ENTHALPY TRENDS AS INDICATOR OF RESERVOIR PROCESSES IN PALINPINON-1, SOUTHERN NEGROS GEOTHERMAL PRODUCTION FIELD, PHILIPPINES

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ABSTRACT

Continuous exploitation in the Palinpinon-1 sector of the Southern Negros Geothermal Production Field resulted to major changes in the reservoir. These changes have been diligently monitored using standard geochemical parameters such as reservoir chloride (Clres), total discharge CO_2 (CO_{2td}), and $TSiO_2$. A supplementary method, the enthalpy method, has been forwarded as a reservoir process monitoring technique. Assessment of the said method in the Palinpinon-1 sector of the Southern Negros Geothermal Production Field reveals that the enthalpy method complements the standard geochemical monitoring techniques in indicating the different processes occurring in the reservoir.

Three major reservoir processes have been identified. The first is reinjection breakthrough brought about by the close proximity and direct fault connections between the production and reinjection wells. Recovery from reinjection returns was detected in some wells alter implementation of mitigating measures such as the transfer of the reinjection sink to a farther location. The second process is boiling induced by pressure drawdown that eventually caused production in the upper two-phase and steam zone in some wells. Lastly, entry of old acid fluid also occurred possibly as an effect of the decline in reservoir pressure.

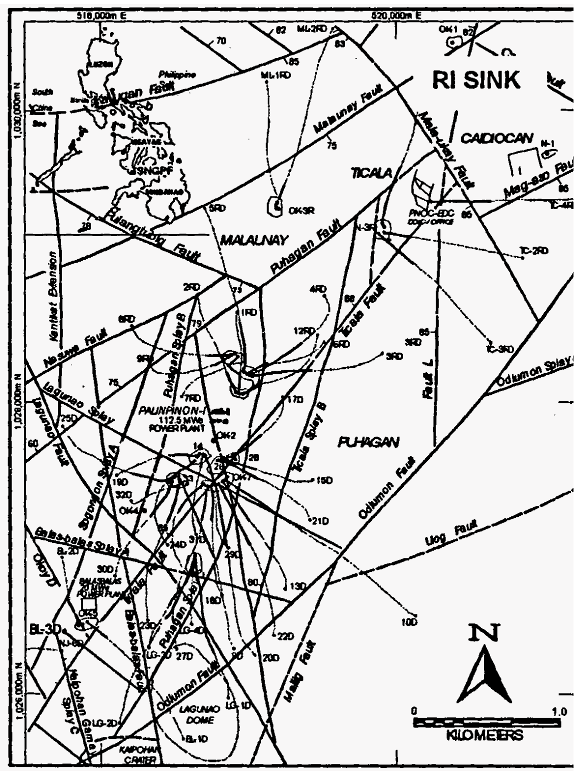

Figure 1. Location and structural map of Palinpinon-I, SNGPF showing tracks of production and reinjection wells

1.0 INTRODUCTION

The continuous exploitation of the Palinpinon-1 resource of the Southern Negros Geothermal Production Field (SNGPF) (Figure 1) since the commissioning of the 112.5 MWe Power Plant in 1983 up to present, have caused major changes in the reservoir. These changes have been effectively monitored as they occur through the use of standard geochemical techniques (Hermoso and Mejorada, 1997; Vidal, et al., 1999).

The application of the enthalpy method as an indicator of reservoir processes has been assessed and proven to be useful in some high-temperature geothermal fields (Siega, 1998; Maturgo, 1999; Truesdell et.al, 1995). This paper will illustrate how the enthalpy method works as it complements the geochemical monitoring techniques in identifying the different reservoir processes in palin pinon-1 geothermal field.

2.0 METHODOLOGY

The enthalpy method forwarded by Truesdell et.al (1995) basically compares the vafues of the enthalpies from one another, from which specific subsurface processes are derived from their relationship. The enthalpies compared are discharge enthalpy (Hm) calculated from Bore Output Measurements (BOM), and solute enthalpies converted from silica (Hsil) and Na-K-C (Hnkc) geothermometers.

The 25 production wells in Palinpinon-I were assessed using chemical data from 1983 to 1999. However, only 4 wells, which best illustrate the processes will be shown in the following discussion.

3.0 RESERVOIR PROCESSES

The response of the Palinpinon-I reservoir to the continuous exploitation is manifested in the behavior of the physical and chemical characteristics of the production wells through time. The different processes occurring in the reservoir have been detected and monitored using monitoring geochemical tools, such as reservoir chloride (Clres), total discharge CO_2 (CO_{2td}), Cl/Ca, sulfate at the reservoir (SO_{4res}), and $TSiO_2$.

The trends as shown by the discharge enthalpy and solute enthalpy complement these processes. The enthalpy trends shown by the wells also reflect the progress of one process to the other.

3.1 Reinjection (RI) breakthrough

The geothermal brine of the Palinpinon field is injected back to the ground. The Palinpinon field provide a very good example of how reinjection fluids (RI) could become detrimental to a producing field. An increase in mass extraction from the field starting 1983 led to an increase in the reinjected fluids back to the reservoir. This immediately caused a reinjection breakthrough in most of the production wells, identified through the changes in the chemical parameters of the discharged fluids.

Aside from the usual indication of increasing Cl concentration, tracer tests conducted as early as 1983 proved that there is a direct interconnection between the production and reinjection wells through the Ticala and Puhagan Faults (Figure 1) hence the fast reaction of the production wells to the reinjected fluids (Vidal et al., 1999). Moreover, due to terrain limitations, the reinjection wells are separated from the production wells by mere 1 km or even less; thus a rapid movement of the reinjected fluids.

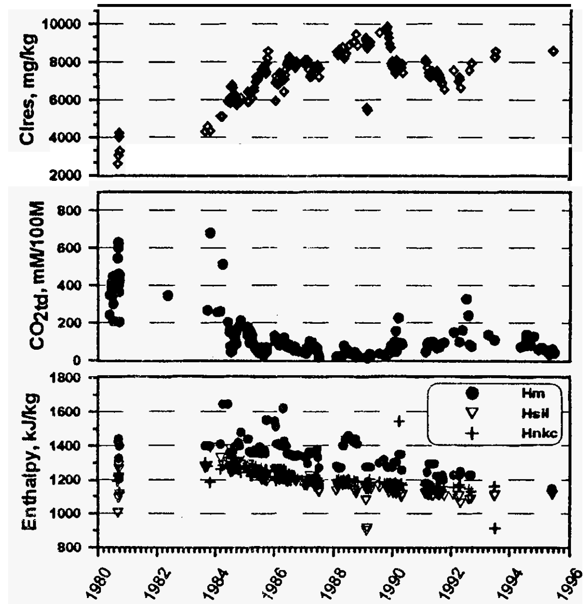

Figure 2. Chemical and enthalpy trends of well OK-7

One well which was affected by RI fluids is OK-7. Figure 2 shows the chemical (Clres and CO_{2td}) and enthalpy trends of the well. The Clres started to increase continuously from 1983 to 1989. CO_{2td}, on the other hand, continuously declined. Flashing of the two-phase fluids in the separator stations tends to concentrate the solutes in the brine while depleting the flashed fluids of CO_2. Thus RI waters (brines) have high Clres and low CO_{2td}.

The incursion of the RI fluids effected a cumulative drop in the output in the production wells, thus the gross generation of the field decreased. This prompted management to transfer the reinjection sector to a farther location in 1989 where communication would not cause a problem. Hence, new reinjection wells were drilled in the Ticala-Malaunay sector, north of the Puhagan production sector (Figure 1).

After the transfer of the RI load, a period of recovery was observed in most wells. From 1990 to 1992, it was observed in OK-7 that Clres decreased from its baseline value of 10,000 mg/kg to about 6000 mg/kg and CO_{2td} increased slightly from about 100 mM/100 M to almost 400 mM/100 M. However, another surge of reinjection breakthrough was observed starting 1994 until the well was closed in 1995. This is caused by the usage of reinjection wells where there is likely direct fault interconnections with the production sectors.

Well OK-7 has a general declining enthalpy trend. Hmeas, Hnkc and Hsil are all observed to be dropping starting 1983. This persisted up until the well was closed in 1995. From 1983 to 1986, the enthalpy trend of the well is Hm>Hsil=Hnkc, which then becomes Hm>Hnkc>Hsil from 1987 up to 1995. This enthalpy trend based on Truesdell's interpretation falls under the boiling category. However, taking into consideration the overall trend of the enthalpies such as their continuous decline along with the trend or behavior of the chemical parameters in this case, Clres and CO_{2td}, the process invoked both by the enthalpy and the chemistry is that of reinjection breakthrough. The continuous decline of the enthalpies denotes the cooling of the reservoir brought about by the incursion of the reinjected waters. Hnkc shows only a slight decline compared to Hsil because of the slower equilibration of the cations as compared to silica (Truesdell, 1995).

Another well which was affected by the reinjection fluids is well PN-15D. Figure 3 shows the chemical and enthalpy trends of the well. The trends of the well not only indicate incursion of RI fluids but also denote other processes such as recovery from RI fluids and boiling. These resulted to shift of production to steam or two-phase zone brought about by pressure drawdown.

RI fluids in this well from 1983 to 1988 are clearly indicated by the increasing Cl concentration and decreasing CO_{2td}. A period of recovery ensued after 1988 to 1990 as evinced by the decline in Clres and rise in CO_{2td}. This recovery coincided with the transfer of the reinjection load to a farther location in the Ticala-Malaunay sector, north of the production wells. Starting 1990, boiling became evident as the pressure in the reservoir started to decline. This is shown by increasing CO_{2td} and Clres.

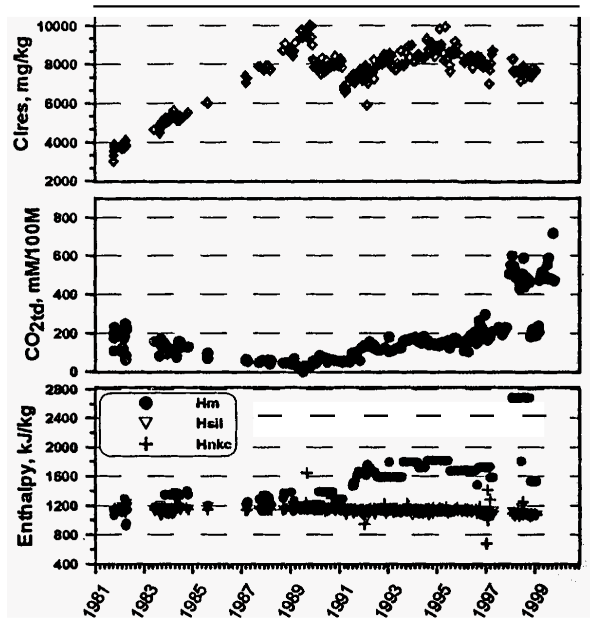

Figure 3. Chemical and enthalpy trends of well PN-15D

The enthalpy trend of the well is Hm>Hsil=Hnkc. The Hm is increasing while Hnkc and Hsil are both gradually declining. This is different from OK-7, where as shown in Figure 2 the three enthalpies are declining all throughout. Reinjection breakthrough is observed from 1981 to 1989, while boiling occurred starting 1991 and eventually progressed to shift of production to the highly two-phase to steam-zone. The increasing Hm after 1991 is caused by the boiling process inside the well. The declining Hsil and Hnkc, also reflect the effect of both RI incursion at the start and boiling later, as fluids cooled brought about by both of these processes.

3.2 Boiling induced by Pressure Drawdown

As the reservoir experiences a drop in pressure due to mass extraction, boiling occurs which leads to the formation of steam-enriched fluid (Truesdell et. al, 1995). The replacement of the original fluid with the newly-formed steam increases the measured enthalpy of the discharged fluid. The residual liquid, on the other hand, tends to cool. The chemical response of the fluid in this scenario is an increase in the gas concentration in the steam phase. The chloride concentration also increases during the initial stages of boiling;

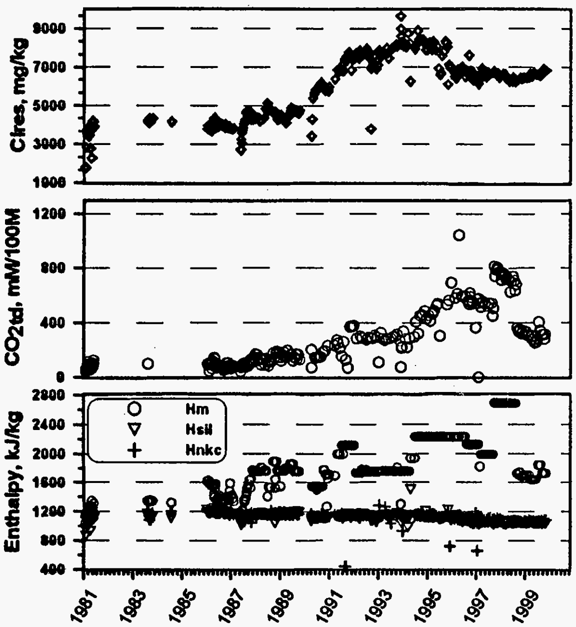

Figure 4. Chemical and enthalpy trends of well OK-10D

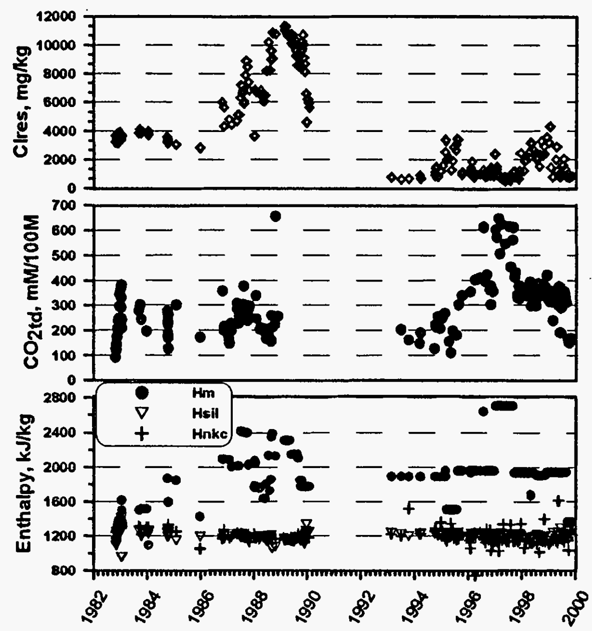

Figure 5. Chemical and enthalpy trends of well PN-20D

however, as boiling progresses, the original water fraction decreases thus, chloride eventually decreases.

OK-10D is one of the wells which best exemplifies boiling in Palinpinon-1. Figure 4 shows the chemical and enthalpy trends of the well. CO_{2td} and Clres of the fluids start to increase from 1987 but the boiling process started to intensify starting 1991. This coincided with the increase in mass extraction as the Negros-Panay interconnection was commissioned in 1990. The enthalpy trend of Hm>Hsil=Hnkc likewise indicates boiling.

The successive drops in Clres in 1995 and continuous increase in CO_{2td} already indicate the shift of production to the upper, highly two-phase zone of the well. This is supported by the increasing measured enthalpy to almost 2700 kJ/kg, very near the enthalpy of pure steam at 2800 kJ/kg. Again, a decreasing trend in both Hnkc and Hsil indicate that the reservoir is cooling as an effect of continuous boiling.

Late 1998 again showed a decrease in CO_{2td} and enthalpies while there is a slight increase in Clres. This behavior could indicate either a localized inflow of the reinjected fluids or that there is an inflow of a more liquid feed into the well.

3.3 Cooler Water Inflow

There are cases wherein a drop in reservoir pressure leads to the entry of peripheral or shallow waters into the well. In the case of Palinpinon-1, there have been cases of inflow of cold, acid-sulfate bearing waters of shallow origin (Vidal, et al., 1999). This was exhibited by wells OK-10D, PN-13D and PN-22D, where the nature of the acid is highly localized and structurally controlled. Inflow of the acidic waters in these wells were detected by their increasing SO_4 and Mg and declining Cl.

The enthalpy method is not able to identify the incursion of acid-waters in these wells. The method can only indicate inflow of cooler waters but cannot recognize whether the fluid entering the well is acidic or not. Characterization of the cooler waters can only be done through chemical method.

One well which demonstrates cooler water inflow through the enthalpy method is PN-20D. Figure 5 shows the enthalpy and chemical trend of the well. Based on the trends, the well from 1986 to 1996 exhibits boiling as clearly indicated in the increasing Clres and CO_{2td} concentrations. In 1997, production eventually shifted to the upper steam zone (H=2700 kJ/kg) as evinced by the increasing CO_{2td} and subsequent decline in

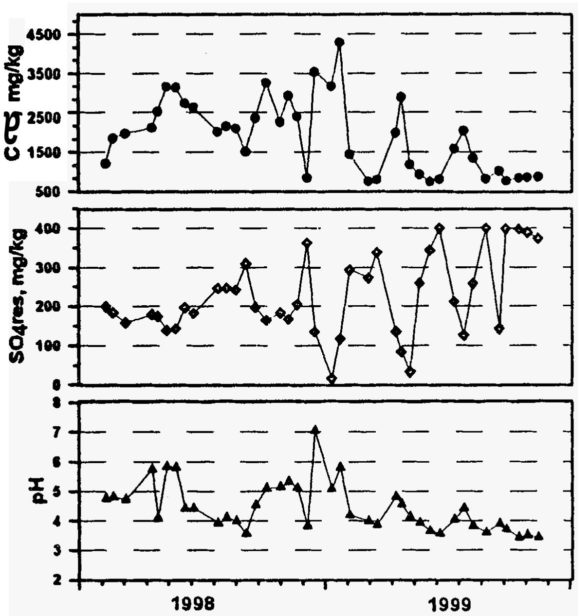

Figure 6. Clres, SO_{4res} and pH trends of well PN-20D from 1998-1999

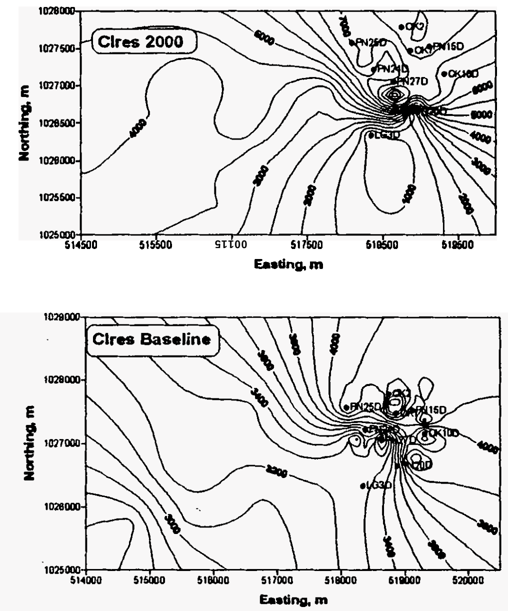

Figure 7. Clres contours showing the change from pre-exploitation to present

the Cl concentration. Starting 1998, however, production shifted back to the lower feed zone as shown by the drop in measured enthalpy to around 1900 kJ/kg and abrupt decrease in CO_{2td} and increase in Clres. There is, however, a continuous drop in CO_{2td} and Clres starting 1999, which already suggest that cooler water is entering the well.

The general trend of the enthalpy is Hm>Hsil=Hnkc which indicates boiling. There is a declining trend in Hsil and Hnkc starting 1996 up to 1998 which suggests cooling in the fluids brought about by continuous boiling. Starting 1999, however, it is obvious that Hm abruptly dropped to near 1400 kJ/kg while Hsil and Hnkc increased to around 1300 and 1200 kJ/kg, respectively. The behavior of the enthalpies suggests that either the well has shifted production to a more liquid-feed, or cooler water has entered the well.

Based, however, on Clres and CO_{2td} trends, where both have decreased drastically, it is more likely that cooler water has entered the well. Figure 6 shows the SO_{4res}, pH and Clres trends of the well between the periods 1998 to 1999. The increasing SO_{4res} along with decreasing pH, starting mid-1999 point that acid waters have entered the well. The decreasing Clres, meanwhile suggests a shallow origin for the water. The acid waters were surmised to have percolated down from shallow acid aquifer.

4.0 FIELD TRENDS

The change in fieldwide reservoir chloride from pre-exploitation period to present is illustrated in Figure 7. Clres during pre-exploitation period ranges from 3300 mg/kg to 4100 mg/kg. Latest data, however, already show increased values to a high of 8000 mg/kg. This increase in Clres is basically attributed to the reinjection fluids that has ingressed the production sector.

The change in $TSiO_2$ also illustrates a major change in the reservoir (Figure 8). There is a general decline in the temperature in most of the production wells which could be attributed to these three processes: the ingress of the reinjected fluids, boiling in the reservoir or inflow of cooler (acid) fluids. All of these processes involve a decline in reservoir temperature.

The fieldwide change in CO_{2td}, however, denote the effect of both reinjection breakthrough and boiling (Figure 9). There is a reversal of the trend in gases. The pre-exploitation gases at the vicinity of OK-7 (i.e. center of resource) have been reduced to as low as 100 mM/100 M from 340 mM/100 M. This

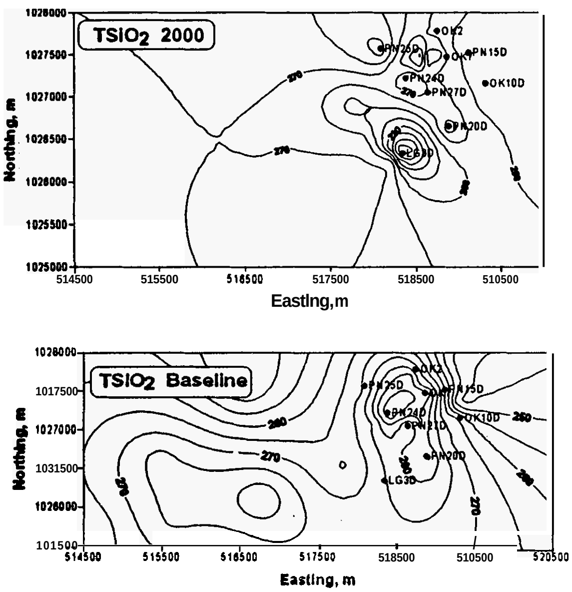

Figure 8. $TSiO_2$ contours showing the change from pre-exploitationto present

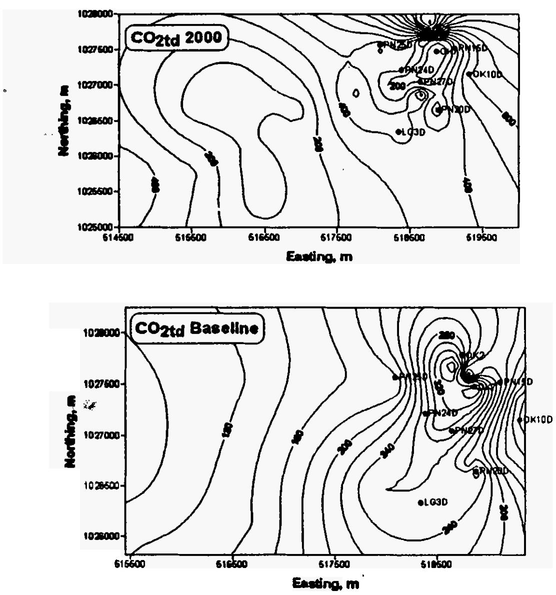

Figure 9. CO_{2td} contours showing the change from pre-exploitationto present

illustrates the effect of the reinjection fluids which affected the reservoir. On the other hand, there is a general increase of gases in the peripheral parts of the sector to as high as 1200 mM/100 M. These parts have been affected by pressure drawdown thus increasing the gas concentration of the wells.

Based on these trends, reinjection breakthrough has been considered the major cause of the changes that the field has been experiencing through the years. This is apparent by the change in Clres and temperature. However, secondary processes such as boiling and cold water inflow (acidic or meteoric) also effected changes in the reservoir, especially seen through gas concentrations as well as temperature.

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