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DESIGN CONSIDERATION, BRINE-HYDROCARBON HEAT EXCHANGER WARM-UP AND TURBINE BYPASS SCHEMES FOR HEBER GEOTHERMAL BINARY CYCLE DEMONSTRATION PLANT

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ABSTRACT

Many engineering problems have been encountered during the detailed design stages of the Heber Geothermal Binary Plant. This paper highlights some of these design considerations related to the brine-hydrocarbon heat exchanger warm-up scheme, sizing of the turbine bypass system, and selection of the brine return pumps.

In the Heber Power Plant, warm-up of the brine/hydrocarbon heat exchangers is accomplished by gradually introducing a varying blended mixture of hot brine from the production wells and cooled, recycled brine through the heat exchangers. Also during the warm-up mode, the hydrocarbon working fluid is gradually warmed up through a separate warm-up circulation loop. A turbine bypass based on 20% of the turbine rated flow is also provided to control turbine inlet pressure during normal operation.

BRIEF PROJECT DESCRIPTION

The Power Division of Fluor Engineers, Inc. is currently involved with the design, detailed engineering and procurement of the equipment for a 70 MWe geothermal demonstration power plant at the Heber KGRA (Known Geothermal Resource Area) located in the Imperial Valley of Southern California. The plant is scheduled for start-up July 1, 1984.

The objective of the Heber Geothermal Demonstration Power Plant is to demonstrate the technical, economic and environmental feasibility of using the binary conversion process to generate electric power. The Heber KGRA produces a liquid dominated medium temperature (360°F) brine, similar to many geothermal resources located in the U.S. and other parts of the world. The ultimate electric power potential of this reservioir alone has been estimated at 400 to 500 megawatts. Due to the escalating costs of other forms of energy in recent years there is a great deal of interest in this project.

The Heber Demonstration Plant will be the first commercial size facility to use a binary cycle; one in which the heat energy of the hot geothermal brine will be transferred to a secondary working fluid that is used in the balance of the power generating cycle. The working fluid will be a hydrocarbon mixture of 90% isobutane and 10% isopentane. This mixture has been selected for its thermal and physical performance properties which are compatable with the Heber geothermal brine temperature characteristics.

The overall project view of the Heber Project has been reported in Reference 1. The conceptual design parameters of major equipment for the Heber Project has been reported in Reference 2. The conceptual design aspects of the Heber binary cycle has been reported in Reference 3.

A. BRINE SYSTEM FILL AND WARM-UP

INTRODUCTION

A fill and warm-up system is provided to limit thermal and pressure shock effects in the brine/hydrocarbon heat exchangers during plant start-up. This requires that the brine and hydrocarbon sides of the exchangers be simultaneously warmed-up to develop the desired temperature profiles in the exchangers at a controlled rate. The minimum hydrocarbon and brine flow rates through the exchangers during initial warm-up is approximately 50% of design flow to assure uniform distribution of hot brine across the tube sheets.

DESIGN SCHEME

For economic reasons, the system is designed for warm-up of one heat exchanger train at any one time. Equipments for the system consist of a brine cooler, cold brine storage tank, fill pump, recirculation lines and control valves V-2 and V-3 (see Figure 1). The system piping configuration and train isolation valves enable each train to operate individually with a dedicated pair of brine return pumps. Thus one train can be placed in a normal operating mode (generating power) while the other is being filled and warmed-up via the warm-up/recirculation line. (See Figure 1 for brine, Figure 2 for hydrocarbon recirculation.)

The initial step is to introduce hot brine (360°F) from the brine production wells through the plant

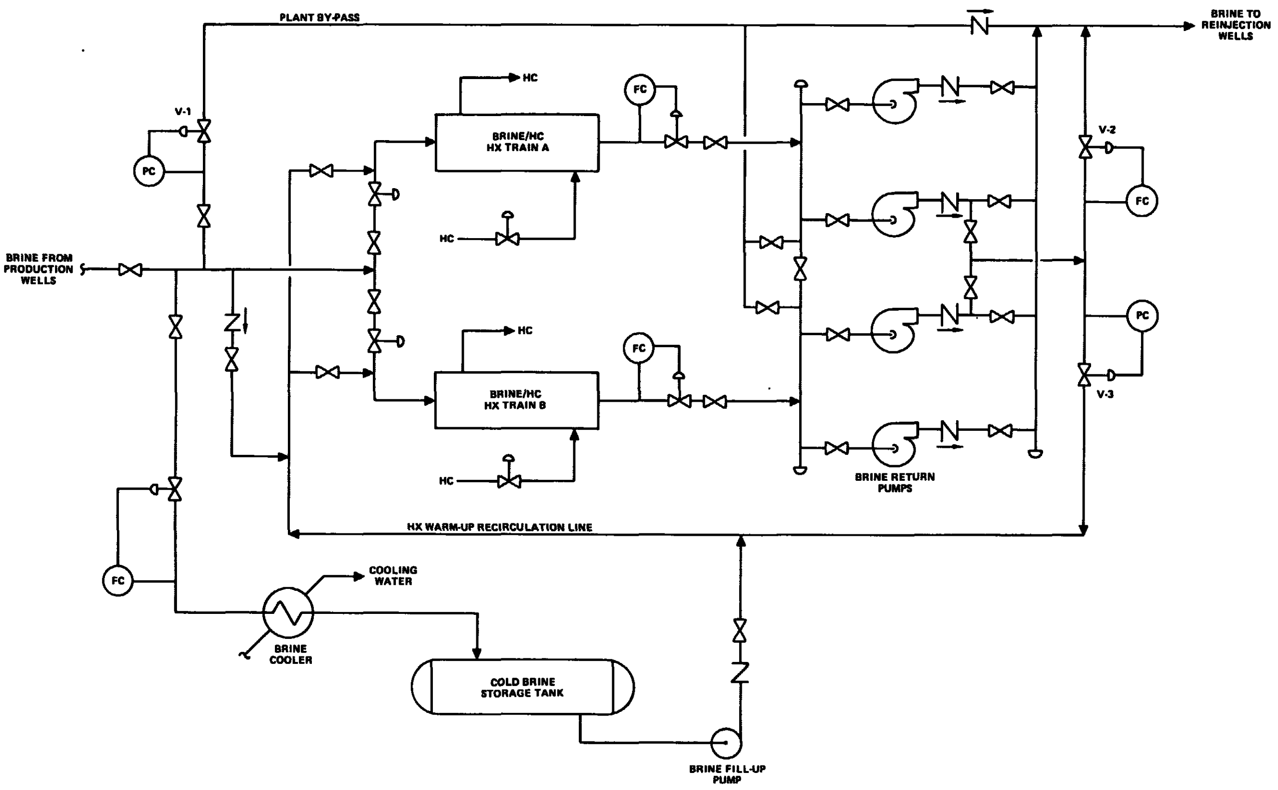

FIGURE 1 – BRINE/HYDROCARBON HEAT EXCHANGER WARM-UP DIAGRAM

and back to the reinjection wells via the plant bypass pressure control valve (V-1, Figure 1) while simultaneously filling a portion of the plant piping system exclusive of heat exchangers and brine return pumps.

The second step is to prepare a batch of cold brine (150°F) in the storage tank by cooling a slip stream of hot brine (100 GPM) through the brine cooler. Prior to initiating brine fill-up, a hydrocarbon flow rate of 7000 GPM (cold circulation) is established through the shell side of one heat exchanger train via the hydrocarbon system warm-up loop. The selected heat exchanger train and associated piping is now filled with cold brine via the fill pump.

Finally, one of the variable speed brine return pumps (depending on which train is to be warmed-up) is started in manual and its speed is gradually increased until a cold circulation rate of 3500 GPM is established. The set point of pressure controller (V-3) is adjusted to a pressure higher than the reinjection well return header at a recirculation flow rate of 3500 GPM. The higher pressure is established to allow brine to be bled from the recirculation line through V-2 during warm-up. Hot brine for warm-up is now established by adjusting flow controller V-2, thus admitting hot make-up brine in and an equal amount of cooled recirculation brine out via the reinjection wells return header.

The rate of warm-up (admittance of hot brine) is limited to insure that a hydrocarbon temperature rise of 50°F per hour is not exceeded and a differential temperature of 150°F between the shell and tubes of the last heat exchanger is not exceeded (each train has four (4) exchangers connected in series).

Once the desired operating temperature and pressure (305°F, 575 psia) is established in the hydrocarbon outlet side of the heat exchanger train, the turbine generator unit can be warmed-up and synchronized. The warm-up circuit can be taken out of service at this time.

With one heat exchanger train in full service, the remaining train is filled with cold brine by taking a slip stream of spent brine from the running train. The second train is then warmed-up in the same manner as discussed above except the pump's suction header block valve is closed and the train's dedicated brine return pumps must be used. A unique feature of this pump scheme is the use of variable speed brine return pumps thus eliminating the need for a separate recirculation pump for system warm-up.

B. TURBINE BYPASS DESIGN

INTRODUCTION

In the Heber power plant, a pressure-controlled turbine bypass is provided to control the turbine inlet pressure by opening the bypass valve allowing the hydrocarbon working fluid to bypass the turbine.

The inlet pressure and temperature of the working fluid must be kept within a certain range to prevent excessive formation of moisture during expansion. Prolonged operation of the turbine in the wet region causes turbine blade erosion which must be avoided.

ANALYSIS OF PRESSURE RISE

There are two basic phenomena which cause moisture formation in turbine operation, they are: 1) increase in pressure at constant temperature and 2) decrease in temperature under constant pressure. The turbine bypass is designed to keep the working fluid away from the wet region by limiting the pressure rise. Temperature decrease is controlled by other means such as increasing the brine flow or decreasing the hydrocarbon flow. To avoid excessive moisture content during expansion, the maximum allowable inlet temperature drop is 5°F, while the maximum allowable inlet pressure increase is 25 psi.

The Heber plant is designed to cope with one type of automatic runback transient. This is a 50% runback scenario representing a failure of one of the two cooling water pumps. The runback transient may cause a momentary pressure surge at the turbine control valve (V-8 in Figure 2). However, the pressure will dissipate rather quickly since the turbine runback signal will activate to modulate not only the turbine control valve (V-8) but also the hydrocarbon feed control valves (V-1A and 1B) to its preset limit. Any residual pressure rise during this transient will be handled by the turbine bypass.

Turbine trip with total loss of cooling water to the condensers will cause maximum pressure surge. Each heat exchanger train will be isolated (automatically), both on the brine and hydrocarbon sides. The turbine bypass will remain closed under this scenario. A study was conducted to estimate the pressure rise. It was reported that the peak pressure or the bottled-up pressure would reach 755 psig. This pressure is considereably lower than the design pressure of the hydrocarbon system which is 850 psig. The design pressure of 850 psig was set to meet the combined shut off pressure of the hydrocarbon condensate pump and booster pump series. Therefore the plant is capable of being bottled-up safely and no bypass flow will occur during this time.

BYPASS SIZING CONSIDERATION

It is desirable that the turbine bypass should be able to handle the turbine synchronizing flow. Before the hydrocarbon is introduced into the turbine, the bypass route is expected to be warmed up and maintained at turbine quality, that is, 560 psig at 305°F with a flow rate at least equivalent to the synchronizing flow. This will facilitate a

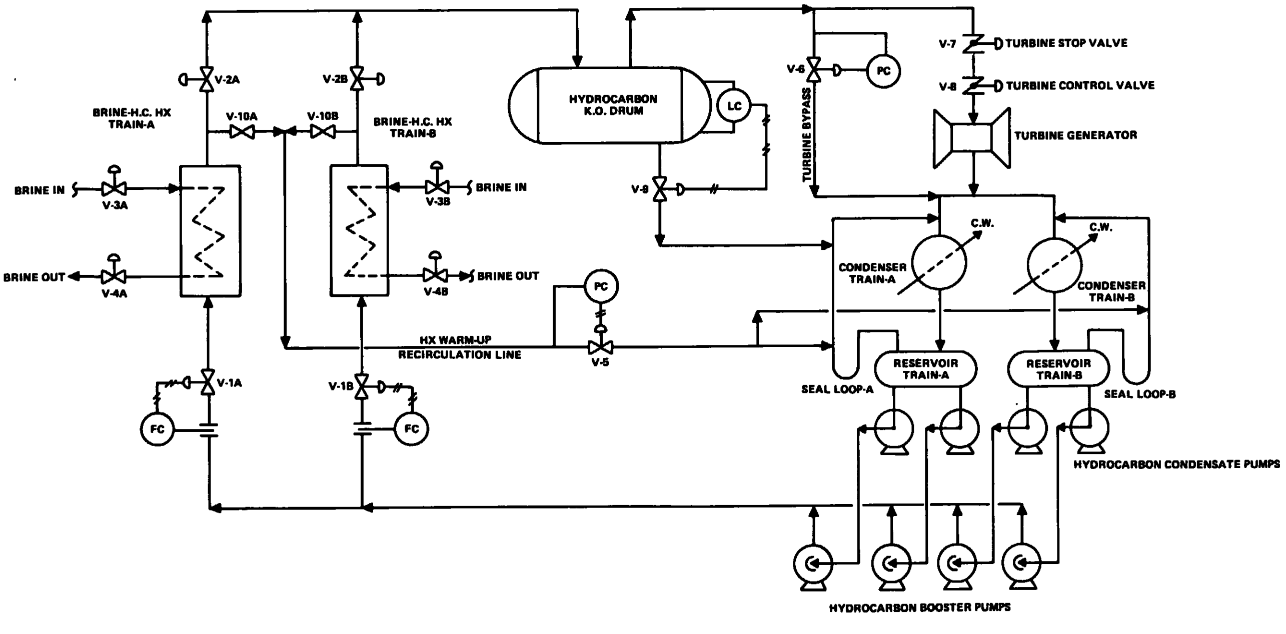

FIGURE 2 – TURBINE BYPASS SCHEME

smooth rolling and lining out the turbine load. The turbine requries 1.3 x 10^6 LB/Hr of hydrocarbon for synchronization which is approximately 15% of the total flow.

Therefore the turbine bypass capacity for the Heber plant is sized to handle the synchronizing flow (15% of the turbine rated flow) plus 5% margin.

C. BRINE RETURN PUMPS

INTRODUCTION

Brine return pumps are located within the confines of the power plant and are required to pump the spent brine a distance of approximately 2.5 miles to the reinjection island. Determining the type of drive system, optimum size and number of brine return pumps was a highly important consideration with regard to overall plant thermal efficiency. Just as important is the ability for the plant to provide energy at the lowest total cost for both operating and fixed charges. The basic factors to be considered in satisfyings these conditions are maximum capacity (demand), capacity factor, and investment.

DESIGN CONSIDERATION

Development of the brine system head curve consisted of examining an array of conditions to be satisfied: 1) variations in suction pressue due to characteristics of the production island supply pumps, 2) variations in discharge pressure due to fouling of wells in the reinjection island, 3) variations in brine flow over the project life due to decay of brine supply temperature (360 to 338°F) and 4) considerations to preclude flashing and gas breakout.

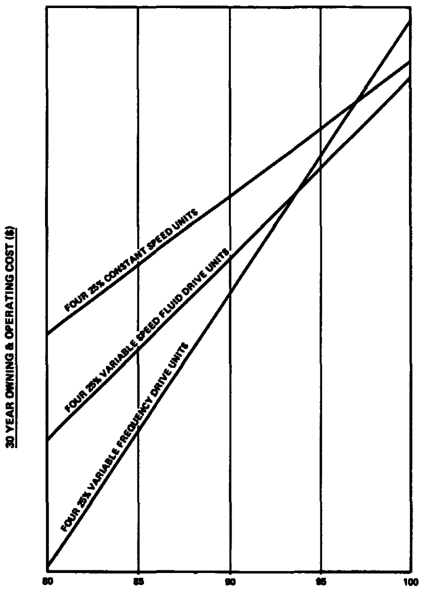

FIGURE 3

ANALYSIS

Various types of drive systems and unit sizes (2 at 50%, 3 at 33%, 4 at 25%) for the brine return pumps were considered and studied to determine the most favorable selection for the system over a 30 year life. The drive systems investigated included: 1) constant speed utilizing control valves, 2) variable speed fluid drive and 3) variable frequency speed drive. Variable speed magnetic couplings were not considered because of the lack of operating experience at the required horsepower and speed (2500 HP, 3600 RPM).

A simple graph plotting plant capacity against owning and operating cost (Figure 3) was constructed to graphically present an economic comparison for the various types of systems. Capital cost estimates for each case were based on manufacturer's input and included auxiliaries such as control valves (for constant speed pumps) and cooling systems (for variable speed drives). Energy costs were calculated for plant capacities from 80 to 100% using efficiencies provided by a typical pump manufacturer.

Having a graphical presentation and knowing the plant capacity factor, the favorable candidate can easily be determined. With a plant capacity factor of 95% as is the case for the Heber Binary Plant, the best selection, and depicted in Figure 3 was four (4) 25% variable speed fluid drive units. Four (4) units also increase operating flexibility with respect to dedication of pumps for warm-up and split flow through the heat exchanger trains.

D. HYDROCARBON SYSTEM FILLING AND WARM-UP

INTRODUCTION

This section describes the procedures and provisions provided for the filling and warm-up operations of the hydrocarbon working fluid (see Figure 2 for reference).

SYSTEM FILLING

The Heber plant is provided with a storage tank capable of storing the entire hydrocarbon required for full load operation. The liquid hydrocarbon working fluid is pumped from the storage tank into the condenser reservoir and the selected brine-hydrocarbon heat exchanger train. As mentioned earlier, the Heber plant is designed to warm-up one heat exchanger train at a time.

The condensers must be in service (i.e. cooling water circulation is established) during the time when the reservoirs are being filled to prevent unnecessary pressure rise in the condensers. Since the turbine exhaust lines are huge (60" diameter) no block valves are provided between the turbine and the condenser due to economic reason. Therefore, the hydrocarbon vapor may fill the turbine and the hydrocarbon knockout drum and associated piping during this time. A level valve (V-9) is provided to drain the condensate formed during the filling operation.

SYSTEM WARM-UP

The layout of the equipment is such that the hydrocarbon liquid level in the heat exchanger will be equalized with that of the reservoir. The Heber plant is designed to circulate the working fluid via a separate warm-up line (from V-10 A/B to the seal loop via V-5 on Fig. 2).

A set of condensate booster pumps will be used to prime the selected heat exchanger train by circulating liquid hydrocarbon from the reservoir, through the pumps, V-1A (or B), the heat exchanger train A (or B), V-10A (or B), and through V-5. The flow control valve (V-1A or B) at the heat exchanger inlet is designed to control hydrocarbon flow in relation to the brine flow during normal operation. The flow control valve will be used to set the warm-up flow rate of 7,000 gpm during the heat exchanger warm-up operation. When the other train is operating and generating power, the individual flow control valve enables running one train in normal operation while the other train is coming up on stream.

As the warm-up hydrocarbon flow is established through the selected heat exchanger train via V-5, brine flow is initiated through the tube side of the heat exchanger train. The temperature of the hydrocarbon effluent from the heat exchanger will rise as the warm-up operation proceeds. The warm-up hydrocarbon bypass valve (V-5) is a pressure control valve designed to meet both liqiud and vapor service. For economic reasons, the valve is sized to handle the warm-up flow of one train (7,000 gpm) only.

A seal loop is provided on each of the condenser reservoir trains to receive the warm-up flow exiting from the heat exchanger. The warm-up stream changes from a cold liquid to a hot vapor as the warm-up operation progresses. The seal loop is designed to handle any phase of the hydrocarbon down stream of the warm-up bypass valve (V-5).

ACKNOWLEDGEMENT

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ERRATA

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1. Article: "Description and Operation of Haakon School Geothermal Heating System", Frank Chiles et.al., page 579.

   Table 2, page 583, under (+Full Resource Use) should read (+ Full Resources Used at 76% savings).

   To achieve the simple paybacks 6.8 or 6.1 years, with or without radian removable, the full resource must be used plus increasing the price of the energy sold to the business district to 76% of the savings price of the energy it replaces.

2. Article: "Design Consideration, Brine-Hydrocarbon Heat Exchanger Warm-Up and Turbine Bypass Schemes for Heber Geothermal Binary Cycle Demonstration Plant", R. S. Kim and E.A. Schaefer, page 19.

   The end of the last sentence in paragraph two should read . . . pressure during startup.