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RESPONSE OF THE PRODUCTION AND REINJECTION WELLS DURING THE INITIAL EXPLOITATION OF THE TONGONAN GEOTHERMAL FIELD, PHILIPPINES

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ABSTRACT

Field monitoring and testing have been undertaken in the Tongonan Geothermal Field since the commissioning of the first 112.5 Mw last March 1983. Well performance and early exploitation data show the changing phases of the geothermal fluid caused by exploitation. An increasing enthalpy and chloride brine in production wells is a general feature in the field. Apparently, because of the two phase condition, the pressure drawdown is only localized and has not been significantly observed at the center of the field.

Indications of slight reinjection returns are noticeable but is not a major feature in the production wells. This paper will discuss the initial exploitation response of the wells which are drilled through a section of two phase and single phase liquid dominated reservoir of Tongonan

INTRODUCTION

The exploitation of Tongonan Geothermal Field commenced after the commissioning of the 3 x 37.5 (112.5 Mw) power plant in the early part of 1983. Twelve (12) production wells distributed in the Lower Mahiao and Sambaloran Sectors (Figure 1) are used to supply steam to the power plant. Total wells capacity is estimated as 134 Mwe. The waste water effluents are reinjected at four *(4)* reinjection wells drilled in the southwestern flank of the two production sectors.

Within the island of Leyte and Samar which compose the power grid, no other plant exists except the Tongonan I power station. Because of this, the plant is designed on a variable load basis such that it will absorb all the fluctuations of the grid, e.g., the base and the peak load demand. A detailed description of the system operation is discussed by Vasquez (1985). At present the load demand in the grid has reached a peak of about 68 Mw with an average load of about 40 Mw. This requires steam consumption of about 181 kg/s and 131 kg/s respectively for the three turbines.

The low power demand and the low steam consumption provided the management of the field more flexibilities in terms of optimizing production in the borefield. Policies are drawn to maintain sufficient supply of steam to the plant without exposing any well to over-exploitation. Wells are classified as base and control wells. Base wells are used to supply the base load requirement while control wells pick-up the surge in the demand. Wells are further prioritized in such a way that production and drawdown in the field will be minimized and distributed.

Todate, approximately 3.9 x 10^{10} kg were withdrawn and 8.9 x 10^{9} kg were reinjected back to the reservoir. Some changes in the output and the physical characteristics of the wells are observed and will be treated in general in this paper.

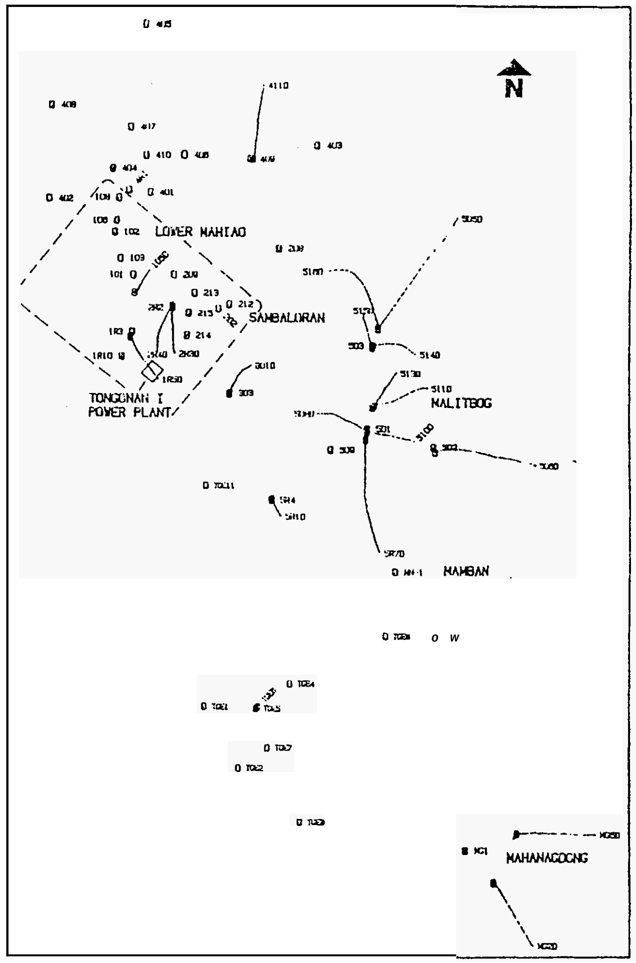

Figure 1 Well location map of the Tongonan Geothermal Field

RESERVOIR DESCRIPTION

The Tongonan geothermal reservoir is a liquid dominated type with a two phase zone overlying the liquid phase in its natural state. Results of the last drilled wells provided informations that enable the subdivision of the field into three (3) areas according to its thermodynamic characteristics:

- Mahiao/Sambaloran upwelling zone with a measured downhole temperature of 270–334°C. Wells are characterized by flow of two phase fluid with some wells discharging fluid enthalpy nearly corresponding to steam.

ii. Mahiao/Sambaloran liquid-filled outflow area with downhole temperature of 250-310°C characterized by single phase liquid discharge.

iii. Mahanagdong anomaly which is separated from Malitbog by the Mamban area and is characterized by high temperatures ranging from 250-321°C with single phase liquid discharge. This anomaly is initially interpreted as separated from the above two (2) sectors although more evidence are still required to reinforce the model.

The two phase zone in most of the wells in the Mahiao and the Sambaloran sectors are identified starting at -800m. The interpreted upflow is located in the central vicinity of 209 and 410 in the north and northeast part *of* the field. Heat in the field is derived by production and convection and inferred to be originating from the Mahiao Plutonic complex. Maximum permeabilities are attributed to the contact of the pluton and the volcanics which is referred to as the contact zone.

The upper two phase zone is underlain by a hydrostatic column of water having a gradient of .8 MPA/100m. The outflow is strongly indicated in the Malitbog sector based on the relatively low pressure, fluid chemistry indicators and temperature reversals in many **wells.**

At full bore discharge condition (FBD), the upper zone dominates producing fluid of high enthalpy. On the other hand, at throttled condition, the two phase zone is suppressed and discharge fluid is predominantly single phase. In some wells, cycling occurs between the upper and lower single phase zones. Wells 208 and 205 (shallow) basically represent typical wells terminated in the two phase zone with discharge enthalpy of 2657 and 2338 kJ/kg. Pressure profiles were vapor static with maximum temperatures ranging from 220-280°C respectively.

The reservoir chloride ranges from 5307-8775 ppm and 6715-9206 ppm **for** lower Mahiao and Sambaloran wells respectively. High chloride concentration persists easterly in the direction of Mahiao and Sambaloran wells which are the seciors providing steam to the power plant.

FIELD MANAGEMENT STRATEGY

As previously mentioned, the excess capacity of the wells due to the low power demand on the grid provides field management greater flexibilities in utilizing wells. Drawdown in the upper two phase zone is minimized in order to reduce the risk of premature intrusion of cold surface water. This is done by throttling the discharge of most of the wells such that the bottom single phase zone will dominate. Big wells are used as control wells while small wells are used as base wells. Table 1 shows the well utilization and prioritization schedule at a certain load demand.

Fluid separation of wells drilled in the Lower Mahiao and Sambaloran sectors are done through two (2) different separators stations. Each separator station has two (2) reinjection wells for waste water disposal. At any one time, only one well is utilized in order to minimize exposure to any reinjection damage. One is **always** acting as **a** reserve well in case there is a well failure or maintenance activity to be conducted.

Table 1 Well Utilization schedule for Tongonan I at a certain load demand.

TONGONAN I

WELL UTILIZATION SCHEDULE

Baseload: 55 MWe, 750 TPH* (210 kg/s)
Peakload: 80 MWe, 924 TPH* (257 kg/s)

*based on 3 units operation and measured steam flow requirement

Control Wells

	Operation	BPP	Base (TPH)	Max. (TPH)
1st Priority 102	Peak	-	40	120
1st Priority 209A	Peak	A4	40	140
2nd Priority 106	Peak	-	50	80
2nd Priority 215	Peak	-	30	70
3rd Priority 105D	Base	A2	70	70
3rd Priority 214	Base	A3	70	70

Baseload Wells

	Operation	BPP	Base (TPH)	Max. (TPH)
101*	Base	A4	120	120
103*	Base	A3	120	120
108*	Base	AS	80	80
202	Base	A4	60	80
212	Base	B1	45	45
213	Base	B1	50	50
			795	1,045

* wells replaced with new BPP

Reinjection Wells

	Operation	Capacity (kg/s)
1R3	In service	70-90
1R5D	Reserve	62-90
1R10	Reserve (condensate R/I)	
2R2	Contingency	
2R3D	In Service	70-85
2R4D	In Service	85-?

WELLS RESPONSE TO EXPLOITATION

Figure 2 shows the exploitation history of **all** the wells in the steam gathering system (SGS). The plant has been on production **for** a cumulative number of 833 days. The frequent cutting in and out of the wells reflects the response of the system on the fluctuating load.

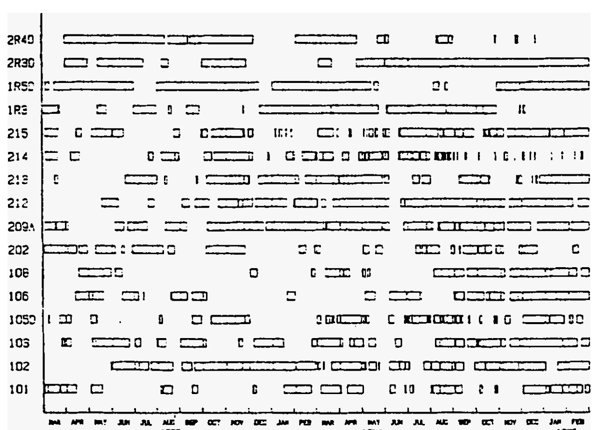

Figure 2 Well production history for the first two (2) years of Tongonan I operation.

Well Output Changes :

The wells are closely monitored by conducting spot output tests over a short period of time, normally one (1) hour. This is done by bypassing the well discharge from the SCS to the silencer after producing for at least a week in the SGS at a constant well head pressure. The operating WHP is simulated using the side valve during the test. The discharge results are used as the current output of the wells at that particular WHP. In some cases, wells are tested for one week to confirm significant changes in the observation. Simultaneous chemical monitoring is also undertaken to trace fluid chemistry changes.

Figures 3,4 and 5 show the plot of massflow and enthalpy vs. WHP of wells in Plahiao taken from 1983-1985. A general increase in enthalpy is noted after long term exploitation even though most of the wells were under throttled condition. This implies that the two phase front has now reached the bottom part of the wells.

Well 106 which was drilled at the periphery of the field and used as a second priority well has been the subject of substantial changes. It has been on line for a total of 299 days with a total discharge of 6.1 x 10^8 kg.

The well was not tested for a long tern period before exploitation. Initial data at FBD yielded an enthalpy of 1950 kJ/kg at .37 MPa implying two phase-condition. The well was throttled at .59 MPa in order to be used for the SGS. Three months after exploitation, enthalpy substantially increased from 1950 kJ/kg to 2600 kJ/kg. The latter is very close to that of the saturated steam enthalpy.

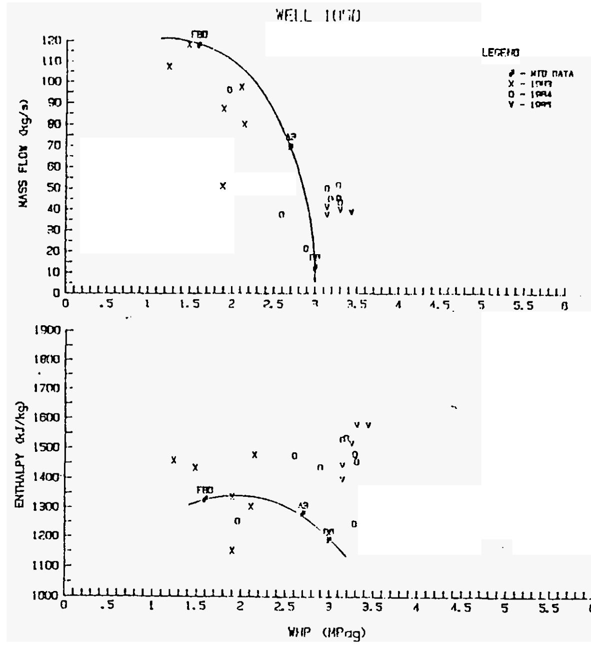

Figure 4 Well 105D Output Graph from 1983-1985.

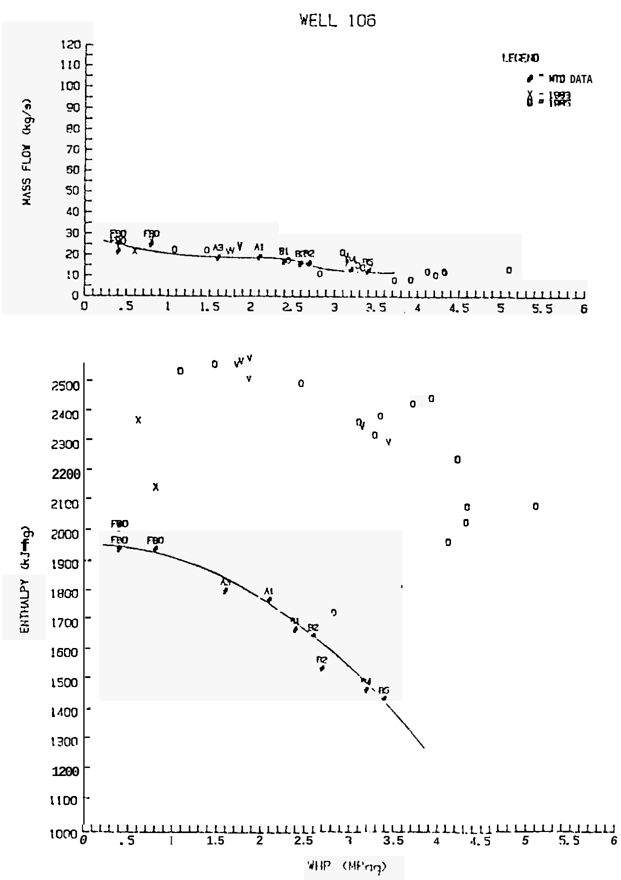

Figure 3 Well 106 Output Graph from 1983-1985.

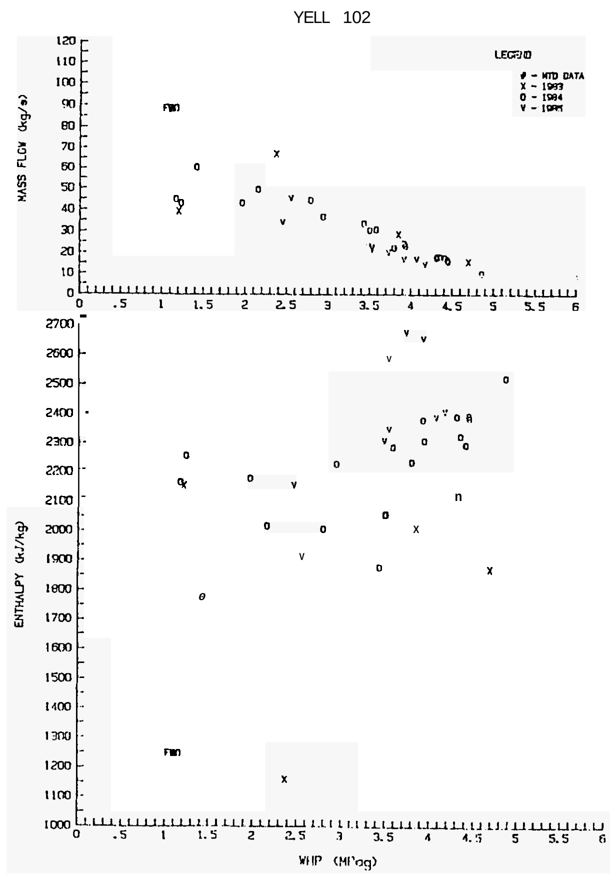

Figure 5 Well 102 Output Graph from 1983-1985

Nearby wells 102, 101 and 103 were also observed to have increased enthalpy. These wells are similarly back pressured in order to suppress the upper two phase zone. Only wells 108 and 105D appear to be insignificantly affected by exploitation. Output data of well 108 arc still within the baseline data although enthalpy of 2100–2300 kJ/kg have been measured. Well 105D is still discharging fluid of 1500–1600 kJ/kg which is very close to that of the pre-exploitation data. However, it is apparent that the upper zone which was only predominant at FBD now also predominates at throttled conditibn.

In the Sambaloran sector, wells appear to have minimal changes in the output. Figure 6 shows typical well output taken from 1983 to 1985. There has been less significant changes on the mass flow and enthalpy at similar WHP before and during exploitation.

Wells 213, 214 and 215 are observed to have output data which are within the range of the initial test results. However, there is an increasing trend that is relatively slower than in the Mahiao wells. This is well noted but no definite conclusicn can be given. Enthalpy ranges from 1450 to 1750 kJ/kg. Output decline at well 209A, the biggest (18 Mw) and deepest well drilled in the field is inconclusive. The blockage at 1800m may have affected the output and could not be used to substantiate changes at the deep section of the field.

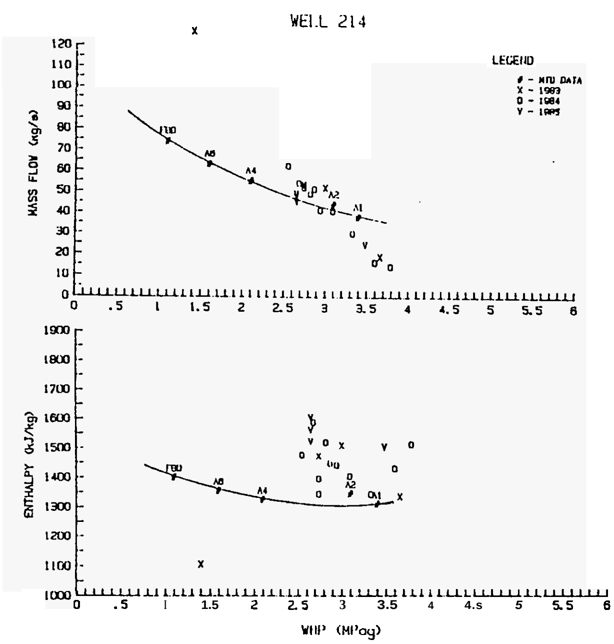

Figure 6 Well 214 Output Graph from 1983-1985.

Temperature and Pressure Chances:

Figure 7 shows the temperature and pressure plots of 106 taken before andafter exploitation. The pressure profile is now vapor static with pressure drawdown close to 5.5 MPag at bieed condition. Latest temperature data showed that hotter fluid is now rising in the well as a result of pressure drawdown creating the flow from deeper to shallower zone. The two phase fluid has expanded to the bottom and is observed in most of the Mahiao wells. Except well 105D, all Mahiao wells are now standing with vapor static column when shut. Temperature gradients are now linear and follow the saturation relation of the fluid. At well 105D, there is also a noted decline in pressure of 2.7 MPag and 8°C when compared to initial data.

In the Sambaloran sector only well 213 has a vapor static column and linear temperature gradient. This well is either on bleed or in discharging condition as shut-in WHP exceeds maximum pressure rating of the wellhead. Wells 213, 202 and 215 have hydrostatic pressure profile although significantly lower than the undisturbed pressure. Pressures of 214 have been within the range of the original pressure and appear not affected by production . It is possible that production in the wells is sustained by reinjection returns from nearby reinjection wells, 2R3D and 2R4D. However, this remains to be verified in the future.

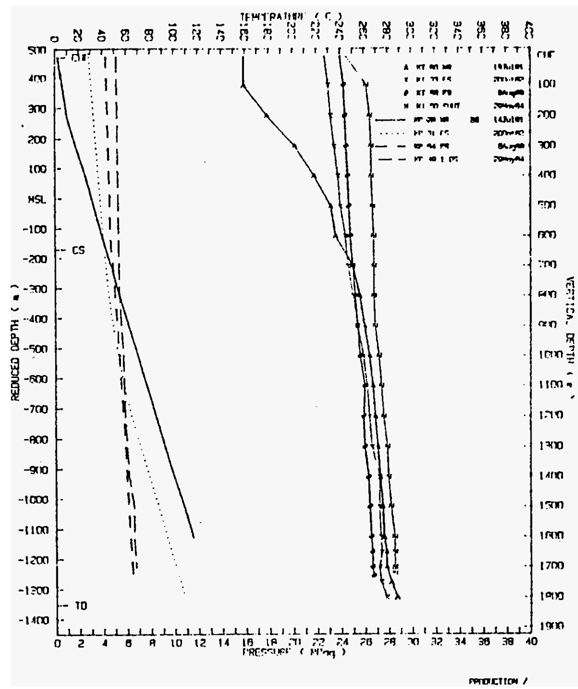

Figure 7 Well 106 temperature and pressure plot.

Figure 8 and 9 show the temperature and pressure plots of 213 and 214.

Although there are temperature, pressure and output changes in the wells, it has not been proven yet whether the drawdown have already spread in the actual reservoir. Pressure monitoring at 2R2 which is located at the center of the field yielded no significant changes in pressure that can be attributed to discharge or continuous exploitation. It is possible that because of the two phase condition in the field, the changes are still localized in the well and have not reached adjacent wells. It is also possible that reinjection return may have been suppressing the drawdown at 2R2. The observations are, however, inconclusive and remain to be studied.

Chemical Changes:

In general, chloride levels have been found to be increasing in wells 101, 103, 105D, 106, 202, 213 and 215. However. at 106 chloride levels are in excess of 30,000 ppm at the weir box. This increase is interpreted to be due to concentration by boiling and not to reinjection returns, Mongcopa (1985). In 214, the reservoir chloride remains increasing and is believed to have been affected by reinjection returns. There are also indications that other wells like 105D, 202 and 213 have been affected by reinjection as the enthalpy are kept constant despite increasing chloride. This is still a subject of closer monitoring and further investigation in the future. Other parameters like gas chemistry and geothermometers are within the range of the initial data.

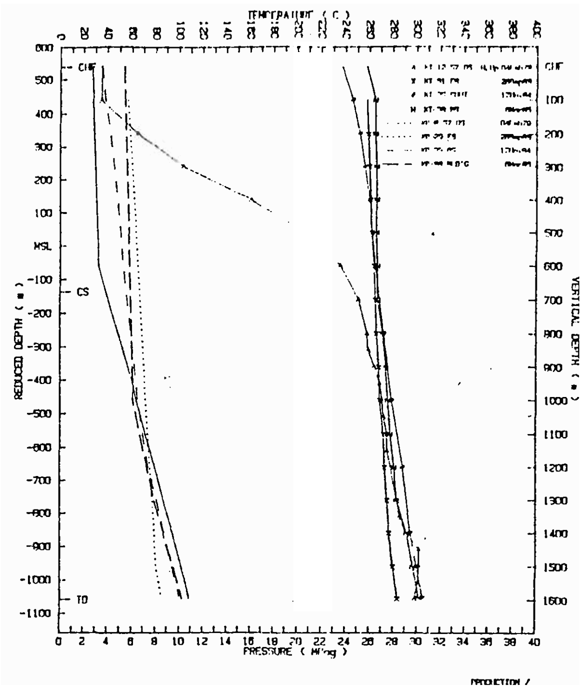

Figure 8 Well 213 Temperature and Pressure Plot.

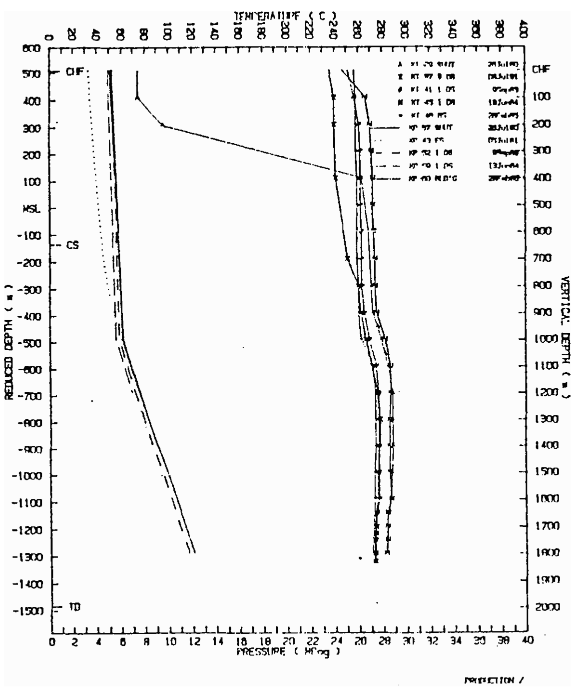

Figure 9 Well 214 Temperature and Pressure Plot.

Chances in Reinjection Well Canacities:

Well 2R3D and 2R4D are reinjection wells intended for the Sambaloran effluents while 1R3 and 1R5D are intended €or the Mahiao wells. In some cases, effluents from Sambaloran are bypassed to Mahiao through a bypass line connecting, the two reinjjection lines. **Wells** 2R3D and 2R4D are directional wells targetted towards the southwestern flank of the main bore field with a total vertical depth of 2208.9m and 2102.6m respectively. Wells 1R3 and 1R5D are completed at depths of 1903m and 2323.7m respectively.

Separator pressure is set at .67 MPa and therefore the expected fluid temperature is closer to 163°C. Silica saturation index fluctuated between .80 - 1.2 to 1.1 - 1.5 for Mahiao and Sambaloran wells respectively. Reinjection chloride ranges from 11,000 to 12,000 ppm.

In order to closely monitor the reinjection capacities of these wells, regular flowmeter, pressure measurement, go devil surveys and recording of separator flooding and increases in RI wellhead pressures are conducted.

Table 2 shows the injectivity and capacity rating of all the RI wells before and during the current exploitation. Injectivity has initially increased after long term injection but later showed a declining trend. Current reduced capacities remained unchanged escept for 1R5D which had recently started refusing water in excess of 40 kg/s.

Table 2 Injectivities and capacities of Tongonan I wells.

Well No.	Max. RI Capacity kg/s	Injectivity Index L/s-MPa		Max. Clear Depth m.VD
		Initial*	Current	
1R3	70-90	47	20	.662
1R5D	45-90	16	27	1419
2R3D	55-85	44	17.50-21.00	2114(?)
2R4D	75-85	37	35.90-43.40	1695

NB: * initial injectivity index measured during completion test.

All the wells have been blocked and inaccessible to bottom. Blockages are believed to be formed by the accumulation of debris which have been left inside the pipe line and vessels during the construction period. Formation damage due to deposition is to be proven and would require the result of the tests after clearing and work-over drilling of the holes.

Well 1R10 which is used as a reinjection well for the condensate from the power plant has also shown a very significant change. When reinjection was stopped due to acidic ph of the condensate, the well remained shut. A blockage was tagged at 1300m which consists mostly of rust flakes and pebbles. After 3 years, gas pressure, mostly CO_2 built up in the well which was not observed before exploitation. No explanation can be provided yet which may link this to the exploitation of the field. Neither the contents of the condensate are sufficient to explain this feature.