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OLKARIA I RESERVOIR AFTER 26 YEARS OF PRODUCTION

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ABSTRACT

Exploitation of Olkaria field started in 1981 when Olkaria I (East) reservoir began producing steam for the 45 MWe Olkaria I power plant. During the twenty six years of production, the reservoir has performed quite well with minimal drawdown in the range of 20 bars in the deep water dominated reservoir. Some decline in production occurred in the first ten years of exploitation due to depletion of the steam zone but after connection of make-up wells in 1996, there has been no more decline experience. Only eight make-up wells have been drilled and total steam available has been in excess since connection of the make-up wells. Deepening of well OW-5 from 901 to 2200 m showed an untapped deeper reservoir. There has been no significant change in overall chemistry but wells located at the center of the field have experienced more boiling. Olkaria I reservoir has reached steady state under the current production rate and no cooler incursion has occurred. In summary, after the twenty six years of production, no significant negative change has occurred.

1. INTRODUCTION

Olkaria is located in the Kenya Rift which is within the East African Rift System (EARS) that stretches from the Afar triple junction in Djibouti in the north to Mozambique in the south and is a N-S trending zone of crustal spreading, characterized by volcanic activity, normal faulting and the formation of large-scale graben structures. The Kenya Rift began to develop in Oligocene time (approximately 30 million years ago) and continues to be an active tectonic zone at present (Figure 1).

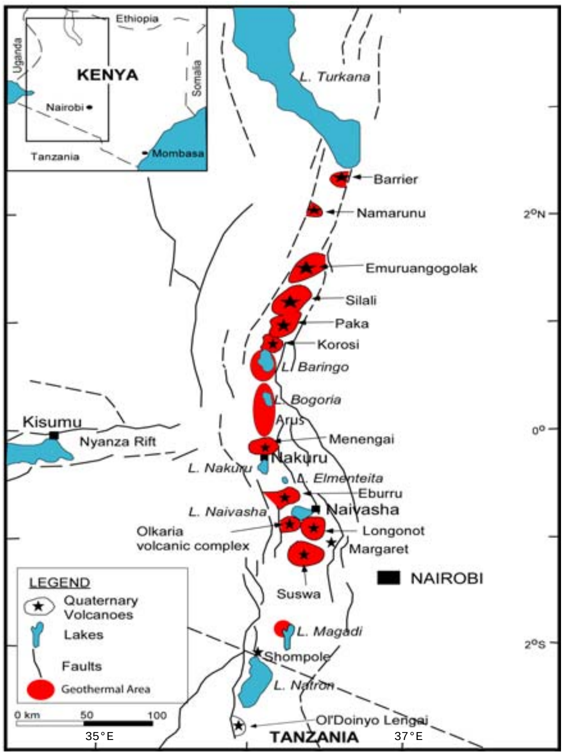

FIGURE 1: Location of Olkaria in the Kenya Rift

Olkaria I (Olkaria East) is one of the several geothermal reservoirs hosted within the Greater Olkaria geothermal area. Others are Olkaria II (Olkaria Northeast), Olkaria III (Olkaria West), Olkaria Central, Olkaria Domes, Olkaria Northwest and Olkaria Southeast (Figure 2). Olkaria I reservoir serves the pioneer 45 MWe plant which was commissioned between 1981 and

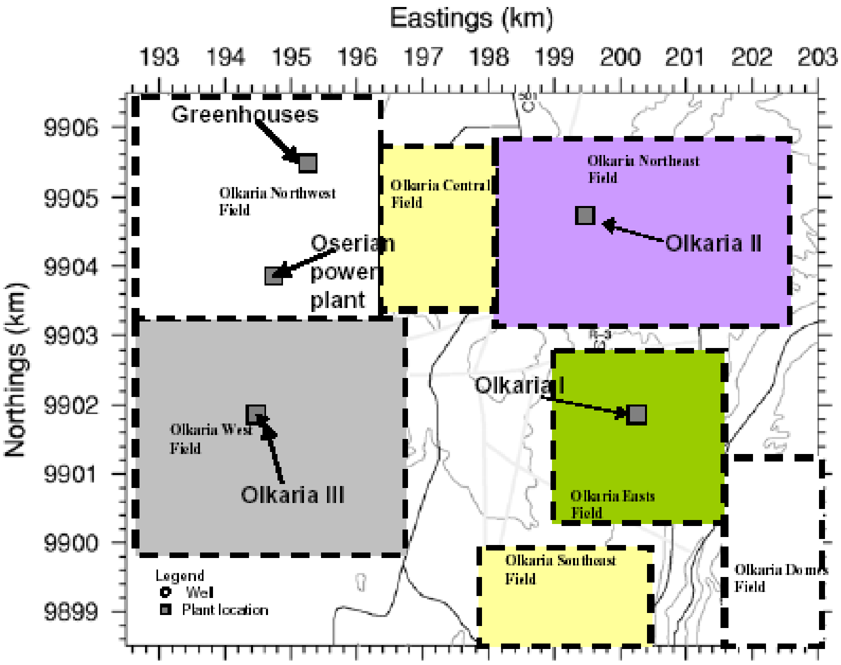

FIGURE 2: Geothermal fields hosted within the greater Olkaria geothermal area

1985, in three stages. The first 15 MWe unit was commissioned in July 1981, the second in December 1982 and the third in April 1985. Olkaria II reservoir serves the 70 MWe plant (now being expanded to 105 MWe) which was commissioned in October 2003 and Olkaria III reservoir serves the 13 MWe plant (now being expanded to 48 MWe) which was commissioned in August 2000. Drilling is ongoing in the Domes area where a 140 MWe plant is planned for if drilling results prove a sufficient resource area.

Olkaria geothermal field is a remnant of an old caldera complex which has been intersected by N-S normal rifting faults that have provided loci for later eruptions of rhyolitic and pumice domes. Faults trending N-S, NE-SW to NNE-SSW, NNW-SSE and E-W characterize the geological structure in the greater geothermal area. Subsurface stratigraphy of Olkaria wells show that from the surface (which is at an average elevation of 2000 m a.s.l) to about 1400 m a.s.l, the rocks consist of Quaternary comendites with an extensive cover of pyroclastics. This top formation acts as the cap rock to the geothermal reservoirs. Below these, the dominant rocks are trachytes with basaltic lava flows and tuffs that mainly occur as thin intercalations. Below the cap rock, permeability is encountered at the fractures, lava contacts and porous pyroclastic beds and tuffs. Faults provide vertical permeability to wells that intercept them.

Resistivity structure of the greater Olkaria geothermal area shows a low resistivity-zone widely distributed in the northern, central and southeastern portions of the Olkaria geothermal field at depths around 1000 m a.s.l. (Figure 3). This low-resistivity zone trends NNW-SSE reflecting a fault structure in this direction. At depth, this trend continues and coincides with the distribution of micro-earthquake epicenters. This NNW-SSE trending structure is the main fault controlling geothermal fluids at depth in the Eastern Olkaria geothermal area where Olkaria I reservoir is hosted.

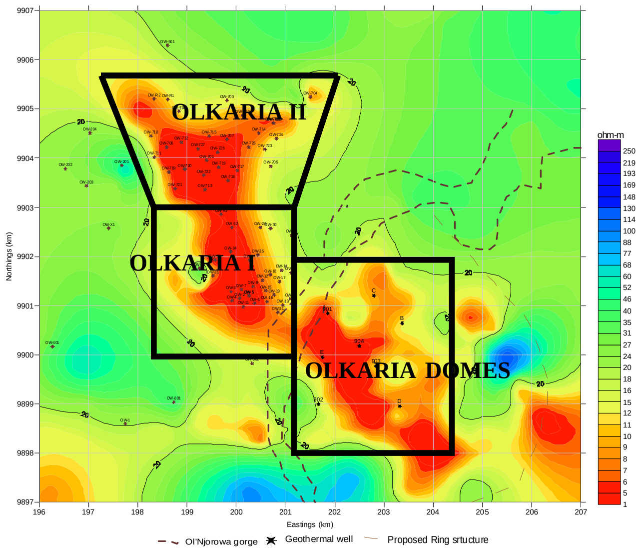

FIGURE 3: MT resistivity at 1000 m a.s.l.

Initial fluid chemistry gives the impression that the reservoir fluid evolves from a deep source of fluid at 340°C with a 600 ppm Cl concentration which rises into the Olkaria II reservoir and separately into the Olkaria I reservoir. Boiling and steam separation (particularly in the upper 2-phase zone) then forms a secondary parent in the Olkaria I area, at about 290°C with 750 ppm Cl concentration.

Olkaria I reservoir has supported the pioneer 45 MWe plant since 1981 and over the years the performance of the reservoir has been keenly monitored. This paper discusses the observed changes in reservoir conditions as a result of 26 years of exploitation and some experiences learnt.

2. RESERVOIR RESPONSE TO EXPLOITATION

2.1 Production history of Olkaria I reservoir

Olkaria I reservoir has been in production since July 1981. At the time of commissioning unit 3 in 1985, 23 wells (all drilled to depths ranging from 900 to 1685 m, except OW-19 drilled to 2484 m) were connected to supply steam to the power plant but as time progressed, some of the wells (mainly drilled to depths between 900 and 1200 m) declined in output and had to be isolated. New make-up wells were then drilled to restore the generating capacity, which had declined to 31 MWe by 1994 (Mwangi, 2000). Four make-up wells were connected in 1995 (OW-27, 28, 29 and 30), two more in 1996 (OW-31 and 33) and another two (OW-32 and 34) in 2001. After connection of the make-up wells, and deepening well OW-5 (in 1998) from 900 to 2200 m, total steam available from the existing exploitable wells increased and since then has remained high exceeding what is required for generation of 45 MWe. The excess steam has been over 300 t/hr and plans are now underway to optimize the use of this excess steam as well as to determine the optimal capacity of the reservoir.

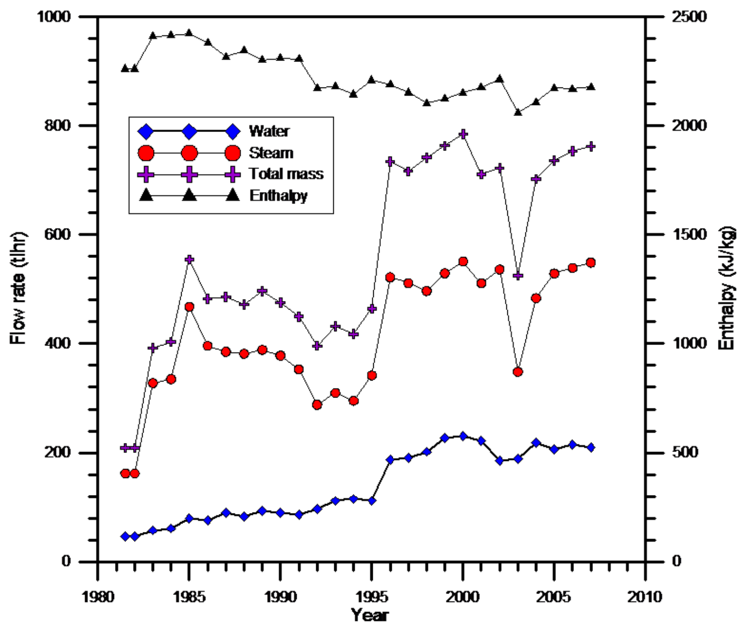

FIGURE 4: Overall production history of Olkaria I reservoir

Figure 4 shows the overall Olkaria I production history, the values of mass production rates are yearly averages and the enthalpies are weighted averages. It is generally observed that the mass output increased after connection of the make-up wells in 1996 and the enthalpy had been on the decline even before the make-up wells were connected. The increase in mass output is attributed to drilling of deeper wells. These tapped deep permeable production zones which produced high mass flows and were more liquid-dominated than the shallow steam-dominated zones that were tapped in the older shallow wells. The decline in enthalpies is attributed to shift from shallow to deeper production zones and injection/re-injection schemes. There seems though, to have been some stability in the last ten years.

Figures 5 and 6 show production histories of wells OW-2 and OW-19, and represent the behaviour of most production wells in Olkaria I. Generally, there was an initial high decline rate of about 3-4% up to early 90's, and from that point the wells show either constant production or increase in output. The decline rate is now practically zero. This has been interpreted to imply that the reservoir has reached steady state.

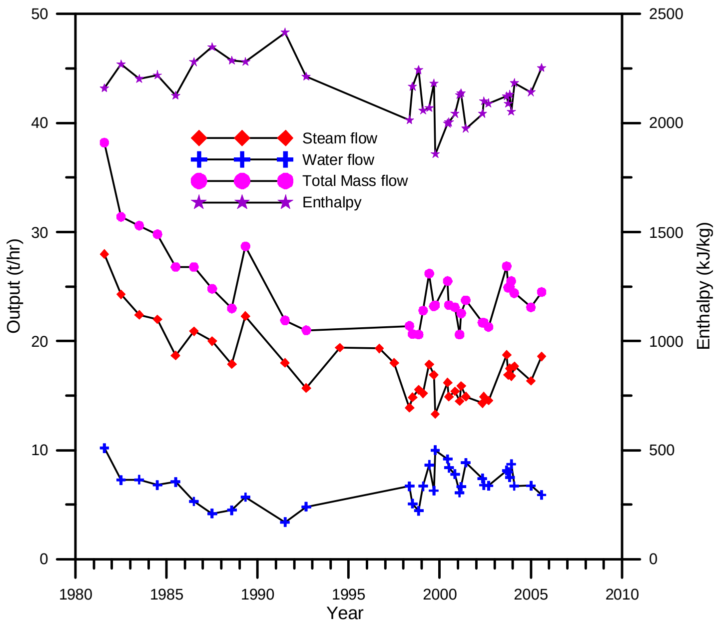

FIGURE 5: Production history of well OW-2

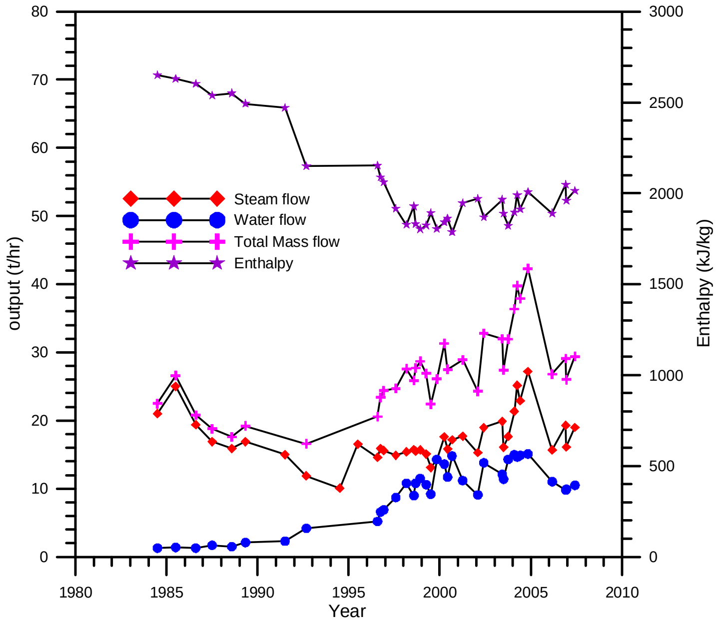

FIGURE 6: Production history of well OW-19

Cold and hot re-injection has also been done in small scale and has had positive effects as wells in Olkaria I and II have responded well with increased or stabilized outputs. Cold injection though has been done intermittently due to breakthroughs leading to drop in enthalpies but after few months of stoppage, the wells do recover and increase their outputs.

Only well OW-34 has had silica deposition problem on surface equipment but studies have shown that this problem is unique only to this well and that the deposition has not affected its output.

2.2 Pressure response due to production

Due to high demand for steam, no wells within Olkaria I production field were available for monitoring pressure response due to production. Only well OW-3 and well OW-9 were considered unsuitable for production and could have been used for this purpose but well OW-3 was used for field injection experiments and well OW-9 had internal flow and was also later on plugged due to its close proximity to the project offices. However, well OW-8 has some good pressure decline history. This well was first drilled to 1080 m in November 1978 and intercepted permeable zones at 600-700 m and 900-1080 m depth. It was then deepened to 1600 m in 1983 intercepting more permeable zones at 1300-1400 m. It remained shut-in from 1979 to 1983 and again to September 1985 when it was connected to the steam supply system. Production from this well continued until October 2000 when it was shut-in. It has remained shut-in to date and is now used as pressure monitoring well.

Well OW-3 was never connected to the production system and has been used for re-injection experiments. It was shut in for a long period of time before 1992 and can give some good pressure drawdown data up to 1992. Well OW-21 has been shut since 2000 and is now logged periodically to monitor reservoir pressures. Figure 7 shows the pressure drawdown at 640 m a.s.l. (1300 m depth), as measured in several wells. The decrease in pressure drawdown in the year 2003 and 2004 is due to shut-in of most wells as a result of long time shut-down of Unit 1 (over 1 year). A water influx model fits the drawdown data reasonably well. The parameters of this fit are a time constant of 2 years and recharge coefficient of 116 kg/MPa.s. This differs from the previous analysis done by this author (Ofwona, 2002) in which the time constant was 7.7 years and a recharge coefficient of 80 kg/MPa.s.

The difference in values has come about because of the more data used in fitting of the later model. However, conclusion is still the same that production from Olkaria I has reached steady state conditions.

2.3 Changes in fluid chemistry during exploitation

Chemical data in Olkaria I wells (Figures 8-11) show large data scatters and irregularities, which are partly due to high-enthalpy production from 2-phase conditions and multiple feed zones, e.g. in zones lying along or very close to the liquid-vapour saturation curve, it takes only very small shifts of temperature or pressure to generate or collapse the steam phase, which causes large shifts of gases in steam. In spite of this, it appears that reservoir chemistry at most of the Olkaria I wells has been relatively stable. Some small trends over extended time are apparent but the pattern of Cl increasing and gases increasing then decreasing over time are evident and can be attributed to boiling in the two-phase zone of the reservoir, which concentrates Cl, causing gases to increase as liquid-dominated zones are boiled off. Subsequent decrease in gases then occurs as a portion of re-supply comes from greater depth, where gases are lower (KenGen, 2004). It is also observed that there is a rise in alkalinity / Cl in some wells and a decline in some. The shift can be attributed to changes in production zones and infiltration from above the reservoir or from the sides.

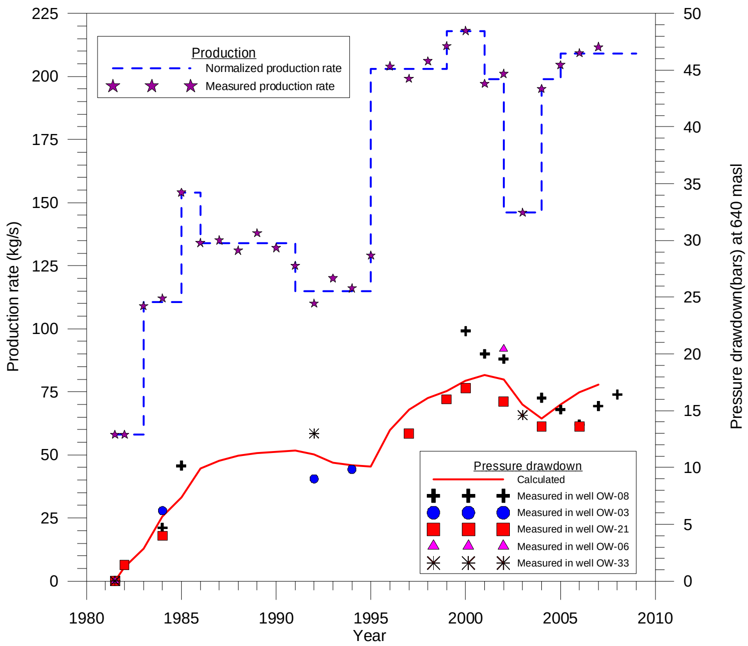

FIGURE 7: Total production rate and pressure drawdown

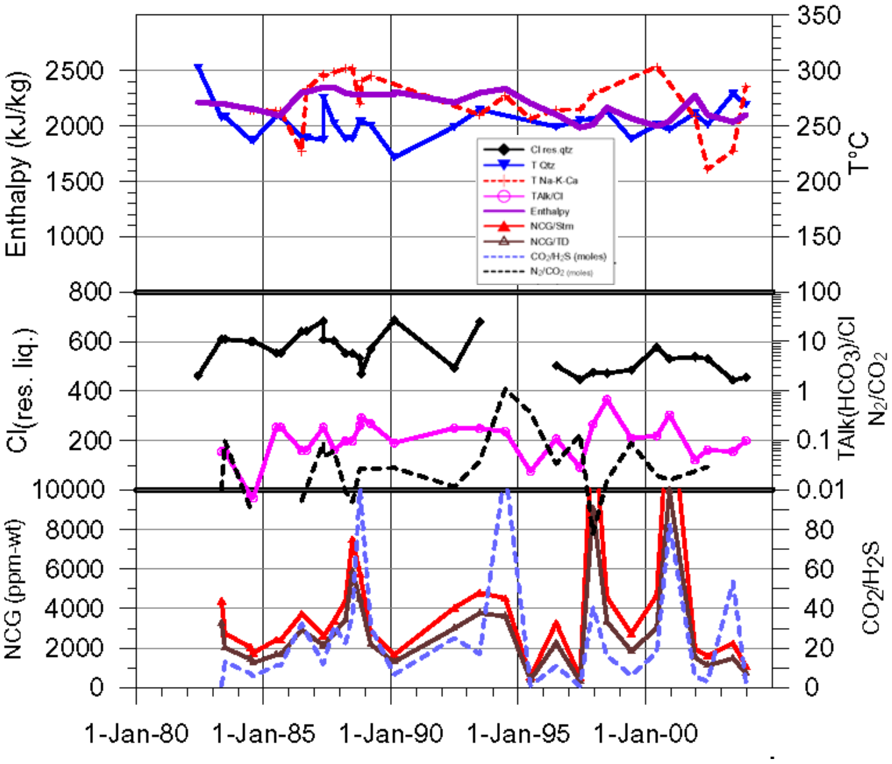

FIGURE 8: Changes in well OW-2 fluid chemistry

However, none of these shifts is large enough to merit a conclusion of major changes to have occurred in the reservoir. The general fact is that production from Olkaria I reservoir does not appear to have induced large amounts of infiltration from above or from the sides of the reservoir.

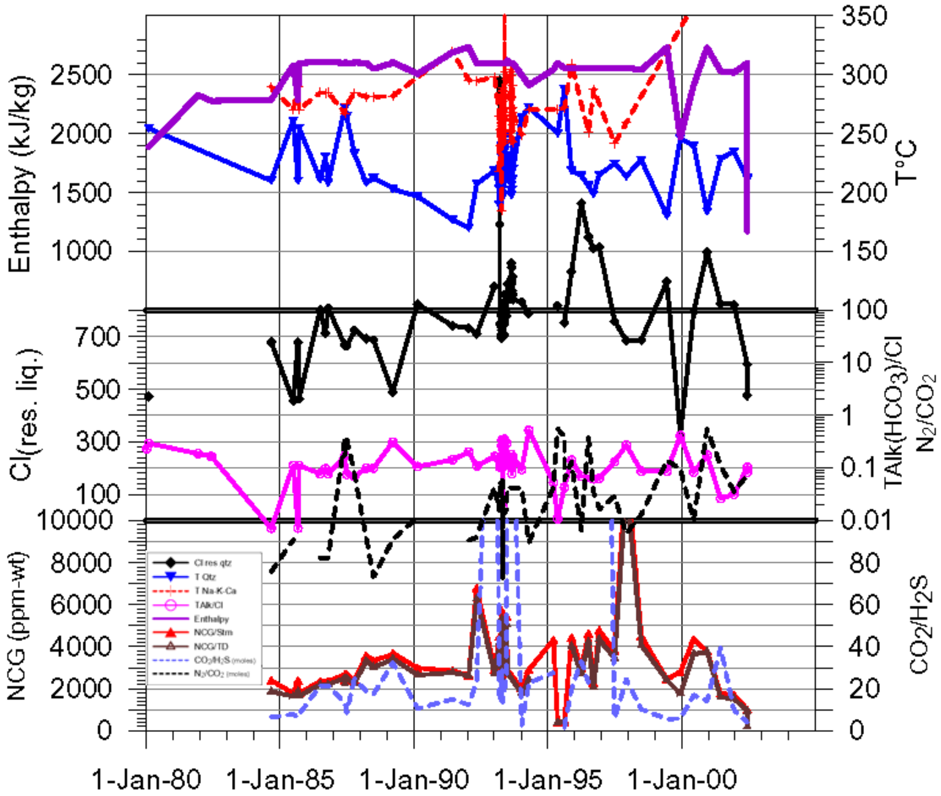

FIGURE 9: Chemical changes in well OW-10

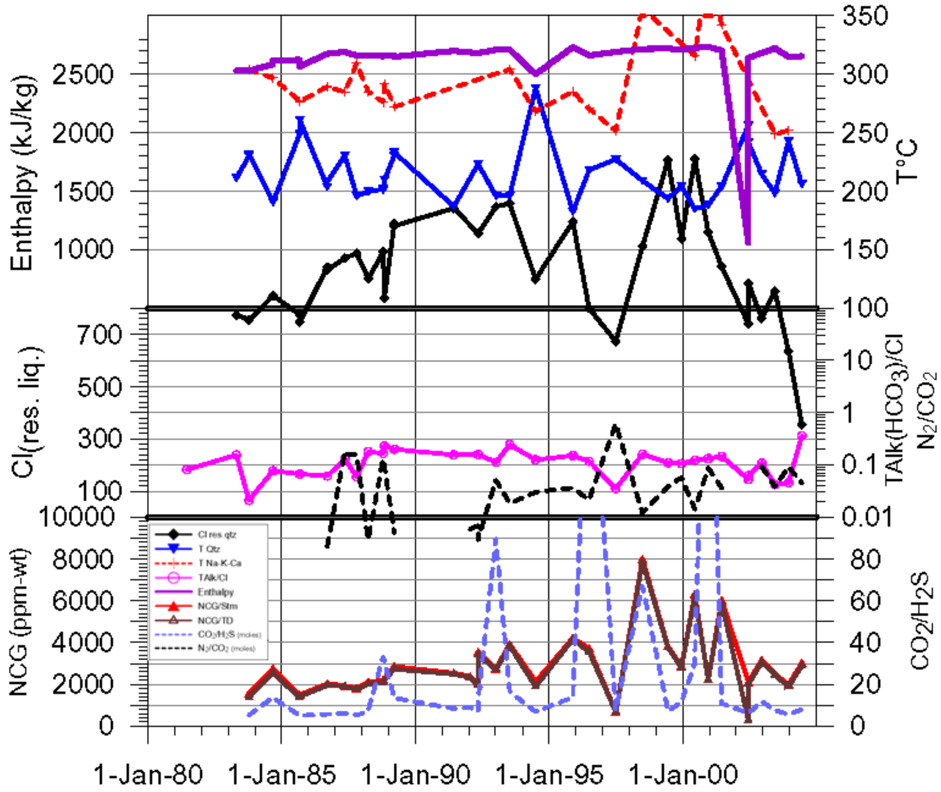

FIGURE 10: Chemical changes in well OW-18

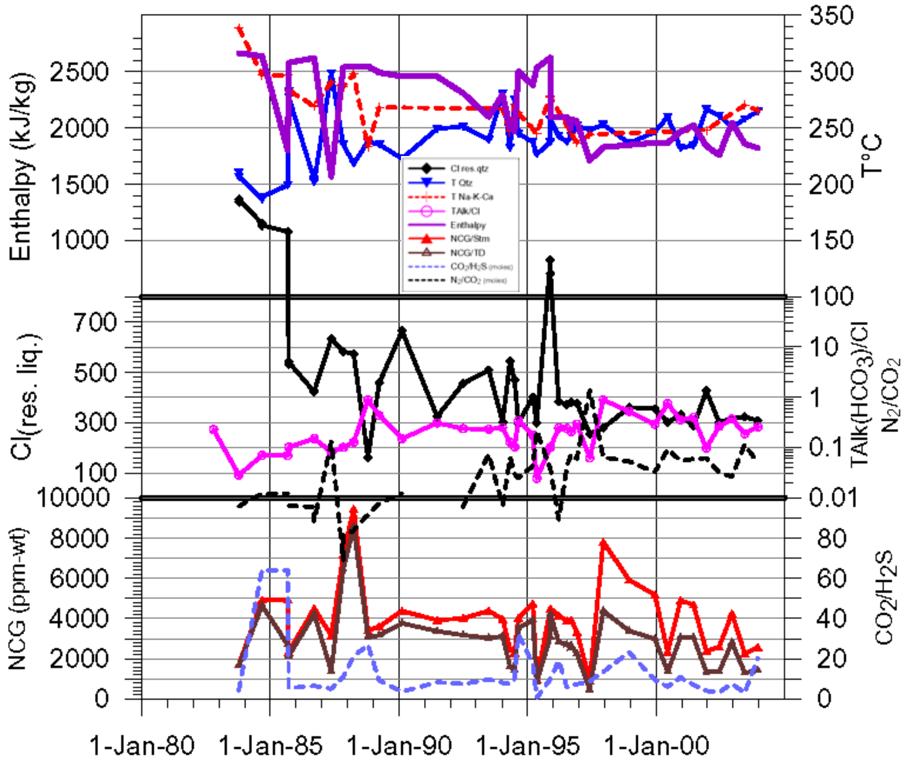

FIGURE 12: Chemical changes in well OW-19

2.3 Experience from operation of Olkaria I field and lessons learnt

During the 26 years operation of Olkaria I field, the following has been experienced.

1. Shallow wells that only tapped into the steam zone like wells OW-5, OW-12 and OW-14 depleted within the first 10 years of production.

2. Deep wells like OW-19 are still producing and have in fact, improved their performance with time as deeper feeders became active with depletion of the shallow steam dominated feeders.

3. Drilling deeper make-up wells and deepening of well OW-5 led to the discovery of untapped reservoirs at depth.

4. Even though more boiling has taken place in the two-phase reservoir, no negative chemical changes have occurred.

5. The production has reached steady state and suggests that the reservoir is not closed and due to the fact that no cold intrusion has occurred, the neighbouring rock is still pretty hot.

6. Scaling problem that occurred in well OW-34 was a local problem only to this well due to failure of the cemented casing.

7. Hot re-injection can be beneficial in the long run and cold injection should not be done within the field.

8. There should be a good data collection programme and this should just be as important as power generation. Field monitoring wells should also be a part of the field development budget.

4. CONCLUSIONS

Olkaria I reservoir has been in production since 1981 and has performed very well. Initial decline in the first ten years was due to depletion of the shallow steam zone. Deep wells that tapped into the water-dominated zone are still producing and some even getting better. Olkaria I reservoir has reached steady-state under the current production rate and no cooler incursion has occurred. The chemistry of the reservoir fluids has not changed much and there is a deeper untapped reservoir which should be drilled into. In summary, no significant negative change has occurred.

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