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DEMONSTRATION OF A BIPHASE TOPPING TURBINE

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ABSTRACT

A wellhead power plant with a Biphase rotary separator turbine is being constructed at Cerro Prieto, Mexico. The Model 30RSB Biphase turbine is a production design with improved performance and reduced cost, resulting from development projects, and proven by demonstration operation under this Department of Energy program at Coso Hot Springs, CA.

The Model 30RSB Biphase turbine is sized for application as a topping turbine for use at most geothermal projects worldwide that have medium to high pressure resources. The first unit will increase the electricity production due to the given well flow by more than 40%. This major improvement in utilization of the resource leads to significant reduction in geothermal power costs, which is the goal of this DOE meeting.

Cost savings have been realized for this turbine by means of a standardized design, by innovative ceramic bearings, and by simplification of the rotating elements. Improved performance by the use of steam blades was proven by the sub-scale tests. Analysis shows that the addition of a backpressure steam turbine significantly improves power output on high enthalpy wells.

Design and projected performance of the initial wellhead plant are 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. The Biphase topping turbine or the flash separator supply steam to a central steam power plant.

Analysis relied heavily on design of two-phase nozzles. Machine tests showed the practicability of liquid/gas separation on a rotating drum, production of power from the rotating element, and recovery of liquid under pressure by means of a diffuser.

Early versions of the Biphase turbine, applied to geothermal brine, converted pressure and temperature energy (enthalpy) in the fluid to kinetic energy by accelerating the fluid in the nozzles. The kinetic energy in the liquid was converted to shaft power on the rotating drum, but the kinetic energy in the separated steam was not converted. Nevertheless, a 1600 kW Biphase turbine operating at Roosevelt Hot Springs for 4000 hours demonstrated a 20% increase in power output above the single flash steam system[2].

In order to utilize the steam kinetic energy, an advanced Biphase turbine was developed which included a single stage of steam blades operating in the separated steam. For a low quality, high pressure, water-steam mixture the addition of steam blading increased the turbine output power by 75%.

By using a single rotor, the advanced turbine achieved simplified mechanical elements. Innovations in bearings and seals were adopted.

To demonstrate the applicability of the single rotor with steam blades to geothermal power production, a program was proposed to operate a sub-scale unit on a geothermal well and to determine steam blade performance. This demonstration would be followed by the design, fabrication and operation of a full size commercial unit in an existing 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 the California Energy Company. The installation site for the commercial Biphase plant was provided by the Comisión Federal de Electricidad.

PROJECT DESCRIPTION

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

Phase 1 is the demonstration of the sub-scale unit under realistic field conditions. The 12-inch Biphase unit, Model 12RSB, which included steam blades, was equipped with nozzles sized for the low pressure fluid at Coso Hot Springs. The portable system was operated for three periods with high, medium, and low enthalpy at a range of speed, pressure, flow, and steam quality. The results were used to evaluate performance of the steam energy conversion as well as durability and performance when operated at the geothermal well.

Phase 2 is the design and operation of a full size (megawatt class) advanced Biphase turbine. Review of worldwide applications resulted in selection of a rotor size of 30 inches for universal application, with interchangeable nozzles for different field conditions. System designs include a backpressure steam turbine stage for very high well pressures. The completed power plant will be installed on a well at the Cerro Prieto geothermal field. Operation is scheduled to start in the Fall of 1996. Separated steam will be sent to the existing CP1 Power Plant. The Biphase turbine will be oeprated for two years to evaluate performance and reliability. Power produced will be supplied to the commercial grid of Comisión Federal de Electricidad.

Phase 2 includes analysis of applications at geothermal fields throughout the world together with economic analyses to determine if a viable American business for domestic and export will develop. The Application and Economic study results showed that the Biphase topping power plants, costing $500 to $750 per kW, can be built and operated at a profit in Mexico, the Philippines, and Indonesia. This export market is estimated at 977 MW by the year 2003.

SUB-SCALE BIPHASE TURBINE

The sub-scale Biphase turbine with steam blades was fabricated for an in-house program using pure steam. The turbine Model 12RSB was equipped with 10 new nozzles sized for the Coso well conditions. The control system was revised for semiautomatic operation, simulating future full automatic operation. The turbine and all accessories were mounted in a highway trailer, with controls in a separate trailer.

The Model 12RSB Biphase turbine was disassembled for inspection after 720 hours operation at Coso. The rotor is pictured in Figure 1. Two of the ten nozzles are shown to illustrate the angle of impingement on the inner rim of the wheel. The stationary liquid diffuser is mounted on the opposite side of the wheel.

The Model 12RSB Biphase turbine incorporated most of the essential features of the full size commercial turbine for the project. The main limitation for the Phase 1 demonstration was the low pressure of the geothermal well which was available at Coso. 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 well with measured results, confirming the utility of the analytical codes.

SUB-SCALE TEST RESULTS

The turbine efficiency defined as (*gross shaft power*) divided by (*isentropic enthalpy difference from inlet to exit*) is shown in Figure 2. Efficiency increases from about 10% of 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.

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.

30RSB TURBINE DESIGN ADAPTABILITY

The full size Biphase turbine has been designed to be adaptable to a wide range of geothermal well conditions. This feature of adaptability is provided by making contour changes to three independent components within the turbine. These components are: 1) the two-phase flow nozzle inserts, 2) the single stage of impulse steam blades and 3) the output liquid diffuser. Altering the design of these three components provides the adaptability of the 30RSB turbine to the range of wellhead conditions shown in Table 1. These conditions are found in the productive liquid-dominated fields worldwide.

Table 1 - Range of 30RSB Operating Conditions

Wellhead Enthalpy	350 to 1000 Btu/lbm
Wellhead Pressures	100 to 1000 psia
Total Flowrates	0.05 to 1.0 MM lbm/hr
Steam Output Pressures	50 to 450 psia
30RSB Output Power	0.5 to 4 MW
30RSB & Back Pressure Turbine Power	1.0 to 12 MW

This adaptability feature also provides the ability to modify an existing machine to meet major resource changes within the above ranges. The Biphase turbine is relatively insensitive to small changes in resource parameters, and ordinarily no hardware changes will be required. Moderate changes can be accommodated by rework or replacement of nozzles, and the machine design is especially made to expedite field nozzle interchange. Significant resource changes may require rework of steam blades by changing blade length.

ROTARY SEPARATOR TURBINE IMPROVEMENTS

The design of the 30RST turbine incorporates major design improvement from prior commercial RST turbine designs to improve the performance, reliability and reduce costs. These are summarized in Table 2. With the exception of bearings and seals, the design improvements were demonstrated during Phase 1 of this program by their application to the sub-scale 12RSB.

Table 2 - 30RSB Design Features

1. Single rotor design.
2. Increased power output from integral steam blade stage.
3. Silicon carbide bearings - water lubricated.
4. Seal arrangement to prevent geothermal process fluids from entering seals or bearings.
5. Cost savings from reduction in overall rotor size from 54 to 30 inches.
6. Improved liquid turbine efficiency by increasing the number of nozzles from 4 to 8.

The single rotor design represents a major reduction in cost and complexity from the prior three-rotor design previously demonstrated in the Roosevelt Hot Springs test turbine. The single rotor design permits the addition of a single stage of steam impulse blades to the rotor disc which more than doubles the turbine output power. The single rotor design replaces the three, cantilevered shaft and bearing assemblies in the prior design with one simpler and less costly trunion shaft design. This design provides a much improved dynamic stability of the rotor.

The rotor bearing and seal assembly used previously was an oil lubricated babbit type bearing with labyrinth seals. The present design replaces these with water-lubricated silicon carbide bearings and low leakage face seals. The replacement of the conventional lubricating oil with water lubrication provides a simplification from elimination of logistic problems associated with lube oil and the handling of contaminated used oil. The major benefit derived from the change from oil to water lubricated bearings is to prevent the leakage of geothermal process fluids (steam or liquid) into the shaft seals. This is accomplished by maintaining the bearing cavity pressurized with the lubricating water flow at a pressure typically 25 psi above the process pressure of 425 psia, within the turbine case. This low pressure differential of 25 psi across the face seal results in little or no leakage of clean water into the geothermal process. The important aspect of this design is that it eliminates the potentially damaging situation of silica scale deposition within the seal if process geothermal steam is permitted to flow into the seal.

30RSB TURBINE DESIGN

The rotary separator turbine which embodies the design simplifications described above is the 30RSB. A cross-section of the 30RSB is shown in Figure 3.

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 face type seal with a clean water purge to eliminate 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. Previous experience with brine velocities of 400 feet per second showed that alloy to be resistant to both corrosion and erosion.

30RSB GEOTHERMAL TEST SITE DESCRIPTION

The site selected for the full size turbine is Cerro Prieto Well Number 103, which supplies steam to the 180 MW Cerro Prieto 1 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 MW. The Comisión Federal de Electricidad, owner and operator, is cooperating in this program.

Figure 4 schematically shows the present operating conditions for well 103 as the design basis for the 30RSB turbine.

The well currently is operated at a wellhead pressure of 755 psia. At this pressure a flowrate of 312,000 lb/h is produced with a steam fraction of 45%. The flow is flashed to 126 psia to produce steam. The steam is utilized by the Cerro Prieto turbines to produce power. At the current steam rate of 24 lb/kWh the steam from this well produced 7410 kW.

Figure 5 schematically shows the addition of the 30RSB power train to the Cerro Prieto well 103. The normal power train consists of the 30RSB turbine which is directly coupled to a 3600 rpm 5 MW synchronous generator. The generator is also connected to a two-stage, backpressure steam turbine. Because of the availability of an existing backpressure steam turbine-generator, the plan is to use separate turbine-generator skids for the 30RSB and backpressure turbine for the first application to well 103. Table 3 gives design parameters.

The total power output from the Biphase system is estimated to be 4353 kW (shaft). A 4% design margin gives a final predicted electrical output of 4180 kWe. The steam produced will generate an additional 6610 kW in the central steam turbine giving a total power output from the well of 10,790 kW. Thus, addition of the Biphase system at this site increases the power production from the chosen well by 45%.

Table 3 - Design Parameters for Biphase Power System for Cerro Prieto Well No. 103

Biphase Turbine	
Inlet Pressure	755 psia
Inlet Flowrate	312,480 lb/h
Inlet Steam Fraction	0.455
Biphase Exit Pressure	424 psia
Rotor Diameter	30 inches
Rotor Speed	3600
Output Power	1135 kW (shaft)
Steam Turbine	
Inlet Pressure	416 psia
Inlet Flowrate	149,700 lb/h
Inlet Steam Fraction	1.00
Exit Pressure	126 psia
Output Power	3218 kW (Shaft)
Total Generator Power from Biphase Plant	4180 kWe (electrical)

Note: Minor adjustment of these parameters, as compared to the paper in Geothermal Program Review XIII, is due to adjusted values of well pressure and flow.

Figure 6 is the general arrangement of the dual skid configuration on the platform of well 103. Major equipment consists of the two turbine skids, two enclosed skid mounted rooms for control and electrical equipment, and an auxiliary separator.

PERFORMANCE VARIATION WITH GEOTHERMAL RESOURCE VARIATION

The two-phase nozzle design code and the Biphase turbine performance code were used to estimate the system performance over a range of resource conditions. The power increase for a single stage flash geothermal turbine with the addition of a 30RSB power train including backpressure steam turbine is shown in Figure 7 for geothermal wellhead enthalpies from 400 to 900 Btu/lbm. These data show for very high well pressures of 900 psia the percentage power increase rises from 23% at an enthalpy of 550 Btu/lbm to 40% at an enthalpy of 900 Btu/lbm. The data show similar results for well pressures of 100, 300 and 600 psia.

The variation of 30RSB system power and total power including a condensing turbine over the same range of variables is shown in Figure 8 for one or more wells with a total flow of one million lbm/h. At the highest well pressure curve of 900 psia the power of 30RSB turbine system is 14.1 MW. This power total consists of 3.9 MW from the 30RSB and 10.3 MW from the backpressure turbine. The second set of data labeled Total Power represents the additional power from a condensing steam turbine with efficiency of 77% and condensing pressure of 1.5 psia. For the enthalpy of 950 Btu/lbm and wellhead pressure of 900 psia, the total power is 49 MW of which 28% is obtained from 30RSB power train.

CONCLUSIONS

The production Model 30RSB Biphase turbine, together with a wellhead system including a backpressure steam turbine, provides a topping power plant which can be built and operated at a profit in existing and future geothermal projects. Total cost of the Biphase power plant is $500 to $750 per kW.

The power resulting from the well flow from well 103 at Cerro Prieto, supplying steam to central plant CP1, is increased by more than 40% by the addition of the Biphase topping plant.

Application of ceramic bearings, lubricated by water, can result in major simplification of Biphase and geothermal turbines.

The single rotor Biphase production design with integrated steam blades represents a major equipment cost reduction and performance improvement.

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," RP1196, Electric Power Research Institute, Palo Alto, 1986.

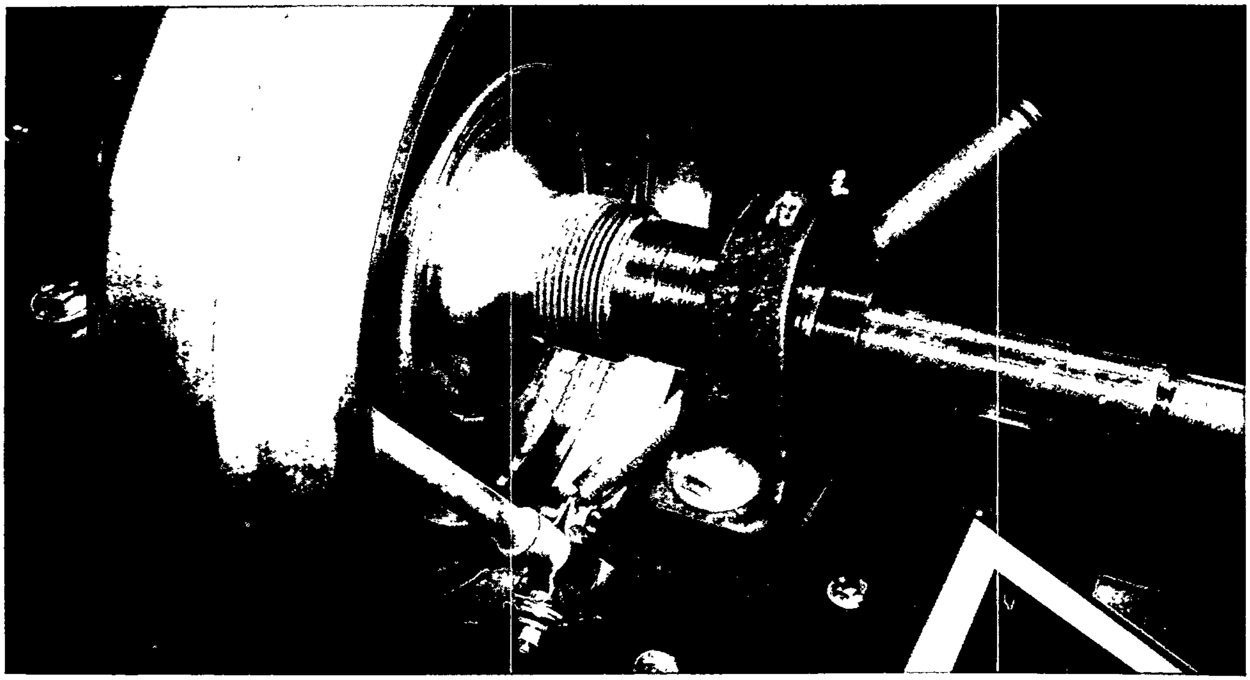

Figure 1. Model 12RSB Rotor after 720 Hours Operation

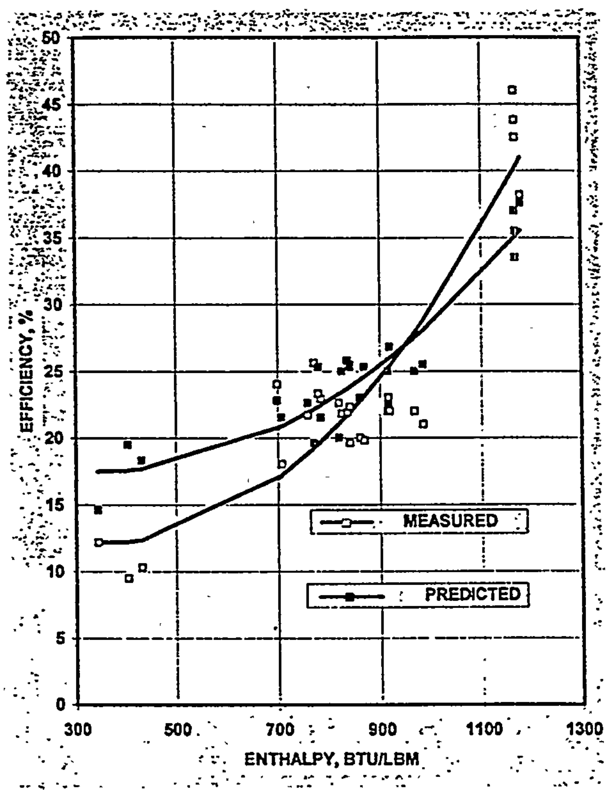

Figure 2. Measured and Predicted Efficiency

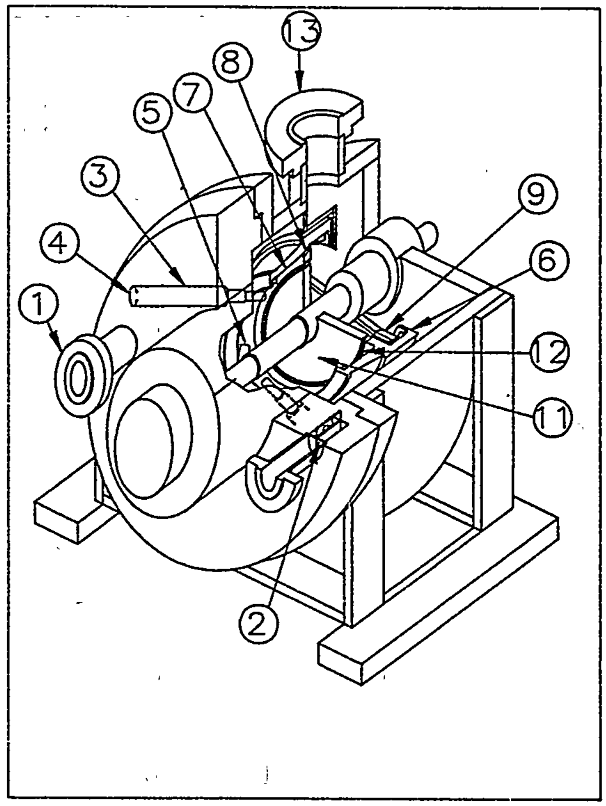

Figure 3. 30RSB Turbine Isometric

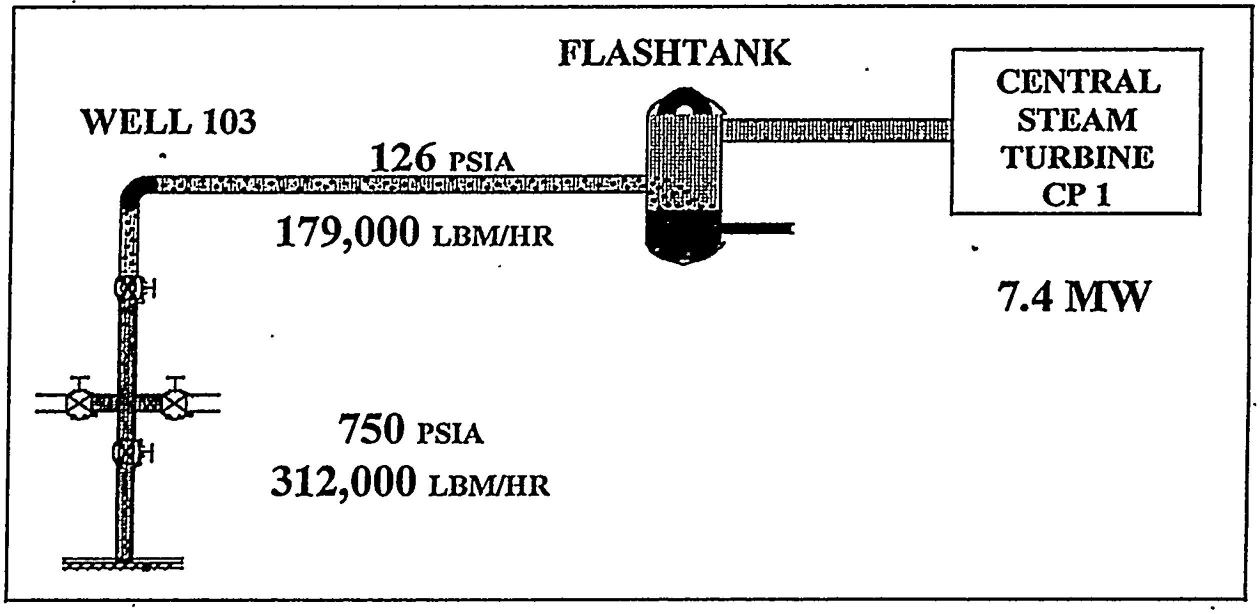

Figure 4. Schematic of Present Well 103 Conditions

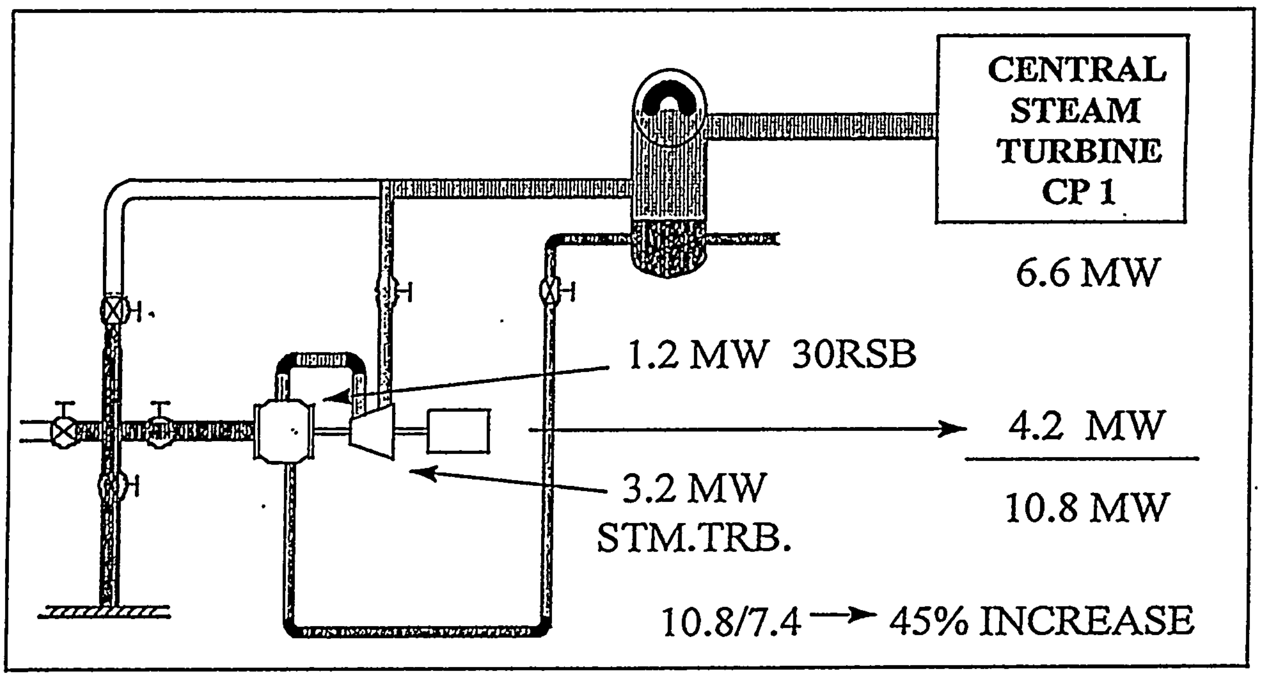

Figure 5. 30RSB Addition to Well 103

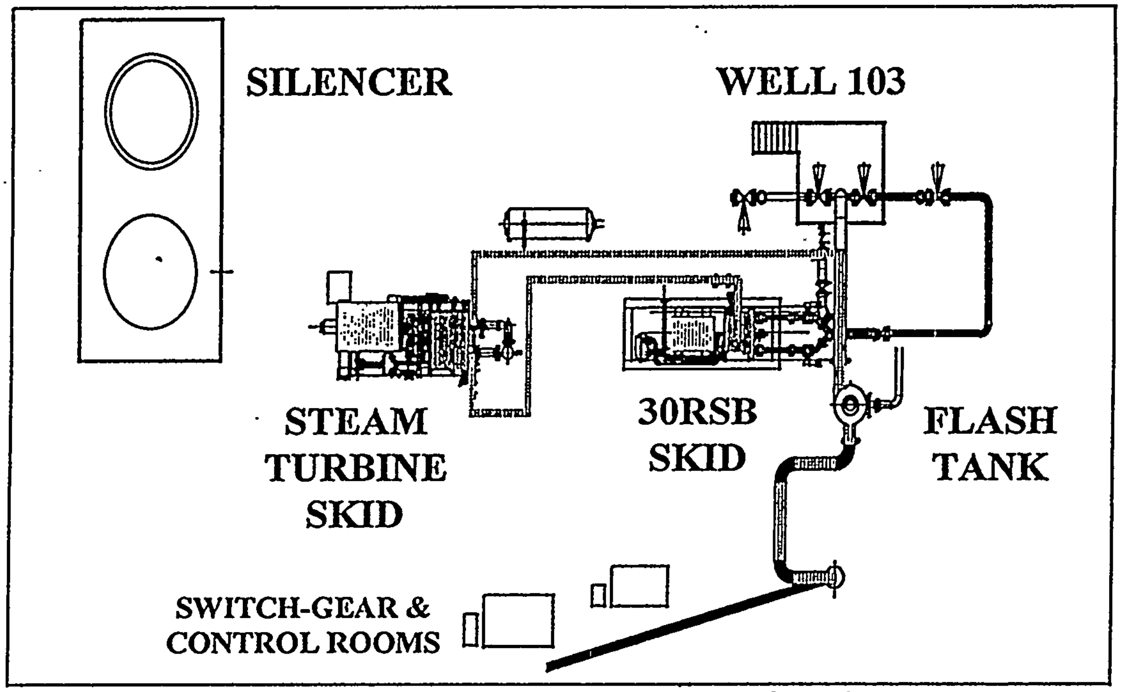

Figure 6 30RSB Dual Skid Plot Plan

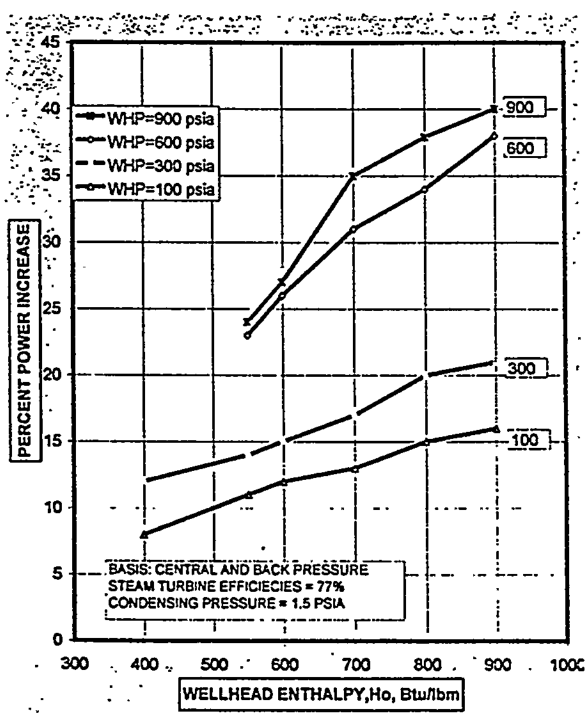

Figure 7. 30RSB Potential Power Increase

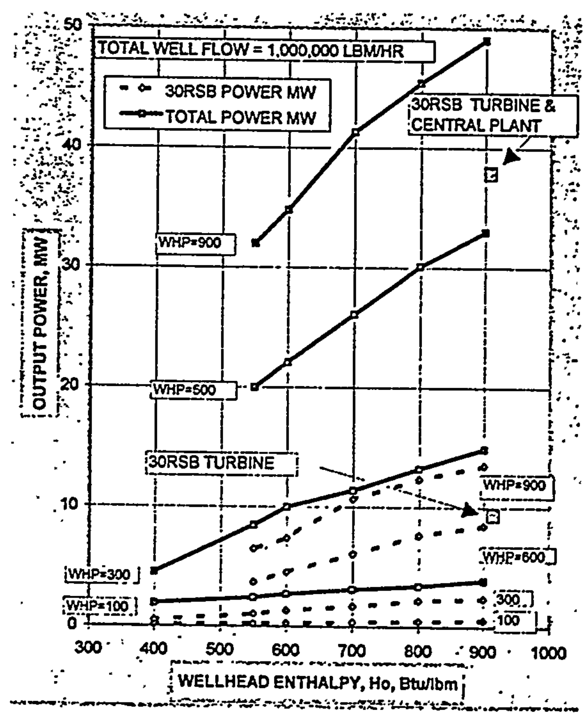

Figure 8. 30RSB System Power Output