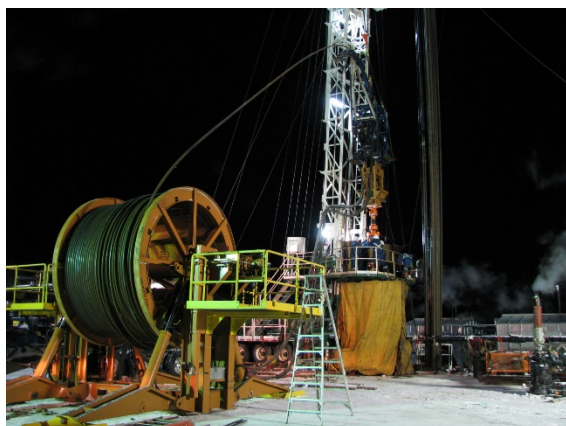


Editor's note: This article is the third in a series of mini-articles that outline the benefits and the value proposition available by Salamander heaters. This article discusses the benefits of the LinkWell™ heater.



Salamander Solutions, a spin-off from Shell, is bringing advanced heater technology to bear on oil field challenges to improve profitability of difficult hydrocarbons. Salamander heaters can add incremental barrels at \$10 - \$15/bbl with payouts of 1.0 to 1.5 years. Downhole electric heaters in steam-based projects can deliver additional barrels at an early stage and with lower water and CO₂ 'footprint'. Deepwater applications can result in simplified field layouts significantly lowering field development costs. Given the right well candidate, heaters can increase production and improve recovery in both cold producers and steam projects with payouts that compete with new drilling.

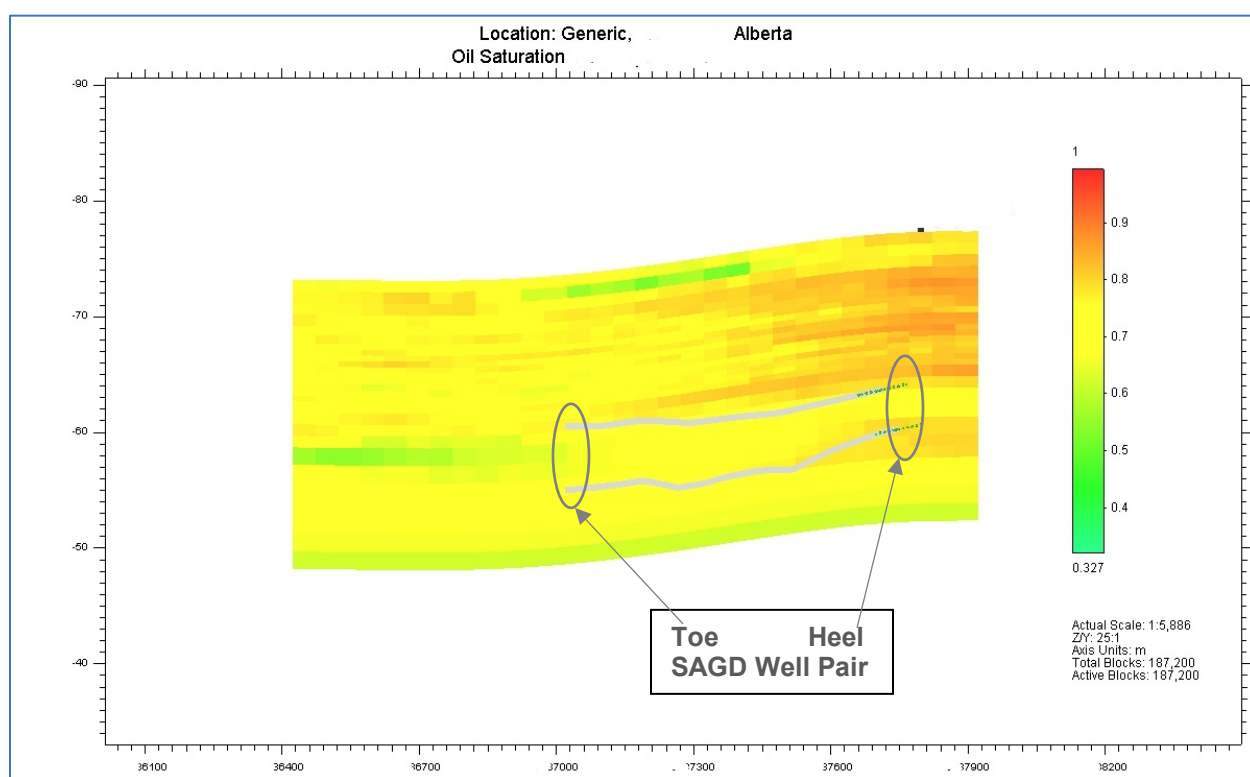
Salamander LinkWell™ Heater

Steam-based thermal recovery methods such as Steam Assisted Gravity Drainage (SAGD) or Cyclic Steam Stimulation (CSS) are established techniques to produce (extra) heavy oil resources. These are very effective in homogeneous reservoirs where the steam can mobilize most of the oil in place but they do not work as well in heterogeneous reservoirs where high-permeability thief zones such as fractures in carbonate rock or pockets of higher water saturation provide preferential channels of steam flow thereby bypassing a significant fraction of the oil. The problem becomes particularly acute in SAGD projects where this lack of steam conformance is established in the first few months of operations, when steam is circulated to establish hydraulic communication within the well pair, and it persists for the multi-year duration of the pattern. This is evidenced by field data from distributed temperature sensors (optical fibers) deployed in SAGD-pair wellbores, which indicate that as much as a quarter of an 800-m-long well may not be receiving any steam, while, in contrast, the heel region of the well pair may be over-swept by steam that preferentially follows the shortest path.

Often when new SAGD pads are drilled, steam is either not available because steam facilities have not been extended to the new pad or steam is in short supply. If this is the case, electric heaters can accelerate oil production. Electric heaters can also increase the conformance of steam by uniformly preheating the targeted volume between the well pair and, as needed, by continuing to inject heat during thermal operations. Heat propagates essentially uniformly in the reservoir and can reduce the viscosity of the oil by orders of magnitude, especially in the vicinity of the heated borehole. This reduced contrast in viscosity between oil and (pockets of higher saturation of) water will help direct more of the injected steam toward the oil and establish a more uniform

steam propagation front. Thus, electric heaters deployed inside steam-injection wells assist and complement their function but do not replace them.

Since data from the deployment of downhole electric heaters in SAGD wells are not publicly available, we have run a series of reservoir simulations to estimate the potential of electric heaters to not only raise the reservoir temperature and, thus, accelerate the production of oil but to also raise the temperature in the vicinity of the SAGD well pair more uniformly and, thus, lead to better steam conformance in the steam-based operating phase. The 800-m-long undulating trajectories of the SAGD well pair that were used in the model, superimposed on a non-uniform distribution of oil saturation and other reservoir properties, are shown by the gray curves in the following display.



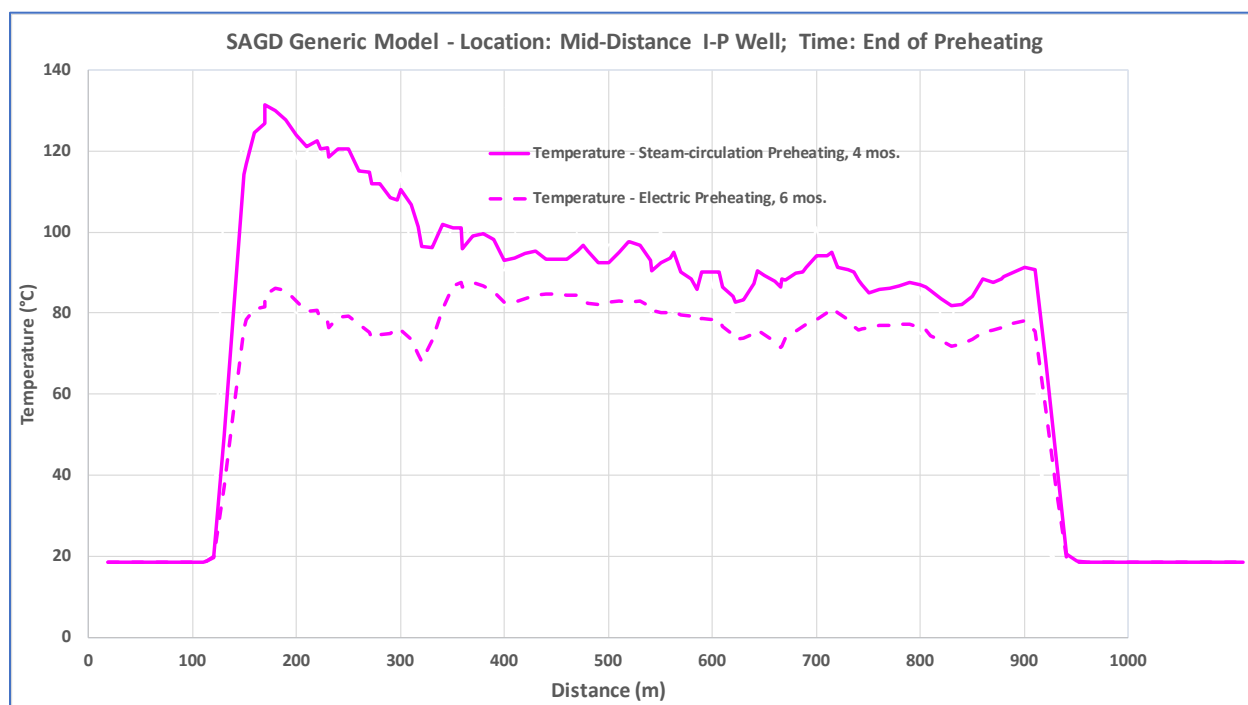
The reservoir model compares two scenarios:

- Preheating by circulation of 150 m³/day of ~100% quality steam at T=250°C for about four months
- Preheating by Salamander down-hole electric heaters in both wellbores with each heater tailored to inject about 400 Watts per meter in the heel region and 550 Watts per meter in the rest of the wellbore for about six months

As can be seen in the graph below, the reservoir temperature at the mid-distance between the wells that is reached by circulating steam is higher than that reached by electric heating; however, it is also much less uniform. Consequently, when the well pair enters the standard SAGD operating

phase, the growth of the steam chamber is adversely affected by this initial non-conformance of temperature, which translates to non-conforming oil mobility.

In contrast, when the electrically preheated well pair goes into SAGD operating mode, the steam chamber grows more uniformly, which translates into a lower Steam-Oil Ratio. The reservoir temperature is lower ($\sim 80^{\circ}\text{C}$) but this is adequate to result in enough mobility to the heavy oil to allow for hydraulic communication between the wells, which is the prerequisite to begin standard SAGD operations. Moreover, the growth of the steam chamber is even more uniform if the electric heater in the steam-injection well remains energized (at a lower power) during SAGD operations.

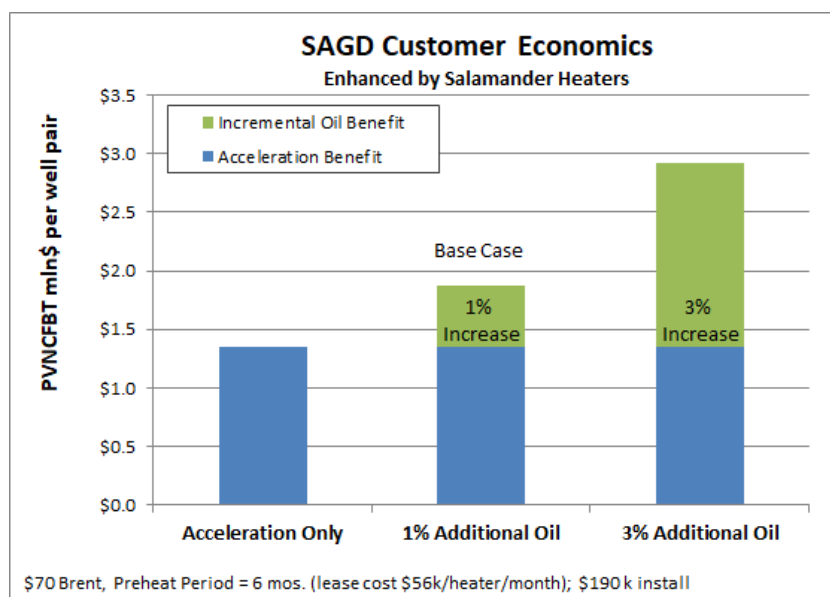


It may also be advantageous to deploy electric heaters in developments based on solvent injection, a heavy-oil recovery technology that is being actively considered and field-tested in Canada. Solvent-injection faces the same conformance issue as steam, which can be mitigated by electric heating. Typical solvents, however, also have lower heat capacity and much lower latent heat than water/steam so they may need to be injected at markedly higher rates to achieve the targeted reservoir temperatures. Higher flow rates of injection translate to higher CapEx for the surface facilities required to process the high throughput. This CapEx can be reduced by the deployment of a downhole electric heater that would raise the temperature of the injected solvent at the sandface so that it can transfer the required amount of heat into the reservoir at lower flow rates.

Another benefit to utilizing electric heaters in SAGD operations may be during shutdowns. In our discussions in Canada, operators have indicated that they have certain “problem” wells that take much longer to reach their pre-shutdown production rates and in a lot of cases produce large amounts of water prior to the return to oil production. In such cases, should the operator place a heater in these “problem” wells and continually inject heat during the shutdown period, the “problem” well could regain its pre-shutdown oil rate faster and limit the water production as well.

Salamander LinkWell™ Heater – Economics

Salamander Solutions’ heaters have not been deployed in publicly disclosed steam- or solvent-injection projects. Private discussions with operating companies in Canada suggest that moderate levels of heat injection, such as the ones used in the reservoir model discussed above, can generate value through a combination of acceleration of the start-up phase of steam injection and maximization of contact between steam and oil during the main production phase. On the basis of field data from our heaters deployed in the field and from steam operations of prospective customers we have run indicative economics that show that acceleration alone (by three months) can pay for the lease of a downhole heater at discount rates of 7% and 10%. Additional value can be gained from a 1-3% increase in cumulative produced oil due to better conformance of steam. The economic value of accelerated production and higher ultimate recovery is captured by the present-value net cash flow, shown in the bar chart at right.



For more information on LinkWell™ and other applications of Salamander Solutions heaters please go to www.salamandersolutions.com or contact us at info@salamandersolutions.com.

Next Article: Salamander heater applications in offshore flowlines will be featured.