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AN ASSESSMENT Of THE IMPACT OF IN-FIELD INJECTION AT THE MALITBOG SECTOR, TONGONAN, PHILIPPINES

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ABSTRACT

The onset of continuous brine injection at the Malitbog sector, Philippines with the commissioning of the 231 MWe Visayas Geothermal Power Company main plant and the 14.56 MWe ORMAT bottoming plant have increased the possibility of reinjection fluid encroachment towards the production sector. This paper examines the changes in reservoir characteristic of the nearby production sector that would identify any effect of brine injection on the individual performance of the production wells and establish the possible movement of the injected fluids across the field.

Large scale brine injection began in mid 1996 during the commissioning of the Malitbog Fluid Collection and Disposal System (FCDS). Since then, brine injection has been continuous except on some occasions when the FCDS is on shutdown for its preventive maintenance and servicing (PMS). The continuing mass extraction has caused the reservoir pressures to fall, with most production and peripheral monitor wells showing uniform drawdown across the field. The declining pressures in effect increase the possibility of reinjection fluid incursion into the production sector, as the pressure difference between the production and reinjection sectors widens.

Historical fluid movement of the field was reviewed and the physical as well as chemical trends of the individual production wells were evaluated. Chemical trends have indicated reinjection fluid breakthrough in four production wells but this has not been reflected in the physical parameters. Ingress of reinjection fluids as evidenced by the changes in the downhole temperature and pressure data has been noted in only one of the nearby monitor wells. In spite of the apparent dispersion of reinjection fluids, injection breakthrough in the outflow region (thermal areas) have gradually ceased. These responses imply change in reinjection fluid movement within the reservoir resulting from the continuing fall in reservoir pressures in the production sector. The lack of evidence for thermal breakthrough in the production wells suggests that injected fluid is being reheated before being discharged.

1. INTRODUCTION

1.1 Historical Background

The Malitbog sector is the southeastern most sector of the Tongonan Geothermal Field, which lies in the outflow region (Figure 1). It is liquid dominated as reflected by the low discharge enthalpy of the Malitbog wells. Most of the wells in this area have been drilled and tested in the late 1970's and early 1980's.

It was only in early 1990's that the sector was finally developed for commercial exploitation. A double flash system was adapted for the low enthalpy field at separation pressures of 1.2 MPaa and 0.7 MPaa for the high pressure and low pressure flash systems respectively. The main plant has a gross capacity of 232.5 MWe (77.5 MWe x 3) while the low pressure bottoming (optimization) plant has a gross capacity of 14.56 MWe.

Steam for the power plant is supplied by both the Malitbog and the South Sambaloran sectors. The former provides the steam requirement of one turbine unit, and the latter provides the requirement of the two other units. Brine from the South Sambaloran wells is injected in Upper Mahiao while brine from the Malitbog production wells is injected in the nearby Malitbog RI sink.

There are nine production wells supplying geothermal fluid to the Malitbog fluid collection and disposal system (FCDS) while seven injection wells were originally connected for the brine disposal requirement of the sector.

1.2 Early Tracer Injection Test

As early as 1982, studies have already been undertaken to determine possible hydrological connection between 5R1D and the surrounding surface features and with the nearby wells. A total of 500 mCi of iodine 131 radioisotope was injected into 5R1D on December 08, 1982 (KRTA, 1983). Brine from discharging wells 509 and 5R4 was injected into 5R1D at a combined flow rate of 65-85 kg/s during the testing period. Fluid sampling was then carried out in wells 509, 5R4, 508D and 514D which were also discharging at that time. Samples were likewise taken from the Bao springs, Malitbog River and Bao River for a period of 28 days. The 28 day monitoring period was based on the radioactive tracer half-life. Results of the analysis yielded no indication of any returns to the monitoring stations. Although no tracer returns were noted from the samples, the study however pointed out that the low injection rate at 5R1D may have influenced the negative response.

2. PRE-COMMISSIONING ACTIVITIES

2.1 Initial Injection

Initial large scale injection began in early 1996 during the pre-commissioning activities of the Malitbog FCDS. Brine flow progressively increased from 50 kg/s to 500 kg/s as the FCDS load was raised for the line flushing and systems testing

activities. One by one all the seven (7) injection wells were connected to the system to cope with the increasing brine load. FCDS full load operation was conducted from June 14 to July 4, 1996 during which a maximum brine load of 500 kg/s was continuously disposed of to the Malitbog injection wells. At that time, the second flash system was not yet in operation and waste water from the high pressure separator vessels was directly sent to the injection wells. Total brine injected into the Malitbog reinjection area from March 27 to August 14, 1996 is estimated to be roughly about 2,590,000 tonnes.

Capacities of the injection wells were measured during full load operations. Well 5R1D had the highest measured capacity of 221 kg/s, followed by 5R4 with an acceptance of 161 kg/s and 5R7D with a capacity of 64 kg/s. The capacity of the four other wells were in the range of 18 – 27 kg/s.

2.2 Tracer Testing

Further study of the hydrological connection between the Malitbog reinjection sink and the Malitbog production wells was again undertaken in 1996 during the Malitbog FCDS testing (Parrilla et al, 1996). A total of 25 kg of sodium flourescein tracer was injected into 5R1D on June 21, 1996 while samples were collected from well 509 and the nearby surface features. Unlike the earlier tracer test, a high injection rate of 220 kg/s was achieved as all production wells were discharging to the system. Samples were initially screened using black lamp, and in cases where flourescence were detected, the samples were further analyzed using a UV-VIS spectrophotometer at 491 nm. Samples found to be positive of tracer returns were then analyzed using Perkin Elmer luminescence spectrometer. Positive returns were detected in the Hot Springs and well 509.

2.3 Surface Thermal Activities

Intensive monitoring of nearby Bao-Banat-i thermal areas was undertaken during the pre-commissioning activities of the Malitbog FCDS to determine any response with increased injection loading at the Malitbog injection sink. Parrilla et al. (1996) noted increased geysering activities in the hotspring area.

The report likewise pointed out that injection at 5R1D had the highest impact on the hotsprings which was supported by the positive tracer returns obtained during the tracer injection test at 5R1D.

2.4 Output Testing

After the FCDS shutdown on mid August 1996, six of the nine production wells were programmed for short term discharge test (STD). This was aimed at updating the discharge output and characteristic of the wells prior to large scale exploitation. Most of the output data then were based on the discharge tests conducted in the late 1970's and early 1980's. The STD was programmed for six days per well at three different well openings. The wells tested were 501, 503, 509, 513D, 514D and 515D.

Results of the tests showed wells 503, 509, 514D and 515D to have higher discharge enthalpy than the original values by 250 kJ/kg. Well 515D had the highest enthalpy of close to 1600 kJ/kg while the other wells have enthalpy ranging from 1350 – 1500 kJ/kg. Only wells 515D and 501 showed a corresponding decline in massflow while the rest of the wells have relatively stable massflows. The rising discharge enthalpy of these wells is attributed to pressure drawdown after prolonged utilization during the pre-commissioning activities. It should also be noted that like the wells in the other sectors, these wells have experienced pressure drawdown in response to the exploitation of the Tongonan 1 production field.

Well 513D on the other hand exhibited a higher maximum discharge pressure and enthalpy than the original output.

3. RESERVOIR CHANGES WITH TIME

3.1 Downhole Temperatures and Pressures

Downhole temperatures and pressures were closely monitored to determine changes in reservoir conditions. Downhole measurements of production wells are usually conducted annually during FCDS shutdown which is scheduled simultaneous with the power plant preventive maintenance and servicing. It should be noted that the Malitbog production wells provide the bulk of brine for second flash for the supply of low pressure steam to the bottoming plant. As such, these wells are operated at fully open condition and any alterations in well openings would significantly reduce the low pressure steam supply. Peripheral wells not hooked up to the FCDS are monitored more frequently.

All three high injection capacity wells 5R1D, 5R4 and 5R7D revealed cooler downhole temperatures as a result of prolonged brine injection. Well 5R1D remains single phase with suppressed temperatures of between 160 – 170 C at its major injection zone. Well 5R1D was previously displaying two phase conditions prior to 1996. It was only during initial large scale injection that the well reverted to single phase condition. In the case of 5R4, cooler downhole temperatures are likewise noted although unlike well 5R1D, two phase conditions still persists in the wellbore. Both 5R1D and 5R4 likewise exhibit stable downhole pressures which imply that the injected brine is dispersed away from the wellbore.

Well 5R7D on the other hand was only surveyed once after large scale injection began in 1996. This well was isolated in October 5, 1998 after it was believed that well 5R7D is responsible for the observed RI breakthrough in wells 508D, 503, 514D and 515D based on the chemical changes in the fluid discharge of these wells. The downhole survey conducted 49 days after it was shut showed that the well is still recovering from the effects of prolonged brine injection with temperatures lower than the measured stable temperatures. Its pressure profile however shows a rather peculiar drop in water level by as much as 100 m and a change in pressure gradient. This is seen as a combined effect of brine injection and drawdown. It is therefore inferred that like the two other RI wells, brine injected into the well is dispersed away from the wellbore. After injection was halted, the well began showing effects of pressure drawdown.

South of the sector and close to the other injection wells, no response to either injection or production was noted at well 5R2D. Well 5R2D is a low permeability well drilled to the

southwest Its downhole pressure was monitored from April 15, 1998 to February 16, 1999 through a Pruett capillary tubing set at 250 mMD. Downhole temperature measurements likewise showed no thermal decline. The negative response implies that there is no flow of injected brine towards the western flank of the sector.

Peripheral monitor wells 502, 5R11D and 5R10D have also been affected by pressure drawdown. Although the first two wells showed relatively stable downhole temperatures, well 5R10D registered a drop in temperature by as much as 15 °C at depth while at the same time showing a 60 m drop in water level and a change in pressure gradient (Figure 2). This response closely resembles that of the response observed in 5R7D. This is attributed to the combined effect of incursion of cooler fluids and pressure drawdown. It should be pointed out that it was only in 1999 that RI breakthrough was observed in this well.

There have also been changes in downhole temperatures in some of the nine (9) production wells. This however is more of an effect of re-equilibration as pressure drawdown continues to occur, thereby producing two phase conditions in the upper section of the well. Aside from this, no change in temperature, particularly at depth where single phase still exists, has been noted that would indicate ingress of RI fluids. It is apparent from the surveys that pressure drawdown has been fairly uniform across the field (Figure 3). Average drawdown of the production wells since 1996 is about 2.8 MPa.

3.2 Output Trends

Since the start of the continuous plant operations in 1997, the output of all Malitbog production wells have been regularly measured using chemical tracer method.

The output trends generally show increasing discharge enthalpy as a result of pressure drawdown (Figure 4). While some wells have exhibited high enthalpy, the others have remained at lower levels. This distinction is related to the well's dominant feed. The high enthalpy producing wells are tapping more from the upper two phase feed zones with some contribution from the lower liquid feed zones. In contrast, the low enthalpy producing wells have major contributions from the lower liquid feed zones. The effects of the increasing discharge enthalpy are reflected in the steadily declining brine availability for second flash.

Closest to the Malitbog injection sink, wells 509, 501, 508D and 510D indicated a rather slow but gradual rise in discharge enthalpy.

The second closest group of wells, consisting of wells 511D and 513D, located north of pad 501 showed a more rapid increase in enthalpy.

The wells farthest from the Malitbog injection sink are wells 503, 514D and 515D. Wells 503 and 514D initially showed a slight fall in enthalpy of about 100 kJ/kg in 1997 compared to the 1996 STD data. The relatively small change in enthalpy does not conclusively signify entry of reinjection fluids. It should also be pointed out that this variance could be inherent to the different methods of output measurements used in 1996 and 1997. The silencer method was employed during the short term discharge test in 1996 while the present measurements are performed using the tracer method.

3.3 Reservoir Chemistry Trends

In the early stages of steam field operations in the Malitbog sector, wells 503, 514D and 515D indicated slight increase in reservoir chloride with a corresponding decline in CO2td (Figure 5). It was initially believed that geothermal fluids from the adjacent South Sambaloran sector particularly in the vicinity of 302 area were migrating towards the northern part of the Malitbog sector (Siega et al., 1997). It was only in February 1999 that the continuing increase in mineralization noted in these wells, accompanied by fall in CO2td and Cl/Ca ratio was postulated to be caused by incursion of fluids from the Malitbog injection sink. This belief was farther strengthened by the indication from crossplots of liquid and gas parameters (Parrilla et al., 1998). Aside from the northern most Malitbog wells, the same trend in fluid chemistry was noted in 508D, a well comparatively closer to the injection sink. Although increase in mineralization and decline in CO2 have been noted in these wells, the silica temperatures however remained relatively stable. It was postulated that the injected fluids are indirectly channeled through flow conduits. The evaluation also pointed to 5R7D injection as having more impact on the affected wells based on historical chemical trends.

After a month long steam field shutdown in May 1998 for its annual PMS, a decline in Clres level and stable CO2td was seen in these wells (Siega et al., 1998). This was interpreted as possible recovery from effects of RI fluid incursion. Finally in October 05, 1998 well 5R7D was isolated from the system and the brine flow was diverted to the higher capacity wells, 5R1D and 5R4. A semblance of recovery was noted in these wells three months after isolation of 5R7D as indicated by the decrease in mineralization and increase in CO2td (Martinez et al., 1999).

Other wells in the Malitbog sector have chemical trends indicative of boiling in response to pressure drawdown. Wells 509 and 510D initially showed stable chemistry in the early stages of operations. Fluid chemistry of these wells eventually indicated effects of drawdown as implied by the increase in CO2td although no significant increase in Clres was noted. It has also been reported that as early as 1997, wells 511D and 513D have already indicated boiling in the reservoir with the observed increase in mineralization and increase in CO2td.

3.4 Surface Activities

The Bao-Banat-i hotsprings again responded to the resumption of 5R1D utilization on April 1997 upon full operation of the Malitbog power plant. Waste water was injected into 5R1D at a lower load ranging from 66 – 119 kg/s. Bolanos and Parrilla (1998) noted that breakthrough of reinjection fluids was again experienced as indicated by the increase in massflow and chloride. However, during the last quarter of 1997 and first quarter of 1998 increasing chloride trend and declining flowrate was noted in the hotspring area. This sudden reversal of mass flow trend was attributed to the lower rain fall due to the El Niño phenomenon and inferred migration of reinjection fluids to the production sector.

4. DISCUSSION

The chemical trends have identified wells 503, 508D, 514D and 515D as being affected by reinjection breakthroughs. The fluid chemistry of these wells have indicated increase in mineralization and decline in CO2. Silica temperatures however remained relatively stable. Detection of the returning fluids has been reported as early as six months after the start of large scale injection. Surprisingly though, well 509 which was previously established as hydrologically connected with 5R1D, displayed no signs of reinjection returns.

The output trends and downhole conditions however have not reflected the presence of reinjection breakthrough in the identified production wells. The only well showing temperature decline associated with reinjection fluid breakthrough is peripheral well 5R10D. The ingress of reinjection fluids into this part of the sector only occurred more than a year after continuous injection began in mid-1997. Re-equilibration of downhole temperatures with pressures especially in the upper two phase section is the only discernible change noted in some production wells. This re-equilibration is brought about by the continuing fall in downhole pressures leading to the creation of two phase conditions. Pressure drawdown appears to be uniform across the field with the four affected production wells showing comparable pressure decline with the other production wells.

The cessation of discharge of injected water in the Bao-Banat-i thermal areas may imply alteration in the natural flow pattern in the reservoir, especially in the outflow sector. The western flank of the field, represented by well 5R2D, also showed negative response to injection. This leaves the production sector in the north as a possible flow path of the reinjected fluids. This may explain the chemical changes noted in some producion wells. The falling reservoir pressures in the production sector makes it more susceptible to fluid recharge.

There are two factors which could have influenced the lack of thermal effects. These factors are: a.) distance between 503, 514D, 515D and the reinjection sink and b) the absence of direct flow channels between these production wells and the injection wells. Waste brine injected into the injection sink at 160 °C is possibly reheated before it finally reaches these production wells.

At present, steps have been taken to further verify the changes observed in the discharge fluid chemistry. Well 5R7D, believed to have more impact on the four production wells, was isolated in October 1998. The effect of its outage is presently being closely monitored

5. CONCLUSIONS

In spite of the suspected reinjection breakthrough in the production wells, no significant impact on the output of these wells has been noted.

The relatively stable downhole pressures of the high permeability injection wells have indicated the apparent dispersion of reinjected fluids away from the injection sector. The thermal features in the Bao-Banat-i area, previously identified as the outflow of the reinjection fluids, have ceased to exhibit any effect of Malitbog injection. The lack of evidence of thermal effects may be due to the absence of any direct hydrological connection, distance between the injection wells and the production wells which causes the returning fluids to be reheated before finally re-emerging.

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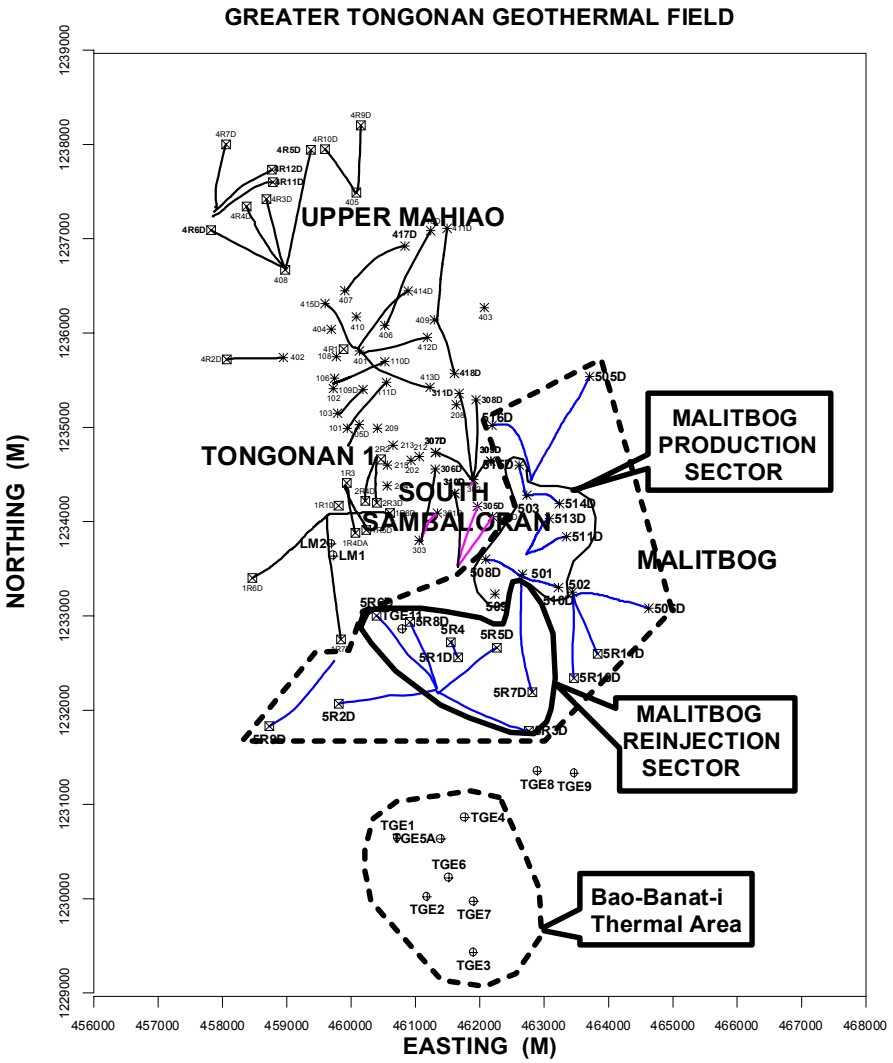


Figure 1. Tongonan Geothermal Field Location Map

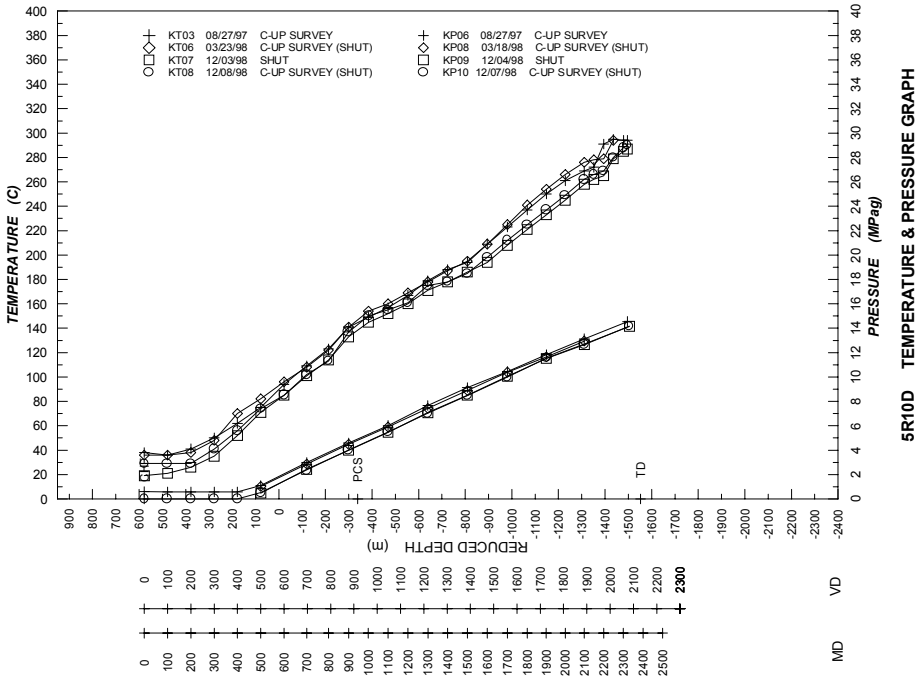


Figure 2. Well 5R10D Tempreature and Pressure Measurements

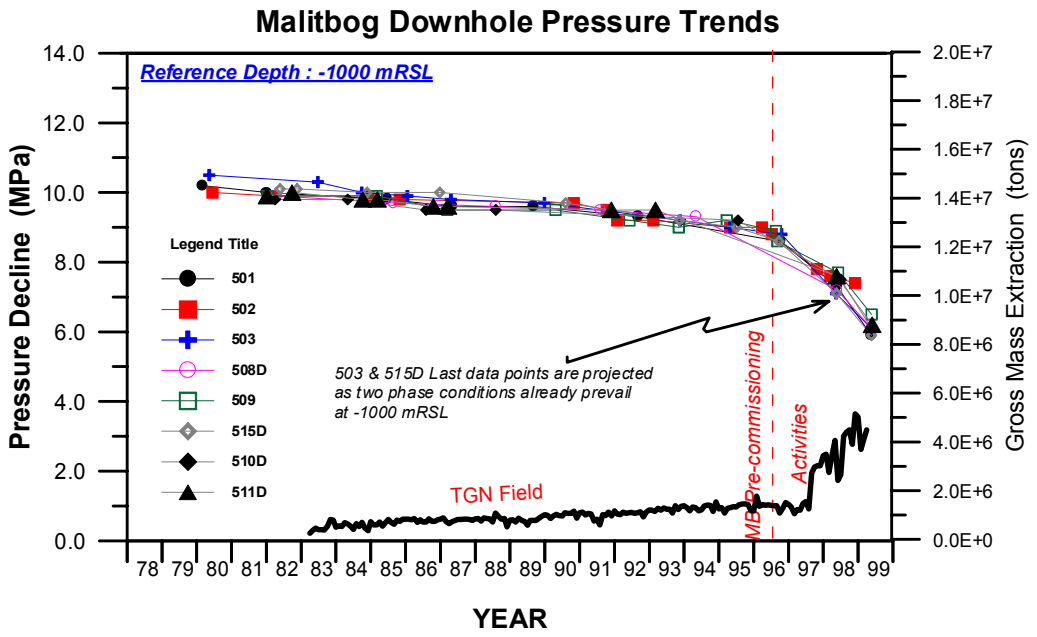


Figure 3. Pressure vs time Plot at –1000 mRSL and Average gross monthly mass extraction vs time

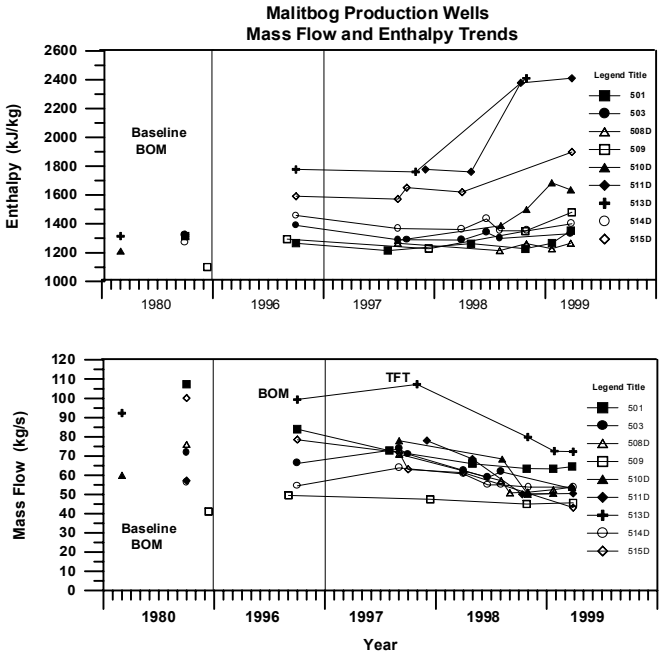
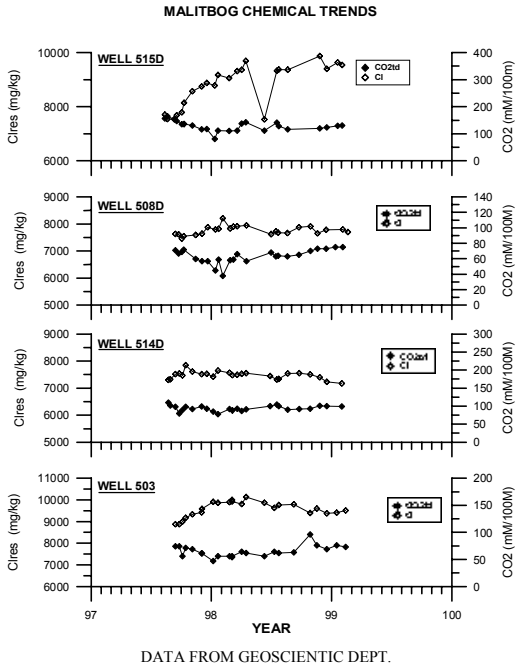


Figure 4. Enthalpy and Massflow vs time Plot



DATA FROM GEOSCIENTIC DEPT.

Figure 5. Clres and CO2td vs time Plot