CONDENSATION INDUCED WATER HAMMER, NEW ZEALAND GEOTHERMAL STEAMFIELD PIPING CASE STUDIES

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ABSTRACT

The production and transport of steam and hot water from geothermal fields needs careful design and operational management to avoid condensation induced water hammer (CIWH). CIWH occurs when a steam space collapses upon mixing with cooler steam condensate or water. The resulting hammer event can be catastrophic. This paper details a number of cases where CIWH has occurred in New Zealand geothermal fields. Causes, events, and risk mitigations are discussed.

1 INTRODUCTION

1.1 Condensation induced water hammer

Condensation induced water hammer (CIWH) can and does occur in many applications (Kirsner 2010), including geothermal stations (Ngomi 2016) where steam or other saturated gas comes into contact with a cooler fluid or surface. During a CIWH event the cooler fluid condenses the steam and the resulting local reduction in pressure can draw in the surrounding liquid at high velocity (Figure 1). High pressure and forces result when the fast traveling liquid has filled the void and stops suddenly. The liquid slug could travel some distance along a piping system and would generate high forces as the momentum is transferred into bends, tees, and structural constraints.

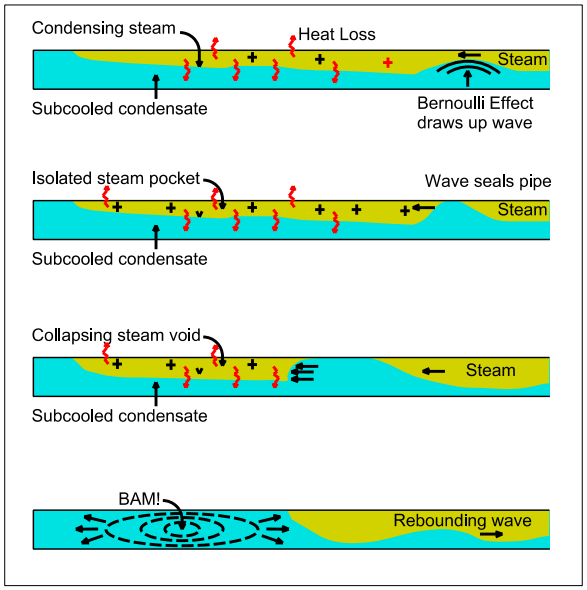

Figure 1. Steam entrapment and slug formation in a horizontal pipe (Kirsner 1998).

CIWH is not the same phenomena as slug flow in two-phase piping. That is slug waves or plugs of water being pushed along by the steam phase flow. This slug flow does not have the rapid reduction in downstream steam pressure and the rapid acceleration of the water slugs in CIWH. Neither is it the vibration and noise that occurs when steam pockets form and collapse in saturated separated water lines, due to pressure reduction (Watson 2013). CIWH does not require a system be flowing, and usually occurs when systems are static or with low steam flow.

1.2 New Zealand Geothermal

New Zealand was first country to use two-phase geothermal fluids for power production in 1958. Currently there are 19 power plants that provide almost 20% of the country's power. The plants range from small (2MW) binary plants to large (140MW) steam turbine systems. Almost all production wells are two-phase, with only a small number of dry steam wells.

2 CASE STUDIES

The following examples of CIWH occurred in New Zealand power plants and steamfields over the last 25 years.

Each case study describes the situation leading to the CIWH event, the result of the event, and steps taken to reduce the risk of reoccurrence.

Case 1a

This event occurred in steam piping where there are two parallel lines connected upstream and downstream. Between the connections there are vertical expansion loops. At the base of the loops are low points and steam trap drainpots.

Leading up to the CIWH event, one of the steam trap assemblies became blocked. The trap pot filled with steam condensate. The condensate continued forming and started to fill the pipe. In most steam lines the steam flow would 'pick up' the condensate and send it to the next pot, but here, as the line filled, the steam flow diverted to the parallel line. The piping continued to fill with condensate, fully blocking this section of the line. (Figure 2). With no passing steam, the condensate cooled to ambient temperature.

This situation was stable for some time. When the blocked steam trap was discovered by the plant operator, they decided to isolate the flooded area by closing an upstream valve. This isolated a pocket of steam between the valve and the cool condensate. This led to a large hammer event (steps 3 and 4 of Figure 1). The steam space rapidly condensed, drawing in the cool condensate. The momentum of the condensate slug was transferred to the piping when the slug hit the valve gate. While there was no pipe rupture, the force may have stretched the valve body. This was calculated to be the order 7000 kN or a pressure on the valve disc of 16 MPa, 10 times the design pressure of the line.

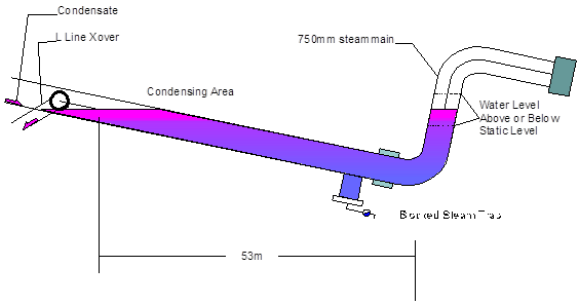

Figure 2 Case 1A. Steamline filled with cooled condensate.

Cases 1b and 1c

Cases 1b and 1c were similar to case 1a. From the 1a experience the operators realized the danger and left the lines operating and the condensate in the line until they had developed a safe plan to remove the condensate.

They did not wish to simply drain out the condensate from the pot. This may have led to an unstable situation where steam could break through over the emerging cold condensate level causing a large mass of cold condensate to be shifted into a large volume of steam upstream or downstream.

In both cases the condensate was removed by heating it up to steam temperature and boiling off the condensate. Case 1b used external heating, and case 1c injected steam and water.

The situation that led to filling the steam line could have been avoided by:

- Avoid designing parallel steam lines with low points.
- Interconnecting the drain pots
- Level monitoring alarms on drainpots

Operation awareness of CIWH did avoid a repeat of the Case 1a event.

Case 2

During the commissioning of a larger steam turbine the plant was left overnight with steam flow to the steam vent and the steam branch line to the turbine left as dead leg.

There is one low point and a steam trap on the leg to the turbine. The steam trap by-pass was being used, being partly open to discharge condensate. But the valve was not open enough to discharge all the condensate, resulting in the condensate partially filling the steam line.

When the steam turbine inlet stop valves were opened the next day, a condensate slug travelled up the steam piping and stopped only at the partly open turbine governor valve.

Damage included; pipe supports, strainer gaskets blow-out, and a damaged turbine governor valve.

Either the cool condensate blocked off the steam line and steam space between the turbine and low point collapsed, or the increase in steam flow drove a condensate slug along the pipe line.

Level detection was fitted to the steam trap pot and a high alarm prevents the turbine valve opening (run permissive).

Case 3

A two-phase line was being commissioned. This line runs downhill to a manifold. During commissioning the line was left running overnight with a small flow to keep the line warm.

The warming flow was vented at the end of the line from a vent line on top of the pipe.

When the two-phase flow was increased the next morning there were hammer events in the manifold. The line was shut down. There was no damage.

The overnight warming flow was small and only flowed across the top of the water in the manifold. The water lower in the manifold cooled. When the flow increased the cooler water was stirred to the surface and collapsed steam vapor in the two-phase flow.

The manifold was reconfigured with the warming line located to the bottom of the manifold. A temperature transmitter was also installed at the bottom of the manifold.

Case 4

A hybrid power plant using organic Rankine power convertor (ORC), cools separated water and condenses steam. The two fluids are mixed at the start of the downstream reinjection line.

When the separated water ORC units are off-line, the water is bypassed direct to reinjection. During unit commissioning there was insufficient reinjection back pressure so the hot water flashed and formed steam vapor in the reinjection line. Because the flow was low, channel flow was created in the line. Condensate flow from the steam ORC unit was started and injected cold condensate into the reinjection steam space. The steam space collapsed and the resulting CIWH sheared off a large concrete pipe anchor. (A colleague of the author working on site saw their desk jump up 100 mm.)

This situation can be avoided or mitigated by;
- Do not by-pass the ORC flow to reinjection during transient situations, dump hot water to pond instead
- Maintain greater than saturation pressure in the downstream reinjection line
- Mix ORC outflow into a section of piping that is always flooded.

Case 5

A separation plant has two two-phase branch lines that run uphill to the plant. The well on line A was closed and the opposing line B was operating. The lines have isolation valves at the separator, these were open. There are rupture discs on the two-phase lines at the separator end.

Line A has a drain at the well end. This was open and discharging water.

Well A was open and flowed into the bottom line A. After a short time there was a CIWH event that ruptured the burst discs. The operator then travelled to the separation plant and closed valve A. This caused another CIWH event.

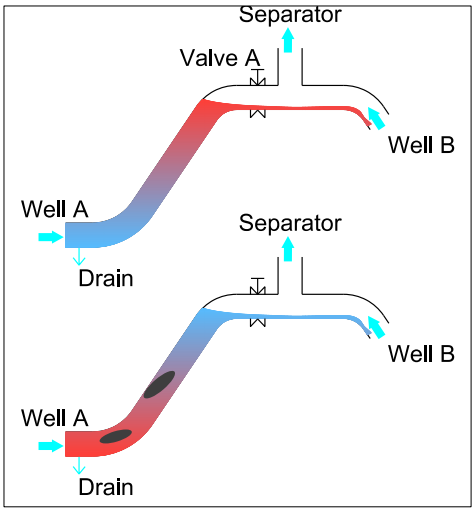

Figure 3 Case 5, before and after Well A started flowing



Figure 4. Line Stop Support Damage case 5. Estimated load 940kN.

Before opening Well A, Line A was filled with water from Line B. The drain on line A was not large enough to drain all the water from line B. The water in line A cooled as it moved toward the drain. This water was also under hydrostatic pressure, so was well under saturation temperature. When Well A was opened, the two-phase fluid entered into a colder fluid zone. The steam fraction from Well A would have been collapsing as it mixed with the water in line A. This steam warmed the water and the point of steam void collapse moved up the line. The voids would have become larger and hammer events more violent. Eventually the pressure wave from a void collapse ruptured the burst disks on Line A.

When the operator closed Well A and then closed isolation Valve A, the steam void became trapped at the top of Line A and there was another hammer event similar to Figure 1.

The lessons from this event include;
- Avoid uphill two-phase lines
- Heat uphill lines from the bottom
- Improved operator procedures and training

3 DISCUSSION

As shown here, CIWH events are a risk in geothermal plant operations. These events do occur in steam, two-phase, and reinjection lines. They can also occur in ORC motive fluid systems. In New Zealand the robust design of piping systems has mitigated the consequences, and not resulted in a loss of containment or serious injury.

Awareness of CIWH by plant operators and engineers is important in reducing the risks to safety and business.

CIWH should be included in your plant HAZID and HAZOP studies and design reviews.

Design systems and procedures to avoid CIWH events being initiated. The forces from CIWH events are large and difficult to predict. Do not expect pipeline restraint structures to be able to absorb these forces.

4 ACKNOWLEDGEMENTS

The permissions to publish the details of these case studies from the plant owners is much appreciated. Sharing experiences will lead to safer plant operation for all plant owners.

The time provided the engineers from these owners to discuss the events and support this paper is also appreciated.

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