THE TOTAL FLOW CONCEPT FOR GEOTHERMAL ENERGY CONVERSION

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A geothermal development project has been initiated at the Lawrence Livermore Laboratory (LLL) to emphasize development of methods for recovery and conversion of the energy in geothermal deposits of hot brines. Temperatures of these waters vary from 150°C to more than 300°C with dissolved solids content ranging from less than 0.1% to over 25% by weight. Of particular interest are the deposits of high-temperature/high-salinity brines, as well as less saline brines, known to occur in the Salton Trough of California. Development of this resource will depend on resolution of the technical problems of brine handling, scale and precipitation control, and corrosion/erosion resistant systems for efficient conversion of thermal to electrical energy. Research experience to date has shown these problems to be severe. Hence, the LLL program emphasizes development of an entirely different approach called the Total Flow concept. This, in principle, consists of passing the total hot wellhead brine-steam mixture directly through a mixed-phase expander to drive an electrical alternator. The purpose of this paper is to define the basic thermodynamics of this concept, expander requirements, and overall system characteristics. The LLL program plans for development of a Total Flow System will be discussed along with comments on current laboratory and field activities.

It is generally accepted that the water-dominated geothermal resources, if developed, could produce a significant supply of clean, low-cost energy. Temperatures of these waters vary from 150°C to over 300°C with dissolved solids content ranging from less than 0.1% to over 25%, by weight.

Of particular interest are the deposits known to exist in the Salton Trough of California. Estimates of the recoverable energy from this region range from about 60,000 to over 10 million megawatt-years. This variation is primarily due to lack of data on the magnitude and distribution of the stored thermal energy, and to uncertainties regarding technological prospects for economic recovery and conversion of the energy from the high saline waters. The current interest in conversion machines and systems designed uniquely for these resources is stimulated mainly because hot water resources are abundant, economic conditions encourage development of machines with highest efficiencies to minimize the number of wells per unit of electrical output, and the range of chemical conditions encountered may require development of special systems, each tailored to specific resources and locations.

Development of the high saline waters, in particular, will depend on resolution of the technical problems of brine management, scale and precipitation control, and corrosion/erosion resistant systems for efficient, economic energy conversion systems. Solution of these problems coupled with a need to better understand the mechanisms governing reservoir lifetimes and productive capacities will require a broad interdisciplinary approach.

Before a commitment to commercial production can be made, a goal oriented research and development program is required to reduce the technological risks to an acceptable level. To accomplish this, a geothermal development program has been initiated by the AEC at the Lawrence Livermore Laboratory (LLL) to emphasize development of methods for recovery and conversion of the energy in the high temperature/high salinity brines. Research experience to date on systems operating from these brines has shown the problems to be severe. Hence, the LLL program emphasizes an entirely different approach called the Total Flow Concept for energy conversion. This, in principle, consists of passing the total hot wellhead brine-steam mixture directly through a mixed phase expander to drive an electrical generator. Figure 1 shows a comparison of this process with the Flashed Steam System on the Temperature-Entropy plane. The Total Flow process involves the expansion of the wellhead product from state point 1 to the exhaust pressure at 2. This is thermodynamically the simplest, and provides an upper bound on cycle efficiency. Regardless of the number of separation stages used in the Flashed Steam System, there will always be some useful energy discarded with the separated brine, e.g., the path A-B.

A detailed analysis of these systems operating from brines of different temperatures has been completed. The results (Figure 2) show that about a 60% increase in power output can be achieved with the Total Flow System if it can be made to function with a 70% engine, or expander, efficiency. This increase, of course, translates directly into a corresponding decrease in the number of required production wells and a reduction in capital investment.

In order to gain this advantage, however, it is necessary to extract the maximum available energy from the wellhead product. Figure 3 illustrates the basic problem. For the particular case shown (p_1 = 360 psia, x_1 = 19%, and expansion to 3.5-inch Hg (120°F) condenser pressure) which is typical of high temperature geothermal wells, it is shown that 2/3 of the available energy is obtained by expansion from about 50 psia down to the sink condition. Hence, any Total Flow System expander must be capable of economic operation over the entire pressure range in order to produce the performance depicted in Figure 2. This means that expanders with limited expansion ratios (such as positive displacement devices) must be multiply staged to recover the available energy. Since the fluid specific volumes, for the example shown, increase from about 0.3 $ft^3/lb.$ to about 70 $ft^3/lb.$, the physical size of the low pressure stages of positive displacement devices increase accordingly, leading to enormous machines, and possibly, high costs. Consequently, development of single stage expansion devices and/or hybrid systems will likely be necessary to gain the full benefit of the Total Flow process. For some applications the latter, for example, may consist of a Total Flow device as a topping stage with exhaust to a Flashed Steam System.

Development of any conversion system for use with a high saline brine is complicated by the presence of as much as 26% dissolved solids. Precipitation of silica and other solids can cause rapid formation of scale on components and outlet piping. Consequently, a system must be designed to either allow continuous removal of scale, or precipitation and deposition control during operation. Coupled with this are problems of corrosion and erosion of materials. While materials technology advances have produced possible solutions, field experience is lacking. Field testing of candidate materials in actual brines under operating conditions must precede final system design. Hence, a complete system approach to development of the Total Flow concept is necessary, and must involve elements of earth sciences, brine chemistry, materials technology, conversion and system engineering.

The LLL geothermal program is directed toward applying and extending these technologies where necessary with emphasis on development of the Total Flow concept for recovery and conversion of the energy in the high saline brines. The key technical issues to be resolved are illustrated in Table 1. Initially, the major program emphasis will be on solutions of the brine chemistry problems and development and testing of expander concepts for energy.

Because of the advantages of full expansion of the wellhead product as shown by Figure 3, it appears that the impulse turbine may emerge as the prime candidate. It is simple, contains one moving part, the technology is already well known, and offers design flexibility. Most importantly, designs utilizing tangential, radial, or axial flow can be used to accommodate a wide range of operating conditions. These machines can be designed to be sufficiently compact to accommodate complete wellhead fluid expansion.

The important feature of the impulse turbine is that the expansion takes place in a converging—diverging nozzle to convert fluid enthalpy to kinetic energy in the form of high velocity jets. The momentum of these jets is then transferred to the impulse wheel which operates at the condenser temperature. Hence, the entire pressure drop takes place in a single component, fixed in space, which offers opportunities for scale control and brine treatment by techniques such as keeping the nozzle walls hot, periodic flexing, chemical treatment, boundary layer control, etc. One concept, among others, under development is shown in Figure 4, which illustrates a tangential flow device currently being designed for test.

It is well recognized that the major technical problems with such devices are the design of efficient nozzles and development of turbine blading to accommodate the mixed-phase flow. Analytical investigations are in progress and indicate, thus far, that efficient transfer of the momentum of the liquid phase is one of the major design tasks. However, the simplifying assumptions inherent in these early calculations limit their value as a precise design tool. Hence, the development of efficient two-phase conversion machinery will require emphasis on experimental techniques.

A geothermal test facility has been constructed at LLL for performance testing of candidate turbines, and to provide a means of test and development of turbine components such as nozzles and blading. This facility consists of a boiler capable of producing about 1.5 lb/sec of water at 1000 psia and 550°F. By flashing, a wide range of typical wellhead thermodynamic characteristics can be reproduced. The facility includes condensing equipment to allow operation at backpressures down to about 3.5 inch Hg (120°F). The capability now exists for complete testing and evaluation of Total Flow machines up to about 100 kW in capacity as well as the means for fundamental investigation of the mechanics of two-phase flow. The system is shown schematically in Figure 5 which shows a cutaway of the test chambers and control room.

In conjunction with this, field testing on a high saline well in the Imperial Valley has begun. This currently is limited to flowing brine through nozzles and over-simulated turbine blades for preliminary material screening and early evaluation of brine handling and scaling problems. Since the brines cannot be adequately simulated in the laboratory under dynamic flowing conditions, it is necessary to carry out brine analyses and treatment experiments in the field, on a flowing well. Preliminary results indicate that one material (Teflon PFA) underwent 100 hours of test without significant scaling in the nozzle or erosion of the wear plate. Additional tests of other materials are being prepared, and field systems for instrumentation and brine analysis are being designed for use this fiscal year.

The overall LLL program goal is the development of complete Total Flow systems for recovery and conversion of the energy in hot water deposits with emphasis on the high salinity resource. Resolution of the key technical issues is planned for early FY 77. Laboratory and field testing of small scale brine tolerant turbines is scheduled for completion by the end of FY 76. Culmination of this development effort should lead to a baseline design for a brine tolerant Total Flow conversion system which will include evaluation of commercial configurations as well as specially designed units. During this time, plans for site selection and development (including drilling) will be made so that construction of a complete demonstration system of about 10 MW capacity can be initiated in FY 77. Depending on the results of the research efforts, installation and operation of the 10-MW experimental power plant is planned for FY 79.

This experimental plant is intended to contain all the necessary elements, including methods for control, fluid handling, reinjection, condensing and cooling, and fully instrumented for determining operation characteristics. It is intended that the system be experimental in nature in order to provide a flexible test facility for evaluation of candidate energy conversion systems. Early involvement of private industries with machines, techniques, or systems for application to the Total Flow process will be actively sought. Current involvement consists of coordination with those doing similar development work, development of agreements to gain access to flowing wells, and negotiations for purchase of existing conversion machines for test and evaluation on the LLL test facility prior to field testing with high saline brines.

Table I.. High-temperature high-salinity geothermal program key technical issues

Conversion	Chemistry and materials	Resource characterization
Total flow concepts	Brine chemistry	Location and magnitude
Develop baseline design	Scaling mechanism	Geochemistry
Component tests	Precipitation	Reservoir lifetime
Small-scale turbine		Productive capacity
System design and optimization	Material selection	
Control	. Corrosion	
Condensing and disposal	Erosion	
Hybrid systems	Fabrication	
Plant characterization		
Economics		

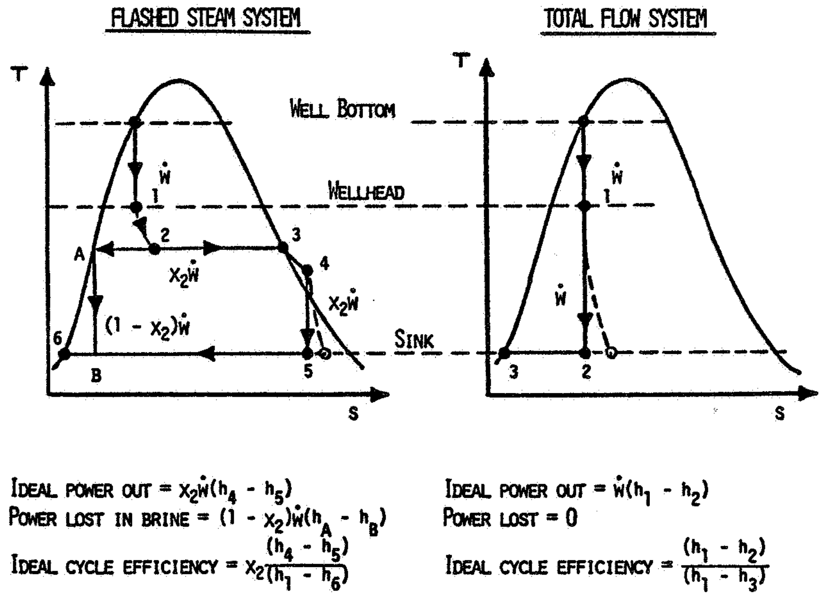

Fig. 1. Comparison of flashed steam and total flow systems

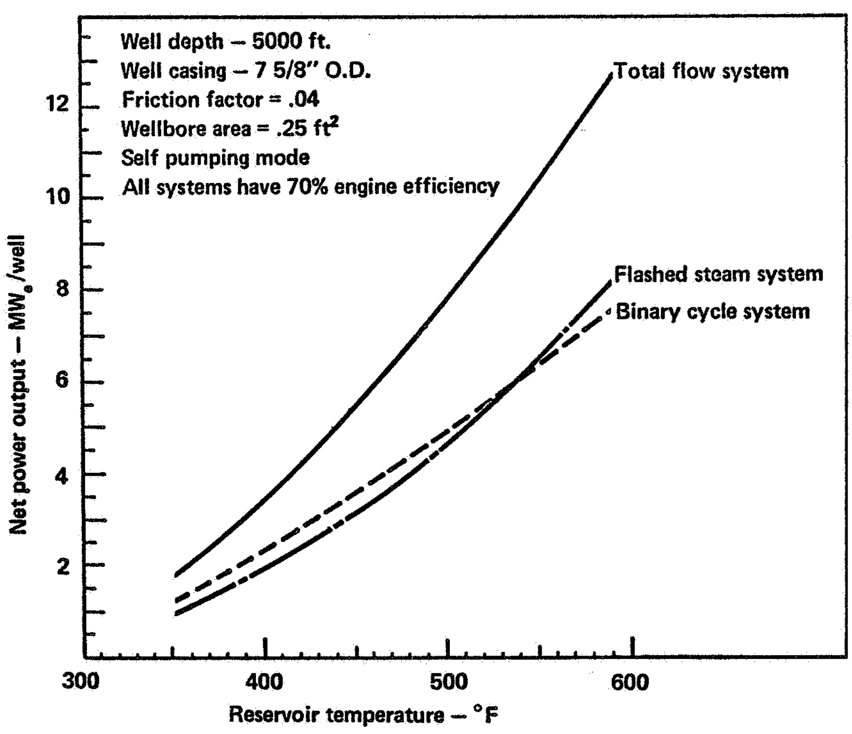

Fig. 2. Comparison of geothermal power systems

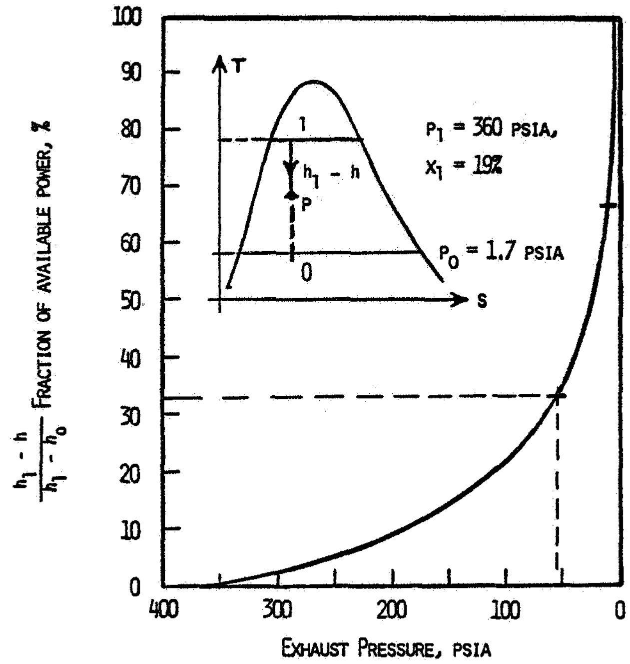

Fig. 3. Recovery of available power for an isentropic expansion of wet steam characteristic of a hot-water geothermal well

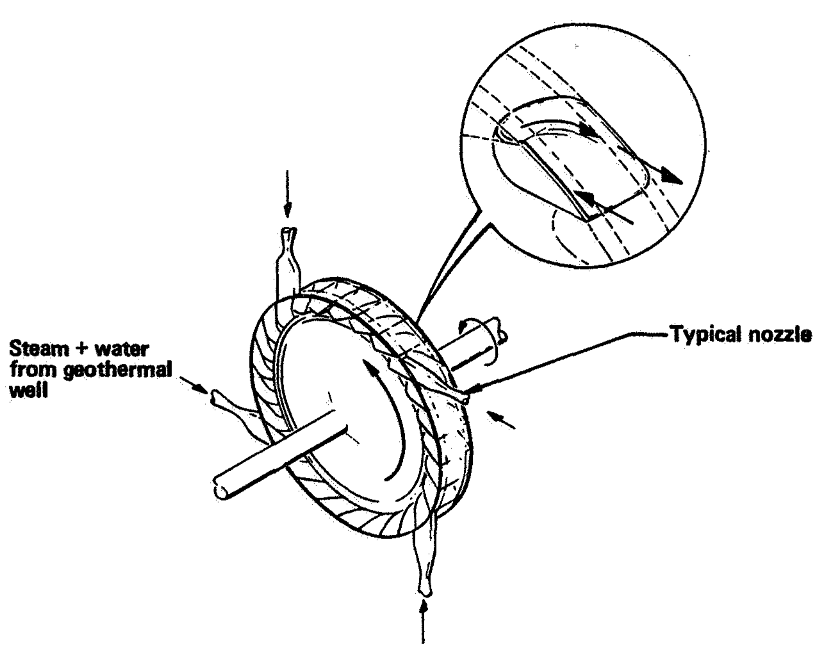

Fig. 4. Tangential flow experimental turbine for total flow geothermal application

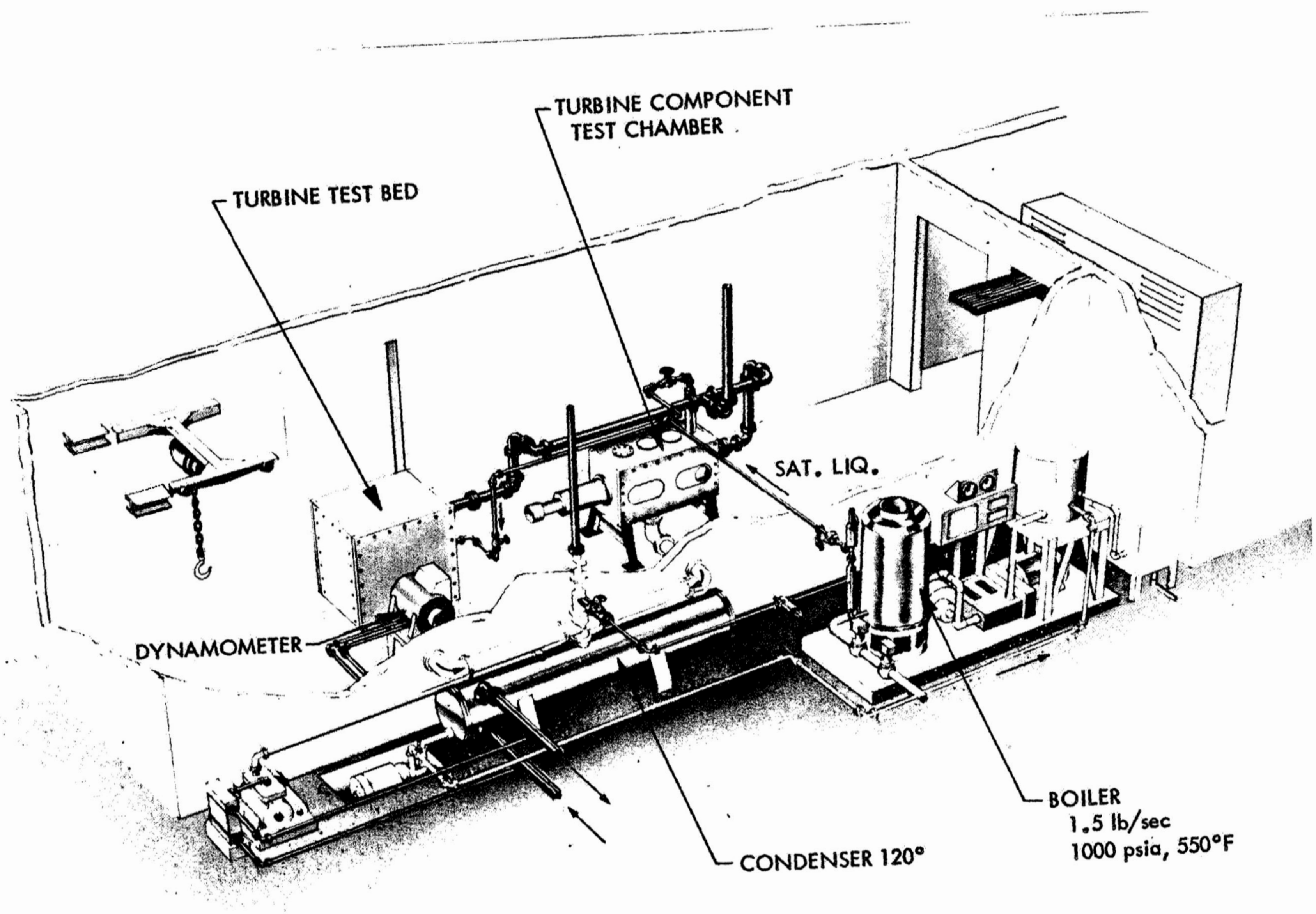

Fig. 5. Geothermal test facility