What every SAGD operator and engineer should know about potential failure from condensation-induced water hammer

by Mike Carlson, P. Eng

The risk of a blowout exists to some degree for every well that is drilled. It is a very small risk, but a risk just the same. At worst, blowouts can create disastrous situations like we saw earlier this year with BP in the Gulf of Mexico. There have been blowouts in the Gulf of Mexico previously — eventually nature repairs the damage and life returns to normal, but there is no doubt that a catastrophic failure can trigger some very negative pressure and have long-lasting effects. It is a twist of fate that this catastrophe has made the oilsands appear relatively more attractive than deep-water drilling. The risk of blowout, however, exists in Alberta as well.

OILSANDS DEVELOPMENT

Alberta has considerable oilsands resources. Both the province and the industry are hoping that we can exploit these resources to make a living and develop our country. It seems our biggest challenges are managing this growth and ensuring that we can do this in a manner that is as safe as possible in a way that minimizes the impact on the natural environment.

Fortunately, the in situ oilsands industry has not had any major catastrophes to date. However, there have been some smaller problems:

Total E&P Canada's Joslyn property had a steam release on May 6, 2006.

MEG Energy had a steam distribution line failure on surface on May 5, 2007.

Devon Canada had a wellhead fail at surface on June 10, 2010, which resulted in a steam release.

The Alberta Energy Resources Conservation Board (ERCB) has prepared detailed investigation reports on the first two events, while the last event has only just recently occurred and there has been insufficient time for a report to be prepared.

The reports are available on the ERCB's website, and reading them is encouraged. This article highlights what the author perceives to be an important issue related to at least one of these events: condensation-induced water hammer.

BASIC PHENOMENON

Collectively, mankind has known about water hammer for a considerable period of time. We know from the days of the early boilers that if condensed water is trapped in a distribution line, contact with steam can cause it to explode. The solution that evolved was the development of the steam trap. There are various geometries, but in essence a steam trap separates hot gaseous steam from cold water. The water drains into a separate lower-pressure line.

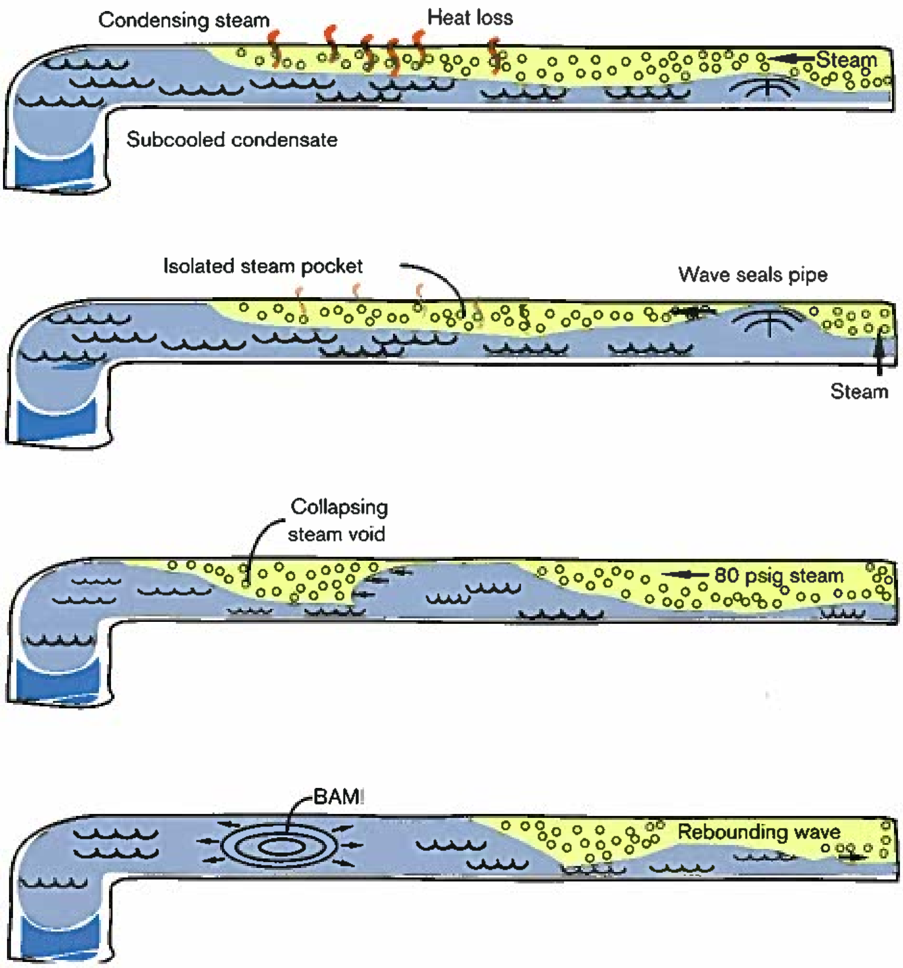
During the development of nuclear power reactors, a series of accidents occurred in the United States during emergency cooling operations. When reactors got too hot, the solution was to simply pump cold water into reactor core. In some 40 incidents, pumping cool water would result in the pipe being blown off the side of the reactor, pipe distortion due to a very strong pressure pulse, or the pipe would get knocked off the pipe racks. In some cases, valves would catastrophically fail with fatal results for the operator of the valve.

Research at the Massachusetts Institute of Technology (MIT) eventually identified the problem as condensation-induced water hammer. (See Bjorge, R.W., "Initiation of Water Hammer in Horizontal or Nearly-horizontal Pipes Containing Steam and Subcooled Water," Ph.D. Dissertation, MIT, January 1983.) A diagram of the process is shown below, although the diagram truthfully does not do the phenomenon justice. Note that the low-pressure (one pound per square inch, or psi) injection of steam is not affected by the water hammers in the liquid phase in the horizontal section.

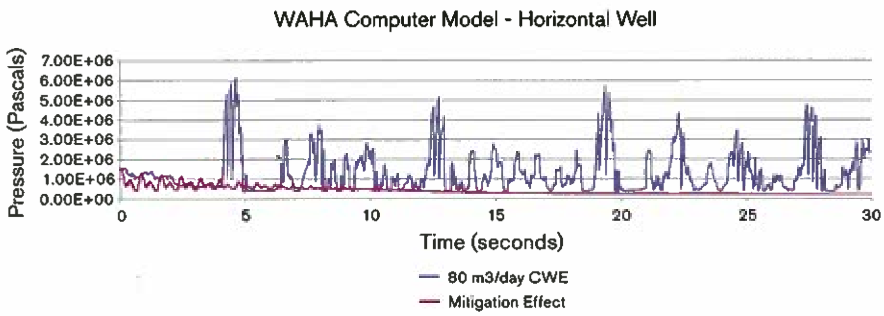
STATE-OF-THE-ART RESEARCH

The nuclear industry has done extensive research on the phenomenon described in the

INITIATION OF WATER HAMMER IN HORIZONTAL OR NEAR-HORIZONTAL PIPES CONTAINING STEAM OR SUB-COOLED WATER



COMPUTER SIMULATION OF CONDENSATION-INDUCED WATER HAMMER



previous paragraphs, in order to safely design reactor cooling systems and the associated steam distribution systems in power plants. This includes not only design monographs, available free of charge from the nuclear regulatory agency in the United States, but sophisticated computer programs as well. Similar research and design software has been developed in Europe by the nuclear industry.

CHRISTINA LAKE STEAM DISTRIBUTION LINE FAILURE

The pressure spike that results from condensation-induced water hammer can be as high as 1,500 psi in a pipeline system operating at pressures of 20 to 40 psi. The spikes are of short duration, but last long enough to cause catastrophic pipe and valve failures. It is this mechanism that was deemed responsible for the failure of MEG Energy's Christina Lake steam distribution line in 2007.

The MEG event is by no means the only failure of this type that has occurred. Other failures include incidents at the Brookhaven National Laboratory in Long Island, New York, the Grangemouth refinery in the United Kingdom, Fort Wainwright in Alaska, a failure on a university campus in Georgia, and at an intersection in Gramercy Park, New York City, which caused a large crater. Most of these failures regrettably involved fatalities.

JOSLYN SAGD FAILURE

The major force that affects a steam assisted gravity drainage (SAGD) project is the thermal expansion of the steam chamber. This is depicted in the figure below:

The expansion results in surface heave of 20 to 40 centimetres observed on shallow steam projects after several years of steaming. (See the ERCB annual in situ progress reports available at ercb.ca.)

Surprisingly, the Joslyn failure in 2006 occurred very shortly after the pre-SAGD circulation phase, almost immediately after the well was put on production. This is too early for the development of significant thermal expansion forces. One possibility is that injection occurred well above frac pressure, which then resulted in a frac to surface. The investigation › doesn't support this, nor do I believe that a field operator would endanger himself by doing this. However, there is always the possibility that some unanticipated physics resulted in lower frac pressures or high wellbore pressures and an unexpected failure.

The investigation report identified a number of potential failures. The most likely failure suggested by the ERCB and Total E&P Canada was one involving a vertical "chimney" of clean McMurray sand that allowed pressure to migrate upwards. With high pore pressures, the strength of the caprock is reduced and a shear failure is postulated. Since a number of possible failure mechanisms are suggested, it would seem that the definitive cause of failure remains unknown. I have not been able to reproduce the postulated mechanism in my modelling.

In general, most well pairs exhibit considerable fluid loss during the circulation phase. This suggests that there would be so much fluid loss to the oilsands in the chimney that significantly increasing pore pressure would be very difficult. Propagation of pressure into the caprock would also be very slow due to the low permeability, and this would delay failure of the caprock.

However, a horizontal well has no built-in steam trap, and after a workover would be filled with cold water. In the event that condensation-induced water hammer were to occur, the pressure response in the well would look something like the computer simulation on the previous page. Note that this computer program (WAHA) was obtained from European nuclear research.

The spikes on the thin blue line are considerably above frac pressure. The volume of the fluid that would escape through the liner would be very small given the very short duration of the spikes. However, if there were enough spikes (the simulation is for only 30 seconds) occurring at the same spot in the wellbore, a frac could eventually be propagated. Since the pressure cycles up and down, there would be partial returns of cool fluids to sustain the water hammers. An eventual death by a thousand cuts (fracs) is suggested.

Once a steam chamber has formed, any fracs caused by the water hammer will leak off in the steam chamber, where fluids would be quite mobile. It is during the early stages of development, when fluid leakoff is lower, that fracs would be able to propagate. (Recall that all wells on circulation do leak.) Mature steam chambers would seem to be less likely to be affected.

MITIGATION

The slightly thicker purple line includes mitigations to prevent the initiation and propagation of the pressures spikes. It does not appear that mitigating these pressure spikes will prove to be particularly difficult.

PERSPECTIVE

To put this in perspective, there have been hundreds of wells in Alberta that have operated without catastrophic failure. Clearly, something was different about the Joslyn well or project. However, there are a number of unexplained difficulties that have occurred on SAGD projects that include shale liquefaction of the caprocks, downhole pressure gauge failures, sand influxes and liner hanger failures that might be explained by a series of high-pressure spikes. The latter problems probably affect 10 per cent or more of SAGD well pairs.

This is a very complex process. SAGD wellbores are very unstable, as documented in N.R. Edmunds and W.K. Good, "*The Nature and Control of Geyser Phenomena in Thermal Production Risers*," JCPT 96-04-04, April 1996, Volume 34 No. 4. Significant slugging is known to exist due to phase changes and heat transfer. This process is exacerbated by including heat transfer between gravity-segregated hot steam overriding cool condensate (water), as demonstrated by the above computer program results. (The nuclear industry programs are different than those used by the oil industry.)

SUMMARY

Clearly, condensation-induced water hammer has the potential to be enormously destructive. The many accidents that have occurred in numerous industries indicate it is not intuitively obvious. The failure of surface lines has been conclusively demonstrated to be the cause of a catastrophic failure of a steam distribution line. I believe every engineer and operator working in SAGD needs a sound understanding of condensation-induced water hammer.

Computer models and well conditions strongly suggest that condensation-induced water hammer is likely to occur in SAGD horizontal injectors. There is a lot of well data that presents apparently anomalous pressure data (i.e. steady state) hydraulically impossible pressure spikes. Condensation-induced water hammers might very well explain the anomalous pressure data, and, if true, could be the underlying cause of a number of SAGD production problems.

There are still uncertainties regarding the underlying cause of the Joslyn failure and although clearly rare, recent events in the Gulf of Mexico show that catastrophic failures can have significant impact on safety, the environment and public perception — an area of current sensitivity. There are also significant economic implications. It does not appear to be difficult to mitigate. If these problems are solved, significant cost savings may be realized. The complexity of the interactions would require some sophisticated research to fully understand. Increased safety and lower costs would be a worthwhile investment. ▪

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