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

Walter R. Studhalter
Douglas Energy Company

Jeffrey L. Hahn
Department of Energy - Golden Field Office

KEY WORDS

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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 turbine. The Biphase turbine produces power from mixtures of liquid and gas. The geothermal application utilizes brine/steam mixtures obtained from geothermal wells. The mixture is fed to the turbine directly from the well; the steam and brine are separated and power is obtained from each. The application chosen for demonstration was a "topping" power plant, in which the separated steam is further utilized in more conventional steam turbines. The "topping" makes power when high wellhead pressures are reduced to the central plant pressures. Biphase power is made from energy otherwise dissipated in the flash process.

The Biphase turbine concept applied to geothermal power has been proven through earlier projects sponsored by DOE and others. For example, at Roosevelt Hot Springs, Utah, a Biphase turbine was compared directly with a single flash steam turbine, and found to demonstrate a 20% increase in power produced. A 4000 hour reliability run demonstrated material suitability and the ability to operate in the geothermal environment. While the concept was demonstrated, the original machine design with multiple rotors was considered to be too complex. Subsequently, the Biphase machine design has been simplified to incorporate a single straddle-mounted rotor, and power is obtained from both the steam and the brine.

The simplified Biphase turbine was proposed to the DOE in response to a solicitation entitled "Demonstration of Economic Benefits of Improved Electrical Generating Systems for Geothermal Application". Following a competitive process Douglas Energy Company was awarded a cooperative agreement to demonstrate the advanced Biphase turbine in October 1993.

The Biphase concept can be applied to geothermal power production in several ways: stand-alone plants, such as the one at Roosevelt Hot Springs; "bottoming" plants, which operate on separated brine from other flash plants; and "topping" plants, which operate at geothermal wells and supply steam to existing steam plants. The "topping" plant was proposed to demonstrate the economic benefits because of its world wide applicability. That is, many geothermal fields throughout the world have high pressure wells feeding into lower pressure steam systems.

The program proposed by Douglas was divided into two phases. Phase 1 modified an existing 12-inch Biphase machine into a subscale geothermal turbine. The subscale geothermal turbine operated on a slip stream from a geothermal well to gain operational data and experience. Phase 2 would design, fabricate and operate a full size Biphase system on a geothermal well for two years to generate reliable data for the economic assessment. The full size design would incorporate the lessons learned from the operation of the subscale turbine.

Phase 1 was completed in early 1996. The 12-inch Biphase turbine was operated at a geothermal well at Coso Hot Springs, California. By manipulating ratios of steam and brine, operation was possible at low, medium, and high enthalpies (low, medium and high steam qualities). The subscale turbine was operated for a total of about 700 hours. Power was measured by a water-brake dynamometer, permitting wide variations in speed. Data over these wide ranges was consolidated by the Biphase computer codes, and were shown to be accurate within 20% in all cases. The hardware was proven to be durable and scale was manageable through incorporation of an innovative "hydroblast" system. The "hydroblast" system, used intermittently, utilized a high- pressure water jet while running to help control scale buildup in critical areas.

Phase 2 is in progress. The design for the Biphase turbine Model 30RSB was released early in 1996. The unit was completed in November, 1996 and the power plant system was assembled on a skid ready for shipment in December 1996. The plant is expected to begin operation in March 1997 and will then be operated for a period of two years, which is an extension of the original schedule.

The plant will be sited at Well No. 103 at Cerro Prieto, Baja California, in the large productive area of the Mexican electric utility, Comision Federal de Electricidad. The power plant will be owned and operated by Douglas Energy Company, and electricity will be sold to the utility at an agreed upon price for two years. The operation as a commercial venture will assure the best analysis of economic benefits. The Cerro Prieto area could support an additional 40 Biphase wellhead power plants which would add more than 100 MW without drilling another well.

An Economic and Application study was published defining the most suitable size for the commercial Biphase turbine to be used in many areas of the world. The system was defined and shown to be fully capable of profitable operation. Many places in the world have wells of sufficiently high pressure that the Biphase topping turbine could be augmented by addition of a back pressure steam turbine. The exit steam from the back pressure turbine is still at sufficient pressure to operate at the inlet of the main plant large turbines. In the present example, during Phase 2 operations, a back pressure steam turbine will be placed in series with the Biphase turbine. This will increase the total output of the well which was 7 to 8 MW with the Biphase turbine, to 10+ MW with both the Biphase turbine and the back pressure steam turbine.

PROJECT OBJECTIVES

The objective of the DOE 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 is taken to mean that the Biphase system can be financed, built, installed and operated at a profit. To reach this objective, the actual Biphase turbine cost is included in the system cost, while operating and maintenance costs will be demonstrated, and the markets defined.

Technical Objectives

Phase 1: Testing of the Subscale Biphase Turbine

- **Gain operational experience through testing the sub-scale unit.** The 12-inch unit was tested under actual field conditions at a CalEnergy well, Coso Hot Springs, CA. Due to some innovative piping arrangements, the well was used for all three energy levels, low, medium, and high enthalpy. Operation at all speeds up to 7000 rpm was possible by the use of a water-brake dynamometer.

- **Validate the analytical model and use it in designing the full scale turbine.** The field data gathered was compared to the analytical model, to show agreement to within 20% over the range of steam fraction from 0.07 to 1.0 and pressures from 33 to 117 psia.

- **Demonstrate automatic operation of the system.** The control system was designed for automatic operation, leading to the future system designs for unattended small plants. The control system used for Phase 1 will also be used for the full size unit.

- **Measure power generated from steam impulse blades.** Impulse blades were installed in the 12-inch turbine. The power contribution from the steam blades was measured directly during tests with 1.0 steam fraction.

- **Demonstrate flexibility of the Biphase turbine by changing the two-phase nozzles for different field conditions.** The wide range of well parameters was accommodated by field change of the nozzles.

The objectives of Phase 1 have been met. Operational experience was gained in a geothermal environment. The accessories and controls of the system were validated to lend confidence to the commercial power plant design of Phase 2.

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

- **Conduct an economic and application study.** Calculate costs of the Biphase wellhead power plants and place in a commercial framework including expected value of the electricity produced. Geothermal projects around the world were surveyed for the applicability of the wellhead systems, and significant markets were found in Mexico, the Philippines, and Indonesia.

- **Incorporate lessons learned from Phase 1 into the design of the Model 30RSB.** These lessons included:

- **Install Hydroblast scale removal system.** During Phase 1 scale formation was observed on the diffuser side. A high pressure water system (hydroblast) was installed to remove scale periodically while operating.

- **Install upstream rock/sand catcher.** The direct proximity of the Biphase turbine to the well exposes the turbine to debris from the well. While the nozzles and rotor are tolerant of considerable solids, it was found that most could be intercepted by an upstream simple strainer.

- **Use verified materials.** The low-alloy steel HY-80 was found to be suitable for the rotor and steam blades. This material is not subject to corrosion, has sufficient strength, and is resistant to hydrogen embrittlement. High density plasma spray of materials such as Inconel 718 was found to be effective on parts exposed to high velocity brine.

- **Incorporate design innovations to improve durability and cost.** These included:

- **Water lubricated bearings.** Lubricating oil systems for turbine bearings are conventional; however, in the geothermal environment the oil systems require high maintenance. The Model 30RSB was equipped with silicon carbide bearings using water as the lubricating fluid. The first unit will utilize pure water for this service; however, the ultimate goal would use the available geothermal brine as the lubricating fluid.

- **Design a nozzle - fluid manifold as integrated unit.** The eight nozzle inserts of the Model 30RSB are positioned in a single plate, internally machined for the nozzles. The same plate is further internally machined for fluid passages in order to avoid external manifolding. Machining of this plate proved to be feasible.

Expected Outcomes

- **Demonstrate economic benefit of increased power.** Addition of the Biphase turbine and back pressure steam turbine is expected to increase the power production of this well by 45% relative to the existing single-flash installation:

- Well No.103 at Cerro Prieto currently operates at a wellhead pressure of 750 psia and a two-phase flow of 86.7 lb/second. At current operating conditions, this flow is throttled to 126 psia, and 49.4 lb/s of steam are sent to the central power plant, where this well flow is responsible for producing 7,410 kWe. This present situation is illustrated in Figure 1, the upper-left circuit.

- The system being installed on Well No. 103 is also shown in Figure 1. The well flow remains the same. The flow enters the Biphase turbine at 750 psia and is expanded in the nozzles to 444 psia, generating 1134 kW shaft power (resulting in 1078 kWe). The separated steam is expanded further in the back pressure steam turbine to 126 psia generating an additional 3235 kW shaft power (3073 kWe). Separated brine flows to the existing separator. The steam exiting the system then flows to the central plant, where it produces 6610 kWe. Thus the total output from the well is 10,760 kWe, a 45% increase.

- The well flow remains the same. There are no adverse environmental effects attributable to the production of the additional power.

- **Demonstrate continuous operation.** The operational period for this project is two years. An availability goal for this period is 90%.

- **Demonstrate untended operation.** The control system is designed for automatic operation. Future operations visualize a number of Biphase units operating from a central control station. The object is to reduce manpower for routine operation.

- **Demonstrate power plant profitability.** Under an existing contract with the Comision Federal de Electricidad, the Mexican National Utility, power delivered by the Biphase plant will be sold for 4.2 cents U.S. per kWHr.

APPROACH

Design of the Full Size Biphase Turbine Model 30RSB

- A sectional Drawing of the Model 30RSB is shown in Figure 2. The machine is split horizontally in order that the rotor can be removed in the field, using fixtures provided. The rotor, which rotates at 3600 RPM is supported at each end by the bearings. The case design pressure is 444 psia (the nozzle outlet pressure) and steam seals are provided on the shaft. The bearings/seals are mounted on readily removable bearing inserts. There are two two-phase fluid inlets, and manifolds to deliver the fluid to eight nozzles. Nozzles are in the form of inserts which are readily replaced in the field. Steam exits at the top, and brine is discharged from a stationary diffuser.

- Silicon carbide bearings for water lubrication are illustrated in Figure 3. Both the journal and the thrust bearings employ tilting pads made of silicon carbide. Stationary parts of the bearing are also silicon carbide.

- The 30-inch rotor is illustrated in Figure 4. This assembly includes an outer rim, and a central web. These parts are assembled by an interference fit. The impulse steam blades are machined in the central web, as shown in Figure 5. All parts of the rotor are alloy HY-80.

- The complete Biphase turbine is shown in Figure 6. Figure 7 shows the skid assembly including the turbine and the direct-driven induction generator. The generator is air cooled in a closed cycle, with heat being removed in an air-to-air exchanger. The electrical parts are sealed from contact with hydrogen sulfide, which will be present in the atmosphere at the field.

Provision for Assessment of Profitability

The first Biphase complete plant serves as a model for the ultimate commercial application, in which the power plant is owned, installed, and operated by a company such as Douglas Energy Company. Power is sold to the utility, who then has no capital expense nor risk in the power operations. The owner and utility agree before hand about the price and delivery circumstances of the electricity. In the case of this first unit, an agreement has been negotiated with the utility, Comision Federal de Electricidad, to purchase electricity generated during the first two years of operation at the price of 4.2 cents U.S. per kWHr. Voltage, protection, and other characteristics are proscribed.

Projections of the financial viability of this operation, which have been published in Reference 3, are that the plant will operate at a profit during the first two years. Data to be obtained include availability, estimated at 90%; maintenance expense, estimated at $0.004 per kWHr; and manned operation. It is expected that the plant will continue in operation following the two year demonstration period.

Parties involved in this project

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

- Douglas Energy Company - Project Manager, developer of the Biphase turbine, and power plant operator.

- Department of Energy - Financial assistance through a Cooperative Agreement with a cost share of $1,482,405.

- California Energy Commission - Provided grant/loans in the amounts of $441,000 and $1,600,000 to Douglas Energy Company.

- California Energy Company (CalEnergy) - Provided geothermal well and fluid during Phase 1.

- Comision Federal de Electricidad (Mexican National Utility) - Providing geothermal well at Cerro Prieto for Phase 2 with full size Biphase turbine, and providing electrical interties.

- Biphase de Mexico, S.A. de C.V. - Mexican company partly owned by Douglas Energy Company who will provide Mexican operating capability.

RESEARCH RESULTS

The project to demonstrate economic benefits is not structured to conduct research; however, the following research topics have contributed to the Model 30RSB design:

- **Impulse steam blades.** The two-phase mixture issuing from Biphase nozzles at high velocity includes very small liquid drops and steam. The liquid drops are separated on the inner rim of the Biphase wheel, and the energy of their velocity is converted to shaft power. The steam also has the high velocity, and this can be converted to power by means of "impulse" steam blades. Impulse blades convert energy from velocity but do not reduce the steam pressure. In the Biphase system where the steam is used downstream we do not wish to reduce the pressure. Previous measurements of the impulse blade contribution to power required subtraction of the liquid power from the sum of liquid and steam power; however, until the Phase 1 tests were made with pure steam, no direct measurement of impulse blade performance was available. Measurements from the Phase 1 blade tests are shown in Figure 8. These data were used to calculate the parameters for the steam blades in the Model 30RSB, where it is unlikely that a direct measurement will be made anytime soon.

- **Water lubricated bearings.** Years of experience with oil lubrication systems for steam turbine bearings have resulted in reliable but complicated systems, which require maintenance, protection against steam leaks into the oil, and produce an environmentally unsafe waste product. Douglas Energy Company was encouraged to consider lubrication by "available fluids", in this case water or brine, by the successful operation of large sea water pumps in North Sea applications using ceramic bearings. Analysis of the application to geothermal machinery lead to the design of silicon carbide bearings for the Model 30RSB Biphase turbine. These bearings were procured from Glacier Inc. Scotland, and incorporated in the turbine buildup.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

- **Geothermal topping applications.** Douglas Energy Company has performed pre-feasibility studies of the Biphase turbine to generate additional power at existing geothermal plants (Reference

3). In studying the addition to high pressure wellheads in the Philippines, and average increase in power of 15% was calculated. In Mexico the average was found to be 22%. The additional power is generated without drilling any additional wells or further exploiting the resource. The total installed cost was estimated to be $500 to $700/kW, depending upon local conditions. The Biphase approach looks very cost effective when compared to spending $1000 too $1500/kW to build a flash steam plant. The cost comparisons may attract investors who will build and operate plants in the noted countries.

It should not be overlooked that the advantages of the topping application can be obtained in new plant designs, and in most cases the integration of the topping units into the original design can yield even greater benefit.

- **Other geothermal applications.** The Biphase technology has been applied to other geothermal applications, in many cases with encouragement and support from the DOE. Stand-alone small power plants were built at Roosevelt Hot Springs, Utah, and the utility, Utah Power and Light, commissioned a study of producing 100 MW at that location, showing that the economics were favorable. Also at Roosevelt Hot Springs, a Biphase bottoming plant was designed in detail for the utility -- the fluid was brine from the separators of the 20 MW flash plant (the bottoms). This plant was rated at 9 additional MW.

- **Industrial applications.** The DOE has encouraged and supported research on applications of the Biphase technology in many other industrial circumstances. The DOE report, *Generation of Useful Energy from Process Fluids using the Biphase Turbine*, Reference 1, helped develop interest in these other applications. In addition, the geothermal developments in Biphase application have led directly to other applications. Following are outgrowths of the machine development:

  - Refrigeration. The Biphase turbine replaces the expansion valve in air conditioners and chillers. Applying the Biphase turbine has led the Carrier Corporation to produce the highest efficiency chiller using safe refrigerants. Retrofit units are being designed.

  - Oil and gas. A Biphase turbine to recover power in a system to eliminate hydrocarbon emissions during offshore tanker loading is operating in the North Sea conducted by Kvaerner Engineering. Additional application is expected.

    Oil and gas production and processing is being addressed by a consortium of major petroleum companies. A 20,000 barrel per day Biphase unit is in operation on a well to demonstrate separation of oil and gas.

  - Waste heat recovery. Biphase technology has been licensed by Pratt and Whitney for a waste heat recovery system used with gas turbine exhaust. A 20% increase in power over a conventional steam turbine recovery system is obtained.

REFERENCES

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Note 1. Not flowing when Biphase turbine operating
Note 2. Actual application at well 103 will employ separate generators for biphase turbine and back pressure steam turbine

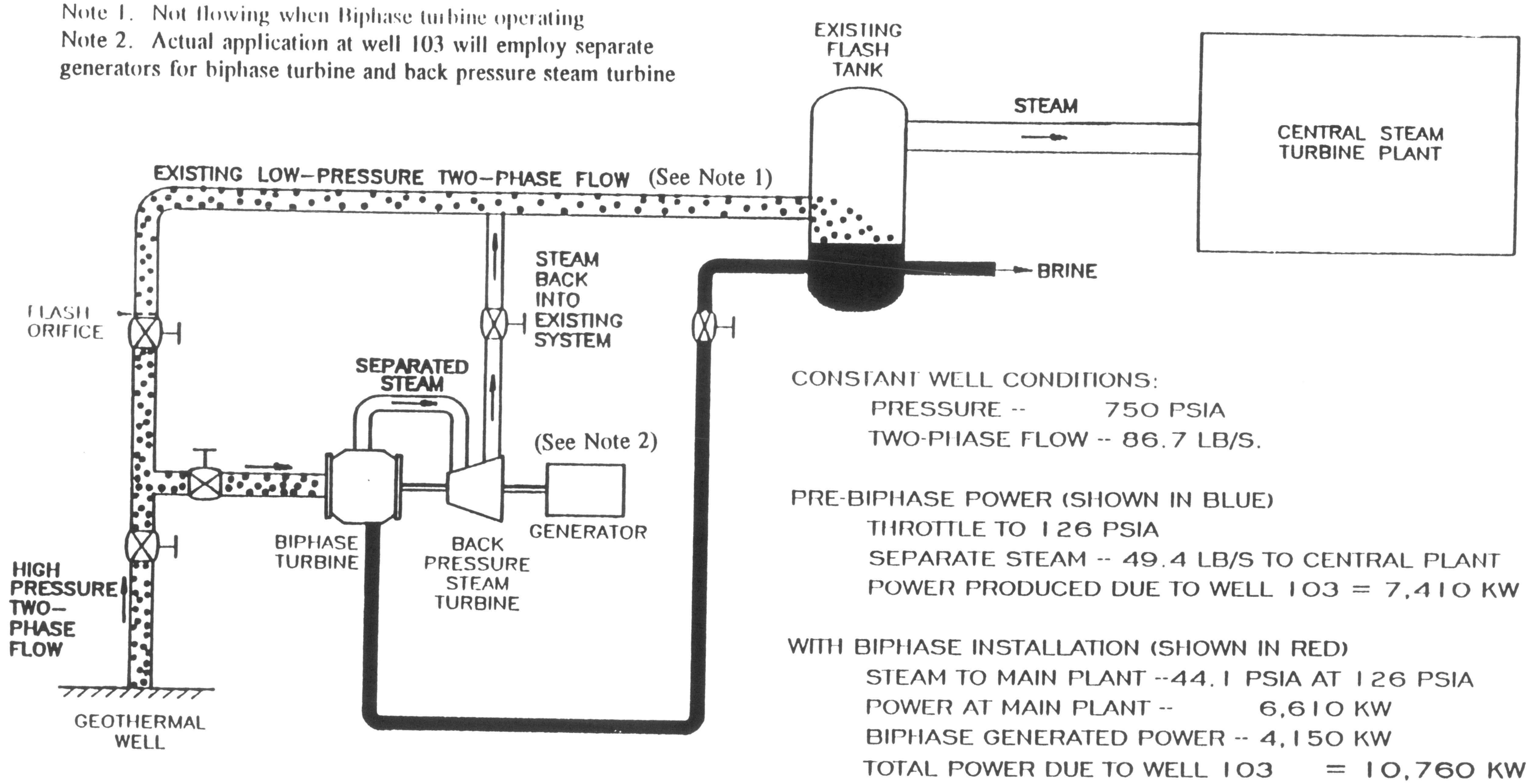

Figure 1. Adoption of 45% more power by applying Biphase turbine to well 103, Cerro Prieto

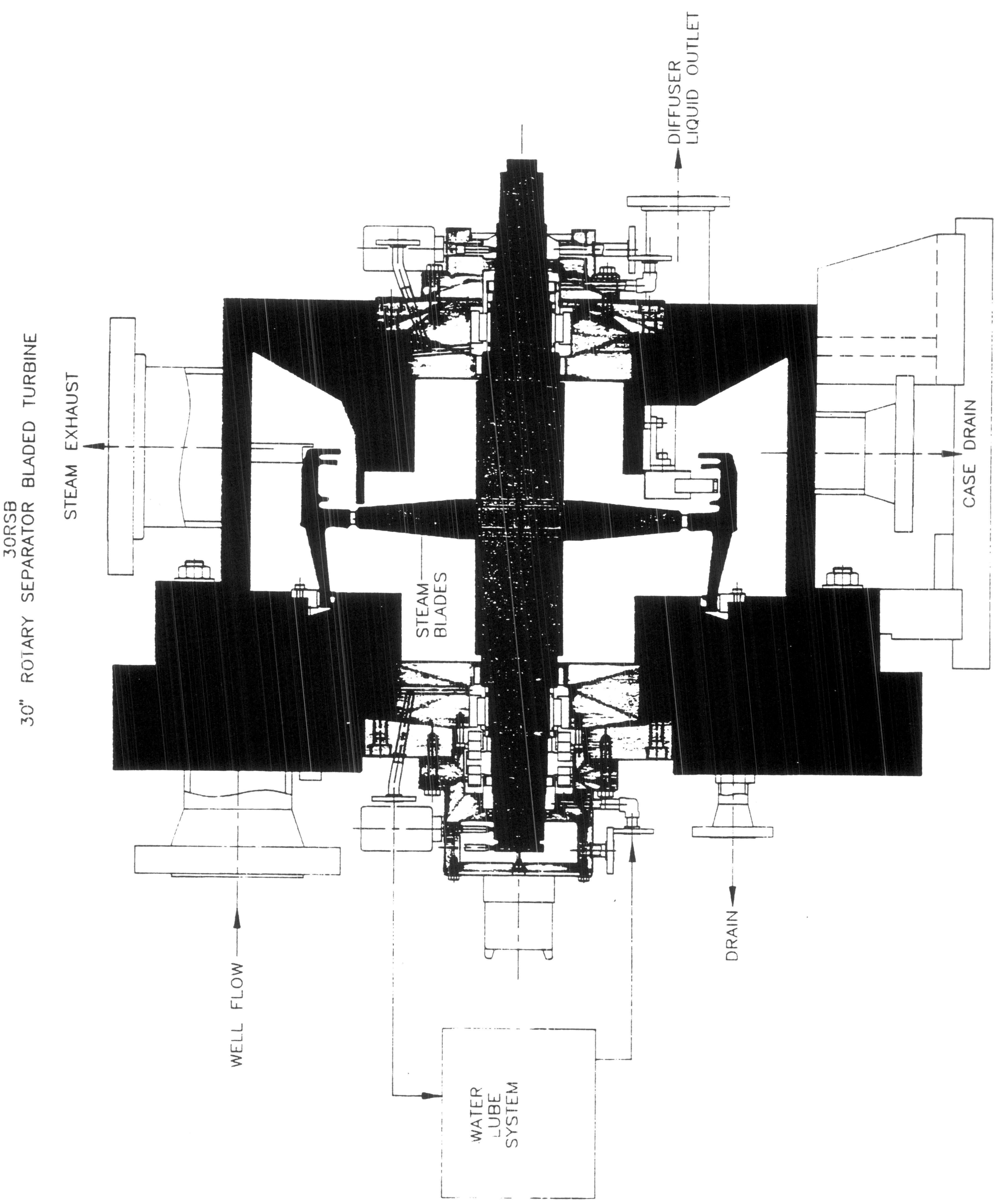

Figure 2. Sectional drawing of Biphase geothermal turbine

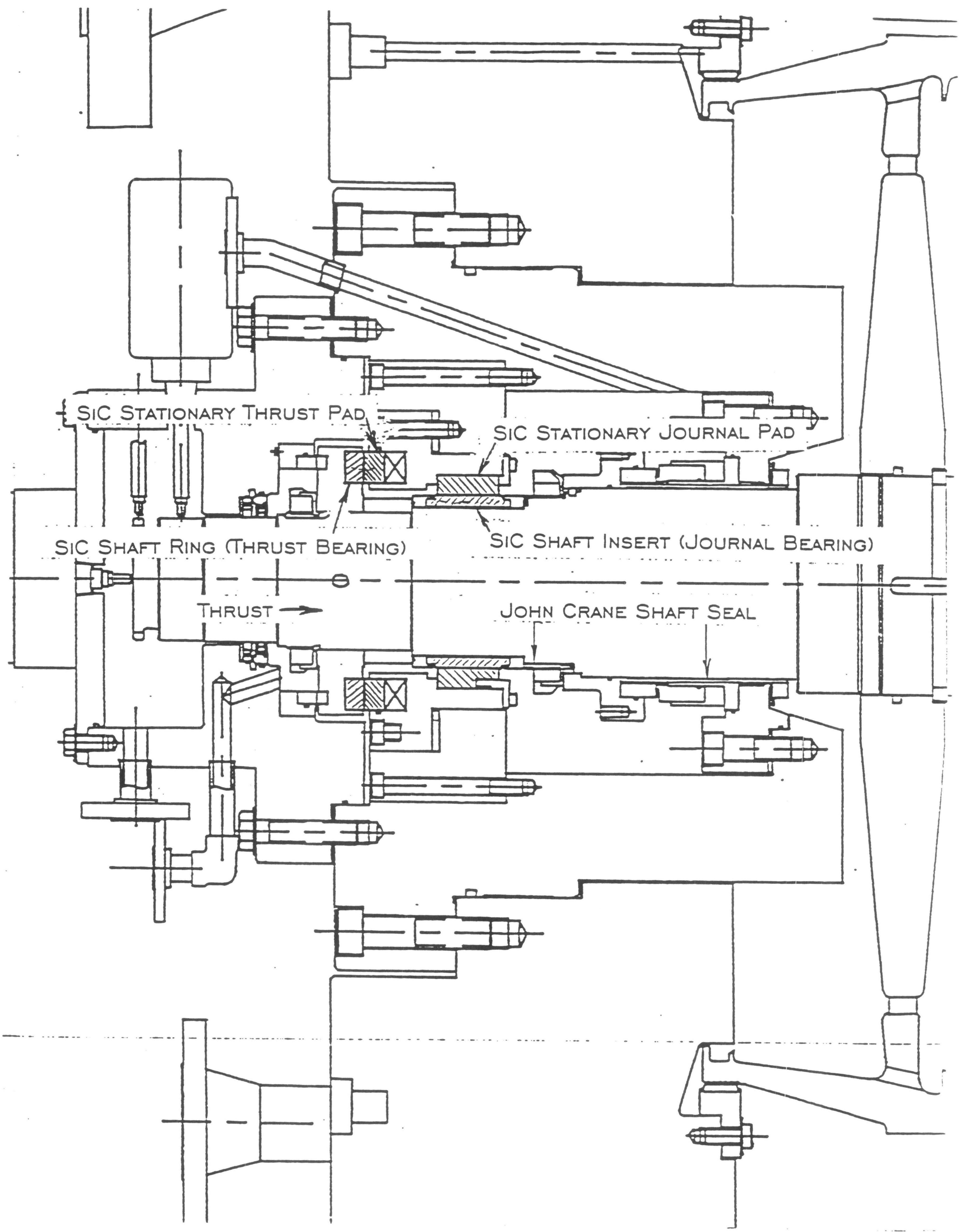

Figure 3. Silicon Carbide Journal and thrust bearing

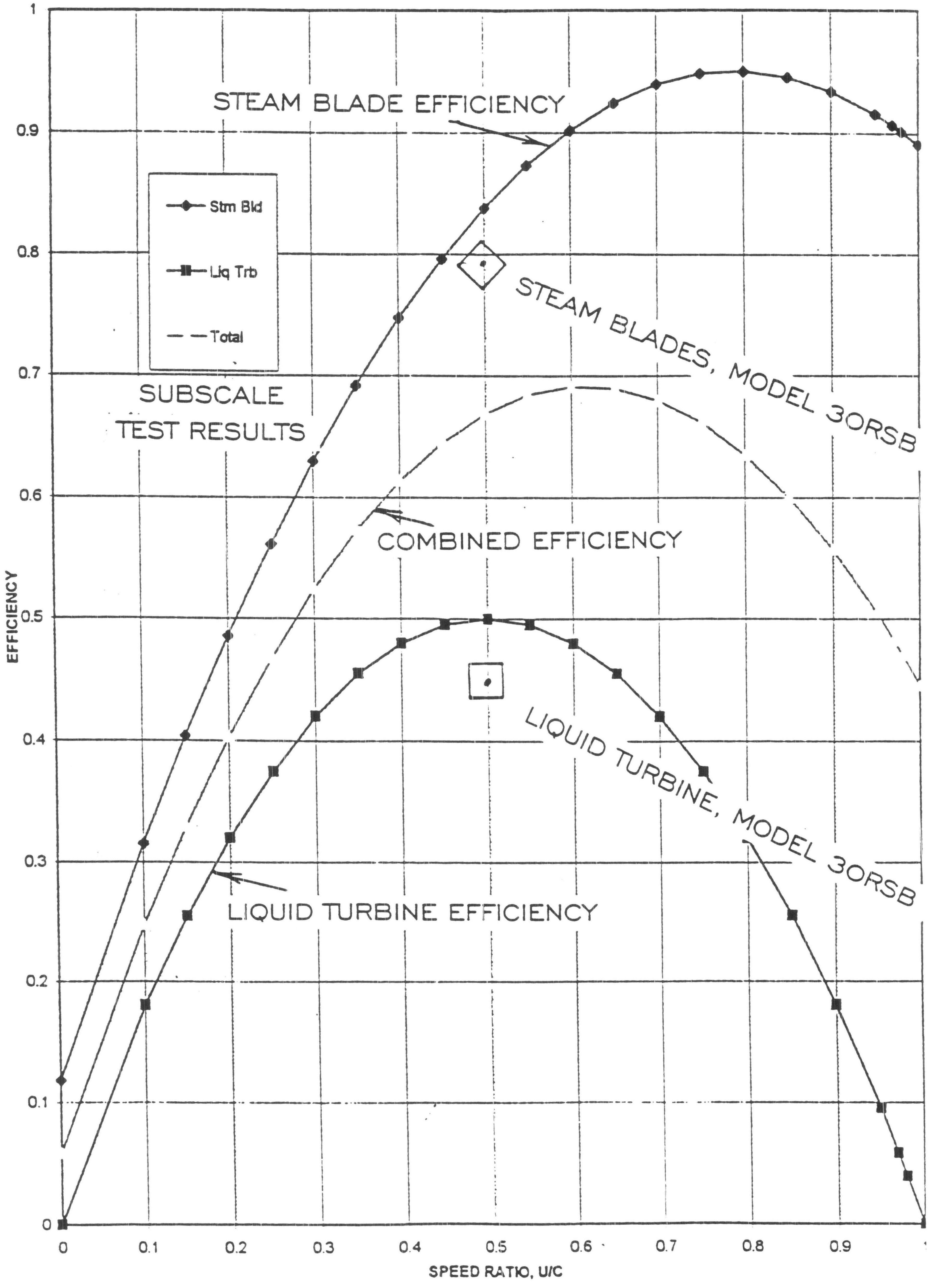

Figure 4. Biphase model 30RSB design points, plotted on subscale test results

LIST OF CONTACTS FOR CONVERSION TECHNOLOGY

Marita Allan
Brookhaven National Laboratory
Upton, NY 11973-5000
Tel: (516) 344-3060
Fax: (516) 344-2359
allan@bnl.gov

Desikan Bharathan
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado
Tel: (303) 384-7418
FAX: (303) 384-7495
Desikan_Bharathan@nrel.gov

Peggy Brookshier
Advanced Technology Division
Idaho Operations Office
785 DOE Place, MS 1220
Idaho Falls, ID 83402-1562
Tel: (208) 526-1403
FAX: (208) 526-5964

Willettia Amos Crockett
Advanced Technology Division
Idaho Operations Office
785 DOE Place, MS 1220
Idaho Falls, ID 83402-1562
Tel: (208) 526-4097
FAX: (208) 526-5964

Dr. D.G. Friend
National Institute of Standards and Technology
Physical & Chemical Properties Div., 838.08
325 Broadway
Boulder, CO 80303
Tel: (303) 497-5424
Fax: (303) 497-5224
daniel.friend@nist.gov

Keith Gawlik
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Tel: (303) 384-7515
Fax: (303) 384-7540
gawlikk@tcplink.nrel.gov

Jeffrey L. Hahn
Project Officer
DOE-Golden Field Office
1617 Cole Blvd., Bldg. 17-3
Golden, CO 80401
Tel: (303) 27504775

Vahab Hassani
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Tel: (303) 384-7464
FAX: (303) 384-7495
vahab_hassani@nrel.gov

Lance Hays
Douglas Energy Company
181 W. Orangethorpe Ave., Suite D
Placentia CA 92870
Tel: (714) 524-3338
Fax: (714) 524-3341

Dr. W.M. Haynes
National Institute of Standards and Technology
Physical & Chemical Properties Div., 838.00
325 Broadway
Boulder, CO 80303
Tel: (303) 497-3247
Fax: (303) 497-5044
william.haynes@nist.gov

J. Henderson
Senior Chemical Engineer
Pacific Electric and Gas Company
3400 Crow Canyon Road
San Ramon, CA 94583
Tel: (510) 866-5491
FAX: (510) 866-5681
jmh6%TesCe%gsv@go01.comp.pge.com

Ms. Gladys J. Hooper
Office of Geothermal Technology Division
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
Tel: (202) 586-1146
Fax: (202) 586-8185

Lawrence E. Kukacka
Brookhaven National Laboratory
Upton, NY 11973-5000
Tel: (516) 344-3065
Fax: (516) 344-2359
kukacka@bnl.gov

Raymond LaSala
Office of Geothermal Technologies, EE-12
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585-0121
Tel: (202) 586-4198
Fax: (202) 586-8185
raymond.lasala@hq.doe.gov

Greg Mines
Idaho National Engineering Laboratory
Lockheed Idaho Technologies Co.
P.O. Box 1625
Idaho Falls, ID 83415-3830
Tel: (208)526-0260
Fax: (208)526-0969

Eugene T. Premuzic
Brookhaven National Laboratory
Department of Applied Science
Biosystems & Process Sci. Div.
Upton, NY 11973
Tel: (516) 282-2893
Fax: (516) 282-2060

Kent Scholl
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Tel: (303) 384-77496
Fax: (303) 384-7595
kent_scholl@nrel.gov

Toshifumi Sugama
Brookhaven National Laboratory
Upton, NY 11973-5000
Tel: (516) 344-4029
Fax: (516) 344-2359
sugama@bnl.gov

Ronald Webster
Brookhaven National Laboratory
Upton, NY 11973-5000
Tel: (516) 344-2845
FAX: (516) 344-2359
webster@bnl.gov