

GEOCHEMICAL MONITORING OF THE RESERVOIR-WIDE PRESSURE DRAWDOWN IN THE TONGONAN GEOTHERMAL FIELD, LEYTE, PHILIPPINES

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ABSTRACT

The use of geochemical tools based on gas chemistry has become increasingly important in monitoring the reservoir processes in Tongonan due to the expansion of the two-phase zone resulting from the increase in the rate of pressure drawdown in 1997 when more power plants were installed. The methods involving gas-gas and gas-mineral equilibria (SNUC and FT-HSH methods) have been applied to evaluate the progress and extent of the pressure drawdown. The results of the SNUC method indicate increasing steam fraction and decreasing partial pressure of dissolved CO₂ across the field. These are consistent with increasing temperature of phase separation from about 260°C to 290°C in the central part of the field between 1997 and 1998, which implies lower depths of boiling and/or vertical expansion of the steam zone. The lateral extent of this process is established by increases in calculated steam fractions, increasing discharge enthalpies and decreasing brine flows from the production wells. The FT-HSH diagrams indicate vapour gain by as much as about 5%.

Conventional water and gas chemistry monitoring tools such as trends of Clres, CO₂td and quartz geothermometer have been meaningful in evaluating the secondary processes. Injection return persists in Upper Mahiao sector in the north and in Malitbog sector in the south, as indicated by continuously increasing Clres and decreasing CO₂td in the affected wells. Aside from this process, the pressure drawdown has also induced migration of cooler peripheral waters from the northeastern boundary of Upper Mahiao sector. In Malitbog sector, which largely represents the outflow zone, the fluid movements induced by pressure drawdown has provided local liquid recharge. Slight increases in Clres and decreases in CO₂td suggest recharge of boiled fluids from the vicinity of some wells.

1.0 INTRODUCTION

The Tongonan geothermal field (Fig. 1) encompasses three production sectors, namely Upper Mahiao, Tongonan-I and Malitbog-South Sambaloran. From 1983 to 1995, field exploitation was concentrated mainly in the Tongonan-I sector with the operation of the first 112.5 MWe power plant. Between 1996 and 1997, two more power plants were installed for an additional generation capacity of 356 MWe. Hence, there was a huge increase in mass extraction rate that resulted to a fieldwide pressure decline in the reservoir.

The most striking effect of the reservoir-wide drawdown in Tongonan is the vertical and lateral expansion of steam zone across the field (Siega et al., 2000). This process created a large increase in the amount of available steam, which exceeded the steam supply requirement of the three power plants. Thus, most of the wells were throttled at varying wellhead pressures to regulate steam flow and prevent steam wastage.

The presence of excess steam supply has led to the conception of a steam line interconnection to address the steam supply deficit in Mahanagdong, an adjacent geothermal field to the southeast. This report presents an update on the status of Tongonan reservoir based on the results of geochemical monitoring during the year 2000. It will also provide the baseline geochemical information prior to and during the first few months of full operation of the steam line interconnection between Tongonan and Mahanagdong.

2.0 STEAM AVAILABILITY

The results of Tracer Flow Tests (TFT) conducted in July-August 2000 show that the available steam in Tongonan field still exceeds the steam supply requirement of the power



Figure 1. Map of Tongonan geothermal field showing well tracks, locations of power plants, production sectors and reinjection sectors.

plants at full generation capacities. In Upper Mahiao, TFT data indicate a total steam flow of 402 kg/sec while the main power plant requirement is only 295 kg/sec (Fig. 2). The largest amount of excess steam was noted in Tongonan-1 sector where available steam flow is 478 kg/sec and steam requirement is only 281 kg/sec. In South Sambaloran-Malitbog sector, the total steam flow is 562 kg/sec while the requirement is only 431 kg/sec. However, the total amount of excess steam for each of the three sectors has declined relative to that in 1999. This can be attributed mainly to the effect of injection returns in Upper Mahiao and Malitbog, local liquid recharge in Malitbog and steam drawdown in Tongonan-1 sector.

3.0 WELL DISCHARGE ENTHALPY TRENDS

Based on mass flows and discharge enthalpies, the Tongonan field can be divided into three regions (Maturgo, 2000). The aerial extent of these regions is shown in Figure 3. Discharge enthalpies between 1800 and 2700 J/g characterize the steam-dominated region, which extends from Upper Mahiao sector towards the northern part of Malitbog. In this region, steam flows constitute more than 50% of the total mass flows in each well.

Encroached in the steam-dominated region is the dry region, which covers almost the whole

of Tongonan-1 sector. The enthalpies in this region exceeds 2700 J/g and as high as 2800 J/g. Since 1999, the dry region has progressed slightly towards Upper Mahiao in the north and South Sambaloran sector in the south. Based on TFT results, ten more wells became dry in 2000 in addition to the same number in 1999. On the other hand, the Malitbog sector, which largely represents the outflow zone, remains as liquid-dominated region where enthalpies in most of the wells do not exceed 1500 J/g.

4.0 RESERVOIR PROCESSES

Production well chemistry monitoring data show the persistence of the reservoir processes that have been occurring since 1998. These processes are: 1) expansion of the steam zone across the field, 2) injection returns in Upper Mahiao and Malitbog sector and 3) inflow of cooler peripheral waters in the northeastern part of Upper Mahiao sector. Recent data suggest that the pressure drawdown has also induced fluid movements that provide local liquid recharge in Malitbog.

An inception of another process termed as steam drawdown is inferred in the central part of the reservoir based on simultaneous decline of steam flow and CO₂td in some dry wells in Tongonan-1 sector.

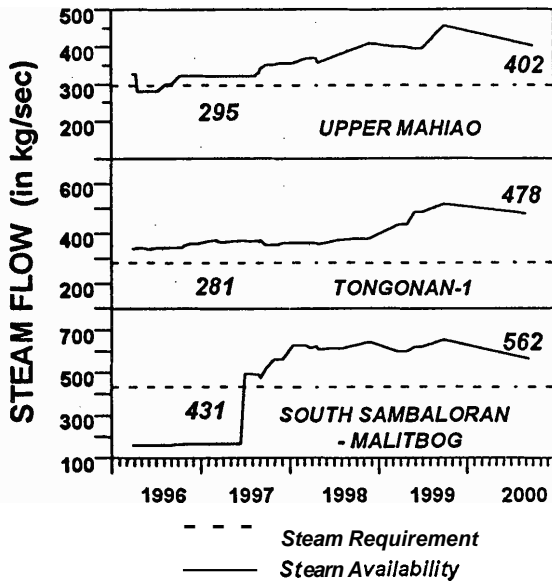


Figure 2. Steam availability vs. steam requirement in Tongonan field based on Tracer Flow Tests data.

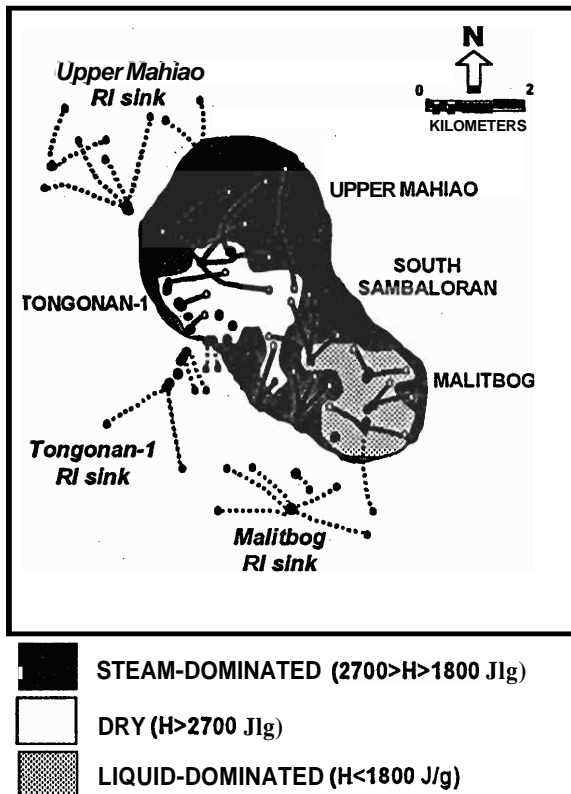


Figure 3. Well discharge enthalpy trends across Tongonan field based on TFT data as of August 2000.

4.1 Steam Addition and Dilution

The update on the application of SNHC method to evaluate and monitor reservoir processes indicates a continuing fieldwide increase of steam fraction in the Tongonan reservoir between year 1999 and 2000 (Fig. 4). This corresponds with the decline of partial pressure of dissolved CO₂ (Fig. 5), which is attributed to the lowering of the water level and subsequent reduction of water fraction as pressure drawdown proceeds (Salonga and Siega, 1999). These trends are manifestations of the continuous expansion of steam zone across the field.

The increase of steam fraction (steam addition) caused dilution of the residual brine by steam as indicated by decreasing Cl_{res} and TQtz values with increasing CO₂td in the affected wells. Steam addition and dilution apparently predominates in Tongonan-1 and Upper Mahiao, extending towards South Sambaloran. This process is depicted in the FT-HSH2 diagram (Fig. 6), which indicates vapour gain by as much as about 5 %.

4.2 Injection Return

Upper Mahiao

Physical and chemical trends indicate that injection returns are persistent in the northern part of Upper Mahiao sector, particularly in wells 410 and 417D. The process started to affect these wells during the last quarter of 1998 as shown by increasing Cl_{res} and declining CO₂td. The typical trends are presented in Figure 7, which shows the trends in well 410.

TFT data show progressive increases of water flow in 410 between September 1997 and July 2000 (Fig. 7). During the same period, steam output dropped by 13.2 kg/sec (from 29.6 to 16.4 kg/sec) for an average decline rate of approximately 4.4 kg/sec per year. While water flow increased by 11.3 kg/sec (from 4.6 kg/sec to 16.9 kg/sec), enthalpy dropped from 2515 kJ/kg to 1777 kJ/kg. However, the relatively stable and high TQtz values of 296-297°C imply that the injected fluids are sufficiently heated-up as they approach and reach the well.

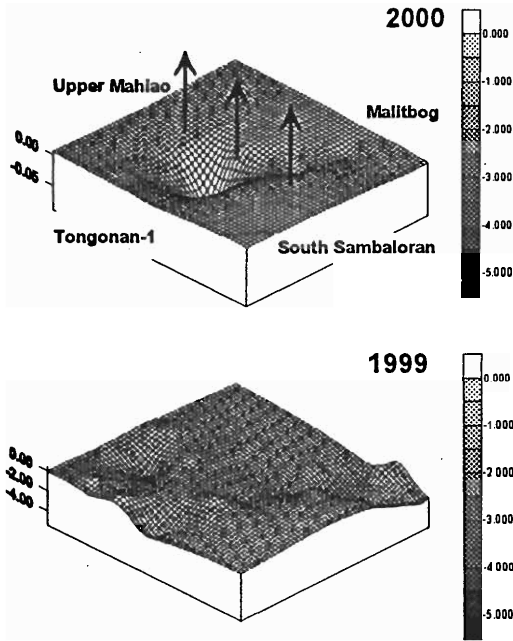


Figure 4. Block diagrams showing the increase of steam fractions (y_{res}) across Tongonan reservoir between 1999 and 2000.

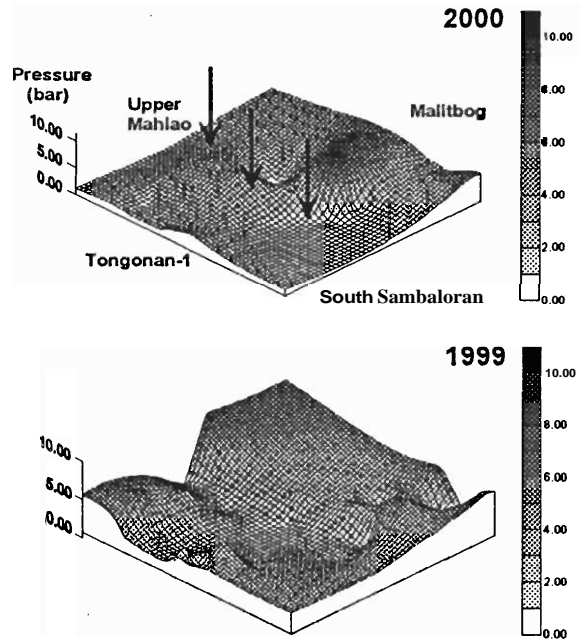


Figure 5. Block diagrams showing the decrease of partial pressure of dissolved CO_2 (pCO_2) across Tongonan reservoir between 1999 and 2000.

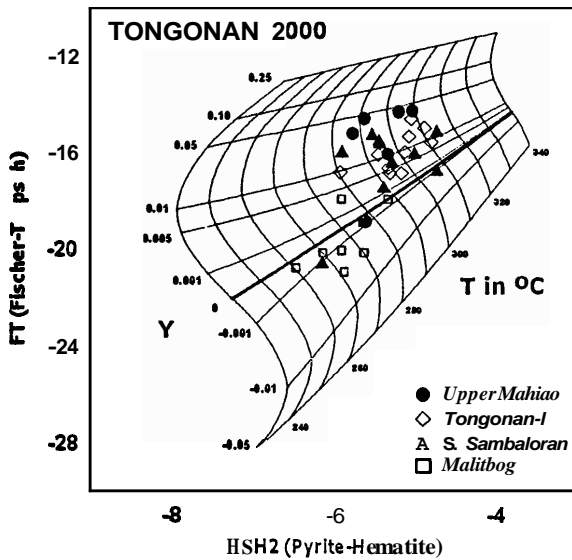


Figure 6. FT-HSH2 diagram depicting the predominance of vapour-gain process across Tongonan field based on gas chemistry data in year 2000.

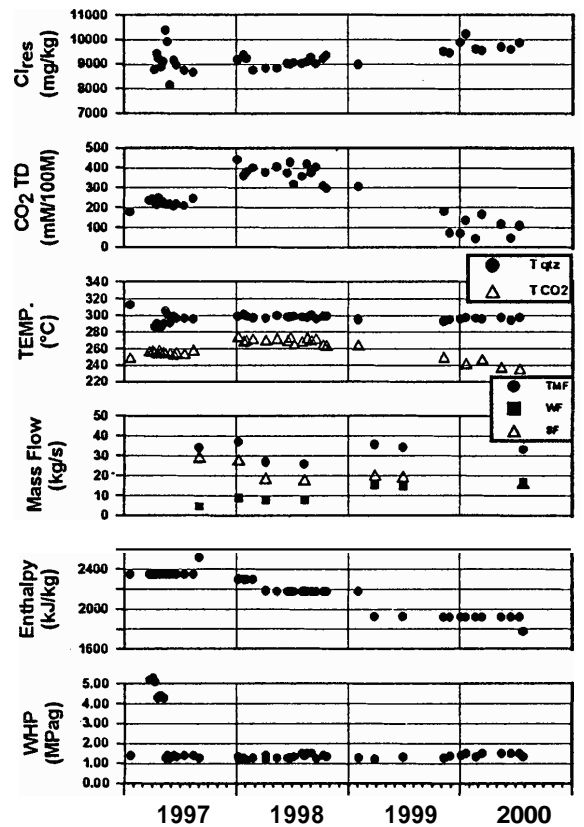


Figure 7. Chemical and physical trends in Well 410 showing the effect of injection returns in Upper Mahiao sector.

Malitbog

In Malitbog, injection returns have been affecting Well 501 and 509 since 1998. In the FT-HSH2 plot, these two wells exhibit the largest shift of data points from the vapor-gain region to the vapor-loss region between 1999 and 2000 (Fig. 8). Chemical trends in 501 indicate the persistence of injection returns as shown by the continuous increase of Cl_{res} and decrease of CO₂td (Fig. 9). TQtz values have declined gradually from about 280°C to around 270°C.

TFT data show almost stable mass flows in 501 since 1998. Without injection return, there could have been significant decline of brine flow and increase of steam flow due to pressure drawdown.

4.3 Inflow of Cooler Fluids

Upper Mahiao

Aside from injection return, the pressure drawdown within the highly two-phase region in the Tongonan-1 sector has induced migration of peripheral waters from the northern part of Upper Mahiao towards well 409. These fluids are characteristically cooler, less saline and relatively degassed as shown by the gradual decline of Cl_{res}, CO₂td and TQtz between January 1998 and December 1999 (Fig. 10). TQtz values decreased from about 295°C to 290°C while Cl_{res} declined from around 8000 mg/kg to 7300 mg/kg.

TFT data show a gradual and continuous increase of water flow in Well 409 from 18 kg/sec in April 1998 to 22.4 kg/sec in June 1999 with a corresponding decline of steam flow from 35.2 kg/sec to 33.4 kg/sec. Enthalpy dropped from 2113 kJ/kg to 1986 kJ/kg. TFT results in July 2000 showed further decline of steam output to 29.5 kg/sec at same wellhead pressures. Hence, the migration of peripheral waters in 409 has resulted to a steam decline by 5.7 kg/sec in about two years.

Based on the hydrogeochemical model prior to the commissioning of power plants in Upper Mahiao and Malitbog, the cooler peripheral waters would be coming from the vicinity of wells 411 and 416D (Salonga et al., 1997). Cooler fluids and temperature inversions were encountered in these wells, characteristic of the northern margin of the Tongonan geothermal system.

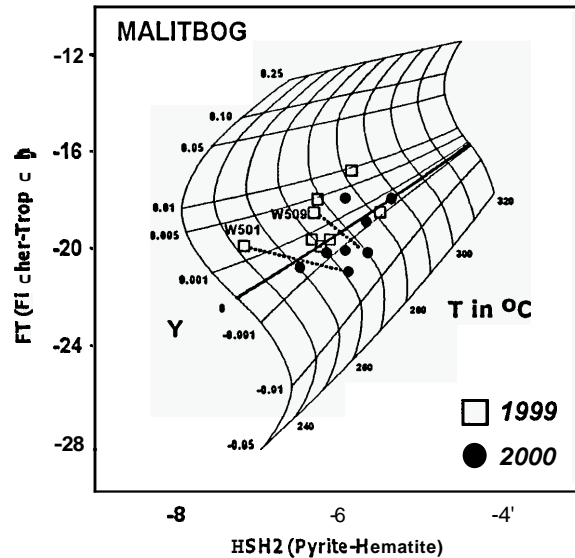


Figure 8. FT-HSH2 diagram illustrating the flow of degassed fluids in Malitbog. Degassed fluids are either local boiled fluids or injection fluids.

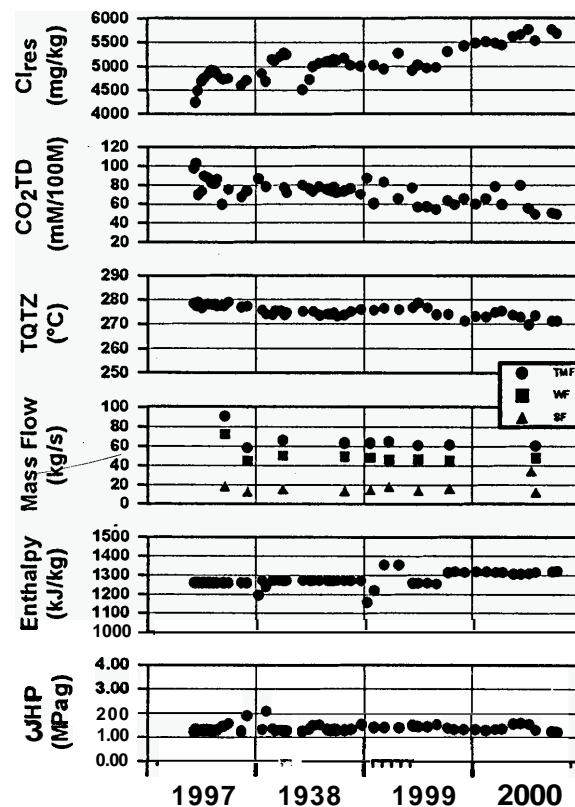


Figure 9. Chemical and physical trends in Well 501 showing the effect of injection returns in Malitbog sector.

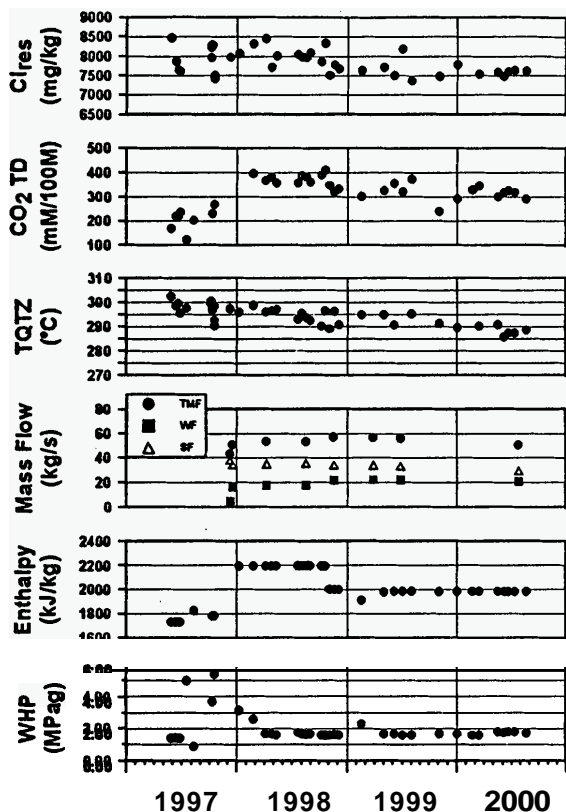


Figure 10. Chemical and physical trends in Well 409 showing the effect of cooler peripheral fluids migrating from northeastern part of Upper Mahiao sector.

South Sambaloran

In this sector, inflow of cooler waters occurs particularly in well 309D. This process was evident in both the chemical and physical trends (Fig. 11). Based on TFT results in August 2000, only 309D showed increase in water flow among the production wells in South Sambaloran. Since June 1999, water flow increased by 12.9 kg/sec while steam flow declined by 7.2 kg/sec. Chemical trends, on the other hand, indicate a significant decrease in Clres from about 11000 mg/kg to 9500 mg/kg while TQtz dropped from 286° to 276°C. However, there was an increase in CO₂td from about 200 to 240-mmoles/100 moles steam.

Initially, the fluids were suspected to be originating from the highly two-phase region in the central part of the reservoir. The residual liquid from this region undergoes steam dilution, which lowers the Clres and TQtz values. However, the current values of Clres, TQtz and

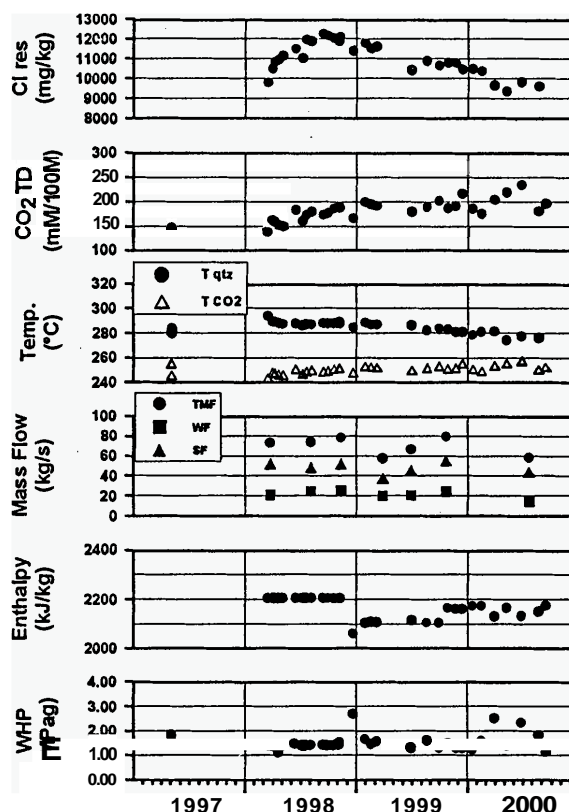


Figure 11. Chemical and physical trends in Well 309D showing the effect of cooler fluids migrating from Malitbog towards South Sambaloran.

CO₂td in 309D suggest that the fluids are more likely coming from the watery sector of Malitbog. The values have approached those in well 515D, the nearest well from the southeast.

4.4 Local Liquid Recharge

This process occurs in the northeastern-eastern part of Malitbog sector. In the FT-HSH2 plot (Fig. 8), the local recharge is manifested by a general shift of the data points towards the vapor-loss region, which implies inflow of relatively degassed residual fluids in the reservoir. TFT data between March 1999 and July 2000 show increases in the brine flows of wells 511D, 513D 514D and 515D. Subsequently, there were decreases of steam flows and enthalpies in these wells.

For example, chemical trends in 511D indicate increasing Clres with slightly declining CO₂td and TQtz values between January and October 2000 (Fig. 12). However, the decrease

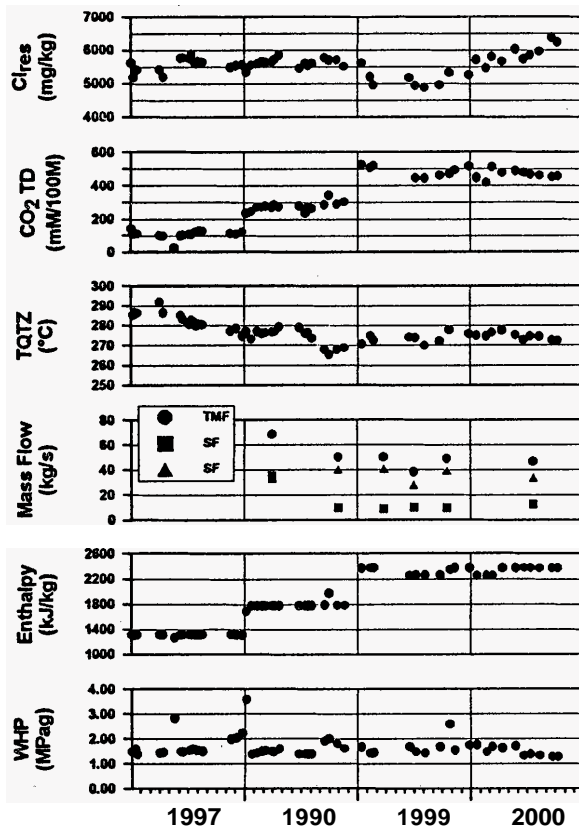


Figure 12. Chemical and physical trends in Well 511D showing the manifestation of local recharge by boiled fluids within Malitbog sector.

in CO_2td values is not as significant as in the wells being affected by injection returns. Thus, the trends in 511D are attributed to recharge of boiled fluids from the immediate vicinity of the well. The increase in enthalpy from about 1300 to 2383 kJ/kg between January 1997 and October 1998 did not progress when brine flow stabilized at around 10 kg/sec.

4.5 Steam Drawdown

Another process termed as steam drawdown was inferred to be occurring mainly in the Tongonan-1 sector. This process can be characterized by decline of steam flows and CO_2td in some dry wells. These wells, namely 101, 106, 109D and 110D have discharge enthalpies exceeding 2700 J/g.

For instance, the significant decline of steam flow in well 106 between December 1997 and August 2000 coincides with a large decline of CO_2td from about 500 to 250 mmol/100 moles

steam. At the same wellhead pressure, steam output declined by 8.4 kg/sec. However, there was a slight increase in CO_2td when the well was throttled in September 2000 from about 1.6 MPag to 3 MPag.

For well 110D, which has been highly-throttled (WHP > 4.0 MPag) since April 1998, TFT results also indicate a decline of steam flow by 4.0 kg/sec between Jul 1999 and August 2000. However, CO_2td has been relatively stable. Minor fluctuations are due to variations in wellhead opening.

TFT results have also shown continuously decreasing steam output by as much as 10.6 kg/sec in 101. Comparison of TFT data between October 1999 and September 2000 indicates a decline of wellhead pressure at fully open condition, with corresponding decline of steam flow from 43.7 to 33.1 kg/sec. CO_2td trends between these periods show decreasing values even at throttled conditions. These could be indications that these wells have reached optimum drawdown condition and are starting to manifest steam drawdown. In 109D, the decline of steam flow was also associated with decreasing CO_2td .

5.0 CONCLUDING REMARKS

The continuing expansion of steam zone across Tongonan field and the decreasing brine injection load suggest that there has been insufficient recharge (natural or artificial) of liquid that will provide pressure support to the production sectors. This may lead to eventual decline of steam output of the production wells. Apparently, it is now being manifested by the decline of steam flows in some dry wells in Tongonan-1 sector.

Moreover, the full operation of the steam line interconnection between Tongonan and Mahanagdong is expected to incur greater mass extraction rate in Tongonan. It could accelerate pressure decline and cause further decrease of brine injection load although it could also enhance fluid movements such as migration of cooler peripheral fluids and injection return. The onset of these processes needs to be monitored closely because of their equally potential adverse effect to the steam availability should they become extensive and continuous. Migration of peripheral fluid may also occur

along the eastern boundary of Malitbog sector based on pre-exploitation hydrological model (Salonga et al., 1997). Thus, TFT should also be conducted regularly to monitor steam availability. Then, appropriate production and injection well utilization strategy should be formulated to sustain steam supply in Tongonan.

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