

Comparative Evaluation on the Performance of Top & Bottom against Side Tapping Sampling Points from Two-Phase Geothermal Pipelines

Romulus G. Arones

41F One Corporate Center, Julia Vargas cor. Meralco Avenue, Ortigas Center, Pasig City, Philippines

arones.rg@energy.com.ph

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ABSTRACT

The collection of representative samples from a geothermal well discharging steam and water is a complex procedure. Sampling plays important role in geothermal operations, as credibility and usefulness of geochemical data depends on the methods used and the care taken in the collection of samples. Methods of sampling in the two-phase lines evolve in different ways. The use of a twin-cyclone separator to collect both gas and water samples at the same time at a horizontal point is slowly been modified by the geothermal steam field operators. To date, most commonly used practice is the separate sampling of gas and water inside a pipe using two different separators intended to capture more realistic representative sample at the top and bottom locations. Comparing the existing method using different sampling locations is evaluated by the use of gas and water chemistry data and also listed amongst are the advantages and disadvantages of each. Comparability and variation in result is determined. The top and bottom configurations were found to be more appropriate, advantageous, practical, and reduce some of the access and maintenance problems. These also address the two-phase flow regime inside the pipe during flow of the geothermal fluid.

1. INTRODUCTION

The collection of representative samples from a geothermal well discharging steam and water is a complex procedure (Ellis 1977). High temperature waters from deep levels source flashes into steam as pressure decrease approaching towards the surface of near well head with varying velocities and mixtures. Sampling plays important roles in geothermal operations, as credibility and usefulness of geochemical data depends on the methods used and the care taken in the collection of samples. The main objective of sampling is to obtain representative samples of the steam and liquid phases as they exist in the pipeline at the sample point, without allowing steam condensation or additional liquid flashing (ASTM 1995). A significant feature of the sampling practices is the use of a cyclone-type separator for high-efficiency phase separation which is operated at flow rates high enough to prevent significant heat loss while maintaining an internal pressure essentially the same as the pipeline pressure and to locate the sampling separator at a point on the pipeline where the two-phase flow is at least partially stratified to aid in the separation process. The separator is usually attached to an appropriately oriented port to collect each specific phase—normally on top of the line for steam and at the bottom for liquid (Hirtz 2008). If the ratio of one phase to another is not extreme, representative samples of each phase can often be obtained from a horizontal port on the side of the pipeline (ASTM 1995). This practice is used whenever liquid or steam samples, or both, must be collected from a two-phase discharge for chemical analysis. This typically includes well-testing operations when a well discharges to a fluid gathering system.

Methods of sampling in the two-phase lines evolve slightly in different ways. The previously introduced method by Ellis and Mahon using a twin-cyclone separator to collect both gas and water samples from a horizontal sampling point location is already improved by the geothermal steam field operators. To date, most commonly used practice is the separate sampling of gas and water inside a pipe using two different separators intended to capture more realistic representative sample. This type of chemical sampling method has no difference with the Tracer dilution Method (TDM) as far as sampling location and sample point of view. The top and bottom configuration has found to be more practical and reduces some of the access and maintenance problems including sometimes two-phase flow regime inside the pipe during flow of the geothermal fluid. Thus, this paper was realize to compare the old, traditional method of capturing representative sample using the horizontal (side) oriented ports with that of the top and bottom orientation whose the latter as practice by most of geothermal steam field operators as practical and more tangible.

This paper will further demonstrate the comparative results of tests done between the two sampling methods and discuss the differences from the port's orientation & equipment, the actual field sampling methodologies and its advantages and disadvantages.

2. RELATED LITERATURE

Ellis and Mahon (1977) discuss the importance of sampling of two-phase fluid by the use of a cyclone separator. High temperature waters from deep levels source flashes into steam as pressure decrease approaching towards the surface of near well head with varying velocities and mixtures. Horizontal sampling location is use as sampling port to install the designed twin cyclone separator to separate gas and water from the two-phase line. (Klyen 1982) discussed the sampling method using a wellhead equipped with a two-stage separation assembly is shown in Figure 1. High pressure steam and water may be sampled (by means of a miniature steam/water separator) but are more reliably collected from the high pressure steam line, through a tee-piece, and the high pressure water line, through a cooler. Low pressure steam samples are collected, through a tee-piece, and low pressure water, through a cooler. Flashed water, at atmospheric pressure, may be collected from a weirbox. The well head separators and the silencers are no longer a common practice for the purpose of gas and water sampling since it is also costly.

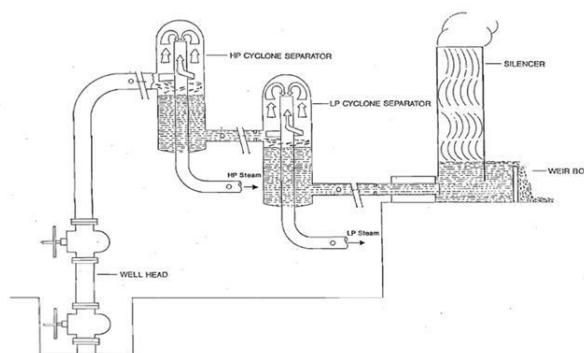


Figure 1. A well head equipped with miniature two-stage separator assembly for sampling high pressure gas and water

The most common design is a Weber cyclone separator. The purpose is to separate the vapor and water fractions of a two-phase steam/water mixture discharged from a geothermal well working pressure: 0.7 -40 bar gauge. (Klyen 1982). A centrifugal separation which takes place in first cyclone from which dry steam and gas is discharged (Figure 2). Separated water is directed into second cyclone, which operates in a slightly flooded condition, and discharged together with any remaining traces of steam and gas. Water, free of gas and steam, from second cyclone may be fed to the cooling system and collected at atmospheric pressure or alternatively, it may be fed to an exterior and independent cooler.

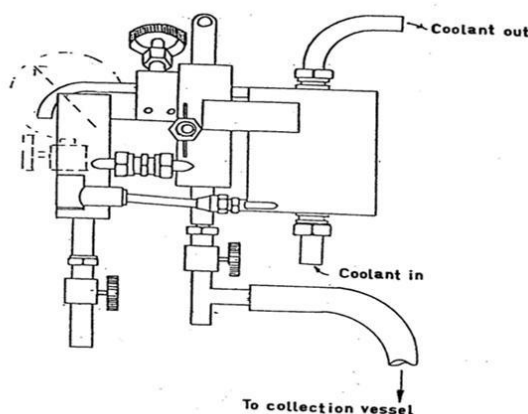


Figure 2. Twin cyclone separator micro design, portable use to sample gas and water at the same.

ASTM (1995), describe the significance of sampling practices also using the cyclone-type separator for high-efficiency phase separation which is operated at flow rates high enough to prevent significant heat loss while maintaining an internal pressure essentially the same as the pipeline pressure. The significant feature of the sampling practices is to locate the sampling separator at a point on the pipeline where the two-phase flow is at least partially stratified to aid in the separation process. The separator is usually attached to an appropriately oriented port to collect each specific phase, normally on top of the line for steam and at the bottom for liquid. A significant feature of the sampling practices is the use of a cyclone-type separator for high-efficiency phase separation which is operated at flow rates high enough to prevent significant heat loss while maintaining an internal pressure essentially the same as the pipeline pressure.

Arnorsson (2006) pointed out that when collecting samples using the Weber separator, it is important that the steam samples are not contaminated with liquid water and, in particular, that water samples are not contaminated with steam and it is important that samples (gas and water) are collected at the pipe / well pressure. Adjustment keeps the separator almost full of water and the steam discharge very wet. This can be done by passing any handy object through the plume; it will get wet if the steam is wet and stay dry if the steam is dry (Arnorsson 2006). The pressure drop from the pipeline to the separator should be minimal so that secondary flashing will be avoided. Steam condensation in the Weber separator should be minimized by insulating the separator well against heat loss.

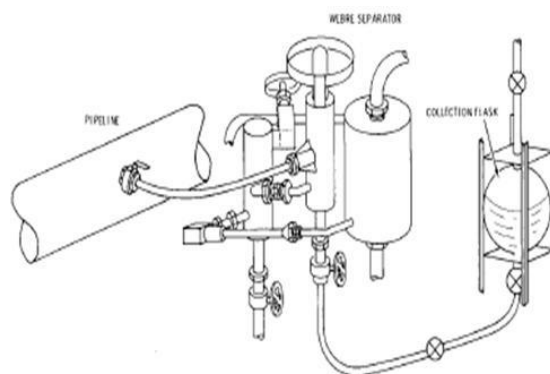


Figure 3. Dual Weber separator

Watson (1978) described that in separation of steam-gas phase from liquid phase while sampling a high pressure source a Dual Weber separator method can be used. When the equipment in Figure 3 is used, the discharge from the sampling point enters the first unit and valves are adjusted to obtain dry steam. The second separator is adjusted to operate slightly flooded, a condition which is recognized by the presence of water in the steam discharged from the steam outlet. This ensures that water entering the cooling coils contains no condensed steam. The unit must be operated with a minimum pressure drop of (0.2 bar) through the separators (Watson 1978). The unit is heavily insulated to prevent heat losses and to reduce the possibility of water samples being diluted with condensed steam.

Sinclair, Knights and Merz (SKM), Contact Energy, Mighty River Power, GNS Science and MBCentury of New Zealand, adopted a modified method described by both Klyen (1982) and ASTM (1995), where top and bottom sampling ports are used to sample for gas and water chemistry in a two-phase horizontal flow production well using the Weber and cyclone type mini-separators. Details of their procedures were not provided due to confidentiality issues but these companies have extended their assistance and support in providing relevant information regarding the sampling methodology.

3. SAMPLING REQUIREMENTS

3.1 Flow Regimes

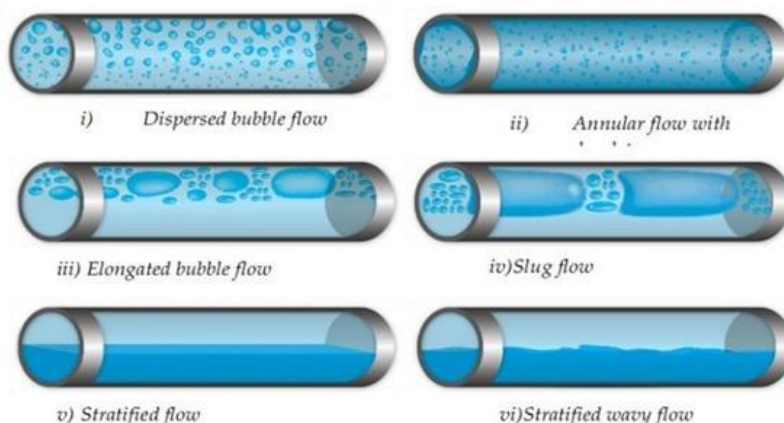


Figure 4. Types of two-phase flow regimes.

The flow patterns of water-steam mixtures in pipes depend on the relative volumes of the phases and their velocities and whether the pipe is vertical or horizontal (Arnorsson 2006). When the steam dominates the volume, the liquid water tends to exist as droplets in the steam phase. This pattern of flow is the most favorable for phase separation and sample collection. When the volume fraction of liquid water increases, the flow may become annular. If the flow is slow enough in a horizontal pipe, the water may flow at the bottom of the pipe and the steam at the top because of their gravitational separation. Alternatively, the water may come in slugs. These flow patterns, in particular slug flow, make separation more difficult as they lead to variable flow of water and steam into the Weber separator thus it is best to describe what happen inside a standard horizontal pipe once geothermal fluid flows. The types of flows are (Figure 4):

(i) Dispersed bubble flow. The bubbles tend to flow at the top of the tube, in this regime the liquid phase is the continuous phase and occupies most of the pipe volume, and the gaseous phase appears as small bubbles distributed through the liquid (Sulaiman 1986).

(ii) Annular flow, occurs at high gas flow rates. There is usually some entrainment of the liquid phase to droplets in the gas core. Film at the bottom of the tube is often very much thicker than the film at the top owing to gravitational effect giving drainage around the periphery.

(iii) Elongated bubble flow (Plug flow), the characteristic bullet-shaped bubbles occur, but they tend to move along in a position closer to the top of the tube.

(iv) Slug flow, the liquid phase remains as the continuous phase, but the bubbles have increased in numbers and size and now join to form a single bubble which form and size approaches the pipe diameter (Ramirez 1983). The velocity of the bubble is by far larger than the velocity of the liquid.

(v) Stratified flow, the gravitational separation is complete, liquid flowing along the bottom of the tube and the gas along the top part.

(vi) Wavy flow, as the gas velocity is increased in stratified flow, waves are formed on the gas – liquid interface giving the wavy-low regime. In a standard geothermal horizontal two-phase flow, a combination of flow regimes might be expected though it often assumed that the flow is turbulent or especially when there are some restriction and pipe bends. Stratified flow is likely observed in a long straight pipe where there is distinct separation of gas and liquid inside the pipe.

3.2 Sampling Location

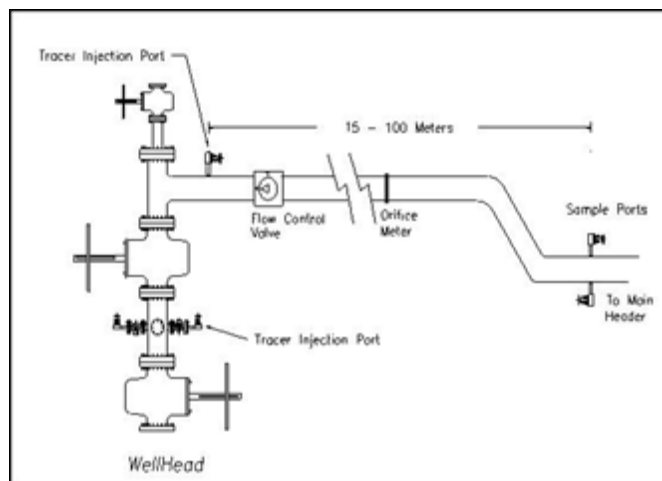


Figure 5. Schematic diagram showing the actual pipe lay-out of a typical two-phase production well.

Sample locations vary and are dependent upon the quantities of each phase at the sample point. If sample ports are properly oriented on the two-phase pipeline, a certain degree of phase stratification will have occurred prior to sampling, facilitating further separation of the target phase through the sampling separator. As shown in Figure 5, ports are ideally located on the top and bottom of the pipeline at least eight diameters downstream and two diameters upstream of major flow disturbances such as pipe bends, reducers, valves, etc (ASTM 1995). The top and bottom sampling method is more appropriate since the fluid flow is stratified where mostly gas stays on top while the water at the bottom. On the other hand, the side sampling port method is less to capture a representative sample of this kind especially if the pipe has minimal water flow. In cases where the fluid contains substantial amount of solid debris that may plug the sample port, the liquid port can be located at 45° angle from the bottom, provided that a sufficient liquid phase is present (ASTM 1995). If the flow regime is known, the number of ports may possibly be reduced to a single port located either on the side, top, or bottom of the two-phase pipeline. Sufficient quantities of each phase must be available at the single port to allow collection of representative steam and liquid samples. The sample ports must be at least 1-in diameter and configured with a full-open port ball or gate valve. This requirement is necessary to ensure that only a minimal pressure drop occurs through the port valve and associated piping. Scale and debris often reduce the effective inner diameter of the port, therefore smaller ports are not recommended. The port size restriction also provides a safety margin given the weight of the separator and force needed to install and remove fittings from the port. The proportions of each phase are not likely to remain the same in a flow stream split off from the main flow line.

3.3 Equipment

Sampling Separator— A cyclone-type separator rated to the pipeline pressure at the sample point, including a pressure gauge, temperature probe, and sight glass (optional). This separator should be designed to attach directly to the sample port to minimize heat loss and pressure drop (ASTM 1995). A typical sampling separator is shown in Figure 6. This is a cyclone-type separator with a 1-in. pipe inlet attached at a tangent to the separator body. A pressure gauge and thermocouple are located at the top of the separator, and steam and liquid sample valves are located at the bottom. Steam is drawn from the top of the separator through a pipe extending up from the bottom of the vessel. Liquid is drawn directly off the bottom. The vent valve on the side of the sampling separator can be used to maintain an excess flow of steam and liquid through the separator, beyond the amount needed for sample collection. If sufficient quantities of each phase are present, the side vent valve will maintain a liquid level about 2 in above the liquid sample valve. This allows collection of both steam and liquid samples from the separator without the need to adjust the liquid level.



Figure 6. Picture showing the required instrument used for sampling a two-phase production well.

Sample Hoses—Sample hoses are stainless steel braided hoses are dedicated to either steam or liquid phases to prevent cross-contamination. The inner diameter of the hose should not exceed 0.375 in. Stainless steel tubing may also be used (0.25 to 0.375-in outside diameter), although it is less convenient. Convolutd, flexible stainless steel hose is specifically excluded due to potential entrapment and contamination problems caused by the internal convolutions.

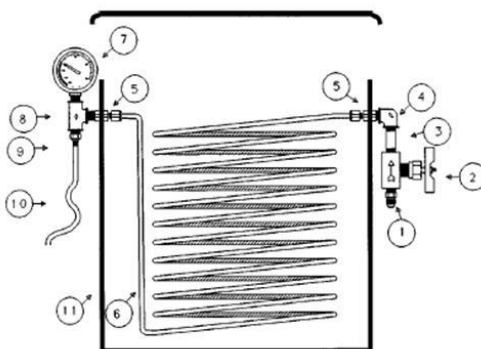


Figure 7. A sample condenser use to cool down geothermal fluid prior to collection

Condenser—Sample condenser configuration with two sets of stainless steel tubing coils is recommended (Figure 7). One set of coils is dedicated for condensing steam and the other is dedicated for cooling liquid. The steam condenser coil has a pressure/vacuum gauge located at the sample outlet and a regulating valve at the inlet. The steam flow can be precisely regulated at the inlet as opposed to regulating the flow of condensate and gas at the outlet that can result in large pressure surges and the hold-up of gas or condensate phases in the coils. Regulating the outlet flow prevents flashing of liquid at the inlet to the condenser where chemical deposition (scaling) could occur. Dedicated condensers with single set of tubing coils for sampling either steam or liquid also can be used. The condenser coil tubing must not exceed 0.25-in.outside diameter to prevent the segregation of gas and condensate phases during the sampling of steam.

4. METHODS

4.1 Current Practice

Standard practice of sampling two-phase geothermal fluid involves the use of a twin-cyclone Weber mini-separator attached into a standard 1" sampling point valve (gate, carbon steel type) connected along the branch line of the production well horizontally (side tapped) oriented (Figure 8). A good assumption on this location is that two-phase fluid flows in turbulent regime thus, both steam and brine are mixed proportionally distributed inside the pipe such that representative sample can be collected at the side sampling location. This method was adopted since prior to the commercial operations of geothermal power plants and introduced by New Zealand consultants. The equipment captures considerable volume of two-phase fluid from the pipe and separates the pure steam from the brine though a tangential flow mechanism. Both steam and brine are transported at different lines for sampling. The two-phase fluid enters the first separator chamber at a certain pressure and will be separated, the steam goes directly inside the standpipe of the separator chamber and exit as pure steam while the brine will enter the second separator chamber for further separator before it will exit in a flooded condition eliminating the possibility of further flashing along the chamber (Ellis 1977). Valve adjustments and manipulations are crucial to attain the required good separation as it is assumed that there is no brine carry-over during separation of steam and no steam dilution on the brine samples during collection. Thus, quality control like analyzing Sodium (Na) in steam to determine the extent of brine that might be carried out to the steam separator. A good steam separation can be judged

by just looking on the discharge plume where bluish tinge color discharge is distinguished or by running the hand quickly through the fluid (Ellis 1977). Steam and gas mixture is collected in a glass bottled filled with a scrubbing alkaline solution (NaOH) to dissolve CO₂ and H₂S and other reactive gases prior to analysis. This will prevent the apparent harmful effects if these corrosive gases to react with the instrument detectors during analysis of other un-reactive gases in the sample. On the other hand, the brine is cooled down to at least 35°C before collection to eliminate possibility of flashing during sampling and collected into desired sample containers with appropriate acidification for sample preservation. A duplicate gas sample is taken for the analysis of NCG components while 1-set of air free, acidified and un-acidified samples are collected for water analysis

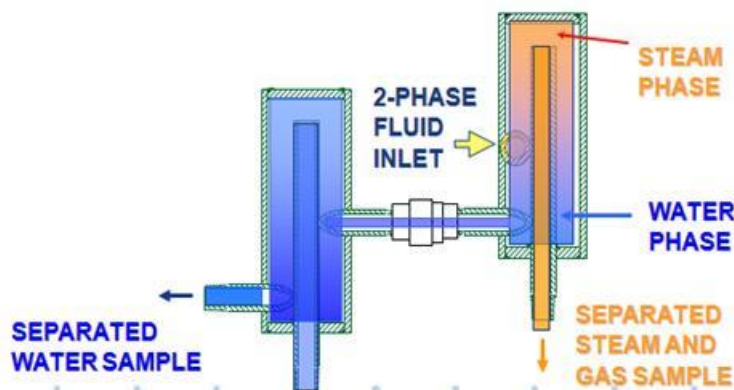


Figure 8. Twin cyclone Weber separator use to collect and separate two-phase geothermal fluid.

4.2 Other Practice

As per communications and personal observations and experienced during the actual sampling demonstrations during the field visit to Mokai in Taupo, sampling in hot two-phase geothermal production well is done in different way.. Contact Energy method includes but not limited to sampling using two different sampling equipments (Figure 9). The method includes installation of two separate Weber cyclone separators, one on top for gas sampling and the other at the bottom 45° tangential for water sampling.



Figure 9. Single cyclone Weber separators are installed at the top for gas sampling and at the bottom (45° angle) for water sampling.

This set-up is intended for both chemistry sampling of gas and water, and for recovery of injected chemical tracer isopropanol and sodium benzoate for gas and water, respectively for mass flow measurements using Tracer Dilution Method (TDM). The method was observed to be effective in optimizing the scheduled sampling and testing of two phase production well. All the sampling requirements are performed including flow measurements, gas and water chemistry and isotopic sampling (Adams 2011). The method was also recommended by SKM (Lovelock 2011) and GNS (Mroczek 2011). Using the premise that the fluid flows in a stratified flow regime inside the pipe, the orientation of the gas and water inside the pipe might be best represented and can be captured if the sampling point is on top for the gas and bottom for the water components. The installation of a 45° tangential orientation for bottom sampling ports is advantageous to minimize the difficulties in the access of the port and reduce the risks to scaling potential of the sampling location. Maintenance and repairs in de-clogging of the port is experienced frequently when the port is vertically installed at the bottom compared to 45° tangential. However the 45° tangential orientation might not capture the water sample if the flow is stratified and the well is flowing mainly steam with a little water fraction.

5. EXPERIMENTAL COMPARISON

Thorough supervision from the beginning of installation of equipment to samples collection was done to ensure credible samples are taken and analyzed. This is to attain and answer the main objective of the study which is comparing the water and gas

chemistry data to evaluate the performance of top & bottom against side sampling locations from two-phase production wells. In the field testing and sampling, simultaneous sampling were done using default sampling method (side, horizontal) and the new method (top & bottom, bottom is vertically oriented) at the same time. The succeeding plots presented are the results in collecting tandem comparative samples of gas and water from two-phase production wells representing and covering different mass flows and enthalpy levels. A total of five production wells were sampled, two wells with low enthalpy ~ 1200 kJ/kg, high water flows (W302 and W510D), one well with medium flow and enthalpy of ~ 1600 kJ/kg (W509) and two wells of low water flows and high enthalpy of ~ 2300 kJ/kg (W310D and W310Di). Plots are constructed and presented per chemical parameters namely; CO₂ and H₂S for gas and pH, Na, K, Ca, Cl, and SiO₂ for water. The plots also show the levels of steam, water and total mass flow data during sample collection. Average percent difference is calculated and presented as a statistical tool to determine the comparability of the results of the samples taken from the two sampling methods.

5.1 GAS SAMPLES

5.1.1 Carbon Dioxide (CO₂)

The concentration of Carbon Dioxide (CO₂) gas in steam is an important factor in assessing the effect of exploitation on subsurface condition of geothermal system. CO₂ comprise majority of the gas in the non-condensable gases (NCG) and is vital as this gives much information on the relative %NCG of the well as it discharges to the production system and in the total efficiency of the turbine power plant output. Figure 10, shows the CO₂ content in gas samples taken from different two-phase production wells with varying enthalpy. The average differences between the CO₂ in top and side sampling points ranges from 0.4% to 12.2%. Generally, CO₂ concentrations are comparable between the sampling ports except for the low enthalpy wells, W302 and W510D whose % differences are at 12.2% and 6.0%, respectively. CO₂ data taken from the top sampling port is relatively higher than of the side sampling port. due to larger proportion of water than gas and the water component fills up most part of the pipe, causing geothermal gases to accumulate on top of the pipe than side. While there is good correlation of data results of CO₂ taken from same ports in a medium and high enthalpy wells can be explained by the low water flows/level inside the pipe where gases can easily occupy.

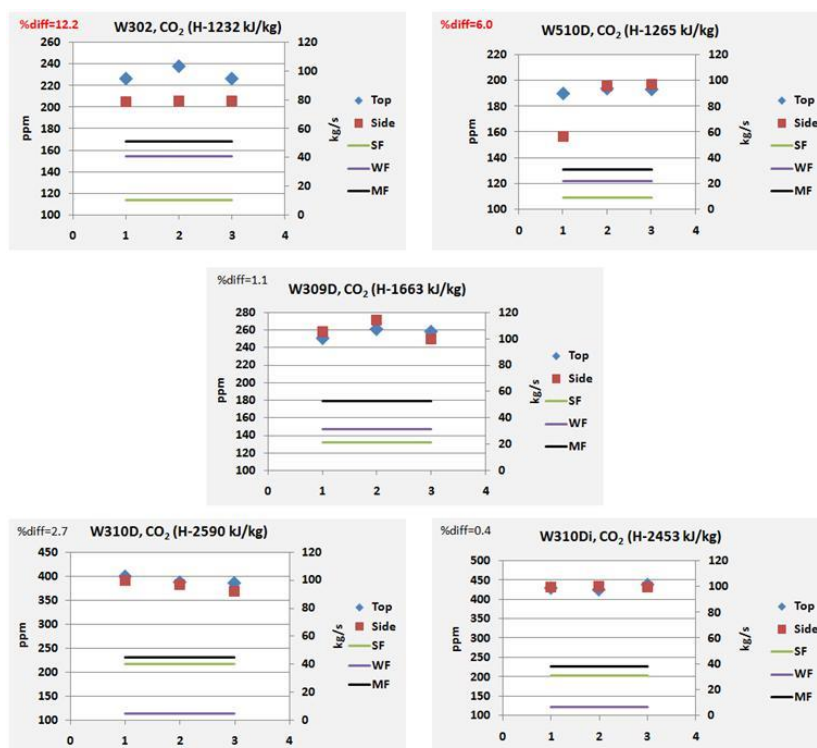


Figure 10. Plots of Carbon Dioxide (CO₂) ppm content in gas samples of different two-phase production wells with varying enthalpy range.

5.1.2 Hydrogen Sulfide (H₂S)

Hydrogen Sulfide (H₂S) is also predominantly present in geothermal fluids and poses more risk than CO₂ (O'Brien 2010). This gas is part of the commonly referred to as 'non-condensable gases'. Hydrogen Sulfide is formed during thermal breakdown of volatile-rich components in reservoir rocks. Condensate related corrosion (i.e. pyrite etc.) is one of the major effects of this gas as it dissolves in water. Consequently, this gas is responsible why the condensate exiting from the condenser for makeup water recycling or re-injection is acidic. H₂S trend of production wells is shown in Figure 11. The two sampling methods have higher average differences, ranging from 0.8% to 32%. In general, H₂S content in samples taken from the top are higher than samples taken from the side ports in low enthalpy wells, W302 and W510D and in high enthalpy well W310Di. This is probably due to low enthalpy fluid mostly high water flow content is filling-up greater part of the pipe including the side and geothermal gases where H₂S is present predominantly exist on top of the pipe rather than side.

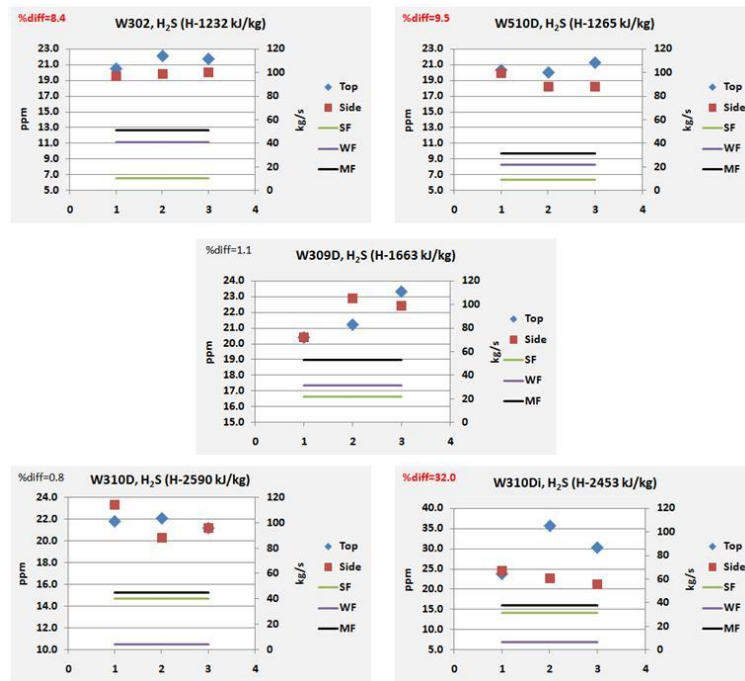


Figure 11. Plots of Hydrogen Sulfide (H₂S) ppm content in gas samples of different two-phase production wells with varying enthalpy range.

5.2 WATER SAMPLES

5.2.1 pH

Hydrogen potential (pH) is one of the most important chemical parameter to be determined in geothermal waters as this will give information on the nature and type of fluid at source.

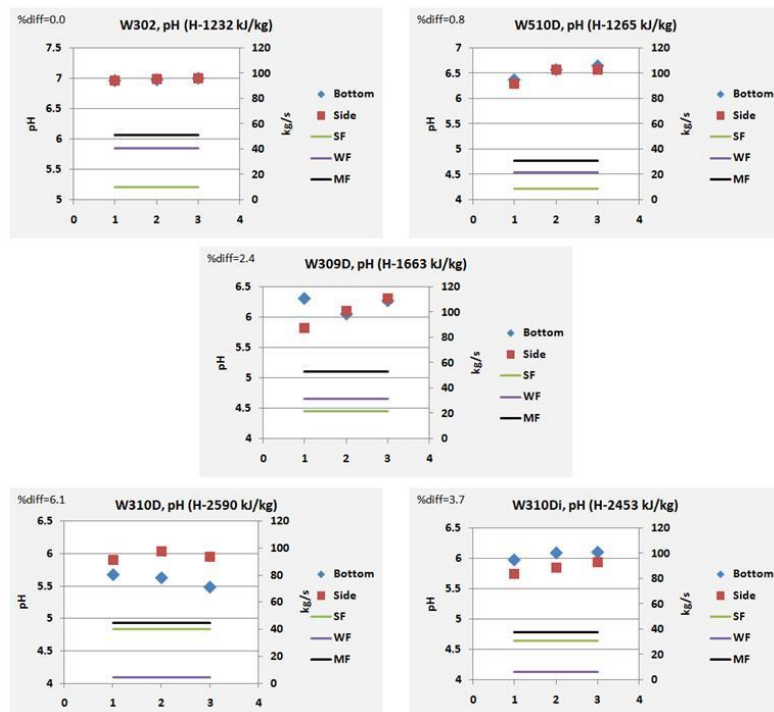


Figure 12. Plots of pH content in water samples of different two-phase production wells with varying enthalpy range.

Figure 12 shows the pH data for the two-phase production wells. The pH values in all wells of different enthalpy are comparable with average difference range of 0.0 to 6.1%. This can be observed in low and medium enthalpy wells W302, W510D and W309D. The highest difference in pH value is in W310D with roughly 0.5 pH units. There is no discrete trend on the data that provides either bottom or the side sampling location is better or neither obtained higher pH values. The only distinct observation is that either of the ports shows comparable results. This signifies that as long as representative sample can be obtained from either port the pH data are all acceptable.

5.2.2 Sodium (Na)

The major cation in geothermal systems is sodium. Sodium (Na) concentration is controlled by mineral-fluid equilibrium, which form the basis for the Na/K geothermometer. The Na/K ratio is important in areas of high temperature, as a lower ratio represents higher temperatures. Lower ratios usually occur in water that reaches the surface rapidly through upflow structures (faults, fractures, joints) or areas of high permeability (Nicholson 1993). Results of the comparative test in Figure 13 show that sodium concentrations on samples taken from both the bottom and side sampling ports are comparable. The average differences from low to high enthalpy wells ranges from 0.8% to 3.7%. All are below 5% in average difference (could be quite good correlation). It cannot be deduced from the data which sampling source/location is better than the other. It is however, assumed that as long as no flashing and stem dilution of samples during collection results are expected to be reasonably similar (same as what is observed in the pH results).

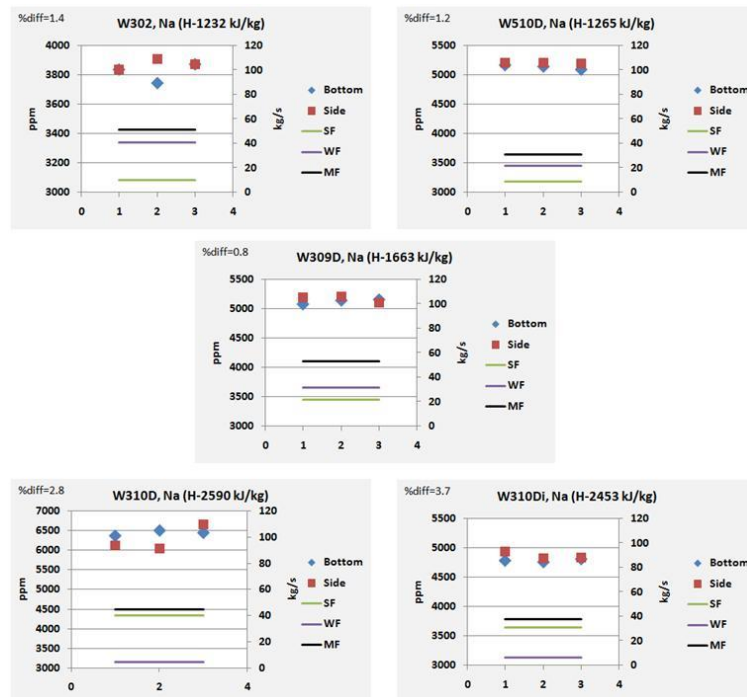


Figure 13. Graphs showing the Sodium (Na) ion content of water samples from different two-phase fluids of varying enthalpy

5.2.3 Potassium (K)

Concentration of K also controlled by mineral-fluid equilibrium like sodium and forms the basis for the Na/K geothermometer (O'Brien 2010). Potassium is present at lower levels than sodium; concentrations are generally a fifth of the concentration of sodium, but it is still a major cation. Comparing the concentration of potassium in samples from bottom and side sampling ports shows remarkable comparability. The average difference of both locations ranges from 0.1% to 3.6%. It can be noted that wells with low and medium enthalpy namely; W302, W510D and W309D all have same average difference of 0.3% (Figure 14). This suggests that potassium results are very similar whether the water sample is taken from the bottom or from the side. There is no general trend that suggests either sampling location is better than the other but only signifying very good correlation.

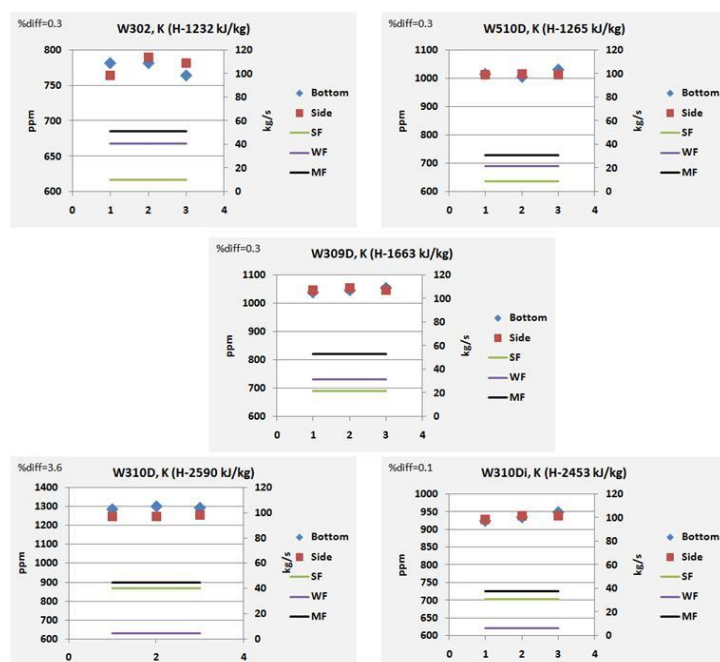


Figure 14. Graphs showing the Potassium (K) ion content of water samples from different two-phase fluids of varying enthalpy

5.2.4 Calcium (Ca)

Calcium concentrations are generally low in geothermal systems (<300 mg/l) but increase with salinity and acidity. Minerals with retrograde solubility, such as calcite, anhydrite and fluorite, and Ca- rich aluminosilicates tend to control the calcium concentrations in fluids (O'Brien 2010). The level of Ca in fluids can also be influenced by the factors that influence the solubility of these minerals; CO₂ as calcite often precipitates as a response to the loss of CO₂ during boiling.

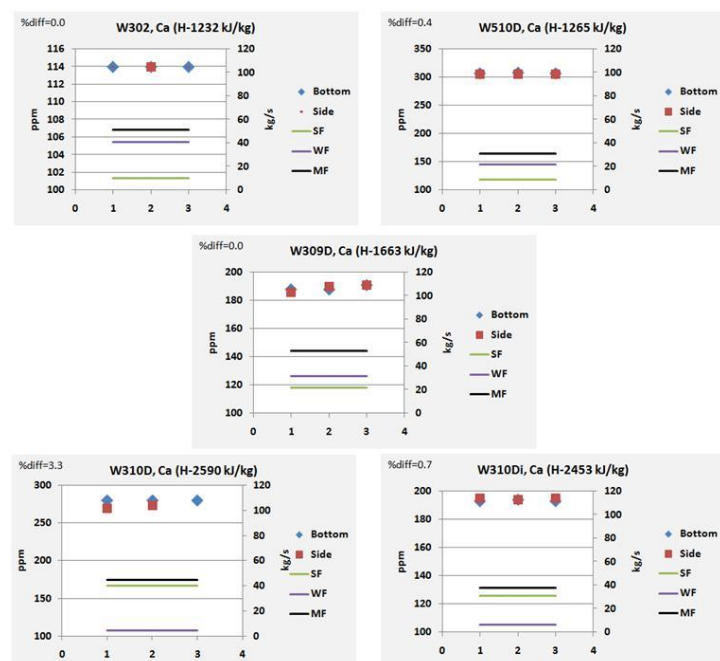


Figure 15. Graphs showing the Calcium (Ca) ion content of water samples from different two-phase fluids of varying enthalpy

Upflow zones can be indicated by the Na/Ca ratio, higher values represent a more direct link to the reservoir. All of the wells (low to high enthalpy) show outstanding correlation on calcium results from samples taken on both the bottom and side sampling ports. The average difference ranges from 0.0% to only 3.3% (Figure 15). With mostly samples from watery wells (low and medium enthalpy) have almost similar calcium concentrations. There is no distinct evidence to prove that the samples taken from either locations are better from the other but only suggest a very good correlation in terms of results.

5.2.5 Chloride (Cl)

Chloride is the most common and conservative element in geothermal waters, making it an important solute in the interpretation of water chemistry. It is used in ratios with other elements to eliminate boiling or dilution effects and to determine common reservoir

sources (e.g.: Cl/B, Cl/F, Cl/As and Cl/HCO₃). High chloride concentrations in spring waters suggest a direct link to the deep reservoir with minimal mixing effects or conductive cooling. Chloride concentrations may range from <10 to >100,000 mg/l (Nicholson 1993). The chloride concentration of samples from bottom and side sampling ports are shown in Figure 16. The overall average % difference between the two locations ranges from 0.1 to 4.6. The small difference of <5% connotes good correlation considering the average chloride concentration of about 7000 to 1100ppm (low, medium and high enthalpy wells). This however suggests that samples could be taken from either sampling locations as long as no further flashing is experienced.

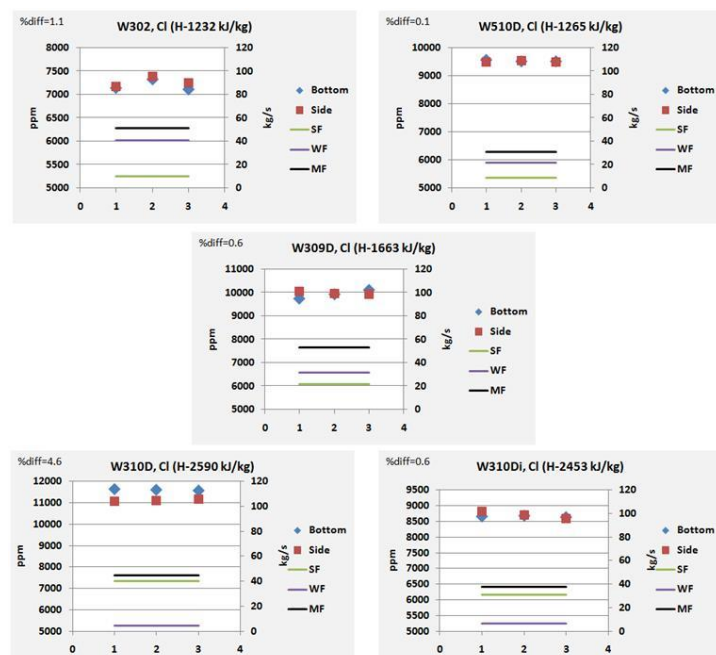


Figure 16. Plots of Chloride (Cl) ppm content in water samples of different two-phase production wells with varying enthalpy range.

5.2.6 Silica (SiO₂)

Concentrations of silica in geothermal fluids are controlled by the solubility of different silica minerals (Mroczek 2011). Silica occurs in various polymorphs or forms (amorphous silica, opal, quartz, cristobalite and chalcedony) which all have slight variations in solubility. Quartz and amorphous silica are of most interest in geothermal systems as their behavior determines the dissolution and precipitation of silica in production equipment and re-injection wells. The extremely soluble silica polymorphs control the concentrations of silica within the liquid until they are dissolved (Nicholson 1993). Figure 17, describes the comparison of silica concentrations on samples from bottom and side sampling ports. The average difference between the two locations is <5% which is between 0.0 to 4.2%.

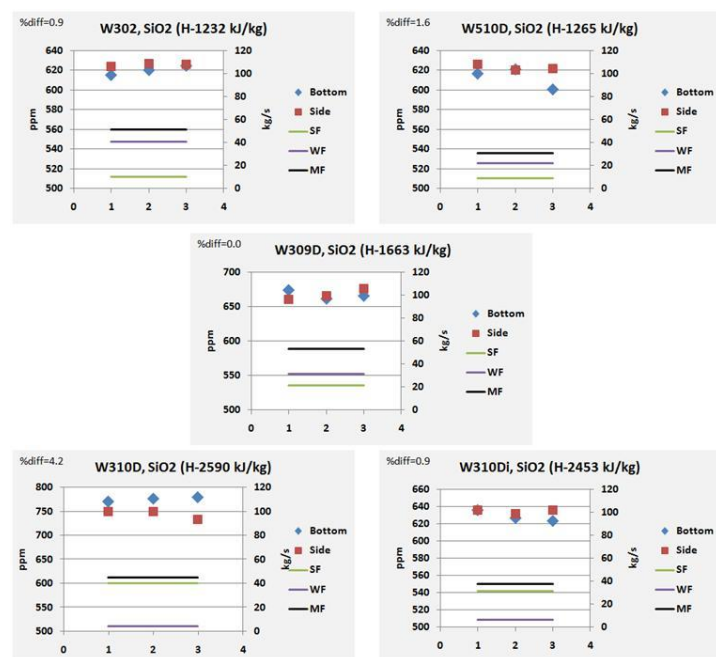


Figure 17. Plots of Silica (SiO₂) ppm content in water samples of different two-phase production wells with varying enthalpy range

Close results are obtained on wells with higher water flows or low enthalpy particularly W302, W501D and W309D. However, it cannot be assumed from the data that the bottom or side is better and yield good results since the trend and result does not support it but it only suggest that superior correlation is achieved making them comparable with each other.

6. SUMMARY AND CONCLUSION

The result of the comparative evaluation based on gas and water chemistry is summarized below:

Table 1. Summary of the results comparing the top and bottom sampling with side sampling location per chemical parameter

Chemical Parameter	% Difference (max)	Remarks
Gas		
Carbon Dioxide (CO ₂)	High; 6.0 to 12.0	For low enthalpy wells (more water flow); in general higher CO ₂ content in samples taken from the top.
Hydrogen sulfide (H ₂ S)	High; 8.4 to 32	For low enthalpy wells (more water flow); normally H ₂ S content in samples taken from the top.
Water		
pH	Low; 6.1	Side and bottom sampling are comparable
Sodium (Na)	Low; 3.7	Side and bottom sampling are comparable
Potassium (K)	Low; 3.6	Side and bottom sampling are comparable
Calcium (Ca)	Low; 3.3	Side and bottom sampling are comparable
Chloride (Cl)	Low; 4.6	Side and bottom sampling are comparable
Silica (SiO ₂)	Low; 4.2	Side and bottom sampling are comparable

Data results shows that in sampling for gas in a horizontal pipe where the flow regime is unknown or if not stratified, it is best to collect sample at the top rather than the side. This is because more gas chemistry component are captured using the top sampling port especially in well with low enthalpy or higher water flows. On the other hand, for water samples in general, the results are comparable whether taken from the bottom or from the side except for the HCO₃ data (more analytical uncertainties).

In addition to, advantages and dis-advantages of the both the top and bottom against the side sampling locations and practices are also tabulated:

Table 2. Summary of advantages and dis-advantages of the two subject sampling locations/methods

	(NEW) Top & Bottom sampling method	(DEFAULT) Side sampling method
Equipment used	1-separator each on top and bottom; separators are lighter	1-twin cyclone separator at side; separator is heavy
Ease of installation	Can be installed easily	Easy cause it has one port but put more load / stress to the sampling point port due to weight
Separation	Single flashing on each separator	2nd flashing occur on the second separator (should be limited) source of possible error might occur
Access	Accessible but sometime difficult if pipeline ground elevation is shorter (but can be modified to 45° degree angle)	Accessible
Collection of sample	Can easily collect representative sample especially if flow is stratified regardless on enthalpy and mass flow	Difficult to collect; separated water if well is high enthalpy (low water flow) and gas if the well is watery or low enthalpy
Sampling timing/savings	Can be done prior to tracer dilution tests	Separate installation and requires additional time to do the sampling

The following are the important findings and observations:

1. The default (side, horizontal) sampling method can still be used provided that the two-phase flow regime is establish otherwise, it would be best to substitute and use the most common top & bottom sampling method technique to capture more representative sample.
2. The top and bottom configuration was found to be more practical and reduces some of the access and maintenance problems including two-phase flow regime inside the pipe.
3. The pre-existing bottom (vertical) sampling port can be modified to 45° tangential orientation especially on pipelines with lower ground elevation.

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