Proc. 5th NZ Geothermal Workshop 1983

GEOCHEMICAL TECHNIQUES APPLIED TO MEDIUM-TERM DISCHARGE TESTS IN TONGONAN

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ABSTRACT

A medium-term discharge test (MTD), typically lasting 6-12 weeks has long been used in Philippine projects for assessing stable well output, at different wellhead pressure conditions.

The format of the MTD has proven to be well suited for obtaining the optimum information from the chemistry of discharge fluid. In particular the changes in discharge chemistry seen during the initial discharge and at varying wellhead pressure have been useful in chemically characterising different production zones within individual wells, and in rationalising overall field trends. This paper describes the geochemical techniques used at the Tongonan geothermal project, as applied to MTD tests.

INTRODUCTION

At Philippine geothermal projects administered by PNOC-EDC, it has become standard practice to determine stable output parameters for all newly drilled wells, at a range of flowing wellhead pressures, with discharge tests. These data are essential for engineering purposes in designing for any later commercial development of the geothermal field. The information is also valuable for reservoir modelling which assists in the formulation of on-going drilling strategy. In addition, the tests are important for long term reservoir management, in that they allow for compilation of base-line reservoir data before large-scale commercial exploitation of the field.

To obtain the necessary output data a standard discharge format has been used in Philippine fields that has become known as a medium-term discharge test or MTD. A MTD typically consists of three phases of testing:

1) INITIAL FULL-BORE DISCHARGE (FBD). An unthrottled discharge to clear the well as quickly as possible of drilling fluids and surface water introduced during well completion tests, and to provide stable data at maximum output.

2) BACK-PRESSURE PLATE (BPP) SERIES. Once stabilization under FBD has been attained, the well is throttled at one-week intervals to successively higher wellhead pressures (WHP), using back-pressure orifice plates. Stable output data is obtained for each BPP. The designations and sizes of the BPP's are given in the appendix.

3) CONCLUDING FULL-BORE DISCHARGE. After stabilisation at the most throttled condition, (highest WHP) the well is returned to FBD to reassess the stable maximum output.

MTD output data is complemented by downhole temperature and pressure measurements obtained during heat-up, discharge, (flowing downhole surveys) and shut-in conditions.

Although the MTD was instituted principally with engineering objectives in mind, its format has been found to be ideally suited for thorough geochemical evaluation of the well. The BPP test series in particular has been found to be as useful for gleaning geochemical information, as it is for developing output curves. The changes in discharge chemistry caused by manipulating WHP, and hence downhole pressures, provide valuable insight into the behaviour of multiple production zones and reservoir processes. As a result the MTD has evolved to the point where it is now considered a joint reservoir engineering and geochemical evaluation of the well, in which the data from each disipline are complementary and together provide a more lucid understanding of the reservoir.

The name 'medium-term' is used to differentiate the MTD from an initial short-term, (several hours) vertical discharge and possible future long-term production discharges. At the Tongonan project environmental constraints have become increasingly more limiting in response to the need to test more wells at any one time. To comply with these constraints the duration of the MTD's are now frequently shortened to 4-6 weeks from the 6-8 month test periods which were previously possible. Nevertheless the basic format of the MTD is still retained, albiet in condensed form.

During the MTD the discharge is usually passed to a standard atmospheric silencer with an end-pipe lip pressure tapping and weir-box to measure discharge enthalpy by the critical discharge pressure method, (James, 1966) and total mass flow. BPP's are installed between the wellhead side-valve and the horizontal discharge spool. The environmental constraints on discharge may be avoided, and longer tests scheduled, by using a wellhead separator and reinjecting separated water.

The chemistry of the Tongonan geothermal field, on which this paper is wholly based, has been described in detail by Barnett (1979), and Lovelock *et* al.(1982). The Tongonan reservoir is a liquid-dominated system with reservoir temperature and chloride concentration ranging from 330°C and 9000 ppm in the postulated central upflow, to 250°C and 5000 ppm at the margins of the currently delineated deep resource.

CHEMISTRY OF THE CLEARING DISCHARGE

Although the most important chemical data from an MTD is that obtained under *stable* discharge conditions, the chemistry of the initial clearing discharge should not be overlooked. During the first few weeks of discharge, chemistry often changes rapidly and consistently and provides information that may not be available subsequently.

If significant losses of circulation are encountered *during* drilling, the local reservoir about the well bore, may be considerably modified with a laterally extensive zone of mixing between cooler drilling fluid (water or mud) with little chloride, and hotter, more-mineralised geothermal fluid. During the well heat-up period before discharge, the reservoir may be modified still further by oxidation by introduced drilling fluids, chemical reequilibrium, horizontal flows, or internal bore flows between separate reservoir zones. Much can be learned about these processes by intense sampling (every 1-2 days) during the clearing discharge period.

TABLE 1
Drilling and discharge data - Wells 403, 405

	WELL 403	WELL 405
Drilling		
Date spudded	April 4, 1980	May 3, 1980
Date completed	July [illegible], 1980	July 6, 1980
Duration of drilling (days)		64
Total Depth (m)	2470	2290
Circulation losses:		
Depth (m) Partial	1330-2400	-
Total	2430-2470	850-2290
Total mass of lost circ'n fluid (tonnes)	67,000 + 20%	69,000 + 10%
Initial Injectivity (l/s.MPa)	9	35
Medium Term Discharge Test		
Date MTD commenced	Aug 17, 1980	Oct 10, 1980
Duration from end of drilling (days)	37	97
Mass flow rate, FBD (kg/s)	30	105
Total mass drilling fluid discharged (tonnes)	28,000 + 10%	Less than 5000

During the initial discharge the most obvious geochemical trend is increasing mineralisation (increasing chloride) as drilling fluid close to the bore is discharged, and undiluted geothermal fluid is drawn in. Figure 1 shows the chloride versus time trends of Wells 403 and 405 at Tongonan. These two wells which had similar drilling histories, differed greatly in their stablisation times; Well 403 requiring three months and Well 405 several days only. (The increase in

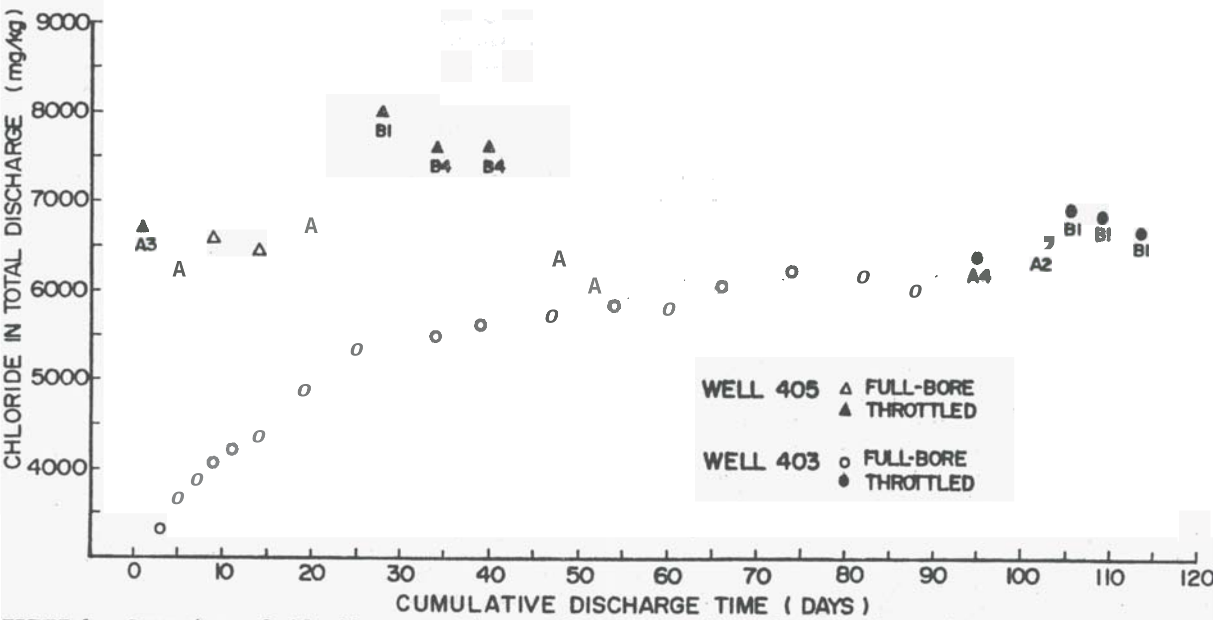

FIGURE 1: Comparison of chloride versus time trends for Wells 403 and 405 during period of clearing discharge.

Chloride concentration for Well 405 under throttled conditions is believed to be due to a second zone; see later section, this paper). To help rationalise this difference, drilling and discharge records were used to estimate the mass of drilling fluid lost to the formation during drilling and the mass subsequently discharged (Table 1). Drilling records showed that both wells received equally large volumes of drilling fluid, (approx 70,000 tonnes) during extended periods of lost circulation. The mass of drilling fluid discharged up to the point of stabilization was estimated fran the degree of dilution relative to the stable maximum. This was calculated at 28,000 tonnes for Well 403 and less than 5000 tonnes for 405.

That Well 405 appeared to discharge only a small fraction of the original drilling fluid lost to the formation suggests that drilling fluid was removed from the vicinity of the well bore by lateral reservoir flows prior to discharge. The high injectivity and rapid heat-up time for Well 405 also support this, together with other evidence for Well 405 being situated in a well-developed outflow frun the centre of the field. Well 403, which had a very long stabilisation time and discharged about 40% of the drilling fluid lost to the formation during drilling, appears to be situated in an area where reservoir fluid is less mobile.

The major assumptions inherent in the above analysis, are that drilling fluid does not gain significant chloride through water-rock reactions prior to discharge, and the well produces frun the zone(s) where circulation fluid is lost.

OXIDATION IN THE RESERVOIR BY DRILLING FLUID

A distinctive feature of many clearing discharges in Tongonan is the relatively high sulphate levels seen at the beginning of discharge and the trend of declining SO_4 as the well clears. This trend is very pronounced for Well 403 as shown in

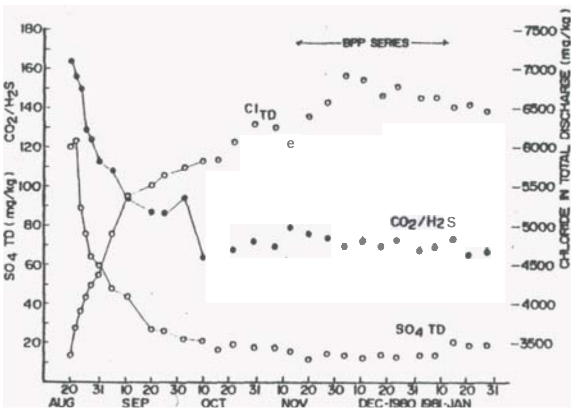

FIGURE 2: Chloride, sulphate and CO_2/H_2S trends during initial clearing discharge of well 403. (Cl, SO4 concentrations are for total discharge)

Figure 2. The initial high SO_4 levels can be attributed to the oxidation of H_2S in the reservoir by oxygenated drilling and completion test fluid. This is supported by the CO_2/H_2S ratio which is also high initially due to depletion of H_2S. As the well clears, both SO_4 and CO_2/H_2S decline as oxidised fluid is removed and undiluted reservoir fluid is drawn into the well. From Figure 2 it is also important to note that both SO_4 and CO_2/H_2S stabilise simultaneously with chloride, confirming that the process of oxidation is directly attributable to the presence of drilling fluid in the reservoir.

MANIPULATING WHP TO DIFFERENTIATE PRODUCTION ZONES

Many Tongonan wells appear to have multiple production m s that differ in temperature, and water and gas chemistry. Different production zones may also have formation pressures that differ relative to the well bore pressures under discharge. Therefore, when WHP is changed at each stage of the BPP series the relative contribution from different zones may also change, and this will be reflected in both the water and gas chemistry of the resulting discharge.

For a well producing from a single production zone, one would not expect total-discharge gas concentrations to change appreciably with changes in discharge enthalpy caused by isothermal boiling in the formation, unless steam is lost before entering the well, (Glover et al., 1981). well 208A, (a well deepened from 835 to 1995m CHF) showed during its MTD a consistent and marked variation of gas and enthalpy with WHP, as shown in Figures 3 and 4. CO_2 levels are highest under full-bore discharge conditions (low WHP) and decline by about 75 percent under back-pressured conditions. The gas in Well 208A is believed to be derived principally from an upper two-phase zone that supplies a greater contribution to the total discharge, when well-bore pressures are lower, compared to a deeper zone. This explanation is supported by the chemistry of the original shallow well 208 which discharged high enthalpy (2500 J/g) fluid with significantly

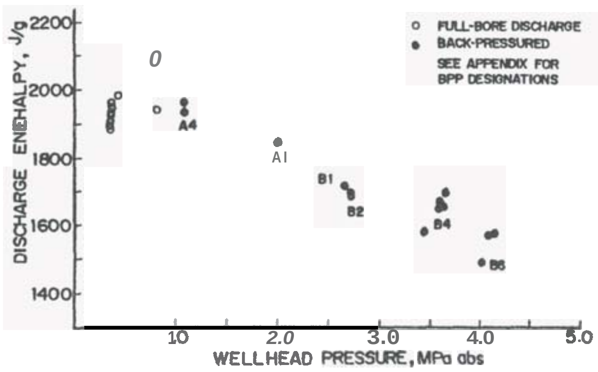

FIGURE 3: Trend of declining enthalpy with increasing WHP, for Well 208A.

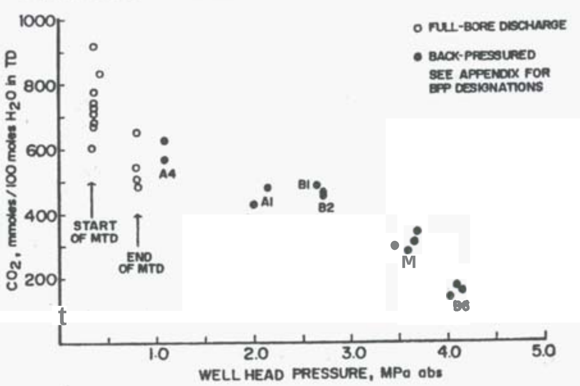

FIGURE 4: Declining CO_2 concentrations in total discharge with increasing WHP, for Well 208A.

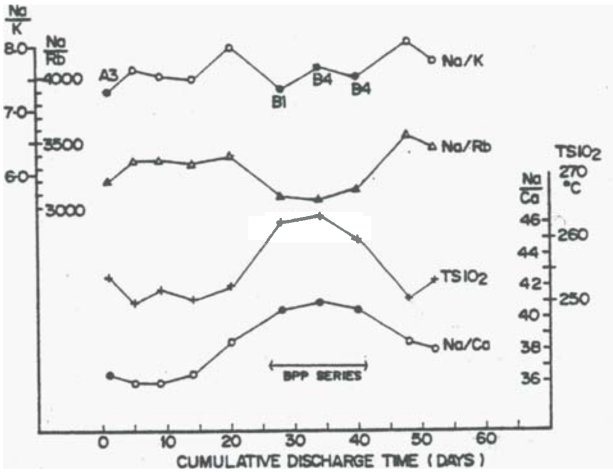

FIGURE 5: Variation of temperature-dependent molar chemical ratios during BPP series of MTD of Well 405. (see appendix for BPP designations)

higher gas levels, (2000 mmoles/100 moles in total discharge), high sulphate (up to 3800 ppm in weir-box) and low chloride (maximum of 1050 ppm), ie: a vapor-dominated zone formed through steam separation fran the deeper chloride water.

It is also possible to recognise production zones of different temperature by variations in molar chemical ratios such as Na/K, Na/Rb, and Na/Ca, which are controlled by temperature-dependent mineral solution equilibria (Ellis and Mahon, 1977; Fournier and Truesdell, 1973). Since chemical ratios are generally not affected by steam loss, they are particularly useful when interpretation of discharge chemistry is confused by enthalpy measurements that are not considered reliable or show large fluctuations.

In Figure 5, chemical ratios are plotted for the MTD of Well 405. The decline in Na/K and Na/Rb ratios and increase in Na/Ca during the BPP series is consistent with an increase in the relative flow fran a higher- temperature production zone, as shown by the silica geothermometer. It is interesting that the Na/Rb response is more pronounced than that of the more often-used Na/K ratio. (The Na/Ca ratio responds in an opposite manner to the Na/K and Na/Rb ratios because of the inverse solubility of calcite with increasing temperature.)

CYCLING WELLS

In sane wells, pressure responses to discharge in different zones combine to produce a periodic variation in the relative contribution of two zones which is manifested in cycling WHP, mass flow and enthalpy. The discharge chemistry of a cycling well can be analysed in much the same way as that for the BPP series of an MTD; the variation of total discharge chemistry with WHP during the period of one cycle can be used to characterise the two zones which are responsible for the effect. Unlike with the BPP series, where stability is usually attained at each WHP stage, monitoring the chemistry of a cycling well is more exacting, (particularly when the period is short) since enthalpy, WHP, mass flow and chemistry are often changing continuously throughout the cycle. Well MG5D in Tongonan was found to cycle under full-bore

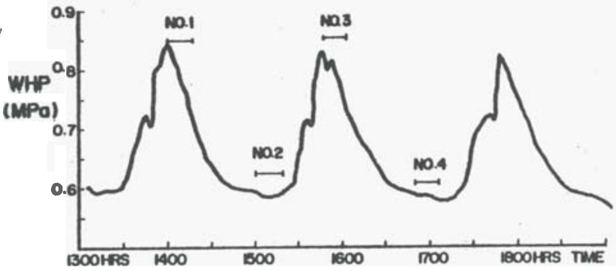

FIGURE 6: Variation of WHP with time for Well MG5D, during cycling on Aug 16, 1983.

TABLE 2: Chemistry and output data of Well MG5D during cycling, August 16, 1983, (refer also Figure 6)

SAMPLE NO	SAMPLING PERIOD	WHP MPa abs	ENTHALPY	MASS FLOW kg/s	Cl (WBX) mg/kg	Cl (TD) mg/kg	GSP MPa abs	CO_2 (GSP) mmoles/100molesH$_2$O	CO_2 (TD) mmoles/100molesH$_2$O
NO 1	1400-1417 HRS	0.84–0.72	? –1280	24.5	3190	1960	0.75–0.65	5450	1560
NO 2	1500–1603 HRS	0.59	1150–1090	22.5	2700	1850	0.54	7380	1650
NO 3	1547–1603 HRS	0.83–0.74	1220–1350	26.6	3280	2010	0.74–0.67	4950	1420
NO 4	1650–1706 HRS	0.58	1160–1100	22.1	2670	1820	0.52	7790	1790

WBX – Weir-box sample (atmos pressure)
GSP – Gas sampling pressure

TD – Total discharge concentration, calculated using averaged enthalpy and pressure data

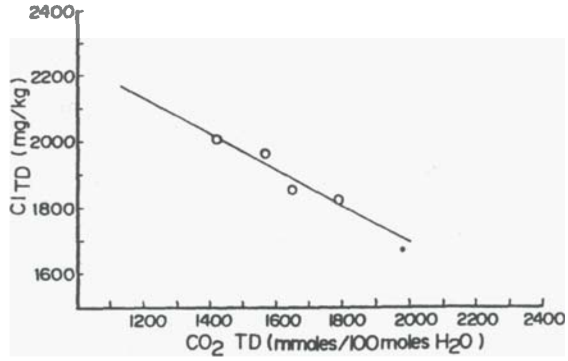

FIGURE 7: Chloride-CO_2 mixing line for Well MG5D, constructed from data in Table 2.

discharge conditions with a period of about 4 hours, (Figure 6). The results of gas and water samples and output measurements, obtained at the peaks and troughs in the WHP cycle are presented in Table 2. In Figure 7, chloride is graphed against CO_2 to produce a mixing line between a high-gas zone and a relatively high-chloride zone. The mixing line may be extrapolated to the possible compositional limits of each zone. In this case a chloride concentration of 2700-2800 ppm is predicted for the high-chloride zone by extrapolating to the gas levels of two neighbouring wells MG1, MG2D. The analysis in this example is made difficult by the enthalpy measurements which vary significantly within the period of sampling and which also require a gas correction for the effect of CO_2 partial pressure on end-pipe lip pressure (Grant, 1983). In addition, the relative variation from the zone(s) causing the cycling is probably only small (10-20%) based on the variation in mass flow and chemistry.

DISCHARGES WITH EXCESS ENTHALPY

Wells which produce from a permeable, hot, liquid-water reservoir generally have a single-phase liquid inflow at the producing zone, under discharging conditions. Subsequent boiling during flow up the well bore is close to adiabatic with the result that total discharge enthalpy measured at the surface corresponds to that of liquid water at the reservoir temperature.

At Tongonan, many wells develop discharge enthalpies significantly above that of liquid water at the reservoir temperature. This excess enthalpy may develop as a result of pressure-drawdown and isothermal boiling in an otherwise liquid reservoir, (due to relatively poor permeability) or may be due to production from a naturally two-phase zone. In Tongonan natural two-phase conditions are believed to be pervasive in the upper part of the central reservoir and data from shallow wells suggests the fluid there is low in chloride and often high in gas (see above, for Well 208). Excess enthalpy is generally greatest under full-bore discharge conditions when downhole pressures are lowest. Under back-pressured conditions discharge enthalpy is seen to decline; a result of higher wellbore pressures suppressing boiling in the formation or suppressing production from two-

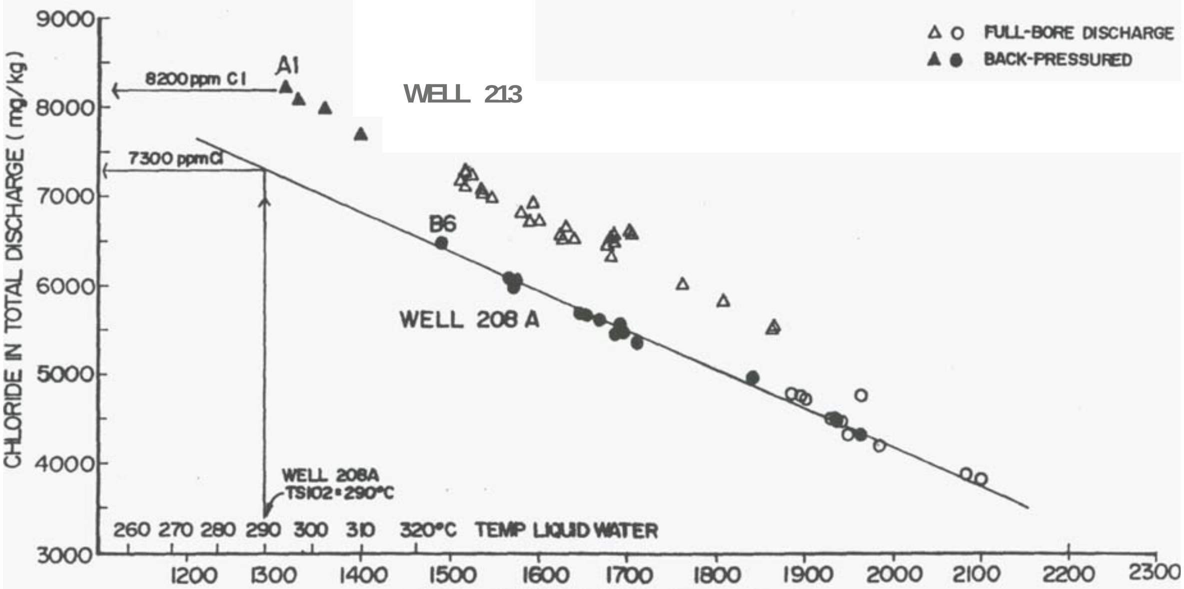

FIGURE 8: Chloride in total discharge versus discharge enthalpy for Wells 208A and 213, showing steam dilution at high discharge enthalpy, (under full-bore discharge and at low WHP)

phase regions. High-enthalpy Tongonan wells show a characteristic trend of declining enthalpy with increasing WHP as shown in Figure 3 for Well 208A.

THE EFFECT OF EXCESS ENTHALPY ON DISCHARGE CHEMISTRY FOR TONGONAN WELLS

Weirbox chloride concentration generally increases with the development of excess enthalpy under full-bare discharge conditions, due to the deminishing water fraction at atmospheric pressure. However, for Tongonan wells which display large increases in enthalpy, the resulting increase in weirbox chloride is relatively small compared to the decrease in the water fraction. As a result, total discharge chloride concentration (Cl_{TD}) declines linearly with increasing discharge enthalpy as shown in Figure 8 for Wells 213 and 208A. The Cl_{TD} versus enthalpy lines appear to describe a simple process of steam dilution since they extrapolate approximately to the enthalpy of stem when chloride concentration is zero.

The steam dilution trend cannot be explained by a simple process of isothermal boiling in a single producing zone since a two-phase mixture moving towards the well bore, with an expanding steam fraction, would still maintain constant total discharge concentrations. The dilution trend is more likely due to the contribution of low-chloride fluid from a separate two-phase region at a shallower level, such as that discussed in the previous section.

For Tongonan wells the Cl_{TD} versus enthalpy trend can be used as an aid in calculating the chloride concentration of the deep liquid-water reservoir. As shown in Figure 8, when Well 213 is back-pressured with an A1 orifice plate, discharge enthalpy declines to about 1300 J/g, the enthalpy of a 292°C liquid inflow. under this condition, with no excess enthalpy, the total discharge chloride concentration of 8200 ppm is also the aquifer concentration, since no steam dilution is occurring. For Well 208A which retains excess enthalpy even under the most throttled condition, (BPP B6) the Cl_{TD} versus enthalpy plot may be extrapolated to the enthalpy of the deep single phase reservoir, (obtained from the silica geothermometer or downhole temperature surveys). In this case an aquifer chloride concentration of 7300 ppm is obtained. This technique has proved useful for mapping iso-chloride contours for the deep Tongonan reservoir. (Lovelock et al., 1982).

The calculation of an aquifer chloride concentration assumes a single major chloride zone exists at depth, which is single-phase under non-flowing conditions.

ACKNOWLEDGEMENTS

The authors wish to thank the PNOC-EDC management for the opportunity to publish the data used in this paper. The advice and comments of colleagues in KRTA and PNOC-EDC are gratefully acknowledged.

REFERENCES

Barnett, P.R., 1979. Geochemistry of the Mahiao Portion of the Tongonan Geothermal Field. Oral presentation, New Zealand Geothermal Workshop, Oct. 1979.

Ellis, A.J., and Mahon, W.A.J., 1977. Geochemistry and Geothermal Systems. Academic Press pp 334-335.

Fournier, R.O., and Truesdell, A.H., 1973. An empirical Na-K-Ca geothermometer for natural waters. Geochimica et Cosmochimica Acta, 1973, Vol. 37, pp 1255-1275.

Glover, R.B., Lovelock, B.G., and Ruaya, J.R., 1981. A novel way of using gas and enthalpy data. Proceedings 3rd New Zealand Geothermal Workshop.

Grant, M.A., 1982. DSIR internal report on visit to Philippines in 1982.

James, R., 1966. Measurement of steam-water mixtures discharging at the speed of sound to the atmosphere. N.Z. Engng., Vol. 21, No. 10, p. 427.

James, R., 1975. Choke Design for Geothermal Bores. Proceedings 2nd U.N. Symposium on the Development and Use of Geothermal Resources, S.F. pp. 1697-1698.

Lovelock, B.G., Cope, D.M., and Baltasar, A.S.J. 1982. A hydrogeochemical model for the Tongonan Geothermal Field. Proceedings of Pacific Geothermal Conference incorporating 4th NZ Geothermal Workshop, Part I, pp. 259-264.

APPENDIX

Designations and sizes of back-pressure orifice plates (BPP's) used at Tongonan

DESIGNATION	ORIFICE DIAMETER (mm)
A8	191
A7	167
A6	147
A5	129
A4	113
A3	99.0
A2	86.8
A1	76.1
B1	66.8
B2	58.6
B3	51.4
B4	45.0
B5	39.5
B6	34.7