Proc. 6th NZ Geothermal Workshop 1984

BIPHASE GEOTHERMAL WELLHEAD PLANTS

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ABSTRACT

The Biphase turbine provides an innovative method of improving performance in single and double flash systems. The Biphase turbine accepts brine and steam and accomplishes the following:

1. Extracts power from the liquid energy.
2. Separates and delivers clean steam to a steam turbine.
3. Repressurizes liquid for reinjection or pumping.

The improvement in energy conversion results in more power production from given geothermal fluid supplies, thereby improving the power plant economies. The result is low overall project costs reflected in reduced busbar costs of electricity. The Biphase Rotary Separator Turbine is a simple and rugged machine which has demonstrated high reliability in the geothermal environment. In the wellhead system, a geothermal steam turbine is used in tandem. The equipment is factory pre-fabricated and skid-mounted, to provide flexibility and portability. Operating and maintenance oosts are low because of small, rugged machinery and high availability.

SYSTEM THERMODYNAMICS

The Biphase turbine was developed to increase the energy conversion efficiency for geothermal power plants by increasing the energy produced from a given flow of brine. The capital cost, brine cost, operating and maintenance cost can be deareased (relative to the power output).

Substitution of a Biphase turbine for a typical flash stage is illustrated in Figure 1. The typical flash stage consists of a throttling valve, a separation vessel and a pump for reinjection. The net power produced for the brine conditions for this flash stage is 6632 kW. A Biphase stage performs the same functions as a flash stage. Separated steam is provided to a steam turbine and repressurized brine flows from the Biphase turbine. However, the net power produced for the same brine conditions is 7808 HI. Thus, use of a Bipbase stage instead of a flash stage for these typical conditions can produce 20% more power while eliminating several components.

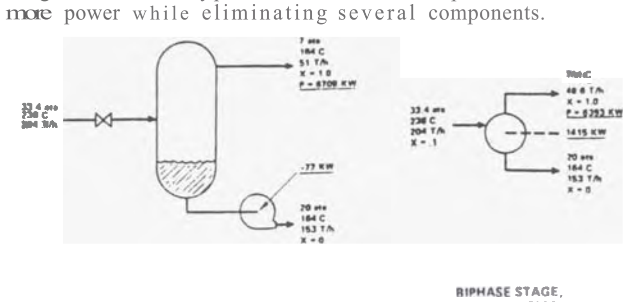
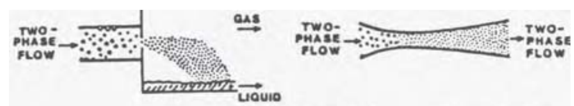


Figure 1. Comparison of Biphase Turbine with Flash Stage for Typical Geothermal Conditions.

Two-Phase Nozzle

The first element of the Biphase turbine is the two-phase nozzle. The purpose of the two-phase nozzle is to use the available thermal energy of brine and steam to impart kinetic energy to the brine droplets and to the steam. This is illustrated in Figure 2 which shows the difference between a conventional flash stage and a two-phase nozzle expansion.



	FLASH ORIFICE INLET	FLASH ORIFICE EXIT	TWO-PHASE NOZZLE INLET	TWO-PHASE NOZZLE EXIT
Pressure (ata)	33.40	6.96	33.40	6.96
Temperature (deg. C)	238	164	238	164
Vapor Flow (kg/s	5.7	14.2	5.7	12.7
Liquid Flow (kg/s)	51.0	42.5	51.0	44.0
Vapor Kinetic Energy (kW)	0		0	564
Liquid Kinetic Energy (kW)	0		0	1963*a
Vapor Available Thermal Energy (kW)		5871*b		5645*b
Total Available Energy (kW)		5871		8172

*a : 81 percent of available energy in isentropic expansion from 33.40 to nozzle exit pressure.

*b : 70 percent of available energy in isentropic expansion from 6.96 to 0.14 ata.

Figure 2 Comparison of Two-Phase Nozzle Expansion with Flash Expansion.

In the flash process, the high pressure brine/steam mixture flows through an orifice or valve, lowering the pressure and causing more steam to flash. Since it is an isenthalpic process all the kinetic energy at the orifice is dissipated as heat. As a result the only usable energy is the thermal energy of the steam. For the example shown, tbe total available energy is 5871 kW if the steam were expanded in a steam turbine with an efficiency of 70%. This process corresponds to path 0-1 in Figure 3 which shows the differences on a temperature-entropy diagram.

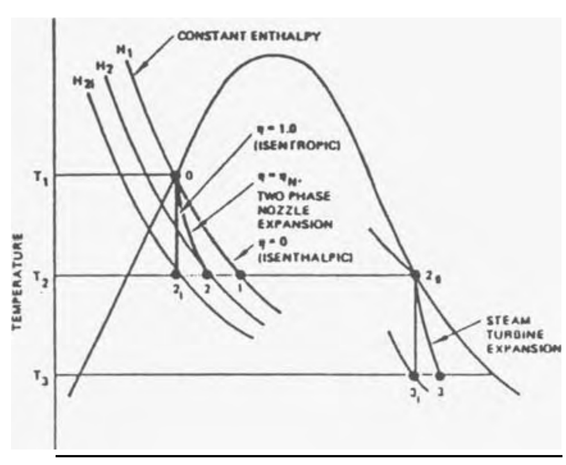


Figure 3. Temperature Entropy Diagram for Rotary Separator Turbine System.

In the two-phase nozzle, the pressure is lowered gradually by changing the cross section. The steam which is formed pushes on the brine droplets as it flows to the nozzle exit. Thus, the steam does work on the brine droplets (much in the same manner as it would on turbine blades) imparting kinetic energy. At the exit of the nozzle there are three forms of usable energy; the steam kinetic energy, the brine kinetic energy, and the steam thermal energy. As shown in the example of Figure 2, these three energy sources are 564 kW, 1963 kW and 5645 kW, giving a total available energy of 8172 kW.

Referring to Figure 3, the flow through the two-phase nozzle follows the path 0-2. The exit point is at a lower enthalpy than the isentropic, path 0-1i. The difference in enthalpy, H_1-H_2, is converted to steam and brine kinetic energy. The amount of steam flashed is somewhat less in path 0-2 than path 0-1. In the example of Figure 2 this accounts for the larger steam thermal energy (5871 kW versus 5645 kW).

Referring to Figure 2, the total available energy at the nozzle exit is 8172 kW compared to a total of 5871 kW for the flash orifice. The difference, 2301 kW, is 40% greater than the energy available from the flash process.

Rotary Separator

The additional kinetic energy in the brine could be partially converted to shaft power by impinging the two-phase jet directly on turbine blading. However, large losses of liquid energy due to friction would be encountered as the brine flowed at high velocity across extended blade surfaces. Many concepts have been proposed that depend upon the brine droplets flowing with the vapor stream lines to avoid this friction. However, because the size of droplets produced in an expansion is relatively large they will impinge on any solid surfaces intercepting their initial trajectory.

Because of this and other disadvantages resulting from direct impingement, the rotary separator was developed to extract the brine energy. Figure 4 illustrates the rotary separator utilized by the Biphase turbine. The rotary separator consists of a rim welded to a disk which is fitted to a shaft. The two-phase Jet impinges at a nearly tangential angle on the inside area of the rim. The drag generated by the liquid component of the jet drives the rotor at a peripheral speed near to the tangential component of the nozzle exit velocity. The high gravitational field created by the rotation cleanly separates the vapor from the liquid. The liquid distributes itself as a thin layer on the inner surface of the rim protecting the material of construction of the rim from erosion/corrosion of the impinging droplets. The liquid layer on the rim is pure liquid and has high kinetic energy. The separated steam flows radially inward and is ducted to a conventional steam turbine where the thermal energy (cf. Figure 2) is converted to shaft power.

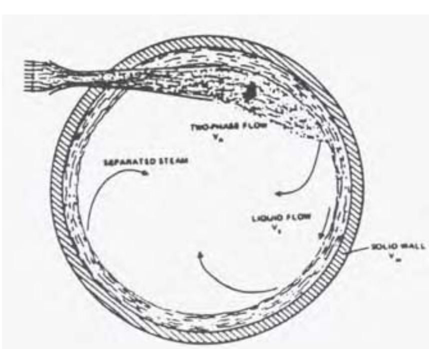


Figure 4. Rotary Separator

Liquid Turbine

The kinetic energy of the liquid on the rotary separator can be converted to additional shaft power by a liquid turbine or it may be converted to pressure by a diffuser. A simple liquid impulse turbine which has been successfully utilized is shown in Figure 5. The brine and separator rim are traveling at a velocity V_s. At maximum power a scoop is immersed in the flow and constrained by a load to rotate at a velocity $V_t = 1/2\ V_s$. The absolute velocity (and energy) of the brine leaving the scoop is $V_e = 1/2\ V_s - 1/2\ V_s = 0$. If the scoop is allowed to rotate at a speed which is greater than 1/2 of the rim speed kinetic energy remains in the liquid exiting the scoop. This kinetic energy may be recovered by a second rotating separator and diffuser.

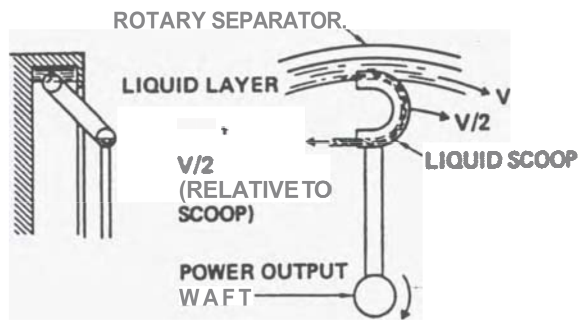


Figure 5. Liquid Impulse Turbine

Another means of converting the liquid energy on the rim to shaft power is the liquid reaction turbine. This type of conversion method is illustrated in Figure 6. The liquid flows radially outward through a passage to the outer radius. The liquid column rotating in a high gravitational force field results in a very high pressure at the outer radius. The high pressure liquid is expanded through a simple liquid nozzle to produce a high velocity which creates a torque on the separator structure. The remaining kinetic energy in this jet may also be converted to pressure by a second rotating separator and diffuser.

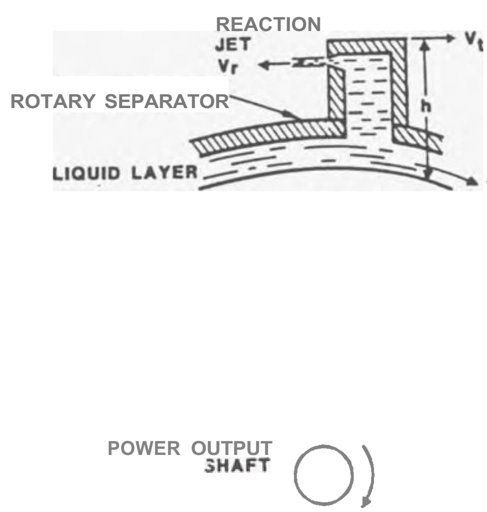


Figure 6. Liquid Reaction Turbine

Biphase Impulse Assembly

The assembly of these components into a complete rotary separator impulse turbine is shown in Figure 7. The brine steam mixture flows through two-phase nozzles and is directed tangentially on the freely rotating drum. The steam is separated by centrifugal forces and flows radially inward and out the port to a steam turbine. The brine layer on the primary rotary separator flows through holes to the other side of the support disk. The brine layer drives a liquid impulse turbine immersed in the flow. The liquid turbine shaft is connected to a generator. The brine leaving the scoop of the liquid turbine is collected on a second freewheeling separator drum. A stationary diffuser, immersed in the flow collects and repressurized the brine for reinjection.

In exploiting the advantages of the Biphase system, Transamerica Delaval Biphase has been one of the pioneers in developing wellhead power plants. The wellhead plant is sized to operate with one or two production wells, and be sited nearby. The wellhead modular plant is small enough to be portable, thus is factory prefabricated. Geothermal resource

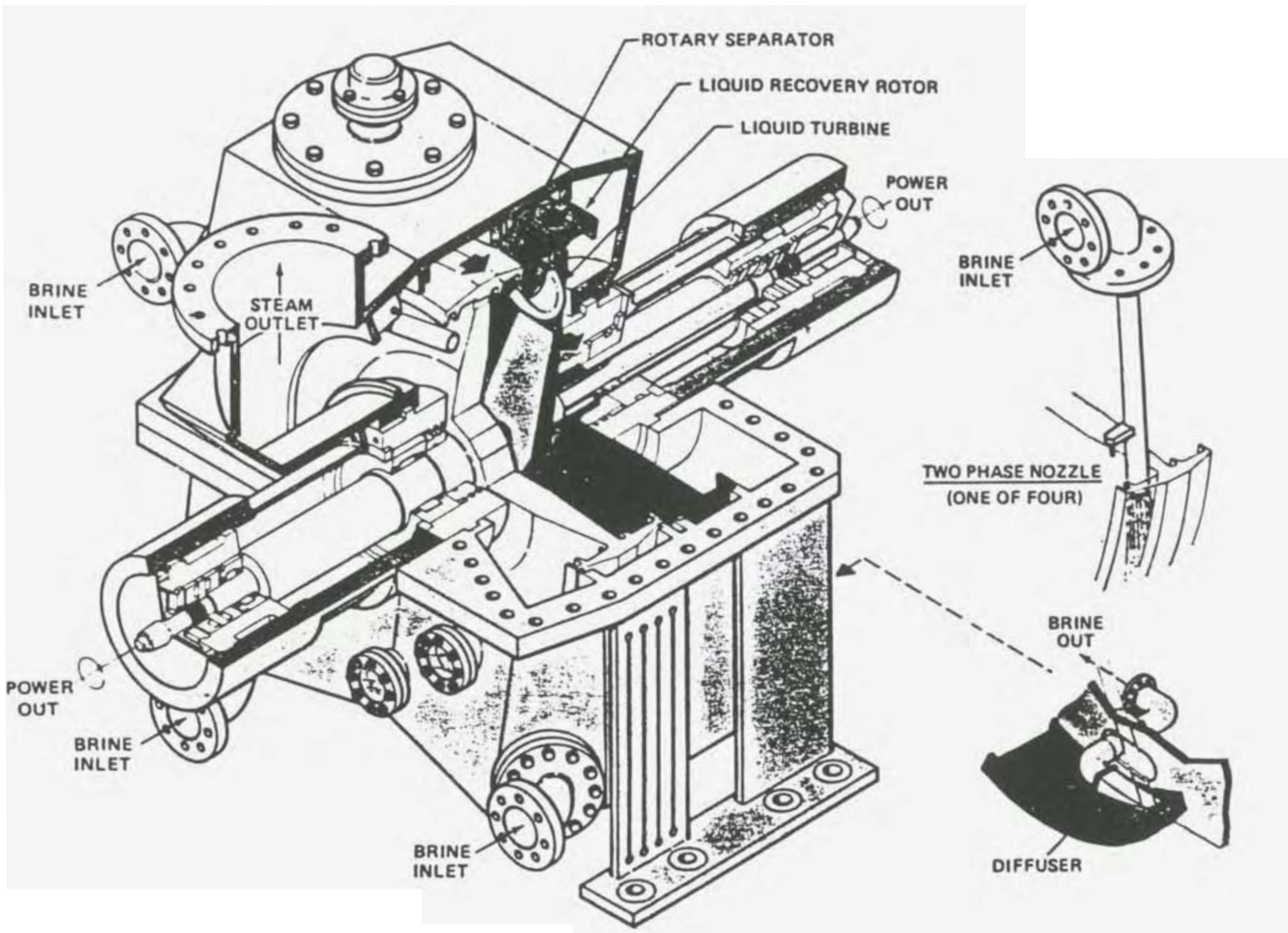
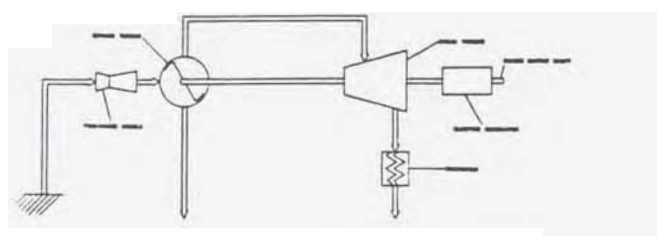


Figure 7. Biphase Rotary Separator Impulse Turbine Model 54RST.

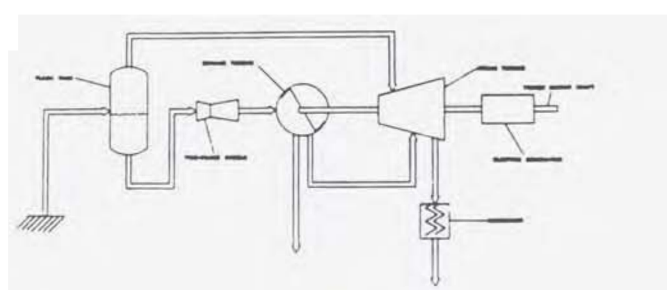
THE BIPHASE GEOTHERMAL SYSTEM

The Biphase Geothermal turbine can be used by itself for a highly portable system used for well proving. The "well-prover" is also useful as a wellhead steam separator, supplying power, separated steam and liquid under pressure for injection. A system with a back-pressure (non-condensing) stem turbine is also portable and flexible. However, for utility electricity production, the system includes a condensing steam turbine.

The Biphase system arrangement produces more power by replacing a flash tank in a conventional system. In a single-flash geothermal system, Figure 8, the Biphase RST replaces the flash tank. This results in a delivered power increase demonstrated at Roosevelt Hot Springs, Utah, of 20-30 percent. When the RST is used to improve a double-flash system, it replaces the low-pressure flash tank, as shown in Figure 8, for an increment of additional power. In either the single or double-flash system, the overall reliability may be improved by arranging the RST in parallel with the flash tank, or by arranging to bypass the RST if needed to allow for maintenance. These piping arrangements are incorporated in Biphase systems under construction in the U.S. for Roosevelt Hot Springs, Utah and Desert Peak, Nevada.



Biphase Improvement of Single-Flash System



Biphase Improvement of Double-Flash System

Figure 8. System Improvement by Replacing Flash Tank with Biphase RST.

development by means of the modular wellhead plant leads to significant project savings in cost and risk.

A developer of potentially large geothermal resources faces the decision to design and build either one large central power generation plant or several moderately sized modular power plants. Because of many economic and scheduling factors, significant advantages can be gained by opting for the modular approach.

The ability to produce revenue during the verification of the geophysical and geochemical characteristics of the resource is a paramount advantage of the modular approach. Typically, the first plant will be on-line and be producing revenue within fifteen months of the original order. Thus, verification of the resource production capabilities and identification of site specific problems will proceed while realizing cash return on the generated power. By evaluating the resource characteristics with this first system, the justification for further development of the resource can be determined. Applying this modular approach in 5 to 15 megawatt incrementa represents the minimal investment route towards total commercial development of the resource and provides a method for avoiding a major commitment to a large central plant.

The modular plants will be located near the wellheads. If problems develop with a resource well, the modular plant can be relocated in a relatively short time to a, new wellhead. This flexibility for relocation of a module provides a significant advantage over the central power plant concept.

Once the resource has been confirmed with one or more of the wellhead power plants for a sufficiently long time period, say six to twenty-four months, viability of the concept to develop the total resource can be established. Based on favorable results from the first plant(s), the resource development then may proceed with a reasonable assurance of long-term success.

The decision to proceed with the full development of the resource would establish the total number of subsequent units required. With this number established, a schedule of fabrication. installation. and start-up of the remaining units could be determined that would not only optimize vendor volume discount and other advantages but also minimize installation and start-up costs. For instance, the manufacturer can employ production-line operation using standardized components to minimize fabrication costs. In the field, smaller construction specialty groups can move from one plant site to the next to reduce field costs.

The total fabrication and installation cycle can be adjusted by the utility to match demands as they develop. Additional significant cost savings are realized in a standardized and relatively inexpensive stock of spare parts, and in reduced maintenance schedule and manpower because of small mechanical elements. Preliminary analyses predict higher availability and reduced O&M costs of the multiple wellhead units as compared to large central plants. In a development in Utah, OW costs to operate one 14.5 mW Biphase plant equal approximately 3 percent of the capital cost per year. When seven units are installed, for 100 mW, O&M costs are reduced to approximately 1 percent per year.

To reiterate, the basic advantage of the modular wellhead power plant approach is manifested by revenue production which begins midway in the development of the total complex and increases each month thereafter. This advantage reduces the time required for the transition Prom a negative to a positive cash flow to occur.

BIPHASE SYSTEM APPLICATIONS

A summary of geothermal projects studied for application of the Biphase systems in shown in Table 1. The wellhead power plants are all designed to be used in multiple; for example, at Roosevelt Hot Springs, seven of the 14.5 mW plants will deliver 100 mW. This field is predicted to eventually produce 300 mW in this manner.

Table 1. Biphase Projects

	Delivered Power MW	Specific Enthalpy BTU/lb	Total Flow lb/hr
Wellhead Power Plants			
Roosevelt Hot Springs, UT, USA	14.5	472	1,000,000
Beowawe, NV, USA	11.7	400	1,125,000
Desert Peak, NV, USA	10.1	376	1,000,000
Heber, CA, USA	6.0	332	1,000,000
Ngawha, New Zealand	15.2	417	1,338,000
Tauhara, New Zealand	17.6	464	1,305,360
Kawerau, New Zealand	24.6	560	1,160,000
Dieng, Indonesia	5.0	694	256,000
	25.0	694	1,185,000
Wellhead Separator			
Wairakei, New Zealand	1.6 Plus injection pumping to 250 psig	473	800,000

The Biphase RST has operated reliably for a 4000-hour demonstration at the conditions shown. Plants for Roosevelt Hot Springs and Desert Peak are currently under construction. The Heber resource, with a specific enthalpy of 332 BTU/lb, is included to illustrate the approximate lowest energy level that Biphase considers economically feasible for electric power generation.

The three New Zealand resources are taken from Biphase data supplied to the Hinistry of Energy. The data also included Mokai and Rotokawa.

The power plant studies at the high-enthalpy resource at Dieng, Indonesia, were the result of Biphase cooperation with Mitsui Engineering & Shipbuilding Company, with Biphase offering the Rotary Separator Turbine and Mitsui the balance of the plant.

The example of wellhead separator results from consideration of the Electricity Division, Ministry of Energy, to commence reinjection at Wairakei, to counter ground subsidence problems. The wellhead separator consists simply of the Biphase RST and a generator. This unit delivers clean steam from the wellhead for at the existing steam mains to the power plant, generates surplus electric power, and provides for the pumping of the liquid. These wellhead separators are currently being discussed with the Electricity Division and New Zealand Electricity.