PERFORMANCE OF A MODEL IN-LINE VORTEX SEPARATOR

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ABSTRACT

A scale model of the Ohaaki vortex separator was tested using air and water to simulate the HP turbine exhaust wet steam. The model separator had a separation efficiency of between 75% and 98% for the ranges of air and water flow rates tested. A small proportion of the injected water vaporized in the warm air causing some water to be unavailable for separation. However, this is analogous to water flashing due to pressure drop in steam-water flow.

The model tests showed that gravity settling rather than centrifugal action appeared to predominate the separating mechanism. The presence of the helicoid vanes appeared to cause water droplets to reentrain in the air stream rather than centrifuged them onto the wall of the separator. Further tests are recommended with the helicoid vanes removed and the vortex separator replaced by a model Ohaaki drain pot.

INTRODUCTION

Most geothermal resources capable of electricity production are water-dominated and current technology is to flash and separate the steam phase to power steam turbines. Depending on the wellhead pressure, the steam can be cascaded to two- or three-pressure systems to maximize steam utilization.

Prior to 1983, Wairakei geothermal power plant was operating a three-pressure system with HP, IP and LP steam at 12.5, 3.5 and 0.1 bar gauge nominal design turbine inlet pressures. Since the flashed steam is saturated, the exhaust steam from each turbine is wet. The HP exhaust steam was approximately 6% wet, equivalent to 15 tonnes/hour condensate.

At Wairakei, an in-line vortex separator was installed close to each HP turbine exhaust within the turbine house to separate and collect the condensate which was then discharged to the atmosphere by steam traps. The vortex separator had the shape of a truncated cone laid with its axis horizontal. Helicoid vanes were positioned slightly downstream from the entrance at the truncated end so that vortex action centrifuged the water droplets onto the wall of the separator. The closeness (less than 10 pipe diameters) of the vortex separators to the turbine outlets had caused erosion of the vortex separators. Although flow regime maps might indicate that the flow at the turbine exhaust was annular flow, the actual flow was likely to be disperse flow because the water droplets were in the process of formation as the steam flowed through the turbines.

The continuous drop in steam pressure at Wairakei since it was first commissioned in 1958 led to a derating program which made the HP steam redundant after 25 years of service. The Broadlands-Ohaalu geothermal field was targeted for development at that time and decision was made to refurbish the Wairakei HP turbines for initial commissioning at Ohaalu. Experience at Wairakei led to a plan to derate Ohaalu within 10 years by which time the refurbished HP turbines would have come to the end of its useful life. The layout of the Ohaalu station pipework is as shown in Figure 1.

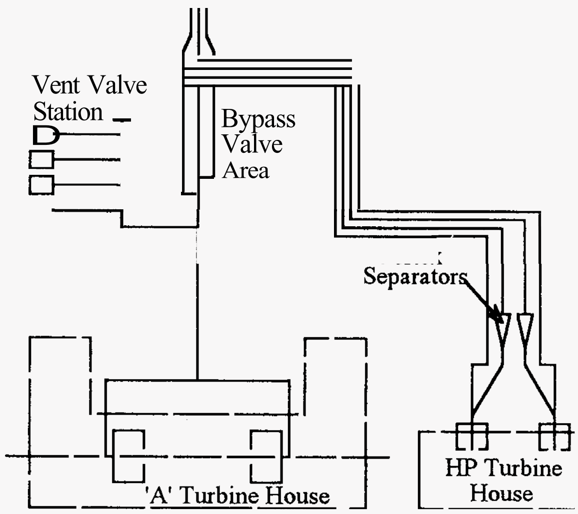

Fig. 1: Layout of Ohaaki staiion pipework (Lee and Jenks 1989)

Experience at Wairakei also led to locating the vortex separators further away from the turbine exhausts and outside the turbine house for ease of maintenance. The design of HP turbine system followed closely that of Wairakei for obvious technical and economic reasons. However, little investigation was made to check the need of the vortex separators whch were large and complicated to fabricate. The performance of the vortex separator was not well understood. It is the author's opinion that the vortex separators were unnecessary and could be replaced by the improved drain pot design made in the early 1980's (Lee 1982).

The aim of the model test was therefore to investigate the performance of the vortex separator and to see if the vortex separator could be replaced by other low cost means such as a drain pot.

EXPERIMENT

The actual Ohaaki vortex separator has a flange-to-flange length of more than 3.6 m, an inlet flange of 900 mm nominal diameter and the large end cone diameter of 2.6 m. The dimensions of the model vortex separator are as shown in Fig. 2. The model was made to a scale of 1:8.8 for ease of connection to existing pipe of 100 mm OD. This gives a maximum air velocity of *28* m/s (limited by the air supply Roots Blower). The Ohaaki geothermal steam transmission velocity at the vortex separators is within **30-40** m/s.

The shell of the body of the model separator was made of clear polycarbonate sheet so that the flow inside could be visualized. The shell was made of three plies because the truncated end of the cone was small and only a thin sheet (0.5 mm) could be bent to form the cone and the body must be reasonably robust for handling. The butt joints were staggered 120° apart and held by epoxy resin glue. The fixed helicoid vanes were glued to the inside wall of the shell and to a center stainless steel cone-shape piece. The exit pipe connector was also made of stainless steel for strength.

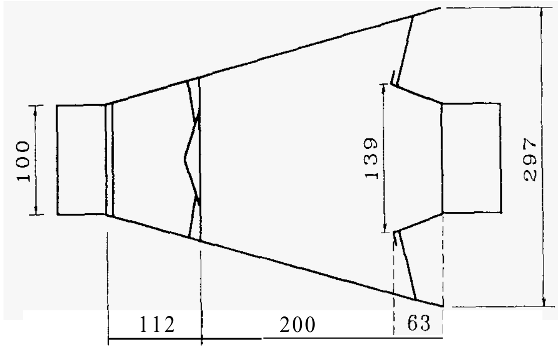

Fig. 2: Dimensions of the model vortex separator.

The layout of the experiment is as shown in Figure 3. The model separator was installed at approximately *50* straight pipe diameters downstream from the water injection point to allow for steady dispersion of the water droplets in the air stream. This also allowed pressure drop measurement in the straight pipe section for comparison with the separator pressure drop. Due to a lack of space, the downstream straight pipe was ignored. The maximum air flow from the Roots Blower (model 810 series 3) was 0.26 kg/s at a pressure of 9.5 kPa gauge. The air flow was measured by a flow nozzle. A mercury manometer gave the upstream pressure and a water manometer measured the pressure drop across the flow nozzle.

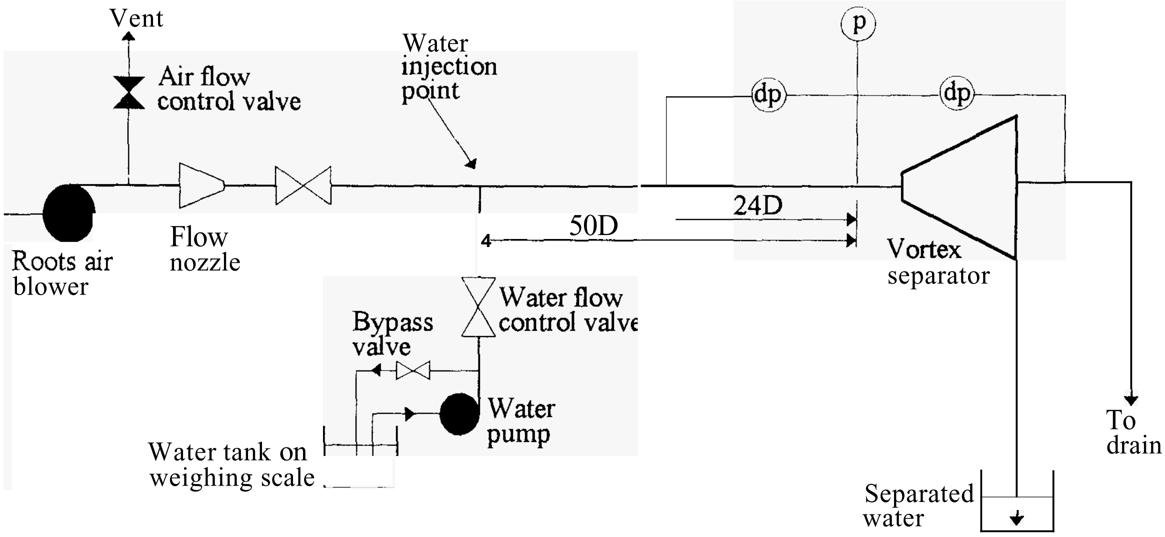

Fig. 3: Layout of the experimental rig.

The water flow was supplied from a centrifugal pump through three needle nozzles injecting radially into the pipe. Due to the small flow required, a bypass circulation was needed to control the water flow. The water flow rate was measured by a mass balance weighing the loss of water from the tank over a period.

Pressure drop measurements were made on the straight pipe length and across the vortex separator. The static gauge pressure at the inlet of the model separator was also measured by a water manometer. As the flow is a two-phase air-water flow, a 'separating pot' was needed at each pressure tapping to trap the water and allowed only the air to the water manometer.

SEPARATING MECHANISM

Mechanisms which may be used for separating liquid particles from gases are (Perry & Green, 1984):

- gravity settling
- inertial (including centrifugal) impaction
- flow-line interception
- diffusional(brownian) deposition
- electrostatic attraction
- thermal precipitation
- flux forces (Stefan flow, thermophoresis, diffusiophoresis)
- particle agglomeration (nucleation) techniques.

Most collection devices rarely operate solely with a single mechanism, although one mechanism may predominate.

The separating mechanism of the vortex separator includes four basic mechanisms: gravity settling, centrifugal action, impingement and reentrainment. Although the name vortex separator may suggest that centrifugal action may predominate in the separating mechanism, observation of the model separator showed that gravity and reentrainment appeared to predominate.

Generally, reentrainment increases with increasing gas velocity. In devices collecting primarily by centrifugal and inertial impaction, primary collection efficiency increases with gas velocity; thus overall efficiency may go through a maximum as reentrainment overtakes the increment in efficiency (Perry & Green, 1984).

Observation of the model separator showed that the water phase flowed at the bottom of the pipe up to the entrance of the separator and the presence of the helicoid vanes caused the water to be picked up and broken up into droplets by the air flow. Although most of the water droplets eventually centrifuged onto the wall and drained away by gravity, the exit air was clearly felt wet by hands and reentrainment was clearly visible. This is clearly shown by the measured collection (separation) efficiency which decreased with increased air flow as discussed below.

RESULTS AND DISCUSSION

In this experiment, the maximum air flow of 0.26 kg/s gave a maximum superficial air velocity (Vsg) of 28 m/s in the 100 mm upstream pipe connected to the vortex separator. To get a reasonable range of air flow so that results could be plotted on graphs, three air flows were selected so that the superficial air velocity had a range of 10 m/s from 18 m/s to 28 m/s. For each air flow rate, nine water flow rates were made up to a wetness of 28%. Separation (collection) efficiency is defined as the ratio of the measured water mass flow rate collected from the separator to the water mass flow rate injected.

Figure 4 showed a graph of superficial air velocity (Vsg) versus separation efficiency. The three air flow rates are clearly identifiable on the graph.

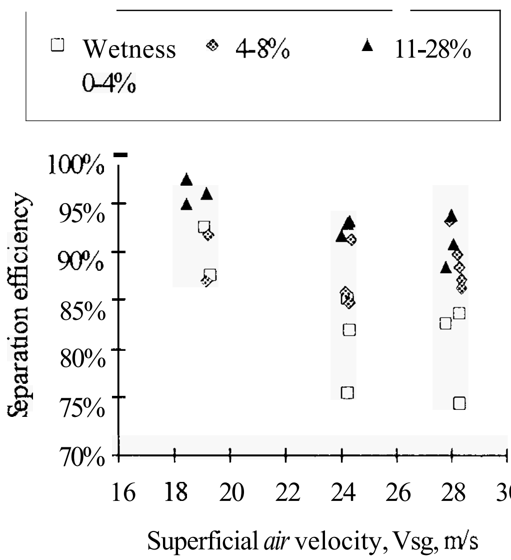

Fig. 4: Superficial air velocity vs separation efficiency

The water flows were divided into three groups accordmg to the wetness of the resulting two-phase fluid as shown on the graph. The graph clearly shows that the efficiency was highest (98%) for low air flow and high wetness. It confirms the observation that high air flow actually caused water to reentrain into the air stream resulting in low collection efficiency. The lowest efficiency of 75% was among the highest air flow rate and lowest wetness group. This low efficiency could also be due partly to the higher fraction of the injected water vaporized in the high air flow. This was worsened by the higher air temperature to maintain the higher air flow from the Roots blower. However, these phenomena are similar to flashing of water due to the pressure drop in steam-water flow. Therefore, one would expect the range of variation of the separation efficiency to be siinilar for both the air-water and steam-water flows.

Figure 4 also shows that the centrifugal action had been overcome by reentrainment at an air superficial velocity of approximately 20 m/s. This is concluded from the spread of the separation efficiencies: the efficiency variation range doubled above 20 m/s.

Figure 5 shows a plot of inlet mass wetness versus separation efficiency for the three superficial air flow rate groups. The graph' shows that mass wetness appeared to be the better collerating (i.e. dominating) factor than the superficial air velocity.

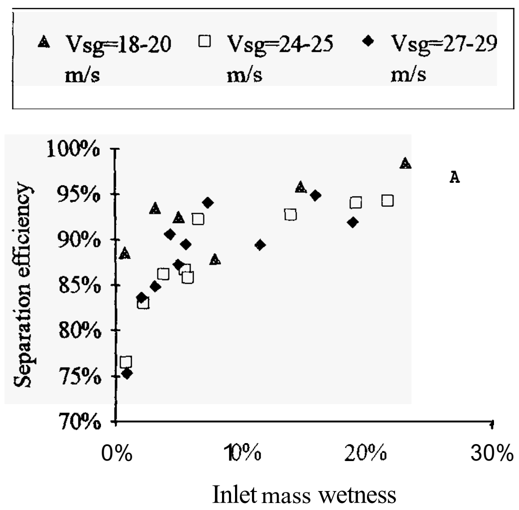

Fig. 5: Inlet mass wetness vs separation efficiency.

The efficiency stays approximately constant between 88% and 98% for Vsg < 20 m/s but varies with wetness from 75% to 95% for Vsg > 20 m/s. The vertical spread of the points would be expected to be less if the helicoid vanes were removed. In other words, the separator would be more efficient without the vortex and just rely on gravity settling. This is still subject to confirmation by further tests. If gravity settling was the predominant separating mechanism, a standard drain pot as used at Ohaaki would be suffice to remove the condensate from the steam pipe.

Figure 6 is a plot of the superficial air velocity versus pressure drop across the vortex separator and that of the upstream piping. The pressure gradients measured across 24 pipe diameters (D) of the pipe for the range of air and water flows were between 5 and 10 Pa/D. The net pressure drop across the separator (deducting the length of the separator) varies between 24D and 35D. The pressure drop across the separator would be due mainly to the helicoid vanes. Therefore, the removal of the vanes not only would increase the efficiency but also reducing pressure drop by up to 35 pipe diameters (350 Pa for the model separator).

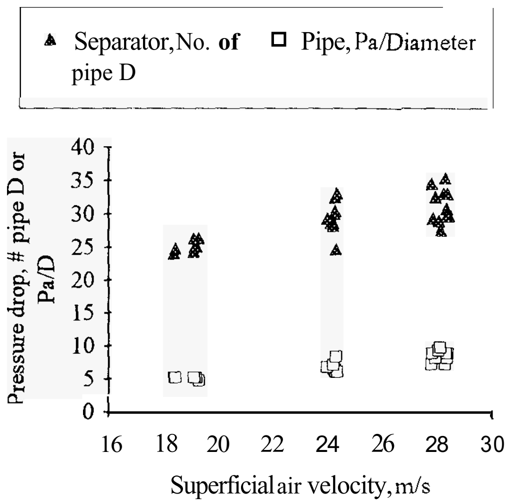

Fig. 6: Superficial air velocity vs pressure drop.

CONCLUSIONS

The vortex separator has four separating mechanisms: gravity settling, centrifugal action, impingement and reentrainment. Gravity settling rather than centrifugal action appeared to predominate.

The maximum collection efficiency was 98% at a superficial air flow velocity of less than 20 m/s. The efficiency decreases above air velocity of 20 m/s due to reentrainment.

Collection efficiency appeared to correlate better with the inlet mass wetness than with the superficial air velocity. The correlation is expected to be similar for steam-water flow because vaporization of water in air flow is analogous to water flashing due to the pressure drop in steam-water flow.

The helicoid vanes of the vortex separator caused reentrainment **of** the water droplets rather than centrifuged and removed them from the air flow.

Removal of the helicoid vanes not only would improve the collection efficiency of the vortex separator by gravity settling, but also reduce the pressure drop across the separator by up to 35 pipe diameters.

As the predominant separating mechanism appeared to be gravity settling, a standard drain pot as used in Ohaalu could be used instead of the vortex separator. This will be confirmed pending further tests.

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