In the western Canadian oilpatch, one of the biggest cost drivers for steam assisted gravity drainage (SAGD) is the substantial amount of energy required to generate steam. The high use of energy contributes to greenhouse gas emissions and has also become a focal point for criticism.

Operators have long recognised that one of the best ways to address this issue was to lower the steam injection pressure. However, this means that the artificial lift (AL) used in their production wells would need to operate at a lower intake pressure and very challenging downhole conditions.
Developing and optimising AL for low pressure SAGD is a significant challenge, but many operators, vendors and research organisations have worked collaboratively to improve this technology over the last 10 years. This article summarises some examples of the challenges for AL in a low pressure SAGD environment, and some recent projects where the industry worked together to push AL technology forward.

The challenges of SAGD

In a typical SAGD application, fluid (including crude oil, produced water, condensed steam, and non-condensable gas) will drain from the upper steam chamber around the injection well towards the production well where the AL is located. The ‘sweet spot’ of the SAGD process is to operate the producing well at a pressure that is just slightly above the steam saturation pressure in the reservoir. Under this low pressure condition, the fluid can drain from the overlying steam chamber but the hot water does not flash into steam when it enters the production wellbore. While steam may not be present in the wellbore, in some circumstances, the pressure drop as the fluid flows into the pump can still be sufficient to cause steam to form. This problem can be further compounded by any variability in the produced fluid properties from the reservoir, such as the presence of gas, or variations in the bulk fluid density and viscosity.

AL is needed in the SAGD producing well since the downhole pressure is usually insufficient for the fluids to flow to surface at suitable rates or conditions (e.g. to maintain a suitable wellhead pressure, or suitable vapour fraction at the surface facilities). Numerous types of AL systems have been (and are being) deployed in SAGD, but the most common types in Western Canada include:
- Gas lift, generally in conjunction with natural steam lift.
- Rod pumps, or sucker rod pumping systems.
- Electric submersible pumps (ESPs).
- Metal-to-metal progressing cavity pumps (MxM PCPs).

Through the 1990s and early 2000s, gas lift – often with steam lift – was by far the most common type of AL used in SAGD, while rod pumps were also used in some early developments. More recently, the goal of operating under low pressure SAGD conditions has helped drive the development of other mechanical AL systems, where operators are now moving towards using high temperature ESP systems and MxM PCP systems. Numerous global vendors currently supply variants of these two types of AL systems for use in SAGD.

While some forms of AL are certainly becoming more common, no specific type of AL system seems entirely free of difficulties and there is no ‘magic bullet’. For example, ESPs can be a good option but are sometimes challenged at higher fluid temperatures (there are few systems that can operate above 250 °C), and under multi-phase flow conditions when steam and gas enter the pump intake. Meanwhile, MxM PCPs are usually not as temperature limited in SAGD applications, but are susceptible to lower volumetric efficiencies that can make it harder to produce suitable volumes of low viscosity high temperature fluid. Despite this, the benefits of implementing low pressure SAGD has driven the industry to develop pumps that can work under these challenging environments. To understand the key factors that affect AL performance and runlife, a variety of approaches have been undertaken, including experimental testing, field data collection and simulation/modelling.

Experimental testing

Experimental testing provides a unique opportunity to evaluate AL systems over a range of real world operating conditions with a closely controlled and instrumented setup. For this reason many operators and vendors have used experimental testing to advance oilfield technology, including AL for SAGD applications.

In order to better meet the challenge of low pressure SAGD, a joint industry project of 13 SAGD operators was initiated in 2004 to construct a high temperature flow loop at C-FER Technologies in Edmonton, Alberta to...
evaluate the performance of various types of AL (Figure 1). This JIP initially targeted fluid temperatures up to 200 °C (392 °F) and combinations of oil, water, emulsions and non-condensable gas under tightly controlled conditions inside a horizontal 9 ⅝ in. casing that simulated a typical SAGD production well in Western Canada. The primary benefit of this experimental programme was to identify what types of AL provided the best performance under representative low pressure SAGD conditions, while also using a consistent test matrix. A key secondary benefit was to provide detailed performance data, and in some cases failure data, to the pump vendors to help them improve their technology.

In some cases these initial high temperature tests resulted in early failures of the pumping systems, demonstrating the significant challenges of the low pressure SAGD environment. However, in part due to the data provided to the vendors, pump performance has improved significantly over time, allowing operators more choice to better address the challenges of higher fluid temperatures and low pressure SAGD. This, in turn, allowed individual operators and vendors to move the technology towards even more challenging conditions. In 2007, and again in 2009, the high temperature flow loop at C-FER was upgraded by one operator to eventually allow testing at fluid temperatures as high as 260 °C (500 °F). Since that time, a number of AL systems have been evaluated.

As the AL systems have improved over the years, the experimental tests have also evolved from short assessments of pump performance under relatively steady-state conditions, to more comprehensive tests over longer durations with challenging transient conditions. As an example, test programmes for new prototype ESP systems now commonly include challenging thermal cycling tests to simulate shutdowns/startups in a SAGD well, and the effect that these operations may have on the ESP motor and ESP seal section(s). Likewise, extended duration tests are now completed on most MxM PCPs to better understand changes in volumetric efficiency that could occur during the ‘break-in’ period of these positive displacement systems. As the tests have grown more comprehensive, the level of instrumentation has also increased significantly to make sure any changes in pump performance are captured. Experimental testing remains a very useful tool for operators and vendors as they continue to qualify and optimise their systems for low pressure SAGD.

Performance tracking
While experimental tests in a laboratory have helped to greatly accelerate AL technology for SAGD, the actual performance of these systems in the field (over the long-term) also needs to be constantly evaluated and optimised. It was recognised early on
that operating companies would benefit from evaluating the performance of their AL systems in a standardised way, and by sharing their experiences and learnings to help them achieve common goals.

Using standardised performance tracking, operating companies can evaluate how their pumps are performing compared to others in a similar environment, and they can track the impact of new pump models and operating procedures as they are implemented by themselves, or other operators. By sharing reliability data and field experiences, such as problems or successes with system design, equipment specification, manufacturing, installation or operation, operators can adjust their day-to-day practices to correct problems, or avoid them altogether. These improved practices contribute to increased pump runlife, fewer well interventions, less deferred production, lower operating costs and thus, increased profits. Under challenging low pressure SAGD conditions, these improved practices can be crucial.

An example of one key tool being used in this evaluation is the ESP-RIFTS (electric submersible pump reliability information and failure tracking system) project, which was first developed under a joint industry project in 1999 with a number of operators. ESP-RIFTS collects pump performance and failure descriptions from operators into a common, open database that currently includes +100 000 individual records from 758 different fields and 24 different operating companies for ESP systems (note: this includes both thermal and non-thermal records). Likewise, PCP-RIFTS was initiated in 2003 to track and improve the operation of PCP systems, where this database currently includes +12 000 individual records from +100 different fields and 11 different operating companies.

Given the common technical challenges faced by the operators (and vendors), these collaborative programmes have resulted in a number of tangible benefits, including standardised performance tracking, comparative metrics, statistical and ‘what-if’ analysis, and metrics to track AL reliability. While work in these large collaborative projects is ongoing, one key goal is to increase the amount of thermal and low pressure SAGD data available to operators in these databases to help identify and implement best practices.

**Component testing and optimisation**

When evaluating AL systems, either experimentally, with performance tracking, or through direct field experience, common trends often begin to reveal themselves. When this happens it becomes possible to focus on the ‘weakest point’, or a single component, instead of the whole AL system. A few examples of this involve recent ESP projects, which are relatively complex forms of AL with many components.

In one example, to better understand the multi-phase performance of the pumping section of an ESP with steam, an operator funded the construction of a novel steam flow loop in 2011 with representative SAGD rates, pressure and steam fractions. This full-scale flow loop allows tight control of the fluid composition entering the ESP intake with varying amounts of steam, liquid water and gas while the pump performance and stage-by-stage pressure contribution is monitored. Various pump stage designs can be considered, and these tests ultimately led to a better understanding of the effects of steam flow through ESPs and the added challenges of producing condensable gas with AL in SAGD.

As another example, analysis of field data from several operators indicated that many ESP failures could be traced to problems in the motor or seal section. Following a ‘drill down analysis’ of the field data in 2012, an operator also funded the construction of a specialised dynamic testing system to subject various types of ESP seal sections to a representative SAGD temperature and pressure under truly transient conditions (Figure 2). This test included applying ESP motor shaft rotation and thrust, and controlling the expansion and contraction of motor oil to simulate installation, operating and shutdown conditions for these ESP systems in the field. These tests provided insight into the heat generation in the ESP seal and thrust bearing, and the performance of an elastomeric seal under representative SAGD conditions.

**Other challenges with low pressure SAGD**

Sometimes when iterating towards a change, it is possible to find a new challenge in a different and unexpected area. Despite the improvement of the technology, the shape and trajectory of SAGD wells can also introduce added challenges when installing AL systems into low pressure SAGD operations. As operators began to install longer and larger diameter systems, such as ESPs and MxM PCPs, they soon raised concerns that these AL systems were being bent as they were installed through the curved and deviated sections of the wellbore in the SAGD wells, or even where the pump was landed. This can be a common concern in the SAGD wells in Western Canada where high build rates and complex well geometries, sometimes with simultaneous build and plan curvatures, can be required to reach the reservoir.

To help operators investigate the relationship between well design and AL geometry, and to assess if certain AL can even be accommodated in highly deviated wells, a numerical model predicting the bending stresses in an ESP system was developed. The model considered the variability in the bending stiffness of the pumping system components and allowed the operator to assess how bending may be concentrated in the weaker sections (e.g. such as at the connections between the individual parts, like between the seal and the intake where ESP systems are typically less stiff). Due to the complexity of the model and the difficulty in estimating the actual stiffness within various ESP components, this model ultimately drew on large-scale laboratory bending tests to benchmark and train the model.

Current work is now focused on taking this a step further and tying wellbore geometry limits, both during installation and operation (which is much more challenging) to the reliability of ESP systems. This is a good example of a real field problem that is being addressed using a combination of performance tracking, experimental testing (both on a component and on the system), and simulation.

**Wrap up**

Operators in Western Canada have been driving the industry toward lower pressure SAGD, for good reason, but the AL systems in these wells must operate under more and more challenging conditions. Despite this, the performance of high temperature AL systems in low pressure SAGD operations has also increased tremendously in a relatively short time. Much of this success can be attributed to the open collaboration and information sharing among operators, vendors and researchers as they use experimental testing, equipment tracking and engineering simulation/analysis to push their technology to new heights.