

## GEOTHERMAL DOWN-WELL PUMPING SYSTEM

Hugh B. Matthews and Warren D. McBee  
Sperry Research Center  
Sudbury, Massachusetts

A key technical problem in the exploitation of hot water geothermal energy resources is down-well pumping to inhibit mineral precipitation, improve thermal efficiency, and enhance flow. A novel approach to this problem involves the use of a small fraction of the thermal energy of the well water to boil and super-heat a clean feedwater flow in a down-hole exchanger adjacent to the pump. This steam powers a high-speed turbine-driven pump. The exhaust steam is brought to the surface through an exhaust pipe, condensed, and recirculated. A small fraction of the high-pressure clean feedwater is diverted to lubricate the turbine pump bearings and prevent leakage of brine into the turbine-pump unit. A project demonstrating the feasibility of this approach by means of both laboratory and down-well tests has just started under an NSF grant. The status and plan of this project are presented.

## I. INTRODUCTION

The Sperry Research Center has been engaged for two years in the analysis and design of a novel type of pumping system for geothermal liquid-dominated wells. Since July 1974 we have been under a grant from the National Science Foundation through its Research Applied to National Needs (RANN) program to build and test this system. Field testing in a geothermal well is expected to begin in July 1975, possibly in the Imperial Valley of California.

## II. WELL DYNAMICS

Figure 1 illustrates in a simplified geologic situation what is known as a hydrostatic well. The water table in the strata surrounding the well is essentially at the surface of the ground and the water increases in temperature as we go deeper in the earth. With the valve closed to prevent flow, the water inside the well casing will assume virtually the same thermal gradient as the water outside and, therefore, being of the same average density, will rise in the casing essentially to the level of the outside water table.

If the valve in our illustration is opened (Fig. 2) and the well caused to start flowing by some means, the hot water flowing up the casing will progressively lower the average density of the water column and the flow velocity will increase accordingly.

When 212°F water approaches the surface, a portion of it will flash into steam, lowering the column density even more and again accelerating flow. The level at which this flashing begins will move down the well as increasingly hot water comes to the surface and will stabilize at a level as determined by:

- (1) The bottom hole temperature (temperature losses up to the flash level in a flowing well are negligible).
- (2) The average density of the mixed liquid and vapor column above the flash point.
- (3) The two phase flow losses from the flash level to the surface.

The mixture of steam and water will arrive at the surface at a temperature of 212°F and (in a 400°F well, for example) as approximately 20% saturated steam.

The quantity of flow from the well will depend on the very complex interrelation between the thermal and saline gradients in the water outside the well, flow losses in the strata feeding the well and in the well casing, and the actual density gradient in the column above the beginning of flashing. When this natural flowing method is used to produce a well, as it is in a few places in the world for generating electricity, an additional impedance is inserted in series at the surface (equivalent to closing down our valve somewhat) so that a pressure drop is introduced between atmosphere and the Rankine cycle conversion equipment. Thus, the water steam mixture will enter the energy conversion process at a higher temperature than 212°F (in a 400°F well, say, at 325°F, 97-psia pressure, and 10% steam).

There are several drawbacks to such a naturally produced well; among them are:

- (1) Well flow is reduced to below that of open wellhead flow by the added impedance.
- (2) Geothermal waters are usually considerably contaminated with dissolved solids. The process of flashing causes the most troublesome of these compounds to precipitate, which then coat the well casing (sometimes seal it) and, more seriously, foul surface equipment, such as heat exchangers.
- (3) The lowered temperature caused by the flashing reduces the efficiency of the surface conversion equipment.

### III. WELL PUMPING

If a pump is introduced into the well below the flash point and sufficient pressure is added to the water so that it will not flash even on the surface, the above problems are largely negated:

- (1) Flow can be increased, even above the well's natural flow rate, with a consequent increase in available energy.

- (2) Water is brought to the surface at or near bottom hole temperature with a consequent increase in surface conversion efficiency.
- (3) If the water remains under pressure, the dissolved carbon dioxide remains in solution and prevents the most troublesome constituents (mainly carbonates) from precipitating. Thus, except for silica, which will precipitate when the water is cooled, the most serious problems are eliminated. The effect of silica remains to be determined, but experiments to date are somewhat encouraging.

#### IV. PUMP WORK

The following factors determine the amount of work to be done by the pump:

- (1) Requirements. The water must arrive at the surface somewhat above the saturation pressure. In a 400° F well, this is approximately 247 psia, and with a 10% pad, 272 psia. If there is a pump on the surface circulating the hot well water, then the net positive suction head (NPSH) requirement of this pump must be added to the pressure.
- (2) Thermal Lift. As mentioned before, the column of water inside the well, when flowing, will be essentially at bottom hole temperature, while the water in the strata outside will have some thermal gradient from the low surface temperature to the high temperature at well bottom. This effect, of course, reduces the amount of pump work and can be of considerable magnitude. A 400° F hydrostatic well of relatively pure water, 5000 feet deep and with a linear temperature gradient in the surrounding strata, will gain approximately 150-psi pressure due to its thermal lift.
- (3) Well Productivity. Bottom hole pressure will, of course, drop as flow is increased because of friction in the surrounding strata, a property described in the oil industry by the term "productivity index." The pump must make up this pressure loss, and the practical matter of energy expenditure would seem to limit consideration to wells where this pressure loss is no more than a few hundred psia at acceptable flow rates.
- (4) Casing Flow Loss. The flow in the casing will always be turbulent, and pressure loss will be proportional to flow squared. A 1000-gpm flow in a 8-5/8-in. casing will generate a loss of perhaps 50 to 100 psi in a 5000-foot-deep well, depending on pipe roughness. A practical casing design for such flows might be 8-5/8 in. up to just below the pump and 10-3/8 in. or 13-3/8 in. above.

## V. CONVENTIONAL PUMPING SYSTEM

Figure 3 shows the elements of a conventional pumping system. If the well is pumped only at the naturally flowing rate, then the pump must be placed in the well a sufficient depth below the natural flash level to provide sufficient NPSH for the pump, which is the required pressure above saturation pressure of the fluid at its particular temperature to prevent the pump from cavitating. If a greater quantity than the natural rate is pumped, then the pump must be at an additional depth as determined by the added flow losses in the strata and in the well casing below the pump. It appears that this depth could well be 1000 feet or more for optimized well production in the general case.

The pump will be driven by energy sent down from the surface in some sort of conduit, an electric cable or a hydraulic tube, for example. This energy will, in fact or in effect, be obtained from the well water itself and before ending downhole as pressure added to the well flow be transformed a number of times, with each transformation resulting in a loss of efficiency. For example, this can be shown for the hydraulic system:

- (1) Heat to turbine torque.
- (2) Torque through alternator to electricity.
- (3) Electricity through motor to torque.
- (4) Torque through pump to hydraulic power.
- (5) Hydraulic power downhole through hydraulic motor to torque.
- (6) Torque through pump to pressure and flow in well water.

## VI. THE SPERRY PUMPING SYSTEM

In order to avoid this multiple-energy conversion problem with its attendant loss in efficiency, the Sperry Research Center is constructing a system which will not bring energy down from the surface to operate the pump, but will instead extract energy from the hot well water downhole at the site of the pump. It will have only two energy conversions--heat to torque and torque to pressure--rather than several. The principle involved is shown in Fig. 4. A small quantity of clean water (perhaps 1 or 2% of well water flow) is sent downhole to a heat exchanger (several lengths of standard oil field casing), dropped in pressure by a  $\Delta P$  valve, and then vaporized and superheated by the well water flowing upward around the outside of the heat exchanger piping. This superheated steam is used to drive a turbine and a mixed flow pump impeller at a speed of from 15,000 to 30,000 rpm. The turbine exhaust is returned to the surface through another concentric pipe, where it is condensed and returned downhole. Thus, the turbine working fluid is contained in a closed loop, and well water is excluded from this system. Figure 4 also shows how some of the clean water continues down the central pipe past the entrance to the heat exchanger and is used to lubricate

the turbine and pump bearings. Since this clean water is at a higher pressure than the well water, the contaminated well water is prevented from entering the turbine.

The boiler manifold contains a threshold valve, which prevents water from entering the boiler unless feedwater pressure is above well water pressure, and the  $\Delta P$  valve (mentioned above), which drops feedwater pressure to permit boiling and also to permit changing boiler pressure by varying feedwater pressure at the surface. Since mass flow to the turbine is a function of boiler pressure, we can effectively control turbine output from the surface.

An additional energy saving accrues from this system, since the energy for pumping ultimately comes from the well water anyway. It is better to remove this energy downhole. The temperature is thus lowered somewhat and arrives at the surface with a correspondingly lower saturation pressure, requiring less pressure added. In a 400°F well, this typically could amount to an additional 20% energy saving. At first glance, this process would seem to place an undue penalty on the efficiency of the surface conversion system as demonstrated by the Carnot principle. Nevertheless, it is easy to show that any pump, however it operates, will remove just its required portion of the available energy from the water. It does not matter whether it takes this energy from the top of the cycle (as we do), from the bottom of the cycle, or from an infinite number of points in the cycle (as in the case of a pump which takes its energy electrically from the main conversion system).

A simplified schematic of the turbine-pump unit for our first test is shown in Fig. 5. It is designed to fit in an 8-5/8-in. casing, although for the field test it will be adapted into a larger casing.

The bearings are hydrodynamic and are of tilting pad design. The thrust bearing has operated on hot water in the lab at three times our design load. The ball bearing operates only during start-up, when the high-pressure well water causes an upward thrust on the shaft until pump thrust builds up and thrusts the shaft downward through a 0.015-in. end play.

The turbine is a two-stage pressure, compounded single-wheel design with its exhaust being redirected upward through its spoked hub.

In the expected test situation, the pump and test parameters will be approximately as follows:

---

Well temperature	400° F
Turbine output, nominal	155 HP
Turbine output, max	220 HP
Pump output	1000 gpm at 200 psi $\Delta P$
Depth in well	850 ft

NPSH	100 psi
Well water $\Delta T$ , nominal	15 to 20° F
rpm	17,000
Specific speed	5,400
Suction specific speed	8,000

---

This first unit has been designed with the objective of a successful test rather than efficient performance or maximum output. The system may remove from the well water as much as 10° F per 100 psia added. (Note that this parameter is independent of the quantity pumped.) With an optimized system and some amount of development, however, we feel that this will drop to 5° F/100 psi added, which is an amount considerably below that of any other approach we are aware of. Efficiency in pumping geothermal fluids is, of course, of prime importance since they have such a small amount of available energy to begin with. It is also evident that if a well has an inherently poor productivity index, a pump or any other expedient will not turn it into a worthwhile asset.

## VII. PROGRAM

Lab tests of the impeller will start by December 1, 1974, and tests of the complete turbine-pump in February, 1975. Field testing is scheduled to begin in July, 1975, probably in the Imperial Valley, and we hope to complete two months' total operation during a four-month period.

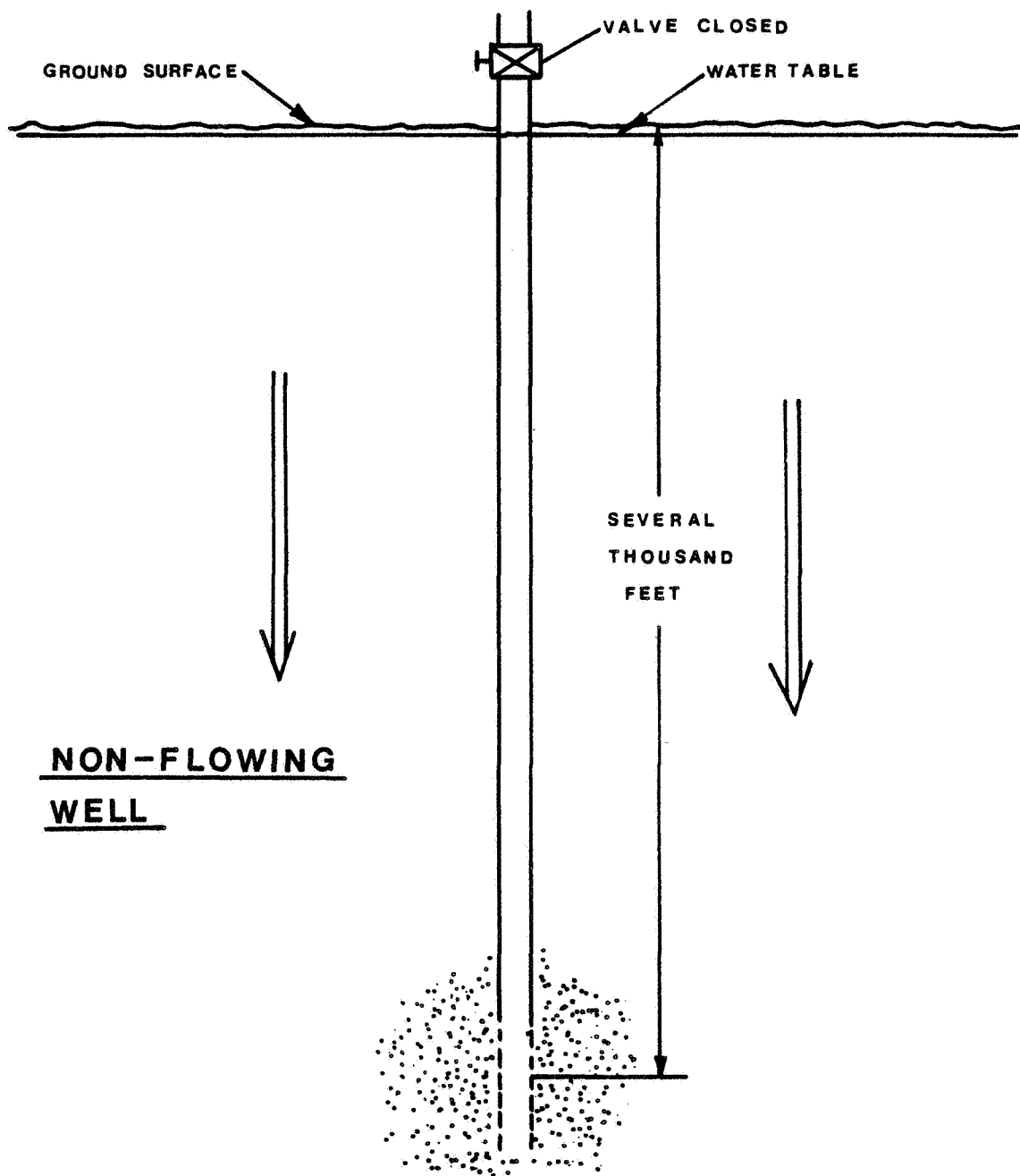


Fig. 1. Schematic of hydrostatic geothermal well

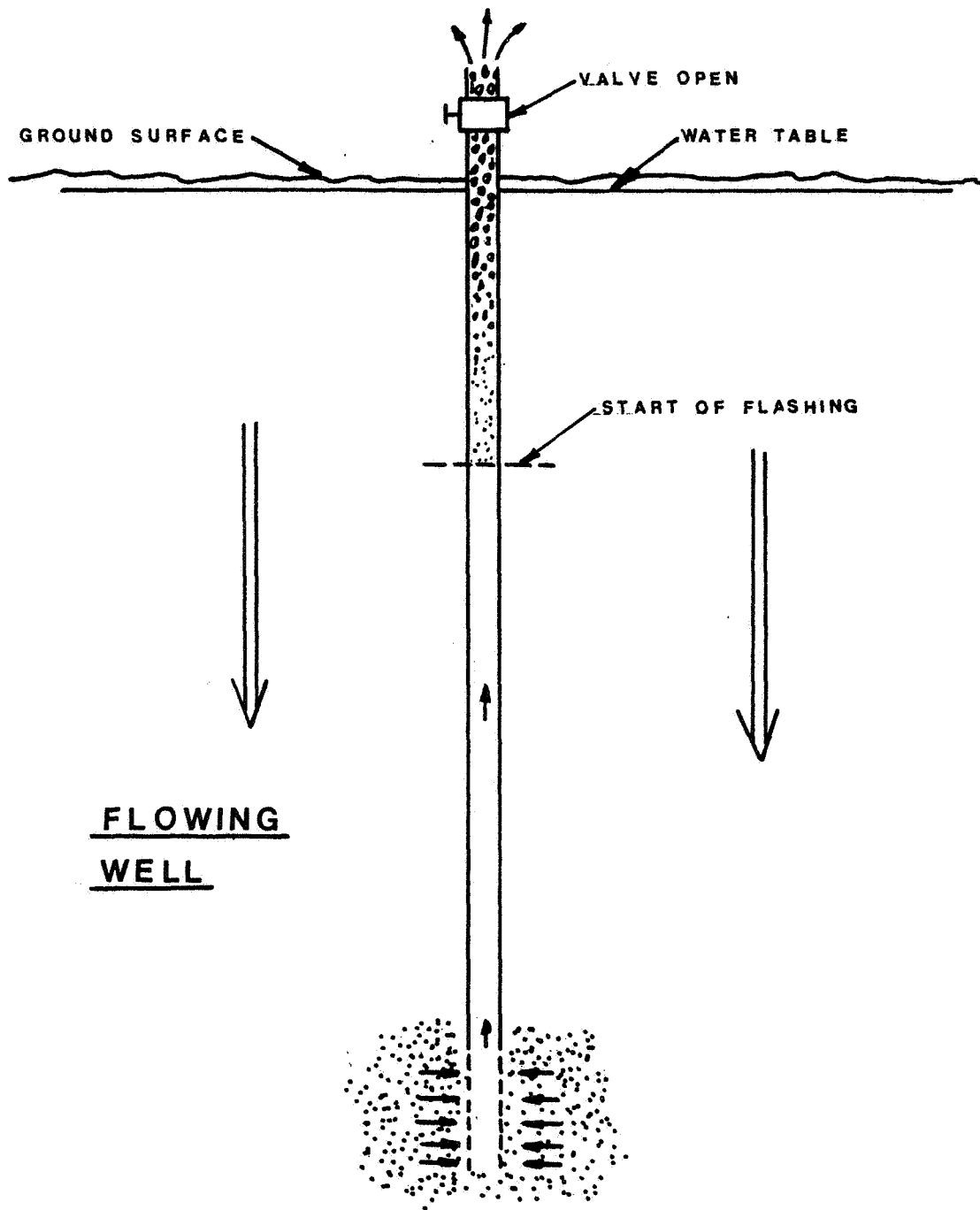


Fig. 2. Well of Fig. 1 with low flow rate



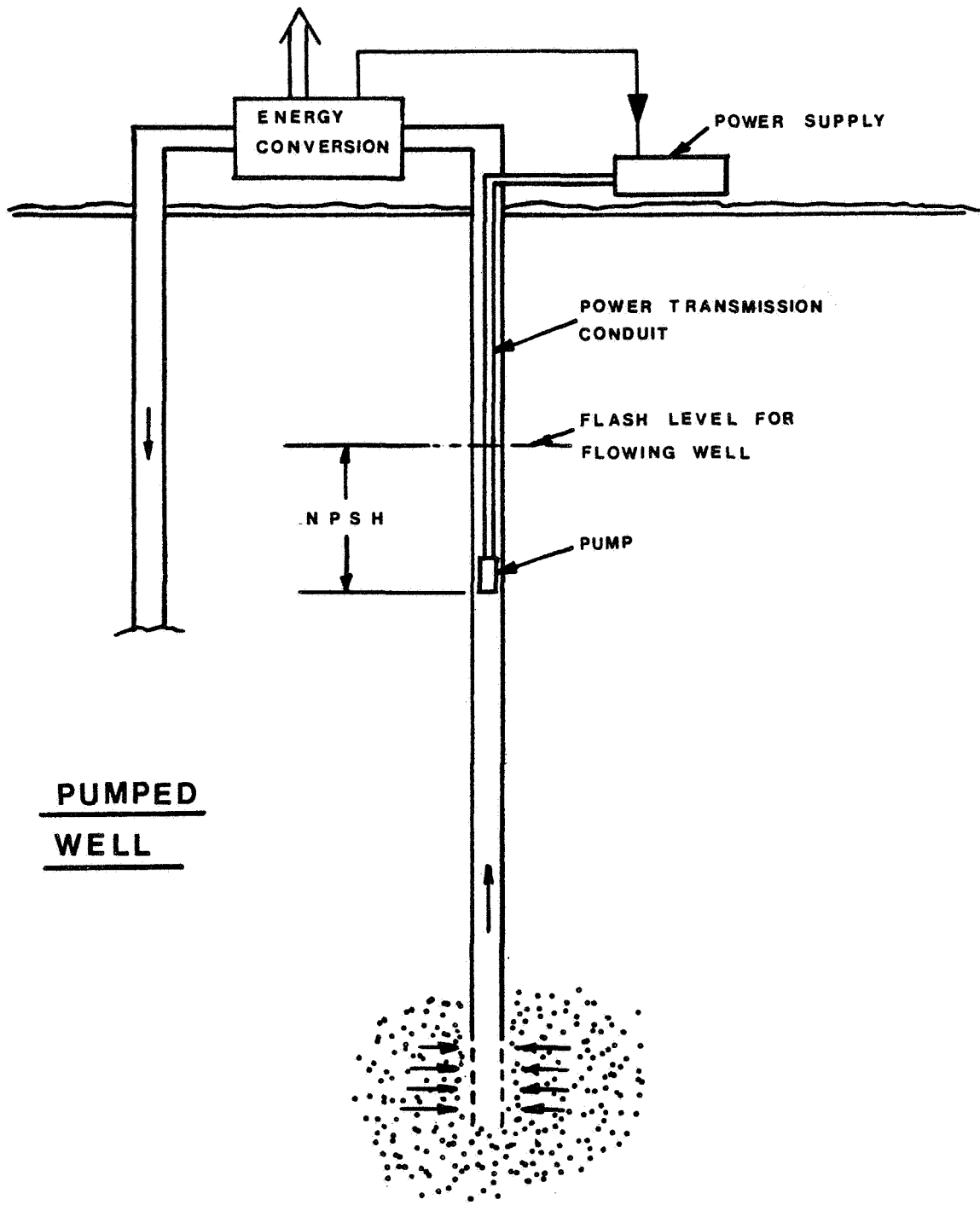


Fig. 3. Schematic of conventional well pumping system

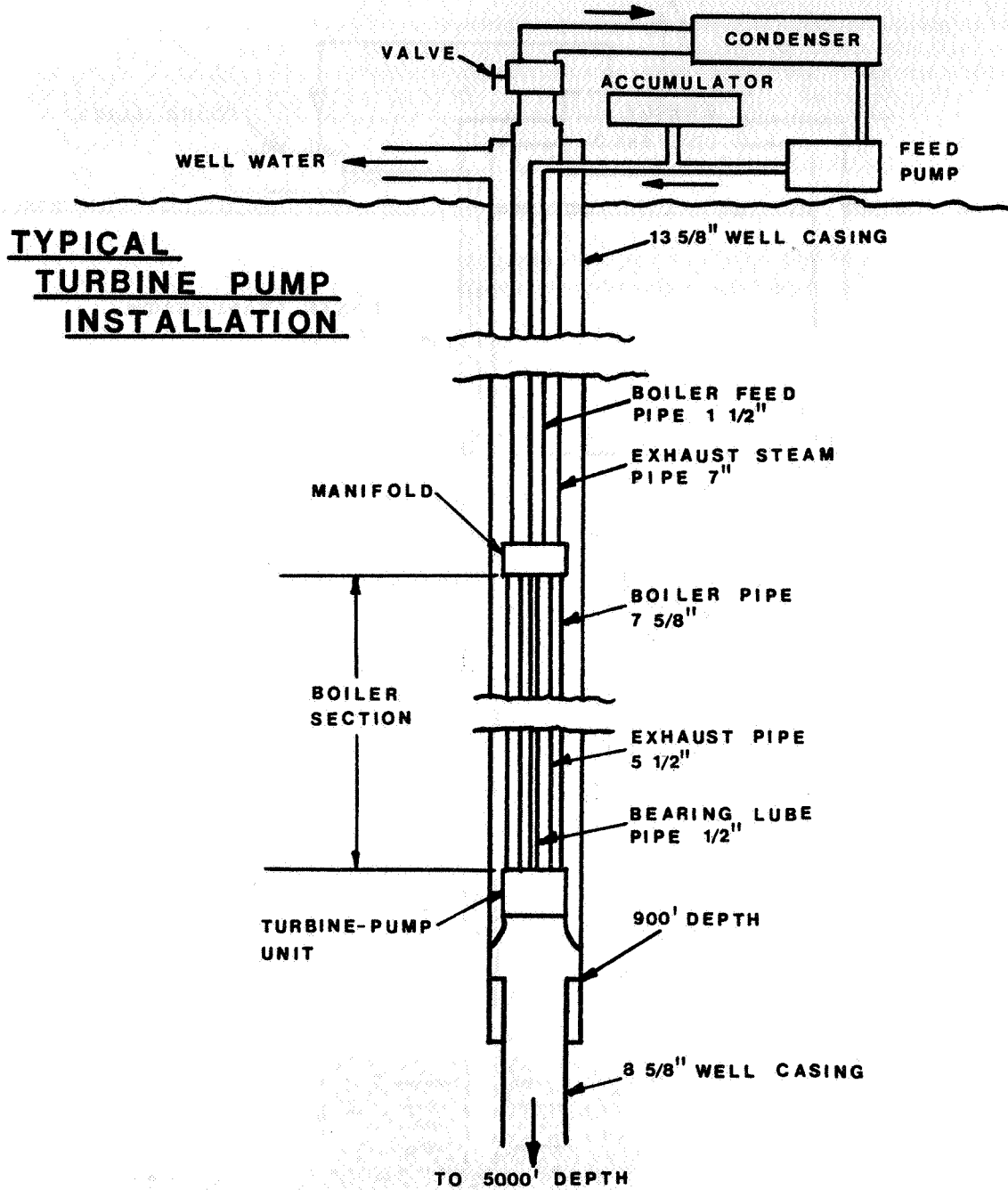


Fig. 4. Schematic of Matthews pumping system for geothermal wells

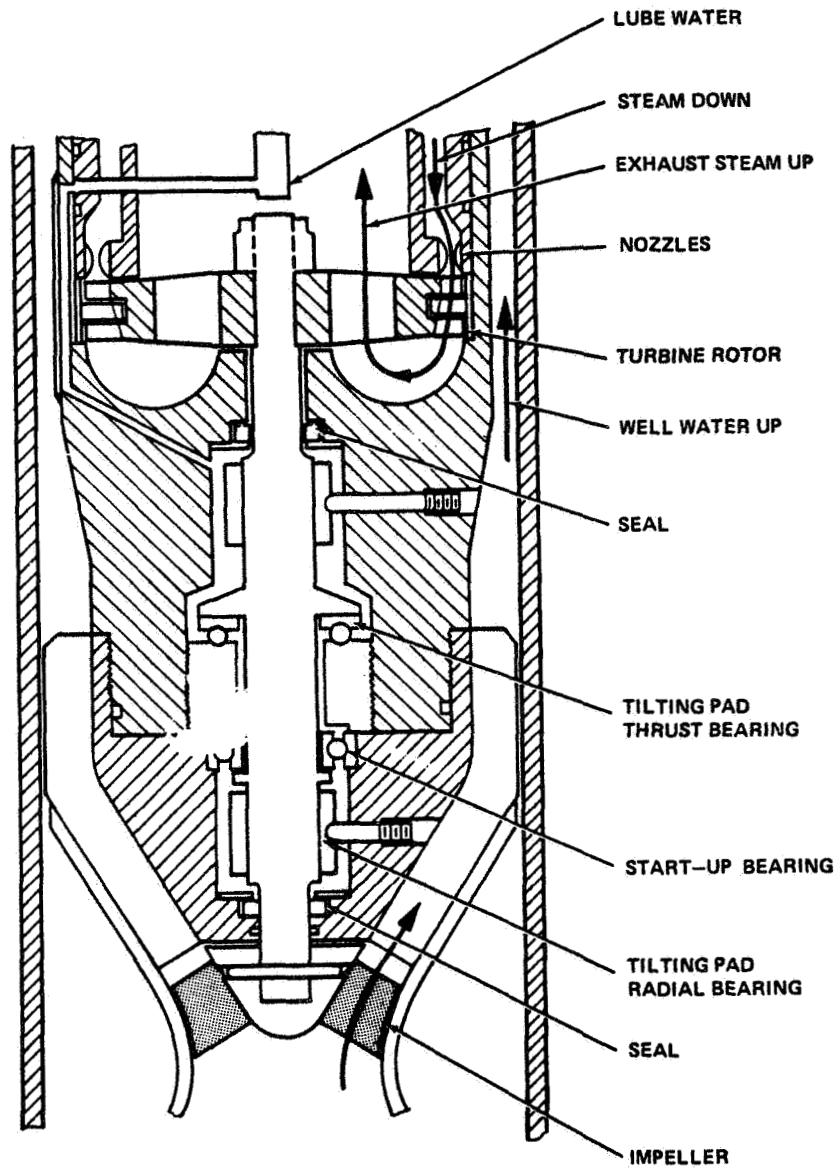


Fig. 5. Schematic of turbine-pump unit for Matthews pumping system