PROCEEDINGS, Thirteenth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 19-21, 1988
SGP-TR-113

RESERVOIR MANAGEMENT - AS CONCEIVED AND APPLIED ON THE PALINPINON RESERVOIR, PHILIPPINES

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ABSTRACT

The present exploitation of Palinpinon reservoir has revealed valuable information on the subsurface characteristics of the reservoir under large scale production. The initial behavior of the field has given signals that there is a need to implement appropriate strategies to optimise its capacity without jeopardizing the supply of adequate steam to the power plant.

Some of the problems encountered such as reinjection returns, mineral deposition, ingress of acid fluid and other phenomena indicated the need to pursue an agressive monitoring capability and timely appraisal of the field response to design an approach which will best suit the optimum management of the reservoir. The results of reservoir monitoring are discussed as well as the policies applied in operating the field.

INTRODUCTION

With only a few years of experience in exploring for and developing geothermal energy, PNOC-EDC and NPC were able to install two 112.5 MW power plants in 1983 in Tongonan and Palinpinon. In both fields, the formulation of reservoir management policies were instituted, especially in Palinpinon where the reservoir properties are considered complicated. The development of the field was conceptualized with over a few wells drilled to support a 112.5 MW power plant. Several constraints (also discussed in Tolentino (1986)) like the commitment to meet the plant commissioning schedule, the rugged terrain, ecomomic cost and the lack of sufficient long term well test data have substantially affected the total development plan of the field. It is in this field where we applied the first compact development plan by drilling more directional wells in a multiwellpad system. The multiwellpads were compressed on the surface resulting to a tightness in spacing within the upper portions of the wells. Identifying the reinjection sectors, the main production sectors and determining the distances between wells, the casing design, the targets of the directional wells and the intersection of the different faults with the wells had been based on the field model inferred from initial drilling results. More data have become available after the initial stage of exploitation showing indications on how the field would behave under long term exploitation. Some uncertainties were recognized especially on the effects of injection fluid to the production wells.

An intensive monitoring program was embarked since the plant was commissioned in 1983. The results have been used in formulating reservoir management strategies which are modified and changed during the period, with the main objective of (1) optimizing the field capacity based on available wells and installations (2) minimizing adverse effects of reinjection fluids (3) ensuring that adequate steam is supplied to the power plant and (4) operating the field with minor expenditures.

The present paper describes the exploitation of Palinpinon reservoir with respect to the results of the monitoring and management schemes implemented up to the present period.

THE PALINPINON RESERVOIR

The Palinpinon geothermal field is located on the island of Negros in the Central Visayan region within a reservation encompassing 133,000 hectares. The first geoscientific surveys in the area were conducted in 1973 followed by drilling the first three shallow exploratory wells N-1, N-2, and N-3 in 1977. This led to the successful discharge of N-3 and the drilling of deep exploratory wells Okoy-2, Okoy-3, Okoy-4 and Okoy-5 with the intention of probing the drainage source of the initial shallow wells. Positive results in the latter wells also led to the development of Puhagan sector for Palinpinon I and the Nasuji-Sogongon sector for Palinpinon II.

Todate, 21 wells have been hooked up to supply steam for Pal I, 18 directional, 3 vertical and 10 RI wells, most of them directional. The results of well drilling and discharge testing indicated that Palinpinon reservoir is a typical liquid dominated system discharging mainly from single-phase liquid feed zones. There exists boiling in the upper part of the reservoir as the pre-exploitation data indicated two-phase zone at shallow levels in OK-2 (at -200 m RL) and in OK-2 (at -750 to -950 m RL) and in PN-31D. A two phase zone also exists in the shallow level of the reservoir in the Sogongon sector. This two-phase zone has been observed in PN-30D and OK-9D as a result of exploitation.

During shut condition, internal flows in the well persist with strong inflows of 260-280 C liquid from -600m to -800m MSL downflowing and exiting at -1600m to -2000m MSL. In the eastern part of the field, temperature inversions are noted, e.g. at PN-15D, PN-17D, Okoy-10D and PN-21D (not continous to bottomhole) indicating outflow features and/or lateral incursion of relatively colder fluids. Fig. 1 shows the temperature contour distribution in the field, depicting the upwelling zone in Puhagan sector beneath Okoy-9, PN-27D and PN-23D. Two major outflow regions are distinguished by (1) long but narrow temperature lobe flowing to the NE across the NE part of the field and (2) broad temperature lobe to the west across the southwestern part of the field. This agrees very well with the chemistry data although these indicate more dilute fluid in Nasuji-Sogongon sectors-in contrast to the NE wells which are highly mineralized.

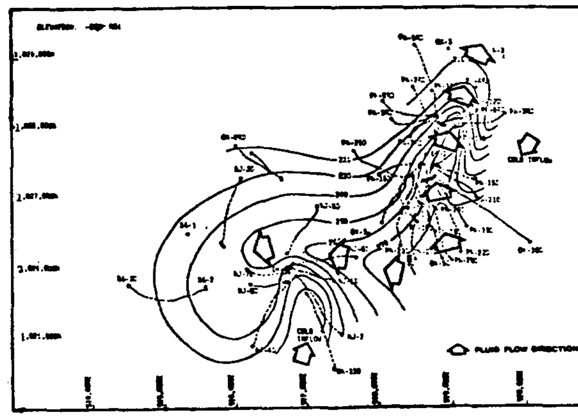

Fig. 1. Temperature Contours at -500 m MSL and Inferred Hydrological Flow

It is inferred that permeability controls have largely affected the flows between the two outflow regions, with the Ticala fault as the most probable channel of fluid to the NE. Fig. 2 shows other faults crisscrossing the field, e.g., Puhagan fault and its splays, Odlumon fault, Lagunao fault and Ticala fault splays which comprise the Puhagan fault system (Alcaraz, 1985). These faults are similarly inferred to have been responsible for the permeability encountered at depths aside from the stratigraphic contacts between formation. Recent data also indicate that these faults are acting as channels of communication among wells and are now causing more problems than were expected before.

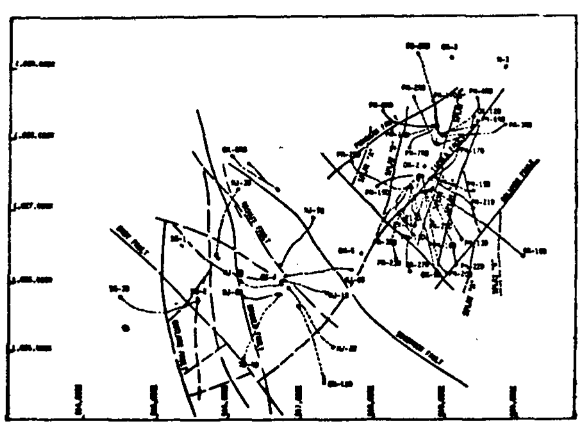

Fig. 2: Geologic Structures Across Palinpinon Field

RESERVOIR MONITORING & MANAGEMENT PARAMETERS

In the middle of 1983, the 112.5 MW power plant was commissioned to generate power for the whole Negros Island. The plant is a variable load power plant which handles load fluctuations by using blow-off system and control valves in the steam gathering system. A typical 31 MW (average) plant load is shown in Fig. 3. Inspite of the plant capacity and the availability of full power potential on the wellhead, only 30-50 MW are currently generated due to low power demand. This situation allows ample flexibility in the utilization of production and reinjection wells, which become beneficial to the management of the resource in terms of providing reasonable time for the field to be observed. It also allows management policies to be changed without introducing immediate and radical solutions to some major problems.

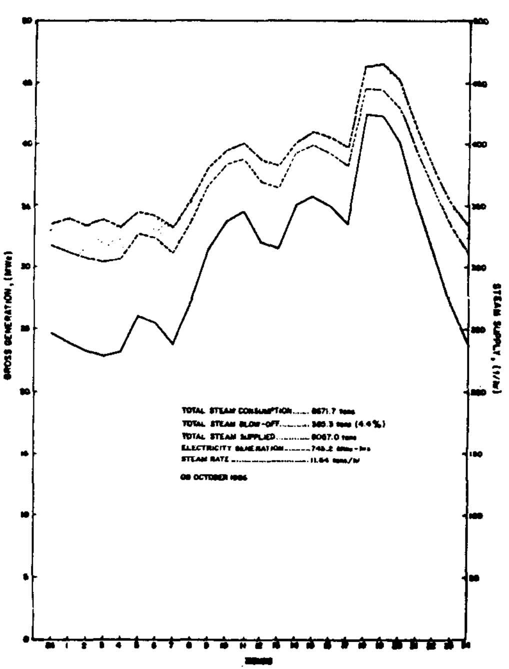

Fig. 3: Typical Power Generation Curve in Palinpinon I Power Plant

In formulating the reservoir management strategy, focus was given to the implications of the folllowing parameters to the prudent management and lenghtening of the deliverability of the field:

Pressure Drawdown

Downhole pressure measurements are conducted on a regular basis in order to determine pressure changes with time. These enable the reservoir engineers to determine which sector of the field is highly affected by production and/or influenced by natural recharge or reinjection fluid returns. As a start, we minimized the creation of large pressure drawdowns which may be localized or confined in a small sector by initially distributing production on a large part of the field. We considered it a first step countermeasure in order to avoid premature incursion of surface meteoric water or lateral flow of relatively colder fluids from the edges of the field. This is attained by throttling the well discharges such that two phase zone is also minimized in the upper zone and contribution from the high temperature bottom zone is enhanced. As a consequence, high volume of waste water were produced necessitating a bigger reinjection capacity as compared to when production is coming from the created two-phase region in the upper zone. Neverthless, this is offsetted by the fact that the two-phase zone easily collapses and condenses upon cooling of reinjection fluid returns and invasion of cold meteoric water.

In the first year of operation, wells in the eastern borefield were utilized (PN-15D, PN-21D, PN-17D, PN-22D, PN-26, Okoy-7 and Okoy-10D) reinjecting into Okoy-12RD, PN-6RD, PN-1RD, PN-2RD, PN-5RD and PN-7RD. These wells were drilled closer to the production wells. While on line, pressure drawdowns were noted but when production was shifted to the western borefield, pressure recoveries were observed. The upper zones in some wells like Okoy-7, Okoy-9D, PN-20D and Okoy-10D, which were going two phase gradually went back to single phase because of the effect of reinjection fluid returns. But in the case of Okoy-10D, it is believed that natural recharge occurs as no RI fluids are detected in this well.

In wells PN-1RD, PN-7RD and PN-9RD, pressure declines were noted although they were under reinjection. This similarly indicates that these wells are connected to the production sector and should be used only minimaly as much as possible. Pressure declines were also noted in Okoy-1, N-1, N-2, and N-3; all drilled further and shallower from the outflow region - hinting connection with the production sector. This connection is inferred to be via the upper zone. On the other hand, Okoy-3, which is also located in the northern outflow region of the field, exhibited a pressure increase of 0.8 MPa during the same period in 1983-1984. We interpreted this to be connected to the main reinjection sector. Fig. 4 shows the pressure changes of the different wells. To date, the average pressure decline after 4 years of exploitation has reached 1.56 MPa with maximum drawdown of 2.6 MPa in PN-24D. PN-14, a vertical well close to the RI sector has had pressure fluctuations highly dependent on production and reinjection wells utilized.

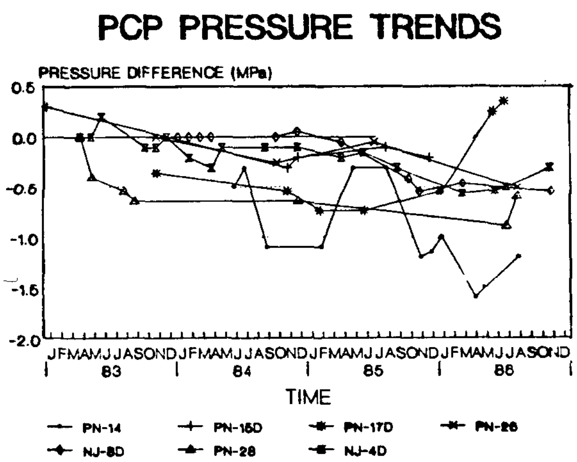

Fig. 4: Pressure Drawdown of Palinpinon I Wells During Exploitation

From 1983-1987, pressure declines were similarly noted in Nasuji-Sogongon sector although with some preference on the eastern wells like Okoy-11D, NJ-8D, NJ-4D and NJ-7D. The decline appears to have been propagated through the faults criss-crossing Pal-I and Pal II wells, most probably from Ticala fault. This observation is being investigated to see its implications on the development of the sector.

Thermal Drawdown

Since reinjection is a main component of the strategy, temperature deterioration due to fluid returns has been the primary concern. Influx of cold meteoric water and lateral flows from the edges of the field are also watched out. It has been our policy to keep reinjection fluid return as minimum as possible if not avoidable.

The most significant observation on the changes in temperature associated with reinjection returns was the decline in temperature at Okoy-7 at the bottomhole from 310°C to 290 in 1985. During the period PN-9RD was on line from about 4 months and fluids were leaving the well @ -2200 m, almost in the same elevation as in Okoy-7 feed zone @ -2000 m. The distance between the two zones is about 800 m. When PN-9RD was shut, the temperature recovered to its original temperature indicating that the temperature decline is a reversible process (see Fig. 5). This may also mean that the cooling in the well is only localized and confined mainly within the walls and vicinities of the fluid channel. Later in 1987, the decline in temperature at the upper zone in Okoy-7 was also noted from 282°C to 268°C. The two phase condition earlier observed has gradually turned single phase also. It is inferred that this phenomenon is due to the reinjection at PN-1RD and PN-6RD, which are both accepting at the upper zone.

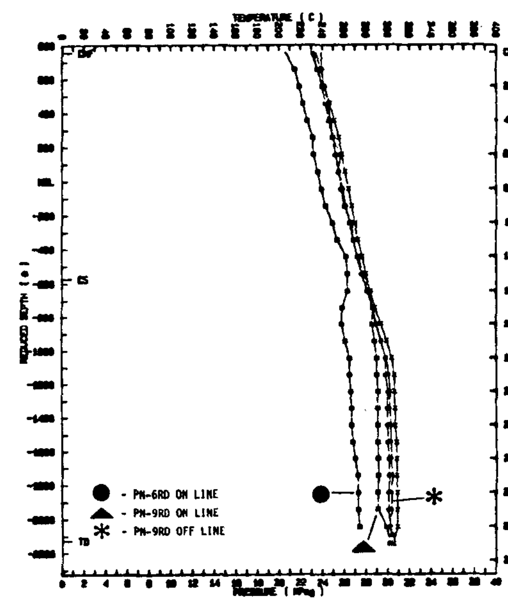

Fig. 5: Well Okoy-7 Temperature Changes With Reinjection Well Utilization

Another well which has suffered from the effects of reinjection return is well PN-26. It has since decline in temperature from 270 C to 238 C. This well is believed to be communicating with PN-9RD, PN-1RD, and PN-6RD. Its silica temperature also substantiated this temperature deterioration and in February 1986, a silica breakthrough was confirmed. The temperature of 258 C was measured while the calculated silica temperature was 267 C.

Some temperature changes have also occured in other wells due to increased reinjection returns but many of them disappear as soon as changes in the dominant zones occur. For example, downflows were initiated when shut but these are suppressed upon discharge from the lower zone.

To make use of the observed temperature decline in the field, a correlation has been established to predict deterioration of temperature in wells due to reinjection returns. The parameter used was the cumulative reinjection return produced from a well as against time. Based on Okoy-7 and PN-26, temperature decline in the wells is expected to be observed after producing a mass flow of 1.5 x 10 tonnes (produced reinjection fluid). This is clearly demonstrated in Fig. 6. Based on the figure, it is expected that thermal decline in many wells is expected to occur in 1987- 1988.

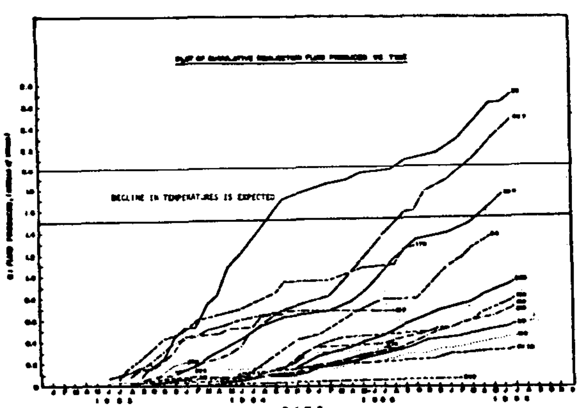

Fig. 6: Plot of Cumulative Reinjection Fluid Produced for Palinpinon I Wells

In view of the above observations and the continuos rapid return of reinjection fluid to majority of the wells, a long term plan is drawn to move the reinjection sector further to the area of Okoy-3, N-3 and northwards. With the full operation of 112.5 MW, it is expected that 75% of the reinjection fluid will be reinjected into this region.

Chemical Changes

Harper and Jordan (1985) have reported the chemical changes in the reservoir in response to production and reinjection at the Palinpinon Field. Not long after the commissioning of the plant, reservoir chloride has already increased despite the absence of highly mineralized source from within the reservoir. This led to the conclusion that RI returns were the principal cause of the increased mineralization. Continuos monitoring of calcium, sulfate, silica, gas and acidity are conducted in order to assess the major implications of reinjection returns to the performance of the reservoir. Fig. 7 shows the reservoir chloride increases calculated from individual wells PN-15D, PN-21D PN-26, PN-28 and Okoy-7. Most of these wells exhibited significant increases while RI wells PN-1RD, PN-6RD and Okoy-12RD were on line. When PN-1RD was put off line, reservoir chloride for Okoy-7, PN-26 and PN-28 decreased, and when PN-9RD was put on line in the middle of 1985, chloride values increased again. These imply good communication between these production wells and reinjection wells. As a result, the production wells were put on reserve and production were shifted to the western sector.

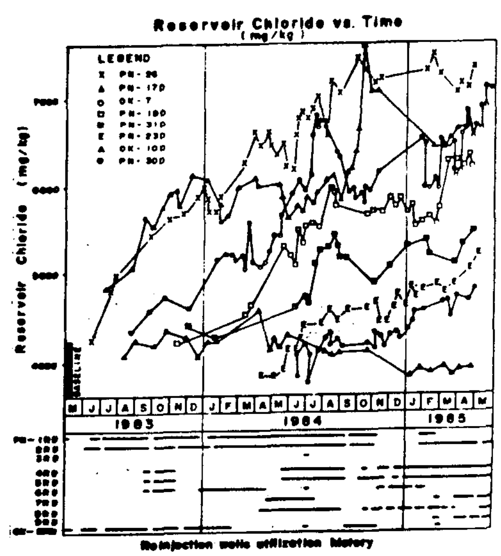

Fig. 7: Reservoir Chloride Changes of Palinpinon I Wells During Exploitation (from Harper & Jordan, 1985)

Tracer Test

To further understand the fluid movements in the reservoir, tracer tests were programmed at certain periods. Urbino et al (1986) discussed in detail the result of the iodine and sodium fluorescein tracer tests conducted in Palinpinon. The results are consistent with the observations from the pressure changes and chloride increases.

In the eastern part of the production borefield, wells PN-15D, PN-17D and PN-28 were found to have communicated rapidly with Okoy- 12RD, with less than a day detection at PN-17D. The mean transit time was from 3.9 to 7 days on the three wells. Based on the sodium fluorescein tracer tests, Okoy-7 also communicates rapidly with PN-9RD, with a breakthrough time of only 1.08 days. The average mean transit time detected from the Iodine tracer gave an average mean transit time of 5.7 days. Breakthrough velocities are calculated to be from 35 m/hr for PN-9RD to Okoy-7 and from 4.7 to 8 m/hr to other production wells. On the basis of the results shown in Table 1, production and reinjection showing rapid communication were given less priorities in the utilization.

TABLE 1 - PN-9RD TRACER TEST RESULTS

Well	% Return	I-131 TRACER Ave. Transit Time DAYS	SODIUM FLUORESCEIN Breakthrough Time DAYS
OK-7	29.2	5.7	1.08
PN-29D	6.8	14.0	6.00
PN-26 *	3.9	11.0	5.50
PN-28 *	1.1	10.3	6.00
PN-18D	0.8	15.6	Not Monitored
PN-30D	0.8	15.7	8.30
PN-23D	0.4	15.8	7.50
PN-31D	0.4	16.0	5.50
PN-16D	Tracer found in samples after 8-19 days		9.80
PN-19D	Tracer found in samples after 8-19 days		6.00
PN-17D	No response		6.00
OK-9D	No response		No response detected

* Wells on heavy bleed. Tracer return values believed to be erroneous to inaccurate mass flowrates used.

Attempts were made to correlate this tracer arrival data to thermal breakthroughs but they were not successful. However, the results were found to be very valuable during the initial exploitation of the field, especially in tracing the preferential flowpath of the reinjection returns and prioritizing well for utilization.

Well Output Changes

Corollary to the above parameters, the performance of the production wells were monitored to detect output decline caused by thermal decline and pressure draw down. From June 1984 - Sept 1985, well PN-26 output characteristics had started changing significantly with its operating WHP declining from 2.4 to 1.82 MPag. As of November 1986, WHP dropped to 1.07 MPag, with a corresponding drop in enthalpy from 1230-1120 kJ/kg. This feature was later observed at Okoy-7 reinforcing the initial concern on the adverse effects of rapid reinjection returns. Since then, well PN-26 and Okoy-7 were given low priority and utilized sparingly during peak hours.

Reinjection Well Capacities

Like the production wells, the performance of the reinjection wells is critical to the performance of the system. Waste water cannot be dumped to the river because of environmental constraints. Regular measurements were conducted to accurately determine changes in the wells' injectivity and capacity.

In general, an increase in capacity has been observed after 1 or 2 years of reinjection, probably resulting from improvement in permeability caused by the contraction of the reservoir rocks as they are cooled by reinjected fluid.

Well PN-2RD had initially suffered a decline in capacity attributed to silica deposition and formation of blockage. In this particular well, fluid residence time has been considered responsible for the silica polymerization since it is tapping from the farthest end of the reinjection header making it insusceptible to the preferential flow of liquid.

To ensure that all wells have short fluid residence time, steps were taken to use all the RI wells at/or near full capacity, e.g. with water level at the CHF. No extra wells are put on line that can cause excess capacity than required.

Accumulation of debris, cuttings and solid materials were also noted to have been responsible for the reduction of well capacities. As a countermeasure, solid traps and strainers were installed to trap and screen out the debris and solid materials transported with the reinjection fluid.

Slugging of hot reinjection fluids are also carried after cutting reinjection wells from the system in order to displace and push the super-saturated silica fluid into the formation with undersaturated liquid.

In view of the general increase in the reinjection capacity, it is difficult to determine any decline in reinjection well capacity caused by an increase in reservoir pressure.

Acidity and Anhydrite Deposition

Prior to exploitation, no signs of acidity were detected in the discharge tests of the wells. However, some acid indications were recognized in the field which is now a cause of concern vis-a-vis the field management. Well PN-22D became acidic after 2 months of discharge to the SGS and was shut merely after 4 months. This was the first well to have shown acid discharge. Another well which has a tendency to become acidic is Okoy-10D, also in the eastern borefield. The discharge of OK-10D indicated higher sulphate concentration com pared to the other production wells, although its discharge has not become acidic as in PN-22D. An adjacent well (PN-20D) is currently showing acidity after having been used sparingly in the last 4 years.

As a result of the ingress of acid fluids, anhydrite blockage were formed as the acid fluid mixed with calcium-rich neutral liquid. This results to a reduction in well output.

Work-over were conducted in PN-22D and Okoy-10D in 1987 to clean the anhydrite blockage and hopefully suppress the acid fluids during production. But this was not successful. Contribution from the acid feeds in the upper zone persists, even under injection condition and during the post work-over discharge. Formation of anhydrite blockage reoccured although Okoy-10D is still supplies the system. Experiments are being undertaken to seal-off these acid feeds and hopefully eliminate this problem.

Calcite Deposition

Only wells PN-13D, PN-15D and PN-21D had suffered calcite deposition so far. This may be attributed to the relatively colder fluid produced from these wells which are aggravated by the contribution from the zones of temperature inversion at the bottom.

After 6 months of discharge, calcite deposits grew up in PN-13D requiring a work-over prior to commissioning of the plant. It was put to operation in 1984 but again suffered calcite problem after 6 months. This well has since been shut and put on low utilization priority.

Pipeline Scaling

Deposition in the SGS pipeline also affects the utilization and program of the production and reinjection wells. From experience, silica deposition accumulates from strategic points in the system which requires inspection and cleaning at regular periods. Collapse of compensator liners, cuttings and commissioning debris left in the pipeline during the construction stage have also promoted silica deposition. To minimize deposition, wells which are exhibiting low silica saturation were put on high utilization also prioritized. Efforts are also made to avoid backflow of reinjection fluid in order to minimize damage to the compensators.

Heat Utilization Efficiency

Since the plant is a variable load plant, the main SGS was designed in such a way that fluctuations in the power would be absorbed immediately by the SGS. Its operation requires installing control valves and blow-off valves. These take into account extra steam which are immediately required to supply steam when demand is increasing and to bypass steam when load is decreasing. Because of this, over protection in the ability of the system to respond load fluctuations had been resorted to. During the initial stage of exploitation, approximately 50-70 TPH of steam are blown-off to the atmosphere. However, with the installation of sufficient control valves and subsequent gain in operating experience, blow-off has been reduced to 20 TPH.

All efforts are also being made to ensure that power generation company utilizes their Mechanical Gas Extractor (MGE) instead of the Steam Gas Extractor (SGE) which consumes 10% to 12% of the total steam supply to the power station. This is intended to minimize wastage and improve the heat utilization of the field.

Other parameters like fluid mass and heat withdrawal/injected, load forecast, microseismic activities, environmental constraints and quality of steam fed to the turbines are also considered in the planning and utilization of wells.

RESERVOIR MANAGEMENT POLICIES

Based on the preceding discussions, management policies have evolved on how to utilize the wells and promote the optimization of the resource.

a. Those wells in the eastern part of the production borefield should be used only as reserve wells considering that they are communicating rapidly with the reinjection wells. In lieu of this, wells located in the western and southwestern part of the field are given higher utilization priorities.

b. Wells PN-1RD, PN-6RD, Okoy-12RD and PN-9RD were proven to be responsible for the rapid returns of reinjection fluid to the production wells. They are also put on low priority.

c. RI wells which have shown minimal effects to the production wells are given high priorities and are always put on line, i.e. PN-2RD, PN-3RD, PN-4RD and PN-5RD.

d. In view of the deteriorating temperature in wells Okoy-7 and PN-26, the wells are also put on reserve. Okoy-7 is to be used only to supply the 1.5 MW power plant.

e. Monthly measurements of well output and RI well capacities are conducted to ascertain flow changes.

f. Wells are throttled such that production in the field are distributed to spread pressure drawdown and avoid creation of localized two phase fluids prematurely.

g. Wells which are acidic are also put on reserve, and studies are being undertaken to combat entry of acid fluids to the well during production.

h. Wells which have calcite deposi tion tendencies are heavily throttled to raise the flashing point higher up in the wells (i.e. in the production casing). They are also put on low priority.

i. Efforts are being made to minimize blow-off in the atmosphere but ensure prompt response of the system to absorb power fluctuations. The use of Mechanical Gas Extractors (MGE) instead of the Steam Gas Extractor (SGE) in the power plant is being pursued.

j. As much as possible, wells are operated to give lower silica saturation index to minimize scaling in the well, separator and the pipeline.

k. Reinjection wells are operated at full capacity to lessen residence time thus reducing silica polymerization.

l. As a long term strategy, replacement reinjection wells will be drilled to the northern sector of the field collared from Okoy-3 or N-3 and targetted farther away from the field. This has been contemplated earlier but flexibility attained in operating the field because of initial low utilization level allow us to delay this plan. Similarly, thermal breakthrough and output decline were much delayed than chemical and tracer arrivals. Activities are now under way for the construction of a pipeline that can accomodate 150-450 kg/s of fluids to these sectors. Once this happens, many of the wells drilled will be fully utilized and production will be thoroughly distributed throughout the field.

CONCLUSION

The present exploitation of the Palinpinon field emphasises the need for a prudent reservoir management in order to fully optimize the full utilization of the resource Pressure drawdown, ingress of acidic fluids, mineral deposition and others have been encountered which put a challenge on the ability of the developer to operate the field properly. The initial operating policies and guidelines have been laid out to minimize these risks associated with reinjection returns. Additional studies are also undetaken in order to accurately predict field performance and to be used in formulating the over-all management strategy for the field.

ACKNOWLEDGEMENT

The authors wish to thank the management of PNOC-EDC for their permission to present and publish this paper. We would like to particularly thank B.S. Tolentino for his review and comments which significantly improved this paper.

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