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Technical Considerations for Geothermal Power Plant Designs

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ABSTRACT

Geothermal power plant designs are unique when compared to conventional power plants, and design features among them can differ significantly. Key technical considerations for proper plant design include reservoir conditions (production/injection characteristics, enthalpy, chemistry, and noncondensible gasses), plant siting (topography, access, geotechnical characteristics, and transmission) and environmental conditions (meteorological data and plant emissions).

This paper summarizes characteristics that must be understood with respect to each of these to correctly establish preliminary plant design and properly address project technical feasibility, thereby mitigating engineering/construction risks before project development commitments are made.

1. INTRODUCTION

Securing a sustainable energy future through geothermal projects in general, and ensuring the commercial success of any given geothermal project in particular, requires that careful consideration be given to designing the plant that represents a good fit with respect to the plant's reservoir, area surface conditions, and the environment. It is important that these are understood when design considerations are made to help ensure that optimal, sustainable plant operation can be achieved.

Conditions that surround and interface with geothermal power plants include its geothermal reservoir fuel source, the surface features on which the facility is constructed, and the surrounding environment used for cooling, discharging emissions, etc. Significant aspects associated with each of these are presented as follows.

2. RESERVOIR CONDITIONS

Knowledge of reservoir characteristics is critical, as this in effect determines the thermal conversion cycle, the size and design features of the plant, materials of construction, the design of the gathering system, and the design of downstream fluid handling facilities. Having an accurate reservoir database for a geothermal plant producing from the same reservoir and which has been in operation for at least several years offers the most reliable basis for understanding the "fuel source" so that optimum design features of the new plant can be evaluated. For greenfield plants where such operating data is not available, development of an accurate reservoir model is necessary to clarify to the extent possible what the expected fluid enthalpy will be for evaluating conversion cycles, and the associated maximum sustainable production rates for establishing plant size. Well testing with a properly designed test rig is required to confirm these characteristics and to clarify other process parameters that affect plant design, such as reservoir chemistry (including noncondensible gases). These are discussed individually as follows:

2.1 Enthalpy

The reservoir may be either steam dominated or liquid dominated. Steam dominated systems are the simplest from the standpoint of plant design in that brine treatment and brine reinjection is not required. Generally speaking, lower enthalpy liquid resources are developed using binary (e.g., organic Rankine) cycles, and higher enthalpy liquid resources using single, double, or even triple flash steam cycles. In any case, having an accurate understanding of the reservoir enthalpy is necessary to enable selection of the most economical power cycle for the plant.

In addition to understanding the reservoir enthalpy at startup, it is important to understand how it may change over the life of the plant so the required flexibility can be designed into the steam turbine and balance of plant equipment. Allowance for the future installation of a separate topping turbine or bottoming cycle in the plant design may be warranted if a significant change in reservoir enthalpy may be expected, for example. As a minimum, having an understanding with the primary turbine supplier regarding steam path modifications if the reservoir enthalpy is expected to change significantly over time is recommended to clarify up front what changes may be required in the future to address this change. Reductions in enthalpy could be a problem with respect to brine handling limitations and plant output.

Changes in enthalpy represent opportunities as well as risks. It is important to have a reasonable understanding of it in either case when evaluating project feasibility, and to clarify features that must be addressed in the plant design to accommodate this change.

2.2 Production/Injection Characteristics

Understanding expected production well flow rate versus wellhead pressure (deliverability curves) and associated decline characteristics (which defines workover/makeup well frequency) is necessary to find the economic optimum balance among production wellhead pressures, sizing of gathering system piping, and selection of turbine inlet pressure(s).

For liquid dominated reservoirs, understanding of injection well flow rate versus wellhead pressure (injectivity curves) and expected declines in injectivity is similarly important to establish the economic optimum balance among injection wellhead pressures, sizing of brine reinjection piping system, and sizing of the brine reinjection pumps.

2.3 Reservoir Chemistry and Noncondensible Gasses

Proper plant design requires knowledge of the reservoir chemistry and its associated noncondensible gasses. This is acquired using data from existing plants producing from the same reservoir, or by long term well flow testing in the case of greenfield plants.

It is important that the flow test rig be properly designed so that conditions duplicate process/mechanical parameters envisioned for the plant (e.g., flash pressures, brine treatment, plant metallurgy, etc.). During flow testing, it is equally important that evidence of scaling, corrosion, and other phenomena detrimental to long term operation of the wells and plant are carefully monitored. Scaling and corrosion expectations based solely on chemistry fundamentals are sometimes inaccurate due to the chemical complexity of geothermal systems.

Clarifying noncondensible gasses (quantity and composition) through such testing, or as can be obtained through other means, is necessary for proper design of the gas extraction system. This also provides a design basis for gas abatement (e.g., H_2S and mercury) if required for the plant.

If the noncondensible gas concentration at startup is uncertain, consideration should be given to designing flexibility into the gas extraction system to address this uncertainty. Installations of parallel trains of equivalent or varying capacities may be considered in these instances. For example, parallel trains of 40%, 60%, and 80% of the design noncondensible gas concentration provide for optimal plant operation for gas concentration in increments of 20% in the range between 40% and 180% (except 160%) of its design value. This should also be considered if the noncondensible gas concentration may be expected to change with time. In either case, the gas extraction system can be designed to accommodate varying gas rates in such a way that plant optimal performance is maintained.

3. SURFACE CONSIDERATIONS

Careful consideration should be given to the area topography when selecting a location for the power plant and determining routes for the gathering/injection system. In hilly or mountainous terrain, topographical surveys should be conducted before plant siting is undertaken if such data does not already exist.

The resource may limit flexibility in identifying well locations, but suitable access should be confirmed before finalizing production/injection wellpad locations. The power plant should be located with respect to these well pads, with the objective of minimizing overall facility costs by considering the following:

- Power plant excavation requirements and soils characteristics
- Equipment orientation
- Gathering/injection system pipeline costs based on preliminary line sizing
- Reinjection pumping costs
- Electrical transmission line costs
- Utility supply (including access to water)
- New access roads
- Existing infrastructure

An understanding of soils characteristics is important to clarify foundation types that will be required, as this can factor significantly into the overall project cost. Excavation requirements should be considered in conjunction with this by evaluating cut and fill requirements and associated costs. Where evaporative cooling towers are employed, proper tower orientation should be taken into account as part of this assessment (longitudinal axis should be oriented parallel to prevailing wind direction).

The area topography can have a significant impact on the gathering/injection system cost, particularly for liquid dominated resources. Although it is generally more cost effective to transmit flow from the wells via two-phase pipelines, flow regimes should be evaluated to ensure stable flow is achieved. Continuous uphill flow, for example, can produce fluid behavior (e.g., surging) which can undermine stable plant operation. In hilly country, it is often necessary to work with the terrain in establishing an appropriate route so these effects are mitigated. Steam/brine separation away from the plant may be required if stable two-phase flow cannot be achieved. Flow modeling of the two-phase pipeline system should be done to clarify pipeline system pressure drops and confirm appropriate flow regimes, with consideration to plant turndown as applicable.

With respect to reinjection, pumping costs are directly affected by injection wellpad elevations and distances with respect to the power plant. Topography permitting, injection by gravity is ideal. Otherwise, the present value cost associated with pumping should be evaluated.

In addition to the above, the costs with electrical transmission, water access, availability of existing infrastructure, and requirements for new roads should be included in defining the optimum power station location and gathering/injection system layout.

4. ENVIRONMENTAL CONSIDERATIONS

Long term meteorological data for the area in the vicinity of the power plant from a reliable weather station is important to ensure proper plant design. As a minimum, this should include:

- Dry bulb temperature data
- Wet bulb temperature data (or humidity)
- Anemometer data (wind speed and direction)
- Precipitation data

Where evaporative cooling towers are employed, for example, the temperature data is needed to optimize the heat rejection system (cooling tower, circulating water system, and condenser), which effectively defines the turbine backpressure and thus the plant output. The wind direction is needed to ensure the cooling tower is oriented properly. Rainfall data is needed for plant drainage system design.

If meteorological data is being sourced from a weather station previously installed for another nearby project, confirmation should be made that it has been properly maintained to ensure the data is accurate, as maintenance of this equipment is sometimes neglected after it has been installed. If no project weather station data exists or its accuracy is questionable, other sources of meteorological data should be considered (e.g., airports, municipalities), provided these are close enough so that conditions at the plant site are reasonably represented.

Statutory limitations regarding emissions (e.g., H_2S and noise) should be clearly understood, as these may significantly affect plant design and operation. In some instances, there are strict emissions limitations while in others, there are none. If such limitations apply, the operating requirements and required abatement equipment should be carefully assessed when evaluating project costs.

5. SUMMARY AND CONCLUSIONS

Proper design of geothermal power plants requires an accurate understanding of its subsurface, surface, and environmental conditions. Understanding these conditions, some of which will change with time, is essential to achieve optimal plant design, to ensure design risks are effectively mitigated, and to ensure sustainable operation over the life of the plant.