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EDC Experience in Vapor Tracing

Maria Victoria M. Olivar, Danilo B. Dacillo, G.M. Aragon, M.C. Medardo, P.G. Lim, F.E.B. Bayon, L.F. Bayrante

Energy Development Corporation, Merrit Road, Fort Bonifacio, Taguig City, Philippines

olivar.mvm@energy.com.ph

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ABSTRACT

Proper management of oil or geothermal reservoirs requires tracing of fluid paths. In geothermal systems, the results of tracing dictate the measures that are put in place to counteract the drastic effect of injection returns, optimize injection well capacities and adopt appropriate production and reinjection well utilization strategies. Energy Development Corporation (EDC) has integrated in its resource management strategy the tracing of fluid flowpaths, especially between reinjection and production sectors. Most EDC production fields are still liquid-dominated, thus water-based tracers have been tested and utilized through the years. Tracers that have been tested in EDC operating steamfields, so far, include naphthalene disulfonate (NDS), sodium fluorescein, sodium benzoate, Iodine-125, and Iodine-131.

Continuous production has transformed some liquid-dominated reservoirs or production sectors into highly two-phase reservoirs, such that liquid-based tracers no longer become relevant. There is then the need to test vapor-phase tracers in producing fields where steam expansion has become very apparent, and where challenges/problems due to injection or cold water incursion occur.

Tritiated water and HCFC have been injected in two EDC production fields, on an experimental basis, and results were evaluated. Tritium breakthroughs have been observed in Leyte production wells from the injector, with tracer recovery and swept-volume calculated. HCFC, on the other hand, injected in Mt. Apo, only manifested a weak signal in the nearby thermal area (gas seepage). Tracer return quantification was not doable given the monitoring data available.

1. INTRODUCTION

The participation of the Philippines in the Coordinated Research Programme (PHI-13130) sponsored by IAEA on Validation of Tracers entails evaluation of tritium and hydrofluorocarbon as vapor tracers in Philippine settings. The research has as its main objective the establishment of the applicability of vapor-phase tracers to Energy Development Corporation's (EDC's) high temperature geothermal environments.

There are EDC-operated producing geothermal fields in the Philippines which are developing thick steam zones. In these types of reservoirs, water-based tracers such as NDS, sodium fluorescein, I-125, I-131 become inapplicable. The collaboration with IAEA and other member-states came at an opportune time to test and develop vapor tracers for reservoir monitoring and management.

Vapor tracers are volatile, and thus require to be soluble at surface conditions (certain T and P) such that it remains dissolved in the injectate (i.e. brine) while being introduced in the well. This will ensure that the tracer reaches the reservoir in liquid form. Upon encountering changes in pressure or temperature, the tracer will fractionate to the steam phase once the injectate boils since gas tracer has the greatest affinity to steam. Since it is volatile, most of the tracer will then concentrate in the steam phase upon the first stage of boiling. It is expected that lower concentration of tracer is left in the subsequent steam fractions formed. Thus, the final destination of the injectate will no longer be traceable in this scenario.

To avoid premature separation with the medium, the tracer should have the same boiling point as the medium. This requirement makes tritium the best tracer in a highly two-phase to vapor environment. There are instances where gas tracers separate earlier than the flashing of the medium. This could happen with hydrofluorocarbons (HFC), thus it is imperative that the monitoring program should take this into consideration.

Tritium and HFC were two of the tracers chosen to be studied for the programme. Tritium was injected in the Tongonan sector of the Leyte Geothermal Production Field and was monitored for breakthrough in the surrounding wells. HCFC was injected in Mindanao Geothermal Production Field and likewise monitored in neighboring areas. The results of these injection and monitoring programmes will be discussed in the paper.

2. TRITIUM TRACING AT LEYTE GEOTHERMAL PRODUCTION FIELD

The tritium program was conducted in Leyte Geothermal Production Field, Philippines (Fig. 1), where there is substantial formation of steam in the reservoir attributed mainly to continuous fluid extraction. In one of the sectors, the reinjected brine/condensate is finding its way back into the production area and causing a substantial decline in the field's steam production. The wells affected are mainly highly two-phase in discharge character. The tracer test conducted was expected to address the concern on determining the path through which the cooler fluids are flowing back into the production zone, apart from the basic objective of evaluating the applicability of vapor tracer in other EDC's producing fields.

Tritium was selected since this has been proven as a vapor tracer in other geothermal fields such as in Indonesia and The Geysers (Abidin et al., 2004; Adams, 2001). Tritium was injected in injection well 1R8D (blue line, Fig 2) used for brine/condensate injector in Tongonan-1 sector. Monitor wells were selected in and around the injector well with priorities on those which showed chemical breakthroughs suspected to be caused by the injection in 1R8D. Monitor wells include: 101, 103, 105D, 109D 202, 209A, 212, 214, 2R2, and 2R3D (red circles, Fig. 2).

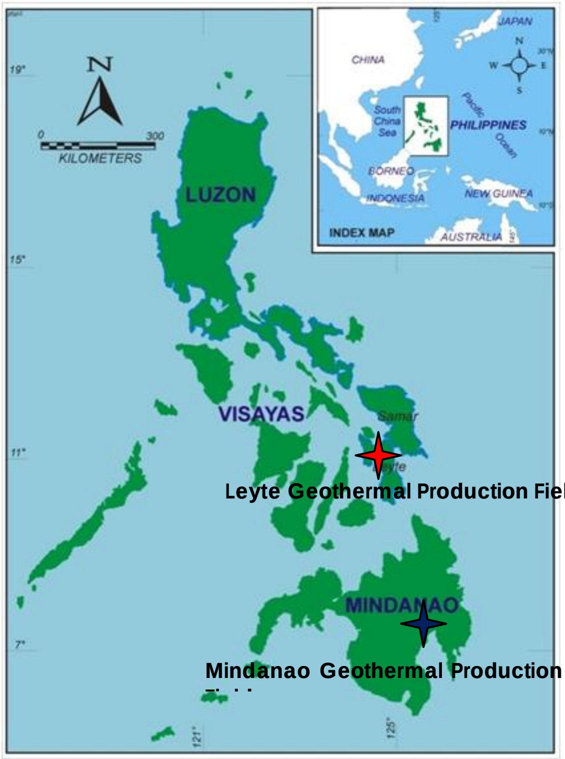

Figure 1: Location Map of the two EDC fields where the tracer tests were conducted.

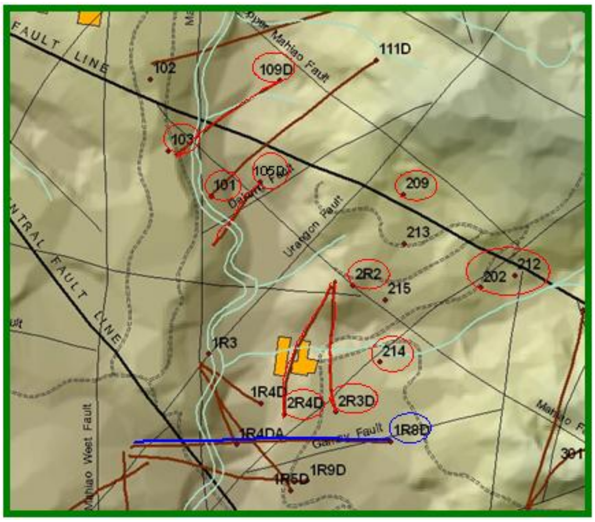

Figure 2: Tracks of wells monitored during the test (red lines). Blue line indicate track of well where tracer was injected.

All of the wells monitored were discharging almost pure steam, although some still had minor water fraction (i.e. 2R3D with H<2000 kJ/kg). Routine geochemical monitoring indicates the incursion of reinjected fluids from 1R8D since early 2000 when this well was used as a sole injector well. Well 1R9D, an adjacent reinjection well was commissioned in 2004 to share the bulk of reinjection at 1R8D (Dacillo, 2006) and hopefully reduce the effect of brine incursion in Tongonan sector. During the tracer testing, partial load was shared with the deeper 1R9D as injection well; the load at 1R8D was 52 kg/s, while 87 kg/s was injected at 1R9D.

2.1 Methodology and Sampling Regime

Ten curie (10 Ci) of tritiated water was injected in well 1R8D on July 12, 2006. Figure 3 illustrates the schematic diagram of injection set-up; the tracer was injected via a bypass line. Two vials of tritiated water were placed in two crusher assembly valves. The brine coming from the separator vessel was diverted through the bypass. After 2 minutes of brine flow, the valve was turned ensuring that the vials were crushed. Continuous flushing (~30 minutes) with brine via the bypass line ensured the transport of tritium down the well.

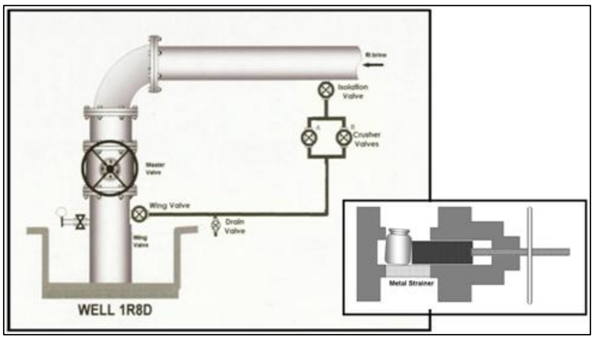

Figure 3: Schematic diagram of injection set-up.

For wells discharging purely steam, condensate samples were collected using a stainless steel cooling coil (condenser equipment) via weber separator connected to sampling points along the two-phase lines (Fig. 4). Wells with water component were sampled for steam condensate as well as for separated water.

Figure 4: Sampling set-up adapted for tritium collection in highly two-phase wells.

Samples were collected from the monitor wells two weeks prior to injection for baseline determination. A thrice-weekly sampling monitoring program was implemented for the first two months; which was reduced to once per month sampling thereafter. Analysis for tritium was done at Philippine Nuclear Research Institute (PNRI) and CAIRT in Jakarta. Data evaluation included mass recovery calculation and reservoir cooling prediction using available softwares (i.e. ICEBOX, Anduril 2.3).

A tandem NDS tracer test was also conducted in the same injector well, with monitor wells concentrated on the "watery" production wells. The results are herewith compared with tritium breakthroughs.

2.2 Results

Among the ten wells monitored for a year, four wells (W2R3D, 2R4D, 214, 202) yielded positive results for NDS tracer (Fig. 5) while three wells showed tritium returns (Fig. 6). Among the production wells nearest to 1R8D, wells 2R3D and 2R4D showed NDS breakthrough 19 days after injection, well 214 manifested breakthrough 40 days after injection, and well 202 breakthroughs occurred much later at 131 days.

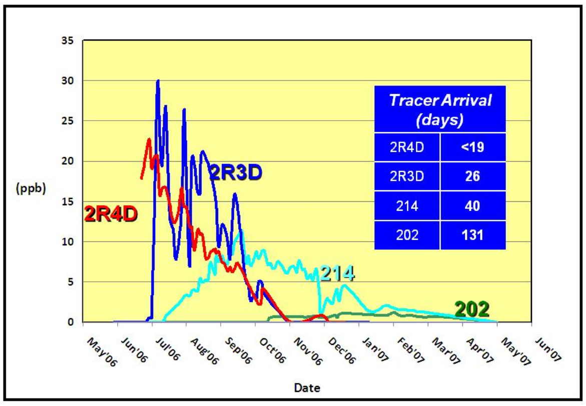

Figure 5: Wells showing positive NDS breakthrough.

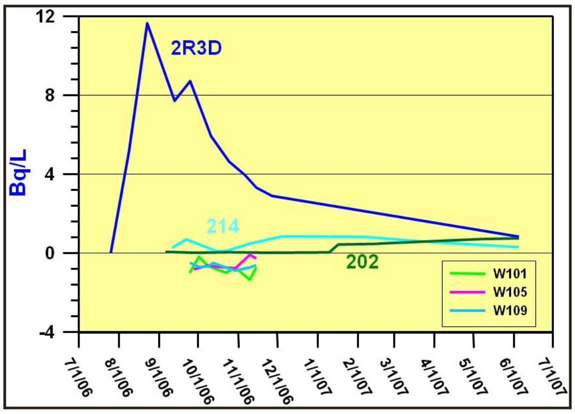

Figure 6: Wells showing tritium breakthrough.

The wells that showed NDS breakthrough also showed positive returns with tritium; and among the wells monitored these were the only wells which gave tritium breakthrough. Tritium in well 2R3D appeared 28 days after injection; while it appeared in wells 214 and 202 61 and 189 days after, respectively. The vapor-rich wells in the northern sector (i.e. 101, 105D, 103, 109D) did not show positive manifestation of tritium even after six months of monitoring, thus analysis in these wells was not extended after December 2006.

Tritium and NDS returns in 2R3D and 2R4D exhibit sharp breakthrough at the start and gradually tapered off through time. This is opposed to the relatively semi-broad nature of the curves for wells 214 and 202.

Processing of tritium and NDS data was done using Anduril software developed by G.E. Maggio (freeware distributed among CRP member-states)). Figure 7 shows the processed curve for well 2R3D for both tritium and NDS tracers. The plots show that there are two pulses of tritium and NDS that entered the well. Well 214 also showed two pulses of tritium breakthrough, while only one pulse was detected for NDS (Fig. 8). Reduction of tritium and NDS curves in well 202 showed only one pulse for both (Fig. 9).

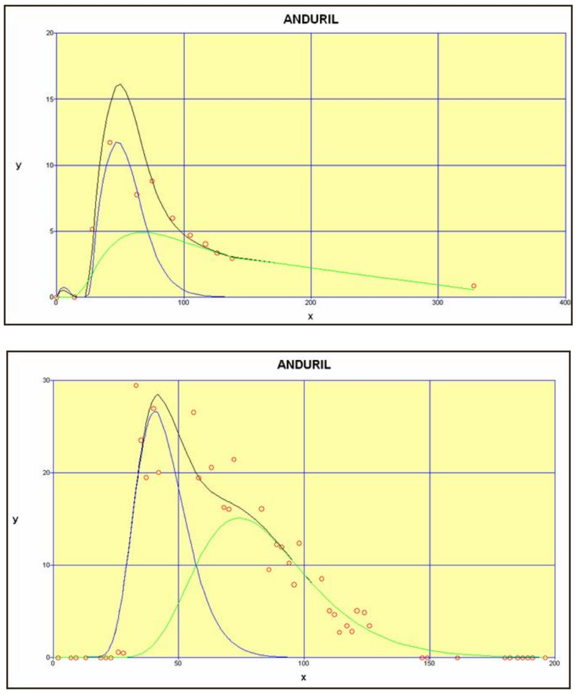

Figure 7: Processed curve for well 2R3D. Top plot is for tritium tracer while bottom plot is for NDS.

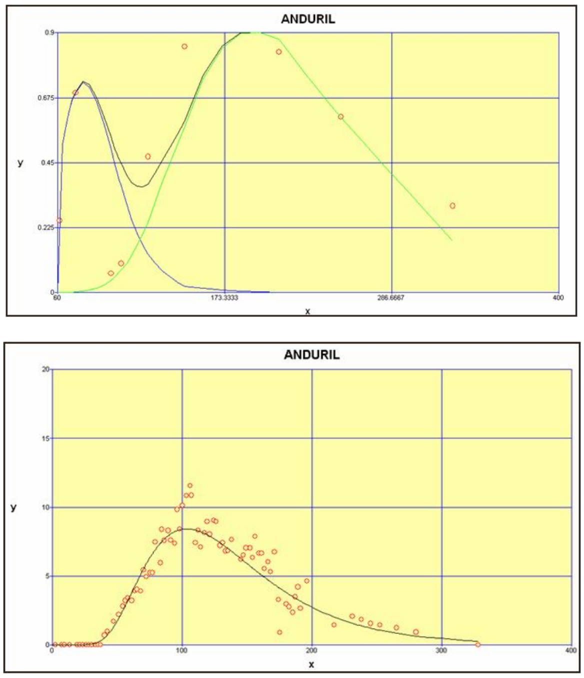

Figure 8: Processed curve for well 214. Tritium – top; NDS – bottom.

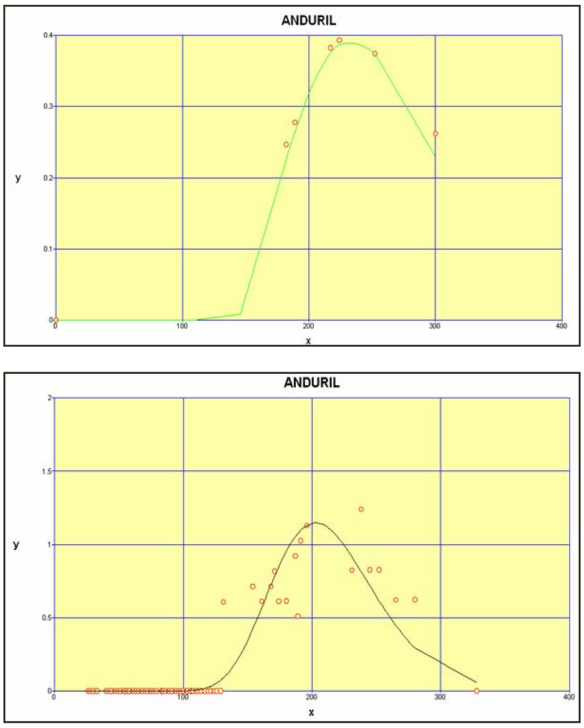

Figure 9: Processed curve for well 202. Top plot shows tritium results, while bottom plot is for NDS results.

Further, recovery yield for both NDS and tritium were different. Well 2R3D yielded 0.4% tracer recovery of tritium, while W214 and W202 both gave a yield of 0.1%. NDS recovery, on the other hand, yielded 1.3% for well 2R3D; while well 214 and well 202 yielded 0.2% and 0.1%, respectively. Based on the results, NDS recovery was higher by almost 100% for wells 2R3D and 214, while recovery was the same for well 202, the well farthest from the injector.

2.3 Tracer Movement

Structural correlation indicates that the main conduit of the tritium and the NDS from 1R8D to the production wells is the Sambaloran Fault. Figure 10 shows the schematic of the fluid path bearing the tracer injected. By first order of approximation, it is logical to think that wells 2R3D/2R4D would yield the tracer first since these are situated nearest the injector well than wells 214 and 202. It would then follow that the tracer recovery would diminish from well 2R3D towards well 202.

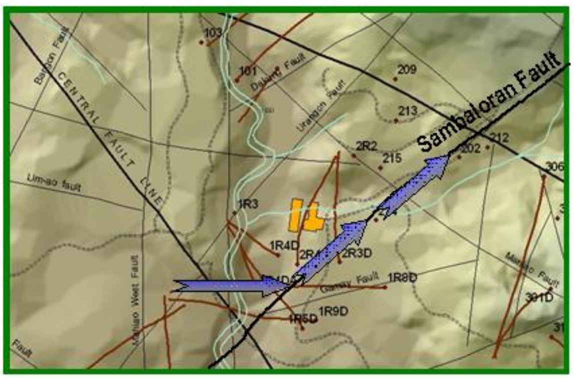

Figure 10: Wells showing NDS breakthrough.

Figure 11 shows the cross section of the wells where tritium and NDS were detected showing the structures intersected by these wells. As shown, Sambaloran Fault is the only common structure intersected by wells with positive breakthroughs. Thus, this is more likely the conduit of the tritiated brine.

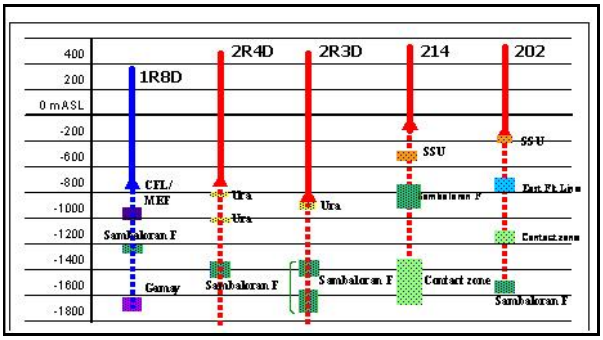

Figure 11: Cross section of wells showing structures intersected. Sambaloran Fault was intersected by all wells shown.

The low tracer recovery in the wells monitored indicates that injection in 1R8D was already optimized at the time of the test, such that there was minimal flow of the reinjected fluids back to the production area in Tongonan sector. The partial transfer of bulk load in well 1R9D could have helped reduced the incursion of flow in the nearby production wells.

Despite the incursion of the injected fluids, albeit at low percentage, the production well fluids still have high enthalpy. This indicates that the 160^{o}C brine incursion in Tongonan sector is heated up before it enters the other wells, thus not affecting the enthalpy of the affected fluids (i.e. 202 – 2056 kJ/kg; 214 – 2691 kJ/kg). This occurrence is not detrimental to the affected wells since the steam zone is not collapsing. If the flow of a lower temperature fluid persists, however, the steam zone may possibly collapse. In reaction to this, well 1R8D was decommissioned in late 2006 and the load was fully transferred to the deeper 1R9D reinjection well (Dacillo, 2007).

The absence of tritium in the northern wells (i.e. 105D, 101, 109D) could indicate the absence of reinjection incursion from 1R8D during the testing period. The lower load injected at 1R8D could have lessened or negated incursion at the northern wells. At the reduced load in 1R8D, the movement of the fluids via Sambaloran Fault is preferred over the movement towards the Mahiao East Fault or towards the north, as indicated by the tracer test. Further, the current hydrological mold of the area favors southern movement of fluids rather than to the north.

The 1R8D brine incursion observed in the northern wells in the previous years (since 2001) was due to the sole usage of 1R8D as injection well. The low gas concentration in the affected wells (i.e. *105D, 101, 110D*) is more likely a result of dilution of the in-situ gas in the well with the degassed brine. During this period, the wells still discharged high enthalpy fluids, which means that the effect of the brine from 1R8D ever since is not collapsing the steam zone, rather the brine is re-heated at depth, flashes upon entering the well and dilutes the in-situ fluids. The partial transfer of reinjection load to 2R4D on November 2002, caused the chemical recovery of northern wells such as increase in CO_2td (Dacillo, 2003).

The two pulses seen in wells 2R3D and 214 imply that the first pulse (part of the returning 1R8D-injected brine) passed through the Sambaloran Fault, and the second pulse which occurred at a later period could mean that the tracer traveled with the rest of the 1R8D brine to the deeper parts of the reservoir, again passed through other structural conduit(s) to appear in these wells, with flashing occurring inside the wells.

A total of 1.2% tritium was detected in the steam samples of three monitor wells. Given that the distribution coefficient of tritium is 1, it can be assumed that 1.2% was also present in the residual brine of these production wells, accounting for a total of 2.4% of the total injected tracer. The remaining ~97% of the tritiated brine may have travelled deeper into the reservoir. Taking the results of the tritium test further, it may be interpreted that the reservoir, although already persistently steam dominated in the upper horizon as tapped by the production wells, still has an adequate liquid in the deeper parts (Dacillo, 2003).

The cooling trend observed in well 202 suspected to be caused by reinjection in Tongonan in the previous years is not validated by the result of the tracer conducted during the recent tracer test. The minimal tritium recovered reflects the negligible and even absence of, flow of the fluids towards the wells monitored from 1R8D. The reduced reinjection load in 1R8D during the test and onwards may have significantly lessened the adverse effect of injection returns to the production wells.

3. CHLOROFLUOROCARBON TRACING AT MINDANAO GEOTHERMAL PRODUCTION FIELD

Aside from tritium, hydrofluorocarbon gas (HFC) was also identified as a possible vapor tracer in a geothermal reservoir. Among several halocarbons tested as tracer in geothermal environments, R-134a seems to be superior among the list (Adams, 2001). Unfortunately, during laboratory optimization, R-134a peak was not detected. Thus, another species of HCFC was considered and tested in the laboratory. Figures 12-14 show the chromatograms for the blank run, with R-134a and with the HCFC. As seen in the figures, the species was detected during the scanning, whereas no peak was scanned for R-134a. Although R-134a would have been the ideal tracer to test, given that useful information on the tracer are already available from published works, laboratory instrument limitations forced the shifting from R-134a to HCFC where limited information are available, especially on its properties as vapor tracer.

3.1 Injection at KL-4RD, Mt. Apo Geothermal Production Field (MGPF)

Similar to the Leyte test, and based on instrumentation constraints, the main objective of the tracer test here was to determine whether or not halocarbon can be utilized as a tracer in a vapor-dominated geothermal reservoir. The test at Mindanao Geothermal Production Field (MGPF) was to qualitatively establish hydrological connections between and among wells through the use of HCFC. Quantification of the tracer could not be done during the test conducted since its detection limit using the ECD-GC was not established. The species' occurrence via a peak detected was used to establish, albeit qualitatively, a positive breakthrough.

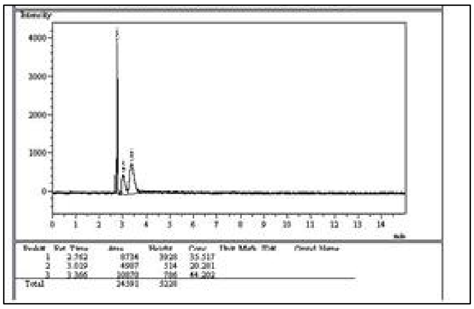

Figure 12: Chromatogram of a blank run

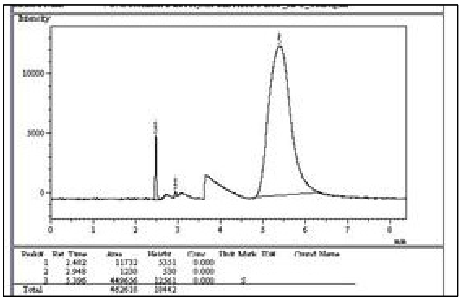

Figure 13: Chromatogram with HCFC injected

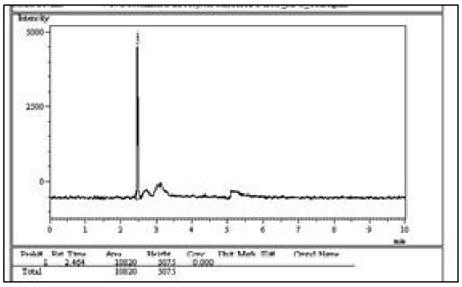

Figure 14: Chromatogram of run injected with R-134a

Figure 15 shows the map of MGPF and the tracks of the well drilled. Encircled is the area where the tracer injection and monitoring was conducted. HCFC was injected in well KL-4RD and monitored in wells APO-1D, APO-2D, SK-1D, MD-1D, Adtapan steam vent/seepage and Mandarangan fumarole. The fumarole and gas vents were chosen as monitor points since these are located near the injection well, and their established hydrological connection to the production fluid make them good points for monitoring.

One hundred eight (108) kgs of HCFC was injected in KL-4RD on August 17, 2007. This amount was patterned after the injection in SE Geysers (Beall, et al., 1994). Due to lack of pertinent information on the HCFC species (i.e. instrument detection limit, minimum detectable concentration, etc.), it was assumed that this amount will be sufficient for the MGPF test. The sector where injection was conducted has a reservoir temperature of ~275^{o}C; no rapid thermal degradation of the tracer was assumed at this temperature.

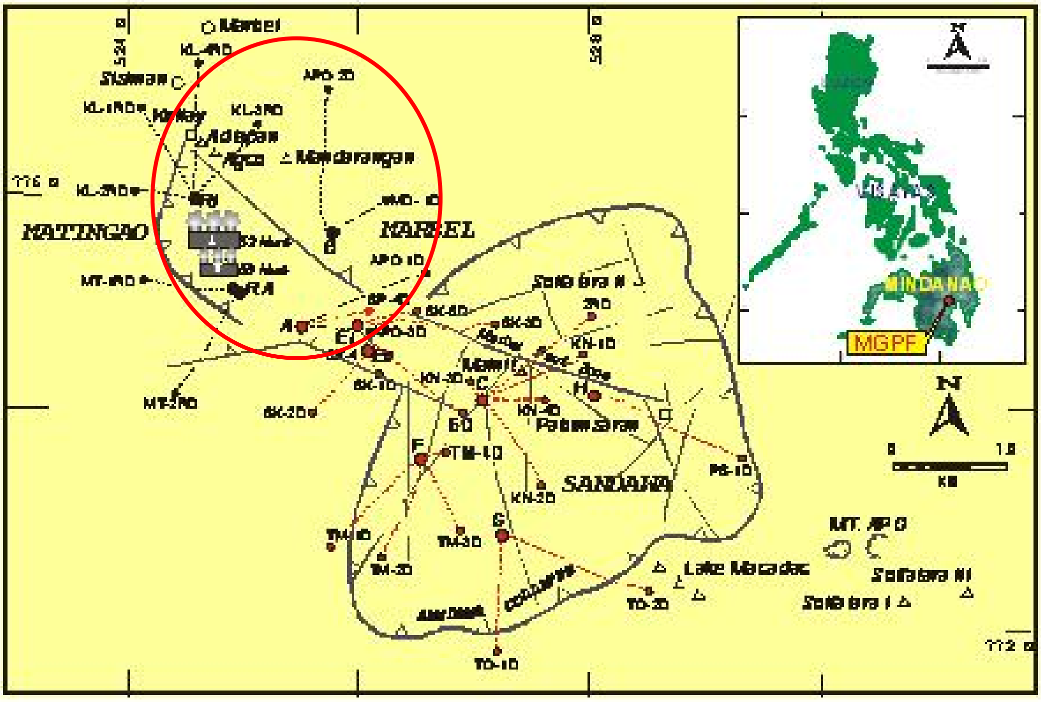

Figure 15: Map showing the different wells drilled in Mindanao Geothermal Production Field. The red circle indicates the sector where the R-22 tracing was conducted

The injection set-up as shown in Figure 16 was likewise based on the experiences and practices of other workers (Adams, 2000). The tracer was introduced via the wing-valve of the well at vacuum wellhead pressure (WHP) to ensure that the tracer reached the reservoir upon mixing with the cold condensate being injected. Fortunately, KL-4RD was being utilized as a cold injection, thus the vacuum wellhead condition.

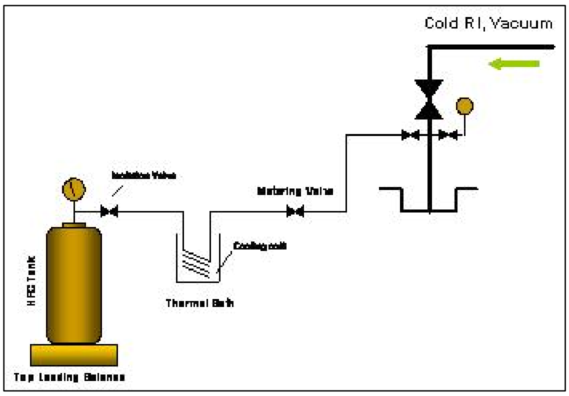

Figure 16: Schematic diagram of the field inejction set-up at well KL4RD

The injection of tracer to well KL-4RD lasted around two hours. Sampling for background data was conducted three days prior to injection. Samples were collected in the monitor wells on a daily basis for two weeks and thrice weekly for the remaining two months. The tracer was analyzed using the ECD-GC. Conventional gas sampling was applied; CO_2 and H_2S gas were scrubbed off from the sampling via NaOH to eliminate the interference with the halocarbon.

Sampling at the monitor wells and thermal areas were conducted immediately after the injection to ensure that the tracer injected would be captured and measured.

3.2 Results and Discussion

Figures 17 and 18 show the blank runs and the run with the tracer standard gas, respectively. Among the six points (production wells and gas seepages) monitored for breakthrough, only the October 5 sample for Mandarangan showed signal of the species (Fig. 19). The peak appears at ~6 mins for the standard run. The tracer peak at the Mandarangan sample appeared at ~6.5 mins. This is the only peak that registered among the monitoring points, even after 2.5 months of sampling and analysis.

Several conjectures could account for the absence of the HCFC in the monitor wells. These include: (1) insufficient amount injected in KL-4RD; (2) the species could have almost completely degraded before it reached the monitor wells; or (3) the tracer could have prematurely fractionated from the injectate and dispersed in the reservoir. Previous NDS tracer test conducted in this area already proved the connection between the injector well and the monitor wells.

Its detection in the Mandarangan thermal area and not at the farther monitor wells (i.e. APO-1D, MD-1D), indicates that the tracer was not able to travel very far. Further, the vaporized HCFC could have found other conduits to pass through, which were not intersected by the monitor wells.

Uncertainties or lack of knowledge in the properties of the species injected could have contributed to the nil recovery. The thermal stability is not well defined, thus at the reservoir temperature of ~270^{o}C, the species could have disintegrated/decayed totally. Similarly, partitioning to steam/water phase is unknown at the reservoir temperature. The presence of NaOH in the sampling bottle could also have a reactivity concern with the HCFC; thus minimal recovery at the start may have occurred. All these, which most likely were not properly addressed by the sampling and monitoring program, could have lead to the tracer not being captured along the monitoring points.

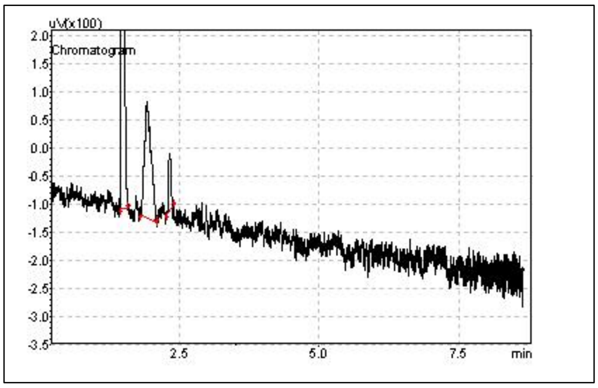

Figure 17: Blank run (Analysis date is 10/13/2007)

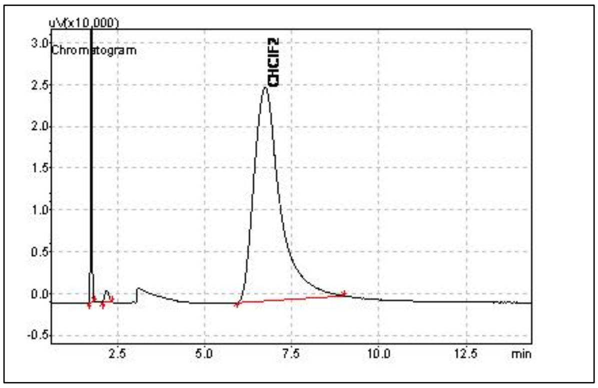

Figure 18: HCFC run (10-13-2007 analysis date)

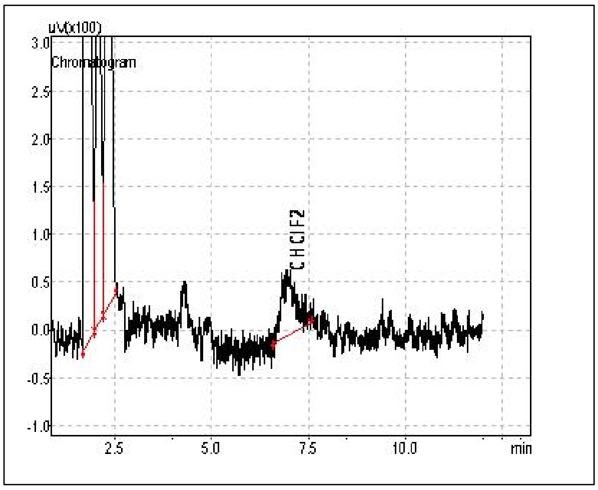

Figure 19: Run of Mandarangan sample (10/5/2007)

4. CONCLUSIONS

The injection of tritium in LGPF has indicated the applicability of tritium as vapor tracer, as these have been detected in three wells and the flow of the tritium-bearing fluids was tagged. The low tracer recovered indicates that the injection at 1R8D is already optimized such that minimal brine flow rapidly returns towards the production area. Consequently, majority of the injected brine is dispersed deeper into the reservoir, where it provides much needed pressure support, at the same time allowing for reheating of the injectate.

In as much as the objective of the tritium testing is concerned, it was demonstrated that tritium can confirm the fluid flowpaths within the reservoir.

In comparison with tritium, the chlorofluorocarbon injected in Mindanao Geothermal Production Field did not yield convincing results. The lack of breakthrough could be mainly attributed to the insufficient knowledge/information regarding the tracer as well as lack of laboratory instrument optimization; the field trial failed to address these issues properly.

Overall, the experiment complemented the limited understanding on vapor tracers. Although only tritium gave a positive outcome, the overall results appear encouraging; efforts to test and evaluate other vapor tracers applicable to two-phase geothermal reservoirs should be pursued further.

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