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RESERVOIR RESPONSE TO 28 YEARS OF PRODUCTION AT OLKARIA I, KENYA

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ABSTRACT

Exploitation of Olkaria geothermal field started in 1981 when Olkaria I (East) reservoir began producing steam for the 45 MWe Olkaria I power plant. During the twenty eight 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 experienced. 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 m 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 seems to have reached steady state under the current production rate and no cooler incursion has occurred. In summary, after the twenty eight years of production, no significant negative change has occurred. Due to this good performance, numerical simulation was done to establish how much more additional power could be generated from Olkaria I and based on the results of the study, additional 140 MWe project is now underway.

INTRODUCTION

Olkaria geothermal field is located in the Kenya Rift Valley which is within the East African Rift System (EARS) that stretches from the Afar triple junction in Djibouti next to Red Sea 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 (Figure 1).

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 2).

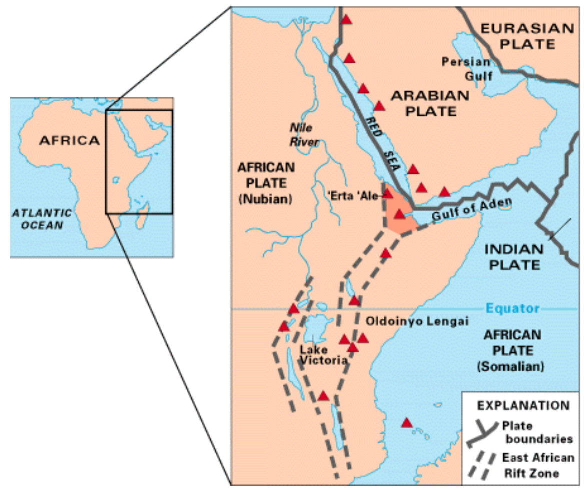

Figure 1: East African Rift System.

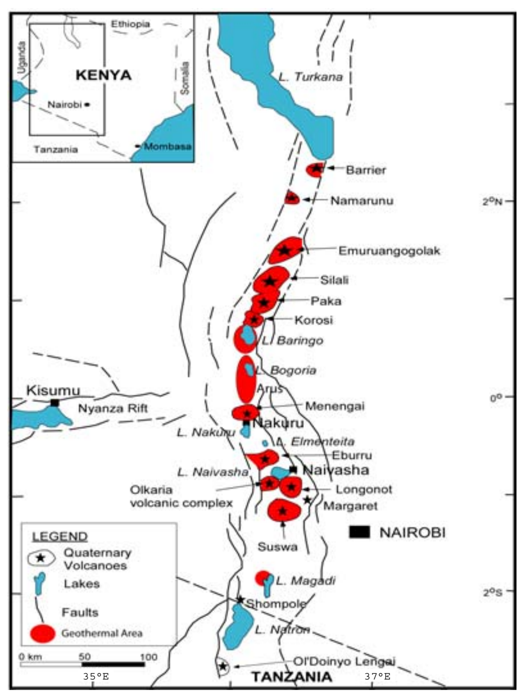

Figure 2: Location of Olkaria in the Kenyan Rift Valley.

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 IV (Olkaria Domes), Olkaria Northwest and Olkaria Southeast (Figure 3 & 4). Olkaria I reservoir serves the pioneer 45 MWe plant which was commissioned between 1981 and 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 105 MWe plant which was commissioned in October 2003 and May 2010. Olkaria III reservoir serves the 55 MWe plant of which the first 13 MWe unit was commissioned in August 2000 and the second 42 MWe unit in January 2009. Drilling is ongoing in the Domes area as well as in Olkaria I. A 140 MWe plant is planned for Olkaria IV and an additional 140 MWe in Olkaria I.

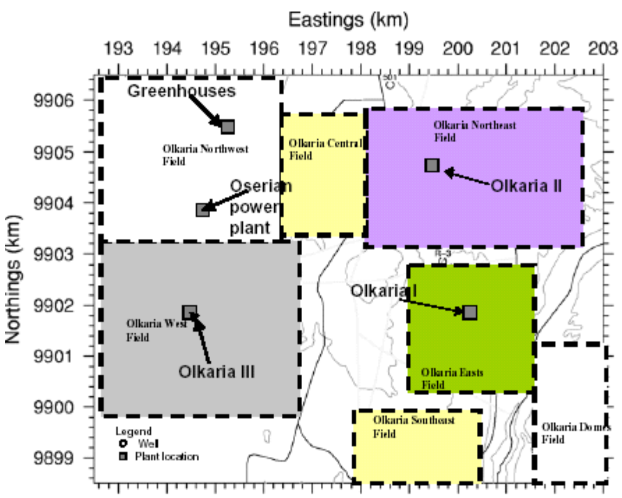

Figure 3: Geothermal Fields within the greater Olkaria Geothermal Area.

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, E-W and a ring structure characterize the geological structure in the greater geothermal area (Figure 4). 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.

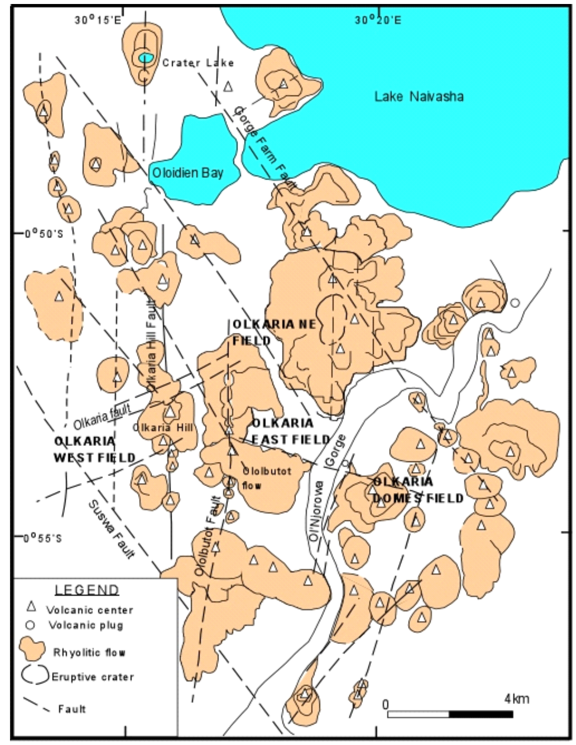

Figure 4: Main geological structures in the greater Olkaria geothermal Area.

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 masl. This low resistivity zone trends NNW-SSE reflecting a fault structure in this direction. At greater depths, 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.

Initial fluid chemistry suggests that the reservoir fluid originates from a deep source of at 340°C with a 450 ppm Cl concentration. During the upwelling, boiling and steam separation (particularly in the upper 2-phase zone) then forms secondary fluids.

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 28 years of exploitation.

RESERVOIR RESPONSE TO EXPLOITATION

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 m 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 m to 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 (Figure 5). After connection of the make-up wells, and deepening well OW-5 (in 1998) from 900 m 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 will be utilized in the additional 140 MWe Olkaria I unit IV and V.

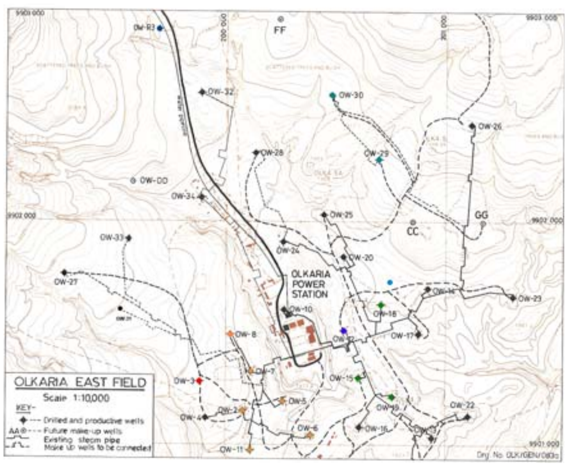

Figure 5: Olkaria I well locations.

Production and Injection history

Figure 6 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 that 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 (Ofwona, 2002). There seems though, to have been some stability in the last ten years.

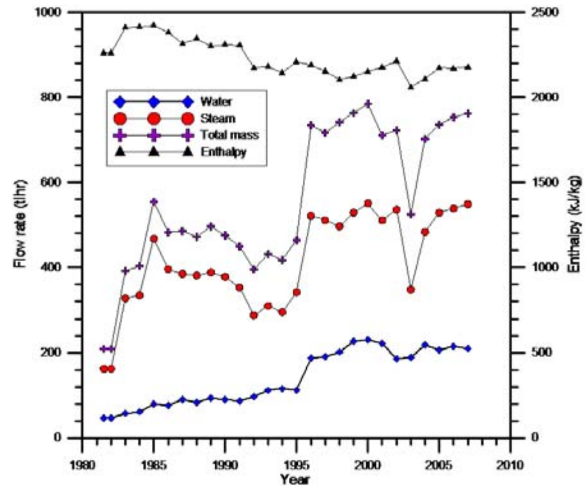

Figure 6: Overall production history of Olkaria I.

Figure 7 and 8 shows production histories of wells OW-2 and OW-19, which represent the behavior 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 then, the wells show either constant production or increase in output.

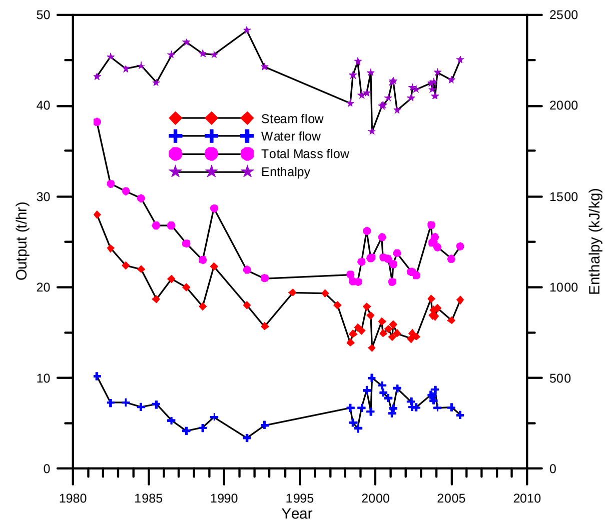

Figure 7: Production history of well OW-2.

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. Figure 9 shows the decline in enthalpies in well OW-15 in 1997 due to cold injection in well OW-12. 100 t/hr of cold water (20°C) was injected well OW-12 between July 1996 to August 1997.

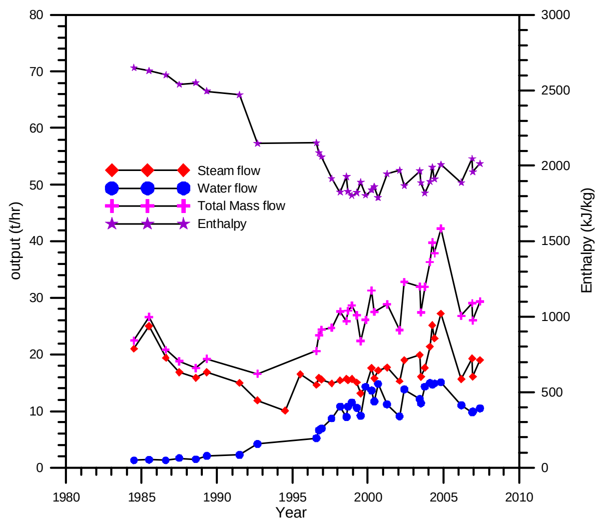

Figure 8: Production history of well OW-19.

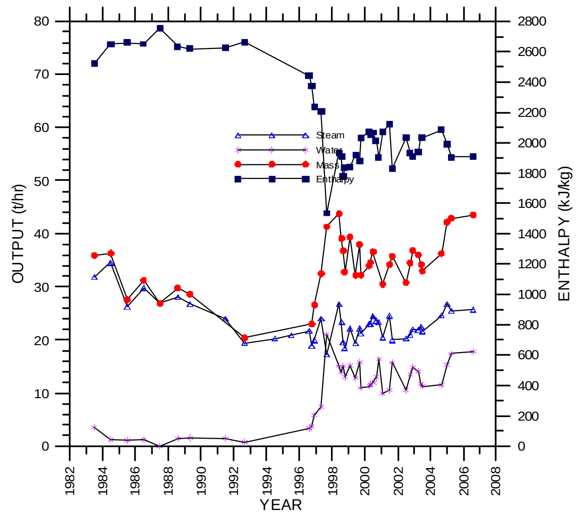

Figure 9: Response of well OW-15 to cold injection in well OW-12.

Pressure response to production

Pressure monitoring in Olkaria I production field has been done in well OW-3, well OW-8 and well OW-21. Some data has also been obtained from well OW-5 and OW-33. Well OW-8 has given the most 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.

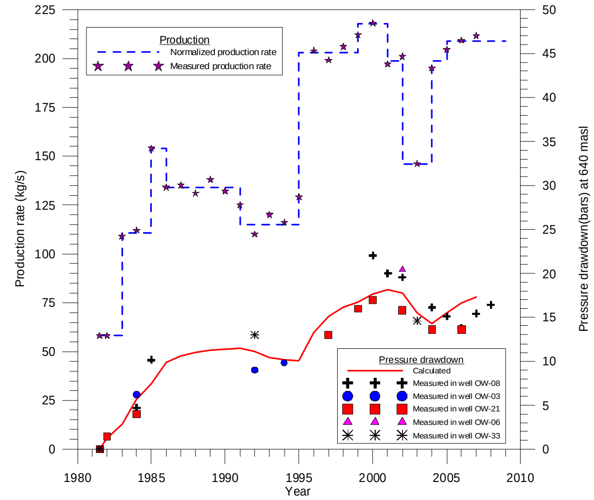

Figure 10: Pressure drawdown at 640 masl (1300 m depth) in Olkaria I.

Changes in fluid chemistry during Production

Chemical data in Olkaria I wells (Figure 11 – 13) 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-vapor 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 occur 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. 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 the sides of the reservoir.

CONCLUSIONS

Olkaria I reservoir has been in production since 1981 and has performed quite well. Initial decline in the first ten years was due to production from the shallow reservoir and depletion of the steam zone. Deep wells that tapped into the water dominated zone are still producing and some even getting better. Output from well OW-2, OW-15 and OW-19 shows that injection has increased well output but resulted in initial drop in enthalpy which then recovers with stoppage of the cold injection. Well chemistry suggests that no cooler incursion from outside has occurred into the reservoir and generally, the chemistry of the reservoir fluids has not changed much. It is evident that there is a deeper untapped reservoir which should be drilled into.

Due to the good performance of Olkaria I and the experience gained during 28 years of exploitation, feasibility studies were done to find out if it is possible to increase production. The results were positive and it is now planned to increase generation in this sector by 140 MWe. Drilling of production wells for this undertaking is on progress.

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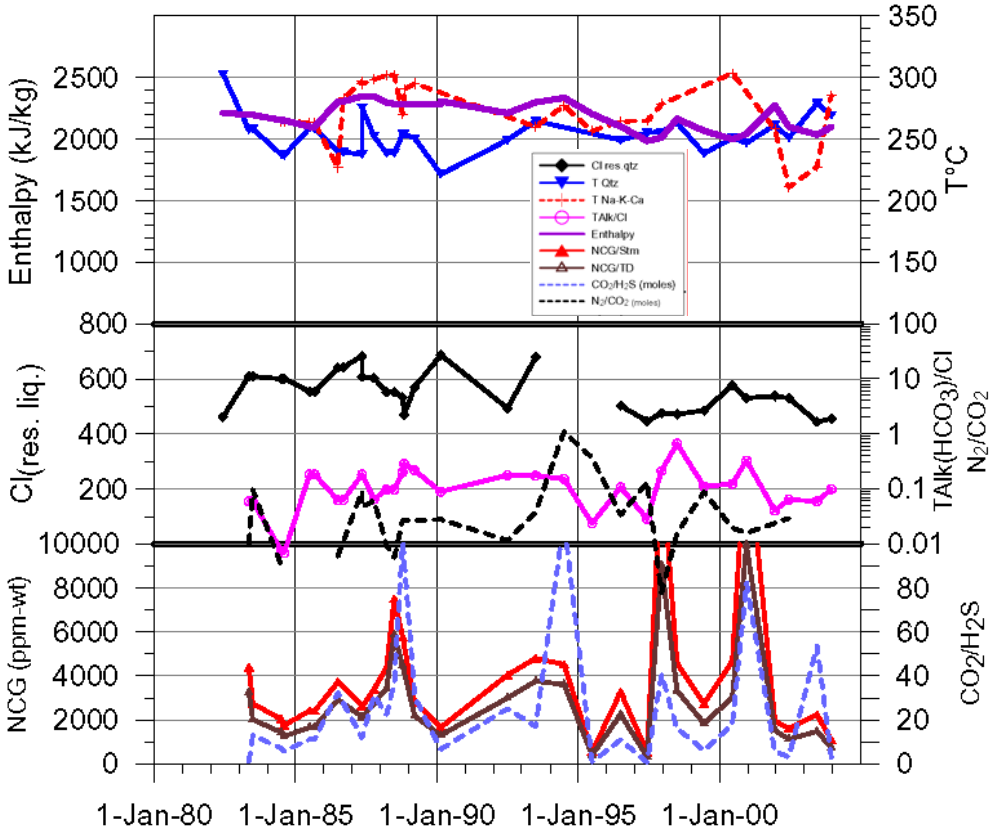

Figure 11: Changes in chemistry of fluids discharged from well OW-2 (Courtesy of KenGen 2004).

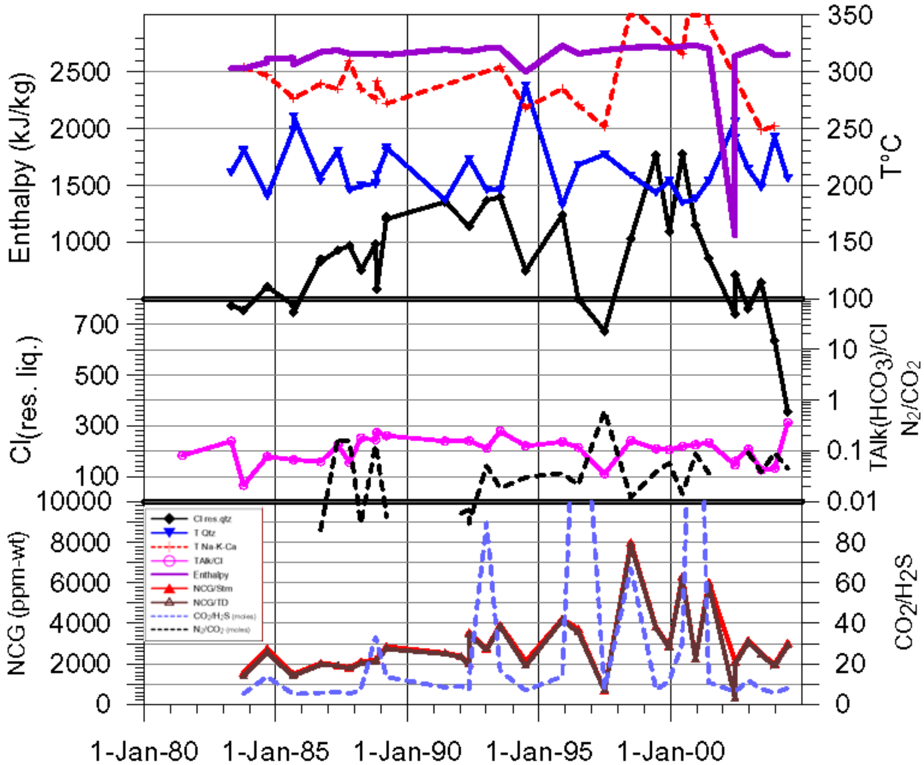

Figure 12: Changes in chemistry of fluids discharged from well OW-18 (Courtesy of KenGen 2004).

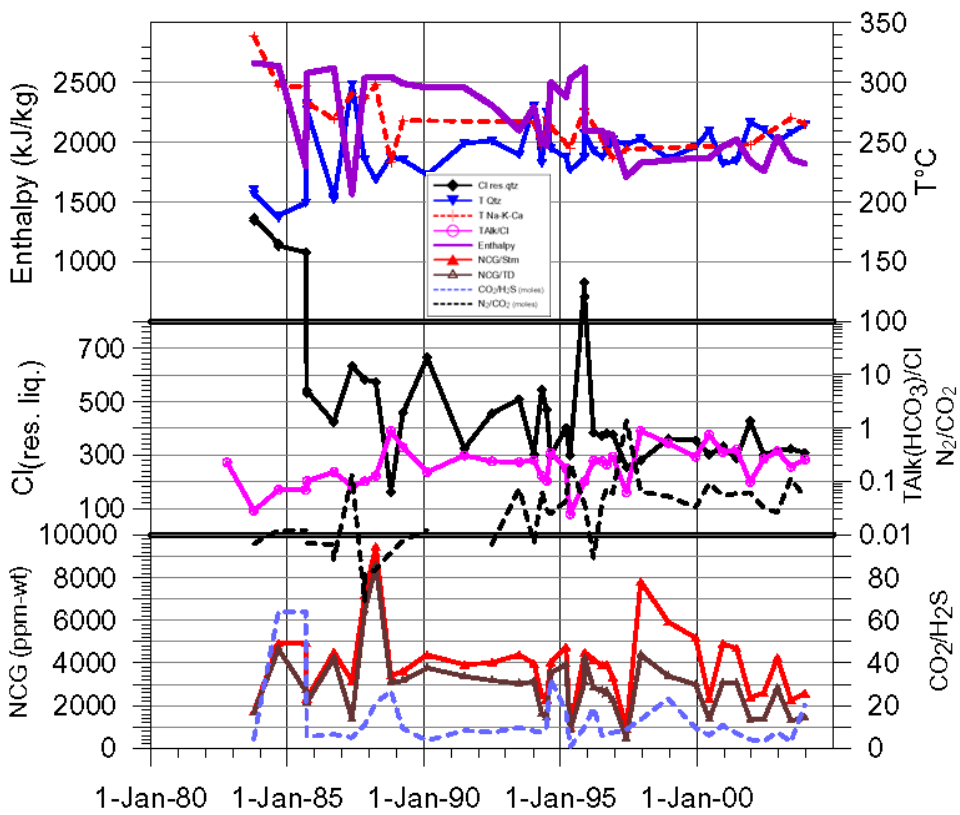

Figure 13: Changes in chemistry of fluids discharged from well OW-19 (Courtesy of KenGen 2004).