PRODUCING GEOTHERMAL STEAM AT THE GEYSERS FIELD

BY

CHESTER F. BUDD - UNION OIL COMPANY OF CALIFORNIA

UNITED NATIONS GEOTHERMAL SYMPOSIUM

FIELD TRIP B-1 AND B-2 TO THE GEYSERS

MAY 24 AND 25, 1975

Reprinted from Geothermal Energy Resources, Production and
Stimulation edited by Paul Kruger and Carel Otte
with permission of the publishers,
Stanford University Press.

INTRODUCTION

The production of geothermal fluids from a reservoir is similar to the production of oil and gas. The extractive system is a steam well, drilled to an appropriate depth to encounter geothermal subterranean fluids, cased and completed to provide a stable conduit through which the fluids can flow to the surface, and the facilities to control and transport the fluids to their point of utilization.

Geothermal fluids are found to exist in either the liquid water or gaseous steam phase in reservoirs. At The Geysers in northern Sonoma County, California, the dominant phase is gaseous steam, a condition which exists in only a few major commercially producing fields in the world, the Larderello Field in Italy and Matsukawa Field in Japan.

Union Oil Company of California has been operating The Geysers geothermal field since entering into a joint venture with the original developers, the Magma Power Corporation and Thermal Power Company in 1967. During this time, the installed generating capacity has risen from 54 mw to 302 mw and the proven capacity of the field has risen from 192 mw to 750 mw. Exploratory drilling is underway to extend the known productive limits of the field. Development drilling within the proven area is continuing in order to increase the production at a rate of approximately 100 mw of generating capacity per year and to maintain production for the presently installed generators.

PLANNING AND DEVELOPMENT

Geothermal steam, because it rapidly loses its heat energy when transported through a pipeline, must be utilized at the point of production. The consumer at The Geysers, Pacific Gas and Electric Company, a utility company, builds its generating facilities within a short distance of the wells. Their turbines require a constant throughput of steam at a con-

---

References and illustrations at end of paper.

stant pressure. The flow rate must be sustained so that the turbines operate at peak capacity and generate the maximum possible income for both the operator and the utility. The generating units now being installed at The Geysers require a throughput of about 1,000,000 lb/hr of superheated steam, from which they generate about 55 mw of electricity. This rate can be delivered initially with about seven wells. As the production declines, new wells are drilled and added into the system so that a steady throughput of steam to the generator is maintained. With this continued requirement of drilling for production maintenance, sufficient additional productive acreage must be set aside and dedicated to a specific generator installation. This area must be adjacent to the originally developed area so that new wells can be easily hooked-up to the existing gathering system.

The total capacity of a geothermal field depends upon how many "blocks-of-power" can be proven-up within the productive field limits, the size of each block being directly related to the life over which the utility and operator agree to amortize their investment. Exploration techniques used to locate geothermal prospects usually identify the limits of potentially productive areas only in very general terms.

There is a logical sequence of steps that are taken to prove-up and confirm the production capacity necessary for a block-of-power. The plants now being built for The Geysers are 110 mw of capacity, one such installation to be completed each year. The general areas in which to build these plants are located by exploratory drilling. The areal limits for a proposed plant site are confirmed by drilling a few wells to locate the depth of the steam reservoir and test its productivity. These early tests provide engineers with the information necessary to determine how much productive area should be dedicated to the proposed plant site, how many wells are initially required and how many additional wells will be required to maintain a level rate of production for the plant life. This has been done with as few as two widely-spaced step-out wells.

Under current California regulations, utility companies are required to submit applications for plant sites three years in advance of commercial operation. Approval is seldom obtained more than two years before anticipated operation. With the time required for evaluation subsequent to discovery, a lead time of four to five years between confirmation drilling and commercial operation is required. The necessary time lapse from discovery to commercial operation caused by the necessity of having available the required steam supply about one year in advance of commercial operation to allow for pipeline construction combine to lower the rate of return on the investment. To improve the economics of geothermal development the producer must optimize his investment schedule during both the development and the production maintenance phases of the operation.

DRILLING AND COMPLETION PRACTICES

Drilling geothermal steam wells has presented unique problems that have not been tackled in drilling oil and gas wells. The first problem is that of the formation itself. At The Geysers, the producing zone is the graywacke sandstone of the Franciscan formation. The Franciscan formation is called basement rock in oil field country. The graywacke sandstone is a tight metamorphosed sandstone that causes extremely slow penetration rates even with bits specifically designed for hard rock drilling. Lost circulation to permeable zones at pressures far below hydrostatic pressure has presented problems when drilling with mud. Drilling with air has improved penetration rates over that with mud and eliminated the lost circulation problems, but air drilling can only be done at depths below water-bearing strata which have been cased off. The heat of the formation along with its abrasiveness takes its toll on subsurface tools and equipment. Once steam is encountered, air circulation pressures rise and annular velocities approach sonic velocity. Tool joints suffer the erosional wear of high speed particle impact. Completion of the well requires proper engineering design of casing and cementing materials to prevent subsequent mechanical failures.

The production rate that can be obtained from a steam well once it is completed is sensitive to the hole and casing sizes. These wells generally are capable of very high mass flow rates associated with steam production coupled with the frictional resistance of the casing and hole limits the flow rates. Much attention has been directed towards designing an optimum completion program at The Geysers in order to obtain an economic balance between cost and flow rate.

From back-pressure[2] and isochronal[3] testing, it has been found that a steam well at The Geysers conforms to the classic formula often used to describe the performance of a gas well. The equation is expressed here as

$$W = C(P_s{}^2 - P_f{}^2)^n$$

where

W = Steam flow rate in lbs/hr

C = A factor which is a function of time, reservoir matrix, fluid properties, flow rate, wellbore condition, etc.

P_s = Static reservoir pressure in psia

P_f = Wellbore pressure at steam entry in psia

n = An exponent which is usually constant with rate within the range of usual production rates, $0.5 \leq n \leq 1.0$

The production, W, is therefore dependent upon the bottom hole pressure, P_f, which is the sum of the wellhead flowing pressure, the total frictional resistance pressure, and the column weight of the fluid. Figure 1 shows the theoretical performance of a typical geothermal steam well completed with different diameters of casing and open hole at The Geysers. Smaller diameter casings offer more friction drop and cause the well to be restricted more and produce less steam flow, all other conditions remaining equal.

The probability of finding an economic steam producing well, one which provides a reasonable return on investment, diminishes quickly with increased depth simply because the increased depth causes a longer conduit for the steam to flow through. This is illustrated in Figure 2, in which it is noted that with all factors remaining equal except depth, the deliverability that can be expected of a well completed at 10,000 ft, is almost 20% less than if that same well were successfully completed at 5,000 ft.

At The Geysers, a typical completion is shown in Figure 3. The wellbore exposed to the steam flow consists of 1,900 ft of 13-3/8 in. casing, 2,100 ft of 9-5/8 in. casing and approximately 2,000 ft of 8-3/4 in. open hole to the steam entries.

Obviously, an optimization analysis can be applied only after a well is drilled and tests are performed to determine values for the constants of the steam flow equation. At The Geysers, as at Larderello, there appears to be no way to predict the productivity of a well prior to drilling, and hence, the values for C and n cannot be accurately predicted. Therefore, the optimization calculation can be made using typical values found on typical wells in the hope that conditions close to average will be encountered.

RESERVOIR PERFORMANCE

As in the exploitation of an oil or gas field, the greatest potential of a geothermal field can be realized only after the producing characteristics of the reservoir can be predicted. Each geothermal field can be expected to have different reservoir matrix and fluid properties which will influence production performance, similar to those differences that exist among oil and gas fields.

The vapor dominated system that exists at The Geysers has been the subject of a continuing reservoir study by Union Oil Co. and others since late 1967[4]. The performance of the field has shown that contrary to earlier thoughts this field cannot be produced at a constant rate of production for an essentially infinite time. Individual wells have declined in production and additional wells have been required to maintain the supply of steam to the generating units. This is also true of the Larderello field where continued drilling is required to maintain a constant generating capacity of 365 mw.

Typical production performance exhibited by wells at The Geysers is shown in Figure 4. The declining productivity that has occured with time is illustrated. Both wells shown are located in close proximity to the other producing wells which comprise a block-of-power to operate a generating unit. They are in an area having an average well density of one well per five acres, developed to produce steam for generating Unit No. 3 since 1967.

Throughout their producing life, the wellhead pressure at each well has been approximately constant and the variation and decline in productivity is not due to changing surface conditions. Pressure buildup tests on these wells have been performed periodically since February, 1967. These tests have shown that no near-wellbore permeability change has occured as would be the case if the drop in production were caused by incrustation of the wellbore or some other mechanical plugging phenomena either in the wellbore or in the formation. This suggests that pressure depletion is a factor in the production decline. Field-wide static reservoir pressure surveys have confirmed this to be true. Reservoir pressure in this area has been declining.

Pressure interference occurs between wells in the particular area of the field where these wells are located. Due to the matrix connectivity of the reservoir, the performance of one well is greatly influenced by nearby wells. Shut-in wells exhibit this interference when their static shut-in pressures are lowered as a result of producing nearby wells. When these producing wells are closed-in, the static pressure of the nearby shut-in wells usually recovers to a value near their static pressure prevailing in the reservoir at the time. Producing wells manifest this interference in decreased production rates occuring when nearby wells are placed on production, or increased rates when nearby producing wells are closed-in. This condition led engineers to attempt a mathematical simulation of the flow conditions within the steam reservoir to determine an optimum well spacing for future expansion of the field. The goal was to arrive at a program that would require a minimum number of wells for the life of the project but still develop the field to its greatest potential.

Various spacing programs were studied and typical results from these studies are shown in Figure 5. As expected, the interference effect is greatest with the highest well density, one well per five acres. The exact shape of each production curve generated is a function of completion techniques and depth as it effects deliverability and the capacity of the formation; the product of permeability and thickness. With the use of such data, engineers are able to select an optimum spacing program and allow for sufficient proven acreage to be held in reserve on which to drill make-up wells to maintain production for the life of the plant.

SURFACE FACILITIES

The gathering system of a geothermal field collects the steam of several wells and delivers it to the plant free of moisture, particulate matter and with as little reduction in available energy as practical. It must be properly insulated to conserve heat, offer a minimum amount of resistance to flow, be equipped with properly operating separating devices and vessels, and have adequate safety features to relieve line pressure in event of a plant shut-down. In addition, the facility must be designed and operated to reduce dead-end segments of the line in which steam could be trapped, cooled and condensed. This condensate cannot be allowed to drip back into the line and further deplete the steam's energy flowing to the plant. The layout of the line should anticipate the continued growth of the system as new wells are added to maintain the required production rate.

The selection of line size must consider the relationship of size as it effects both heat loss and pressure loss due to friction. The objectives of maintaining maximum steam deliverability with a minimum of heat loss at a minimum of cost are somewhat conflicting goals. Maximizing the deliverability from a system of wells can be accomplished by reducing the frictional pressure loss with large diameter piping so that the wellhead pressure will be as low as possible. Increased production of the wells is possible because a greater formation draw-down is possible, but heat loss is also increased because of larger surface area. This increases the cost of the pipeline. Consequently, the design engineer is faced with a set of problems which requires careful study to arrive at a design which optimizes these three variables in relation to cost.

Such a system was designed at The Geysers for the purpose of delivering 2,000,000 lb/hr of dry superheated steam through two separate systems to two units which will generate 110 mw electricity. A schematic diagram of this system is shown in Figure 6. The apparently circuitious routing of the lines is necessary because of the irregular mountainous terrain of the area. The largest pipe size is 36 in. nominal diameter, at the final runs into the two separate turbines of the installation, telescoping down to 10 in. at some individual wells. The main trunk lines are over-sized at their extremities to allow for the production of additional wells to be drilled and hooked-up when the original group of fourteen wells declines in productivity.

Near each wellhead is a vessel for separation of liquid and solid particulate matter from the steam. Because the steam produced at The Geysers is dry and superheated, liquid separation is necessary only under unusual conditions such as a mechanical failure of the well casing. There is, however, a continuous but minute amount of particulate matter transported along with the steam. It consists largely of formation dust and corrosion particles. They are handled with centrifugal type horizontal separators that are 99% efficient in removing particules 10 microns and larger in size.

Also near the wellhead of each well is a meter run for continuous recording of each wells' production rate and producing pressure. This information is used not only for calculating royalty disbursements but also to obtain accurate production records for the reservoir studies. Enthalpy measurements and steam quality measurements as well as particulate content tests are routine operational functions carried out on a scheduled basis with specialized adaptations of conventional equipment and instrumentation.

Wellhead pressures reach 480 psig when wells are shut-in. If the generating plant would shut-down, this shut-in pressure would be exerted on the line. To relieve the line of excessive pressure, air actuated control valves are positioned in the line near the plant intake to discharge the steam to the atmosphere when the operating pressure increases from the normal 100 - 120 psig to 150 psig. This valve system is designed to pass the full line load, that is, the full capacity of all wells hooked into the system, at 170 psig. Additional backup safety is provided by rupture discs installed at selected points along the line that protect the line to pressures less than 180 psig.

The control valve exhausts are equipped with mufflers to provide attenuation of a particularly difficult noise spectrum. The low pressure and high mass flow of the steam relief system produces a noise spectrum with an unusually high intensity of low frequencies. Attenuation of this noise is very difficult and much trial and error work has been done at The Geysers to reduce the nuisance effect of the noise.

Dirt-legs that present a place for larger particles to come to rest are provided at selected points in the line. A dirt-leg is a tee through which the steam flow path is changed 90 degrees. The remaining leg of the tee is fitted with a dead-end length of pipe to form a receptacle for the heavier particles. A valve is provided for blowing-down the dirt-leg to get rid of accumulated debris.

In addition to the dirt-legs, wellheads are equipped with blow-down tees so that wells can be opened to the atmosphere and blown-down to line pressure before being produced into the gathering line. This prevents the large particles (up to fist size) from getting into the pipeline system during the initial blow-down period. The use of these blow-down tees and dirt-legs has greatly reduced the excessive erosion that has occured in some of the generating units at The Geysers.

A typical wellhead configuration and pipeline hook-up showing the blow-down tee, centrifical separator, meter run and a dirt-leg is shown in Figure 7. This type of installation is currently in use at The Geysers on new installations, and old installations are being converted to this type of arrangement.

PRODUCTION MANAGEMENT

When a "block-of-power" has been developed with the required wells and gathering system, and the utility's plant is constructed, the operations utilizing the geothermal resource require close communication and co-operation between the steam-field operator and the utility company.

The initial warm-up of the steam line is started approximately 24 to 36 hours before the steam is needed at the plant. All wells on the system are opened-up gradually to the atmosphere through their blow-down tees to evacuate the formation dust, rocks, and condensed water. Thermal shock on the formation and casing is minimized as the pressure and temperature are reduced slowly. As wells are cleaned-up of debris and moisture and their flowing pressures brought down to the line pressure of 100 to 120 psig, the blow-down valves are closed and the steam is directed into the line. With the main steam valve at the plant closed, the main control valve is automatically actuated to vent the steam to the atmosphere through the muffling devices. Moisture which has accumulated in the line is blown from the steam line vents and drain valves as the line is brought up to operating temperature.

After the wells are producing into the line and the line is "hot" the plant is ready to draw steam from the line to purge the lines within the plant and finally to roll the turbine. At this point, the plant operator is in control of the steam wells and coming-up to load too quickly could cause an excessive instantaneous draw-down on the line. This would be quickly reflected at the wells and cause dust, dirt and debris to be brought up from the wellbore by pressure and temperature reduction. To minimize this, it has been found to be better to have all wells open into the line rather than only two or three wells even if the plant is operating on a reduced load, as when initially starting-up a unit to check the turbine balance. This reduces the possibility of human or mechanical error causing a sudden drain on the steam line which would be transmitted to the well.

Once the steam gathering system is in operation and the plant is running, the operation settles down to periodic inspection of meters and scheduled blow-down of separators. There are, however, scheduled and unscheduled shut-downs that occur. Ideally, when a shut-down occurs unexpectedly when a mechanical malfunction of the utility's plant causes an outage, the control valves begin to open on response to a 10 to 15 psig increase in pressure. The line pressure is raised only slightly in this way and the wells do not experience great fluctuations in temperature or pressure. This has been found to be the best way of preserving the clean production character necessary in geothermal production. If the shut-down is to be for an extended duration, such as for a major repair of the unit, it has been the practice at The Geysers to shut-in the wells in order to perform pressure-buildup tests and obtain a static reservoir pressure observation for use in reserve studies. Line maintenance is also performed during these periods.

REINJECTION

The utility's power plant liquid effluent consists of about 25% of the total condensed steam throughput, the remainder being evaporated in the cooling towers. This effluent contains most of the water soluble constituents of the steam and cannot be discharged into surface waters that have domestic or agricultural use. It is therefore reinjected into the steam formation through injection wells.

The low reservoir pressure of 500 psig and the high permeability of the formation allows very high injection rates to be sustained, over 1,000 gpm in some cases. No plugging or decrease in injectivity has been observed so far although reinjection is fairly new to The Geysers operation. The first reinjection was started in April, 1969. Two other idle steam wells have since been converted to reinjection wells and all plant condensate effluent is now returned to the formation. This condensate will probably be revaporized and produced again and should extend the life of the field.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to his many associates in the Magma Power Company, Thermal Power Company and Union Oil Company who have either directly or indirectly contributed to the writing of this paper, and in particular to Mr. Delbert E. Pyle, Division Manager of Operations, Union Oil Co. of California.

REFERENCES

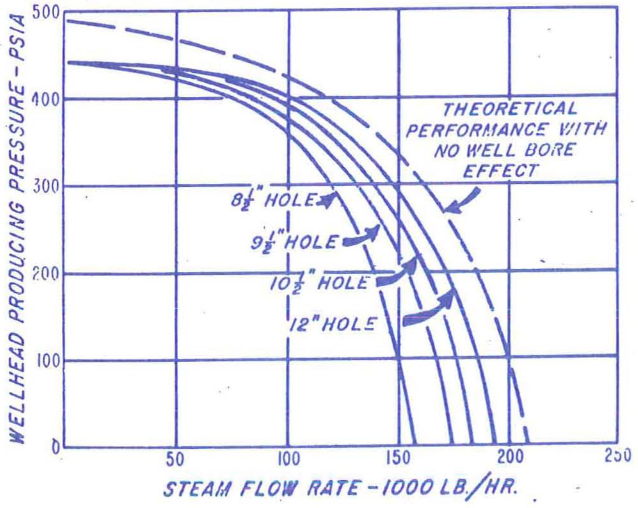
1. Koenig, James B.: The World Wide Status of Geothermal Exploration and Development: Compendium of First Day Papers Presented at the First Conference of the Geothermal Resources Council, P. 1-4 (Feb., 1972)

2. Craft, B.C. and Hawkins, Murray F., Jr.: Applied Petroleum Reservoir Engineering, Prentis Hall, P. 326-327 (1959)

3. Cullender, M. H.: The Isochronal Performance Method of Determining the Flow Characteristics of Gas Wells, Trans. AIME, V. 204, P. 137 (1955)

4. Ramey, H. J., Jr.: Petitioners v Commissioner of Internal Revenue, 1969 Tax Court of The United States 52 T. C. No. 74, 1970

STEAM FLOW RATE
VS
WELL HEAD PRESSURE
FOR VARIOUS EQUIVALENT DIAMETERS
FOR A TYPICAL 5000' STEAM WELL
AT THE GEYSERS



STEAM FLOW RATE
VS
WELL HEAD PRESSURE
FOR TWO WELL DEPTHS
FOR A TYPICAL STEAM WELL
AT THE GEYSERS

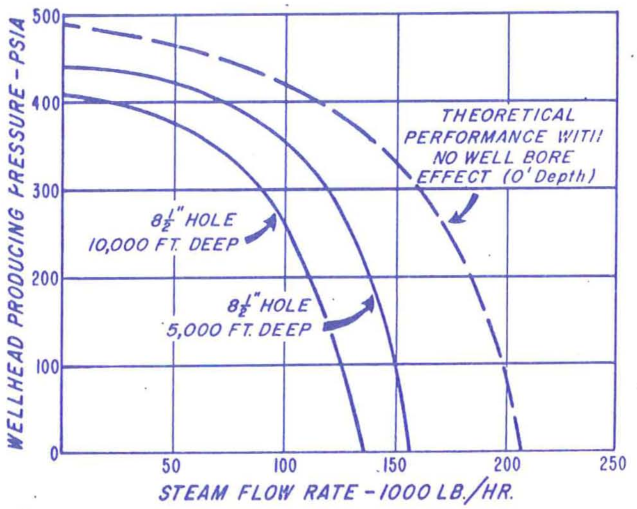
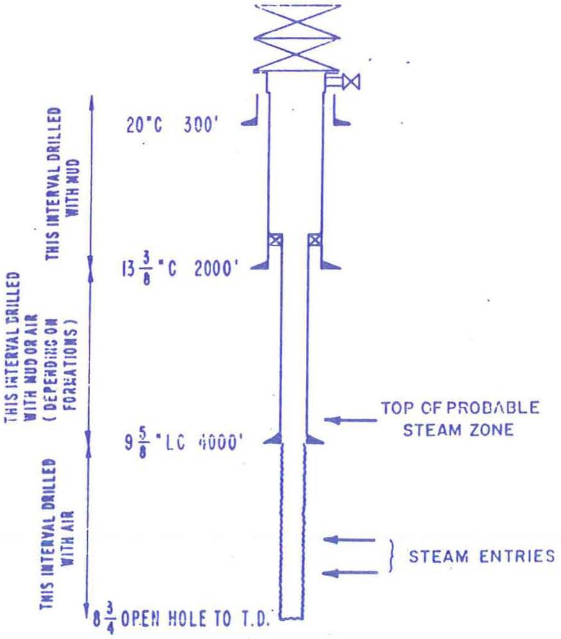


Figure 2



TYPICAL WELL COMPLETION
AT
THE GEYSERS GEOTHERMAL STEAM FIELD

Figure 3.

STEAM PRODUCTION RATE
VS
TIME
FOR GEOTHERMAL STEAM WELLS
AT THE GEYSERS

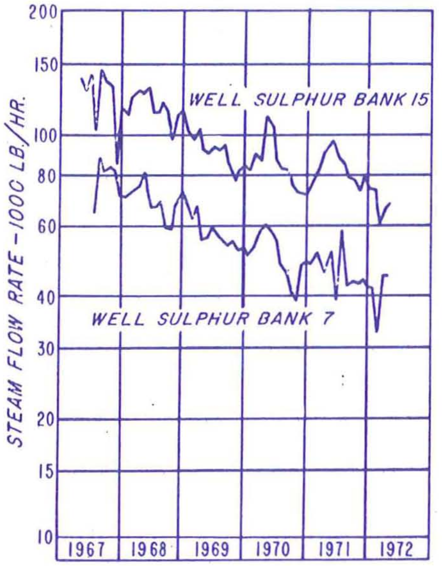


Figure 4.

EFFECT OF WELL DENSITY
ON PRODUCTION RATE AS
DETERMINED BY A RESERVOIR
SIMULATION MODEL

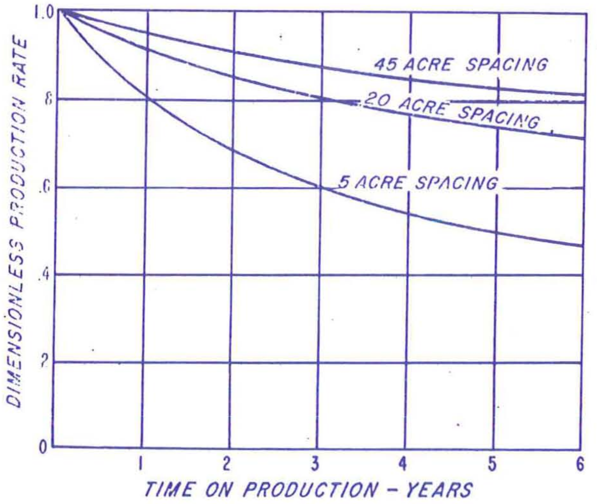
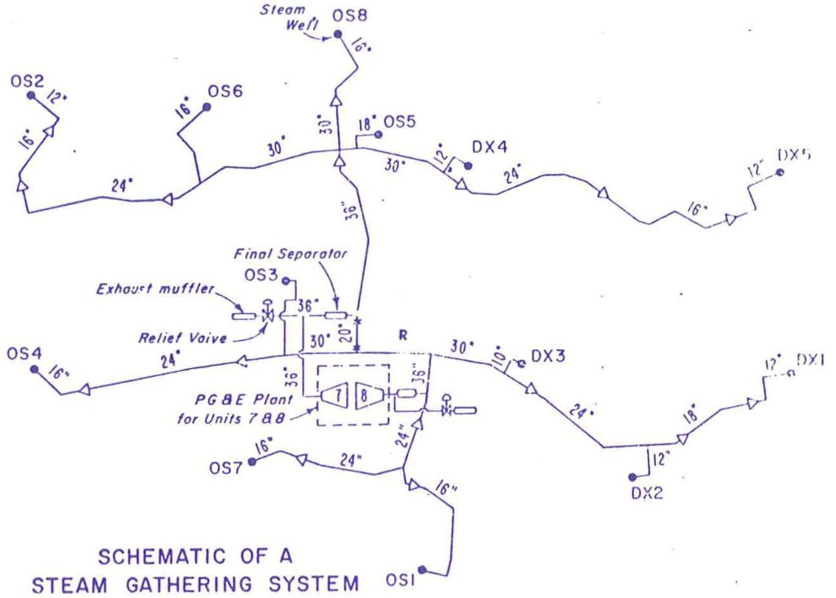


Figure 5.



SCHEMATIC OF A
STEAM GATHERING SYSTEM
AT
THE GEYSERS GEOTHERMAL FIELD

Figure 6

SCHEMATIC DIAGRAM OF
TYPICAL WELLHEAD CONFIGURATION
OF A STEAM WELL AT THE GEYSERS

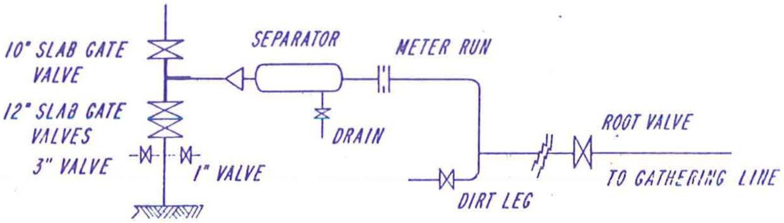


Figure 7