Condenser And Hybrid Gas Removal System Design For A High Non-Condensible Load Plant

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ABSTRACT

The amount of non-condensible gas contained in a geothermal resource affects the design considerations for an efficient and cost effective power plant. This discussion will be centered on the design considerations for the condenser and hybrid ejector/compressor gas removal system for the Central California Power Agency No. 1. (CCPA No. 1) Coldwater Creek Geothermal Power Plant. The plant design utilizes two 65 MW steam turbine generators with a net output of 116 MW. Plant non-condensible loads are estimated in the range of 1.7-2.2% of total flow. Each turbine has a 166,000 sq. ft. condenser and each condenser is serviced by three 50% capacity non-condensible gas removal systems. Two of the systems are hybrid steam ejector/centrifugal compressor systems. The third system, for standby use, is a three stage steam ejector.

INTRODUCTION

In preparation for the procurement of equipment for the Coldwater Creek Power Plant, CCPA No. 1, through its engineers, Stone and Webster Engineering, undertook the investigation of alternate technology applications for non-condensible gas removal from steam condensers. After an extensive investigation carried out over several months it was determined that alternate technologies to conventional steam ejectors could be utilized in a cost effective manner. Specifications were prepared which allowed contractors the option of assessing and offering various combinations of technologies.

In the fall of 1984 contractors were invited by CCPA No. 1 to submit economically competitive proposals for furnishing and erecting the main condenser and supply of the gas removal system for the Coldwater Creek Geothermal Plant. The plant consists of three floors and the physical space allocated by CCPA No. 1 for the gas removal equipment is limited to a single bay within the plant 25’0” wide by 300'0" in length. CCPA No. 1 stipulated that any rotary equipment which might be proposed must be placed on the first floor with allowance made for future additional equipment should the plant experience an increase in the non-condensible load at some future date.

In December a contract was awarded to RCI Engineers and Constructors for the furnishing and erecting the main condenser and supply of the non-condensible gas removal system. RCI’s approach to the project was to recruit the expertise and services of Graham Manufacturing Co., Inc. and Transamerica Delaval Inc. then to divide the scope of the work to be performed into three phases with RCI retaining ultimate responsibility to CCPA No. 1 for the system performance:

A) Project management, engineering and fabrication of piping system, quality control, and field installation of all equipment and controls.

B) System process engineering, engineering and fabrication of main condensers, and ejectors.

C) Engineering and fabrication of compressors and lube oil equipment.

SYSTEM DESIGN

The condenser and gas removal system are designed for a non-condensible load of 20,692 lb./hr. at cooling water temperatures of 69 F. The non-condensible gas system for each condenser consists of three trains of equipment each sized to remove 50% of the load from the condenser at the condenser design pressure 2.11 in. Hg ABS. The gas removal systems are designed to discharge to an H_2S abatement system at a pressure of .25 PSIG. Two of the non-condensible systems are considered base operation systems, the third system is for standby use.

Selection of the non-condensible gas removal system was made by optimizing the system based on total evaluated cost. Evaluation factors were provided for steam, electrical, and cooling water consumption. System selection was left to the contractor and process engineer based on their evaluation of the system taking into account the total evaluated cost consisting of capital cost, capitalized fuel cost and capitalized replacement energy cost. The evaluation was performed on the base operating units. As the standby unit would only operate a total of approximately 10% of the time it was not included in the evaluation. For this reason the third train could be of different design than the two base trains to minimize the capital expense. For system optimization the following factors were supplied in order to evaluate the operating cost of possible system configurations:

Capitalized Utility Cost

Steam	$312.60/ lb./hr.
Electricity	$4,793/ kw.
Cooling Water	$110/ GPM

Systems could be proposed which utilized steam ejectors, centrifugal compressors, liquid ring vacuum pumps or any combination of these types of equipment.

From a pure capital standpoint an all steam ejector system is the most economical. From an operating cost standpoint, however, it was the most expensive system based on the evaluation factors unique to this plant. In evaluating the cost and the possible system configurations it became apparent that the best system was one which minimized steam consumption. Ideally, an all compression system would probably offer the best overall evaluation, however because of space limitations this type of system could not be offered. It was determined that the best system was a combination of a first stage steam ejector with a multistage compressor.

The ejector operating conditions were determined by taking full advantage of the compressor performance and designing for the lowest suction pressure. A comparison of utilities consumed for an all ejector system vs. a hybrid system are tabulated below:

Utility Consumption Based on Two 50% Operating Units

	All Ejector	Hybrid System
Steam	101000	18640 lbs./hr.
Electric		1018 kw
Cooling Water	13200	11746 GPM

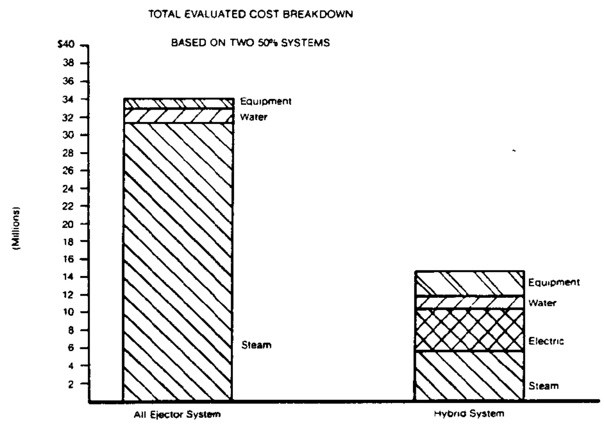


Figure 1

A breakdown of the total evaluated coat of the two system types is shown on Figure 1. The cost analysis is based on two 50% operating units. The analysis includes equipment cost (ejectors, compressor systems, intercondensers, intercoolers, and piping) and evaluated operating cost only and makes no allowance for installation cost.

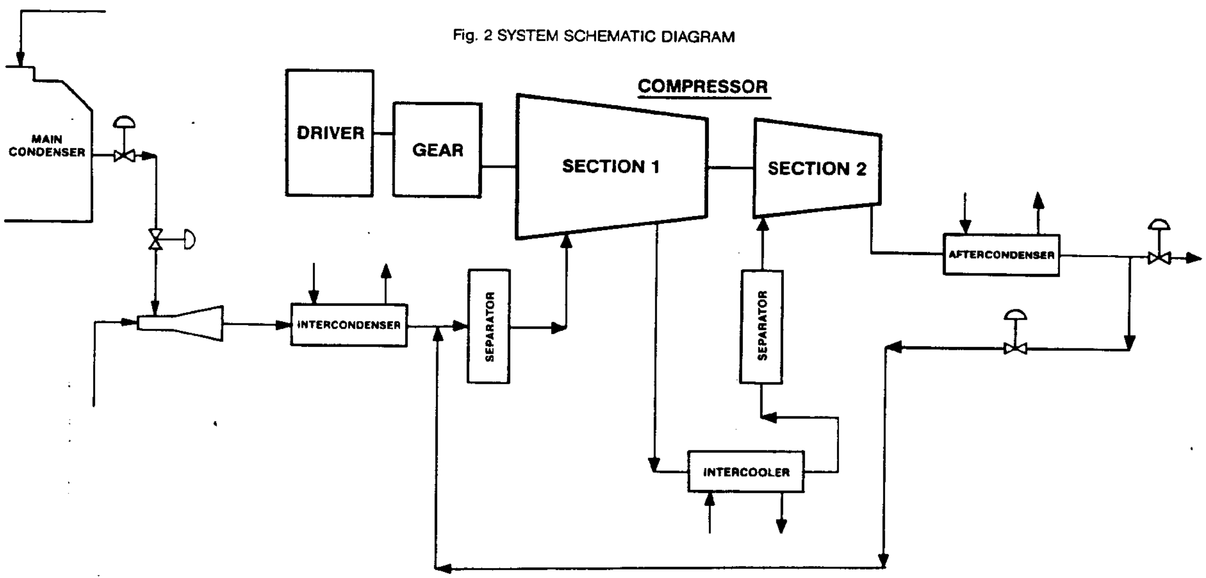
A schematic diagram of the system is displayed in Figure 2. The system operates in a free, open state without the use of control valves. In order to protect the compressor from surge during low flow operation a single bypass line is used to recycle flow around the compressor. For start up of the system the third standby train is used as a hogging train to evacuate the system of all air and provide the necessary vacuum conditions to start the compressor. Each train is isolated with check valves in the inlet prior to the ejector and in the discharge downstream of the aftercooler. Aftercoolers are provided to maintain a 105 F discharge temperature of the gas to the hydrogen sulfide abatement system.

EQUIPMENT DESIGN

As with all geothermal installations the presence of highly corrosive gas poses special design requirements in materials selection. The high non-condensible gas content imposed additional design considerations in equipment selection.

The condenser for this application is designed and being manufactured by Graham Manufacturing Co., Inc. and has 166,000 sq. ft. of heat transfer surface area. The condenser shell is 304L stainless steel. Tubesheets are 316L stainless steel. Tubes are made of titanium. The standard calculation procedures used for heat transfer in steam surface condenser design as displayed in Heat Exchange Institute (HEI) Standards were considered not applicable to services where there are high non-condensible loads. Specifically, the overall heat transfer coefficient and log mean temperature difference (LMTD) were corrected to compensate for the effect of condensing steam in the presence of high non-condensible gas. LMTD is lower than the HEI method since gas cooling must be considered along with the partial pressures of steam and air affecting the condensing temperature. In calculating the thermal performance proprietary computer programs were utilized. In order to provide for the greatest possible subcooling of the gas prior to its exiting the condenser the internal gas cooling

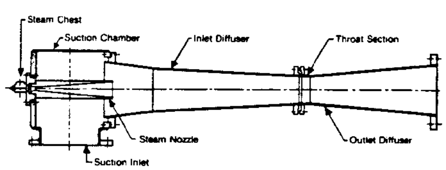
Fig. 2 SYSTEM SCHEMATIC DIAGRAM



sections are located so as to remove non-condensibles from all areas of the shell. The gas removal section is arranged such that the total non-condensible load passes across the first (coldest) cooling water pass before exiting the condenser.

The hybrid train consists of a single stage ejector with a shell and tube intercondenser upstream of the compressor. The all ejector train is comprised of three stages of ejectors with shell and tube intercondensers and aftercondensers. The material of construction is 304L stainless steel throughout with titanium tubes used in the condensers and compressor inter/after coolers. An ejector is easy to operate, durable and generally trouble-free because there are no moving parts. It is to be emphasized that the ejector is probably one of the most trouble-free pieces of apparatus that

Figure 3



THESE PARTS MAKE AN EJECTOR

STEAM CHEST. This is the connection through which the high pressure motive steam supply is introduced.

SUCTION CHAMBER. This provides a plenum chamber with the appropriate connections for the suction inlet, diffuser and steam nozzle. This part can sometimes be eliminated by incorporating the diffuser connection and steam nozzle connection in the vessel which is to be evacuated. Frequently more compact designs and savings in cost can result from such designs.

STEAM NOZZLE. This is the heart of an ejector since it converts the energy of pressure to velocity and directs the flow of motive steam into the diffuser.

INLET DIFFUSER. This provides a correctly shapped introductory section and converging diffuser section to handle the high velocity flow of fluids. It is in this section that entrainment and mixing of the motive and load fluids is completed and the energy of supersonic velocity is converted to pressure.

THROAT SECTION. This is the transition piece between the converging supersonic inlet diffuser and the diverging subsonic outlet diffuser.

OUTLET DIFFUSER. This provides a correctly shaped diverging diffuser section for completing the conversion of velocity to pressure. After the fluid flow has passed through the throat of the diffuser, the flow is essentially subsonic. The outlet diffuser section further reduces the fluid velocity to a reasonable level so as to convert practically all the velocity energy to pressure energy.

operates in any vacuum cycle. Figure 3 describes the basic construction of an ejector. Ejectors, inter/after condensers and compressor inter/after coolers are designed and being manufactured by Graham Manufacturing Co., Inc.

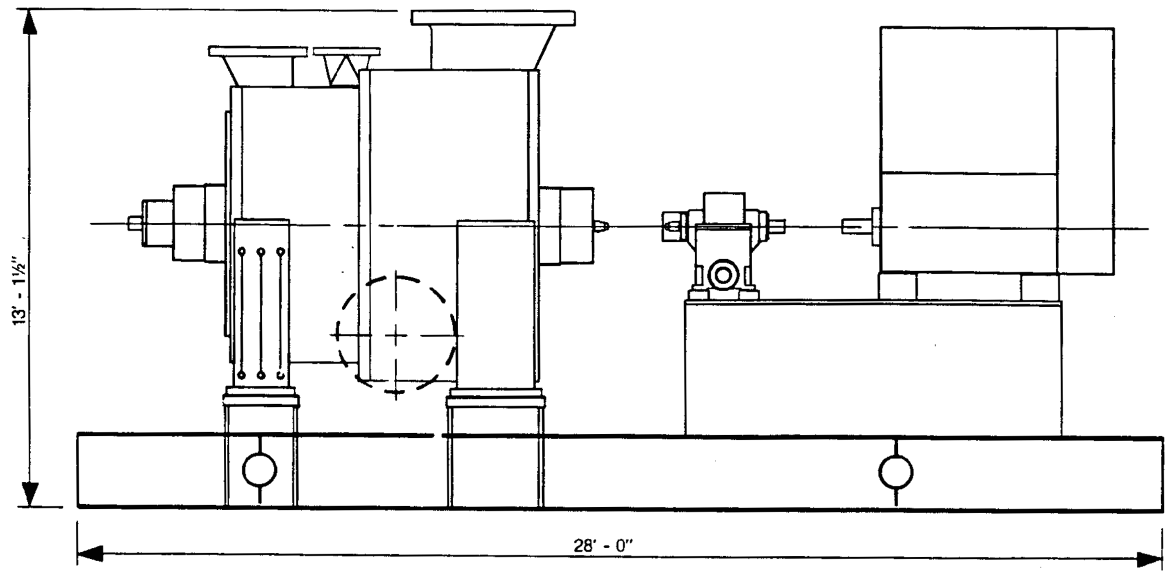
The compressors utilized in the gas removal system are API 617 process design compressors. Typically in high volume low pressure applications, usually for air or inert gas services, blower type compressors are considered. In this application because of the high pressure ratio, the corrosive and toxic nature of the gas, and critical nature of the service requiring long periods of trouble-free operation API 617 process design compressors were specified. The compressors are Transamerica Delaval model 9BK52 multistage intercooled vertically split case designs. In order to guard against corrosion of the compressor internal elements the first stage of each compressor section is made of stainless steel as are the first stage diaphrams of each section. Each successive impeller of each section is made of a low yield material, HYBO. This material has been used in process applications with H_2S concentrations as high as 13%. The compressor train is equipped with a high inertia motor for starting and a double helical speed increasing gear. Lube oil to the compressor and gear are provided from an API 614 lube oil system mounted on a separate baseplate. In order to guard against corrosion all piping is 304L and lube oil cooler elements are stainless steel. An outline of the compressor train is shown in figure 4.

PLANT SETTING

The Geysers are located in both Lake and Sonoma Counties, about 100 miles north of San Francisco. This extremely rugged and remote area has been used for geothermal commercial development for over 25 years. At the time of writing, site work for the Coldwater Creek Power Plant had not begun. Access to the site is permitted only by one very steep dirt road at this time. In the near future, the plant will be accessible by two paved roads.

Due to the plant site being located on the edge of a cliff, the physical size and design of the plant was quite restrictive. This fact, coupled with limited space of 16 feet between plant floors, required comprehensive calculations to be performed in determining the possible layouts for a variety of alternative equipment. Ejectors. inter-condensers and coolers were placed on the upper

Fig. 4 COMPRESSOR TRAIN OUTLINE



floors of the structure. The centrifugal compressors are located on the grade level. Because of the restricted overhead space. which severely hampered the removal of the compressor casing upper half for maintenance purposes, a vertically split barrel casing design is utilized. Use of maintenance area was maximized by situating the compressors such that the inner assemblies are removed outward into the condenser tube maintenance area.

SUMMARY

By utilizing state of the art gas processing technology in conjunction with traditional power plant gas removal equipment the overall operating efficiency and cost of high non-condensible load geothermal power plants can be significantly improved. Whereas the initial capital cost of a hybrid system is higher than a traditional all ejector system the savings in operating cost, depending on site specific cost evaluation factors, can justify the added investment. The use of API quality equipment offers a high degree of reliability. Additionally, in the authors' opinion the use of this technology can make geothermal resources once thought to be uneconomical due to their high non-condensible loads, viable power producing resources.