PROCEEDINGS, Thirty-First Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 30-February 1, 2006
SGP-TR-179

FLOW TESTING IN INDONESIA USING ALCOHOL TRACERS

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ABSTRACT

Tracer flow testing trials have been conducted in Indonesia to assess the accuracy of the isopropanol (IPA) tracer flow testing procedure. Flow measurements from production wells were compared with physical measurements and alternative tracer flow measurements (SF_6).

The testing was conducted with production well flowrates in the range 25-110 kg/s and enthalpies in the range 1350 - 2800 kJ/kg.

Results are presented for tests conducted between 2001-2003. The mean difference in steam flows for IPA and SF_6 tracer testing was about 6%, with no systematic bias. For dry steam wells, the difference between IPA flows and orifice plate measurements was a mean 1.2% for 12 tests. The results confirm that IPA tracer flow testing is a viable method over a wide range of operating conditions.

INTRODUCTION

Tracer flow testing (TFT) procedures are increasingly becoming the standard method for flow testing wells at operating geothermal power plants. The method allows for on-line testing of wells, avoiding disruptions to power station operations and the need for dedicated well test facilities. The TFT procedure involves the quantitative injection of small amounts of chemical tracers (one for the steam and one for the water) into the discharge line of the production wells. The tracers become diluted by the fluids in the pipeline, by a degree dependent on the flowrate - the higher the flow the lower the concentration. At some distance downstream, where the tracers are well mixed, steam and brine are sampled and analysed for the tracers. Simple equations relate the concentration in the sample to the flowrate and injection rate:

$$\text{Flow (t/h)} = \frac{\text{tracer injection rate (g/h)}}{\text{tracer conc in sample (g/t)}} \quad \text{- (1)}$$

There are currently two TFT methods described in the literature, one using sulphur hexafluoride (SF_6) as the steam phase tracer (e.g.: Hirtz *et al.*, 2001) and the other using isopropanol (IPA). For brevity in the text below, they are denoted the IPA and SF_6 methods.

The IPA method was developed in New Zealand and is described by Lovelock (1995, 2001) and Lovelock and Stowell (2000). Using volatile organic liquids was recognised as a possible way of simplifying equipment and sampling techniques and lowering the cost of well testing. The essential practical difference between the IPA and SF_6 methods is that IPA is a liquid at room temperature and only exists as a gas inside the pipeline. This allows the IPA to be injected with conventional liquid dosing pumps and sampled without special gas bottles. IPA is injected into the two phase pipeline where it boils and travels down the pipeline as a gas. At a downstream sampling point the steam is separated and condensed along with any IPA. Some of the IPA is dissolved in the brine and a separate brine sample is collected for IPA analysis. Therefore, to obtain steam flow (SF), equation (1) is corrected for this dissolved IPA, i.e:

$$\text{SF (t/h)} = \frac{\text{IPA injection rate (g/hr)} - [\text{ WF (t/h)} \times T_W \text{ (g/t)}]}{T_S \text{ (g/t)}}$$

where T_W and T_S are the IPA tracer concentrations in water and condensed steam, and WF is the water flow, obtained by a separate water phase tracer. The steam to water distribution ratio for IPA is about 20:1 at 180°C. The above correction becomes smaller as the water fraction reduces. At enthalpies above about 1500 J/g and at typical pipeline pressures (5-10 bar), the correction is small and IPA in brine can be assumed based on known distribution ratios. At lower enthalpies the correction becomes more important and a good analysis of IPA in brine must be made. Full background to the method is given in Lovelock (2001) and Lovelock and Stowell (2000).

This paper has been written primarily to address statements made by Hirtz *et al.* (2001) regarding the accuracy of IPA tracer flow testing. It presents results of field trials carried out in Indonesia where measurements using IPA, SF_6 and physical methods (orifice plate) were compared.

ERRORS IN TRACER FLOW TESTING

Errors can be introduced into TFT results by a number of processes including:

1) incomplete separation of water and steam at the sampling point
2) loss of tracer by reaction or thermal degradation
3) loss of tracer by volatilisation.
4) incomplete mixing of tracers
5) analytical errors

Careful testing of new tracers and rigorous field and laboratory procedures should minimise all of these. The first three processes will result in anomalously low tracer concentrations, and therefore high calculated flows. Therefore, in comparing the results of a TFT method with some other method (e.g.: physical measurements or other tracer), the emergence of consistently low tracer concentrations (high flows) is a tell-tale sign of inherent problems with methodology.

Errors may also occur with the analytical method (e.g.: incorrectly prepared standards) but these are equally likely to give high or low results. Similarly, incomplete mixing of the tracers in the pipeline will give either high or low results, depending on the flow regime and orientation of the sampling points. This may be seen as variable concentrations in consecutive samples.

WAYANG WINDU TRACER FLOW TESTING

Well Characteristics

The Wayang Windu discharge waters have high-salinities (10,000 - 30,000 mg/kg TDS). A representative analysis is given in Table 1. Discharge enthalpies for this testing were in the range 1350 to 2800 kJ/kg, mass flow: 20 to 110 kg/s and steam mass fraction: 25 - 100%.

Several field-wide TFT surveys were conduced on Wayang Windu production wells, in the period 2001-2003, where both IPA and SF_6 based methods were used. Table 2 presents all the IPA flow results for six wells collected over this period. The IPA flow testing was carried out by Indonesian field technicians and the data was provided by Star Energy, the current operator of the field. For confidentiality reasons, well names have been replaced with letter designators. The IPA flow testing was generally conducted within one month of the SF_6 testing. Physical measurements (orifice plate) were available only for the dry steam wells. All flows re-calculated to the separator pressure of about 10.5 b.g.

Table 1. Typical composition of Wayang Windu geothermal fluid (concentrations in fluids separated at collection pressure)

Well		WWQ-2
Date		March 5, 2002
Enthalpy (kJ/kg)		2134
Collection Pressure (b.a.)		11.7
Na	mg/kg	8970
K	mg/kg	2120
Ca	mg/kg	674
Cl	mg/kg	17,500
SO_4	mg/kg	21
B	mg/kg	595
SiO_2	mg/kg	803
Gas in steam	wt%	0.45

IPA Tracer Flow Testing Procedure

To simplify the IPA tracer injection procedure, the IPA and the water phase tracer (sodium benzoate) were mixed and injected as a composite tracer (generally 50 wt% IPA - 10 wt% Benzoate). The tracer solution was injected into the two-phase branch line, close to the wellhead, using a portable injection pump. Injection rate was measured by weight loss over time from a delivery vessel. Tracer injection was carried out for a period of 5-10 minutes during which water and steam samples were collected at line pressure (8-10 b.a.), using miniature sampling separators. Each sample set typically consists of 3 water samples for benzoate analysis (100 ml plastic bottles), two water samples for IPA analysis and three steam samples for IPA analysis (30 ml screw-cap bottles). The injection and sampling generally took 10-15 minutes, with about one hour required for the whole test, including set-up and dismantling the equipment.

For the Wayang Windu testing, the injection-to-sampling distance was 20 to 40 meters. The samples for IPA analysis were analysed by the Institute of Environmental Science and Research in New Zealand, using head-space gas chromatography. Benzoate was analysed by ion chromatography.

Background information on the SF_6 method can be found in Hirtz and Lovekin (1995) and Hirtz *et al.* (2001).

RESULTS AND DISCUSSION

Steam Flows

Table 2 includes a comparison of TFT steam flows and physical measurements where these are available. Orifice plate steam flows are available for the three dry steam wells at Wayang Windu and these provide a good calibration check on the TFT measurements. The orifice plate flows were stable throughout the 2 year period. The IPA steam flows all agree with the orifice plate flows to within 4%, with an average difference of 1.2%. The IPA method therefore shows excellent accuracy for the dry steam wells. For the same wells SF_6 flows deviate by 2-12% (average 5.9%).

Comparing the IPA and SF_6 steam flows for the 23 tests, 10 agree within 5%, 6 deviate by 5-10% and 3 differ by more than 10%. The average absolute difference is 2%. There is little bias in the results with the difference IPA-SF_6 averaging +1.9%. This is an important result as it suggests that the systematic errors related to either method are small and that the discrepancies are more likely the result of errors related to individual tests or changes in well characteristics in the time between the SF_6 and IPA surveys.

Brine Flows

Table 2 includes a comparison of brine flows measured by tracers at the same time as the steam flow measurements. For the IPA flow testing, benzoate was used as the water phase tracer, mixed as a 10% solution with the IPA. For the SF_6 testing a

Table 1. Comparison of flows measured by orifice plate and tracer flow testing: isopropanol (IPA) and SF_6 methods. Flows are calculated at the separator pressure of 10.5 b.g.

Well	Measurement Date		Enthalpy	Steam Flows (kg/s)			Differences (%)			Brine Flow (kg/s)		Diff. (%)
	SF_6 and Orifice	IPA	kJ/kg	Orifice Plate	IPA	SF_6	IPA vs Orifice	SF_6 vs Orifice	IPA vs SF_6	IPA [1]	SF_6 [2]	IPA vs SF_6
A	01-Sep-01	27-Sep-01	~2800	45.7	44.8	43.2	-2.0%	-5.4%	3.6%		dry steam	
A	11-Mar-02	27-Mar-02	~2800	41.0	42.3	39.5	3.2%	-3.7%	7.2%		"	
A	29-Aug-02	29-Aug-02	~2800	39.9	40.2		0.8%				"	
A		13-May-03	~2800	43.3	42.9		-1.0%				"	
B	01-Sep-01	27-Sep-01	~2800	34.4	34.3	32.1	-0.2%	-6.7%	7.1%		dry steam	
B	04-Mar-02	27-Mar-02	~2800	33.5	34.0	37.5	1.7%	12.0%	-9.2%		"	
B	29-Aug-02	29-Aug-02	~2800	34.8	34.8	31.6	0.0%	-9.1%	10.0%		"	
B	13-May-03	13-May-03	~2800	37.6	37.2	35.8	-1.1%	-4.8%	3.9%		"	
C	01-Sep-01	27-Sep-01	~2800	59.4	60.1	57.6	1.2%	-3.0%	4.4%		dry steam	
C	04-Mar-02	27-Mar-02	~2800	60.3	60.5	61.6	0.3%	2.2%	-1.9%		"	
C	29-Aug-02	29-Aug-02	~2800	59.7	59.0		-1.2%				"	
C		13-May-03	~2800	58.9	59.9		1.6%				"	
D	05-Mar-02	26-Mar-02	1330	-	32.2	31.0			3.9%	87.6	79.4	10.3%
D	30-Aug-02	29-Aug-02	1330	-	27.3	26.6			2.9%	74.2	69.5	6.7%
D	15-May-03	12-May-03	1370	-	26.4	21.7			21.8%	64.2	64.6	-0.7%
E	02-Sep-01	28-Sep-01	2180	-	12.9	13.0			-1.3%	5.5	5.5	1.4%
E	11-Mar-02	26-Mar-02	2140	-	12.0	12.1			-0.8%	5.6	5.8	-3.0%
E	29-Aug-02	30-Aug-02	2520	-	12.6	12.0			5.6%	1.9	3.6	-47.0%
E	13-May-03	12-May-03	2310	-	13.4	13.7			-2.5%	4.2	3.0	39.7%
F	02-Sep-01	28-Sep-01	2370	-	23.4	24.5			-4.4%	6.2	9.3	-33.7%
F	05-Mar-02	26-Mar-02	2540	-	23.3	25.9			-10.1%	3.3	3.1	6.1%
F	29-Aug-02	30-Aug-02	2370	-	25.4	28.3			-10.3%	6.6	6.2	6.5%
F	13-May-03	12-May-03	2600	-	34.1	32.3			5.6%	3.4	2.3	45.1%

Wells A, B and C are dry steam producers. Enthalpy for wells D, E and F calculated from alcohol flows

[1] Benzoate used as brine phase tracer. [2] Proprietary brine phase tracer used.

proprietary tracer was used. For Well D, which has a relatively high brine flow, the agreement in flows is reasonable (0.7, 6.7 and 10%). For the other two well brine flows are very low and agreement is less satisfactory, although there is no systematic bias in the results one way or the other. The variation in brine flows here is possibly real, reflecting the potentially large percentage changes in water flow that can occur at high enthalpies (>2300 kJ/kg).

Pipeline Mixing

Hirtz *et al*. (2001) suggest that IPA flow testing may be constrained by incomplete mixing of the IPA in the pipeline. This was not the case for this trial which was conducted with injection-to-sampling distances of 20 - 40 meters. In all cases uniform tracer concentrations were obtained for consecutive samples collected over several minutes (Table 3). The reproducibility shown here is typical for wells with stable flows.

Equilibrium distribution of the IPA between steam and water also occurred as indicated by uniform distribution ratios for all the wells (although equilibrium distribution is not required for accurate results, so long as steam and water samples are separated at the same point on the pipeline).

Good IPA flow results have been obtained at other fields with injection to sampling distances of 10-15m. The minimum injection-to-sampling distance for achieving complete mixing will depend on a number of factors including flow regime (turbulence), injection point design and enthalpy. Gas phase tracers could be expected to mix faster than liquid tracers and so ultimately the injection-to-sampling distance may be determined more by the mixing behaviour of the liquid phase tracer. Mixing the IPA and benzoate prior to injection is considered to be advantageous since the process of flashing the IPA as it enters the pipeline helps to disperse the benzoate.

IPA Stability

Hirtz *et al*. (2001) suggest that IPA tracer flow testing may be affected by reaction of isopropanol with silica, boron or the benzoate with which it is combined. However, the good agreement between IPA steam flows and physical measurements indicates that such reactions are not significant under the conditions of this trial. The absence of degradation products on laboratory chromatograms is further support.

Brine at Wayang Windu has high boron and silica concentrations compared to most fields (Table 1) and the trials therefore represent a good test of the stability of IPA. Reaction of IPA would result in low analysed IPA concentrations and erroneously high calculated steam flows. This was not seen. Composite IPA-benzoate standards stored for several months have shown no significant change in IPA concentration, although benzoate has been found to degrade slowly over several months - possibly as a result of bacterial activity.

The combined IPA-benzoate tracer has been tested at pipeline temperatures up to approximately 220°C. Separate injections of benzoate and benzoate-IPA mixtures at this temperature gave the same brine flow rates, indicating no reaction between the two tracers.

Table 3. Reproducibility of analyses for consecutive samples. Tracers injected as an 10%-50% Benzoate-IPA mix. Samples from August 2002 (see Table 1)

Well	Sample	IPA in Steam mg/kg	IPA in Brine mg/kg	Benzoate in Brine mg/kg
A	1	136	(dry steam)	
	2	135		
	3	134		
B	1	159	(dry steam)	
	2	156		
	3	154		
C	1	94	(dry steam)	
	2	91		
	3	90		
D	1	173	11	14.5
	2	174	11	14.5
	3	174		14.4
E	1	429	24	271
	2	425	24	292
	3	434		288
F	1	215	13	163
	2	212	13	164
	3	209		164

Sampling and Analyses

As with all tracer flow testing, accurate results rely upon good separation of water and steam at the sampling points and rigorous procedures are in place for ensuring this. Samples for IPA analysis are collected into 30ml open screw-cap bottles. Lovelock (2001) has shown that there is insignificant loss of IPA from open water samples at temperatures less than 40°C, even when gas is passing through the liquid. This is confirmed in the field by IPA concentrations which fall within a narrow range for multiple samples.

Methods are well-established for the analysis of isopropanol in water. For the Indonesian well

testing, samples were analysed by head-space gas chromatography. IPA can also be analysed by GC using direct injection, usually with internal standards to ensure good precision.

CONCLUSIONS

Tracer flow testing using IPA has been trialed successfully at the Wayang Windu field in Indonesia. Steam flow results from the IPA method compare well with physical measurements and other tracer results and indicate that the IPA method can provide accurate results for most geothermal conditions. The concerns raised by Hirtz *et al*. (2001) are shown to be invalid.

ACKNOWLEDGMENTS

The authors acknowledge the permission of Star Energy to publish data from the Wayang Windu field.

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