A PRACTICAL APPLICATION OF CHLORIDE MASS BALANCE METHOD TO THE EVALUATION OF A GEOTHERMAL STEAM GATHERING SYSTEM IN INDONESIA

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ABSTRACT

A new geothermal power plant with an 85 MW generation capacity was built last year in Muara Laboh, West Sumatra, Indonesia. The double-flash geothermal steam generation system consists of two high pressure separators and one low pressure separator. As the performance of the separators is critical to the safe and efficient operation of the turbines, a testing program was developed and conducted to verify the performance of the separators.

A key indicator of separator performance is the steam dryness measured on the pipeline downstream of the separator. A natural tracer mass balance method is used to measure the steam dryness, with chloride selected as the natural tracer due to its abundance in geothermal fluids and being preferentially dissolved in brine rather than in steam.

Representative steam and brine samples were collected from steamline and brineline test points downstream of the separators and analysed for chloride and sodium in the laboratory. These chloride and sodium concentrations are used to calculate the steam dryness using a mass balance method. Special traversing isokinetic probes were developed and successfully used to collect representative steam samples in the tests.

1. INTRODUCTION

Muara Laboh geothermal field is located about 135 km SE of Padang, the capital city of West Sumatra, Indonesia. The geothermal resources are mainly hosted in the granitic-dioritic intrusives in the Great Sumatra Faults basin. The deep reservoir produces geothermal fluid at the temperature of ≥270°C. Supreme Energy and its joint venture counterparts have initiated to build a power station of 255 MW production capacity by utilizing the local geothermal resources. The phase-one power plant has been completed and has commenced commercial operation in Dec. 2019 with a generation capacity of 85 MW.

As a crucial part of the plant, a unique steam gathering system (SGS) was constructed to provide steam to the downstream steam purifying facilities and turbines. This double-flash system consists of two high pressure separators (HP A and B) and one low pressure separator (LP) as shown in Figure 1

The geothermal fluid from the reservoir is saturated with chemicals and impurities due to water-rock reactions. These chemicals and impurities in the brine carry-over have the potential to cause serious damage to the turbines and other plant equipment, by effects such as scaling, corrosion and physical damage. The separators are the first-stage and the most important apparatus to remove chemicals and impurities and to provide steam for the downstream facilities. To verify the performance of the separators, an effective sampling method was developed and carried out to produce a reliable evaluation result.

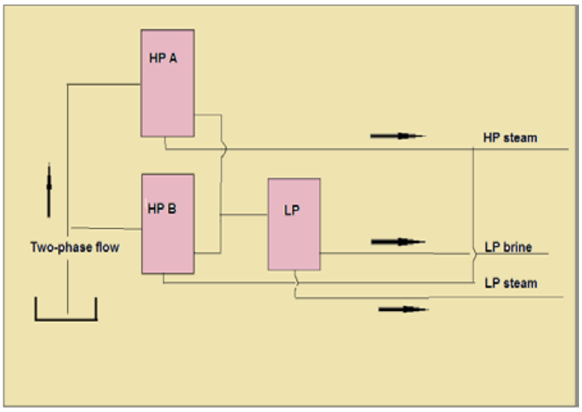

Figure 1: Diagram showing two-phase fluid flows through two HP separators and one LP separator. HP and LP steam are supplied to downstream facilities and LP brine is reinjected.

2. TESTING METHOD AND CALCULATION

2.1 Testing theory

Assessment of separator performance involves measurement of geothermal steam dryness and purity at the steam test points, which is a measure of the percentage of geothermal brine that is carried over with the steam from the separators. It is determined by measuring either the chloride or sodium ions in the representative samples of the separated steam and brine (Fig. 2). This is referred to as natural tracer mass balance method.

Chloride is an ideal natural tracer for separator performance testing, owing to its special properties: it is abundant in the geothermal fluid and under normal conditions dissolved in the liquid phase only. It is stable and easy to detect with a high degree of analytical accuracy. Sodium ion was also analyzed, and the concentrations were used to check the quality of the data and the calculated results.

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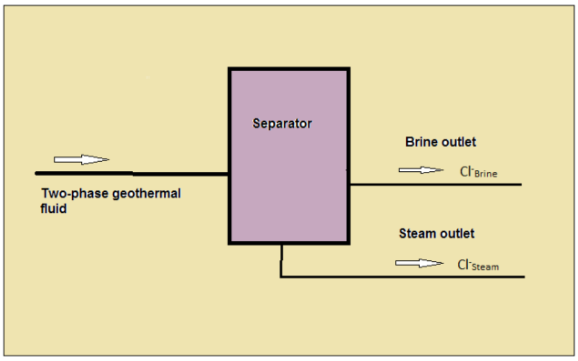

Figure 2: Diagram shows geothermal fluid is separated and samples are collected at steam and brine test outlets for Chloride and Sodium analysis.

2.2 Dryness calculation

It is assumed that:

- The separated steam is a mixture of pure steam and a tiny amount of carry-over brine.
- Pure steam contains no chloride and all the detected chloride is from the carry-over brine. It is the same with sodium.
- The carry-over brine in the steam is the same as in the separated brine. So, the brine carry-over in the steam contains the same concentrations of chloride and sodium as in the separated brine.

Steam dryness is defined as the percentage of pure steam in the total steam flow.

Dryness calculation:

Steam dryness = $\left(1 - \frac{Cl^{-}{}_{Steam}}{Cl^{-}{}_{Brine}}\right) \times 100\%$

Where:

Cl^{-}_{Steam}: Chloride concentration in steam condensate.

Cl^{-}_{Brine}: Chloride concentration in separated brine.

3. SAMPLING EQIPMENT AND METHODS

Appropriate sampling equipment and sampling techniques are very important to ensure the samples are representative, contamination free, and producing reliable results.

3.1 Traversing isokinetic probe

It is previously believed that the chemicals and impurities are dominantly dissolved in the tiny droplets in the steamlines and the droplets are not distributed homogeneously cross the pipe section. Therefore, traversing isokinetic probes are required to obtain representative samples of non-gaseous impurities from different depths of the steamlines.

The probes for the tests were designed and manufactured by MB Century, with a traversing capacity of 745 mm, which is long enough to reach the center of the largest diameter steam pipe. 3.0 mm and 5.0 mm face diameter nozzle probes were used in the first test in August 2019 and December 2019 respectively.

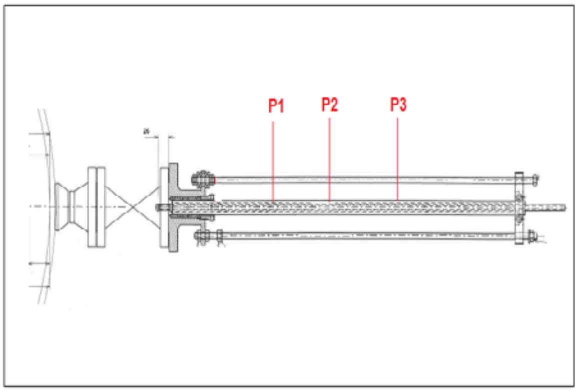

Figure 3: Drawing of the isokinetic probe, three traversing points marked on the probe guide before testing.

Figure 4: Traversing isokinetic probe with a 5.0 mm face ID nozzle, which is mounted onto the sampling port and connected to a stainless-steel cooling coil to collect steam condensate samples.

The probes were mounted on the steam sampling ports isolation valve and connected with stainless steel cooling coils via a regulation valve. The sampling flowrate can be controlled by adjusting the regulation valve to achieve isokinetic sampling. Cool running water was constantly supplied to the bucket to cool the steam down to condensate at ≤30°C.

3.2 Brine sampling

Brine samples were taken from the HP and LP brine outlets with stainless steel cooling coils. Isokinetic sampling was not required for the collection of the brine samples.

Figure 5: Brine sampling point, a cooling coil was connected to the point for brine sampling.

3.3 Probe traversing depth calculation

The steam samples were collected from three different traverse depths using the traversing isokinetic probes. Each point represents one third of the intersectional area of the steam pipelines.

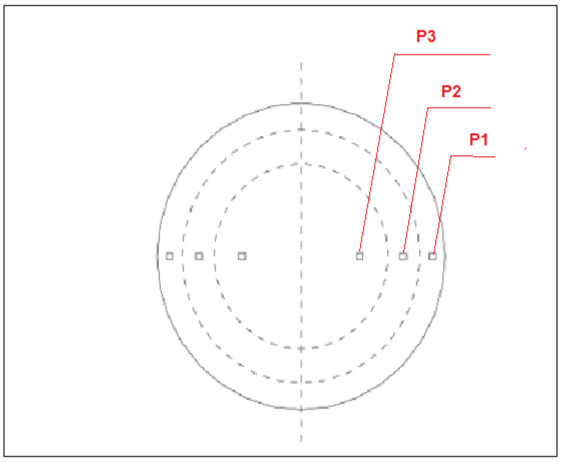

Figure 6: Traversing point indication in a cross-section of a team pipeline.

The three steam pipelines being tested have the same diameter: DN900, OD: 914.4 mm, wall thickness: 11.13 mm, ID: 892.14 mm. The offset for the probe insertion is 321.13 mm.

Traverse point number	Depth from the pipe wall as percentage of the pipe ID	Traversing depth from the reference point
1	4.4%	Offset+4.4% pipe ID
2	14.6%	Offset+14.6% pipe ID
3	29.6%	Offset+29.6% pipe ID

Figure 7: The calculated Probe traversing depths for the three sampling points.

3.4 Sampling flowrate calculation

To take representative steam samples, the sampling flow rate should be properly controlled so that the steam velocity entering the sampling nozzle equals that in the steam pipelines. A calculation equation is given as below:

$R_{sample} = (D_n/D_p)\ (16.7)\ Q_s$

R_{sample} = Sampling rate, g/min, steam condensate.

D_n = Diameter of nozzle face.

D_p = Inside diameter of pipeline (must be the same unit as nozzle).

Q_{steam}= Steam flowrate, kg/hr.

The tests have been carried out at different operational conditions. NCR stands for Normal Continuous Rating and MCR for Maximum Continuous Rating.

	NCR		MCR2		MCR3	
	Steam flowrate (kg/s)	Sampling flowrate (g/min)	Steam flowrate (kg/s)	Sampling flowrate (g/min)	Steam flowrate (kg/s)	Sampling flowrate (g/min)
HP A	61.5	116	63.25	119	61.5	116
HP B	61.5	116	63.25	119	61.5	116
LP	26	49	30.5	58	35	66

Figure 8: Steam sampling flowrate, based on the probe nozzle face diameter 5.0 mm.

4. RESULTS FROM THE TESTS

The calculated results from both tests in August and December 2019 show very consistent dryness: over 99.99% at all operational conditions for both HP and LP separators.

Sodium ions were also analyzed for quality control reasons. Like chloride, the sodium and Na/Cl ratio also show consistent results for both tests at all operational conditions.

These results showed that the testing program, testing equipment and method were successful and has produced reliable and convincing results.

HP separator A	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.05	0.05	1.00	99.997%
Traverse point 2	0.06	0.02	0.33	99.997%
Traverse point 3	0.05	0.02	0.40	99.997%
Traverse point 1 dup	0.07	0.04	0.57	99.996%
Traverse point 2 dup	0.09	0.03	0.33	99.995%
Traverse point 3 dup	0.08	0.02	0.25	99.996%
Brine at start	1898	1120	0.59	
Brine at end	1906	1122	0.59	
Brine average	1902	1121	0.59	
Average			0.48	99.996%

HP separator B	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.06	0.03	0.5	99.997%
Traverse point 2	0.04	0.02	0.5	99.998%
Traverse point 3	<0.01	0.07		
Traverse point 1 dup	0.09	0.04	0.44	99.995%
Traverse point 2 dup	0.06	0.02	0.33	99.997%
Traverse point 3 dup	0.05	0.02	0.40	99.997%
Brine at start	1898	1120	0.59	
Brine at end	1906	1122	0.59	
Brine average	1902	1121	0.59	
Average			0.44	99.997%

LP separator	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.07	0.03	0.43	99.997%
Traverse point 2	0.06	0.03	0.50	99.997%
Traverse point 3	0.07	0.03	0.43	99.997%
Traverse point 1 dup	0.11	0.05	0.45	99.995%
Traverse point 2 dup	0.08	0.03	0.38	99.996%
Traverse point 3 dup	0.07	0.03	0.43	99.997%
Brine at start	2014	1192	0.59	
Brine at end	2022	1184	0.59	
Brine average	2018	1188	0.59	
Average dryness			0.44	99.996%

Figure 9: Calculated steam dryness for the first test in August 2019. Operational condition for HP: NCR; LP: MCR3.

HP separator A	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.03	0.008	0.27	99.999%
Traverse point 2	0.02	0.008	0.40	99.999%
Traverse point 3	0.03	0.01	0.33	99.999%
Brine	2004	1171	0.58	
Average			0.33	99.999%
HP separator B	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.05	0.02	0.4	99.998%
Traverse point 2	0.01	0.005	0.5	100.000%
Traverse point 3	0.01	0.005	0.5	100.000%
Brine	2004	1171	0.58	
Average			0.47	99.999%
LP separator	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.17	0.14	0.82	99.992%
Traverse point 2	0.16	0.08	0.50	99.993%
Traverse point 3	0.15	0.08	0.53	99.993%
Brine	2147	1238	0.58	
Average dryness			0.62	99.993%

Figure 10: Calculated steam dryness in MCR2 condition for the second test in Dec. 2019.

HP separator A	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.03	0.02	0.67	99.999%
Traverse point 2	0.03	0.01	0.33	99.999%
Traverse point 3	0.03	0.01	0.33	99.999%
Brine	2034	1176	0.58	
Average			0.44	99.999%
HP separator B	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.12	0.06	0.50	99.994%
Traverse point 2	0.03	0.01	0.33	99.999%
Traverse point 3	0.02	0.006	0.30	99.999%
Brine	2034	1176	0.58	
Average			0.38	99.997%
LP separator	Cl^- (ppm)	Na^+ (ppm)	Na / Cl ratio	Dryness (%)
Traverse point 1	0.16	0.09	0.56	99.993%
Traverse point 2	0.16	0.08	0.50	99.993%
Traverse point 3	0.19	0.10	0.53	99.991%
Brine	2166	1258	0.58	
Average dryness			0.53	99.992%

Figure 11: Calculated steam dryness in NCR condition for the second test in Dec. 2019.

CONCLUSION

Natural tracer mass balance method provides a reliable and accurate means of evaluating the performance of geothermal steam separators. Field testing results showed successful application of this method.

A full practical testing procedure is in the progress of completion. This procedure can be used as reference for evaluating and verifying geothermal separator performance, both old and new separators.

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