PRELIMINARY ASSESSMENT OF THE GEOTHERMAL SIGNATURE AND ECBM POTENTIAL OF THE HUNTLY COALBED METHANE FIELD, NEW ZEALAND

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SUMMARY – The Huntly coalfield is being prospected as a coalbed methane (CBM) play. Five exploration wells and six production appraisal wells were drilled between late 2005 and mid 2007. A number of well tests were conducted (completion, interference and production testing) including measurement of the stable downhole temperature gradients. The temperature data have shown that the field has a gradient of 52 to 55 $^{\circ}C$/km which corresponds to an average natural thermal flux of ≥ 100 mW/m^2. It is believed that the Mesozoic-age greywacke basement acts as a constant pressure boundary affecting the water and gas production in the overlaying coal seam in areas where coal measures directly overlay the basement. The Na-K, K-Mg geothermometers imply a deep geothermal reservoir temperature of more than 90 $^{\circ}C$. This can be related to the close proximity (within 120 km) of the Huntly coalfield to the Taupo Volcanic Zone (TVZ).

Temperature gradients along with other reservoir data have been used to create a three-dimensional numerical model of the Huntly coalfield CBM play. The model is used to forecast gas and water production under different development and stimulation scenarios. The model is also being used to investigate enhanced coalbed methane (ECBM) recovery using carbon dioxide, nitrogen or other possible combustion-flue gas compositions.

1. INTRODUCTION

Natural gas (methane) is an important source of clean fossil-fuel energy that is experiencing a growing demand in New Zealand. At the same time there is a reduction in supply from existing fields. This has prompted the investigation of unconventional resources such as coalbed methane (CBM) also known as coal seam gas (CSG).

CBM exploration is booming in many developed countries (Australia, Canada, China, India, United Kingdom and the USA) and currently CBM accounts for about 10 % of the USA natural gas consumption and 9 % of the natural gas reserve.

Production of CBM may be economically viable from the deep low rank coal deposits that are abundant in New Zealand. These can be difficult to mine and are prone to spontaneous combustion upon exposure to air.

Several fields have been investigated for their potential for CBM production in New Zealand including Ohai, Maramarua, Huntly and other fields.

Coal is the source and the reservoir for methane (CH_4). The gas is physically attached (adsorbed) to the surface of the coal as a consequence of the high pressure associated with deep reservoirs. Once the pressure is decreased from the coal through dewatering using a downhole pump, the methane will desorb from the coal and move toward the production well through macro, meso- and micro fractures in the coal, called coal cleats. Commercial CBM wells can range from less than 50 to 1200 m (or sometimes more) in depth. CBM wells are relatively cheaper to drill compared to oil, gas and geothermal wells. The common production casing size is 7”. The main component of completion is the cost of the stimulation programme to improve the well productivity. CBM wells are completed by either open hole with under reaming or cavitations. The most popular completion technique is hydraulic fracturing using proppant (sand).

A key component for modelling CBM reservoirs is down hole temperature, but little is known about this in most fields. In the Huntly coalfield, down hole stable temperatures and water geochemistry have shown a strong geothermal signature. The geothermal signature has been quantified and it’s implicates are given in this paper.

This research also details the development of a computer model for the simulation of production of CBM and enhanced recovery of CBM (ECBM).

2. GEOLOGY

The Huntly coalfield (Fig 1) is situated within the Waikato coal region which is comprised of thirteen coal areas. The coal measures are typically around 50-100 m thick with claystone and siltstone dominating the lithology. Three main coal seams are found in the Huntly coalfield. These seams are (from top to bottom): the Ngaro, Renown and Kupakupa respectively (Fig 2). The coal at Huntly is subbituminous A to C in rank.

The field is currently being developed by Coal Bed Methane Ltd under the petroleum exploration permit no. 38605 (Fig .1).

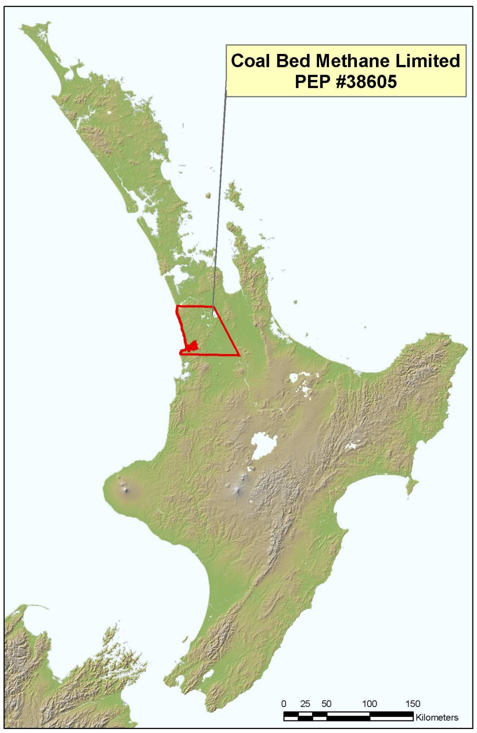

Fig. 1 The location of PEP 38 605 which encompasses the Huntly coalfield. .

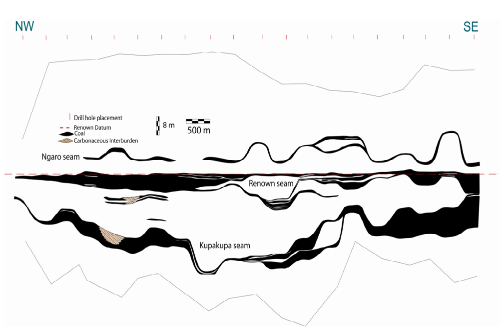

Fig. 2 NW-SE cross section through the Huntly coal field showing the Ngaro, Renown and Kupakupa coal seams.

The Huntly coalfield lies within the Waikato geothermal region which has a significant number of low temperature geothermal springs (Fig. 3). About 36 thermal springs and shallow geothermal wells have been identified (Thain et. al., 2006). Measured temperatures ranging from 23 to 93 $^{\circ}C$ have been reported and several direct use applications currently exist in the area mainly involving swimming pools and a small greenhouse. There is a relatively high geothermal gradient in the area (Thain et. al., 2006) with temperature increasing from east to west as the HCO_3/Cl generally increases from west to east (Reyes et al., 2005). However, there is not a thorough understanding of the permeability structure of the field, because geothermal utilisation tends to be restricted to areas with natural springs or where shallow ground water drilling has encountered hot water.

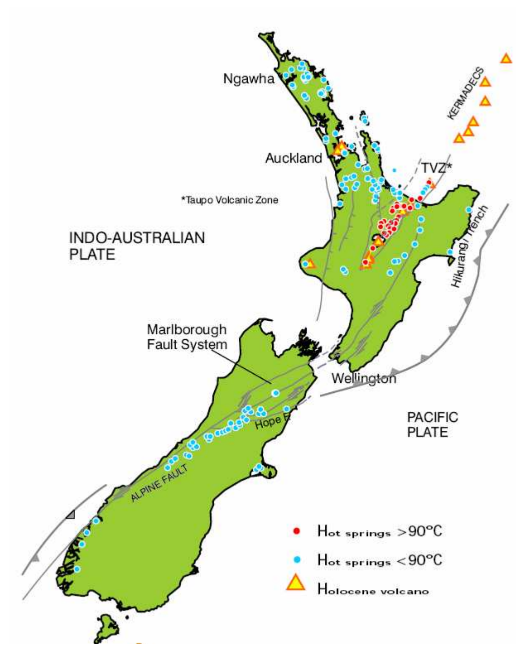

Fig 3. Shows the location of New Zealand low temperature geothermal resources (from GNS, 2007).

3. GEOCHEMISTRY

There are no natural thermal springs in the Huntly coalfield area, but water samples were taken from two wells (Jade-1 and Mimi-1). These wells are cased to 406 m and 411 m respectively and were sampled after extended period of production to collect representative water quality samples (Table 1).

The produced water tested negative to sulphate reducing bacteria (SRB). SRB can degrade the produced gas quality through the biological conversion of sulphur in the coal into H_2S and generates enzymes that cause a rapid corrosion to steel equipments (casings, pipes, pumps etc.) when encountered in CBM developments.

The gas composition, given in Table 2, shows high methane content, and no hydrogen sulphate was detected. From isotopic gas analysis, it was determined that the methane is of biogenic origin (Mares and Moore, 2007; Butland and Moore, 2007).

Cons. ppm	Jade-1	Mimi-1
pH	7.3	7.2
Cl^-	5300	5500
SO_4^{-2}	2	-----
K^+	38	-----
Na^+	3000	2900
B	3.8	3.7
Mg^{2+}	53	55
F^-	0.35	0.39
Al	0.02	0.02
Fe	21	27
Cu	0.023	0.036
Zn	0.007	0.009
NH_3	16.2	18.1

Table 1. Deep water chemistry for Huntly.

Gas	basis	Mean	Stand. Dev.
CH_4	%	98.43	1.77
CO_2	%	1.52	1.77
C_2H_4	ppm	0	0
C_2H_6	ppm	338.72	280.38
H_2	ppm	154.9	403.94
O_2	%	0	0
N_2	%	0	0

Table 2. Mean Gas composition (from 41 measurements) from the Renown and Kupakupa coal seams (Moore and Twombly, 2006; Mares and Moore, 2007; Butland and Moore, 2007).

Using the data from Table 1; The K-Na Giggenbach (1988) geothermometer indicates a reservoir (basement) equilibration temperature of 108 $^{\circ}C$.

$$T = \left[\frac{1390}{\{Log(Na/K) + 1.75\}} \right] - 273.15 \qquad (1)$$

The K-Na Fournier (1979) geothermometer indicates a temperature of 87 $^{\circ}C$.

$$T = \left[\frac{1217}{\{Log(Na/K) + 1.483\}} \right] - 273.15 \qquad (2)$$

The K-Mg Giggenbach (1988) geothermometer indicates a temperature of 78 $^{\circ}C$.

$$T = \left[\frac{4410}{\{14 - Log(K^2/Mg)\}} \right] - 273.15 \qquad (3)$$

With an average temperature of about 90 $^{\circ}C$ this result is consistent with geothermometer temperature estimates of the Naike hot springs (Simandjuntak, 1983) located about 17 km NW of Huntly.

The water type is sodium chloride water with high *Cl/B* ratio suggesting that the hot water moves through sedimentary rocks.

Stable temperature profiles (temperature vs depth) measured through the casing for four vertical wells at Huntly (Jasper-1, Baco-1, Kaiser-1 and Groover-1) are shown below in Figs. 4 to 7.

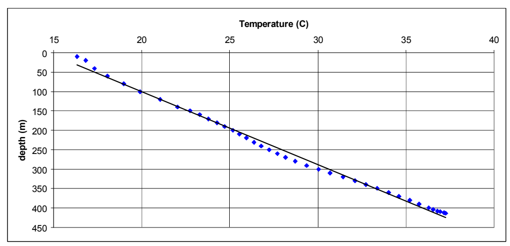

Fig 4. Temperature vs depth at Jasper-1.

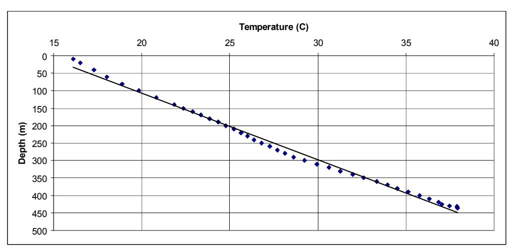

Fig 5. Temperature vs depth at Baco-1.

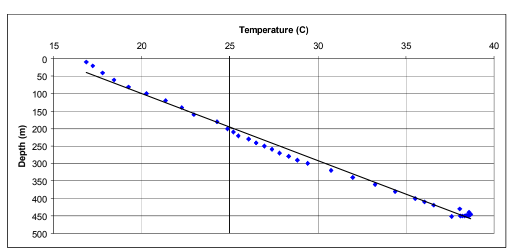

Fig 6. Temperature vs depth at Kaiser-1.

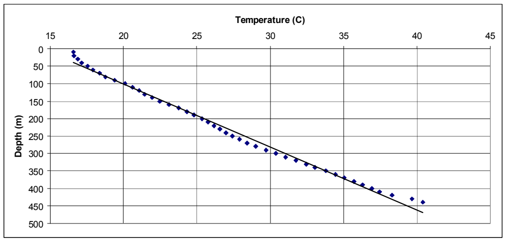

Fig 7. Temperature vs depth at Groover-1.

The local temperature gradient of the field ranges from 52 to 55 $^{\circ}C$/km, which corresponds to an average thermal flux of ≥ 100 mW/m^2. It is evident that the anomalous high local temperature gradient is related to the close proximity (about 120 km) of the Huntly coalfield to the Taupo Volcanic Zone (TVZ). This is the first reported detailed conductive measurements taken at such depth in this area north of the TVZ. However other coal exploration drilling has encountered hot water on many occasions in the Waikato coal region e.g. the Mangatawhiri area (White, 2006).

Temperature variation as seen in Figs. 4-7 can be related to the local variation of the thermal conductivity of the different rock formations. Since local heat flux at any given area is relatively uniform and the heat flowing through each formation is constant as this relationship follows Fourier's law of thermal diffusion. The high heat flux will have important implications for background heat flux used in geothermal reservoir simulation.

4. WELL TESTING

Pressure falloff testing the Kupakupa coal seam has shown that the underlaying Greywacke basement may act as a constant pressure boundary (Fig 8) completely enclosing the well. The equilibrium reservoir pressure (steady state) pressure is the same constant pressure as the boundary. For the well shown in Fig 6, the reservoir pressure is a hydrostatic head about 5 m below the casing head flange.

The calculated distance between the pressure boundary and the well is about 3.5 m indicating that this boundary is more likely to be the basement rather then a nearby fault. From the field geology, completion testing and interference testing in other wells in the field, no faults have been identified in this part of Huntly CBM coalfield. When repeating the injecton/falloff test in the Renown seam after isolation the Kupakupa with a bridge plug and perforating the casing, no boundary effect was detected in the Renown seam.

Temperature vs depth plots in two wells which have penetrated the basement (Groover-1 and Kaiser-1) showed significant increase in temperature gradient in proximity to the greywacke basement is possibly the result of convective behaviour (Fig 4 and Fig 5). The temperature inversion at Kaiser-1 (Fig 4) is related to a water enhancement job (high water injection rate of about 20 bbl/min used to breakdown the coal prior to production). The data in Fig 4 were taken two months after the water enhancement.

The results from the production testing and water chemistry analysis indicate that there is no communication between the coal seam reservoirs and the shallow ground water aquifer. This can be related to the low permeability of formations overlaying the coal seams acting as the reservoir cap. Extended interference testing also did not show any communications between the two main coal seams (i.e. no communication between the Renown and Kupakupa) even though these seams are only 20 m apart. Downhole resistivity surveys indicate highest permeabilities are only within the coal seams, and all other formations are lower in permeability (Fig. 9).

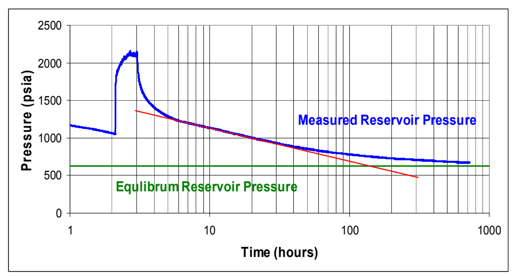

Fig 8. Diagnostic semilog plot showing the constant pressure boundary (red straight line) in the Graywaki basement below the Kupakupa seam.

More than seven months of production testing has shown clear communication in the Renown seam between all six production wells and the single monitoring well in the coalfield within the Renown seam. However, no communication was established between the Renown and the Kupakupa seams.

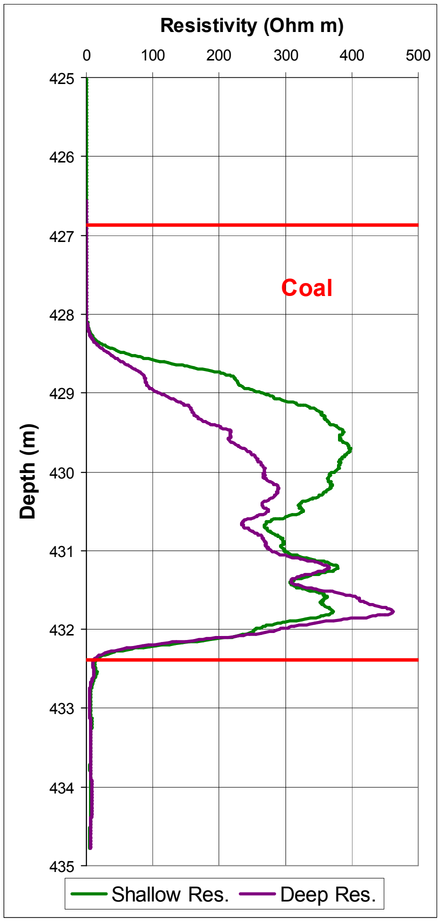

Fig 9. Shallow resistivity and deep resistivity logs showing a qualitative permeability (area between the two logs) within the Renown coal seam.

5. RESERVOIR MODELING

Modelling CBM and ECBM reservoirs requires high degree of parameter definition. The reservoir data are collected from field geology, lab tests of coal core samples, well testing and production testing. Reservoir modelling plays a key role in field assessment, well spacing and forecasting gas and water production.

A new equation of state for water, CH_4, CO_2 and N_2 mixture, has been developed for the three dimensional modelling of ECBM reservoirs using the TOUGH2 reservoir simulator. The new module has been trialled on several test problems and the model results have been compared with results from existing commercial packages (Zarrouk, 2004). The model has been used successfully in the assessment of the potential of several CBM fields in New Zealand and overseas.

The work has also been extended to encompass the investigation of enhanced recovery of CBM through the reinjection of flue gases from conventional fossil-fuelled power stations into deep coal systems for permanent disposal (Zarrouk, 2007).

Temperature gradients (Figs 4-7) along with other reservoir data have been used to create a three-dimensional numerical model for a portion of the Huntly coalfield (Fig 10 and Fig 11) using the new module for the TOUGH2 simulator. The reservoir simulator was primarily used to simulate gas (methane) production for the first 5 years of the field history. The model was then used to investigate enhanced coalbed methane (ECBM) recovery using carbon dioxide (Fig 12 and Fig 13), nitrogen (Fig 14 and Fig 15) and other possible combustion-flue gases (Fig 16 and Fig 17). The dual benefits of the ECBM are the economic returns from the carbon credit and the increased methane production.

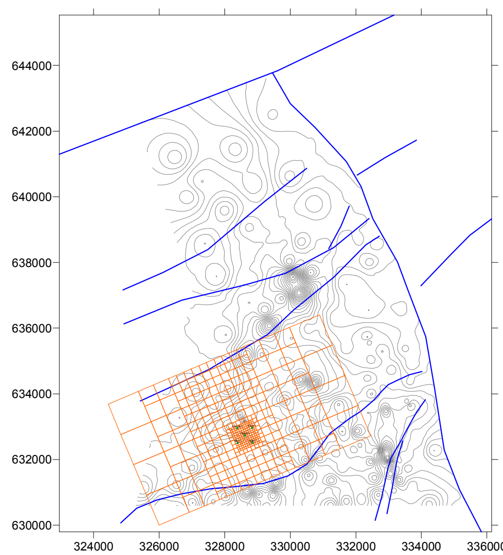

Fig 10. Computational grid for the Huntly model, showing; coal isopatches, main faults lines and the computational grid.

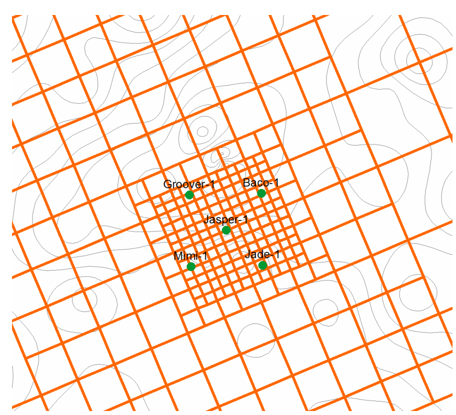

Fig 11. Close up of the model grid (shown in Fig 10) showing the five spot production well (appraisal) arrangement.

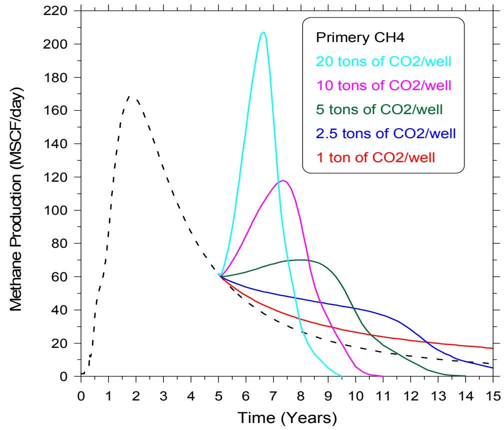

Fig 12. Primary methane production for the first 5 years followed by enhanced methane production at different CO_2 injection rates.

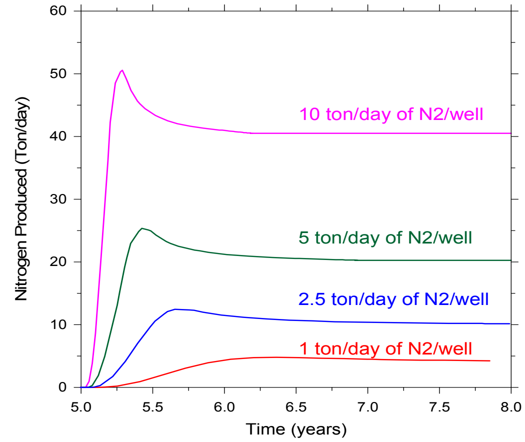

Fig 15. N_2 breakthrough in production wells for different N_2 injection rates in boundary wells.

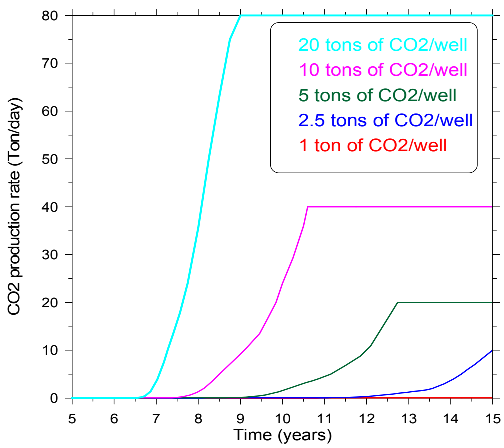

Fig 13. CO_2 breakthrough in production wells for different CO_2 injection rates in boundary wells.

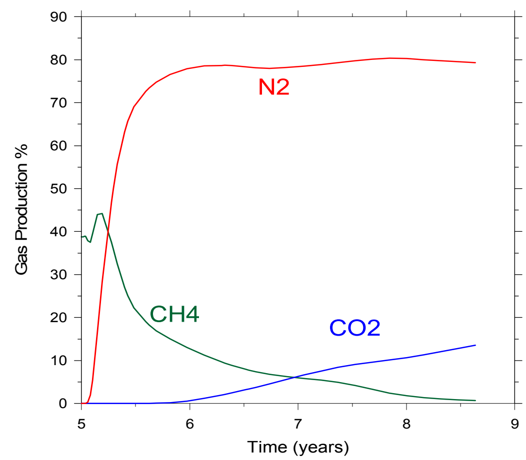

Fig 16. Gas produced % due to the reinjection of 5 ton/day flue gas (25% CO_2 +75% N_2)

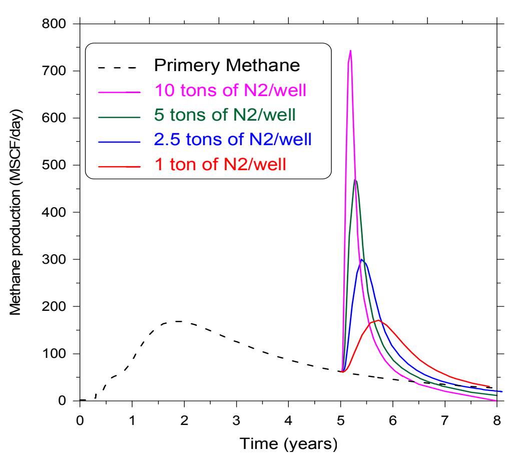

Fig 14. Primary methane production for the first 5 years followed by enhanced methane production at different N_2 injection rates.

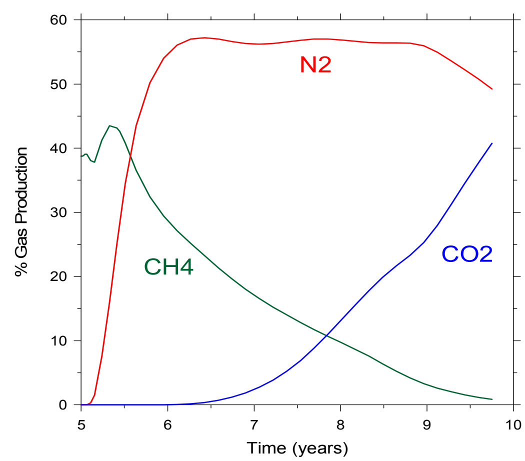

Fig 17. Gas produced % due to the reinjection of 5 ton/day flue gas (75% CO_2 +25% N_2).

The modelling results show that:

- The injection of CO_2 and N_2 significantly increase the rate of recovery for methane (Fig 12 and Fig 14).
- The breakthrough of N_2 (Fig 15) is much faster than that of CO_2 (Fig 13), because of the low adsorption capacity for N_2 compared to CO_2.
- The use of captured CO_2 is recommended for the enhancement of methane recovery, flue gas injection is not recommended.

6. CONCLUSIONS

From well test analysis, it is clear that the Greywacke basement is the source of the geothermal fluid. This is of significant interest for low enthalpy heat production/development in the Waikato region.

Water chemistry indicates that reservoir equilibration temperature average more than 90 $^{\circ}C$. Indicating that source of the water is deeper than 1000 m.

Having a background conductive heat flux of more than 100 mW/m^2 in this area north of TVZ, can have important implications when setting the background heat flux in geothermal reservoir models within and outside the TVZ.

The Waikato geothermal region has a good potential for sustainable low temperature geothermal direct heat applications for an extended future use.

Research is required to investigate methods for enhancing geothermal fluid production. This work will allow commercial development of low temperature direct use, particularly in areas with high energy demand.

7. ACKNOWLEDGMENT

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