FIELD-WIDE APPLICATION OF CHEMICAL TRACERS FOR MASS FLOW MEASUREMENTS IN PHILIPPINE GEOTHERMAL FIELDS

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Abstract

Chemical tracers are widely utilized in Philippine geothermal fields to accurately measure the bore output of production wells, injection line flow rates, and steam inlet rates to power plants. Based on these flow measurements, a production-injection well utilization strategy is formulated to optimize production and minimize injection fluid breakthrough to the production sector. The reservoir response to field utilization is fully assessed based on the total steam and brine flow measurements with time and individual injection well capacity trends.

Recent on-line bore output measurements using sodium benzoate for brine flow and sulfur hexafluoride for steam flow demonstrated a good correlation with the James tube method for several production wells tested. Similarly, steam flow rates measured by tracer compared well with venturi flowmeter measurements at power plant inlets.

Magnesium chloride has been extensively used as a chemical tracer for water flow measurements by PNOC. These test results yielded close agreement with orifice plate flowmeter and spinner flow measurements. Other chemical tracers, such as sodium benzoate and sodium fluorescein, were compared with the magnesium chloride tracer and produced similar results.

1.0 INTRODUCTION

The chemical tracers used in PNOC-EDC geothermal fields in the Philippines include magnesium chloride ($MgCl_2$), sodium fluorescein (Na-fluorescein), and sodium benzoate (Na-benzoate) for brine flow measurements and sulfur hexaflouride (SF_6) for steam flow. Of the tracers mentioned, $MgCl_2$ has been extensively applied since the early 1990's because of its proven good correlation with flowmeter, orifice plate, and downhole Spinner methods. In 1997, PNOC-EDC started to apply the simultaneous injection of Na-benzoate and SF_6 in two-phase lines. Na-benzoate produced results similar to $MgCl_2$ tests, while steamflow measurement by SF_6 correlated with venturi meter. On the other hand, the application of Na-fluorescein is still not implemented due to its relative lower precision and higher costs.

The objective of this paper is to determine the accuracy and the precision of the above-mentioned chemical tracers. They are compared with standard methods, like James Lip Pressure for two-phase tests, venturi meter for the steam flow, and flowmeter for the brine flow. It is also the objective of this paper to identify possible errors for each method and quantify them through error bands.

2.0 METHODOLOGY

2.1 Field Testing

Chemical tram are injected into the pipelines. A distance of 40 times the pipe diameter is maintained between the injection point and sampling point to attain homogeneous mixing of the tracer and the fluids. For $MgCl_2$ and Na-fluorescein, tracers are *mixed* in a 20 liter pressure vessel, which are injected into the pipe through the help of pressurized gas. For Na-benzoate and SF_6, an electronically controlled equipment is *utilized* to inject the tracers into two-phase lines. This is called in this paper as TFT or Tracer Flow Test. Sufficient number of *samples* are collected to establish breakthrough *curves.* For $MgCl_2$, it is customary to collect 20 samples for a period of 6.6 minutes. For Na-benzoate, it is a standard procedure to collect 5 samples , and for SF_6 4 gas samples are collected per trial run

2.2 Laboratory Analyses of Chemical Tracers

Na-benzoate is analyzed using High Performance Liquid Chromatography (HPLC) with a W detector set at 230 nm and methanol-phosphate buffer as eluent. Concentrations of as low as 0.1 ppm can be analyzed although the usual working range is from 10.0 ppm to 100.0 ppm. Magnesium is determined using atomic absorption spectrophotometer (AAS) at 285.2 nm wavelength with nitrous oxide-acetylene flame. Sample concentrations range from 2.0 ppm-5.0 ppm which is at least ten times the background levels found at LGPP wells. Fluorescein analysis is done using a spectrofluorophotometer set at an excitation wavelength of 450 nm and emission wavelength of 512 nm. Concentrations in parts per billion (ppb) levels can still be detected although the usual sample concentration range is 0.1 ppm to 2.0 ppm.

SF_6 gas is analyzed in HP 6890 gas chromatograph with electron-capture detector (GC/ECD) and argon-methane mixture as carrier *gas.* SF_6 concentrations of as low as 6.00E-6 ppm can still be *detected* although usual sample concentration range is from 0.001 to 0.100 ppm. Quantitative determination of tracer samples is made using a spreadsheet developed by Thermochem, Inc.

3.0 DISCUSSION OF RESULTS

The following sections compare the results of the tracer tests with the accepted field methods. Likewise, the tracer methods are compared with each other to determine their advantages and disadvantages. Tracer tests were conducted in Leyte Geothermal Power Project (LGPP), a geothermal field operated by PNOC-EDC situated in Central Philippines.

3.1 TFT: Two-Phase Flow Measurement

3.11 Steamflow : TFT vs. Venturi Meters

Shown in Table 1 are the results of the comparative testing between TFT and Venturi meter. The testing was conducted in a separator vessel at Malitbog Sector of LGPP . The SF_6 was injected at the *two*-phase line leading to the separator vessel and gas samples were collected at the *steam* he. Simultaneously, for every gas sample taken, a venturi meter reading was taken. As shown in the table, the maximum percentage difference between the two is ±4%.

Separator Vessel	Date	Average Steamflow by TFT, (kg/s)	Average Steamflow by Venturi, (kg/s)	Percent Difference, (%)
SV-501	19-Jul-97	64.63	62.07	4.04
	22-Jul-97	79.43	76.2	4.15
	24-Oct-97	82.1	80.32	2.19
	31-Oct-97	65.58	68.4	-4.21

Table 1: Comparison of steamflow measurement by TFT and Venturi Meter.

3.12 *Two-Phase Flow: TFT vs. James Lip Pressure Method*

Table 2 shows the results of bore output testing by James Lip Pressure Method and TFT done simultaneously on the same well. There is close correlation between the absolute values of results obtained. The difference between output parameters are as follows: around 3 kg/s for mass flow; around 60 kJ/kg for enthalpy; and almost 1 kg/s for steamflow. Unfortunately the wells tested have minimal waterflow, that is why, a difference of about 4 kg/s was obtained for the water flow.

Production Well	**Method**	**WHP, (Mpa)**	**Enthalpy, (kJ/kg)**	**Steam Flow, (kg/s)**	**Water Flow, (kg/s)**
213	TFT	0.97	2001	19.6	11.3
	JLPM	1	2191	19.6	7.5
212	TFT	1.3	2712	35.1	1.1
	JLPM	1.1	2678	34	0*

**Weirbox level very low (not measurable by JLPM)*

Table 2: Bore output measurement by TFT and James Lip Pressure Method

3.2 $MgCl_2$: Brine-flow Measurement

3.21 *$MgCl_2$ vs Turbine Flowmeter*

The use of $MgCl_2$ tracer started as an alternative method to the orifice plate and flowmeter in the early 1990's, (Macambac, 1992). Precision and accuracy were tested for 1.3 years (August 1991 to December 1992) parallel with flowmeter. Table 3 shows that the capacity test results of the flowmeter and $MgCl_2$ tracer have close agreement falling within 5% difference. Because of the good correlation, thenceforth, the $MgCl_2$ tracer has been used in all brine flow measurement in reinjection wells and load in main lines.

Production Well	**DATE**	**$MgCl_2$ Tracer, (kg/s)**	**MWD Flowmeter, (kg/s)**	**Percent Difference** (YO)
1R3	Sep-91	39.9	41.4	3.7
	Jun-92	59.6	59.3	0.5
	Sep-91	61.1	57.9	5.4
1R4DA	Jun-92	87.1	82.3	5.7
	Dec-92	75.7	76.6	1.2
1R5D	Oct-91	33.6	33.4	0.6
	Jun-92	57.2	59.7	4.3
	Sep-92	64.8	64.1	1.1
1R8D	Oct-91	125.7	124.4	1.0
	Mar-92	116	119	2.6
	Juri-92	120.2	116.8	2.9
2R4D	Oct-91	18.6	17.9	3.8
	Jun-92	16.2	16.3	0.6

Table 3: Calibration of $MgCl_2$ tracer with the flowmeter

3.22 *$MgCl_2$ vs Spinner Survey*

Selected waterflow measurements were conducted in LGPP wells simultaneously with $MgCl_2$ tracer and Spinner survey. Although only few tests were conducted, the results at fluid flow rate of less than 30 kg/s show that spinner surveys and $MgCl_2$ are comparable within a flow difference of less, than < 5.0 kg/s (Table 4). Note also that all spinner survey results are below the $MgCl_2$ results.

3.23 *$MgCl_2$ vs Na-fluorescein Tracer*

Disodium fluorescein dye ($C_{20}H_{10}Na_2O_5$), has been routinely mixed in small amount with $MgCl_2$ tracer solution to determine whether the injected brine has already reached the sampling location. This can be determined by directly observing the changes of color of the brine from colorless to yellowish signaling the start of sampling. Since fluorescein dye is always used during every $MgCl_2$ tracer testings, a study was conducted to determine its ability to quantitative waterflow measurement (Paraon, 1997).

Production Well	WHP (MPa)	Spinner Survey, (kg/s)	$MgCl_2$ Tracer (kg/s)	Difference (kg/s)
5R3D	1.50	23.3	23.4	0.01
5R5D	1.40	21.1	25.8	4.7
5R8D	1.50	20.4	24.9	4.5

Table 4: Comparison of $MgCl_2$ and Spinner Survey Results (May 1994)

Comparison of $MgCl_2$ tracer with fluorescein dye show close agreement for 70 percent of the tests conducted based on the 5 % relative difference limit criterion (Table 5). In other testings of the fluorescein dye, the tracer falls short in terms of precision with the $MgCl_2$. The reason could be due to the irreversible thermal decay at temperature greater than 260 °C, or to the dye's sensitivity to ultra-violet rays.

Reinjection Well/Line	WHP MPa	Average WaterFlow, (kg/s)		Percent Relative Difference (%)
		$MgCl_2$ Tracer	Na-Fluorescein Tracer	
5R7D	1.08	49.6	51.9	4.53
	1.04	49.0	49.8	1.62
MG-9RD	0.23	139.4	138.3	0.79
MahMRL	0.52	94.3	92.4	2.04
MG-21D	0.75	108.0	107.3	0.65
MN-3RD	1.80	23.5	20.2	15.1
Sam MRL	0.52	68.4	55.0	21.7

Table 5: Comparison of waterflow measurements by $MgCl_2$ and Na-fluorescein tracers

3.24 *$MgCl_2$ vs Na-benzoate*

Table 6 summarizes the results of waterflow based on the simultaneous testings of $MgCl_2$ and Na-benzoate tracers conducted in several reinjection wells and main reinjection line. The accuracy of Na-benzoate over the MgCl2 falls within the acceptable relative difference of 5%.

4.0 VARIANCES AND ERRORS

4.1 Error Bands for $MgCl_2$

Variance for $MgCl_2$ flow measurements at different reinjection loads were also established, taking into consideration both the field and laboratory errors (Siega and Arones, 1996). Figure 1 shows that for higher flows rates between 140-225 kg/s, the variance is between ±10-15 kg/s, while at lower flows between 25-100 kg/s, the variance is between ±5-7 kg/s. Shown also in the graph is the general equation of the regression line.

Reinjection Well/Line	Waterflow, (kg/s)		% Rel Difference
	$MgCl_2$ Tracer	Na-benzoate Tracer	
Sam MRIL	83.5	82.2	1.56
	96.9	96.0	0.93
MG-7RD	177.1	182.2	2.88
5R7D	47.1	47.4	0.64
4R3D	97.0	100.3	3.40
5R4D	177.8	170.1	4.33
5R1	79.2	74.9	5.43
5R5D	22.8	23.8	4.39
5R3D	23.9	24.8	3.77

Table 6: Comparison of waterflow measurements by $MgCl_2$ and Na-benzoate tracers

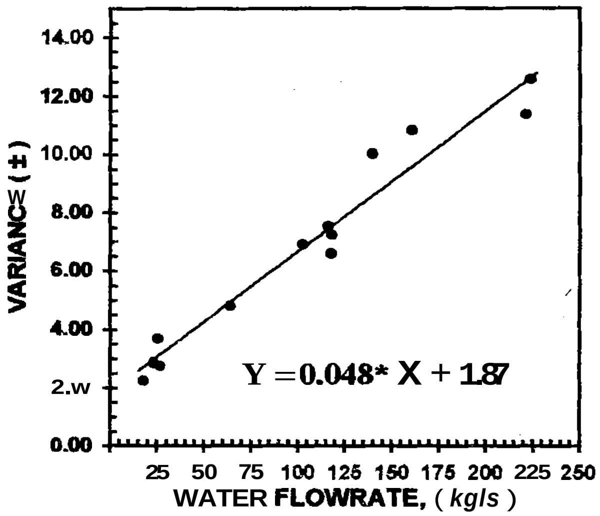

Figure 1: Variance in brine flowrates in $MgCl_2$ tracer

4.2 Error Bands for SF_6 and Na-benzoate

Tabulated in Table 7 are the estimated maximum errors for water flow, steam flow and enthalpy associated with TFT testing using sodium benzoate and SF6 tracers

Measurement	Error	Max Percentage error (%)
Steamflow	Gas Tracer Analytical	2.0
	Gas Tracer Injection Rate	2.0
	Mixed Sample Analytical	2.0
Cumulative		3.5
Waterflow	Liquid Tracer Analytical	1.0
	Liquid Tracer Injection Rate	2.0
	Mixed Sample Analytical	1.0
Cumulative		2.4
Enthalpy		1.7

Error for the water flow measurement is 2.4% while error for the steam flow is 3.5% for flow rates ranging from 20 kg/s to 300 kg/s. These values are the possible maximum errors under normal testing conditions. These errors contribute to maximum of 1.7% error for calculated enthalpy for values ranging from 700 to 2800 kJ/kg (Villa and Magdadaro, 1997).

5.0 FIELD APPLICATION OF CHEMICAL TRACERS

Intensive field testing proved that the results obtained from chemical tracer method are comparable to those obtained from the accepted field methods. Moreover, it has proven that the results of the chemical methods are repeatable at the same testing condition. It is also interesting to note that a simple set-up utilized in $MgCl_2$ tracer method could give comparable results to a more sophisticated and electronically controlled TFT as far as brine flow measurement is concerned.

Having proven their precision and accuracy, chemical tracers are being extensively applied to the management of Philippine geothermal fields. The following are some examples of their practical applications:

5.1 Mass flow and enthalpy measurement in production wells using TFT

New environmental laws prohibit direct disposal of waste brine to the environment, and thus the James Lip Pressure method will have limited applications. In line with this method, TFT has been adopted to update well bore output for at least twice a year. With the updated data, it is easier to formulate production well utilization based on the decline or improvement of well's mass flow and enthalpy.

5.2 Waste brine flow measurement using $MgCl_2$

Inventory of brine flow to reinjection wells is imperative for a sound reservoir management, because only through precise and accurate measurement *can* a reinjection strategy be formulated $MgCl_2$ tracer method offers a quick and efficient way of assessing brine load, and has been applied in Tongonan and Mahanagdong geothermal fields. Moreover, assessing the reinjection capacity of each well gives information on the decline or *gain* in injection capacity of the field, leading to decision either to drill a new well or perform work-over operations.

5.3 Brine audit for optimization of power plants

Bottoming cycle power plant was installed in Malitbog sector of LGPP, which utilized brine from main flash plants to generate an additional 14 MWe. Prior to the plant commissioning, brine audit was performed using Na-benzoate and $MgCl_2$ tracer tests to determine the sustainability of the power plant.

In the past years, chemical tracer method has been a valuable tool in managing geothermal field because of their proven reliability. However, as in any tool, this method must be constantly improved and refined through trials of other chemical tracer and design modification.

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