

Safety: Against the Grain

In a wide range of areas, both environmental and health and safety concerns are driving the oil and gas industry towards closed systems. Regulators such as the Occupational Safety and Health Administration (OSHA) are keen to minimize potential for hazardous liquids or vapors to escape into the environment or come into contact with workers. Consequently, manual dipping has largely given way to closed solutions in level gauging, for example.

In proving, however, the size and operating principle of the ball prover inevitably exposes workers and the environment to potentially high temperature and dangerous products.

First, as ball provers rely on a sphere that must fit tight within the prover’s bore, this must be loaded and removed from the launch chamber (Figure 1). This unavoidably puts operators in contact with the liquid or vapors of the product metered. Consequently, for products such as naphtha (considered hazardous by the OSHA Hazard Communication Standard, 29 CFR 1910.1200), significant precautions are required during this process.

Similarly, both environmental and safety concerns dictate that provision needs to be made for safe, controlled draining and venting of the system for servicing or storage. For a 24 inch (0.61m) bidirectional prover with a 14 second actuated four way valve used for naphtha, for example, this means draining 16m³ (4,226 gal) of naphtha –16,000 liters – a challenge not made any easier by the limited space available around many ball provers.

Figure 1: A 12” (0.35 m) sphere, ready for loading. The proposed sphere for naphtha might be as large as 24” (0.61m), and weigh 200 kg (441 lb)
**Maintenance: Back-Loaded Expense**

The limitations of pipe provers in terms of reliability also become more apparent over time. Many oil companies with ageing metering stations using these provers have already faced rising maintenance costs. Problems arise commonly around four areas:

- **The 4-way diverter valve** (Figure 2): Common to bi-directional pipe provers, the 4-way valve is required to change the direction of travel of the displacer sphere (the ball) by switching the direction of flow through the prover. It can also be a consistent source of problems in the field. Maintenance is labor intensive and hampered by the fact there are only two manufacturers of the valves globally. The result is long lead-times (over 30 weeks) and high prices if a replacement is required.

- **The ball**: The displacement sphere is sensitive to damage from the product if material is not properly selected. Material for its liner must be chosen to be compatible with the liquid metered and ensuring it will seal through the operating temperature range. Commonly used materials are neoprene, polyurethane, Viton, Nitrile rubber and fluorocarbon for bidirectional provers; unidirectional provers usually use polymer spheres. Suitable materials to withstand some hazardous products, however, may be hard to find, and, again, the products the prover will work with may change over time. Degradation of the ball will create leakage and inaccuracy. Additional problems, such as the ball deflating or getting stuck, also result in particularly burdensome maintenance.

- **Pipe linings**: The pipework of ball provers are, like the sphere, lined to prevent damage to the sphere or piston seals. Linings applied to carbon steel pipe are usually epoxy or phenolic material, and also must be chosen carefully since not all non-metallic linings resist aromatic hydrocarbons and some can become thermoplastic at high temperatures. If liners do degrade it may be a significant source of downtime.

- **Corrosion**: Like all pipework, the exterior of the pipe prover is also subject to deterioration. The size of the ball prover makes piping made of stainless steel unreasonably costly, so carbon steel is used. In offshore, seaside and other corrosive environments this adds another potential source of problems.

![Figure 2: Bi-directional pipe/ball prover, with 4-way valve (center-left “Flow reversal valve”).](image)

Where work is needed as a result of theses or other issues, maintenance and servicing is hampered by ball prover designs intended to limit their footprint. The ball prover is frequently below the metering sections, making access for maintenance difficult (Figure 3). At the end of its life, meanwhile, companies face the cost and difficulty of disposing of large amounts of contaminated metal. Unsurprisingly,
those that have buried their provers to promote temperature stability (see below) may be tempted to simply to leave them after flushing and making safe. It is not an ideal solution.

![Figure 3](image.png)

**Figure 3.** A typical compact bi-directional proving and metering system.

**Accuracy and Repeatability**

Built-on-order, assembled in place – pipe provers are manufactured by systems integrators across the globe. The simplicity of the technology has benefits, but since the provers may be manufactured anywhere, there is scope for inconsistent quality in the search for cost savings. Practice can vary, from highly controlled, standardized products to more ad hoc, less expert efforts. This may be at least partly responsible for the divergent views regarding the effectiveness of the solution. In many cases ball provers turn out to be an effective reliable solution. Elsewhere they are beset with recurring problems.

However, some potential weaknesses are due to the design principle rather than the quality of manufacturer.

One such problem is pressure. If the ball is not inflated enough, leakage and poor repeatability result; inflated too much and pressure drops cause problems. Given that certain product and sphere material combinations may also cause the sphere to expand, achieving the correct pressure when inflating the sphere is a technical, specialist job.

Another issue is the potential for increased uncertainty at high and low temperatures – a function of the prover’s size. With perhaps 20m or more of metal pipe work, thermal expansion and contraction can cause inconsistencies in measurements when working in hot or cold climates and with high or low temperature products. Attempts to achieve stable temperatures by burying the proving in the ground, meanwhile, add significantly to maintenance costs.

The requirement for a stable temperature is also a challenge when it comes to calibration. The influence of temperature changes in the prover should not attribute more than 0.01% of the thermal expansion during the process. Combined with long calibration times (several hours for larger pipe provers) this usually means water draw calibration has to be undertaken overnight in hot climates, for example.

In any case, confident calibration of larger provers is complicated by the large volumes of liquid required. Calibration of a large prover using 20 or more 500 l cans is not uncommon, leaving scope for read-off errors from multiple measurements during the water draw, due to the very large volumes of water required. This results in uncertainty in determining the ball prover’s base volume, and must be determined and mentioned in the prover WD certificate (ISO 7278). As a result, the uncertainty of a typical bidirectional ball prover may be between 0.039 and 0.052%. The repeatability of Honeywell’s SVP, by comparison is better than 0.02%.
In reality, it is not the prover that is responsible for this difference, but the uncertainty of the calibration method in determining the base volume. In practice, however, the distinction makes little difference. The base volume is what is used to calibrate the flow meter, and repeatability is what determines the quality of the prover.

An alternative solution

No solution is perfect, of course. However, the issue with ball provers is not just that they may present some drawbacks that become apparent over time. They are also not necessarily the best solution available in any case.

Small volume provers overcome many of the difficulties common to ball provers, as well as providing potential benefits in terms of versatility and life cycle costs.

Most obviously, SVPs are much smaller than pipe provers. In the example in Table 2, the overall volume of the SVP would be 60 times smaller and eight times lighter than the equivalent ball prover. (The 4-way valve in the ball prover alone accounts for 10% of the pipe prover’s volume.)

<table>
<thead>
<tr>
<th>Model</th>
<th>SVP</th>
<th>Ball prover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (gal; m³)</td>
<td>25 gal; 0.095 m³</td>
<td>400 gal; 1.5 m³</td>
</tr>
<tr>
<td>Maximum flow rate (GPM; m³/h)</td>
<td>3500 GPM; 795 m³/h</td>
<td>2830 GPM ; 650 m³/h</td>
</tr>
<tr>
<td>Dimensions (m)</td>
<td>4 x 0.9 x 0.95</td>
<td>19 x 3 x 4</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>3.5</td>
<td>228</td>
</tr>
<tr>
<td>Dimensions (feet)</td>
<td>13.5 x 3 x 3.1</td>
<td>63 x 10 x 13</td>
</tr>
<tr>
<td>Volume (cubic feet)</td>
<td>125</td>
<td>8050</td>
</tr>
</tbody>
</table>

Table 2: Example comparison for a standard 1500 l (400 gallon) prover of 650 m³/hour with a maximum flow rate of 795 m³/hour.

This should make the prover much easier, simpler and cheaper to install, and makes it particularly suitable in applications where space is constrained, such as offshore. It also has significant consequences for servicing and maintenance throughout the prover’s life.

First, the size means the SVP can be built in higher grade materials such as stainless steel or even highly corrosion-resistant duplex stainless steel without prohibitive expense, making the prover resistant to external corrosion. Inside, the AISI 304L flow tube material with hard chrome bore is more wear resistant than both, epoxy or phenolic material liners in a bi-directional prover. The simple, straight-through design (Figure 4) and size also minimizes the scope for pressure problems. With a ball prover, the extent to which the ball is inflated can have a significant impact on the pressure.
Likewise, problems regarding thermal expansion are overcome due to the smaller volume of metal, as well as facilitating quicker calibration times due to much smaller volumes of liquid used. Draining is significantly less of a problem, too; in the example above of the ball prover draining 16,000 L of naphtha, the equivalent SVP would drain only 284 L. As it is, an SVP can be provided as a mobile unit (Figure 5) and removed from the meter site for draining and storage in a safe location.
Finally, workers on an SVP are much less likely to come into contact with the product for other reasons, too. There is, for instance, no displacer to load or get stuck, and in normal operation the prover is a fully sealed system that does not have to be opened. No 4-way valve is required and the piston does not require any grease. Where maintenance is needed, accessing the prover is simple, making it safer and less challenging. More modern provers even allow maintenance without having to disconnect the process piping.

**A Flexible Alternative**

The operational range of ball provers also compares poorly to the SVP. The latter offers a much higher turndown ratio (1200:1 for the SVP against 10:1 for unidirectional and 5:1 for bidirectional pipe provers). It also overcomes limitations in terms of product temperature and pressure, usually -29°C for a ball prover (unless more expensive low temperature carbon steel is used) to 100 °C, and a maximum of 100 bar (due to the elastomer of the sphere). Improvements in SVP materials are seeing them operate in ambient temperatures of -40° to 60°C and up to 250 bar, and with product temperatures up to 250 °C. The lack of a spherical displacer enables use with a greater range of viscosities, flows (up to 17500 barrels per hour) and fluid types.

Without a bore lining or ball to worry about, only the seals in an SVP need to be considered and these can easily be selected for compatibility with a wide range of fluids and conditions. Where there is less flexibility, however, is in the quality if the manufacturing process. Standardization and quality control in an SVP can be supported by an ISO9000 manufacturing process.

**Manufactured pulses**

Despite the challenges regarding manufactured pulses, ball provers are not alone in being able to prove ultrasonic and coriolis meters. Using pulse interpolation techniques and a “double chronometry” algorithm, an SVP can limit uncertainty and repeatability to the required levels (0.01% and 0.02%) without sufficient prover length for 10,000 pulses between switches – the historic requirement. This has been demonstrated with both ultrasonic and coriolis meters from various manufacturers.

While SVPs have not been able to successfully prove all ultrasonic meters – particularly common legacy models – this is an issue with the meter rather than the prover. Choosing a different meter, rather than opting for a less ideal proving method is likely to be a more efficient alternative for most applications. It is also preferable to the use of a transfer meter – a turbine master meter in series with the prover. This enables the meter to be proved, but it fails to address the root cause of the problem. Master meters also bring additional problems – high maintenance, internal wear, short lifetimes, and an additional source of uncertainty in the loop.

In other cases, the SVP meets the standards of API Manual of Petroleum Measurement Standards Chapter 4 Section 2 and is explicitly recognized as a solution”. More importantly, the efficacy of the solution is demonstrated by users across the globe, with several major oil companies replacing ball provers with SVPs. Offshore, SVPs have become the standard, not only due to their small footprint, but also due to their reliability and resistance to external corrosion and stress corrosion cracking – a growing safety concern. Onshore, they are found in some of the most demanding environments on the planet.
Conclusion

With pipe provers usually specified as standard, the need for an alternative proving solution in oil applications is not yet widely accepted. Ball provers can and do prove meter accuracy in a wide range of applications.

However, they also can impose a significant burden on operators in terms of maintenance, particularly as they age and at the end of their life. Over the entire life cycle, they may not be the most efficient solution. Nor are operational safety and flexibility always ideal. These are all issues that arguably do not receive the attention they deserve from contractors and consultants when specifying the prover.

Moreover, the potential weaknesses must be set alongside the importance of the prover to the custody transfer basis and, crucially, the existence of viable, proven alternatives. Given this, the preference for ball provers over more modern alternatives is, if not inexplicable, increasingly hard to defend.

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i “Areas for Improvement in Hydrocarbon Liquid Metering Systems See Major field problem component”, slide 6, Dr Mohammed Salim, Saudi Aramco, 6th Custody Measurement Technical Exchange Meeting 2011

ii API Chapter 4 Section 2, 2011 “3.3 Temperature measurement” specifies a Ctl factor of 0.0001 or less.


iv For 10” & 20” provers, according to Trapil: http://www.trapil.com/uk/presta_etalonnage_debit.asp

v In the introduction, for example, which notes: “It includes provers that were commonly referred to as either ‘conventional’ pipe provers or ‘small volume’ provers.”