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DEMONSTRATION OF AN ADVANCED BIPHASE TURBINE AT COSO HOT SPRINGS

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ABSTRACT

A rotary separator turbine (the Biphase turbine) with a single rotor was developed to generate power from mixtures of steam and brine. This advanced Biphase turbine separates the steam and brine, generates power from each phase, and internally pressurizes the separated brine. The U.S. Department of Energy supported a cost shared program to demonstrate the commercialization of this advanced Biphase turbine. The first phase demonstrated performance of a sub-scale turbine with steam and brine from a geothermal well at Coso Hot Springs, California. Results are reported herein.

The second phase will consist of operation of a full size commercial unit at Cerro Prieto geothermal field for a period of two years. Design of the full size unit and expected performance are also reported.

BACKGROUND

The rotary separator turbine was invented in 1975[1]. This turbine, the Biphase turbine, generates power from mixtures of gas and liquid. For geothermal flash steam power plants, application of the Biphase turbine to the wellhead flow can generate power from the available two-phase energy otherwise dissipated in frictional heating in the flash process.

After developmental testing, a full size unit was installed and demonstrated with the full flow from a geothermal well at Roosevelt Hot Springs, Utah[2]. The unit generated 1600 kW and demonstrated a 20% increase in power output above a single flash steam turbine. As a result of this 4000-hour demonstration, the Electric Power Research Institute evaluated the Biphase turbine to be a viable commercial technology[2].

This original Biphase turbine, although efficient in the generation of power from the separated brine, had two major limitations:

1. Three rotors were required to separate, generate power and pressurize the separated brine. This design feature increased the cost. The complexity of maintaining the speed of the three rotors at separate values increased the cost and difficulty of operation.

2. Only the brine kinetic energy was converted to shaft power. No method was provided to convert the kinetic energy of the separated steam to shaft power. For high enthalpy wells the benefit of the Biphase turbine was limited by the lack of a means to generate power from the steam phase.

In order to overcome these limitations, an advanced Biphase turbine with a single rotor and steam blading was developed. This unit was successfully demonstrated with clean water and steam mixtures.

For a low quality, high pressure, water-steam mixture the addition of steam blading increased specific power from 4 kW/lb/s to 7 kW/lb/s.

To demonstrate the applicability of the single rotor Biphase turbine to geothermal power production, a program was proposed to test the sub-scale unit, previously tested with clean water and steam, on a geothermal well. This demonstration would be followed by demonstration of a full size commercial unit for a two year period in a commercial geothermal flash steam power plant.

The proposal was accepted by the U.S. Department of Energy. The project was joined by the California Energy Commission. The sub-scale test site was provided by California Energy Company. The installation site for the full size Biphase turbine was provided by the Comision Federal de Electricidad.

PROJECT DESCRIPTION

The project for demonstration of the advanced Biphase turbine is being conducted in two phases:

Phase 1 is the demonstration of a sub-scale unit with geothermal flow. The existing high pressure machine (the 12RSB) was modified for use with low pressure geothermal fluids. The unit was operated for three periods with high, medium and low enthalpy fluids at Coso Hot Springs geothermal field. The results were used to evaluate performance of the steam energy conversion as well as two-phase performance with the geothermal fluid.

Phase 2 is the design and operation of a full size (megawatt class) advanced Biphase turbine. The unit is designed to operate directly with the flow from a high pressure geothermal well. The completed unit will be installed, together with a tandem steam turbine, on a well at the Cerro Prieto geothermal field. This Biphase turbine will be operated for two years on this project to evaluate performance and reliability. Power produced will be supplied to the commercial grid of Comision Federal de Electricidad.

Phase 1 has been completed and the results are reported herein.

SUB-SCALE BIPHASE TURBINE

A cutaway of the sub-scale Biphase turbine demonstrated on this project is shown in Figure 1.

A mixture of brine and steam from the geothermal well is supplied to ten two-phase nozzles, 1, spaced around the turbine circumference. The flow is accelerated in the nozzles producing high velocity two-phase jets, 2. The jets impinge tangentially on the inner surface of the rotating seperator, 3.

The separated brine forms a film on the separator surface which is slowed by friction to the velocity of the rotor. After slowing and transfering torque to the rotor, the brine flows through transfer holes, 4, to the other side of the disc supporting the separator. The brine enters a diffuser, 5, which is immersed into the brine layer, where the remaining velocity head is converted to pressure. The brine leaves the turbine through the diffuser outlet and flows to a disposal pit.

The separated steam flows into a row of impulse blading, 6, which convert the steam kinetic energy to power. For the sub-scale unit the blading is radial inflow blading. The steam leaving the blades flows through the steam exhausts, 7, and is discharged to atmosphere.

The sub-scale Biphase turbine incorporated most of the essential design features of the full size Biphase turbine for the project. The main limitation for the phase 1 demonstration was the low pressure of the geothermal well which was available. The maximum well pressure was only 100 psia compared to the original design pressure of 400 psia for the sub-scale turbine and 800+ psia for the full size turbine. The low pressure available limited the nozzle efficiency and flowrate (and, hence, power output). However, analysis of the off-design performance was made which agreed closely with the measured results.

DEMONSTRATION INSTALLATION

The sub-scale Biphase turbine was installed on a geothermal well at the Coso Hot Springs resource of California Energy Company. The available well was not providing fluid to the central power plant at the time of the demonstration.

Figure 2 shows the general arrangement of the demonstration installation. Flow from the geothermal well flowed through a rock trap and flow splitter to the sub-scale turbine, which was installed in a test trailer. Brine leaving the turbine flowed through a steam trap to the fluid disposal pond. Steam leaving the turbine flowed through a pipe to the fluid disposal pond also.

The flow streams and turbine were completely instrumented to measure pressure, temperature, flowrate, steam quality and power. Data acquisition and controls which will be used for the full size unit were used in the sub-scale demonstration to evaluate their performance and ability to control the turbine on an unattended basis.

Figure 3 is a photograph of the test installation, showing both the well and portable trailer which enclosed the sub-scale turbine, dynamometer and controls. Figure 4 is a picture of the sub-scale turbine mounted in the portable test trailer with controls.

DEMONSTRATION RESULTS

The sub-scale turbine was operated during three periods for a total of 700 hours. A high enthalpy test with dry, saturated steam was conducted for 250 hours. Enthalpy ranged from 1178 to 1188 Btu/lb. A medium enthalpy test was conducted for 250 hours. Enthalpy ranged from 332 to 1084 Btu/lb with most of the operation at 600 to 800 Btu/lb. The final low enthalpy test was conducted at 330 to 800 Btu/lb with most of the operation at 400-500 Btu/lb.

The geothermal well had been inactive for a period of time and was very unstable when it was activated for the testing. A great deal of debris, including sand and rocks, periodically entered the turbine, causing some seal and bearing problems. However, the rotor and steam blading were undamaged by the debris.

No scale formation occurred in the nozzles or on the nozzle side separator. However, scale formation was observed on the diffuser side of the separator. Operation of an on-line, hydroblast scale removal system proved effective during the test and will be incorporated into the full size Biphase turbine.

The performance was monitored continuously during the operation. The wide fluctuations in flowrate, steam fraction and pressure produced a wide range of operating conditions, virtually all of which were off-design for the turbine. A steam blading performance model provided by Mechanical Technology, Inc.[3] under a subcontract was utilized to predict steam blading efficiency.

The results of Figure 5 show agreement to within 20% over the range of steam fraction from 0.07 to 1.0 and pressures from 33 to 117 psia. Results in the mid-power range, 20-30 kW, correspond to values closest to the design enthalpy for the two-phase nozzle - 550 Btu/lb, and agree within 10%.

The two highest points were obtained with 100% steam with nozzles designed for steam only. The excellent agreement validates the steam blade efficiency model.

The turbine efficiency defined as *(gross shaft power)* divided by *(isentropic enthalpy difference from inlet to exit)* is shown in Figure 6. Efficiency increases from about 10% at the lowest enthalpy to 46% for the highest enthalpy. These values were obtained for very low values of the ratio of blade speed to jet speed (typically 0.18 to 0.25). The optimum steam blade efficiency occurs at a value of 0.5.

Once again, the agreement is strongest in the mid-range and at the highest enthalpy. The results validate the nozzle code and rotor performance codes over a wide range of operating conditions. The close agreement of the steam blade performance and previously demonstrated agreement of the two-phase nozzle code and rotor performance at design conditions validate their use to design the full size Biphase turbine and to predict performance.

FULL SIZE BIPHASE TURBINE DESIGN

The full size Biphase turbine was designed for operation for a wide range of geothermal well conditions. The sub-scale unit established the feasibility of single rotor operation from a steam quality of 7% to a steam quailty of 100%. Previous clean steam water tests combined with the geothermal tests established an operating range of 70 - 400 psia for the inlet pressure. Variations in pressure, steam quality and flowrate are accommodated by changing simple nozzle inserts.

A modified cross-section of the full size Biphase turbine, the 30RSB, is shown in Figure 7.

Well mixed two-phase flow enters one of two inlets, 1. An internal splitter, 2, divides the flow into four equal streams, each feeding a two-phase nozzle, 3. The two-phase nozzle is formed by a contoured insert which can be removed and replaced through an external port, 4. The flow is accelerated in the nozzle, forming a two-phase jet, 5, which is separated on the rotary separator surface, 6.

The separated liquid, 7, is slowed to the velocity of the separator by frictional forces, converting the momentum to torque. The liquid subsequently flows through holes, 8, in the separator disc to the opposite side where it enters a diffuser, 9. The flow is decelerated to convert the remaining velocity head to pressure and exits through a port, 10, in the casing.

The separated steam, 11, flows through axial impulse blades, 12, converting the steam kinetic energy to power. Steam subsequently exits through the steam port, 13.

The Biphase 30RSB has conventional labyrinth seals with a clean water seal wash to reduce scaling. Tilting pad bearings are used to provide the straddle mounted rotor with the required stiffness.

The operating speed is 3600 rpm enabling direct drive of the generator. The first critical is at 4500 rpm, a 20% margin above the operating speed.

The rotor and blades are manufactured from HY 80, an alloy used for previous Biphase geothermal units. Parts exposed to high velocity brine will have a high density plasma spray coating of Inconel 718 or will be fabricated from that alloy. Previous experience with brine velocities of 400 feet per second showed that alloy to be resistant to both corrosion and erosion.

SITE FOR FULL SIZE BIPHASE TURBINE DEMONSTRATION

The site selected for the full size turbine is Cerro Prieto well number 103, which supplies steam to the 180 megawatt Cerro Prieto I power plant installation. The Cerro Prieto geothermal field is located in Mexico, approximately 25 miles southwest of Calexico and Mexicali. The total power produced at the field is 620 megawatts.

Figure 8 is a photograph of well 103 and the separator. The well currently is operated at a wellhead pressure of 790 psia. At this pressure a flowrate of 312,000 lb/h is produced with a steam fraction of 45%. The flow is flashed to 125 psia to produce steam. The steam is utilized by the Cerro Prieto I turbines to produce power. At the current steam rate of 24 lb/kWh the steam from this well produces 7410 kW.

Figure 9 is the general arrangement for the demonstration project. Two-phase flow from the well enters the Biphase turbine at 750 psia and is expanded to 444 psia. The separated steam is expanded further in the back pressure steam turbine to 126 psia. The steam flows to the existing separator at 125 psia. The separated brine is also flashed into the existing separator at 125 psia.

A bypass line is provided for startup. The bypass is also automatically actuated in the event of a turbine trip to keep the well flowing at the desired conditions.

The Biphase turbine skid and a switchgear/control enclosure are located between the wellhead and the existing silencer. Sufficient clearance for well rework and separator or piping maintenance is provided. The Biphase skid is highly rigid and is portable in the event it is desirable to relocate to a different wellhead.

PREDICTED PERFORMANCE OF FULL SIZE BIPHASE TURBINE

The full size Biphase turbine was designed for the wellhead conditions of the demonstraton site. The two-phase nozzle code and Biphase turbine performance codes were utilized to determine the performance and to design the unit.

The design parameters and performance are summarized in Table 1. The total power output is predicted to be 1080 kW. As shown, this corresponds to a net Biphase turbine efficiency of 55%.

The total power output from the Biphase system is estimated to be 4380 kW. A 5% design margin gives a final predicted output of 4150 kW. The steam produced will generate an additional 6610 kW in the central steam turbine giving a total power output from the well of 10,760 kW. Thus, addition of the Biphase system at this site increases the power production from the chosen well by 45%.

Table 1 - Design Parameters for Biphase Power System for Cerro Prieto Well No. 103

Biphase Turbine	
Inlet Pressure	750 psia
Inlet Flowrate	312,000 lb/h
Inlet Steam Fraction	0.45
Biphase Exit Pressure	444 psia
Rotor Diameter	30"
Rotor Speed	3600
Output Power	1080 kW (shaft)
Steam Turbine	
Inlet Pressure	440 psia
Inlet Flowrate	148,300 lb/h
Inlet Steam Fraction	1.00
Exit Pressure	126 psia
Output Power	3520 kW (shaft)
Total Generator Power	4380 kWe

CONCLUSIONS

Results of tests at Coso Hot springs geothermal field of a sub-scale Biphase turbine with a single rotor and steam blades agreed to within 20% of predicted performance over an extremely wide range of enthalpy. Steam blade efficiency was measured with 100% steam from the well and agreed to within 5% of the values independently predicted by a turbomachinery manufacturer.

The same design codes were used to design a full size Biphase turbine which will be demonstrated with a back pressure steam turbine on a geothermal well at the Cerro Prieto geothermal field. The Biphase turbine system for the demonstration was predicted to generate 4150 kW from the two-phase well flow. The additional power will increase the power produced from the selected well by 45% with no additional well flow.

The results of the program to date, if verified by the full size demonstration, show the Biphase turbine can add significant power to existing and planned flash steam power plants which utilize high pressure geothermal fluids.

REFERENCES

1. Hays, L.G., Elliott, D.G.,"Two-Phase Engine", U.S. Patent No. 3,879,949, April 1975.

2. Hughes, E.E., "Summary Report: Rotary Separator Turbine", RP 1196, Electric Power Research Institute, Palo Alto, 1986.

3. Mechanical Technology Incorporated, "Final Summary Re-port on Development of Optimum Blade Geometry for Biphase Turbine", June 1994.

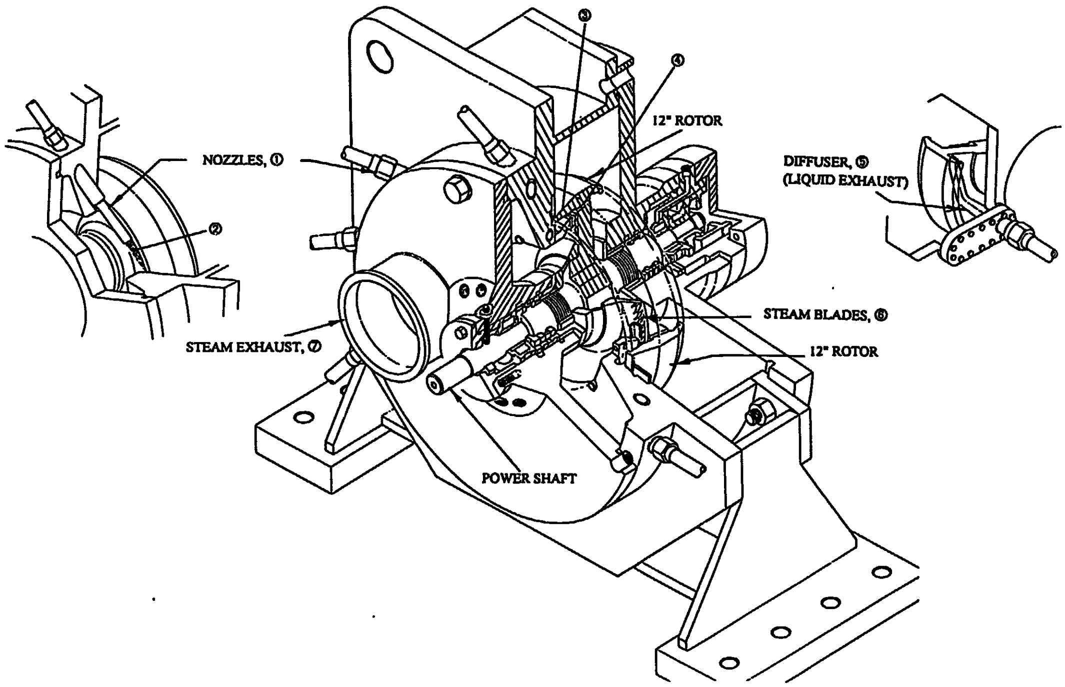

Figure 1. 12RSB Biphase Turbine, Nozzle Side, Isometric 1/4 Cutaway.

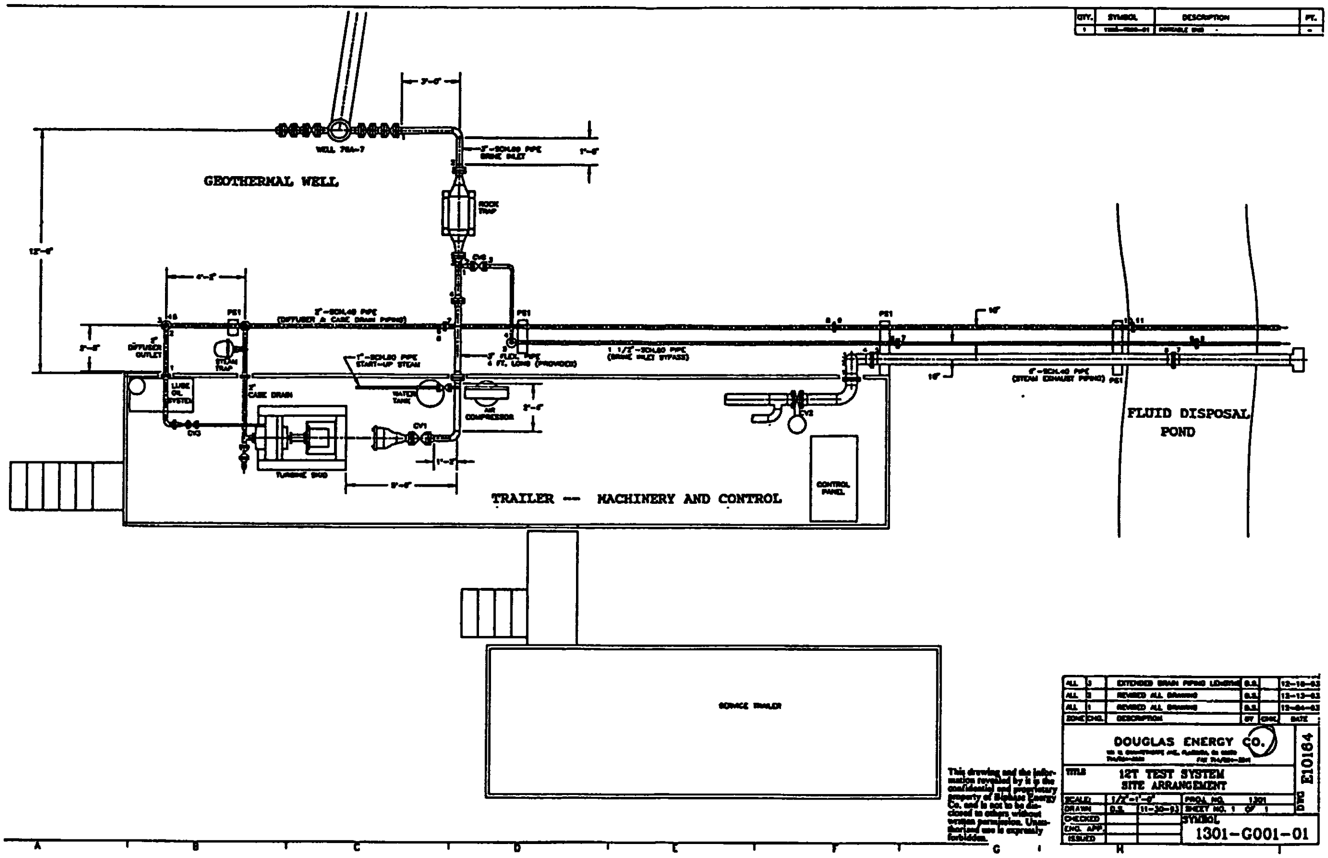

Figure 2. 12T Test System Site Arrangement.

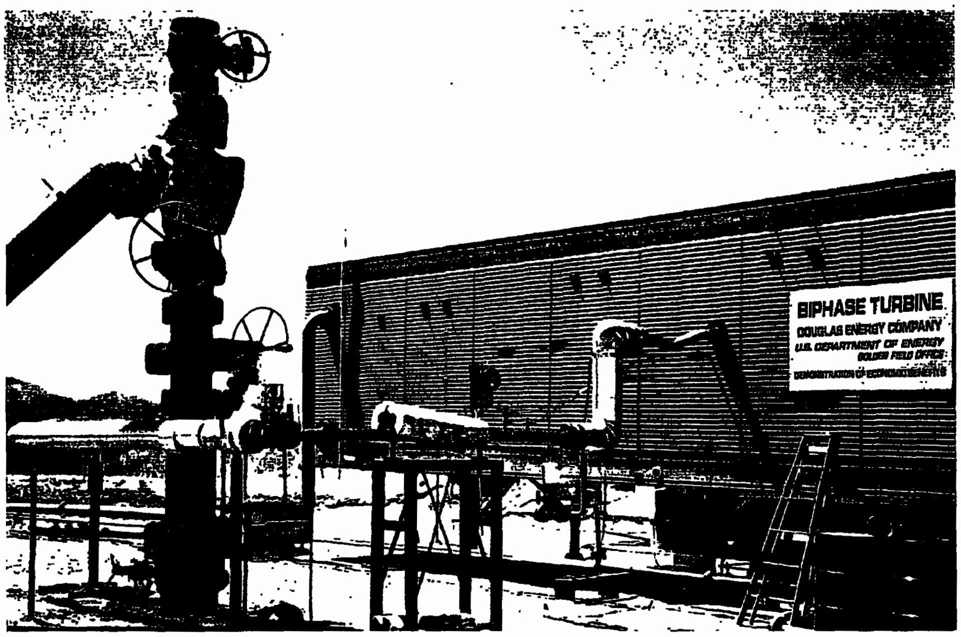

Figure 3. Biphase Turbine System Trailer at Coso Geothermal Well.

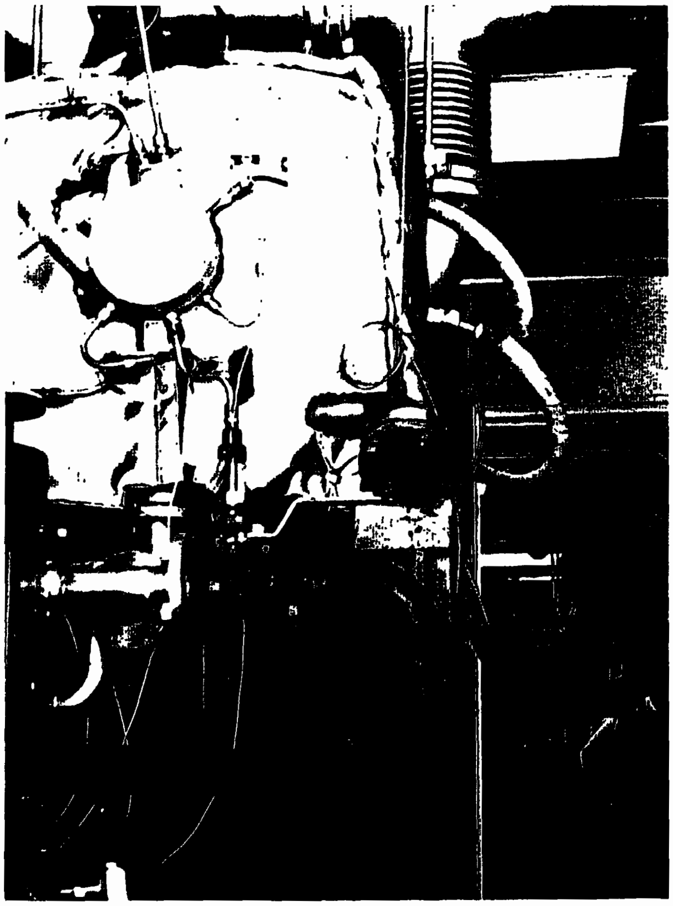

Figure 4. Biphase Model 12RSB Geothermal Turbine Mounted in Trailer, Control Section Beyond.

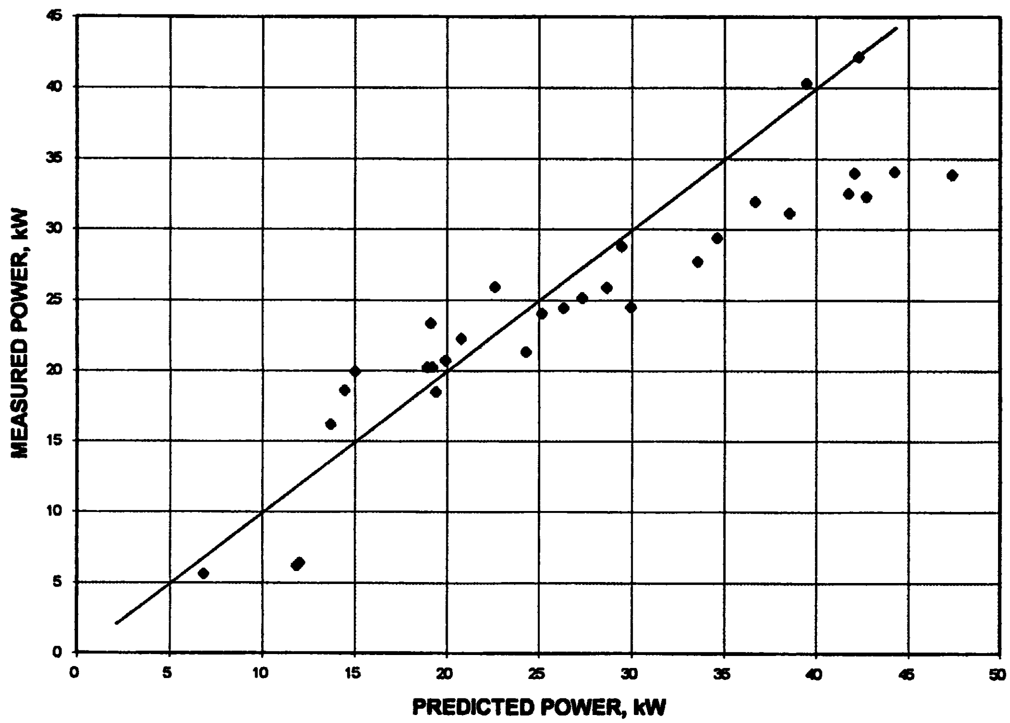

Figure 5. Measured Power Output Variation With Predicted Power Output.

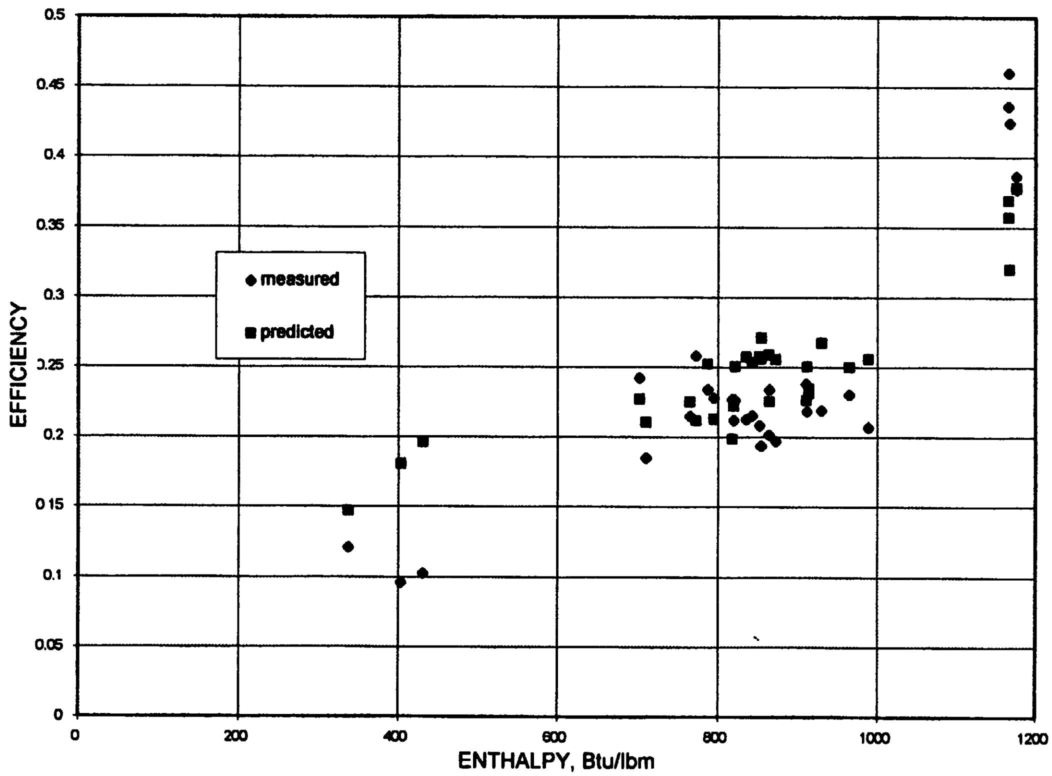

Figure 6. Measured and Predicted Efficiency Variation With Inlet Enthalpy.

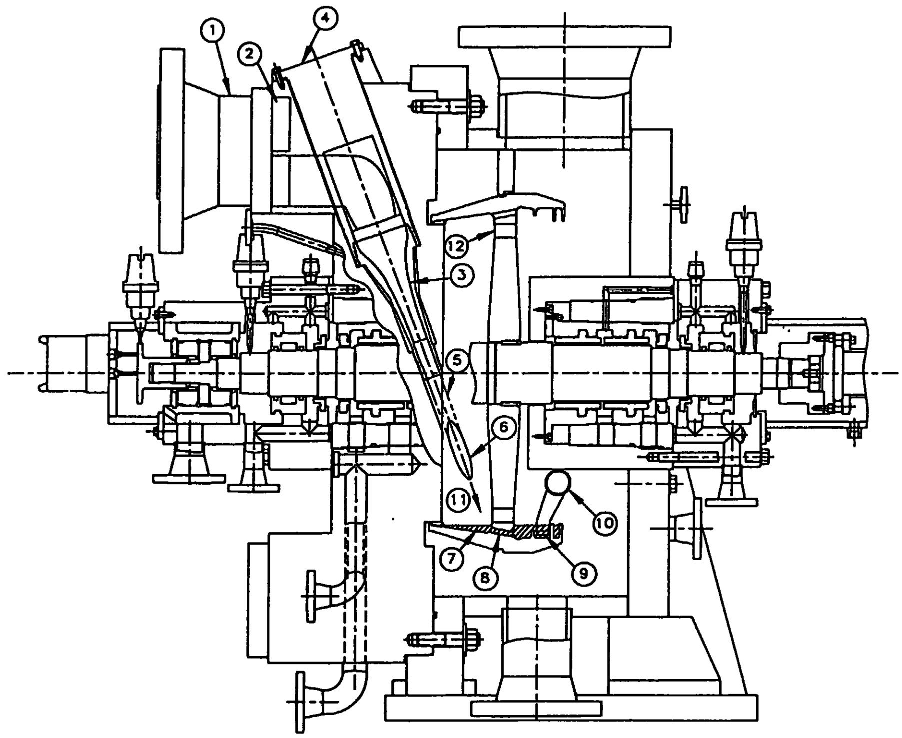

Figure 7. Schematic of 30RSB Biphase Turbine.

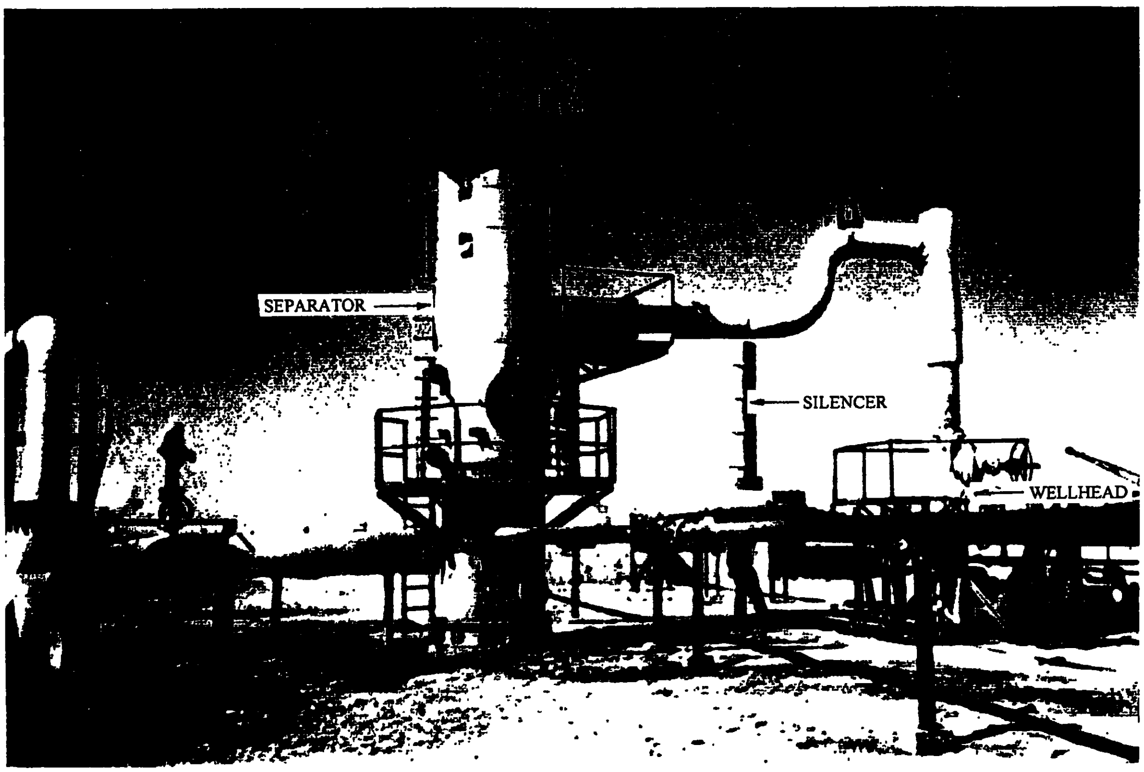

Figure 8. Well No. 103 at Cerro Prieto Geothermal Field.

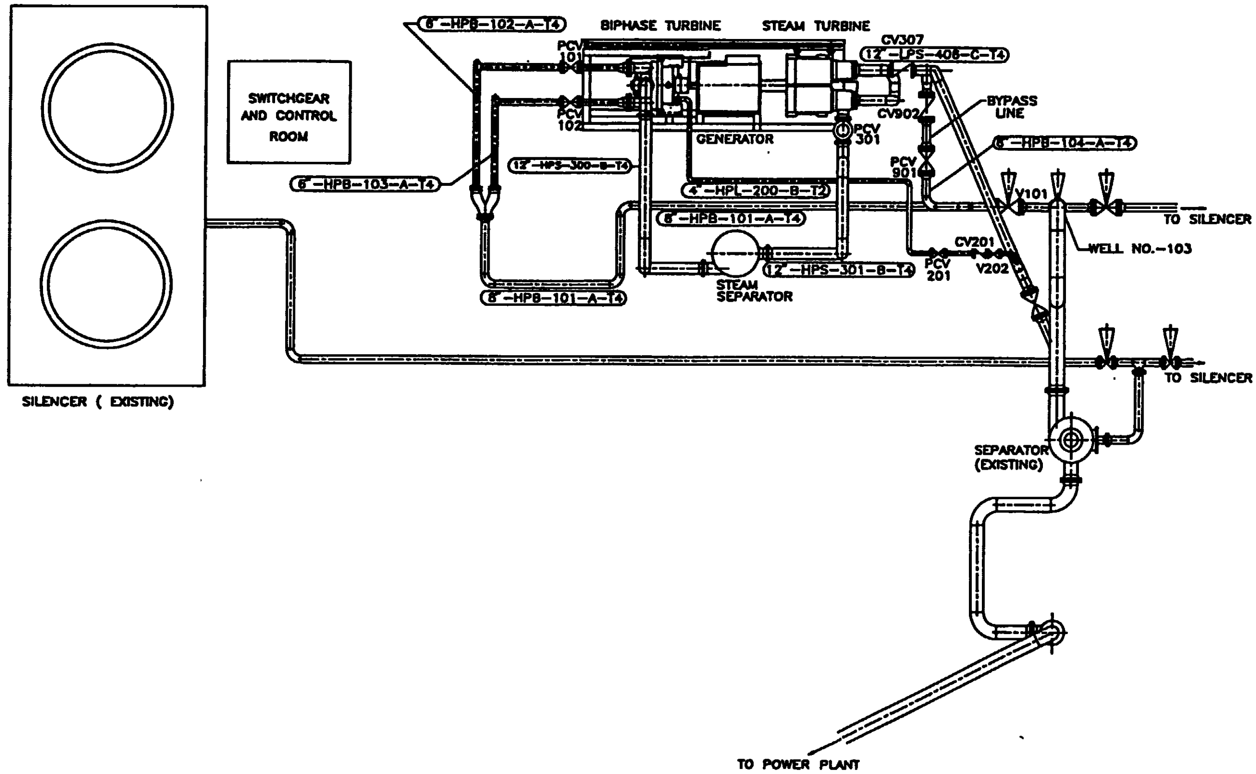

Figure 9. Arrangement of Biphase Wellhead Power Plant.