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LOW TEMPERATURE GEOTHERMAL FLASH STEAM PLANT

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ABSTRACT

A performance and cost comparison is presented between a flash steam and binary power plant using 230°F geofluid. This geofluid temperature is well below the 300°-350°F range that has traditionally been the minimum cut-off temperature for flash steam plants. However, this study shows that by using a new, low pressure steam turbine design, the geofluid utilization for a low temperature flash steam plant is comparable to a typical binary plant and the capital cost of the binary plant is 60% higher.

INTRODUCTION

This study was motivated by the need to reduce the cost of power that is produced with low temperature geofluid. With current technology, this power can only be produced with high cost, equipment intensive binary plants. The comparison presented below shows that with the proper plant equipment, a flash steam plant can achieve high utilization of the geofluid at a much lower cost.

With high temperature geofluid, flash steam plants are more cost-effective than binary plants. This is primarily due to cost differences in the heat addition and heat rejection systems. The heat addition system in a flash plant (throttle valve and liquid-vapor separator vessel) is much less expensive to procure and install than a comparable system in a binary plant (surface heat exchangers). Similarly, the heat rejection system in a typical flash plant (direct contact condenser, cooling tower with circulating pump, and non-condensible gas removal system) have lower procurement and installation costs than the comparable system in an evaporatively-cooled binary plant (surface condenser and cooling tower with circulating pump). High temperature flash steam plants have an additional advantage due to the good availability of steam turbines that are well suited to those process conditions.

With low temperature geofluid, the flash plant maintains a cost advantage for the heat addition and heat rejection systems. However, low temperature flash plants have been limited by the very high flow rates of low pressure steam that they must process. With low temperature geofluid, the pressure and enthalpy of the steam that is generated in the flash process decreases. Consequently, the steam flow rate for a low temperature flash plant will be much higher than a plant producing the same power with higher temperature geofluid.

Traditionally, flash steam plants have not been considered for geofluid temperatures below 300°-350°F. This is partially due to the large pipe sizes required for high volume flow rates of steam but the major limitation has been that there are no steam turbines currently on the market that will handle these high flow rates of low pressure steam. Currently available steam turbines are designed for much higher inlet pressures. These turbines can be modified to handle lower inlet pressures by removing the higher pressure stages. However, this approach increases the cost of the turbine (on a $ per kW basis), and the resulting cost of power is not competitive.

With an appropriate steam turbine, it would be possible to use low cost flash steam plant technology for low temperature geofluid applications. This paper will present the results of preliminary work that has been completed for a new, commercial scale, steam turbine that is specifically designed for the high flow rates of low pressure steam that will be generated in a flash steam plant using 230°F geofluid.

PLANT COMPARISON

In order to demonstrate the advantages that can be achieved with a low temperature flash plant, a comparison has been made of the performance and cost of a flash plant versus a binary plant. Table 1 lists the site conditions that were used as a basis for the plant comparison. The conditions are representative for a bottoming plant using effluent geofluid from a double flash plant. Tables 2-5 compare the process conditions and performance characteristics of a flash steam plant and a comparable binary plant. Figure 1 shows site plans for the two plants.

The low temperature flash plant uses conventional design concepts. The geofluid entering the plant is throttled across a control valve and the two-phase flow is ported into a liquid-vapor separator vessel. Preliminary analysis indicates, that a 16 ft. diameter by 20 ft. high separator will handle the required flow and achieve the phase separation with a steam pressure drop of about 0.1 psi. The liquid from the separator is pumped to the injection well and control of the liquid level in the separator is maintained with a control valve downstream from the injection pump. The vapor from the separator flows through a 4 ft. diameter pipe and is ported into the two turbine expanders through 16 in. by 30 in. rectangular ducts. Since the separator vessel and all of the turbine inlet piping operate at 190°F and 9 psia, the components can be lightweight and thin walled.

The steam is expanded in two turbines that are coupled to each other and to a single gear box-generator unit. (The design and performance of the turbines will be discussed below.) The steam from each turbine housing flows into a direct contact condenser where subcooled water from the cooling tower condenses the steam at 100°F. The cooling water and condensate are pumped from the condensers to the spray bars in the cooling tower. There is also a stream of non-condensible gas (NCG) that must be removed from the condensers with a liquid ring vacuum pump. The NCG comes from gas that is released from the geofluid in the flash process and from air that is dissolved in the cooling water. However, since most of the gas has been released from the geofluid in the preceding two flashes and the concentration of air in the cooling water is very low, the NCG stream is small and a small vacuum pump can be used.
The gross generator output for the flash plant is 5053 kW. The plant parasitic load is approximately 7% of this gross output, which produces a net electrical buss bar output of 4690 kW.

The site plan for a comparable binary plant is also shown in Figure 1. It is based on conventional design concepts and uses isobutane as the working fluid. (The low geofluid temperature would suggest the use of a lighter hydrocarbon, but because of the minimum geofluid temperature limit, isobutane provides comparable performance.) The gross electrical output of the binary plant is higher than the flash plant at 5341 kW. However, approximately 16% of this is required for plant parasitics resulting in a net power output of 4492 kW, which is lower than the flash plant.

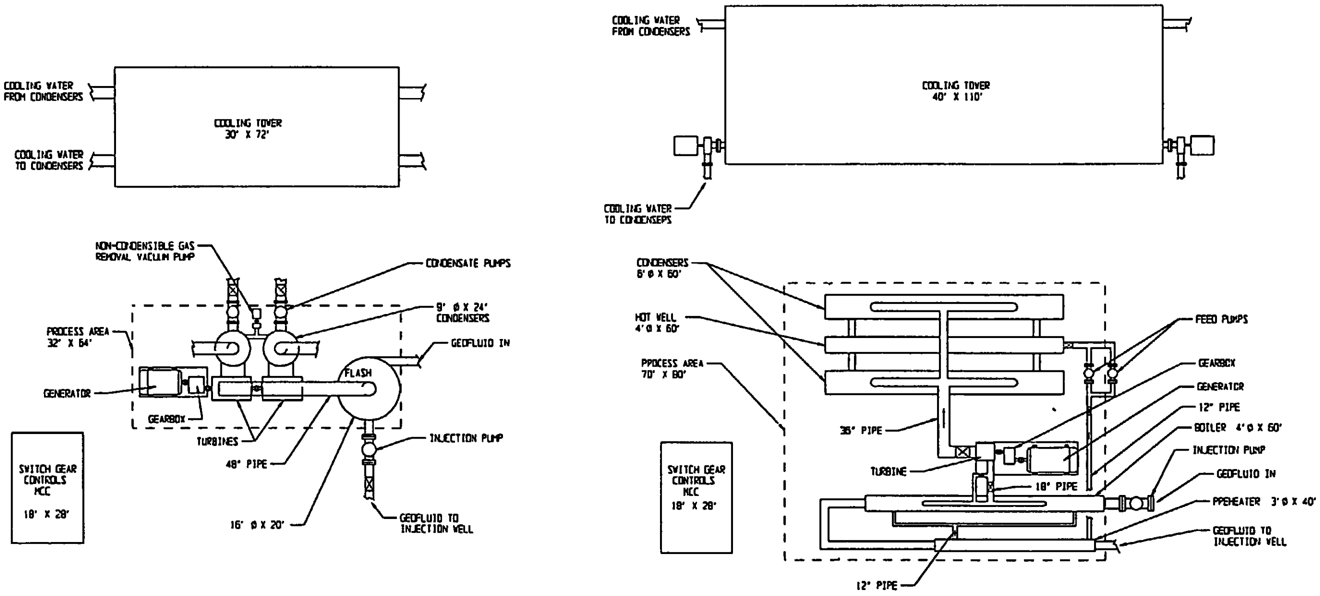
Table 6 lists the cost breakdown for the flash and binary plants. The flash plant has a significant cost advantage for heat addition and heat rejection equipment. (The difference between the cooling tower costs is due to a difference in optimum condensing temperatures, 90°F for the binary and 100°F for the flash.) The binary plant also has significantly higher costs associated with the feed pump, need for a fire protection system, and higher construction costs due to the larger foot print and more extensive piping. The only category where the flash plant has significantly higher costs is the turbine-generator system. However, with a cost-effective steam turbine design, this is a minor effect and the installed cost of the binary plant is 60% higher than the flash plant (in $ per net kW).

It should be noted that this cost comparison is based on an evaporatively cooled binary plant. At sites where cooling make-up water is not available, a binary plant would have to use air-cooled condensers. This will increase the binary plant cost by about 10% and will result in less power output when ambient temperatures are high. Since the low temperature flash plant can always utilize evaporative cooling (by evaporating the condensate), it will have an even more significant cost advantage if the binary plant must be air-cooled.

It is expected that the flash plant will also have an advantage in the area of O&M costs. It is impossible to quantify this advantage until some operating experience is gathered with the low temperature flash plant. However, by eliminating tube-in-shell heat exchangers in scale prone regions, it is likely that O&M costs for the flash plant will be lower than the binary.

In addition to performance and cost advantages, the flash plant also has an advantage over a binary plant in the area of fugitive emissions. The binary plant will experience isobutane emissions from turbine and pump seals, valve stems, and gasketed joints. With good design and appropriate maintenance these emissions can be kept low, but with the prospect of tighter standards for volatile organic chemical emissions, this is another consideration that would favor the flash plant.

TABLE 1 - SITE CONDITIONS	
Geofluid Inlet Temperature	230°F
Minimum Geofluid Exit Temperature (Limit is due to scale considerations.)	190°F
Average Ambient Wet Bulb Temperature	50°F
Geofluid Flow Rate	4,280,000 lbm/hr



LOW PRESSURE FLASH PLANT

BINARY PLANT

FIGURE 1 - SITE PLANS

TABLE 2 - FLASH PLANT PROCESS CONDITIONS	TEMP (F)	PRESS (psia)	SP VOL (ft^3/ lbm)	ENTHLPY (BTU/ lbm)	M FLOW (lbm/ hr)
GEOFLUID STREAM					
Plant Inlet	230			198.3	4,280,000
Separator Inlet	190	9.34		198.3	4,280,000
Turbine Inlet	189.7	9.24	41.4	1141.8	175,290
Turbine Exit					
Isentropic	101.7	1.00	300.4	1002.4	175,290
Actual	101.7	1.00	311.6	1037.2	175,290
CONDENSER STREAMS					
Condenser Inlet					
Cooling Water	75			43.1	7,401,050
Steam	101.7	1.00		1037.2	175,290
Condenser Exit					
Condensate and Cooling Water	98	.95		66.1	7,575,860
Non-Condensible and Water Vapor		.90			480

TABLE 3 - FLASH PLANT PERFORMANCE	COMPONENT EFFICIENCY	MOTOR EFFICIENCY	POWER - OUTPUT/INPUT (kW)
Turbine	0.75		5371
Gear Box	0.98		5264
Generator	0.96		5053
Condensate Pumps	0.80	0.93	173
Cooling Tower Fans		0.93	120
NCG Vacuum Pump			70
Net Elec Output			4690

TABLE - 4 BINARY PLANT PROCESS CONDITIONS	TEMP (F)	PRESS (psia)	SP VOL (ft^3/ lbm)	ENTHLPY (BTU/ lbm)	M FLOW (lbm/ hr)
GEOFLUID					
Plant Inlet	230			198.3	4,280,000
Boiler Exit	207.3			175.6	4,280,000
Plant Exit	190			158.3	4,280,000
ISOBUTANE					
Boiler Exit	203.3	264.5	.324	-618.1	997,300
Turbine Inlet	202.9	261.5	.327	-618.1	997,300
Turbine Exit					
Isentropic	112.2	62.9	1.518	-642.4	997,300
Actual	123.0	62.9	1.557	-637.5	997,300
Condenser Exit	90.0	62.9	.029	-791.3	997,300
Pump Exit	92.8	303.5	.029	-789.7	997,300
Preheater Exit	203.3	263.5	.037	-715.5	997,300
COOLING WATER					
Condenser Inlet	65				7,669,200
Condenser Exit	85				7,669,200

TABLE 5 - BINARY PLANT PERFORMANCE	COMPONENT EFFICIENCY	MOTOR EFFICIENCY	POWER - OUTPUT/INPUT (kW)
Turbine	0.80		5677
Gear Box	0.98		5563
Generator	0.96		5341
Feed Pump	0.80	0.93	514
Cooling Tower Fans		0.93	160
Condenser Pumps	0.80	0.93	175
Net Elec Output			4492

TABLE 6 -

FLASH AND BINARY PLANT COST COMPARISON

	FLASH PLANT		BINARY PLANT	
	QTY	TOTAL COST	QTY	TOTAL COST
ENGINEERING AND DESIGN		400,000		500,000
EQUIPMENT COSTS				
HEAT ADDITION EQUIPMENT				
SEPARATOR VESSEL	1	100,000		
PREHEATER			1	170,000
BOILER			1	640,000
SUBTOTAL		100,000		810,000
HEAT REJECTION EQUIPMENT				
COOLING TOWER	1	250,000	1	470,000
CONDENSER	2	140,000	2	1,060,000
HOT WELL			1	20,000
COOLANT PUMP	2	70,000	2	50,000
GAS REMOVAL EQUPMENT	1	90,000		
SUBTOTAL		550,000		1,600,000
TURBINE-GENERATOR WITH ACCESSORIES	1	1,300,000	1	900,000
FEED PUMP			2	150,000
CONTROL VALVES				
SEPARATOR EXIT WITH LEVEL CONTROLLER	1	40,000		
TURBINE START WITH SPEED CONTROLLER	1	10,000	1	10,000
TURBINE INLET	2	60,000	1	30,000
TURBINE EXIT			1	50,000
FEED PUMP INLET			1	30,000
FEED PUMP EXIT WITH LEVEL CONTROLLER			1	30,000
CONDENSER EXIT WITH LEVEL CONTROLLER	2	60,000		
SUBTOTAL		170,000		150,000
CONTROLS, SWITCH GEAR, INSTRUMENTATION	1	400,000	1	400,000
WORKING FLUID				20,000
TOTAL EQUIPMENT COST		2,520,000		4,030,000
DELIVERY COST AND TAXES (10%)		252,000		403,000
DELIVERED EQUIPMENT COST		2,772,000		4,433,000
SUPPLIES, MATERIALS AND CONSTRUCTION COSTS				
SITE WORK		90,000		90,000
CONCRETE		100,000		130,000
MECHANICAL EQUIPMENT, STRUCTURAL		170,000		170,000
FIRE SYSTEM				70,000
PIPING		200,000		400,000
ELECTRICAL		220,000		280,000
TOTAL CONSTRUCTION COST		780,000		1,140,000
START UP		120,000		150,000
SUBTOTAL		4,072,000		6,223,000
MANAGEMENT (2.5%)		101,800		155,575
BONDS AND INSURANCE (4%)		162,880		248,920
CONTINGENCY (10%)		407,200		622,300
PROFIT (10%)		407,200		622,300
PROJECT COST		5,151,080		7,872,095
NET POWER OUTPUT (KWe)		4,690		4,492
$ PER INSTALLED KWe		1,098		1,752

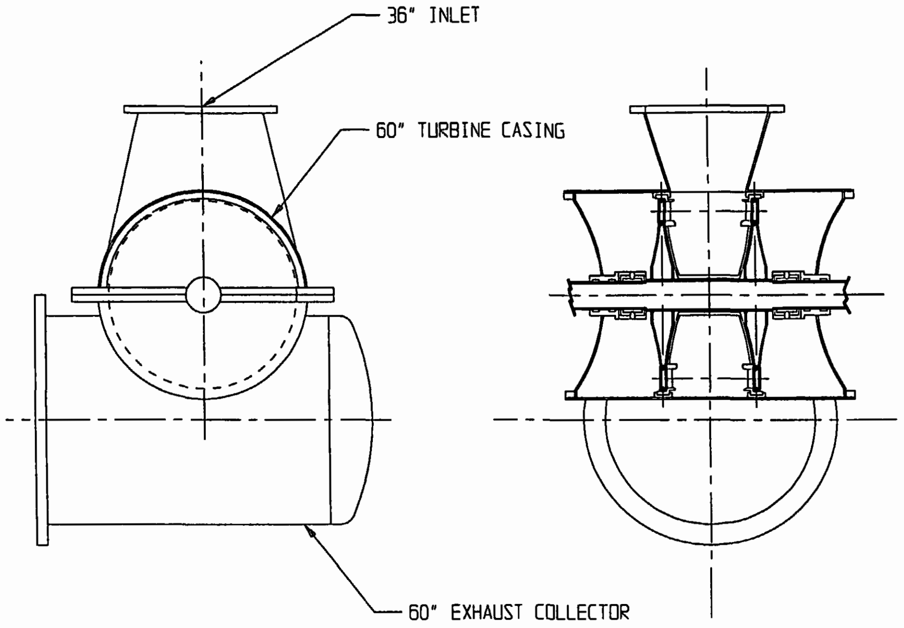


FIGURE 2 - LOW PRESSURE STEAM TURBINE

LOW PRESSURE STEAM TURBINE

The critical equipment component that is required to permit flash steam plants to be used with low temperature geofluid is a cost effective, low pressure steam turbine. A drawing for a new split flow, single stage, axial, low reaction turbine is shown in Figure 2. The performance characteristics of the turbine are listed below. (Two of these turbines would be required for the hypothetical plant described above.)

Turbine Inlet:	
Temperature	189.7°F
Pressure	9.24 psia
Flow Rate	88,000 lbm/hr
Turbine Exit:	
Temperature	101.7°F
Pressure	1.00 psia
Wetness (Act)	0.07
Head (Isent)	139.4 BTU/lbm
Turbine Description:	
Rotor Tip Dia	54 in
Blade Height	6.0 in
Shaft Speed	7000 rpm
Specific Speed	72
Efficiency	0.75
Output Power	3600 HP

To handle the high volume flow rates, a split flow turbine is used. The steam enters the middle of the turbine housing through a rectangular duct and flows axially through the housing in both directions. The steam flows through single stage expander components at both ends of the turbine and is ducted out the bottom of the housing to an exhaust pipe that connects to the condenser. A horizontally split housing is used, and the turbine nozzles and bearings are mounted on lateral supports in the bottom portion of the housing. Since the steam temperature and pressure are low, the cost of the fabricated housing can be minimized by using relatively thin walled, carbon steel plate and piping components. With the low inlet pressure steam, the turbine head drop is relatively small so that low cost, single stage, axial flow expanders can be used. Where the turbine shaft penetrates the housing, steam buffered labyrinth seals will be used. Since the seal steam pressure needs to be greater than atmospheric, a small stream of higher pressure steam from the topping plant will be used.

The turbine shaft will be supported on water lubricated, fluid film bearings. The water lubricated bearings will eliminate the need for both an oil lubrication system and the seals that would be required to isolate the oil from the steam. This approach contributes to the simplicity and low cost of the turbine design. Water lubricated bearings will operate with a smaller film thickness than comparable oil bearings. However, preliminary analysis indicates that with a fairly conventional bearing design, an acceptable film thickness (approximately .001 in.) can be achieved.

There is some concern about potential long term damage of the turbine rotors due to corrosion-erosion damage caused by wetness at the turbine exhaust. These components will be manufactured from high chrome stainless steels and should stand up to the operating conditions for many years of service. However, should the rotors require periodic replacement, one of the attractive aspects of this design is the low cost of the single stage rotors (approximately $20,000 each).

The low pressure steam turbine, with minor variations, will work for a wide range of conditions. Different geofluid inlet temperatures and flow rates will change the turbine steam flow rate and can be accommodated by changing the number of turbines that are used in the plant. Different condensing temperatures will change the turbine head and can be accommodated by changing the shaft speed and making minor changes to the design of the nozzle flow path and to the rotor blade height. Different geofluid exit temperatures will change both the steam flow rate and the turbine head and can be accommodated by the adjustments that have been discussed above.

Given this flexibility, it should be possible to take advantage of the benefits shown in this plant comparison for a wide range of low temperature plant applications. The concept is well suited for both bottoming plants and stand alone plants with low temperature resources.

CONCLUSION

Low temperature geothermal resources are more abundant and can typically be produced for a lower cost than higher temperature resources. However, with current technology binary plants, low temperature resources cannot be used to produce cost competitive electric power. With the development of a new, low pressure steam turbine, it will be possible to exploit low temperature resources with flash steam plant technology. The installed cost of a low temperature flash steam plant is approximately 35% less than a comparable binary plant.