Making Geothermal Cost Competitive Production Equipment and Facilities Cost Reduction

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ABSTRACT

To meet the challenges of a competitive energy market, the cost to develop and operate a geothermal power project must be significantly reduced. Edification and improved technology will help reduce cost directly and enhance efficiency. *The production equipment and facilities* represent a segment of the overall project cost that can be reduced through judicious planning, and by applying new and developing technology. Effective cost-reduction by 30%, by the year 2000, may be possible with expedient effort.

Introduction

Production equipment and facilities (PEF) encompass everything between the well-casing and the power plant. This includes the production gathering, processing, and reinjecting facilities. Basically, once the drilling is complete, *the fluid must be brought efficiently to the power plant where it can be used and then recycled if possible.* As the industry looks for better and less costly ways to find more steam and to utilize it more efficiently on both ends of the project spectrum, the overlooked area of production equipment and facilities must also be challenged for cost-saving opportunities. This area represents an untapped harbinger of technology awaiting development that can help improve the cost competitiveness of the industry.

Clearly, more efficient methods for resource location and evaluation, such as fracture mapping, neural net reservoir simulators, etc., and the reduction in drilling cost, as well as more efficient and lower cost power plants, could significantly improve the technical/cost aspects associated with developing geothermal projects. These dominating areas of geothermal activities must be pursued, for they represent the highest expense areas of geothermal development. However, the question remains; when will these new technologies from *exploration, drilling and power plants* be available to the industry, and how much cost saving can be realized within the critical next few years?

It is the author's opinion that significant technical improvements and cost-savings can be achieved in the area of *production equipment and facilities*, within the next few years if action and not just talk prevails. This segment could represent many millions of dollars in capital cost-savings, and reduced operational and maintenance expense, per project.

The synergistic relationship between the resource, *production equipment and facilities*, and the power plant is often overlooked but is of integral importance. For instance, generic designs can be expensive. Some examples might be a lackadaisical sizing and design of the piping systems which restricts the amount of fluid that can be produced from each well. To compensate, additional wells may need to be drilled to make-up for the lack of flowing pressure. At $3,000,000 per well, this would drive up cost. Poor steam processing can lead to the clogging, erosion, corrosion and stress cracking of the turbine and other equipment. An undetected slug can destroy a turbine. Here lower efficiency, reduced equipment life and down-time can significantly impact the cost of operating and maintaining a project.

This paper will address areas where design philosophy application, and synergy with the other disciplines is important. It will furthermore address *research topics and developing technologies that have good probabilities for success* and the ability to reduce cost. It is this focus approach, and the development of cost-saving technology that can result in significant reductions in operating cost and the cost to install production equipment and facilities (PEF). Seeking better ways to design and revamp systems to enhance performance and reduce overall cost can help improve the competitiveness of the industry.

Potential Areas for Cost Reduction

The following are some of the technical areas where good potential exists for reducing cost via training, synergistic applications, or identifying and developing new technology with a high probability for success.

Design Philosophy and Application

- Piping System Design-*Impact Design Team*-25% Material Reduction
- Materials-*Alloys, Lining, In-Situ Placement of Coatings*
- Scaling and Corrosion-*pH MOD, Inhibitors, and Pigs*

Synergy

(Resource + PEF + Powerplant)

- Metering Accuracy Improvement-*20% Error Common*
- Two-Phase Flow Meter-*Production and Resource Management*
- Well-Head Throttling Valves-*Erosion Resistant, High Turn-Down*
- Turbine Scaling Mitigation-*Impurities and Gradient Effects*
- Continuous Steam Quality and Purity Monitoring-*Turbine Protection*
- Facility Optimization-*10% to 20% Production Increase*
- Two-Phase Eductors/Steam Ejector-*20% Production Stimulation*

Production Equipment and Materials

- Separators-*2/3 Cost Reduction*
- Rock Catchers-*2/3 Cost Reduction*
- Special Drip Pots-*to 200'/s @ 90% Eff.*
- Polishing Separators & Scrubbers-*2/3 Cost Reduction*
- Vent Separators and Mufflers-*Low Emissions*
- These topics will be discussed in the following pages.

Design Philosophy and Application

This section is directed at application awareness of what philosophical and technical methods may be available to the designer, and where some cost-savings may be challenged. The designer's attitude can critically impact the cost direction of the project.

Piping System Design

Labor and Material Reduction-25%

Geothermal projects can include tens of miles of pipelines. The piping design team can play an important role in reducing cost. An experienced impact design team can eliminate as much as 1/4 the amount of material on some projects. The team must concurrently adjust for the aspects of terrain, environment disturbance, material selection, flow, transients and stress optimization. In refinery or power plant piping, routes are limited and optimization is difficult. Geothermal piping systems are more flexible and open to creativity.

Although the pipelines must be rigorously designed to the ASME/ANSI B31.1 Power Code, the power of the portable computer and advance stress analysis programs can now allow onsite analysis. *Good designers will evaluate where higher stresses can be allowed and where more conservatism is the best virtue.* Distributing loads from bending to torsion, applying guides, limit stops and directional anchors; judicious use of cold spring for equipment loading, utilizing induction bent pipe when advantageous, optimizing expansion loops, all must be considered to help reduce pipe, fittings, insulation, support materials, labor, pressure drop and the bottom line—cost.

An example of this application can be seen at The Geysers where one designer, with a conventional steam power plant background and not experienced with geothermal cross-country piping, placed vertical loops roughly every 100 feet. In a nearby installation, a more efficient designer placed horizontal expansion loops every 400+ feet. And yet another didn't use any standard loops at all except for the curvature of the terrain. This is just an example of cost reduction by eliminating unnecessary pipe and fittings. *Each large loop can cost upward of $30,000.* If 100 expansion loops can be eliminated from a project, that would represent a significant cost and pressure loss savings. *A critical "impact design team" can help reduce millions of dollars off a project with judicious computer analysis and good common sense.*

Materials

Most projects can be constructed out of conventional mild steel where the bulk of the material is in pipe. But in highly corrosive environments, other materials must be used. For low temperature applications, this could include fiberglass reinforced pipe (FRP), high density polyethylene (HDPE) pipe and to a lesser extent now epoxy lined carbon steel. For higher temperature service, metallic alloys could include austenitic stainless steels, duplex, and precipitation harden stainless; titanium, inconell, etc. Alternatives could be include coatings such as various inorganic or polymer cement lined, or explosion cladded alloy steels.

The industry is in need of corrosion resistant liners for corroded pipelines and casing. If a cost-effective high temperature coating for in-situ placement to control corrosion can be developed, tens of miles of production pipelines, injection pipelines and well casing could be rejuvenated and useful life extended.

Scaling and Corrosion

Inhibitors

Corrosion and scaling can be a serious concern in fields where these conditions exist. Catastrophic failures can be a safety as well as an environmental nightmare. The high cost of alloying up can add significant cost to projects. Scaling can plug pipelines, valves, fittings, instrumentation, increasing maintenance and reducing flow capacity to and/or from the plant. A descaling operation can contribute to a toxic waste disposal problem. If a pipe is too severely plugged, it must be removed and discarded which increases O&M cost.

Uniform corrosion, pitting, erosion/corrosion, stress corrosion cracking, cavitation are just some forms of corrosion attack in geothermal facilities. Acid gasses, low pH fluids, chlorides, sulfides can severely attack even high grade stainless steels. At The Geysers, outskirts of the field contain corrosive hydrogen chloride and other gasses in the super-heated steam. Carbon and stainless steels are readily attacked in this environment. Here the solution can come in the form of titration and/or dilution followed by separation. This de-superheating technique robs energy from the system and reduces power generating output. A dry form of steam scrubbing (Fisher/Jung) could recover much of the energy loss, however development will need to demonstrate cost-effectiveness.

In saturated two-phase systems where low pH fluids are encountered, titration can be uneconomical. High volumes of basic (high pH) chemicals are costly and/or can induce the formation of scale itself creating serious plugging concerns. If a cost-effective corrosion inhibitor can be developed to protect conventional carbon steel materials, significant savings can be incurred. The use can be on production gathering systems, reinjection systems and on down-hole casing.

Advancements have been made in controlling scaling under certain conditions. Carbonate scaling across the flash zone can be controlled via the use of inhibitors injected down-hole below the flash zone or in front of flashing control valves. Silica based scaling can often be controlled by temperature, and pH modification (Gallup). Drew and Nalco are developing silica inhibitors that are showing promise. In cases where scaling has already occurred, mechanical means of scale removal by E-P & Associates is encouraging.

Synergy

(Resource + PEF + Power Plant)

This section identifies *how production equipment and facilities* can influence the cost of the *resource and power plant* segments. Team Geothermal can work concurrently to disseminate information, improve operation and reduce cost.

Steam or Brine Metering Improvement

It is not uncommon for geothermal projects to incur steam and brine flow metering errors of plus or minus 20 percent. In some fields, three flow meters within the same basic pipeline will present three very different readings. There are many reasons for this discrepancy, but the fact is the metering of gaseous, dirty, scale and corrosive geothermal fluid can be complex. Accurate flow measurement is important for sizing equipment, determining equipment performance, resource assessment and predicting imminent problems. This is an important monitoring tool that can and should be resolved for the benefit of the industry. Preliminary research error analysis indicates flow conditioning and training are the source of the problem. *Additional research and testing are required to fully investigate and resolve this problem.*

Two-Phase Flow Meter

Accurate measurement of production fluids is of vital importance for both reservoir and production management of geothermal resources. A change in the fluid enthalpy or a change in flow rate can be a prime indicator of an obstruction in the gathering system, mechanical problems occurring down-hole, or even a declining resource. A delay in identifying the problem can be costly, and can result in substantial production and revenue loss. Under a worst case scenario, a permanent production loss could occur; the wrong facilities are constructed, the timing to drill new wells is delayed; or a lack of clear data would lead to the over-development of a resource; resulting in a diminished project life.

For geothermal flash-steam systems, the monitoring of production is expensive. A multitude of techniques has been tried, but the separator station is the most accurate means to measure brine and steam production. A fully instrumented and automated separator metering station can add a cost upwards of $150,000 per well. Because of the expense and complexity, very few fields are equipped with separator stations on each production well. Some fields will incorporate one separator for a group of wells, while others depend on periodical portable separator or lower accuracy Jamestube (James) or tracer dilution (Hirtz) updates. It is during this time gap between updates that serious problems or mistakes are more likely to occur.

A novel two-phase flow meter, based on *flow conditioning*, offers refreshing possibilities for accurate, moderate-cost, *continuous production monitoring*. The basic operating concept is to condition the flow and measure various signals generated. A microprocessor solving multiple equations will compute the steam and liquid fraction rates. This versatile concept could be used on single-phase as well as multi-phase systems. The flow conditioning would even mitigate upstream disturbances. Preliminary air/water testing appears encouraging (not shown). The projected cost for this meter may be as low as $10,000, for a 12 inch diameter unit. *Additional research and testing are required to fully develop this cost-saving two-phase flow meter.*

Two-Phase Throttling Valve

Geothermal fluids are hot, scaling, erosive and corrosive. These fluids can contain rocks, dissolved solids, liquid, and gasses along with the steam. Throttling equipment performance on geothermal fluids at the wellsite, using conventional control valves, has been marginal largely because of erosion, scaling and high turn-down requirements. At low open positions, it is not uncommon to erode holes though the valve body or in the down-stream piping in a relatively short period of time. In the full open position, it is not uncommon to hold five psi to 50 psi or more against the valve. *This high back-pressure* *can restrict the amount of production from a well.* For many resources, every psi of back-pressure eliminated, one to 15 percent of additional steam can be delivered to the plant.

In view of the changing power plant operating climate from base load to load following, the need for a cost-effective well-site throttling valve is becoming increasingly important. A valve is needed that can provide erosion and scaling resistance; with a throttling ability from 0 to 100% of opening, at a moderate cost.

A novel custom design throttling valve for the industry is being conceptually modeled for possible development (not shown). The concept design offers high throttling capability at low openings without pipeline or external body damage. The valve will have low pressure drop in the full-open position. The projected cost for these valves could be similar to high quality well-head valves. *Research and testing are required to develop this cost-saving valve.*

Turbine Scaling and Mitigation

The geothermal fluids contain various gasses, solids, and dissolved solids. Each field is different as each possesses different erosive, corrosive and scaling characteristics. Some formation fluids are more scaling than others and more difficult to process. Separator carry-over into the power plant is the primary cause of turbine scaling (Jung). Scale is formed by precipitation. This can occur when brine carry-over becomes supersaturated with minerals. Deposits can be induced from the heat-transfer gradient effects such as nozzle flow expansion, or silica concentrations in the vapor phase in transition across the Wilson Line (TPE).

For an equivalent steam quality and purity entering geothermal turbines, scaling build-up can be substantially greater at a lower pressure. This is caused by chemical kinetics, compounded by thermodynamic effects and thermal gradients within the nozzles and rotating blades. Certain turbine types appear to have a greater affinity for scaling than others because of unfavorable gradient effects.

Fuel fired generated steam is a factor of 10 to 100+ times cleaner that those produced from geothermal resources. To mitigate turbine scaling, liquid, solids and dissolved solids must be removed. This will require improved separators, scrubbers and the monitoring of the incoming steam for upsets.

Continuous Steam Quality and Purity Monitoring

All conventional fuel fired steam power plants continuously monitor the effective steam entering the turbines. *Inlet steam quality and purity are critical to efficient and cost-effective operations.* Yet, in the geothermal industry continuous monitoring does not exist and grab sampling and analyses are sparse and inconsistent. The clogging of strainers, compressors, turbine nozzles and the erosion, corrosion, cracking, and impact failures from high liquid loading to the turbine blades are still common occurrences.

The accurate monitoring of geothermal steam quality and purity is difficult because of sampling complexities and the interfering effects of various constituents entrained with the steam. An accurate instrumentation system to monitor this steam could provide protection against process upset conditions by signaling such occurrences and initiating corrective action to mitigate impending damage. This protection would improve efficiency, power generating output, and reduce O&M cost.

Two types of monitoring systems are required by the industry. The first would be a *catastrophic indicator* that would quickly respond to imminent slugs or high moisture proceeding to the turbine. Here the response time must be within a second or two, to provide protection. The second type of continuous monitoring is for *low ion tracer detection*. A 10 ppb lower limit would be highly desirable to inform operators of deteriorating conditions. Accuracy and reliability are important. Additional research and testing are required to fully develop these cost-saving devices. *Note: PNOC has reportedly developed a steam purity monitoring system based on a flame photometer technique.*

Facility Optimization

Increasing steam deliverability to the power plant, with a declining resource, is a major concern for mature steam fields. Conventional method for increasing mass production is to employ more reservoir simulators, drill more production wells or to install larger pipelines. With steam wells averaging $3,000,000 each, with installed pipelines at roughly $10 per diameter-inch-foot installed, plus miscellaneous other cost, make-up steam in today's low energy price is expensive.

As stated earlier, in moderate to lower pressure fields *every psi decrease at the well-head could mean a one to 15% increase in steam flowing to the power plant.* Modifying the production equipment and facility to reduce bottle-necks is generally less expensive than drilling new wells. The modeling of the facilities with neural net simulators can help identify bottle-necks and determine if it is cost-effective to eliminate, to enhance productivity. A 10% to 20% increase in production is often possible with a rather low expenditure, in comparison to drilling.

Two-Phase Eductor or Steam Ejector

Another possible way to increase steam production to the plant is with the use of eductors and ejectors. High pressure (HP) wells in the field can be used to induce flow from weak wells (LP). This is accomplished by the use of an eductor or ejector type of device (Jung/Counsil). This venturi effect device reduces the effective line pressure to the weak wells enhancing flow. Preliminary trials in one field indicated a *40% increase in flow from weak wells* with a 10 psi decrease in header pressure. Additional research and testing are required to fully develop this technology.

Production Equipment and Materials

This section represents new cost-saving ideas for production equipment that have a high probability for successful development.

Primary Separators

Separators represent a large capital expenditure for geothermal facilities (except binary). Separators are required to isolate solid, liquid and vapor phases to mitigate system damage, or to increase the distance fluids can be economically transported. Differing areas and fields offer varying erosive, corrosive, scaling and loading parameters, which dictate certain designs are better than others in specific applications (Jung).

Separator vessel cost is often only a small part of the total installed cost. An example would be a large vessel that may cost under $200,000 to purchase. Once shipping, foundation, piping, expansion loops, insulation, safety platforms, valves, vents, diffusers, instrumentation and engineering are included, the total installed cost can often exceed $500,000. Multiply that times a number of installations in a field and the summation can be quite high indeed.

Some separator configurations can process up to twice the amount of steam and brine than standard designs with the same vessel size. An example would be a downflow centrifugal separator vs. an "upflow" centrifugal design (Jung). In the upflow, steam and brine must flow counter-current to allow for drainage. When the upward vapor drag forces exceed the gravitational forces, the liquid is entrained along with the vapor. On a down-flow configuration, both the vapor and liquid are flowing in the same direction with gravity. The phase disengagement is less traumatic. There are other considerations involved in separator selection, however, this is one example of how capacity can be increased, utilizing the same amount of steel.

There are designs in the early research stage that may have five times the capacity of an upflow design, with nominal pressure drop. These designs, based on controlled boundary layer transposition in low profile configurations, would reduce foundation, platform and inlet/outlet piping cost. If this development could be realized, the total installed cost on flash separators might be reduced by as much as 2/3. *Additional research and testing are required to fully develop these lower cost separators.*

Low Cost Rock Catchers

In dry steam fields or areas where open hole completion is predominate, rock catchers are employed to reduce separator loading and erosion damage. Conventional strainers have low holding capacity, are too fragile, clog easily and incur high pressure drop. Special rock catchers of The Geysers type design now approach $40,000 each when fabricated to ASME Section VIII requirements (Jung).

A less expensive alternative is being developed with a projected cost-reduction of 2/3. This is accomplished by reducing impingement loading on the screen, designing self cleaning features, making the rock catcher an integral part of the piping system, utilizing standard piping components and constructed to ASME B31.1 vs. Section VIII, Division 1 requirements. There is a fine line defining where piping ends and pressure vessels begin. This is being investigated. *Additional research and testing are required to fully develop these low cost rock-catchers.*

High Efficiency Condensate Collectors

Drip-pots are installed by the hundreds in geothermal fields around the globe. There are many types of condensate collectors from simple drains installed on the bottom of the pipe to full size tee pots. In many areas their effectiveness is marginal to nil. Where the total installed cost can approach $10,000 each to install, a considerable amount of money is often wasted. As a rough rule of thumb, drip-pots require hundreds of feet of straight runs of pipe and are ineffective at velocities above 100'/s. Application is very important for cost savings (Jung).

A new boundary layer condensate collector being developed has demonstrated superior catch efficiency and requires much shorter runs of pipe to be effective. *The principal operating concept is flow conditioning and pseudo flow regime modeling.* Line velocities approaching 200'/s, with as little as six diameters of straight run of pipe with a catch efficiency of 90% have been obtained. These devices incur low pressure drop and are rugged. There is still much to be learned about devices under differing conditions and application. *Additional research and testing are required to fully develop these low cost systems.*

Polishing Separators and Scrubbers

Wet and dirty steam destroys power plants. Steam entering geothermal power plants is worst than any fuel fired steam generating facilities in the world. *Geothermal power plants incur higher maintenance and failure rates than any other steam driven turbines.* Although improvements have been made, high steam quality and purity to the power plant are of utmost importance.

The polishing separator and/or scrubber is only part of the process, but it is the final segment used to remove small amounts of liquid and impurities from the steam. It is this liquid, solid and dissolved solids entrained in the steam that primarily causes erosion, corrosion, scaling and stress corrosion cracking on the turbine and other components. Most polishing separators cannot protect against large slugs of liquid (Jung). Some demisters are easily damaged or deteriorate in efficiency over time. A steam wash is often used to enhance performance. Final polishing separator systems can cost in excess of a $1,000,000 to fully install in larger plants.

A novel inline boundary layer polishing separator, which utilizes the pipeline itself as part of the process, is a potential cost-saving option. Unlike vertical units that require large foundations, expansion loops, safety platforms, etc., these inline units are designed for placement between pipe supports. Unlike large multi-tubular scrubbers that can scale and render the device impotent, these *new isokinetic designs are scale resistant*. It is projected that up to 2/3 of the total installed cost savings may be possible with these compact separators. *Additional research and testing are required to fully develop these low cost devices.*

Low Emission Vent Separators and Mufflers

The start-up, venting and testing of production wells can create considerable noise and particulate emissions. This carry-over of solid and liquid materials ejected from vent stacks drift and rains down on the surrounding area. In the case of hydrogen sulfide gas abatement, some of the caustic and corrosion byproducts are also entrained along with the steam. In areas where environmental compliance is important, up to a 100 fold reduction in the amount of particulate emissions, can be obtained with better designs. There are no cost-savings here except for possible fines, legal fees and project delays.

Summary

- Training, awareness of available methods, and a *"cost-effective attitude"* can help designers improve the bottom line. Up to a 25% saving may be an attainable goal, although even 10% would be good start.
- Synergy, the performance of the *production equipment and facilities* have a significant influence on the *resource and power plant section* of the project. Outstanding data collection, low pressure drop, exemplary steam processing, etc. can save millions of dollars on a project. Drilling fewer wells, more efficient running turbines, and lower operating and maintenance expenses are side benefits.
- The development of cost-effective technology, focusing on ideas with a high probability for success, and a short window period for development, will provide the most bang for the research buck (this is not to suggest the scrapping of good mid/long-term research programs). The cost-savings over conventional techniques could be greater than 50%. *Is this goal realistic?* Yes, we think it is.

A list of 12 solvable research and development projects in the area of *geothermal production equipment and facilities* outlined in this paper is summarized in Table 1.

Table 1. List of Solvable Research Projects for Production Equipment and Facilities

No	RESEARCH & DEVELOPMENT PROJECTS
1.	Metering Improvement
2.	Two-Phase Flow Meter
3.	Well-Head Throttling Valve
4.	Continuous Steam Quality & Purity Monitoring
5.	Turbine Scaling Mitigation
6.	Facility Optimization
7.	Two-Phase Eductors / Steam Ejector
8.	Separators
9.	Rock Catchers
10.	Special Drip Pots
11.	Polishing Separators & Scrubbers
12.	Vent Separators & Mufflers

Conclusions

There are geothermists who feel that cost cannot be significantly reduced in *production equipment and facilities*; that new technology is pie in the sky and should be left up to others to research, develop and to prove successful. But who will pay for this up front research and development to save the industry money and to keep it competitive? Who will pay to keep innovators working, and rewarded if the project is successful in improving the competitiveness of the industry?

Small companies unfortunately may not have the resources to develop and market innovations to a risk intolerant industry. While larger companies may not have the innovators to achieve results. Without major cost-saving innovations, how will the industry reduce cost without resorting to more re-engineering or down-sizing?

The industry needs cost-effective results to remain competitive with other energy sources. *Production equipment and facilities*, represent an area where sizable cost-savings, can be made within the immediate future. However, the outcome will depend on the support from industry, government, research organizations and innovators.

If funding is not available, no one will do the work; and if no one is willing to try out new ideas and technology, no cost-savings will be made. This will be the upcoming challenge. Cost-reduction and improve competitiveness is not going to happen by itself. It will take leadership and motivated individuals seeking better ways of getting the job done.

Recommendation

Synergy between industry, small innovative companies and government sources can be drawn together to develop cost-saving technology. This concept can work if funding is provided, results are provided and rewards are provided. Government funding must be streamlined, small innovative companies must provide timely cost-saving results, and industry must reward small companies for significant cost-savings such that they can continue to develop new and improved technology, to support the geothermal industry, without government assistance.

References

Fisher and Jung, 1996. Alternatives to Traditional Water Wash, GRC *Transactions*, Vol 20, p. 737.

Gallup, D., 1996. Brine pH Modification, GRC *Transactions,* Vol 20, p. 749.

Hirtz, P., 1995. Tracer Dilution Measurements, GRC *Transactions,* Vol 19, p. 563.

Jung, D., 1995. Geothermal Steam Quality Testing, GRC *Transactions,* Vol 19, p. 575.

Jung and Counsil, 1996. Surface Inducement, Production Enhancement Technique, GRC *Transactions,* Vol 20, p. 757.

Jung, D., 1989. An Overview of Geothermal Separators, GRC *Transactions,* Vol 13, p. 319.

Jung, D., 1995. Drip-Pot Application, GRC *Transactions,* Vol 19, p. 569.

James, R., 1970, Factors Controlling Bore-Hole Performance, *Geothermics,* Vol. 2, p. 1502.