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Application of Tracer Flow Tests (TFT®) in the Menengai Geothermal Field, Kenya: Implications for Reservoir Management

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ABSTRACT

The first two 35 MW (net) power plants in the Menengai geothermal field, Kenya, are fully operational while the third plant is undergoing pre-commissioning tests. GDC supplies steam to the power plants while continuously monitoring steam field performance and reservoir response to production. Well discharge enthalpy, mass flow and fluid chemistry are among the key parameters monitored to support sustainable reservoir management. To enable discharge enthalpy and mass flow measurements without interrupting steam supply, the Tracer Flow Test (TFT®) technique, a non-invasive method increasingly applied in geothermal operations, has been adopted. Tracer flow measurements in Menengai were initially conducted approximately two months after commencement of production to establish baseline conditions for future reservoir performance assessments. Measurements were undertaken through collaboration between GDC, JICA, WestJEC, and Thermochem using naphthalene sulfonate and sulfur hexafluoride (SF_6) tracers for liquid and vapor phase flow measurements, respectively. Results were compared with production separator measurements, initial well discharge test data, and estimates obtained during steam gathering system commissioning. The TFT results showed good agreement with production separator measurements, confirming the suitability and reliability of the technique for determining well mass flow and discharge enthalpy. However, some wells exhibited reductions in steam output and changes in enthalpy relative to earlier measurements. Temporal variations in chloride (Cl), silica (SiO_2), and non-condensable gases (NCG) provided additional evidence of evolving well conditions and possible changes in feed-zone contributions. In MW-09, NCG concentrations increased progressively from approximately 2 wt.% during discharge testing to more than 5 wt.% during production, while similar declining trends in Cl and SiO_2 were also observed in relatively stable wells. These observations suggest that fluid chemistry changes may precede measurable variations in production performance and therefore provide early indicators of evolving well and reservoir conditions. The integrated use of TFT and fluid chemistry monitoring provides an effective framework for well surveillance and supports informed reservoir management decisions for sustainable geothermal production.

1 INTRODUCTION

The Menengai geothermal field is one of Kenya's key geothermal developments and is currently supplying steam to two Independent Power Producers (IPPs), Sosian Menengai Geothermal Power Limited (SMGPL) and OrPower 22, each generating 35 MW (net) under Phase I of the Menengai Geothermal Development Project. The third IPP, Globeleq, is undergoing pre-commissioning activities. SMGPL was the first of the three IPPs to commence commercial operations in 2023. The Geothermal Development Company (GDC) is responsible for steamfield operation and geothermal reservoir management to ensure sustainable steam supply to the power plants.

Effective reservoir management requires continuous monitoring of key performance indicators, including well discharge enthalpy, mass flow, pressure, and fluid chemistry. These parameters provide critical information on reservoir response to production, well performance, and long-term resource sustainability. Separator pressures and flow rates are continuously monitored through the steamfield control system, while fluid samples are collected periodically as part of routine reservoir surveillance programs. Geochemical monitoring is particularly important because changes in fluid composition can provide valuable insight into reservoir processes such as boiling, fluid mixing, recharge, and feed-zone evolution during exploitation. Arnórsson & D'Amore (2000) emphasized the importance of fluid chemistry in understanding the behavior of geothermal reservoirs under production. Direct measurements of well mass flow and discharge enthalpy, however, are typically undertaken periodically due to operational and logistical considerations.

In Menengai, reservoir monitoring activities have benefited from support provided through the collaboration between GDC and the Japan International Cooperation Agency (JICA) under the Project for Capacity Strengthening for Geothermal Development in Kenya. As part of Phase II of the collaboration, known as the Project for Capacity Strengthening for Geothermal Steam Supply and Management, tracer flow testing (TFT®) was undertaken to determine well mass flow and discharge enthalpy under operating conditions.

The TFT® technique has gained widespread acceptance in geothermal operations because it allows accurate determination of mass flow and enthalpy without interrupting steam supply to power plants. The method is particularly valuable for fields under commercial production, where conventional flow testing can be operationally disruptive and costly. Consequently, TFT® has become an important reservoir surveillance tool in many geothermal developments worldwide.

This paper presents the results of TFT® measurements conducted in the Menengai geothermal field and compares them with historical well discharge test data, SGS commissioning results, and production separator measurements. Particular emphasis is placed on discharge enthalpy and its implications for reservoir performance assessment. In addition, temporal fluid chemistry trends are evaluated to provide complementary insight into observed changes in well behavior. The combined interpretation of TFT® measurements and fluid chemistry data demonstrates how these approaches can be used together to improve reservoir surveillance, identify evolving well conditions, and support informed reservoir management decisions. Figure 1 shows the location of Menengai geothermal field, production wells, power plant sites, and associated steamfield infrastructure.

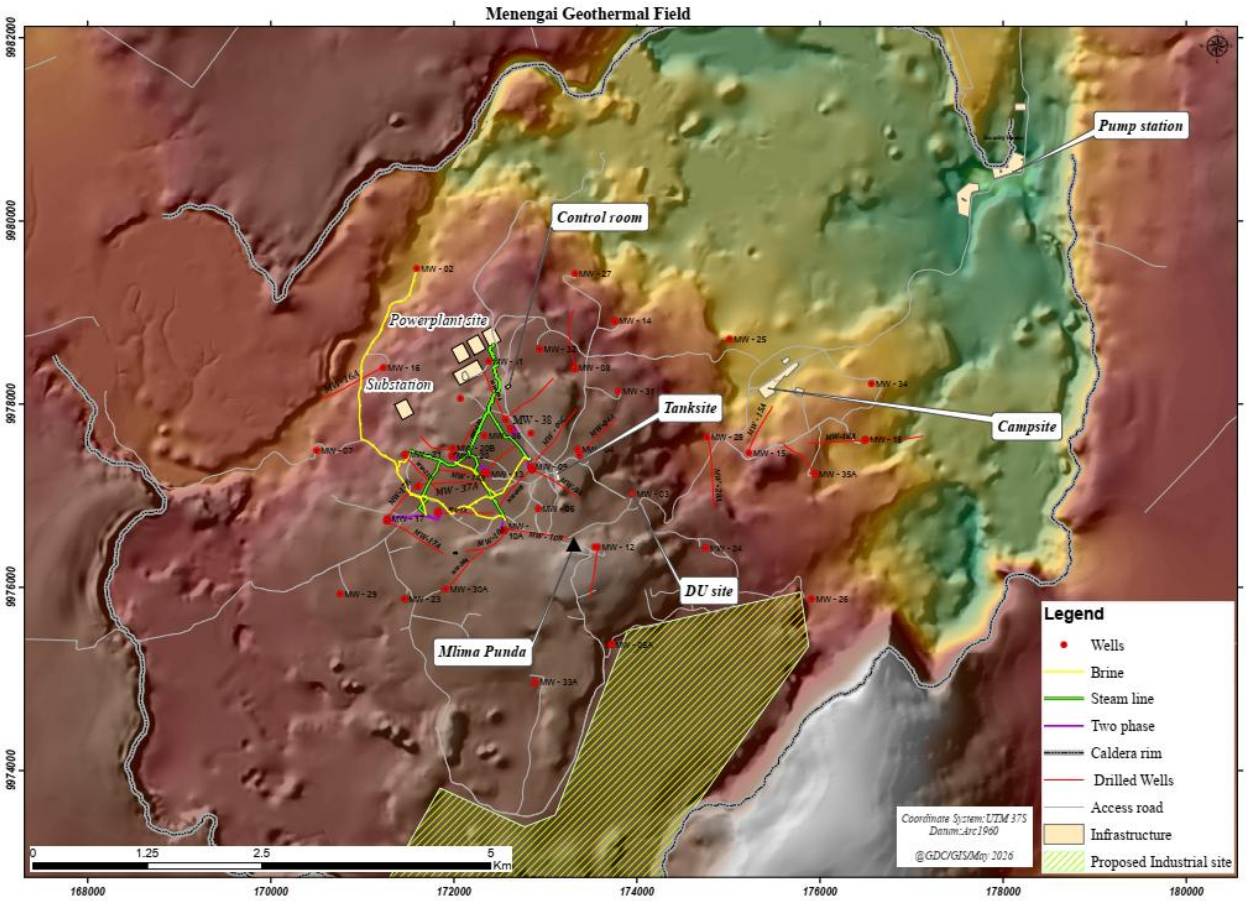


Figure 1. Map of Menengai showing location of the geothermal wells, the SGS and other surface installations and infrastructure (GDC, 2026).

2 RESULTS OF PREVIOUS FLOW TESTS

A summary of the results from individual well discharge tests and measurements obtained during commissioning of the Steam Gathering System (SGS) in 2020 is presented in this section. These datasets provide

the historical basis for evaluating well performance and assessing subsequent changes observed during production.

2.1 Discharge Tests

Flow tests were conducted following thermal recovery of the wells to determine their mass flow rates, discharge enthalpies, and fluid chemical characteristics. The tests were undertaken between 2011 and 2018 as the wells were progressively drilled and completed. The results established the initial production characteristics of the wells and provided important insights into the nature and productivity of the Menengai geothermal reservoir.

During discharge testing, mass flow and enthalpy were determined using atmospheric separators, James Tube measurements, and weir box techniques, which are widely applied in geothermal well testing and generally provide reliable estimates of well output (James, 1970). The discharge test results are summarized in Table 1.

Four wells, MW-09, MW-13, MW-13A, and MW-20, exhibited near dry-steam discharge conditions, as reflected by their high discharge enthalpies and elevated steam fractions presented in Table 1. These wells produced only minor quantities of separated liquid and were characterized by steam fractions approaching unity.

The high enthalpies and elevated vapor fractions observed in these wells indicate the presence of high-temperature reservoir zones undergoing significant boiling. The results suggest that portions of the Menengai geothermal system contain well-developed steam-rich regions capable of supporting high steam production. Such characteristics are commonly associated with proximity to upflow zones and permeable reservoir structures that facilitate fluid circulation, heat transfer, and steam generation. The discharge test results therefore provide an important baseline against which subsequent production data and TFT® measurements can be evaluated.

Table 1. Enthalpy and steam fraction estimates from well discharge tests

Well Code	Date of Flow Tests	Enthalpy (kJ/kg)	Steam Fraction
MW-01	2018*	1280	38.5%
MW-09	2013	2675	96%
MW-09C	2017	2280	74.8%
MW-10A	2014	1797	49.2%
MW-13	2013	2675	96%
MW-13A	2017	2675	96%
MW-19	2014	2408	78.5%
MW-20	2015	2540	93.8%
MW-21A	2015	1146	24.1%

*The last flow tests before the well was connected to the SGS, the well underwent several discharge episodes since 2011.

2.2 Steam Gathering System (SGS) Commissioning

Thirteen (13) wells were initially connected to the Steam Gathering System (SGS) at Menengai, although only twelve (12) wells were discharged during SGS commissioning in 2020. During commissioning, mass flow and discharge enthalpy were determined for the producing wells. The resulting enthalpy and steam fraction estimates are presented in Table 2.

Variations are observed in the enthalpy and steam fraction values obtained during SGS commissioning relative to those determined from individual well discharge tests. These differences may reflect the effects of multi-well discharge, including well interference and changes in reservoir pressure conditions, which can influence boiling processes, fluid mixing, and phase distribution within the reservoir. However, uncertainties associated with field operating conditions during commissioning and the methodologies used to estimate flow and enthalpy may also have contributed to some of the observed differences. Consequently, the SGS commissioning data should be interpreted within the context of these potential sources of uncertainty.

Further evaluation of the SGS commissioning results alongside subsequent production monitoring data and TFT® measurements is presented in later sections to provide additional insight into the observed variations.

Table 2. Enthalpy and steam fraction estimates from SGS commissioning

Well Code	Enthalpy (kJ/kg)	Steam Fraction
MW-01	1361	29.4%
MW-09	2315	77.5%
MW-09C	2508	87.3%
MW-10A	2052	65.9%
MW-13	2492	87.1%
MW-13A	2760	100%
MW-19	2150	70.2%
MW-20	2033	64.3%
MW-20A	2032	67.7%
MW-21A	1066	12.6%

3 (TFT®) MEASUREMENTS

Tracer injection and fluid sampling and analysis were done in conjunction with WestJEC and Thermochem according to Thermochem's tracer injection and fluid sampling protocols.

3.1 Field Sampling

Existing ports on the SGS were used for the (TFT®) field execution. The side ports located about ten to fifteen meters from the wellheads of the wells that are usually used for routine fluid sampling were utilized as tracer injection ports. Side ports positioned at varying distances from the injection ports ranging from fifteen to fifty meters were employed for the vapor phase sampling while brine drain ports (BDP) located near the vapor phase ports allowed for brine sampling. Pressure and temperature measurements were recorded before and during fluid sampling.

The liquid and vapor phase tracers were mixed prior to injection. Naphthalene Sulphonate was the liquid phase tracer while Sulphur Hexafluoride (SF6) was used as the vapor phase tracer for steam flow measurements. Eight (8) wells were flowing at the time of carrying out the measurements although some were not fully opened, while brine could not be obtained in one (MW-13A) due to some blockage. A different mini separator was used for each phase to allow for sampling of brine and steam concurrently at timed intervals.

3.2 Analysis

The fluid samples were analyzed at the Thermochem Laboratory following Thermochem's established in-house protocols for geothermal fluid and tracer analyses. The analytical procedures included determination of tracer concentrations as well as common fluid chemistry parameters used to support interpretation of well performance and reservoir behavior.

3.3 Tracer Flow Tests Results

The mass flow and enthalpy results from the 2023 and 2024 Tracer Flow Test (TFT®) campaigns in Menengai are presented in Tables 3 and 4. Overall, the TFT® results compare well with measurements obtained from the production separators, demonstrating the reliability of the technique for determining well mass flow and discharge enthalpy under field operating conditions.

For well MW-13A, a few liquid droplets were insufficient during the 2023 TFT® campaign for representative liquid-phase tracer measurements. Consequently, the calculated brine flow and enthalpy values for that campaign based on the brine flow difference for MW-13 and total flow at the weir box shared by the wells are considered less representative of the actual well discharge conditions. The results obtained during the 2024 TFT® campaign are regarded as more representative of the well's performance and are consistent with its predominantly dry-steam discharge characteristics.

As noted in the previous section, some wells, including MW-01, MW-13, and MW-21A, were not fully opened during the 2023 TFT® measurements due to operational constraints. Consequently, the flow measurements obtained for these wells may not fully represent their maximum production capacities under normal operating conditions. This does not rule out other production related limitations like calcite scaling which could have

continued to drop in steam quantities in these wells. Nevertheless, the results provide valuable baseline information for evaluating well performance and subsequent changes during production.

Table 3. Enthalpy, mass flow and steam fraction results from the (TFT®) measurements.

Well Code	Date of Measurements	Total Mass (t/hr)	Brine Flow (t/hr)	Steam Flow (t/hr)	Enthalpy (kJ/kg)	Steam Fraction
MW-01	25-Sep-23	177.7	134.3	43.4	1180	24.4%
MW-09	2-Aug-24	45.1	1.04	44	2713	97.7%
MW-09C	23-Sep-23	112.3	37	75.3	2071	67.1%
	2-Aug-24	138.2	71.1	67.1	1689	48.6%
MW-10A	23-Sep-23	36.7	11.4	25.3	2112	68.9%
	2-Aug-24	50.2	15.7	34.4	2105	68.5%
MW-13	24-Sep-23	17.6	4	13.6	2280	77.3%
	3-Aug-24	19.6	4.95	14.7	2231	75.0%
MW-13A	24-Sep-23	62.5	16.3	46.2	2214	73.9%
	3-Aug-24	40	0	40	ND	100%
MW-19	22-Sep-23	68.4	14.1	54.3	2331	79.4%
	4-Aug-24	59.4	10.5	49	2396	82.5%
MW-20	25-Sep-23	81	15	66	2371	81.5%
	6-Aug-24	123.7	23.6	103.9	2365	84.0%
MW-20A	6-Aug-24	129.8	22.5	107.3	2395	82.7%
MW-21A	26-Sep-23	91.3	72.3	19	1109	20.8%

Table 4. Flow and steam fraction estimates from production separators during the (TFT®) measurements.

Well Code	Date of Measurements	Total Mass (t/hr)	Brine Flow (t/hr)	Steam Flow (t/hr)	Enthalpy (kJ/kg) from TFT	Steam Fraction
MW-01	25-Sep-23	177.6	134.4	43.2	1180	24.3%
MW-09	2-Aug-24	45	0.9	44.1	2713	97.7%
MW-09C	23-Sep-23	112.3	37	75.3	2071	67.1%
	2-Aug-24	138.2	71.1	67.1	1689	48.6%
MW-10A	23-Sep-23	36.7	11.4	25.3	2112	68.9%
	2-Aug-24	50.2	15.7	34.4	2105	68.5%
MW-13	24-Sep-23	17.6	4	13.6	2280	77.3%
	3-Aug-24	62.5	16.3	46.2	2231	73.9%
MW-13A	24-Sep-23	62.5	16.3	46.2	2214	73.9%
	3-Aug-24	Data not obtained				
MW-19	22-Sep-23	68.4	14	54.4	2331	79.5%
	4-Aug-24	59.4	10.5	49	2396	82.5%
MW-20	25-Sep-23	81	15.1	65.9	2371	81.4%
	6-Aug-24	123.6	23.2	100.4	2365	81.2%
MW-20A	6-Aug-24	129.9	22.5	107.4	2395	82.7%
MW-21A	26-Sep-23	91.3	72.4	18.9	1109	20.7%

Figure 2 graphically depicts the datasets in Table 1, Table 2 and Table 3. Variations are evident among the three datasets and may reflect a combination of factors, including multi-well discharge effects, production-induced changes in the reservoir, and differences associated with the measurement methods employed.

For some wells, notably MW-09, MW-19, MW-20, and MW-20A, the enthalpy and steam fraction values obtained during SGS commissioning appear lower than those derived from both the initial well discharge tests and the subsequent TFT® measurements. This observation suggests that the SGS commissioning estimates may have underestimated the discharge enthalpy and phase distribution for these wells. Potential explanations include limitations associated with the measurement approach used during commissioning, operational conditions at the time of measurement, and the complexities introduced by multi-well discharge. Further evaluation would be required to quantify the contribution of these factors.

The close agreement between the TFT® measurements and production separator data lends support to this interpretation. Furthermore, the observation is particularly noteworthy given that the wells are predominantly steam-producers and whose discharge characteristics would be expected to remain consistent with relatively high steam fractions and enthalpies. The higher values obtained from both the initial well discharge tests and the TFT® measurements therefore suggest that the SGS commissioning estimates may not have fully captured the actual discharge conditions of these wells.

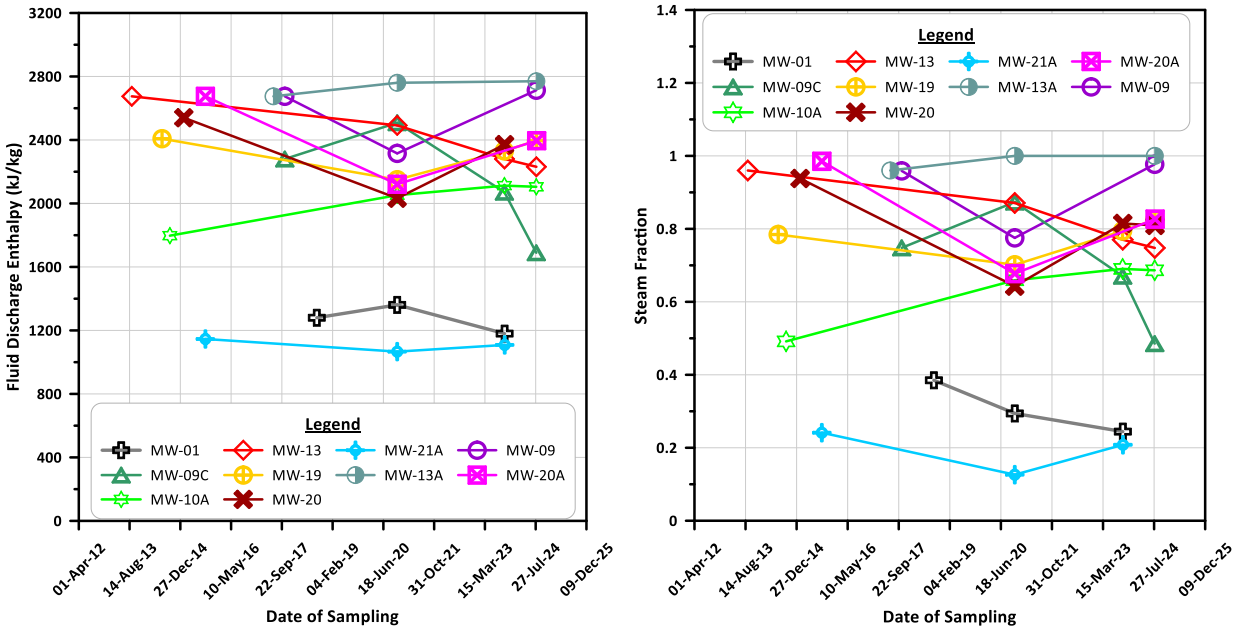


Figure 2. Enthalpy (left) and steam fraction (right) for the Menengai production wells during discharge tests, SGS commissioning and (TFT®) tests.

3.4 Geochemical Evidence of Reservoir Response to Production

Ofwona (2024) evaluated the performance of the Menengai reservoir after the first year of production and reported overall reservoir stability, although indications of enhanced boiling in some sectors and dilution effects in zones tapped by some production wells were observed. To further investigate production-related changes and their potential implications for well performance, temporal variations in chloride (Cl), silica (SiO_2), and non-condensable gases (NCG) were examined for selected wells.

The brine and steam samples were collected with the aid of a min-separator at the two-phase flow line, typically 10 to 15 m wellheads of the wells connected to supply steam to the power plant. Fluid sampling followed the protocols described by Arnórsson et al. (2006). Liquid (brine) samples were collected into plastic bottles and preserved appropriately for various analyses while gas samples were collected into typical Giggenbach flasks prepared with 40% /v NaOH solution and evacuated. Cl was analyzed using the ion chromatograph (IC) and by Mohr titration whenever the IC experienced technicalities. SiO_2 was determined using the UV-Visible spectrophotometer. CO_2 and H_2S were analyzed by titration using approximately 0.05M HCl and 0.001M mercuric acetate, respectively, while the other NCGs were determined using the GC. The results are depicted by Figure 3 and Figure 4.

Particular focus was placed on MW-09 and MW-13, which showed notable changes in enthalpy and/or mass flow during production. Additional evaluation was conducted for MW-09C and MW-19, which have remained

relatively stable in terms of discharge enthalpy and steam flow, to assess whether fluid chemistry trends were consistent across wells with differing production responses.

MW-09 and MW-13 initially discharged under near dry-steam conditions during well testing (Table 1). However, subsequent production monitoring indicated significant reductions in steam output exceeding 20 t/hr in both wells. Two TFT campaigns conducted in 2023 and 2024 captured these changes, with MW-13 monitored during both campaigns and MW-09 monitored during the 2024 campaign while on discharge.

Well MW-13 showed a progressive decline in both enthalpy and mass flow accompanied by decreasing Cl and SiO_2 concentrations that later approached relative stability. Similarly, MW-09 exhibited declining Cl and SiO_2 concentrations while maintaining discharge enthalpy characteristic of near dry-steam conditions despite a substantial reduction in steam output. Temporal variations in NCG concentrations showed a more pronounced response in MW-09, increasing progressively from approximately 2 wt.% during well discharge testing in 2017 to about 3 wt.% at the onset of production in 2023 and subsequently rising to more than 5 wt.% during the current monitoring period. In contrast, MW-09C, MW-13, and MW-19 showed only minor variations in NCG concentrations over the same production period.

Recent downhole assessments indicated downhole obstructions in MW-09 and MW-13, potentially resulting from calcite deposition or other wellbore-related restrictions. The progressive increase in NCG concentrations in MW-09, coupled with declining steam output and relatively stable discharge enthalpy, suggests a change in the relative contribution of feed zones supplying the well. The observations are consistent with reduced contributions from deeper, lower-gas feed zones and increasing influence of vapor-dominated feed contributions associated with the currently controlling zones. It is possible that downhole restrictions may have preferentially limited flow from deeper feeders, thereby increasing the relative contribution of fluids with higher gas contents.

The relatively stable wells MW-09C and MW-19 showed no significant changes in steam output or discharge enthalpy during the monitoring period except for an increase in MW-09C brine subsequently lowering its steam fraction (Figure 2). However, these wells exhibited declining Cl and SiO_2 trends similar to those observed in MW-09 and MW-13. Additionally, MW-09C showed a significant increase in brine flow during the 2024 TFT measurements of approximately 26 t/hr. Although these changes have not yet translated into measurable reductions in steam output or discharge enthalpy, the observed chemical evolution may indicate early changes in fluid contributions or reservoir conditions.

The combined interpretation of TFT measurements and temporal fluid chemistry trends suggests that changes in fluid composition may precede measurable variations in well performance. Consequently, geochemical signatures may provide early indicators of evolving well and reservoir conditions before significant changes become evident in production characteristics.

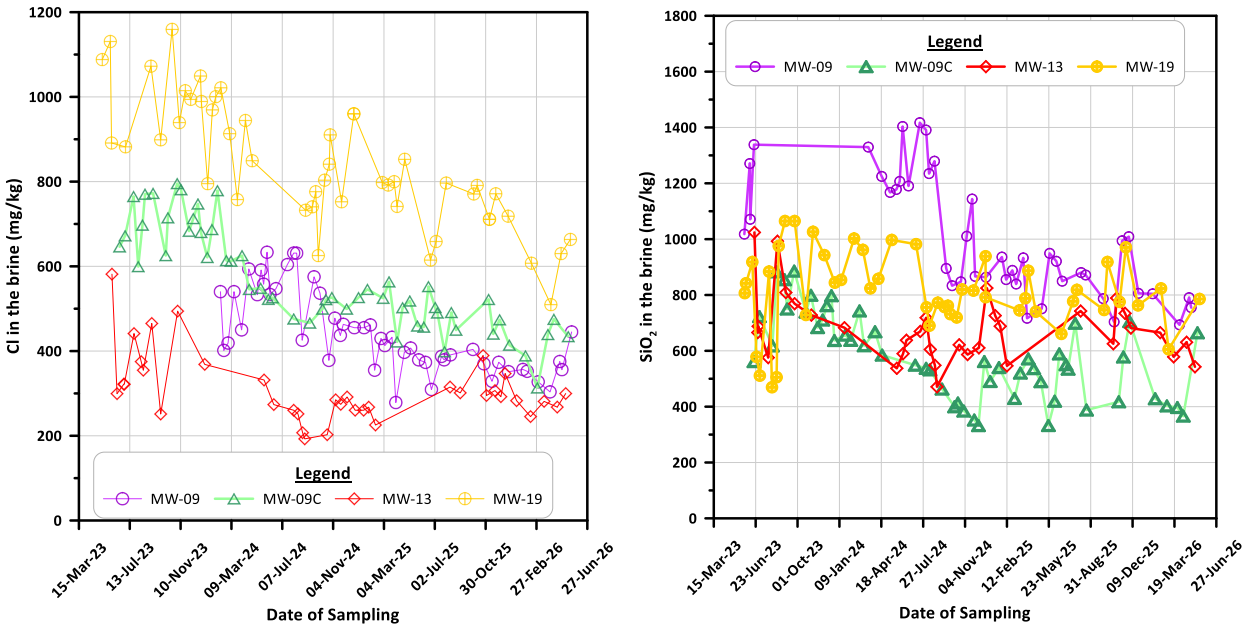


Figure 3. Temporal variations in Cl and SiO_2 in Menengai wells MW-09, MW-9C, MW-13 and MW-19.

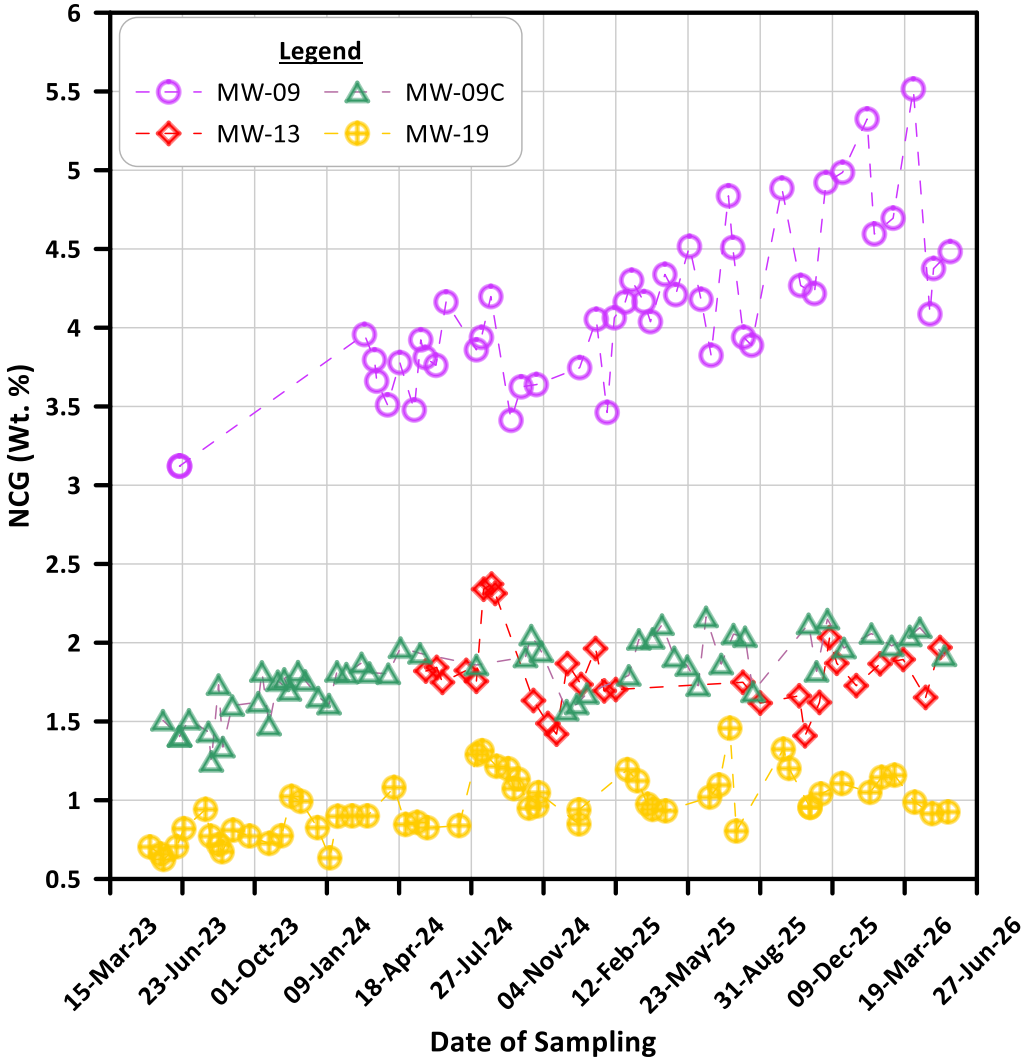


Figure 4. Temporal variations in NCG in Menengai wells MW-09, MW-9C, MW-13 and MW-19.

3.5 Implications for Well Performance and Reservoir Management

The application of TFT in Menengai provided valuable quantitative information on well performance through direct measurements of mass flow and discharge enthalpy that were consistent with separator measurements and observed production trends. The technique was effective in identifying changes in well output and evaluating temporal variations in production performance.

Fluid chemistry monitoring provided an important complementary line of evidence. Variations in Cl, SiO_2, and NCG concentrations corresponded with changes observed through TFT® measurements and improved understanding of processes influencing production behavior. Changes in fluid chemistry are widely recognized as sensitive indicators of reservoir processes such as boiling, fluid mixing, recharge, and changes in feed-zone contributions during geothermal exploitation (Arnórsson & D'Amore, 2000; Barragán et al., 2016; Lu et al., 2020). The declining trends in Cl and SiO_2 observed not only in wells showing measurable production changes but also in relatively stable wells suggest that chemical evolution may precede observable variations in mass flow or discharge enthalpy. These observations highlight the value of routine geochemical monitoring as a reservoir surveillance tool and support the integrated use of production and geochemical data for early detection of evolving well and reservoir conditions.

The progressive increase in NCG concentrations observed in MW-09 highlights the value of gas chemistry as an additional surveillance parameter. Unlike Cl and SiO_2, which showed declining trends across both stable and production-affected wells, the pronounced increase in NCG in MW-09 coincided with measurable reductions in steam output and may represent a more diagnostic indicator of changing feed-zone contributions or flow

restrictions. Monitoring temporal gas chemistry variations may therefore provide additional insight into evolving well conditions and complement conventional production monitoring approaches.

This observation has important implications for reservoir surveillance and management. Continuous geochemical monitoring may provide an early-warning mechanism for identifying wells undergoing changing reservoir conditions or feed-zone contributions prior to measurable production decline. Wells exhibiting persistent chemical trends may therefore warrant targeted investigation using TFT measurements and other diagnostic approaches.

The observations from Menengai are consistent with reservoir surveillance approaches increasingly adopted in geothermal developments worldwide, where production data and fluid chemistry measurements are interpreted jointly to improve understanding of reservoir response to exploitation and support proactive management decisions (Barragán et al., 2016; Lu et al., 2020). The integration of these complementary datasets enhances the ability to detect evolving reservoir conditions, identify well performance issues, and optimize monitoring and intervention strategies.

The observed increase in NCG concentrations in MW-09, together with evidence of downhole obstructions and declining steam output in some wells, warrants further investigation into the role of mineral deposition processes, particularly calcite scaling, as a potential contributor to well-performance decline.

The findings of this study demonstrate that TFT® measurements and fluid chemistry monitoring provide complementary information on well and reservoir performance. While TFT® offers direct and reliable quantification of mass flow and discharge enthalpy, temporal variations in fluid chemistry may provide earlier indications of evolving well conditions, feed-zone redistribution, and reservoir response to production. The integrated application of these approaches therefore provides an effective framework for reservoir surveillance and supports proactive reservoir management.

4 CONCLUSION

The following deductions are made from available flow and fluid chemistry data.

- Results obtained from flow measurements using the Tracer Flow Test (TFT®) technique in Menengai showed good agreement with production separator measurements, confirming the suitability and reliability of the technique for determining well mass flow and discharge enthalpy
- Temporal TFT measurements indicated changes in production characteristics in some wells, including reductions in steam output and variations in discharge enthalpy. While some of the near dry-steam wells initially exhibited relatively stable characteristics during well testing, subsequent measurements during production showed evidence of evolving well behavior.
- The observed changes are interpreted to reflect combined influences of reservoir response to production and possible wellbore effects including flow restriction associated with mineral deposition or mechanical obstructions
- Fluid chemistry monitoring provided important supporting evidence through temporal variations in Cl, SiO_2, and NCG concentrations. In MW-09, NCG concentrations increased progressively from approximately 2 wt.% during discharge testing to more than 5 wt.% during production, suggesting changing feed-zone contributions and possible flow restriction effects.
- Declining trends in Cl and SiO_2 were observed not only in wells exhibiting production changes but also in relatively stable wells, suggesting that chemical evolution may precede measurable changes in well performance and may therefore provide early indicators of evolving reservoir conditions.
- TFT® and fluid chemistry monitoring provide complementary reservoir surveillance tools that support evaluation of well performance and detection of evolving reservoir conditions. While TFT® measurements directly quantify changes in mass flow and discharge enthalpy, temporal variations in fluid chemistry may provide earlier indications of changes in feed-zone contributions, well conditions, and reservoir response to production.
- The integrated application of TFT® and fluid chemistry monitoring approaches strengthens reservoir monitoring and supports informed reservoir management and operational decision-making, consistent with contemporary geothermal reservoir-management practices.

5 RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

- The TFT® technique should continue to be applied in Menengai and future geothermal developments because of its demonstrated accuracy and reliability in determining well mass flow and enthalpy
- TFT measurements should be incorporated into routine reservoir surveillance programs to facilitate identification and tracking of changes in well performance
- Continuous monitoring of fluid chemistry parameters, particularly Cl, SiO_2, and NCG concentrations, should be maintained as these may provide early indications of changing feed-zone contributions, evolving reservoir conditions, or wellbore restrictions.
- Temporal monitoring of NCG concentrations should be integrated into routine surveillance programs, as significant changes in gas content may provide additional evidence of evolving feed-zone contributions, flow restrictions, or changing reservoir conditions.
- Wells showing persistent temporal changes in chemical signatures should be prioritized for targeted TFT campaigns and further diagnostic evaluation, particularly where budgetary constraints necessitate optimization of monitoring resources.
- Additional investigations should be conducted to determine the causes of the observed downhole obstructions, including potential scaling and mechanical effects, and to quantify their impact on mass flow, enthalpy, and fluid chemistry. Improved understanding of these processes will support the development of targeted mitigation measures and enhance long-term reservoir and steamfield management.
- Continued long-term monitoring is recommended to improve understanding of reservoir evolution under sustained production.

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