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

[1]Rico V. Macambac, [1]Allan Troy N. Salazar, [1]Ruperto R. Villa, Jr., [1]Edwin H. Alcober,
[1]Medardo C. Magdadaro, Jr. [2]Paul Hirtz and [2]Russell Kunzman

[1]Philippine National Oil Company-Energy Development Corporation
Makati City, Metro Manila, Philippines
E-mail:macambac@edc.energy.com.ph

[2]Thermochem Incorporated
3414 Regional Parkway Suite A
Santa Rosa, CA 95403, U.S.A.
E-mail:PH_TCI@compuserve.com

ABSTRACT

Chemical tracers are widely utilized in Philippine geothermal fields to accurately measure the bore output of production wells, reinjection 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 reinjection 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 reinjection 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 reinjection 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. However, magnesium chloride is not a practical tracer to use for brine flow from high temperature two-phase production wells due to potential deposition of $MgCO_3$ and $Mg(OH)_2$.

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 hexafluoride (SF_6) for steam flow. Of the tracers mentioned, $MgCl_2$ has been extensively applied to reinjection wells since the early 1990's because of its proven good correlation with turbine flowmeter, orifice plate, and downhole spinner methods. In 1997, PNOC-EDC started to apply the Thermochem method of simultaneous Na-benzoate and SF_6 injection into two-phase lines for production flow measurements (Hirtz, et. al., 1995). Na-benzoate injected into single-phase reinjection brine lines produced results similar to $MgCl_2$ tests, while single-phase steam flow measurement by SF_6 correlated with venturi meters. The application of Na-fluorescein is still not implemented due to low precision and high cost.

The objective of this paper is to compare the accuracy and precision of the above-mentioned chemical tracers in flow measurement applications. They are compared with standard methods, such as the James Tube method for two-phase flow (James, 1965), venturi meter for steam flow, and turbine flowmeter for brine flow. It is also the objective of this paper to identify possible errors for each method and quantify them through error bands.

METHODOLOGY

Field Testing

Chemical tracers are injected into the pipeline at a distance of 40 times the pipe diameter upstream of the sampling point to attain homogeneous mixing of the tracer and pipeline fluids. For MgCl, and Na-fluorescein, tracers are mixed in a 20 liter pressure vessel, then injected into the pipe by pressurized gas. For Na-benzoate and SF_6, electronically controlled equipment supplied by Thermochem is utilized to inject the tracers into two-phase lines. This is referred to in this paper as TFT or Tracer Flow Test. **A** sufficient number of samples are collected to establish steady-state curves for the tracer concentration. For MgCl,, it is customary to collect 20 samples over a period of about 10 minutes. For TFT, the standard procedure is to collect **5** to 8 Na-benzoate samples, and 4 SF_6 gas samples per test over a period of about 20 minutes.

Laboratory Analyses **of** Chemical Tracers

Na-benzoate is analyzed using High Performance Liquid Chromatography (HPLC) with a UV detector set at 230 nm and methanol-phosphate buffer as the eluent. Concentrations 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 an 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 in LGPP wells. Fluorescein analysis is done using a spectrofluorometer 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 by an HP 6890 gas chromatograph with electron-capture detector (GCIECD) and argon-methane mixture as the carrier gas. **A** gas inlet system designed by Thermochem is used to introduce the gas samples to the GC. SF_6 concentrations as low as 6.00E-6 ppm can be detected although the usual sample concentration range is from 0.001 to 0.100 ppm. Quantitative determination of tracer concentrations and the resulting flow rates and enthalpy is made using a computer program developed by Thermochem.

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 at the Leyte Geothermal Power Project (LGPP), a geothermal field operated by PNOC-EDC, situated in the central Philippines.

TFT: Two-Phase Flow Measurement

Steam Flow : TFT vs. Venturi Meters

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

Vessel	Date	Average Steamflow by TFT	Average Steamflow by Venturi	% Diff
SV-501	19-Jul-97	64.63	62.07	4.04
	22-Jul-97	79.43	76.20	4.15
	24-Oct-97	82.10	80.32	2.19
	31-Oct-97	65.58	68.40	-4.21

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

Two-Phase Flow: TFT vs. James Tube Method

Table 2 shows results of bore output testing by the James Tube method and TFT done simultaneously on the same well. There is close correlation between the absolute values of results obtained for steam flow and enthalpy. Unfortunately the wells tested have minimal water flow, so a significant difference was obtained for the water flow measurements. The estimated error for the weir box water flow is +/- 33% for well 213, while the TFT error is estimated to be only +/- 2.4%, as discussed later. The steam flow rates agree within +/-3% for the two methods.

Prod Well	Method	WHP, Mpa	Enthalpy, (kJ/kg)	Steam Flow, (kg/s)	Water Flow, (kg/s)
213	TFT	0.97	2001	19.6	11.3
	JTM	1	2191	19.6	7.5
212	TFT	1.3	2712	35.1	1.1
	JTM	1.1	2678	34.0	0*

Table 2: Bore output measurement by TFT and James Tube Method (JTM)

MgCl$_2$: Reinjection Brine Flow Measurement

MgCl$_2$ vs. Turbine Flowmeter

The use of MgCl, tracer was initiated as an alternative method to the orifice plate and turbine flowmeter in the early 1990's (Macambac, 1992). Precision and accuracy were tested for 1.3 years (August 1991 to December 1992) parallel with the turbine flowmeter. Table 3 shows that the results of the turbine flowmeter and MgCl$_2$ tracer are in close agreement, falling within +/-5% difference. Because of the good correlation, thenceforth, the MgCl, tracer has been used for all brine flow measurements in reinjection wells and main reinjection lines.

Well	DATE	MgCl$_2$ Tracer, (kg/s)	Turbine Flowmeter, (kg/s)	% Difference
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
	Jun-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 turbine flowmeter

MgCl$_2$ vs. Spinner Survey

Selected water flow measurements were conducted in LGPP wells simultaneously with MgCl, tracer and spinner surveys. Although only a few tests were conducted, the results at flow rates of less than 30 kg/s show that spinner surveys and MgCl, are comparable within 20% (Table 4). Note also that all spinner survey results are less than the MgCl, results.

Well	WHP (MPa)	Spinner Survey, (kg/s)	MgCl$_2$ Tracer (kg/s)	% Diff
5R3D	1.50	23.3	23.4	0.04
5R5D	1.40	21.1	25.8	20
5R8D	1.50	20.4	24.9	20

Table 4: Comparison of MgCl$_2$ and Spinner Survey Results (May 1994)

MgCl$_2$ vs. Na-fluorescein Tracer

Disodium fluorescein dye ($C_{20}H_{10}Na_2O_5$), has been routinely mixed in small amounts with MgCl, tracer solution to determine when the injected tracer has reached the sampling location. This can be determined by directly observing the change in color **of** the brine from colorless to yellow/green, signaling the start of sampling. Since fluorescein dye **is** always used during MgCl, tracer testing, a study was conducted to determine its capability for quantitative water flow measurements (Paraon, 1997).

Comparison of MgCl, tracer with fluorescein dye shows close agreement for 70 percent of the tests conducted based on a 5% difference limit criterion (Table 5). In other tests of fluorescein dye, the tracer falls short in terms of precision with the MgCl$_2$. The reason could be due to thermal decay or to the dye's sensitivity to ultraviolet rays during sampling.

Well	WHP	Average Water Flow (kg/s)		%
	MPa	$MgCl_2$	Na-Fluor	Diff
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 water flow measurements by $MgCl_2$ and Na-fluorescein tracers

$MgCl_2$ vs. Na-benzoate

Table 6 summarizes the results of water flow based on simultaneous tests of MgCl, and Na-benzoate tracers conducted in several reinjection wells and main reinjection lines. The results of Na-benzoate compared to MgCl, fall within an acceptable relative difference of *+/-5%.*

Well	Water flow, (kg/s)		% Difference
	$MgCl_2$	Na-benzoate	
Sam	83.5	82.2	1.56
		96.0	
MG-7RD	177.1	182.2	
MRL 5R7D	96.9	47.4	0.64
	47.0 49.0	46.1	0.93
4R3D	97.0 47.1	100.3	2.88 3.40
5R4D	177.8	170.1	0.64 4.53
5R1	79.2	74.9	5.92 5.43
5R5D	22.8	23.8	4.39
5R3D	23.9	24.8	3.77

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

VARIANCES AND ERRORS

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 flow rates between 140-225 kgls, the variance is between ±10-15 kgls **(+/-4-11%),** while at lower flows between 25-100 kgls, the variance **is** between ±5-7 kgls (+I-5-28%). Shown also in the graph is the general equation of the regression line for variance.

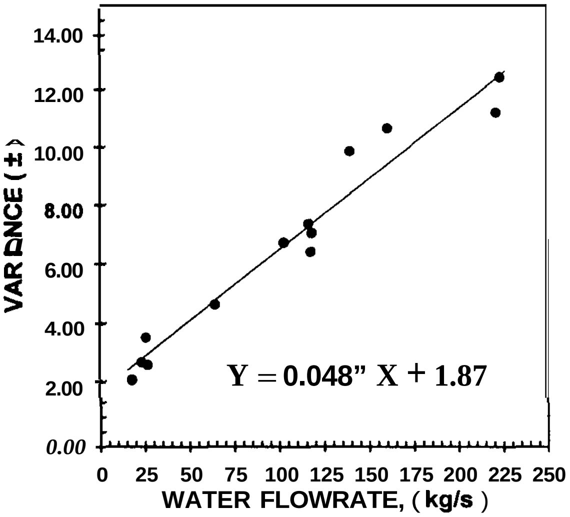

Figure 1: Variance in brine flow rates for $MgCl_2$ tracer

Error Bands for TFT: 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 SF_6 tracers injected by a Thermochem "Tracer Injection Skid" (Villa and Magdadaro, 1997).

Measurement	Error Source	Max % error
Steam flow	Gas Tracer Analytical	2.0
	Gas Tracer Injection Rate	2.0
	Mixed Sample Analytical	2.0
	Cumulative	**3.5**
Water flow	Liquid Tracer Analytical	1.0
	Liquid Tracer Injection Rate	2.0
	Mixed Sample Analytical	1.0
	Cumulative	**2.4**
Enthalpy		1.7

Table 7: Error bandsfor TFT Measurements

Error for the water flow measurement is +/-2.4%, while error for the steam flow is +I-3.5% for flow rates ranging from 20 to 300 kgls. There is no definite lower flow rate limit for the TFT method and the upper limit is only restricted by the amount of tracer that can be injected. The errors contribute to a maximum of +I-1.7% error for calculated enthalpy values ranging from 700 to 2800 kJ/kg.

	Error Contributions by Source			
Measurement	Well Level +/-1cm	Tube Diameter +/-0.25cm	Lip Pressure +/-5% gauge range	Cumulative Error
St l	1.2%	3.5%	13%	13.5%
Brine Flow	33%	NA	NA	33%
Enthalpy	7.7%	0.8%	2.5%	8.1%

Table 8: *Error bands for James Tube Method, Production Well 213*

Error Bands for James Tube Method

Table 8 lists the errors in the James Tube method for each major contributing source in the measurement. This error analysis was performed for Well 213, which was tested by both the TFT and James methods (Table 2). The high water flow error is due to the relatively low water production rate of the well, resulting in substantial weir height reading errors, especially when the flow is surging.

FIELD APPLICATION OF CHEMICAL TRACERS

Intensive field testing proved that the results obtained from chemical tracer methods 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 the simple set-up utilized in the $MgCl_2$ tracer method gives comparable results to the more sophisticated and electronically controlled TFT method for reinjection brine flow measurement.

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:

Mass flow and enthalpy measurement is production wells using TFT

New environmental laws prohibit direct disposal of waste brine to the environment, and thus the James Tube method will have limited applications. The TFT method is also significantly more accurate *than* the James Tube method. In addition, TFT can be performed on-line without diverting steam flow from the power plant. TFT has been adopted to update well bore output with a testing frequency of 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 mass flow and enthalpy.

Waste brine flow measurement using $MgCl_2$

Inventory of brine flow to reinjection wells is imperative for sound reservoir management, because only through precise and accurate measurement can **a** reinjection strategy be formulated. The $MgCl_2$ 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 reinjection capacity of the field, leading to decisions either to drill a new well or perform work-over operations.

Brine audit for optimization of power plants

A 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 audits were performed using Na-benzoate and $MgCl_2$ tracer tests to determine the sustainability of the power plant.

In the past years, chemical tracer methods have been valuable tools in managing geothermal fields because of their proven reliability. However, as with any tool, these methods must be constantly improved and refined through trials of other chemical tracers and design modifications.

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