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ACHIEVABLE IMPROVEMENTS IN GEOTHERMAL POWER GENERATION CYCLE

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ABSTRACT

The addition of proven absorption refrigeration hardware to well known binary cycle techniques produces significant gains in energy conversion efficiency. The improved geothermal power generation cycle is described. When compared to a modern dual-flash steam plant, it shows a 24.3% increase in net output for the same brine flow. Cooling load per kW is reduced by 32.4%. Further improvements in net output and cost are expected as the system is optimized.

INTRODUCTION

Improvements in energy conversion technology could expand New Horizons of geothermal power. Higher efficiency and reductions in cooling requirements would both provide welcome additions to expand the application of geothermal power. Such improvements will increase the economic development of existing and potential geothermal resources--for conventional, geopressured, and hot dry rocks. This paper describes an improved geothermal power generation cycle and equipment to significantly enhance the viability of geothermal power.

BACKGROUND

Geothermal energy conversion systems use steam or hydrocarbons as the working fluid. Condensers are air cooled or liquid cooled with the waste heat usually rejected to air in a cooling tower. Both media types are affected by ambient temperature--steam to a minor extent, hydrocarbon based systems significantly.

A steam system is limited by the inherent properties of steam. The lowest condensing temperatures obtainable are controlled by realistically achievable vacuum levels in the condenser. For a vacuum level of 2-1/2" Hg.abs., the condensing temperature is limited to approximately 109°F. Ambient temperatures lower than the design point will produce relatively minor changes in net power output as the coolant flow is reduced and coolant pump power decreased.

On the other hand, air cooled hydrocarbon systems can show significant increases in power as ambient temperatures are reduced during daily and annual cycles. With a fixed resource temperature, the lower condenser temperature permits a higher output from the hydrocarbon turbine while reducing the percentage of the resource input converted to waste heat.

In addition to natural cyclic variations in condenser temperature, many attempts have been made to artificially reduce condenser temperature. These include the use of off-peak thermal storage and the vaporization of liquid natural gas fuel in the condenser. Like the natural cyclical temperature differences cited above, these are "batch" or intermittent processes.

Using "stand alone" refrigeration, attempts to link artificial refrigeration with power generation have failed. The system losses are greater than any potential gain in output power. Such "stand alone" systems inherently violate the Second Law of Thermodynamics.

One of the authors (J.H.R.) recognized that when refrigeration heat losses are captured and fed back into a binary cycle, gains in total cycle efficiency are made. Using existing absorption refrigeration (AR) technology and pass-thru heat techniques in a coupled cycle, a new improved energy conversion cycle was developed. This new system passed thermodynamic review and met the requirements of the First and Second Laws of Thermodynamics. U.S. and foreign patent coverage has been obtained. This energy conversion system represents a "breakthrough" in thinking, but not in hardware. Existing, proven hardware is used. The components achieve significantly improved results without the risks of unproven technology.

This paper describes an example of the improved energy conversion cycle and compares it to a current dual-flash plant.

EXAMPLE CYCLE AND RESULTS

For comparison, a modern dual-flash plant has been used as a reference. It has the parameters listed in Table I. The example system uses identical brine source and reinjection conditions.

TABLE I

Dual-Flash Reference Plant Parameters

Brine Source: $4.65 \cdot 10^6$ lbs./hr.
Two phase flow -- 13% steam, 87% liquid
150 psia at 450°F.

Brine Return: Reinject at ≥ 200°F. at 135 psia.

Gross Power Produced:	60 MW
Less: Total parasitic load	5
Net Power:	55 MW
Waste Heat:	255.58 btu/lb. brine 20,769 btu/gkW

Figure 1 shows a block diagram of the example system. The left hand shaded area contains elements which are normally included in off-the-shelf packaged absorption refrigeration units. Absorption refrigeration is a 100-year old well-proven technology which utilizes low grade heat input to generate below-ambient temperatures. An AR system is essentially a collection of heat exchangers and plumbing which is inherently very simple and reliable. Small AR units have no moving parts! Larger systems utilize relatively small pumps which minimize parasitic power.

The right hand shaded area of Figure 1 consists of elements normally included in conventional binary systems. The elements added in the new system are:

a) subambient turbine,
b) subambient turbine hydrocarbon boiler
c) a second hydrocarbon pump

Heat coming from the geothermal source is used to operate the two separate subsystems. A portion of the heat energy drives the absorption refrigeration system to generate a very low condenser temperature--well below normal ambient. For the geothermal example presented herein, the condenser or "Synthetic Sink" temperature is -35° F. The balance of the resource heat is used to vaporize a hydrocarbon working fluid as part of a binary power cycle. In contrast to a conventional binary cycle, in this system a secondary hydrocarbon working fluid is expanded down to and condenses at a temperature of -25° F. Like conventional binary systems, the primary working fluid is condensed at ambient temperature. Waste heat from the AR system is passed through and used to preheat both working fluids before they enter the hydrocarbon boilers. Heat is rejected externally from the system at ambient.

Engineers from industry and academic institutions have reviewed the system and find that the concept is both feasible and fully compatible with thermodynamic principles. In addition, the system has been verified by the powerful Aspen Plus™ process flowsheet simulation software [1].

One set of operating characteristics for the example system are shown in Table II. Other sets will show even better performance. It should be noted that none of the steam and its entrained pollutants would be exposed to the atmosphere, unless a portion of the steam were condensed to provide makeup water for the cooling towers.

TABLE II

Improved Geothermal Binary Cycle Plant
Example Parameters

Brine Source: $4.65 \cdot 10^6$ lbs./hr.
Two phase flow -- 13% steam, 87% liquid
150 psia at 450° F.

Brine Return: Reinject at ≥ 200°F. at 135 psia.

Upper Hydrocarbon Turbine:	
Media:	Isobutane
Turbine Entry:	800 psia @ 320° F.
Turbine Exhaust:	53 psia @ 90° F.
Flow:	1.32 lbs./lb. brine
Lower Hydrocarbon Turbine:	
Media:	Propane
Turbine Entry:	800 psia @ 290° F.
Turbine Exhaust:	22.9 psia @ -25° F.
Flow:	0.20 lbs./lb. brine
Absorption Refrigeration Subsystem:	
Source Temperature	320° F.
Flow:	0.062 lb. NH_3 /lb. brine
Synthesized Condenser Temperature	-35° F.
Gross Power Produced:	83.21 MW
Less: Total Estimated Parasitic Load	14.8
Net Power:	68.37 MW
Waste Heat:	239.35 btu/lb. brine 14,036 btu/gkW

A comparison of the two cycles is shown in Table III. Note that for the same brine flow, this example shows a net bus bar output improvement of 24.3% and a 32.4% reduction in waste heat discharge per kW. Figure 2 shows that both systems start with the same heat input and illustrates the shifting of thermal energy from waste heat to saleable power.

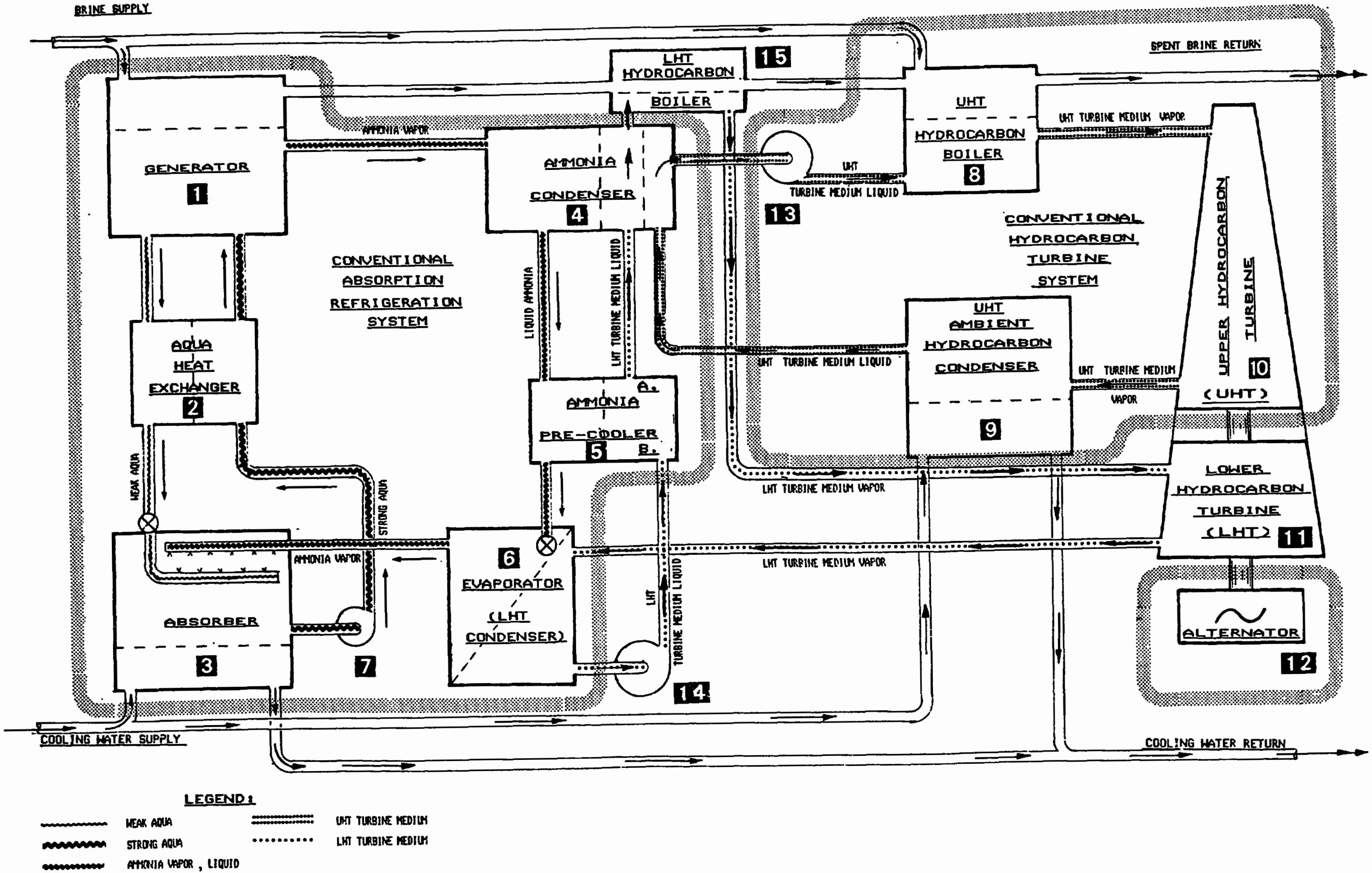

Figure 1 -- Block diagram of improved geothermal binary cycle plant. The area within the tint border on the left contains elements normally included in commercial absorption refrigeration packages. Tint bordered areas on right contain elements used in conventional binary systems.

TABLE III

Performance Comparison

Parameter	Dual-Flash Reference	Improved Binary Cycle Example	Change	Notes
Gross Power Output--MW	60	83.21	+38.7	1
Parasitic Power--MW	5	14.8	+196%	2
Net Plant Output--MW	55	68.37	+24.3	3
Waste Heat--btu/kW	20,769	14,036	-32.4%	4

Notes: 1. Both examples use identical brine source and return conditions.

2. Parasitic power is increased three-fold primarily due to hydrocarbon pumping.

3. As shown, the increase in gross power more than offsets the higher parasitics.

4. Reduced system cooling load results from the increase in gross power.

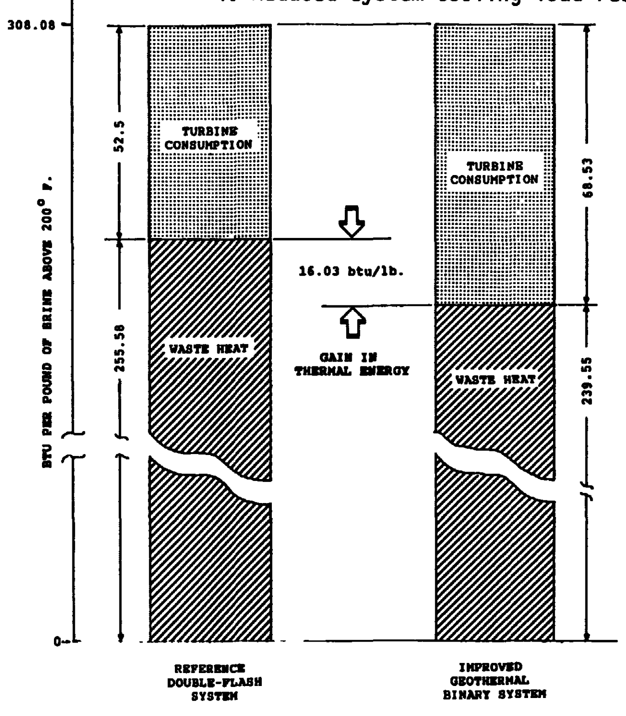

Figure 2 -- Comparative allocation of thermal energy in the reference and improved plants. Note that total energy above 200° F. is the same in both cases. The additional gross power of the improved binary plant is offset by a corresponding reduction in waste heat.

DISCUSSION

A) Performance. The example described above shows the very significant increase of 38.7% gross and 24.3% net power for a fixed brine flow. Although the improvement is already striking, the system has not yet been optimized. Additional cycles are being calculated. This example cycle is based on a 10° F. pinch point for all heat exchangers. It shows marked improvement over the previous calculations both in increased output and reduced parasitic load. Choice of hydrocarbon media [2], use of hydrocarbon mixtures [3,4], crossover temperature, and synthesized condenser temperature are just a few of the items to be optimized. Further performance improvements are expected. Cost/benefit analysis will suggest appropriate tradeoffs between performance and capital costs for a specific site. Further results of the optimization will be reported at the 1988 Geothermal Resources Council Annual Meeting.

B) Cost. The total cost of plant equipment for the new energy conversion system for a given brine flow will be greater than the cost of the reference dual-flash plant. Scaling from published data [5-7], the total plant cost is estimated to be $10M, or 17.8% higher than the reference. However, the site capital cost for wells and plant equipment per kW will be reduced from $1,369 to $1,256 or by 9.2%. Effective operating costs over the life of the plant will be reduced by 19.5% per kW regardless of whether the brine is purchased from a thermal supplier or if the wells are maintained and replaced by the site owner. Further optimization is expected to improve the relative cost figures.

C) Implications. The 24.3% performance increase described in this paper indicates a significant change in the economically developable geothermal resources. Many resources presently thought to be unsuitable may become economically feasible. Presently marginal sites would become profitable. The net result would be to substantially expand the size of commercially viable resources in the U.S. and overseas.

CONCLUSIONS

The improved geothermal cycle described uses the well-proven old technologies of binary cycle turbines and absorption refrigeration. In comparison to a modern dual-flash plant, the example presented shows a 24.3% increase in net power output for a fixed brine flow. Cooling load per kW is reduced by 32.4%. Total capital costs are reduced by 9% per kW while operating costs should decrease by 19%. Further improvements are expected as a result of working fluid and system optimization.

After completion of the next optimization round, a small to medium scale plant is planned to demonstrate actual system performance.

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