

Carbon Dioxide Injection Field Pilot in Umurlu Geothermal Field, Turkey

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Keywords

Carbon Dioxide Injection, Umurlu Geothermal Field, Turkey

ABSTRACT

The Umurlu geothermal reservoir located in Buyuk Menderes Graben, Turkey initially contained around 2% by weight CO₂ dissolved in geothermal reservoir fluid. The produced CO₂ rate declined over one year of production time due to dilution of reservoir gas by degassed injectate. Since CO₂ has a considerable role on Umurlu reservoir performance and energy production, produced non-condensable gas (NCG) has been injected simultaneously with colder degassed injectate from an injection well for the last two months. Produced CO₂ monitored in some production wells showed a marked increase as a result of continuous injection. Apart from reducing CO₂ emissions, it has been observed that CO₂ has a profound effect on the behavior of reservoir pressure around these production wells.

1. Introduction

Injection of CO₂ into geothermal geological formations is considered as one of the mitigation methods to reduce CO₂ emissions (Pruess, 2006; Pruess, 2008; Salimi and Wolf, 2012). However, there are only a few studies on CO₂ injection into geothermal reservoirs. Pruess (2008) conducted reservoir simulations to evaluate mass and heat extraction performance of enhanced geothermal systems that are operated either by water or CO₂ as working fluid.

Gunnarsson et al. (2015) proposed a gas abatement method to dissolve the NCG's in effluent water from the power plant and re-inject them back into a geothermal reservoir. Geothermal

gases were separated based on their solubility in water in order to get rid of the poorly soluble geothermal gases prior to reinjection. As a result, the amount of water needed to dissolve these gases before injection was reduced.

The Cranfield Site has been under near continuous CO₂ flood since December 2009 as part of a U.S. Department of Energy demonstration of CO₂ sequestration (Freifeld et al., 2016). Two wells separated by a lateral distance of 100 m have been used for injection and production of CO₂. Thermal breakthrough was not significant after several years of injection. As a result, the project did not meet expected flow rates or energy production rates.

Projects for the geological storage of CO₂ generally plan for its injection under supercritical conditions in order to maximize the stored CO₂. A different option that consists of injecting CO₂ dissolved in brine has been proposed by Kervevan et al. (2014). The infrastructure is based on a doublet configuration of a production and an injection well that allows pumping the brine from the reservoir and then re-injecting it after having been saturated in dissolved CO₂. It is claimed that pressure buildup and migration of the initially present brine and the risk of CO₂ migration into overlying geological formations may be minimized as no light gaseous or supercritical phase is involved. The proposed method further provides additional advantages such as the heat recovered from the warm brine can be pumped from the production well for local use by the industrial CO₂ emitter for its own process or heating needs, and possibly for feeding a heating network close to the storage facility.

In this study a dual string – dual phase CO₂ injection method is proposed. NCG produced from a geothermal power plant located in Aydın, Turkey has been injected in an injection well for the last two months. Produced CO₂ monitored in some production wells showed a marked increase as a result of continuous NCG injection. Apart from reducing CO₂ emissions, it has been observed that CO₂ has a profound effect on the behavior of the reservoir pressure around these production wells.

2. Umurlu Geothermal Field

Büyük Menderes Graben in western Anatolia, Turkey is characterized by high temperature geothermal fields aligned along east–west trending normal faults that are likely related to ongoing N–S extensional tectonics in the region. It is the most prominent E–W trending graben structure in western Anatolia with a length approximately 175 km. The Umurlu geothermal field is located in the Büyük Menderes Graben, 15 km east of Aydın, Turkey (Figure 1). The typical stratigraphy of the Umurlu geothermal reservoir is as follows. The Menderes metamorphics of Paleozoic age form the basement rocks. The disconformity overlying Neogene series rocks consist of Pliocene and Miocene aged units. Quaternary aged alluvial deposits that crop out in the area are located at the top (Karahan and Güdücü, 2008). As a result of the N–S extension and continuous elevation of the Menderes basement rocks, parallel step fault systems have developed at the northern side of the Büyük Menderes Graben. A similar step faulting system developed at the southern side, below the alluvial deposits, completes the horst – graben structure. The N-S, NW-SE and NE-SW faults that cut the E-W direction normal faults of the Büyük Menderes Graben, are important structural elements of the Umurlu geothermal field. The conglomerates of the Neogene series form a low temperature shallow reservoir in the area. Hard

and compact basement rocks consisting of marble, calc – schist and quartzite have developed secondary porosity due to active graben tectonism. These rocks form the deeper reservoir in Umurlu geothermal system. There are two cap rocks: shallow Neogene age sandstone, claystone and mildstone and deeper impermeable schists of the Menderes Massive. Reservoir temperatures range between 149°C and 202°C and specific electrical conductivities range from 4300 to 5610 $\mu\text{S}/\text{cm}$. Geothermal waters are Na – HCO_3 , whereas colder ground waters are of Ca – HCO_3 and Ca – Mg – HCO_3 type waters (Bülbül, 2010). Two 12 MWe geothermal power plants were commissioned in 2015 and 2016 respectively. Waters produced from seven production wells initially contained around 2% by weight CO_2 dissolved in the reservoir fluid. The produced CO_2 rate declined over one year of production time due to dilution of the reservoir gas by degassed injectate. Since CO_2 has a considerable role on the Umurlu reservoir performance and energy production, the produced NCG has been injected simultaneously with colder degassed injectate from an injection well after one year of operation. This paper reports on the results obtained for the last two months from October to December 2017.

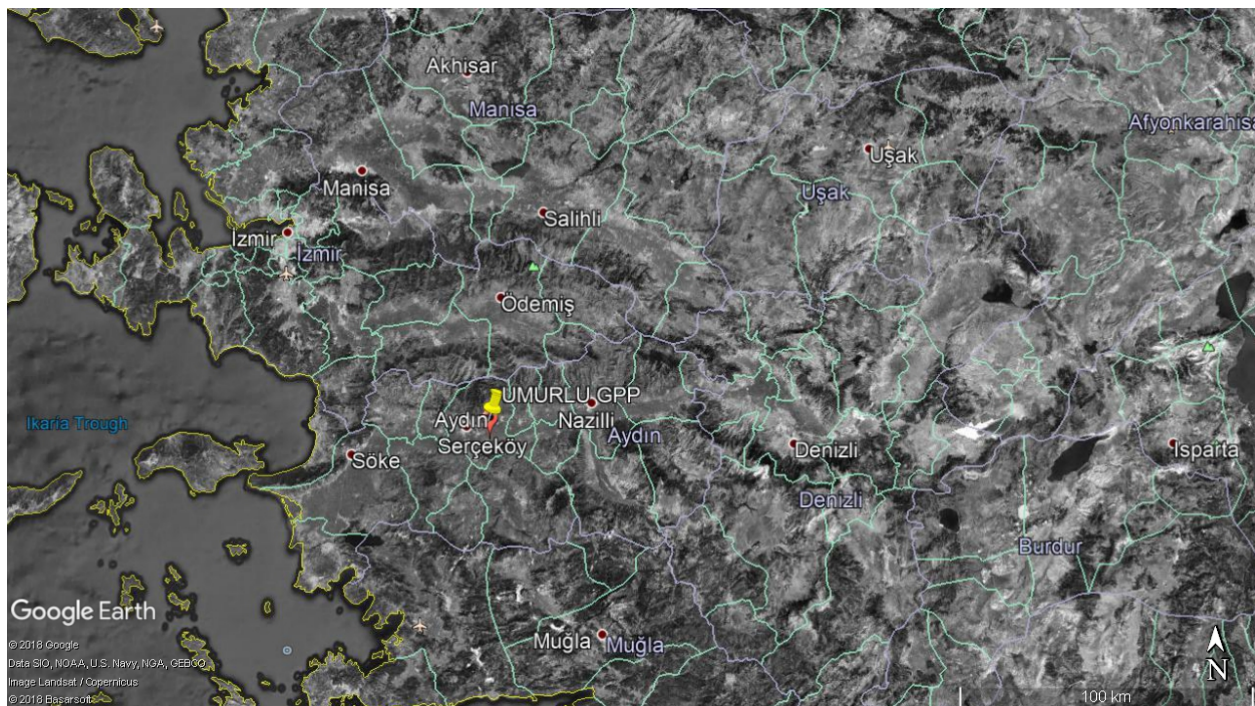


Figure 1. Location of the Umurlu geothermal field.

3. Results and Discussions

3.1. NCG Injection System

A dual string – dual phase NCG injection system consisting of one parasite string in the well casing for cold water and NCG injection and a specifically designed compressor is shown in Figure 2. The compressed NCG and fresh cold water are mixed in an injector (Figure 3) and pumped in an injection well to a depth greater than 700 m in an isolated tubing. The compressed NCG with fresh water and reinjection brine are mixed at a depth greater than 700 m. Cold water

and compressed NCG injected from the isolated injection tubing aims to improve the solubility of CO₂ in water and provide CO₂ to be supercritical. The colder geothermal injectate collected from the geothermal power plant is pumped from the well head at an average temperature of 64°C. Operational parameters are given in Table 1. During the field pilot NCG was injected 20 days continuously into an injection well. During this period 134,400 m³ (1,248 tons) of CO₂ was injected into the reservoir at an average flow rate of 2.65 ton/hour. The average energy consumption was 165 kW/hr. It was observed that a peak injection flow rate of 8 to 10 ton/hour is possible (Figure 4). At the peak injection rate energy consumption is not more than 250 kW/hr. The spool pressure dropped from 2 bars to 0.5 bars during the pilot study.

Table 1. Operational parameters applied during injection

Pump Flow Rate (M ³ /Hours)	Pump Pressure (Bar)	Water Temperature (°C)	CO ₂ Flow Rate(M ³ /Hours)	CO ₂ Inlet Pressure (Bar)	CO ₂ Outlet Pressure (Bar)	Brine Re-Injection Flow Rate (M ³ /Hours)	Brine (Injectate) Temperature (°C)	Well Head Pressure (Bar)
9.5	56	16	280 (2.65 Ton/Hr)	2.8	52	72	64	0.85

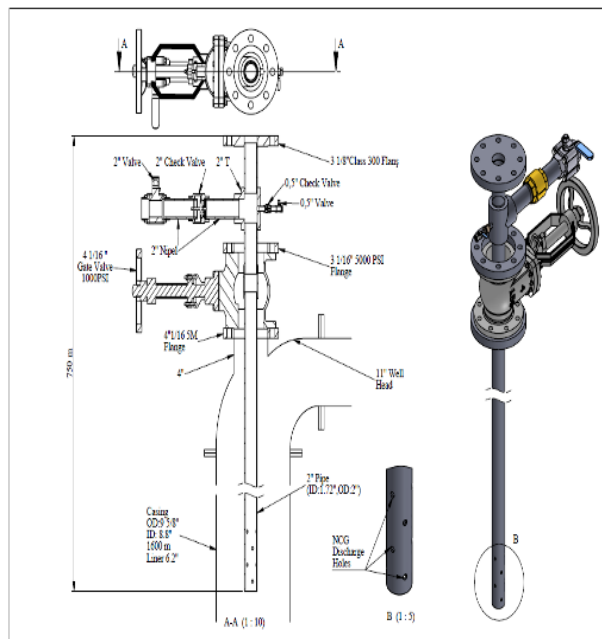


Figure 2. Dual string – dual phase NCG injection system.

ME-WS Patent, Patent No:3905/TR2018/02472

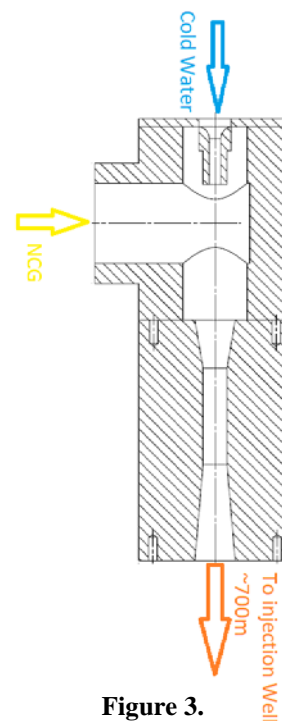


Figure 3.

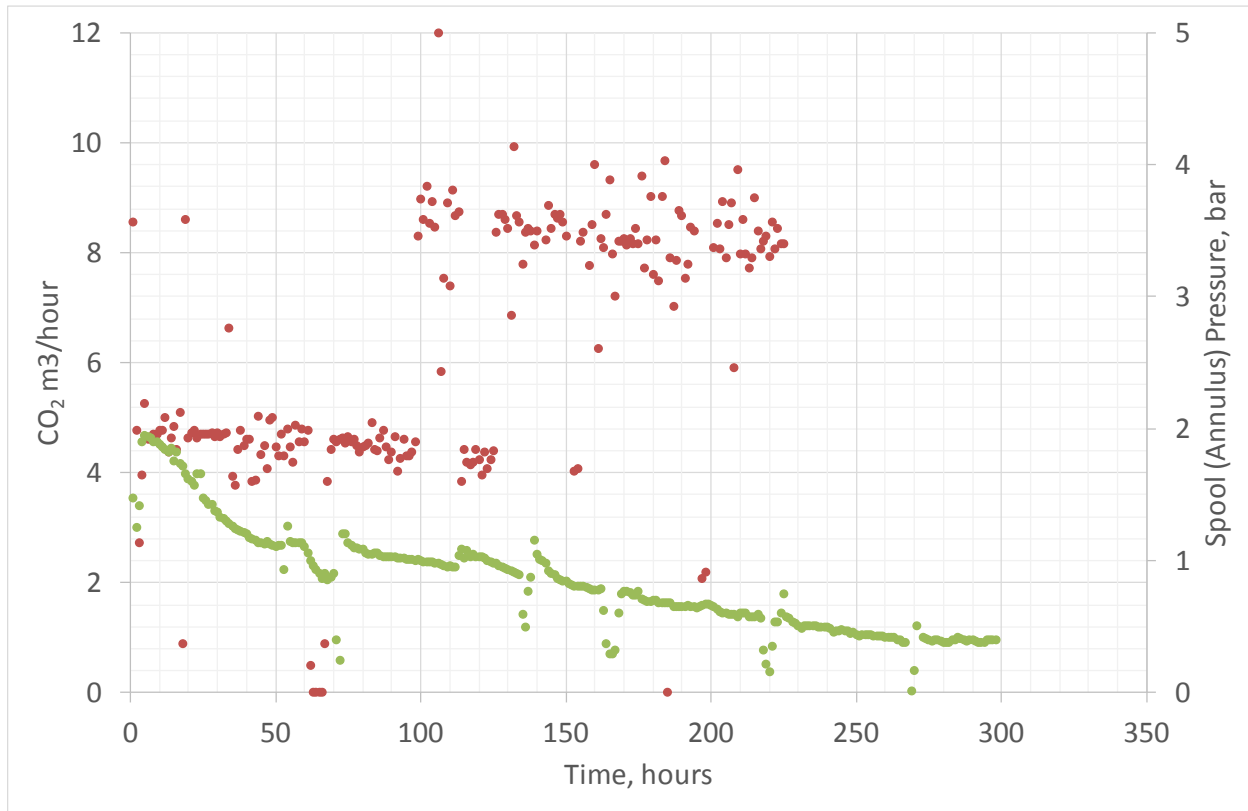


Figure 4. CO₂ injection rate during the pilot study.

3.2. Produced CO₂

The efficiency of NCG injection in Umurlu geothermal reservoir field was evaluated by monitoring the CO₂ content in the production wells. The location of the NCG injection well (ASK-1) and production wells are given in Figure 5. During the pilot study the CO₂ content of the production wells were obtained from separator data (Figure 6). It was observed that the CO₂ content of the production wells that are located closer to the CO₂ injection well showed a clear increase. On the other hand, wells that are located farther from the injection well (i.e. A-1) showed little or no change in the CO₂ content. It could be speculated that given enough time, these wells would also show an increase in the produced CO₂. The efficiency of NCG injection and sweep, as well as the safety of operations highly depends on reservoir properties, which may change following CO₂ and/or cooled water injection and potential reaction. In this regard, additional measurements such as pH, mineral deposition as well as pressure and temperature have to be monitored.

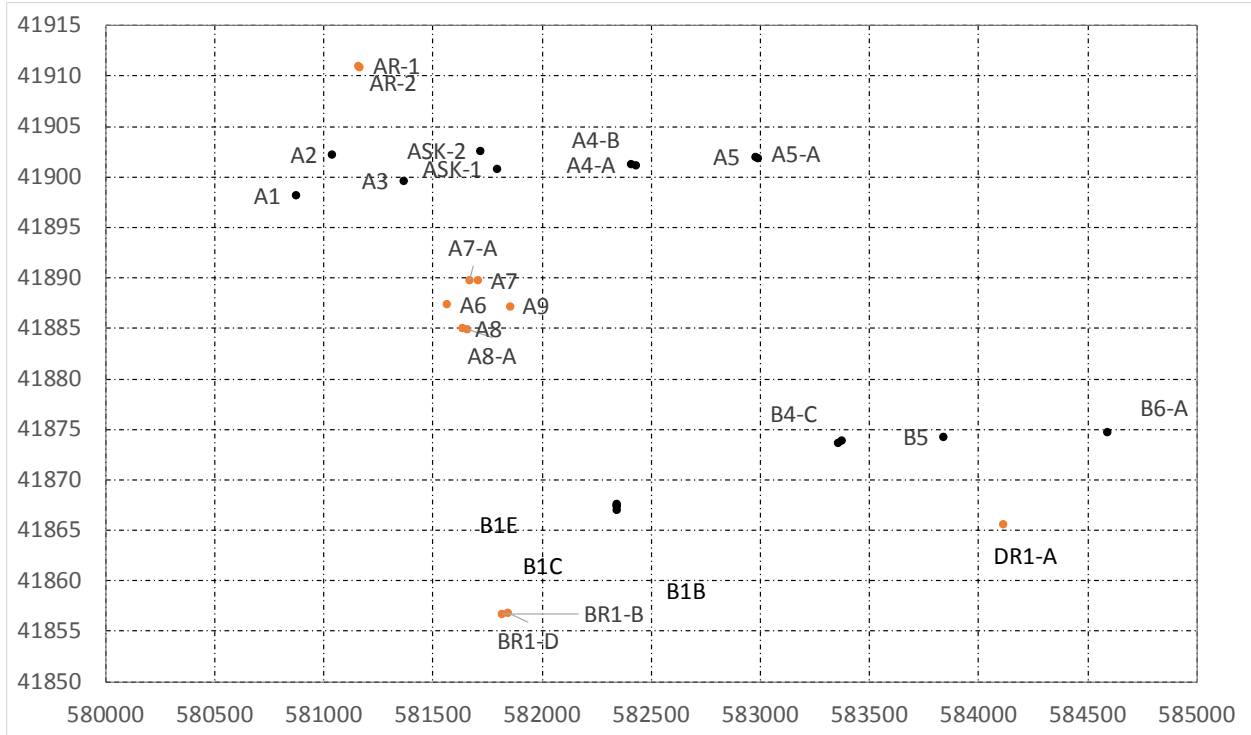


Figure 5. Location of CO₂ injection and production wells.

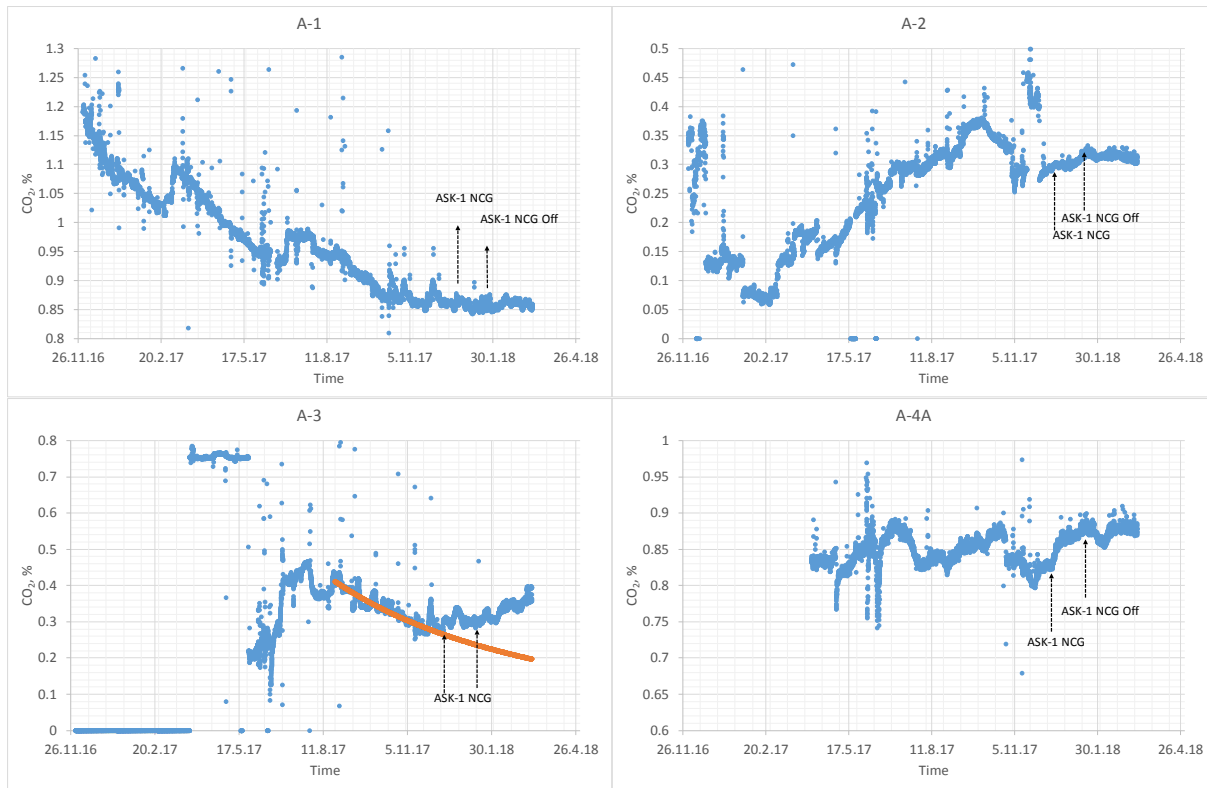


Figure 6. CO₂ (weight %) change production wells.

3. Conclusion

A dual phase - dual string configuration was developed to inject NCG in a geothermal well. The configuration is tested in a geothermal well in the Umurlu geothermal field, Turkey. NCG produced from a geothermal power plant was injected simultaneously with colder degassed injectate for a period of two months. It has been shown that it is possible to inject NCG at a rate of 10 ton/hour continuously. Produced CO₂ monitored in nearby production wells showed a marked increase as a result of NCG injection. Apart from reducing CO₂ emissions, it has been observed that CO₂ has a profound effect on the behavior of reservoir pressure around these production wells.

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