Geothermal Resources Council TRANSACTIONS, Vol. 17, October 1993

RESPONSE OF OLKARIA EAST GEOTHERMAL FIELD TO PRODUCTION

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ABSTRACT

Physical and chemical data collected from wells in Olkaria East Geothermal Field over a production period of more than ten years are used to determine changes in the reservoir state and to asses the effect these changes have had on well and field productivity. The most conspicuous change in Olkaria East Field has been pressure decline, this being most severe in the field center where this has led to increased segregation of vapor and liquid phases, increase in salinity of the discharged fluids and higher rates of decline in steam flowrates of the shallow wells. On the field edge, there is evidence of entry of cooler water at depth as seen from development of inverted temperatures in wells, decline in discharge enthalpy and dilution trends in fluid chemistry. Temperature change in the field center are however low and shows that large amount of energy is still present in reservoir rocks. As part of the programme to restore well and field production, deepening of shallow wells and pilot reinjection tests are being considered.

INTRODUCTION

Olkaria East Geothermal Field has been under exploitation since 1981 when the first of three 15 Mw turbines was installed. The two other units were installed in 1982 and 1985 thus bringing the total generation capacity to 45 Mw. The number of production wells has increased with every unit from seven (7), to fourteen and eventually to twenty three (23) wells which all together deliver over three hundred and twenty (320) tones per hour of steam to the power generation plant as at July 1992. Over this period of production the wells and the reservoir have undergone some changes and these and the factors affecting them are discussed in this paper. These changes are discussed in two inter-related portions namely changes in the physical parameters and well productivity, and changes in chemistry of the discharged brine.

As part of the field management requirement and general field assessment, Olkaria East Reservoir has since inception of the first unit, been monitored for changes in steam output by various methods which included routine check on steam flow and general well deliverability for changes in steam flowrates and enthalpies. Routine downhole temperature and pressure surveys were initially limited to replacement wells and two non-productive wells (OW-3 & OW-9). Following connection of the replacement wells to the plant by 1986, these surveys have also been done in production wells during individual well outage or during plant or unit shutdowns. However the wells have only been available for comparatively short times and measurements therefore represent various stages of thermal and pressure recovery. Inspite of this limitation it has been possible to make general qualitative and quantitative deductions that have proved useful in understanding the various reservoir processes.

Along side the physical measurements, chemical data including level of overall fluid salinity i.e total dissolved solids, chloride , ph and the Quartz and Cation ratio geothermometers of the separated water at the weirbox have been determined on an annual basis upto 1989 and at twice that frequency since 1990. However due to the cyclic nature of the wells only limited success has been achieved in applying conventional interpretation techniques to the data. No geophysical methods of reservoir monitoring have been used in the field.

There have been indications of obstructions and blockages from recent downhole surveys in three wells apparently due to silica deposition. However the extent of this deposition and its effect on well delivery are not established and are still being investigated.

Figure 1 shows the well sites. The area enclosed by the dashed line is referred to in the text as the central area.

NATURAL STATE

The Geology and the thermodynamic state of the pre-production reservoir in Olkaria East Field and the general production characteristics of the wells have been discused by Svanborjonsson et al (1985). In summary the reservoir was classified as two phase liquid dominated overlain by a thin 100 to 200m thick steam dominated zone at 240°C . This zone was widest in the south eastern part of the field and thinned in the northern direction. Below the steam zone exists a two phase system of boiling water and the temperature and pressure follow the boiling point for depth relation. Above the steam zone is a caprock which marks the top of the reservoir and is composed of impermeable basalts and trachytes which lie 400 to 700m below the surface. The bulk of the reservoir rocks are mainly trachytic in composition (Muchemi,1988).

The vertical extent of the reservoir is unestablished but is believed to be in the order of several hundred meters (Bodvarsson and Pruess, 1984). Temperatures intercepted by wells are generally high (250°C) with

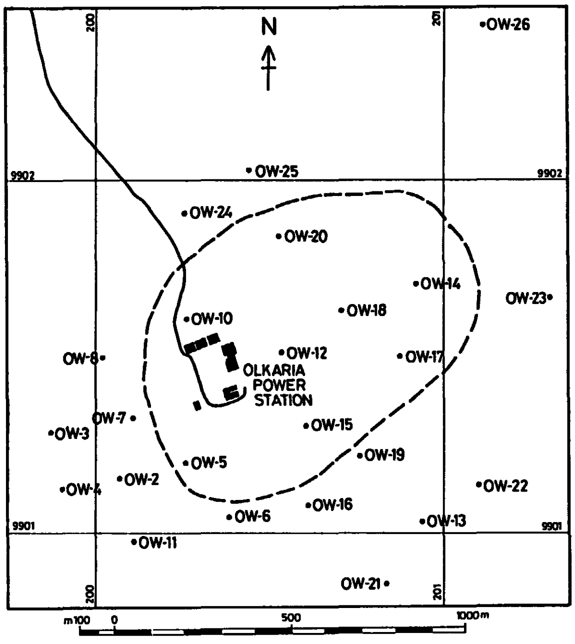

Fig.1 Well Locations

bottom hole temperatures being above 270°C. The static water level was variable between wells but was between 400 and 700m in most wells. Initial temperature and pressure distribution in the field constructed from well data showed that both temperature and pressure increased northwards and indicated that the general hydrological gradient was such that water movement was from North to South. This has now been confirmed through drilling in the northern parts of the field where most bottom hole temperatures exceed 310 C and the steam zone which is present in East Olkaria Field is replaced by a shallow two phase zone (Haukwa, 1988; Ambusso, 1990;Ambusso and Ouma,1991).

The wells were drilled to depths between 901m and 2485m and production casing set between 488 and 948m. Analysis of pressure transient tests on well completion and shut-in following discharge tests revealed low hydrologic parameters with average permeability thickness product of about 2.0 Darcy-meters (Haukwa,1985). On discharge the wells displayed different production features with average mass flows ~40 t/hr, and discharge enthalpy in excess of 2000kj/kg. Temperature and pressure profiles taken in discharging wells revealed two phase conditions in most wells and showed that phase separation occurred mainly in the formation. In addition most wells showed instability on discharge caused by production from two or more production zones with low permeability (Haukwa, 1981).

The chemical composition of the reservoir fluid was characterized from weir-box samples and downhole samples. In summary the brine had a near neutral ph (8) with comparatively low salinity (< 1500 ppm) and chloride levels ranged from 200 to 700 ppm and increased both with depth and from north to south. A thin condensate layer was present in the upper parts of the reservoir as seen from low chloride levels and dissolved solids in the discharge of some wells. Quartz and cation ratio geothermometers always showed temperatures that were comparable but slightly higher than the measured temperatures in static wells while the discharge enthalpy at the silencers exceeded the corresponding enthalpy at the silica temperatures and also shows that most flushing during flow occurs in the formation rather than the wellbore. Table 1 shows a summary of fluid characteristics.

Table 1

Initial fluid Chemistry

	ppm
Boron	1-7
Calcium	0-30
Chloride	170-700
Carbon dioxide	28-1278
Floride	15-116
Hydrogen Sulphide	2-57
Potaasium	14-85
Lithium	0-2
Magnesium	0
Sodium	62-470
Silica	200-640
SO_4^-	8-90

RESPONSE TO PRODUCTION

Steam decline

Since commencement of production, total steam output from the wells has shown various regimes of decline from an initial 5-6% decline per year from 1981 to 1988 when the decline rate subsided to about 4% per year at which it remains presently. The individual wells however display more varied decline rates with most wells in the field having decline rates of 2% and 4% per year for steam and mass respectively. The lower rate of decline in steam being due to the simultaneous increase in discharge enthalpy which increases the relative proportion of the steam in the total discharge.

The shallower wells particularly in the central parts of the field have higher rates of decline (8% per year). Most of these wells have attained dryout conditions and produce only steam. Downhole pressure surveys in these wells during brief shut-in have shown presence of slightly superheated steam in the wells. This single phase state in the reservoir and the reduced formation storage associated with it is a probable cause of the higher rates of decline. Deeper wells in the field center have had moderate rates of decline with a gradual increase in discharge enthalpy. Figures 2(a) and (b) show the output characteristics of OW-17 and OW-18 as examples of shallow and deep wells in the central parts of the field respectively.

Further off the field center and towards the periphery of the field wells display more diverse trends in production characteristics. Wells on the eastern margin of the field have shown increased instability in production with increased water output during parts of the cycle. These wells unlike the central ones have had decrease in

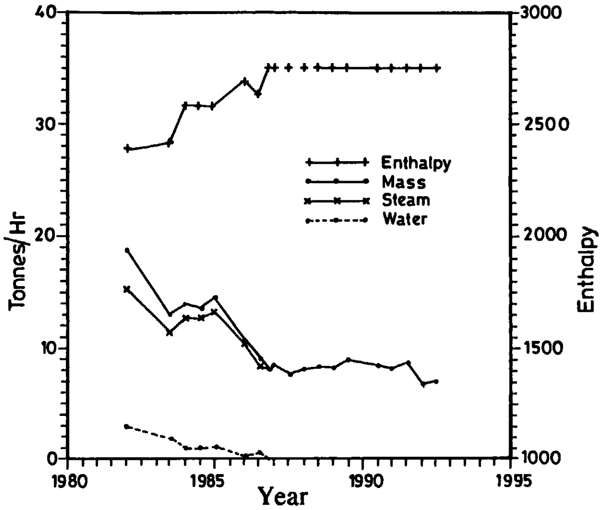

Fig. 2(a) OW-17, Production history.

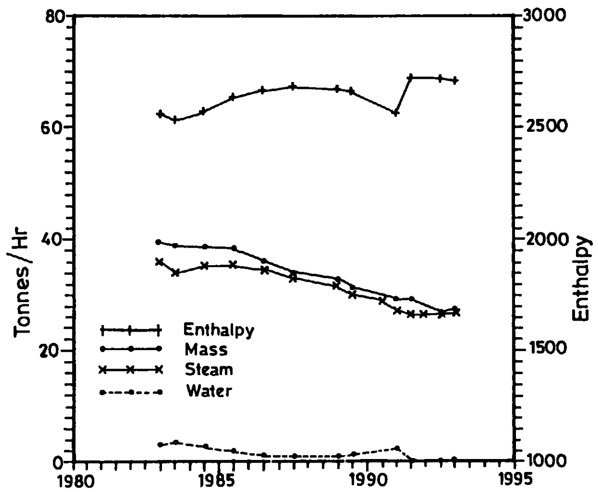

Fig. 2(b) OW-18, Production history.

discharge enthalpy which gets even lower during the surges. This as the downhole temperature surveys in these wells have shown is caused by entry of cooler fluids at well bottom. Figures 3(a) and 3(b) respectively show the steam, water and enthalpy variation for OW-22 over complete cycles during discharge tests in 1983 and in 1993 after seven years of nearly continuous production.

The effects of the entry of the cooler fluids in the less peripheral wells has been a gradual increase in water flow accompanied with decrease in discharge enthalpy with no apparent effect on well production stability. The rate at which each well is affected however varies between wells and depends on well closeness to the field edge and local permeability. Figure 4(a) and 4(b) shows production histories of OW-16 and OW-19 which are within 300 m of each other. OW-16 is a big producer and is drilled on an extension of an inferred north-south fault while OW-19 is an average Olkaria well but is deeply cased and has no production from the steam zone. The increase in water flow and decrease in enthalpy was fairly rapid for OW-16 and was noticed after only two years of production while for OW-19 this was more gradual and was only evident after more than four years of production.

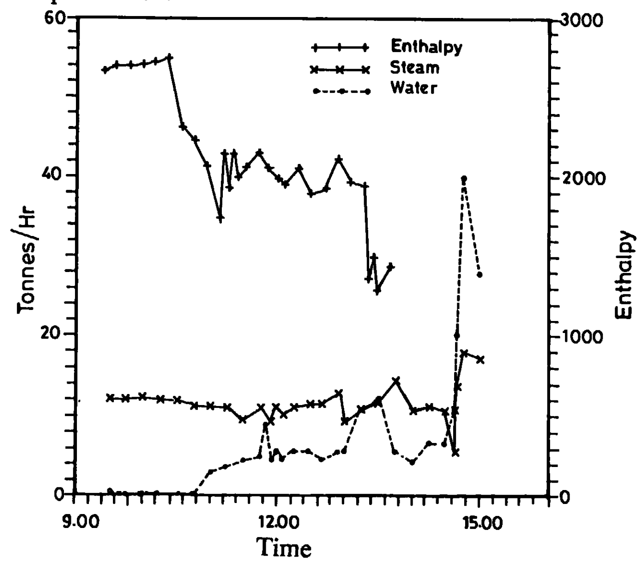

Fig. 3(a) OW-22, Output over whole cycle, 1982.

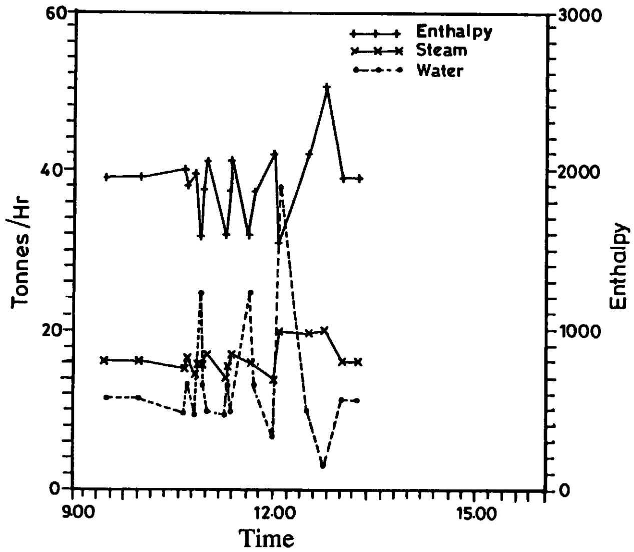

Fig. 3(b) OW-22, Output over whole cycle. 1993.

Changes in Temperature and Pressure

Though systematic monitoring of reservoir state has been done since commencement of production through routine temperature and pressure surveys in shut-in and producing wells, there were no measurable changes in the physical parameters during the first three years of production when temperature and pressure surveys in selected shut-in wells revealed fairly static conditions (Haukwa, 1984). However in the subsequent years gradual and consistent changes were recorded revealing

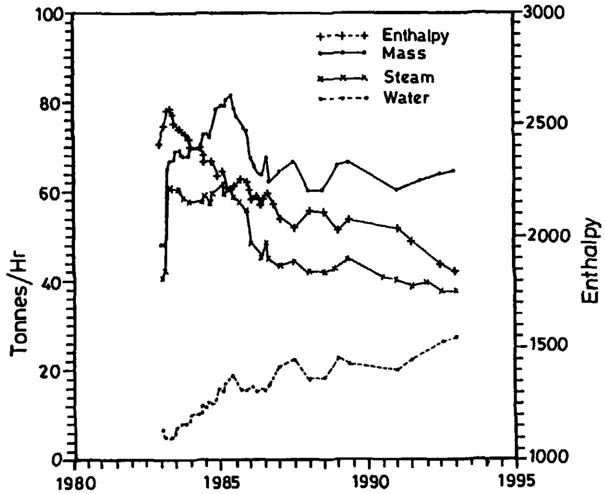

Fig. 4(a) OW-16, Production history.

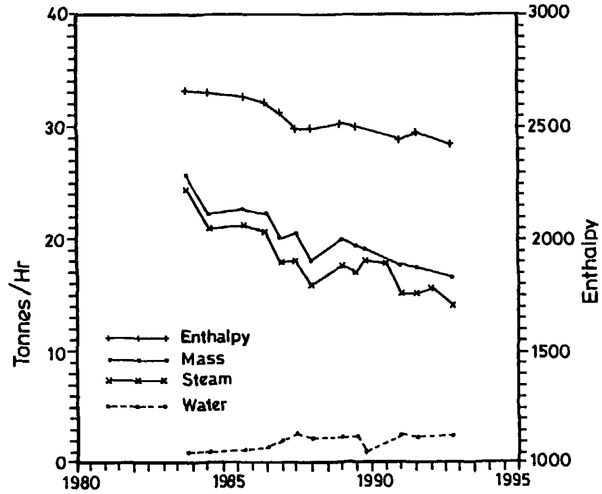

Fig. 4(b) OW-19, Production history.

the combined effect of increased exploitation and slow propagation (diffusivity) of changes which is characteristic of low permeability two phase reservoirs.

The most conspicuous change in Olkaria East Reservoir over the first ten years of production is pressure decline in the system. This is most severe in the central parts of the field where this has led to increased segregation of vapor and liquid phases and higher rates of decline in flowrates of shallow wells. In the field center the reservoir state has changed from two phase water dominated to steam dominated. Profiles taken in wells producing only dry steam show presence of superheated steam in upper parts of the wells while no water levels have developed in these wells even after extended periods of shut-in and shows that water is now immobile in the upper parts of the reservoir. Fig.5 shows pressure profiles taken in OW-17 several days after discharge tests in 1982 when water rest level in the well was at about 700 m depth and other profiles taken in the same well during a brief outage after nearly ten years of continuous production in 1992 when no water level developed even after shut-in for 36 hours. Formation pressure in the upper parts of the reservoir as inferred from pressure recoveries during short shut-in tests during well outages show a decrease between six (6) and ten (10) bars. This value is less than projected from numerical simulations and indicates movement of fluid into the upper parts of the reservoir. The pressure drop in the lower zones which are the main producers have not been measured directly due to demand for steam. However, it is likely that the pressure drop in this zone is of the same order as that measured in the steam zone.

To the north, pressure surveys show very little decrease and a pressure change of only one (1) bar has been recorded in a recent survey in one well that has produced for over seven years (OW-25). This too indicates substantial fluid movement into this zone of the field presumably from the upflow in the north. On the southern part of the field pressure change have been measured in a nonproductive well (OW-3). The pressure change has recently started to stabilize after an initial trend of systematic decline (Fig.6). This stabilization is attributed to the entry of cooler water at

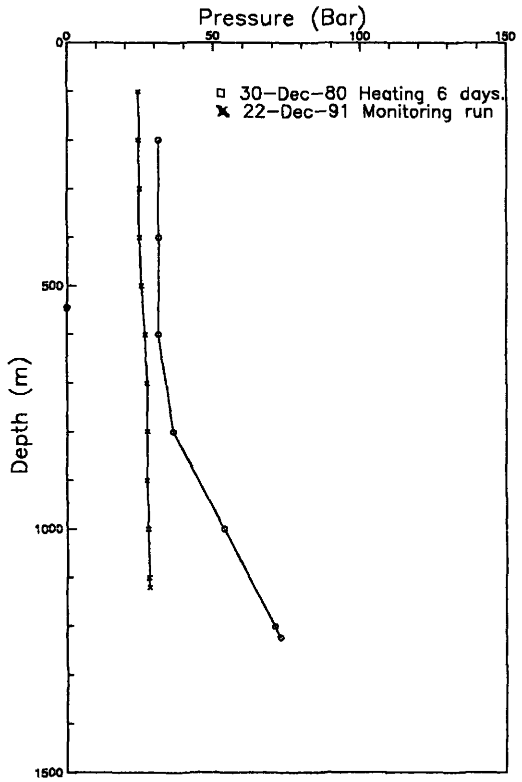

Fig. 5 OW-17 Pressure Profiles

depth as seen from development of inverted temperature (Fig.6)

Temperature changes in the central area have only been partially determined on a limited number of wells and can only be estimated from projected recoveries of no more than 48 hours. However the recovery during a 36 hour shut in of OW-17 (Fig.7) did show that temperatures for most parts of the well were only 5 °C below the pre-production values in 1981. This shows that decline in

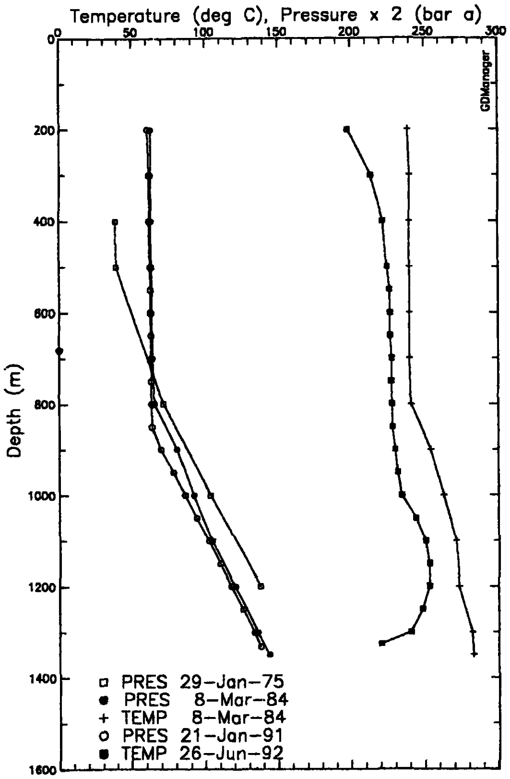

Fig.6 OW-3 Downhole Profiles

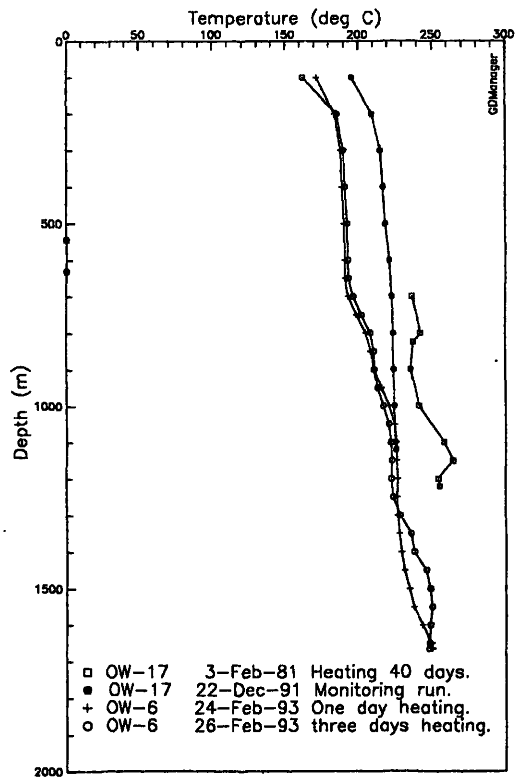

Fig.7 OW-6 and OW-17 Temperature Profiles

production is mainly due to fluid depletion while most stored heat is still in place. To the south temperature measurements have been less frequent. However a recent measurement in OW-6 during a one week shut-in period showed temperature recovery rate was far less rapid as compared to OW-17 with most well parts having temperatures 30-40^0 C below the pre-production ones. This shows a possible effect of influx of cooler fluids from the adjacent formations.

Chemical changes.

Chemical changes in Olkaria East Field have been diverse and vary both in type and degree across the field. Interpretation of the data has further been complicated by well cycling and production from several horizons. However for a number of wells the extent of variation has been minimal and these have been used to infer changes in the reservoir.

For central wells taping the deep reservoir fluid, the overall trend in changes in fluid chemistry has been a gradual increase in concentration of the dissolved constituents with time. This is quite clearly seen for the conserved species such as chlorides. This observation is consistent with extensive boiling and loss of steam from the reservoir due to pressure decline as has been observed from physical measurements. Fig.8 shows a plot of variation in chloride and conductivity of OW-18 as a typical central well. For shallow wells (e.g OW-5) decline in chloride levels has been observed and implies an increase in condensate level in well discharge. The increase in condensate is attributed to cooling of reservoir caused by boiling.

On the field edge brine chemistry has shown greater fluctuation in levels of dissolved constituents. However unlike the central wells the general trend has been one of partial stability and occasional decrease in dissolved constituents. This aspects taken in context with the physical observations imply less boiling and a possible

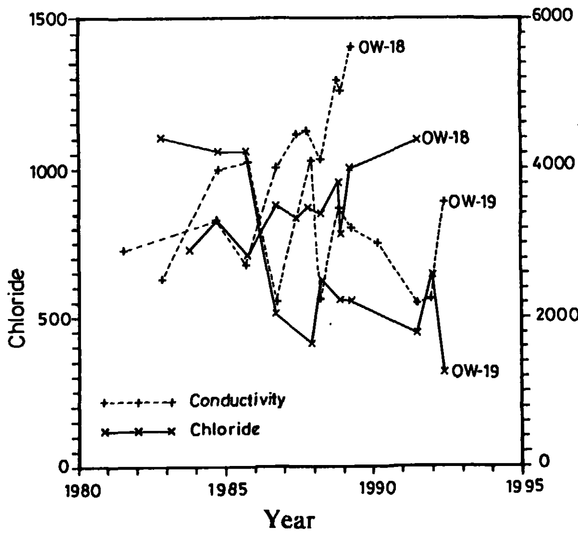

Fig. 8 Chemistry of OW-18 and OW-19

effect of entry of less mineralized waters. Also shown on Fig.8 is the chemical history of OW-19 which is known from physical measurements to be affected by entry of cooler fluids.

For the geothermometers, the trend has been a decline in the apparent reservoir temperature with time. Both show decline of about 20^0C which is higher than the drop from the physical measurements. However, the cation ratio geothermometer has always given values that are higher than those of the quartz geothermometer. These two observations and given the rapid equilibration time for the quartz imply cooling in the near well zones due to near well flushing.

DISCUSSION

The production aspects of Olkaria East Field as outlined above shows that several parameters and processes affect reservoir production and a fair understanding of these aspects are fundamental for performance projection and estimates of overall field power potential. Though the main processes can be known from measurements of physical and chemical parameters, the low reservoir permeability and well cyclicity imply that only a unified interpretation from the two sets of data can give sufficiently reliable results on which reservoir management decisions can be based

Drilling replacement wells as a means of getting additional steam to meet plant demand has been done in various parts of the field and presently nearly 200 t/hr is available from these wells. However the amount of additional steam needed for this purpose can be reduced substantially if some of the lost production of the wells already on line can be restored. From the production history of the central wells it is evident that deepening of the shallow wells so as to intercept the deeper parts of the reservoir is likely to restore steam flow from these wells to higher levels and reduce the decline rates to reasonable rates. Workover operations are presently being considered for some of these wells.

Another way of restoring steam production is by reinjection. There are indications of entry of cooler fluids in the wells on the field edge and the effects of the fluids have had on reservoir have been outlined above. However the rate of entry seems slow and the low permeability also means that the entry rates can never be sufficient replenishment for the parts of the reservoir distant from the edge. Thus, reinjection in the field center where large amount of energy is still stored in the rocks is considered appropriate. To determine a priori the best possible injection strategy and evaluate the effects that the reinjected fluid will have on the reservoir and well performance, tracer tests are to be done shortly.

CONCLUSION

On the basis of production and chemical trends together with changes of physical parameters over an exploitation period of more than ten years, the dominant changes in the Olkaria East field and the fields drawdown characteristics have been identified. The overall assessment shows that deepening of shallow wells in the field center and reinjection could improve well production and reduce decline rates of steam production.

Acknowledgement.

The authors are grateful to the management of The Kenya Power Company Ltd for the permission to publish this paper. We are also most indebted to Mr. Charles Muchemi who prepared all the diagrams in this paper.

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