DEMONSTRATION OF ECONOMIC BENEFITS OF A BIPHASE TURBINE IN A GEOTHERMAL APPLICATION

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KEY WORDS

biphase turbine, cooperative agreement, demonstration, flash plants, energy conversion

PROJECT BACKGROUND AND STATUS

The Douglas Energy Company was awarded a cooperative agreement through the Golden Field Office to demonstrate the economic benefits of a Biphase topping turbine. This patented device separates the steam from the brine and generates power from each phase. For a flash steam power plant, the Biphase turbine can recover useful work that would otherwise be dissipated in the flash process.

The Biphase turbine concept has been proven through an earlier DOE sponsored project. At Roosevelt Hot Springs, Utah, a Biphase turbine accepted the full flow from a geothermal well during a 4000 hour demonstration. The unit generated 1600 kW and demonstrated a 20% increase in power output when compared to a single flash steam turbine. However, the design of this Biphase turbine included three rotors, each rotating at different speeds, which increased the cost, complexity and maintenance to an unacceptable level. This unit's design also converted only the brine's kinetic energy to shaft power. Therefore, the benefit of the Biphase turbine was limited on high enthalpy wells (i.e., wells with a high steam fraction) by the inability to generate power from the steam phase.

An advanced Biphase turbine was developed to overcome the previous unit's limitations. The three rotors were replaced by a single rotor and impulse steam blades were added. The single rotor Biphase turbine design was proposed in response to a solicitation entitled "Demonstration of Economic Benefits of Improved Electrical Power Generating Systems for Geothermal Applications." Following a competitive process Douglas Energy was awarded a cooperative agreement to demonstrate the advanced Biphase turbine.

The program proposed by Douglas Energy was divided into two phases. Phase 1 involved operating a 12 inch diameter, sub-scale Biphase turbine on a slip stream from a geothermal production well. The small turbine would be operated on low, medium and high enthalpy flows. Phase 2 would incorporate the lessons learned from the small turbine into a full size unit that would be manufactured and operated in a commercial geothermal flash steam power plant environment.

Phase 1 of this program is completed. California Energy Company provided access to a geothermal well at Coso Hot Springs in California. The sub-scale Biphase turbine operated in each of the high, medium and low enthalpy regimes. Three 250 hour tests provided valuable information and operating experience. An analytical model developed by Douglas Energy was verified and the operating experience brought about several design changes to the full size unit.

Phase 2 is well underway. The lessons learned have been incorporated and the full size Biphase turbine is being manufactured. The new unit will be demonstrated at Cerro Prieto, Mexico and is expected to generate approximately 1 megawatt of electricity.

PROJECT OBJECTIVES

The objective of the above mentioned solicitation was to support geothermal projects that would demonstrate economic benefits of improved electrical power generating systems. Within that context, the overall objective of this project is to demonstrate the affordability of the Biphase turbine. This includes, the capital costs to purchase and install as well as the maintenance required to operate and service the unit.

Technical Objectives

Phase 1: Testing of the Sub-Scale Biphase Turbine

- **Gain operational experience through testing the sub-scale unit.** The 12 inch diameter Biphase turbine (12RSB) had been tested previously with water and air. However, no amount of laboratory testing can match field testing. California Energy Company provided access to a geothermal well at Coso Hot Springs. Due to some innovative piping arrangements this well was used for all three (high, medium and low) enthalpy tests.

- **Validate the analytical model and use it in designing the full scale unit.** Douglas Energy had developed a model to predict the efficiency of the turbine. From the data gathered, the computer model was able to be validated and used in the design of the full size unit. The model showed agreement to within 20% over the range of steam fraction from 0.07 to 1.0 and pressures from 33 to 117 psia .

- **Measure power generated from the steam impulse blades.** 100% pure steam was used for the high enthalpy test so that the steam blades input could be measured directly. A water-brake dynamometer was used to measure the power from the Biphase turbine. This allowed for greater control and accurate measurements.

- **Demonstrate the variability of the Biphase turbine by changing the two-phase nozzles for different flow conditions.** That is, a different set of nozzles, specifically designed for the flow conditions, were used for each test.

Technical Objectives (continued)

- **Demonstrate the computerized control system.** The Biphase system was instrumented and control equipment put in place for automatic control. The control system is designed so that one operator could control many Biphase units from a remote location. The control system used during phase one will also be used for the full size unit.

The objectives of Phase 1 have been met. Operational experience has been gained in a geothermal environment. Improvements to the advanced Biphase turbine have been realized. The modeling codes used in the design process have also been validated.

Phase 2: Manufacturing, Installation and Operation of the full Size Unit

- Incorporate the following lessons learned from Phase 1 into the design of the full size, 30 inch diameter unit:
    - **Install hydroblast scale removal system** - No scale formation occurred in the nozzles or on the nozzle side separator during Phase 1 . However scale formation was observed on the diffuser side of the separator. A hydroblast scale removal system was installed and proved to be effective.
    - **Install upstream rock/sand catcher** - The geothermal well at Coso Hot Springs had been inactive for a period of time and was unstable when it was activated for testing. A great deal of debris, including sand and rocks, periodically entered the turbine, causing some seal and bearing problems. The rotor and steam blades were undamaged by the debris.
    - **Use corrosion resistant material** - The rotor and steam blades will be manufactured from HY-80. 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 has shown Inconel 718 to be resistant to both corrosion and erosion.

Expected Outcomes

- Demonstrate economic benefits of the Biphase turbine.

- Demonstrate increased efficiency. Addition of the Biphase system at the chosen well is expected to increase the power production by 45%.

  - The well to be used at Cerro Prieto is currently operating at a well head pressure of 790 psia. At this pressure, a flowrate of 312,000 lb/hr is produced with a steam fraction of 45%. The flow is flashed to 125 psia and sent to the steam turbine. The steam from this well produces 7410 kW.

  - The system to be installed at Cerro Prieto is shown in Figure 1. The two-phase flow from the well enters the Biphase turbine at 750 psia and is expanded in the nozzles to 444 psia generating 1080 kW shaft. The separated steam is expanded further in the back pressure steam turbine to 126 psia generating an additional 3520 kW shaft. The separated brine flows to the existing separator and is flashed to 125 psia. The steam then flows to the Cerro Prieto steam turbine where it will produce an additional 6610 kW giving a total output from this well of 10,760 kW electric output.

- Demonstrate continuous operation - The operational period for this project is two years.

APPROACH

A cutaway of the sub-scale Biphase turbine used in Phase 1 of this project is shown in Figure 2. From the well, ten two-phase nozzles direct the two-phase high velocity jets tangentially onto the inner surface of the rotating separator. Centrifugal force separates the brine from the steam as the brine forms a film on the separator surface and is slowed by friction to the velocity of the rotor. After slowing and transferring the torque to the rotor, the brine flows through transfer holes to the other side of the disc supporting the separator. The brine enters a diffuser which is immersed into the brine layer where the velocity is slowed converting the kinetic energy into pressure. The brine exits the turbine and flows to a disposal pit.

The separated steam flows through a row of impulse blades adding to the torque of the turbine. The steam leaving the impulse blades exits the turbine and is discharged to the atmosphere.

The full size Biphase turbine (30RSB) is shown schematically in Figure 3. From the rock catcher, the two-phase flow enters the two inlets, 1, to the Biphase turbine. An internal splitter, 2, divides the flow into four equal streams, each feeding a two-phase nozzle, 3. The eight two-phase nozzles are formed by a contoured insert which can be removed and replaced though 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 though 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 on top.

The Biphase 30RSB has conventional labyrinth seals with a clean water seal wash to reduce scaling. Ceramic bearings, cooled with clean water, will be used to provide the straddle mounted rotor with the required stiffness.

The operating speed is 3600 rpm, enabling direct drive of the generator.

The parties involved in this project and their respective responsibilities are as follows:

- Douglas Energy - Project manager and developer of the Biphase turbine.
- Department of Energy - Project management through Cooperative Agreement.
- California Energy Company - Provided geothermal well during phase 1 activities.
- California Energy Commission - Providing loans to Douglas Energy.
- Comision Federal de Electricidad - Providing geothermal well at Cerro Prieto for full size Biphase turbine.
- Biphase de Mexico - Mexican partner will install and help operate the Biphase system.

RESEARCH RESULTS

The performance of the sub-scale turbine was monitored continuously during its operation. The wide fluctuations in flowrate, steam fraction and pressure produced a wide range of operating conditions.

The turbine efficiency, defined as the gross shaft power (measured by the dynamometer) divided by the isentropic enthalpy difference from inlet to exit is shown in Figure 4. The efficiency varied from 10% at the lowest enthalpy values to 46% at the highest enthalpy. These values were obtained where the ratio of steam blade to jet velocity was between 0.18 and 0.25. However, the optimum steam blade efficiency occurs at a value of 0.5.

The measured power output vs. the predicted power output is shown in Figure 5. The power was measured over a range of steam fraction from 0.07 to 1.0 and pressures from 33 to 117 psia. The two highest measured power points were obtained using 100% steam with nozzles designed for steam only.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Douglas Energy Co. has performed a pre-feasibility of the Biphase turbine to generate additional power at existing geothermal plants. One application is to generate power from high pressure wellheads. In the Philippines the average increase in power was 15%. In Mexico the average was found to be 22%. The additional power is generated without drilling any additional wells and further exploiting the resource. The total installed cost was estimated to vary between $500-$700/kW, depending on additional piping requirements. When compared to spending $1000-$1500/kW to build a flash steam plant, the Biphase turbine looks very cost effective.

In a non-geothermal application, the Biphase turbine has been licensed to Carrier Corporation for worldwide refrigeration applications. Environmental considerations require the use of chlorine-free, high pressure refrigerants in air conditioners. These new refrigerant fluids are not as efficient as the fluids they have replaced. Part of the inefficiency results from flashing. Douglas Energy designed and manufactured a two-phase turbine for energy recovery in industrial air conditioners using R134A refrigerant. The Biphase turbine was installed in a large chiller and tested by Carrier at their Syracuse factory. An efficiency in excess of 50% was measured. In a centrifugal chiller the Biphase turbine replaces the expansion valve and generates power while chilling the refrigerant. The addition of the Biphase turbine will make the Carrier air conditioning units efficient as well as environmentally safe.

In the oil and gas industry, Biphase Energy Co. has entered a joint venture with Kværner a.s. Studies of conventional off-shore separation equipment have shown a fivefold reduction of footprint and weight is possible. The size reduction is achieved while generating power from the previously wasted two-phase flow energy. The first unit sold under the agreement has been installed in a proprietary system to reduce VOC emission during off-shore loading of tankers. This unit will generate power and separate inert gases from the crude oil. Laboratory tests have shown a 90% reduction in emissions.

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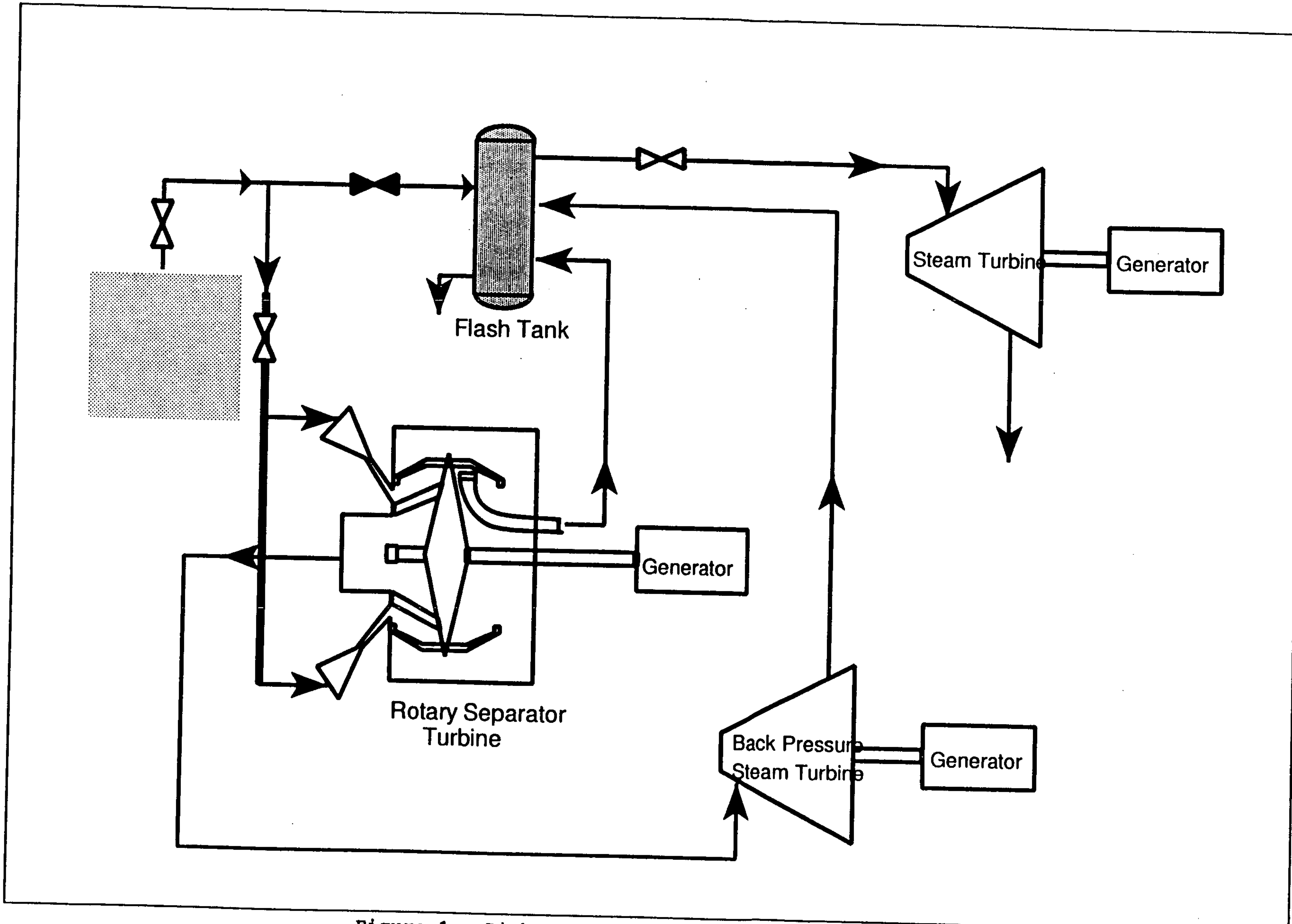

Figure 1. Biphase System at Cerro Prieto, Mexico

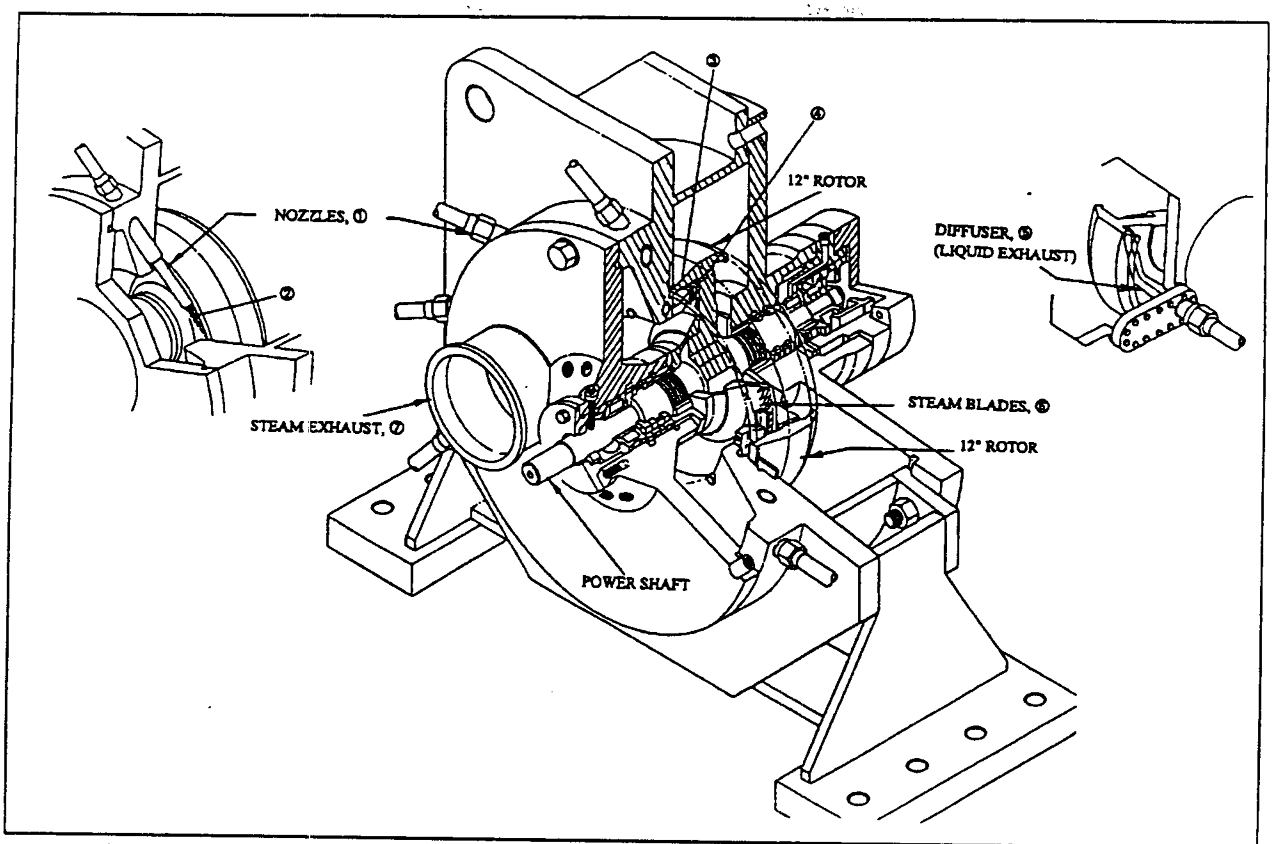

Figure 2. 12RSB Biphase Turbine, Nozzle Side, Isometric 1/4 Cutaway

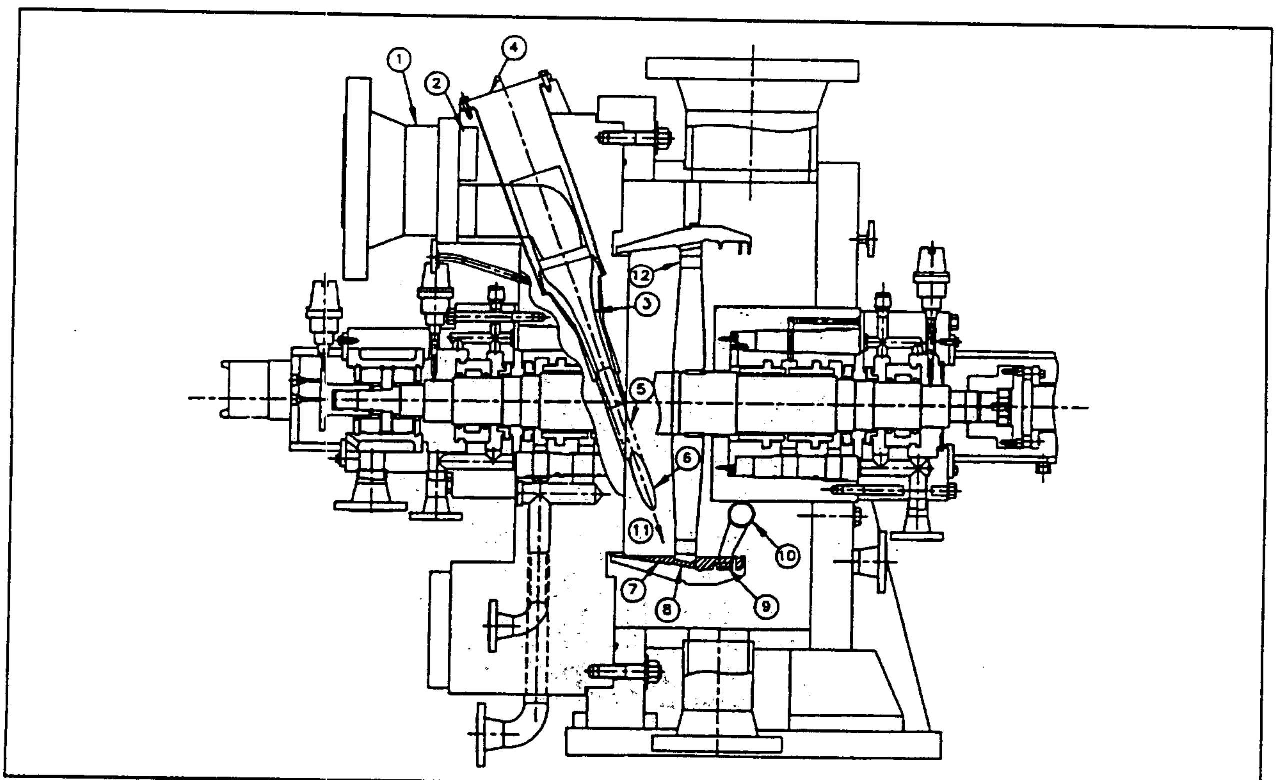

Figure 3. Schematic of 30RSB Biphase Turbine

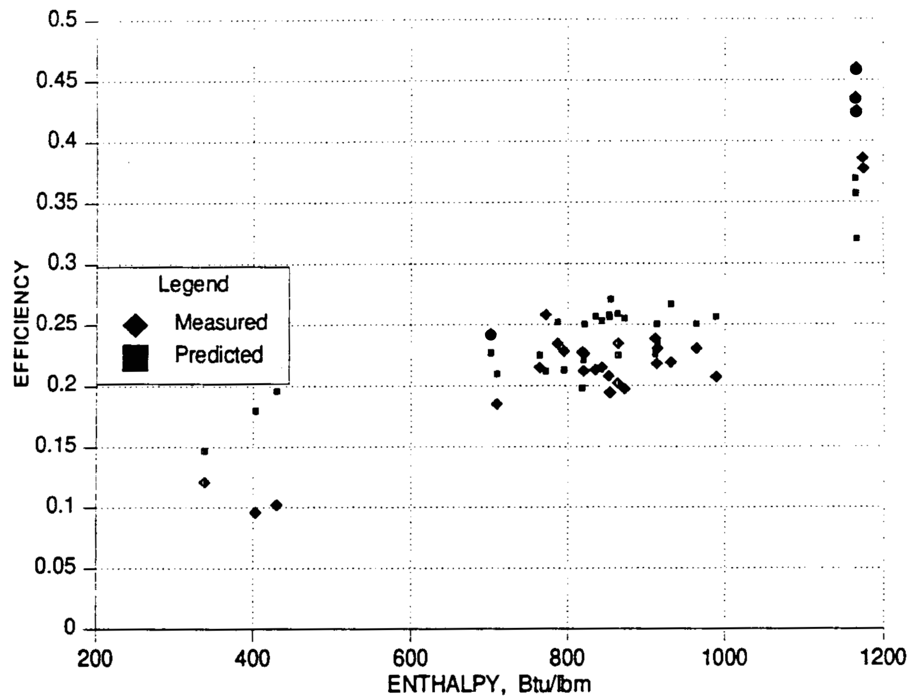

Figure 4. Measured and Predicted Efficiency Variation with Inlet Enthalpy

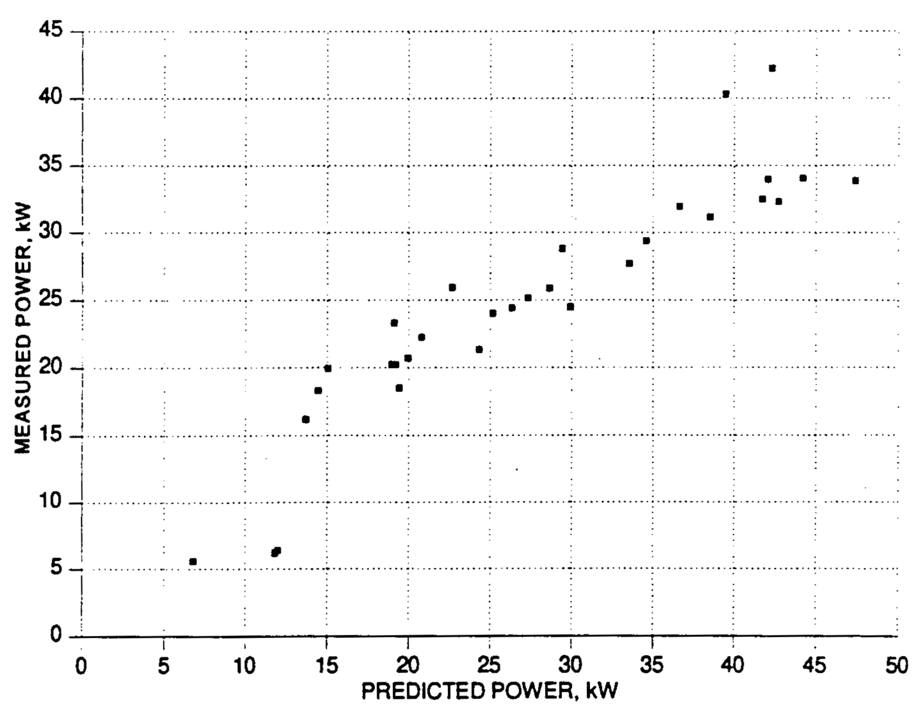

Figure 5. Measured Power Output Variation With Predicted Power Output