Brady Power Plant Steam Quality and Purity Enhancement

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ABSTRACT

Brine carry-over from the high pressure and low pressure separators was causing heavy scale build-up on the turbine nozzles and components. This resulted in higher maintenance, reduced power generation and contributed to premature failures of a turbine rotor. Several options to mitigate the impurity laden steam problem, including conventional and experimental methods, were investigated. ESI, seeking cost-effective technology to improve the bottom line, chose a promising but unconventional low-cost, fast track alternative to revamp the facility. This commitment resulted in up to a 25 fold improvement in steam quality and purity; and was engineered and installed in one half (50%) the time, for one third (33%) the cost of a conventional geothermal design.

Introduction

The Brady Power Project is located approximately 60 miles east of Reno, Nevada, next to Hwy. I 80. This 26 MW Gross, pumped-well, dual flash plant, utilizes two high pressure (HP) turbines (9 MW each) and one Low Pressure (LP) turbine (8 MW). The project is owned and operated by Brady Power Partners (BPP) and Brady Power Services, Inc. respectively, affiliates of ESI Energy, a wholly owned subsidiary of the FPL Group.

In May 1992, the power plant began operation and incurred a number of technical problems that were systematically resolved. Turbine scaling and subsequent damage would, however, continue to plague the plant. Scaling had become severe on the two HP and the one LP turbines as a result of poor steam quality and purity. Heavy scaling would form on the 1st, 2nd, 3rd, and 4th stage nozzles compromising turbine efficiencies. LP turbine rotor blades have been replaced as a result of massive blade failures experienced.

Several options to mitigate the impurity latent steam problem were evaluated. High cost conventional methods utilizing stand-alone high efficiency centrifugal and impingement separators were studied as well as low-cost techniques with no proven track record. Standard high-cost methods required long fabrication lead time, extensive piping, and structural additions including a long shut-down window for installation and a corresponding loss of generation. The low-cost techniques offered high pay-back but required risk assessment.

In January 1995, the Brady Power Plant underwent a major steam purification revamp to enhance the removal of mineral and liquid impurities from the vapor fraction. The LP and HP separators' primary sections and secondary "demister" sections were internally modified. Special high performance condensate collectors were installed to further enhance the steam prior to entering the turbine. All the work was coordinated and installed during a one day shut-down. Turbine scaling was mitigated following the modification.

On October 31, 1996, new higher efficiency LP steam turbine internals were installed. After nearly six months of operation, an inspection reviewed a return of scaling on the first stage nozzles. A comprehensive steam quality and purity testing program was initiated to determine the cause of this scaling. The investigation pin-pointed the problem to a plugged brine drain line. The line has since been cleared and secondary measures are in place to improve impurity removal. This malfunction demonstrated the need for a continuous steam quality and purity monitoring system. Currently, the geothermal industry has no proven or developed means to accurately and continuously monitor steam quality and purity. Had a system been available, this problem could have been detected and corrective action taken earlier.

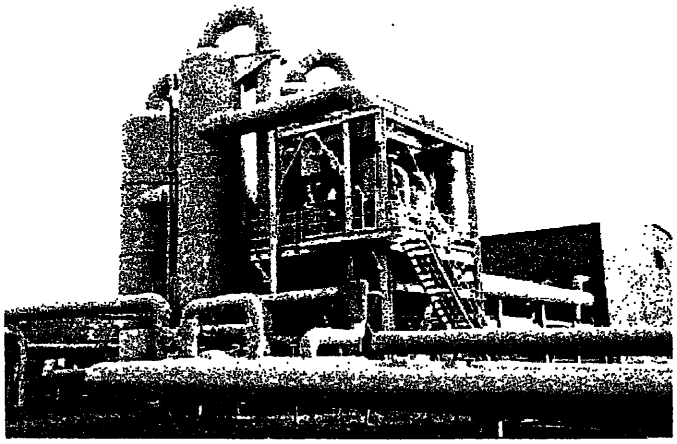

Figure 1. Turbine separator station and turbine building.

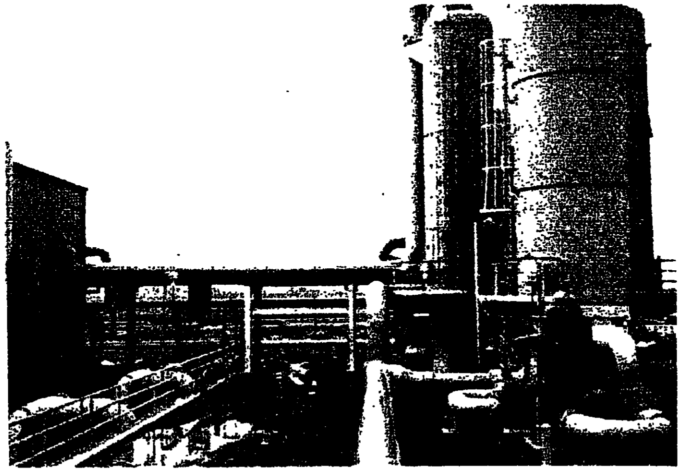

Figure 2. Brady steam piping to turbines *(left of picture).*

Field Operations

The Brady Hot Springs Field currently has 6 producing wells and 3 injection wells. Each production well has a 500-700 Hp downhole pump. Instead of allowing the fluid to naturally flash in the wellbore and flow as two-phase fluid to the plant, each production well is pumped, keeping the fluid in the liquid state. The hot brine is collected under pressure through a gathering system network and flashed at the plant separators (Figures 1 and 2) to maximize utilization efficiency.

The plant was originally designed to process 12,000 gpm of pumped brine at 350°F. The hot brine enters the plant where the flow is split and is flashed in two HP separators . Approximately 380,000 pounds per hour of steam at 60 psia is produced, approximately one-half (1/2) going to each turbine generator (TG).

The combined brine fraction from the HP separators is gathered for a second flash in the LP separators to produce additional steam. The 1,160,000 pounds per hour of rejected brine at 60 psia and is flashed at 34 psia to produce approximately 220,000 pounds per hour of LP steam. The steam flows into TG 1 producing approximately 8 MW of power. The brine leaving the LP separator is distributed and re-injected into the periphery of the geothermal field.

Original Separator Design

The Brady Power Project utilizes three centrifugal separators to purify the steam for power generation. There are two vertical HP units and a single vertical LP unit each in series with several drip pots per line to remove condensate during start-up, prior to the turbine inlet. The tightly grouped separators are positioned directly adjacent to the turbine building to keep the land and pipeline usage to a minimum. As we will see later in the paper, this tightly packaged process layout, beneficial to offshore platforms, has inherent draw-backs for geothermal steam processing facilities.

The vertical centrifugal separators are an upflow design incorporating an internal liquid guide plus a secondary centrifugal demister element. The flashing brine flows through the tangential entry of the vessel causing a spin. The centrifugal force isolates the brine fraction against the vessel shell where gravity draws the denser brine to the bottom of the vessel. An internal guide is employed to force the liquid fraction downward. The steam fraction spirals upward and enters the centrifugal demister prior to exiting the vessel.

Conventional power plant type drip-pots are installed along the pipeline between the separator to the turbine entry. Close coupled elbows, discharge vortices, short straight runs of pipe, high velocities and pot designs reduced the ability of these scrubbers from removing liquid.

Turbine Damage

Turbine scaling was severe on all the turbine units. As can be seen in Figures 3, 4 and 5. Power output would decrease on a daily basis resulting from clogged nozzle passages. The build-up would create high bowl pressure requiring frequent shutdowns for cleaning. Online turbine washing was later implemented to erode away turbine nozzle scaling and blade build-up, to keep the system operating efficiently.

During the first year of operation, the centrifugal demister on the LP separator lost a bottom plate, allowing brine to enter the LP turbine creating severe damage (see Figure 6). Turbine nozzle scaling and turbine blade scaling would continue to present problems in the LP unit. The damage may be compounded by effects of stress corrosion cracking (SCC). The LP turbine internals have recently been replaced with a new, higher performance design by Elliot. This design can operate better at lower pressures, improves steam usage efficiency, and incorporates a scale resistant turbine coating.

Excess separator carry-over is the cause of turbine scaling. In the case of the Brady Power Plant, the carry-over from the primary section of the separator escapes the demister section, and proceeds unabated into the steam turbines. The drip-pots down-stream of the demiters are rendered useless because of the high turbulence, short scrubbing distance between the ves-

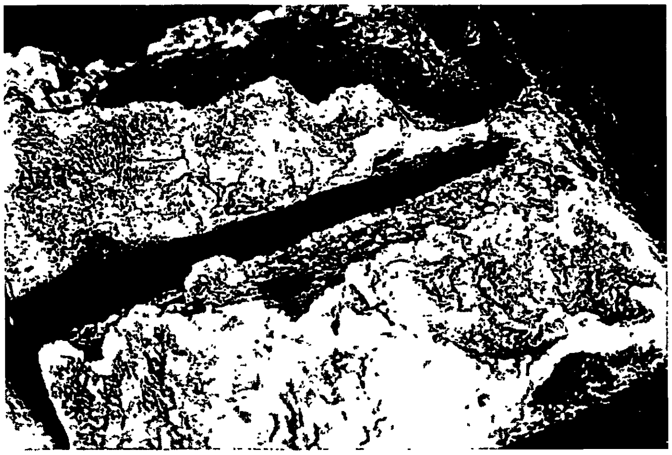

Figure 3. TG-1 LP turbine diaphragm scaling.

Figure 4. TG-2 HP turbine diaphragm scaling.

sels, and high velocities to the turbine inlet. The carry-over causes excessive scaling on the turbine nozzles and blades.

Scale is formed by precipitation. This will occur from supersaturated brine carry-over, or can be induced from heat-transfer gradient effects such as nozzle flow expansion; or silica concentrations in the vapor phase in transition across the Wilson Line. Chlorides and other impurities that concentrate can contribute to SCC on the turbine blades.

Performance Modeling

The separators were modeled and the analysis showed the primary section removing the bulk fluids. The explosive inlet however, create a considerable amount of particulate shatter. This "Borda Carnot Transitional Shock" cause liquid droplets on the inside tangential entry to shear and blow inward away from the vessel wall. The small finer droplets are sucked into a low pressure gradient zone and are entrained upward along with the steam phase.

The demisters were installed near the top of the separator to remove carry-over escaping the primary section. These demisters are of a centrifugal canister design with slotted louvers to directionally spin the brine droplets out of the vapor fraction. Although, these devices can be effective in small diameter cans, the particulate migration distance, short spin transition and reduced centrifugal force experienced in the larger diameter devices render these units ineffective for removing small particles. Particle size would need to be very large for these devices to be effective. Performance modeling indicate the exit steam quality from the HP separators would be 99.7% to 99.8%, and the LP separator with an exit steam quality of 99.5% to 99.7%.

The drip pots installed in the pipeline were ineffective in scrubbing the carry-over from the demisters. Straight runs of pipe to the turbine building are less than 50 feet, with velocities up to 200 feet per second. Drip pots are stratified flow devices and do not function well within a disperse, annular or slug flow regime. The use of these pots was restricted to piping system warm-up during start-up operations.

Revamp Options

The options on how best to revamp the facilities were complicated by a number of issues. These concerns could effect the performance, time and cost of installed facilities. Some of these included:

1. Limited space between the vessels, piping corridor, structural interference.
2. High exit velocities from separator and discharge piping.
3. Short pipe runs to turbine.
4. High pressure drop considerations.
5. Fluid Chemistry-corrosion and scale potential.

To control turbine scale build-up, the effective steam quality had to exceed 99.95%. Down-time had to be held to a minimal to prevent loss of generation. The options proposed to ESI included the following:

1. Install stand-alone polishing cyclone separator.
2. Install stand-alone mesh separator.
3. Install stand-alone serpentine separator.
4. Revamp existing separators with "multitubular" or custom serpentine internals.
5. Revamp separator inlet, demister and drip pots.

Cyclones

Polishing multistage cyclone separators used in geothermal service incur a pressure drop of typically 2 to 5 psi. This pressure loss would result in too great a reduction in generating efficiency and steam flash rate for pressures under 100 psi. For a lower pressure drop, centrifugal vessels can achieve high efficiency with a large vessel strategy. The vessels required would be big and costly to install and erect. Practical droplet size catching ability for centrifugal units are generally above 40 microns and depending upon the shear and formation rate, the effective removal particle size could be sondierable larger. It is estimated that the cost of fully install three high efficiency centrifugal unites at Brady would be approximately $850,000.

Mesh Pad

Mesh is an impingement separator. Droplets strike and coalesce onto the pad forming large particles. Gravitational forces drain the mesh, allowing the denser liquid fraction to fall to the vessel bottom. Mesh separators are restricted to low amounts of relatively clean fluid. The separation efficiency can be the highest among options being evaluated. However, the vessel size would correspondingly be the largest. Practical droplet size catching ability can be below 10 microns. It is estimated that the cost to install three units at Brady would also be approximately $850,000 because of the high specific volume and rates.

Serpentine Plates

Serpentine plates are impingement separators much like the mesh. Droplets strike and coalesce onto the bent plates forming larger particles that drain to the bottom. Serpentine separators can be installed in a smaller vessel but are restricted to low amounts of fluid if high efficiency is desired and structural damage is to be averted. These devices work well if the plates are clean, however, many designs are highly susceptible to performance degradation caused by corrosion, fouling and structural damage. Even small amounts of corrosion or fouling, affecting the relative roughness, can significantly reduce the effective through-put. The separation efficiency is very good if the gradients are controlled and the particles are moderate in size. Practical droplet size catching ability is generally good above 20 microns but can be greater than 40 microns. It is estimated that the cost to fully install three units at Brady would be approximately $750,000.

Revamp Existing Separators with Multi-tubular or Custom Serpentine Internals

A major internal revamp of the existing separators would involve simulating the two-phase flow profile within the vessel to better understand the interrelationship of the internal components. The revamp would entail a redesign of the inlet, internal baffling, flow conditioning and custom multi-tubular or custom serpentine demisters. Gradients within centrifugal devices are complex and must be accounted for in design. The vessel modifications would involve cutting and welding onto the vessel body dictating an ASME Type R Stamp requiring a certified ASME inspector on site. The downtime could take several weeks and could only be justified during a major power plant overhaul. Outside of that time frame, the cost to revamp the unit including lost generation would exceed $800,000.

Low Cost Revamp - Enhance Separator Inlet, Demister and Drip Pot

To minimize down-time, unconventional means were also investigated. The modeling of the system indicated that improvement in separation efficiency could be achieved with detailed engineering. The inlet could be modified to reduce the transitional shock effects, the demister could be modified to improve catching ability, and high efficiency condensate collectors could be installed to reduce separator carry-over. As a result of the short piping runs and tight space constraints, the available options were limited. The cost to revamp the facilities was estimated at $200,000.

BPP evaluated the options, and selected a fast-track approach utilizing new and more unconventional techniques. The selection process was based on the following criteria:

- Cumulative loss generation caused by turbine scaling was reducing project revenues.

Figure 5. TG-3 HP turbine diaphragm scaling.

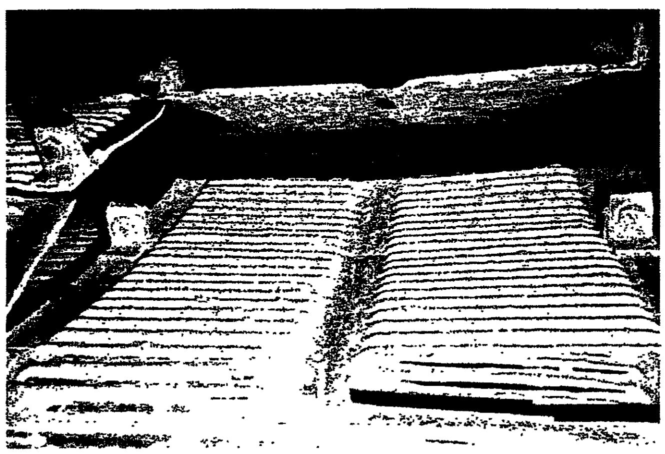

Figure 6. Scale damage to the demister on the LP separator.

- A turbine rotor had been severely damaged numerous times as a result of poor steam quality and purity.
- Additional turbine damage was imminent.
- Cumulative exposure to poor purity steam would contribute to stress corrosion cracking (SCC).
- Long downtime for revamp would be unacceptable. A short shut-down period of one day for installation was required.
- These novel techniques proposed to be used would save 2/3 or roughly $500,000 over more conventional methods.
- There was a high level of confidence on the ability of engineering team.
- A ten fold improvement in effective steam quality and purity was targeted.
- The installation would incur negligible pressure drop and flash rate loss.

Low-Cost Revamp

To fast-track the revamp, the design, long lead time material order, prefabrication and set-up were concurrent. A very short window period of one day in January was allocated for the shut-down. During this period, the plant had to be shut down, vessels drained, system cooled, confined work areas ventilated with fresh air and safety procedures implemented. Internal scaffolding and protective barriers within the vessels would be installed, consuming considerable time. Work coordination and timing would be critical.

Turbine Protection

Modifications to the system could effect the piping design and correspondingly, the stress on nozzle components. High turbine nozzle stress could result in flange, bearing and turbine problems. To mitigate this possibility, a base line stress analysis was performed under ASME B31.1 Power Piping Code for pressure, dead-weight, thermal and Seismic Zone 4 requirements. It would be compared to the pre modified system for reference and compliance.

Separator Modifications

The cardinal rule for the revamp was "don't touch the pressure vessel shell". Welding onto the vessel pressure components would require time delaying special procedures, ASME stamps and outside certifying inspectors. All welding on the vessel had to be achieved on existing support structures with none on pressure holding components. The separator modifications would include the following:

The Nozzle Inlet Transition would be modified to control the transitional shock. The abrupt influx would cause liquid droplets on the inside tangential entry to shear and blow inward away from the vessel wall. The small finer droplets are swept into a low pressure gradient zone and are entrained upward along with the steam phase. To reduce this effect, several options were available. The modification complexity, time required to install modification, and the incremental performance enhancement were considered.

An approach to partition the brine away from the inner edge of the cyclone entry was adopted to enhance the primary separation. By reducing the amount of brine for particulate shear at the entry, less primary carry-over is generated. There are secondary modes of carry-over generation. As a general rule, the less liquid loading the demister will encounter, the less carry-over it too will generate.

The Demisters are of a centrifugal can design with slotted louvers to directionally spin the brine droplets out of the vapor fraction. Although, these devices can be effective in a small six (6) inch diameter can, in large multi feet diameter drums, the particulate migration distance, short spin transition and low centrifugal force render these units only effective for removing very large particles. The strategy to enhance the separation efficiency of the centrifugal demister was to increase the particle droplet size significantly.

A special agglomerator was designed and installed upstream of the centrifugal demisters. As the vapor and entrained liquid penetrate / impinge on to the mesh pad, the slip differential increases as the particulate strike, coalesce and drain. The outlet particles have now enlarged to droplets exiting the agglomerator, then entering the centrifugal demisters to be spun out and removed. Larger mass droplets are far easier to remove than fine spray or Brownian particles. Mesh type, thickness, brine/vapor ratio, effective through-put and gradient effect all dictate removal efficiency. Chemical kinematics and material stress corrosion effects were also studied prior to the mesh selection.

High Efficiency Condensate Collector

All primary flash separators exhibit carry-over which is why secondary polishing separators are required. Properly designed and applied, drip-pots can be adequate devices, but often require 1,000 feet or more of long, straight runs of pipe to be effective. Elbows, fittings and other turbulence creator effects all disrupt the separating efficiency of stratified flow drip-pots. With conventional fossil fuel steam plant type drip pots installed in short straight runs of pipe (50 feet), and high vapor velocities (to 200 feet per sec.), the separating efficiency was virtually zero at operating conditions. The pots installed were only useful during warm-up periods when the system is starting up.

Extensive simulation of the flow profile and conditions were performed. Conventional high performance drip-pots would be grossly inadequate for the application with efficiencies in the order of less than 15% removal. A novel proprietary boundary layer condensate collector was employed to remove additional impurity from the steam. Again, inadequate space, short pipe runs, multiple tube turns would be a deterrent for optimum design.

The new boundary layer condensate collector would depend on flow conditioning for enhance removal efficiency. With nominal conditions, our modeling expectations was for a target 70% removal rate. There was no precedence for actual performance, only mathematical predictions based on in-house theory. This level of performance, when later confirmed, was a significant advancement in low cost geothermal steam scrubbing technology.

Post-Modification Testing Results

Chemistry results can often be misleading if there are errors in representative sampling, calibration and problems with contamination. In the BPP testing, two techniques were used to converge into a solution. It is very probable that, had conventional testing methods been utilized, substantial errors would have been incurred, showing far less carry-over than actual.

Laboratory results from steam sample probe runs show an average tracer concentration of 220 parts per billion (ppb) sodium entering the LP turbine prior to any adjustments to the system. Tracer dilution technique shows that if all the carry-over from the LP separator enters the turbine, the tracer concentration would be 280 ppb.

Following adjustments, the steam sample probe tracer element dropped to an average concentration of 35.5 ppb (from 220 ppb). Tracer dilution technique shows the projected sodium concentration to be 37 ppb (from 280 ppb).

The results of the steam probe sampling and the brine tracer dilution study (35.5 vs 37), are amazingly close. Steam probe representative sampling is difficult even under uniform conditions. Sampling and analytical errors of ±/- 20% are considered very good with steam probe sampling. These cross confirming results show the testing to be representative of the actual flowing conditions.

The testing show the modified LP Separator discharging an exit steam quality of 99.967%. That is to say 0.00043% of the discharge is brine carry-over. Typical high performance steam separators discharge an exit steam quality of 99.90%. That is, 0.00100% of the discharge is brine carry-over. The BPP modified separator has a higher exit steam quality as a comparison.

The total performance of the system includes the modified separator, plus the new BPP condensate collectors. When the removal efficiency of the BL condensate collectors are included in the calculations, the effective exit steam quality improves to 99.996% (99.967% sep. only). As a comparison, it should be noted that high performance separator/demisters incur an exit steam quality of 99.98%. If a conventional demister was installed directly on the discharge of the LP flash separator, the tracer steam purity would be 58 ppb vs 35.5 ppb with the current system. The performance is rather impressive considering it is a low cost option. This not to say current steam quality and purity are good enough. Turbine scaling is much more pervasive in low pressure systems and require less impurities to create a problem. Although significantly improved, additional improvements can be made.

The performance of the HP separators exceeds the performance of the LP unit. Steam quality testing shows an exit steam quality of 99.99%, with a effective total system performance of 99.998%. Scaling has been effectively mitigated in the HP units.

Conclusions

1. Brine carry-over from the BPP separators was causing lost plant generation from excessive turbine scaling, lost generation, and turbine damage.
2. BPP evaluated conventional methods, and new, cost-saving innovative techniques to resolve the poor steam quality and purity problems.
3. BPP selected a novel technique, with no proven track record, based on risk assessment and confidence in the ability of the design team.
4. The net result was:
   - 25x improvement in effective steam quality and purity
   - Project lead time reduced by 50%
   - Short one day shut down for facility modifications
   - Installed cost 33% of a conventional system @ $500,000 savings
   - HP scaling has been mitigated on strainers and turbines
   - LP scaling mitigated on strainers and substantially reduced on turbine
   - Pressure drop was minimal, with no detrimental effect on flash rate
   - Results exceeded expectations for this difficult, low cost revamp
5. BPP sought out new technology and was rewarded. Improved technology can help reduce the cost of designing, installing and operating geothermal facilities.

Recommendations

1. Consider Phase II revamp to further enhance the LP system steam quality and purity. This would involve reducing gradients within the demister and adding an internal scrubber.
2. Support the development of a continuous steam quality and purity monitoring system for geothermal power plants. Two types of instruments are required:

- *Fast Response Catastrophic Indicator* for detecting large amounts of brine carry-over. A system such as this could be used to prevent turbine destruction from transients or separator malfunctions, such as the one which damaged an earlier BPP turbine.
- *High Sensitivity Steam Purity Monitor* for tracking low impurity levels. This instrument would be used to monitor pos-

sible degradation in steam purity such as the one which scaled the upgraded LP turbine because of an undetected plugged drain line.

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