THE USE OF VENTURI DURING BINARY PLANT PENTANE EVACUATION

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ABSTRACT

The use of a binary cycle to extract energy from geothermal fluid for power generation is a well-established method. The main Achilles heel with these systems is the common use of a hydrocarbon based motive fluid in the process and the accompanying risks which are present when managing a flammable substance. One such instance of exposed risk occurs during maintenance work when breaking into the closed system. It has now become common in NZ to demand a full pentane evacuation and inert gas purge, utilising a vacuum pump and nitrogen gas generation plant, before a permit is issued to the work party; In doing so, striving for a full elimination mindset of workplace risk reduction.

An additional method has been developed by Ngawha Generation Limited which can be used in conjunction and complements existing practices to reach desired Lower Explosive Limits. The utilisation of an air driven Venturi known as an Air Horn or Eductor has been trialed. These are commonly used in meeting confined space ventilation requirements for underground storage tanks in the industrial and wastewater sectors. In the application it was used at Ngawha, the eductor was placed on the shell side of the recuperator vessel just downstream of the turbine outlet spool. During the works involving the removal and re-installation of the spool piece the eductor drew in air at the work front and expelled it to a safe location using ducting. The air carried away any pentane vapor that was still being liberated. The large volume of air displacement compared to that of pentane vapor resulted in a vented mixture which did not reach lower explosive limits at the discharge point. No hydrocarbons were detected at the work front, which is something current methods often fail to achieve.

1. INTRODUCTION

1.1 Binary Plants and the use of pentane

Binary plants allow the efficient extraction and greater utilization of thermal energy from geothermal fluid. Typically being utilized in geothermal fields in which the fluid chemistry and/or enthalpy do not allow for the use of direct steam turbines. The main Achilles heel with these systems is the common use of a hydrocarbon based motive fluid in the process and the accompanying risks which are present when managing a flammable substance. In this case N-Pentane (C_5H_{12}) is used, it has a lower explosive limit of 1.5% vol and boils at around 37°C.

1.2 Ngawha Geothermal Power station

Ngawha Generation owns and operates 4 Ormat geothermal binary plants, the first of which were commissioned in 1998. The current total combined output of these units is a nominal 57MW Net.

Ngawha Generation is a subsidiary of the Top Energy group, which is wholly owned by the Top Energy Consumer trust. All profits generated are put back into the community.

The Ngawha geothermal field is a medium enthalpy field of around 1000 kJ/kg and 200°C with various minerals dissolved in solution. As such a binary plant is the only practical means of electricity generation from this field.

The location and the distance to geothermal operators in the central plateau means specialist equipment and skills are less readily available and accessible.

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1.3 Ngawha Generation OEC4

OEC4, a 32.5MW net ORMAT geothermal binary plant, was commissioned late 2020/ early 2021. After approximately 4 months of generation, it experienced a very early bearing failure on the clock-wise turbine coupling side bearing. Resulting in an unplanned forced outage which took 658 hours to repair.

The working volume of pentane in this plant is 330m^3. A volume which itself creates challenges around transportation and storage, let alone the major hazard facility requirements.

The condenser structure has been separated into two compartments by design, to allow for generation on one turbine while the other is having work completed on it, this feature was not utilized during this outage. This split system nonetheless helps with storing the volume of pentane, along with the shell side of the preheaters and vapouriser.

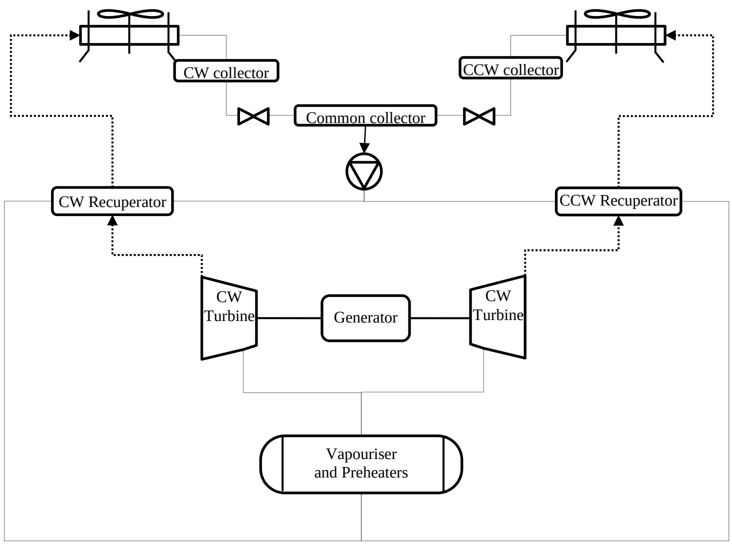

Figure 1: Simple process flow diagram of Ngawha OEC4 (Geothermal fluid excluded for simplicity)

2. TURBINE EVACUATION PRE-WORK

The preparation needed to allow safe access to the turbine requires two main steps. The first step being to remove as much pentane liquid as possible and draw down remaining vapor, to allow step two to be completed, remove the spool behind turbine and install a blank flange. The second process takes roughly 1 hour, with vigorous controls around pentane detection and the use of spark free tools. Once the blank has been installed, the turbine overhaul team can focus on their work at hand with a greatly reduced risk of pentane in their work environment.

No hot works were planned or completed during this outage. Different precautions would be needed and are outlined in McLellan et al.

2.1 Pentane Transfer and Nitrogen pressurization

In the first instance all liquid pentane which can easily be removed is transferred out of the system which is to be broken into. Typically, it is transferred to onsite storage tanks or parts of the plant which will not be worked on, such as the shell side of the heat exchangers and in OEC4's case the opposing turbine/ condensing tower. Complete removal of all pentane is not practical and would create far greater risks, such as station to road tanker transfer and transportation on public roads though densely populated regions of NZ.

Nitrogen is added to the condenser to collapse and turn the pentane vapor that is still present in the system into a liquid. Pressurizing the system also aids with the speed of liquid transfer as it increases the net positive suction head delivered to the pneumatic pumps.

The importance of low point drains cannot be overstated when designing binary plants. The size of them need not be larger than 1" and they do not need to be hard piped into the transfer system.

2.2 Vacuum pump

Once all easily accessible pentane has been removed from the system in question, typically a vacuum pump is utilized to boil off any remaining pentane. The pressure required for this to take place along with the temperature is shown right.

Once the pentane starts to boil and change phase, energy is absorbed from the surrounding mass for its latent heat of vaporization. These areas become cool to touch and can easily be spotted using thermal imaging cameras. The localized cooling of pentane makes it more difficult to continue boiling it, as a lower pressure is now required. To counteract this and speed up the process external warming can be applied, such as warm water. Care must be taken that no freezing takes place on pressure piping as this can have effects on long term metallurgy properties of steel, such as ductility or crack propagation from defects. As such, vacuum pumping does not come without its own new risks.

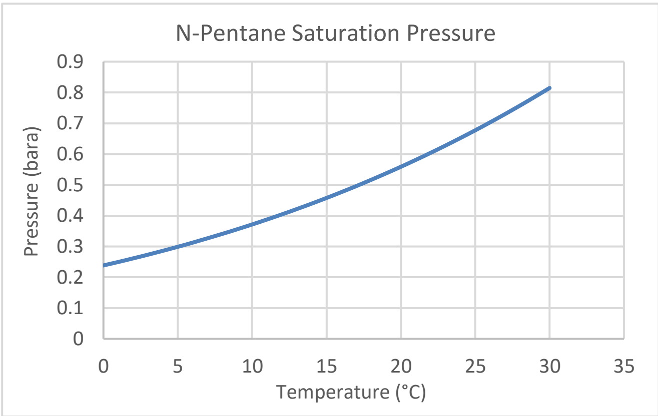

Figure 2: N-Pentane Saturation pressure with respect to temperature.

2.2.1 Vacuum pumping and nitrogen addition of OEC4

While OEC4's CW Condenser structure was pumped down to remove any residual pentane vapor and liquid, it became evident that the valves isolating this system from the adjacent systems were passing.

The graph below shows the primary draw down and corresponding flattening of pressure as pentane begins to boil inside the CW condenser structure form t=0 to t=5 hrs. However, while this is taking place communication with the adjacent system (Common collector) and the system connected to that (CWW condenser) is clear. Continuing to draw down the CW side would have resulted in continued pentane carry over from around the plant, negating the purpose of drawing down a vacuum.

From t=5 hrs, the vacuum pump was stopped and the vacuum broken with nitrogen, until around t=7.5 hrs, at which point the system was pressurized to 1.2 bara with nitrogen, this was done to collapse any pentane vapor present. From t=7.5 to t=20 hrs all three systems equalized in pressure to 1.05 bara, again confirming communication between the systems.

This is a demonstration that an elimination mentality is not always achievable.

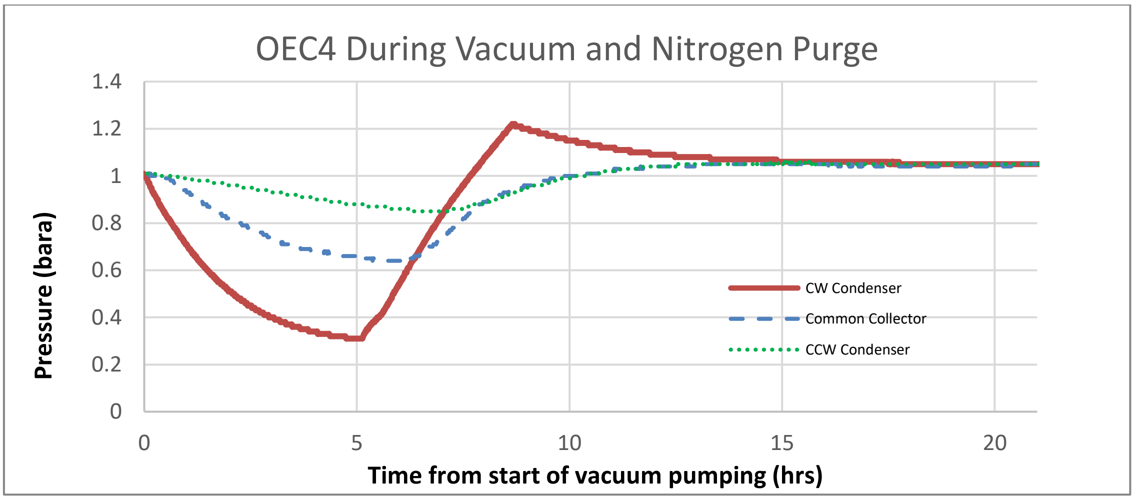

Figure 3: Pressure readings across three separate systems during vacuum pumping and nitrogen filling.

3. REVIEW OF STANDARD PRACTICES IN OTHER INDUSTRIES

The similarities of the hazards workers are exposed to in a coal mine or other confined spaces and that of opening a pentane system are striking.

Eliminating flammable gases and liquids or any other dangerous gases from a work front should be the goal. However, if attempting to do this creates new and less manageable risks or it is simply not possible, means of alternative risk reduction need to be implemented. The most commonly used method is forced ventilation.

Methane strata emitting rock faces in coal mines are much the same as sweating pentane from steel surfaces or that from passing valves. Mines apply enough air at a great enough volume and velocity to dilute these gases to acceptable levels. This allows heavy machinery and personnel to work non-stop at the coal face, even with the knowledge of vast volume of methane constantly being emitted around them, as outlined in Kissell, F. et al.

3.1 Venturi Eductors

One way to create a high displacement of air is to utilize a Venturi eductor, also known as an air horn. These are commonly used to ventilate confined spaces or long underground pipes and ready them for personnel entry. Venturi eductors run on the principle of the Venturi effect, the Venturi effect is the reduction in pressure that results when a substance flows through a constricted section of a pipe. This reduction in pressure can draw in matter from a secondary system. In the case of the eductor, compressed air is forced through small holes around the internal periphery of a cone causing a reduction in pressure, this draws up air from below the cone, and together the two gas flows exit the cone at the top.

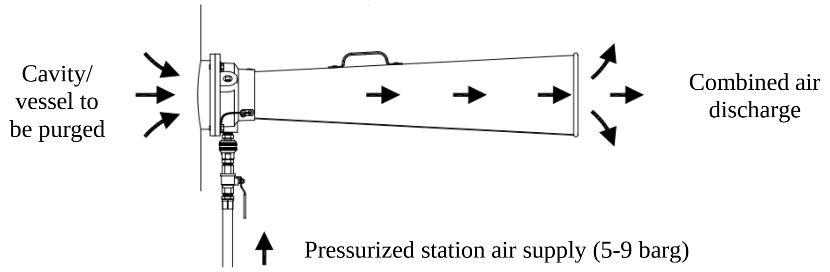

Figure 4: Simple operation of an air driven Venturi eductor.

A total flow to compressed air ratio is roughly 30:1, with the model used at OEC4 a total flow of roughly 3500 cfm or 100 m^3/min was achieved per unit. Two units were used in the case of OEC4.

3.2 Eductor venting location

This method of venting was by no means thought of during the design or the building of the plant. It is strongly suggested that more focus is put on this particular job when designing Binary plant using flammable motive fluids. It was fortunate that two 6” CL150 inspection flanges were found on the recuperator shell side heat exchanger, large enough to not impair the high air flow required. Each inspection flange received a new isolation valve, which are now permanently fitted for future use.

Figure 5: Location of 6" CL150 Inspection hatches on recuperator

3.3 OEC4 ventilation

To further improve the work environment during the turbine spool removal and blank flange install, an eductor was used to divert and dilute any pentane vapor which may have still been present in the condenser structure. This is shown in the diagram below. The small volume of pentane that drifts down to the recuperator (in green) is mixed with air drawn in from openings (blue) around the turbine/ spool area. These openings are created, and valves opened just as the eductors are turned on.

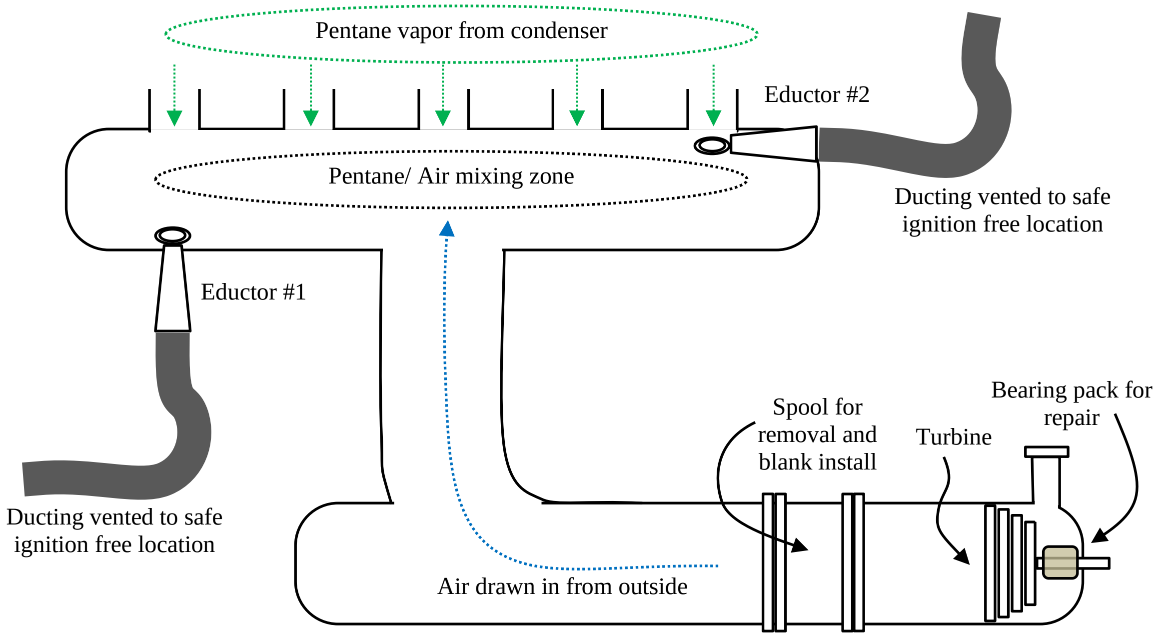

Figure 6: Schematic of the venting operation ready for the spool piece to be removed.

The resulting air and low pentane mixture was vented off to a safe location away from any sources of ignition with intrinsically safe 250mm ducting. This discharge was routinely measured and had a peak LEL of 4% (around 600 ppm) at the start of the venting, dropping off to levels not detectable with handheld personal gas detectors. A MiniRAE 3000 + was used and measured around 50ppm throughout the job.

The caveat with this method is that there is still a small volume of pentane/O_2 mixture present inside the shell side of the recuperator which would see 100% LEL conditions. Though a very small amount, it is still to be considered, though it is extremely unlikely for an ignition source to be present.

All fixed equipment is earthed to the plant earth grid by design and temporary equipment such as the eductors and ducting was also earthed. The working party was around 10m away from this pentane air mixing zone, with a fresh air separating the two. The end of the ducting exhibit conditions which do not allow combustion to take place, both with respect to gas mixture as well as spark generation. Anecdotal comments from the working party working on the spool piece mentioned that this was the first time they had not detected pentane in their work front on any plant when completing this task.

Figure 7: Left- Venturi, ducting and isolation valve installed on inspection hatch. Middle- Turbine halfway through repairs, with two Venturi eductors and ducting still in place. Right - Spool piece being removed ready for blank flange install.

CONCLUSION

The use of forced air ventilation by use of venturi educators is a practical way of further reducing the risk of a pentane incidents when preparing for turbine repairs. Particularly when full eliminations of pentane vapor is not possible, which is often the case during turbine spool removal. It is suggested that future designs of these plants incorporate additional drain points in locations pentane may pool, extra isolations are included where practical and blanked flanges are incorporated to allow for high air flow venting.

ACKNOWLEDGEMENTS

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