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Developing New Tracer Method for Determining the Steam Wetness in Geothermal Field

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ABSTRACT

One important aspect of the process of operating geothermal wells is steam quality. Based on the Steam or Electricity Purchase Agreement, it is stated that the first party (company) has an obligation to ensure that the steam delivered to the customer meets the conditions agreed upon in the contract. The futility to manage this can result in the failure to achieve the company's annual electricity production target due to high maintenance cost, high downtime, and loss of revenue. Steam wetness is a part of impurities in the steam beside non-condensable gas (NCG), silica content, and total dissolved solids (TDS). It is stated that steam should contain less than 1% of liquid water from total transferred fluids. The method commonly used to measure steam wetness is throttling calorimeter. Nevertheless, there are several conditions that must be fulfilled so that the measurements are taken care accurate, such as the system limitation, depending on the pressure, roughly a maximum 7% of wetness. This paper is offering a new method in determining steam impurities in term of steam wetness. By using tracer technic and special chemical material, it is possible to measure steam wetness in limitless of range. This material is only soluble in the liquid phase and environmentally friendly.

1. INTRODUCTION

Because it is produced from nature, geothermal fluids will never be avoided from the content of impurities that affect the quality of the fluid. Usually, the turbine manufacturer gives the limitation of tolerance value of permissible impurities. This is intended to protect the material of construction, especially turbines from things that are destructive. In addition, in the steam buying and selling business scheme, the contract is usually explained in term of the steam quality requirement that must be fulfilled by the seller. Among these requirements are the geothermal steam entering the turbine with maximum 1% of wetness, total dissolved solids (TDS) not exceed 10 ppm, silica content not higher than 0.5 ppm and non-condensable gas (NCG) should less than 2%.

Besides, due to maintenance management factors, steam quality is the most thing that accused in achieving reliability values and cost-effectiveness in both the steam field geothermal and the power plant. In an effort to guarantee steam quality conditions, scrubbing lines, scrubbers and demisters are usually installed so that the steam entering the turbine is steam with very minimum impurities content. Fluids sampling and its analysis, especially steam, are very necessary to find out how good the quality of steam is in terms of the desired minimum requirement.

One important parameter that must be maintained in relation to steam quality is steam dryness. There are at least two methods which are believed to be effective in measuring steam dryness, namely the tracing methods and throttling calorimeter methods. Both of these methods have their respective weak points.

This paper tries to conduct a study of improvement towards the tracing method so that it can eliminate the weakness of the previous method.

2. EXISTING STEAM QUALITY MEASUREMENT METHODS

2.1 Standard Throttling Calorimeter

The standard throttling calorimeter method has been widely used for more than one century ago. This method is classified as very simple and not complicated to use in determining the value of steam dryness. The process starts from taking fluid samples through a sampling connection where here is assumed adiabatically so that the steam flowing through the probe does not experience heat loss or kinetic energy changes. Therefore, there is no change of enthalpy in the inlet and outlet. When wet saturated steam is throttled across a small control valve, the liquid fraction is atomised and vapourised into super-heat with the pressure drop from high-pressure to low-pressure. By measuring the amount of super-heat existing within the calorimeter, the amount of moisture can be determined.

The following equation can state the basic relationship:

$$h_{fl} + x.h_{fg1} = h_3$$

Where h_{fl} is the saturated liquid enthalpy and h_{fg1} is the enthalpy of vapourisation, at the main steam line conditions, h_3 is the superheated steam enthalpy in the throttling calorimeter typically at atmospheric pressure conditions.

Solving the previous equation for the steam quality gives:

$$x = \frac{h_3 - h_{fl}}{h_{fgl}} = \frac{h_3\,(p_3, T_3) - h_{fl}(p_1)}{h_{fgl}\,(p_1)}$$

Assuming superheated conditions in the calorimeter, the enthalpy h_3 can be closely approximated as follow:

$$h_3 = h_{g3} + c_{p3} \cdot (T_3 - T_{3sat})$$

Where c_{p3} is the constant pressure specific heat capacity in the calorimeter, which is reasonably constant over a wide range of temperatures.

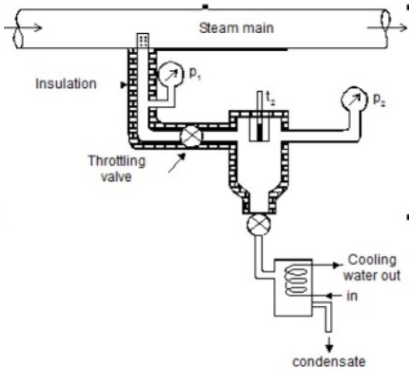


Figure 1: Throttling calorimeter configuration.

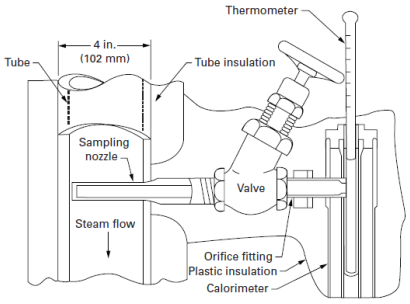


Figure 2: Throttling calorimeter showing sampling tube installed in the steam pipe.

Standard throttling calorimeter use thermodynamics approach to determine the steam dryness through the pipe. Its accuracy depends on the pressure and temperature measurements so that the accuracy of pressure and temperature gauge and transmitter are very important to get high sensitivity. Standard calorimeter measurements in the geothermal application can be highly erroneous. Errors >> ± 0.50% mass rates are common (Jung, 1995).

2.2 Improved Throttling Calorimeter

In practice, the use of standard calorimeters is very difficult to achieve the ideal condition. Poor thermal insulation and less standard sampling techniques often produce inaccurate measurement values. The throttle valve that is set manually and even uses a fixed type orifice produces a non-isokinetic flow. In fact, to get the measurement of steam quality with accurate values, it is vital that the velocity of steam at each port sample in the isokinetic probe must be exactly same as the velocity of the stream being sampled at the location of the sampler. That condition only can be achieved by adjusting the flow rate that passes through the probe. The following figure shows how non-isokinetic sampling results in an inaccurate measurement.

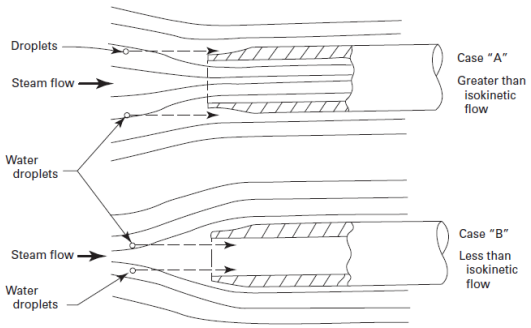


Figure 3: Effect of non-isokinetic sampling.

In case A where the steam sample velocity is greater than the velocity at which the steam pipe is occurred, water droplets will form and continue to flow parallel to the probe due to greater momentum. In this situation, the moisture content is undersampled. In the case of B, the steam sample velocity is less than the velocity in the main steam pipe. This condition will form water droplets which will eventually flow around the tubing on the outside, which is usually known as oversampled. Both under and oversampled will significantly affect the results of the steam dryness test.

Standard throttling calorimeter is modified with the addition of a valve in the downstream of the chamber, and automatic control devices are added so that the flow of steam entering the probe has the same velocity as the main steam. In this way, measuring steam dryness using throttling calorimeter can increase accuracy.

2.3 Radioactive Tracer Methods

Since 1970, radioactive tracer methods considered as one of the methods to determine steam quality. Detail technique described in ASME PTC 19.11. The tracer technique does not require a representative sample of water-steam mixture; the only sample the water phase is required. This technique is widely implemented in the pressure water reactor.

Because of using inorganic salt and radioactive material, this technique not too feasible to be applied in a geothermal field. Use of this method immediately may have the potential to get less accountable results.

3. IMPROVED TRACER METHOD (AKUBAPER)

Based on ASME PTC-6, there are several methods for measuring steam wetness, including throttling calorimeter, tracer, and extraction method. As discussed earlier, the throttling calorimeter method has a limitation, including limited accuracy and less extensive measurement range. The extraction method has a better level of accuracy but a long processing time and a large operational cost make this method rarely used. Among the three methods, the tracer method is the most accurate. In the ASME PTC-6, the chemicals used as tracer material are radioactive and inorganic salts. Radioactive material is a chemical that is dangerous and capable of adversely affecting humans and the environment. In addition, inorganic salts are naturally contained in geothermal fluids. For these two reasons, the utilisation of radioactive and inorganic salt as tracer material is not preferable.

3.1 Selection of Tracer Material

To get suitable material, the authors set criteria that must be met, including the following:

- Tracer chemistry must be stable, which is not easy to act with other substances
- A tracer must not be easy to degrade
- Because geothermal generally operate at high temperatures, the tracer material must be resistant to high temperatures
- Tracer material must be easily dissolved in the liquid phase and not easily dissolved in the vapour phase
- Has a low detection limit (ppb)
- Naturally, tracer material is not present in geothermal fluids
- Not a radioactive material

In the US patent (US 478848 A) it is stated that other materials are used as a tracer, namely from the aldehyde, ketone and alcohol groups. However, the three organic materials have a low boiling point so that they are not suitable to be applied to geothermal fluids that have high temperatures. Based on chemical searches, chemicals are found which are in accordance with the required specifications, namely sulfonated aromatic compounds. This material is well known as sulfonated Pyrene/Pyrene Tetra Sulfonic Acid (PTSA).

3.2 Pyrene Tetra Sulfonic Acid (PTSA)

Besides technical factors, the selection of PTSA as a tracer material has several advantages such as readily available, inexpensive, and extremely water-soluble. Physically, PTSA has characteristics nearly colourless and odourless. It is reported to be highly detectable by fluorometry down to 0.1 part per billion in solution with capable devices. It is less susceptible to quenching at increased concentrations than many other common fluorescent tracers, resulting in higher than normal linearity in fluorometers of five orders of magnitude or more, as compared to three to four orders with common tracers such as Rhodamine WT and fluorescein (Turner Design, 2013a).

United States Environmental Protection Agency (EPA) explained that PTSA has physical characteristics as follows:

- Water solubility : 4.47e-01 ml/L
- Density : 2.11 g/cm^3
- Melting point : 289 °C
- Boiling point : 402 °C
- Surface tension : 116 dyne/cm
- Vapour pressure : 1.4e-10 mmHg

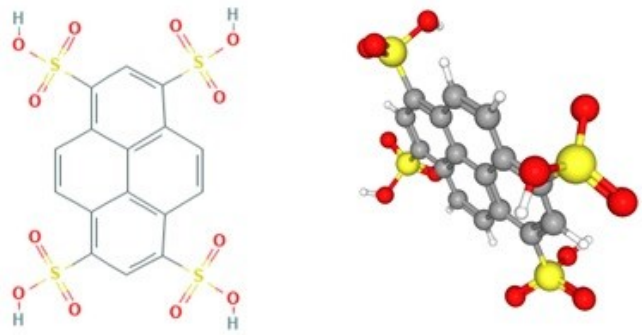
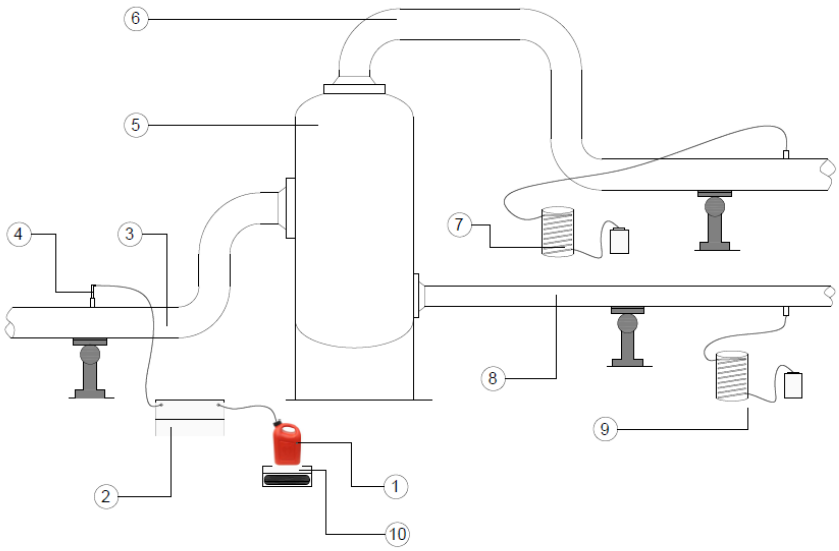


Figure 4: (a) Chemical structure depiction (b) Interactive chemical structure model.

3.3 Design and Basic Principles



1. Pyrene Tetra Sulfonic Acid (PTSA)
2. Tracing apparatus
3. 2 phase line (from well)
4. Injection probe
5. Separator / Scrubber
6. Steam line
7. Condenser
8. Brine line
9. Condenser
10. Digital scale

Figure 5: Schematic diagram.

Tracing material (PTSA) is injected into the geothermal fluid line, then sampling is carried out on steam and brine lines. The distance between the injection point and the sampling point is at least eight times the diameter of the pipe, and the sampling point is at least twice the diameter of the pipe from the turn, fittings, and other things that can cause unstable fluid flow. The sample is analysed using a measuring device to obtain the amount of tracer value which will be correlated with the amount of the value of water carried in the vapour phase. The PTSA concentrations in the samples from the steam line (C_{ts}) and PTSA concentrations in the samples from the brine line (C_{tb}) were compared so that the steam wetness was obtained. The following equation indicates moisture content (%) in the steam:

$$\%\ moisture = \frac{C_{ts}}{C_{tb}}\ x\ 100\%$$

3.4 Tracing Apparatus

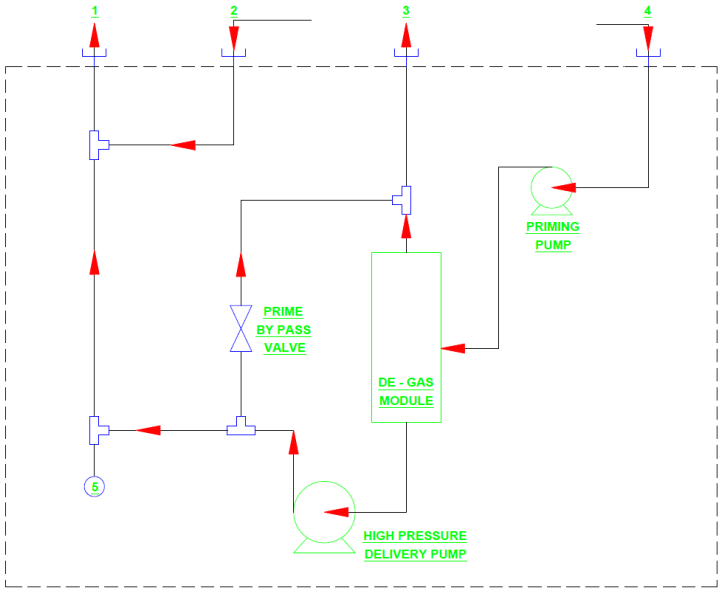
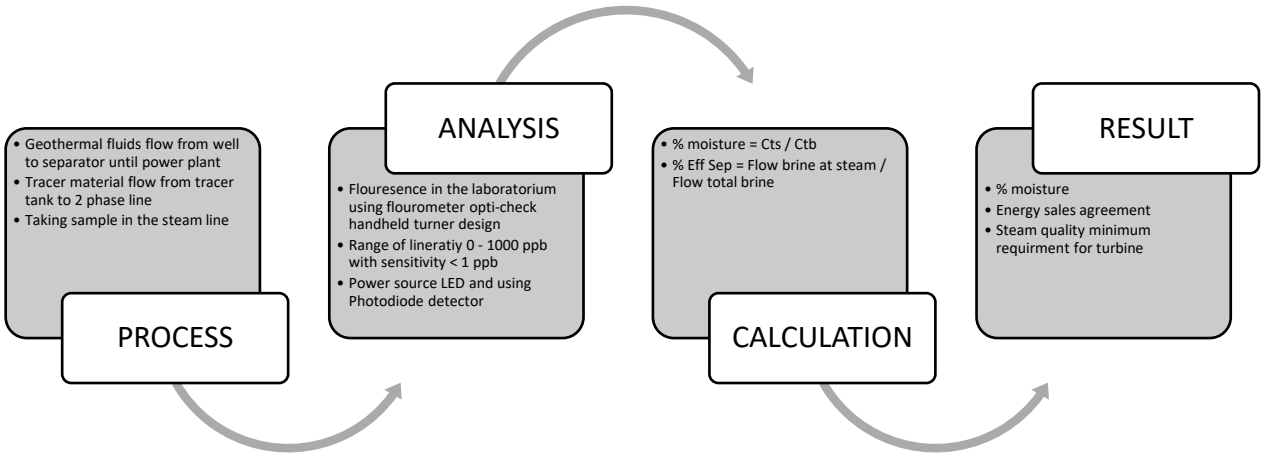


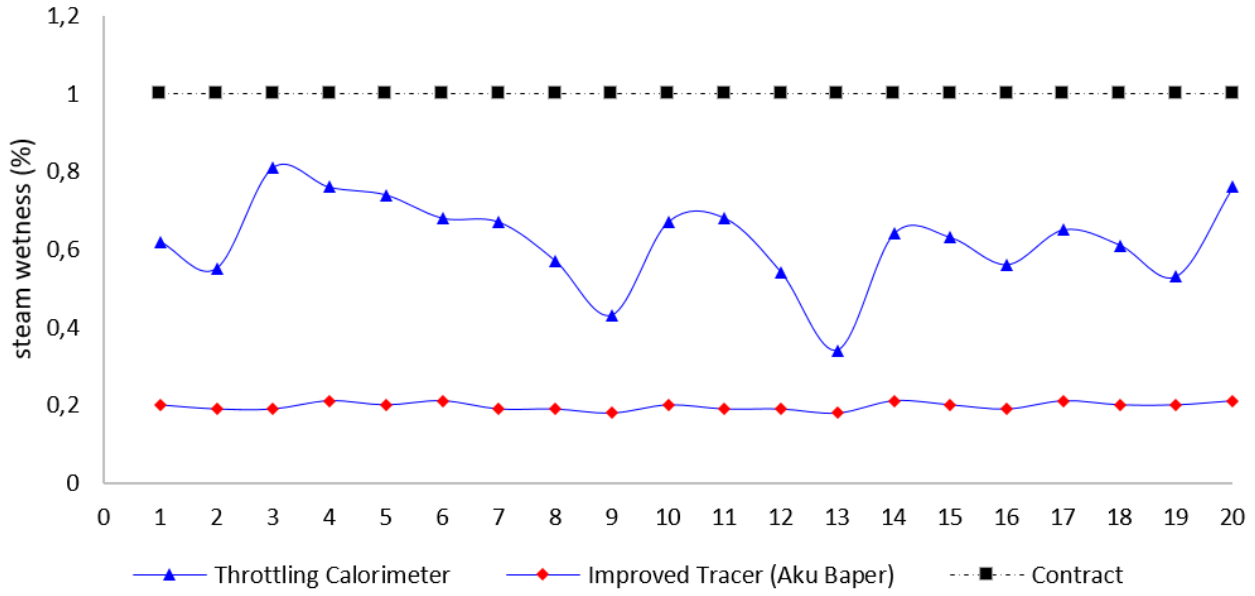
Figure 6: Schematic diagram tracing apparatus.

The equipment needed in this method is a pump with capacity of 10 – 50 mL/minutes with minimum discharge pressure 1000 psi which functions to inject PTSA to the fluid line; digital scale with capacity at least 6000 gram and sensitivity 0.01 gram; geothermal fluid sampling equipment that complies with the standard ASTM E 1675; fluorometer to analyse PTSA concentration in the sample with measurement limit 0 – 1000 ppb.



4. DATA EVALUATION

4.1 Result Comparison Throttling Calorimeter and Improve Tracer (AKUBAPER)



From the data of steam wetness measurement using the improved tracer method (AKUBAPER) and compared to throttling calorimeter, there is a deviation. This deviation is due to the measurement using the calorimeter method, which has many factors that can influence measurement uncertainty such as heat loss, non-isokinetic flow, and pressure and temperature gauge error.

4.1 Precisions Measurement

Precision is a measure of proximity between a series of analysis results obtained from several measurements in the same homogeneous sample. Usually, precision is measured as the standard deviation (SD) or relative standard deviation (SRD). RSD is also known as the coefficient of variation (CV).

$$SD = \sqrt{\frac{\sum x_{i^2} - \frac{(\sum x_i)^2}{n}}{n-1}}$$

where SD, $\sum x_{i^2}$, $\sum x_i$, and n are standard deviations, the number of squares of individual measurement, number of individual measurement, and the number of samples analysed.

$$RSD = \frac{SD}{x}$$

where RSD and x are relative standard deviation, standard deviation, and average measurement value.

Association of official analytical chemists (AOAC) stated that a method with measurement concentration value of about 0.1% is declared good if it has a value RSD < 3.7%.

Based on data calculation, improved tracer method (AKUBAPER) has RSD 0.0098% so that, it means AKUBAPER has good precision.

5. CONCLUSION

Acceptance testing method of steam quality before entering the turbine is a significant operational activity that needs high precision and easy to be implemented. The proposed alternate tracer (AKUBAPER) method to determine steam quality offer geothermal developer to get data more accurately. Representative data makes it easier to analyse the reliability of equipment, even more number of power plants. The objective of it all is to reduce operational and capital cost.

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