Carbon Sequestration in High Temperature Liquid-Dominated Geothermal Reservoirs

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ABSTRACT

Possibility of carbon sequestration in high temperature liquid dominated geothermal reservoirs is analyzed by means of reservoir simulations. Several different simulations with differing carbon dioxide injection rates and injection pressures were conducted on a fractured simulation model by using a commercial reservoir simulator. It was observed that it is possible to sequester CO_2 with small temperature drop (approximately 5°C) if CO_2 is injected near the meteoric water feed zone for short periods of time. Premature breakthrough of CO_2 was observed in other cases where side and center injections with differing injection pressures and rates were considered. As fracture density decreased from 10/m to 20 /m in vertical direction CO_2 breakthrough time decreased considerably.

1.INTRODUCTION

The environmental load caused by the continued use of fossil fuels has led to a growing concern as to the effect of increasing emissions. It has become evident that the earth is undergoing a warming process due to the additional greenhouse gas content in the atmosphere (Holt et al., 2000). International agreements have increased the focus on and the importance of the sequestration of greenhouse gases, which is proposed as a means for reducing global warming.

Carbon sequestration can be defined as the process of capturing and securely storing carbon, which would otherwise be emitted to or remain in the atmosphere (Reichle et al., 1999). The underlying idea is to keep carbon emissions from reaching the atmosphere by means of capturing and channeling them to a secure storage, or to remove carbon from the atmosphere by various means and store it. Carbon sequestration has the potential of becoming a major tool for reducing carbon emissions caused by the use of fossil fuels. Bearing in mind the amount of carbon emission reduction required to stabilize the atmospheric CO_2 concentration, there is a need for multiple approaches to carbon management, which should take potential synergies into consideration. Carbon sequestration allows for the continued large-scale use of fossil fuels, and provides an outstanding reduction in CO_2 emissions to the atmosphere. Thus, formulating new sequestration techniques and improving existing ones in terms of speed and efficiency would help decrease the net positive carbon flux to the atmosphere (Reichle et al., 1999).

Carbon sequestration focuses on six technical and scientific areas, which, through collaborative research efforts, have been established as the main processes and methods defining CO_2 sequestration both before and after reaching the atmosphere (Reichle et al., 1999);

1) Separation and Capture of CO_2

2) Ocean Sequestration

3) Carbon Sequestration in Terrestrial Ecosystems

4) Advanced Biological Processes

5) Advanced Chemical Approaches

6) Sequestration of CO2 in Geological Formations

The most direct carbon management strategy for long-term removal of CO_2 from the atmosphere is the CO_2 sequestration in geologic formations (Westrich et al, 2001). In geological sequestration, CO_2 is stored in underground reservoirs. Oil fields, coal seams and non-hydrocarbon-bearing geological traps are all envisaged as potential candidates for sequestration. There are three principal mechanisms for sequestering CO_2 in geologic formations. First, CO_2 can be trapped as a gas or supercritical fluid under a low-permeability cap rock. Secondly, CO_2 can dissolve into the fluid phase. Finally, CO_2 can react either directly or indirectly with the minerals and organic matter in the geologic formations and become part of the solid mineral structure (Reichle et al., 1999).

In this study possibility of sequestering CO_2 in high temperature geothermal systems is proposed as an alternative strategy. In a typical geothermal reservoir the produced water is reinjected back to maintain reservoir pressure or attain maximum thermal sweep. The basic idea in geothermal sequestration is then to sequester CO_2 while keeping the pressure and temperature at the desired levels.

A high temperature geothermal field located in West Turkey was used to demonstrate the applicability of the proposed solution. Several numerical simulations were conducted using a commercial simulator. Optimum injection location as well as optimum injection parameters were identified. It is shown that it is possible to sequester CO_2 for short periods of time provided that CO_2 is injected near the meteoric feed zone.

2. DESCRIPTION OF THE FIELD

Kizildere geothermal field is selected for a convenient high temperature liquid – dominated geothermal field. Kizildere geothermal field, liquid dominated reservoir with 195-212 °C temperature at 300-800 m. depths, is located in the western extreme of the B. Menderes graben. There are 9 active production wells (Fig. 1) in the field (KD-6, 7, 13, 14, 15, 16, 20, 21, and 22). The rest of the wells in the field are used for observation and reinjection purposes. A recently drilled injection well explored a new reservoir at 243 °C under the existing reservoir (Serpen and Satman, 2000). It is estimated that total capacity of field is approximately 200 MWe. Denizli-Kizildere geothermal power plant was commissioned with 20.4 MWe and according to the 2001 records; its annual production is 89.6 GWh/yr (Gokcen et al, 2004).

The field suffers from silica scaling problem and gas extraction from condensers. It is speculated that in the shallow and deep reservoirs CO_2 is present 1.5-1.7% and 2.5-2.7% by weight dissolution respectively. The produced CO_2 is used in a dry ice production plant (Karbogaz Co) (Gokcen et al, 2004). The excess amount of unused CO_2 is released to the atmosphere.

2. METHODOLOGY

STARS thermal simulator (CMG, 2003) was used to device solutions for the sequestration of CO_2 into high temperature liquid-dominated geothermal reservoirs. The historical production, temperature and pressure data obtained from Kizildere geothermal field, Turkey were used for calibrating the dual porosity simulation model (Uraz and Akin, 2003) using the parameters given in Table 1. Recent analysis of experimental tracer tests (Akin, 2001a) that simulate tests conducted in Kizildere geothermal field showed that there are secondary fractures yielding high fluid velocity and small mean arrival time. For these flow paths Peclet numbers were somewhat large when compared to the shorter main fracture path meaning a convection dominant system. However for the main flow path the fluid velocity was relatively small and yielded a small Peclet number. For this flow path, molecular diffusion was insignificant compared to that of the secondary paths. Thus a double porosity model was selected to model this behaviour. Rectangular grids (Fig. 1) of identical dimensions (60x60 m) were used except for the outer boundary grids (120x120 m). The depth of the blocks matched that of the production reservoir divided into five equal sections. The depths of the grid tops are shown in Fig. 2. The thickness of the reservoir is between 10 and 60 m. approximately, and is supported by a thermal aquifer (Uraz and Akin, 2003). The developed simulation model was in accord with hydro-geological models (Dominco, 1974) that consider infiltration of meteoric water into deeper sections of the Earth and up-flow of it after heating. The permeability data, which had initially been derived from the well test analysis (Akin et al., 2003), was modified in order to achieve a reasonable match (Fig. 3) to available water production, pressure and temperature data. A sample match is given in Fig 4. Final temperature and pressure distributions at the end of the 25 years of history match are given in Fig 5.

CO_2 injection for sequestration purposes continued for 25 years. Although there are reports suggesting the presence of CO_2, it was assumed that there was no initial CO_2 in the reservoir.
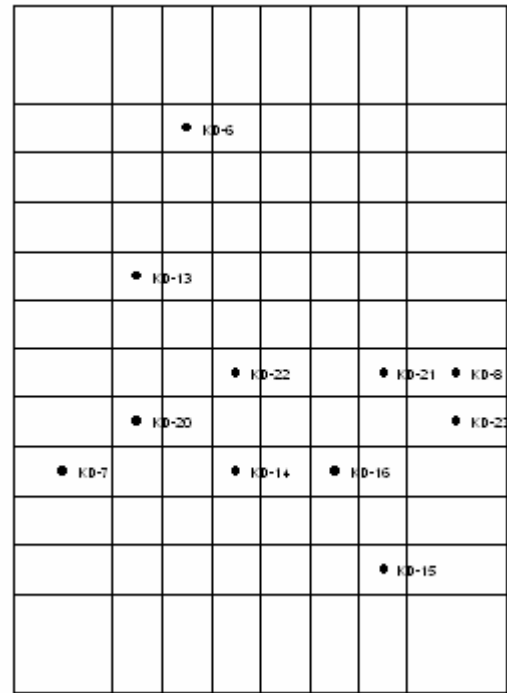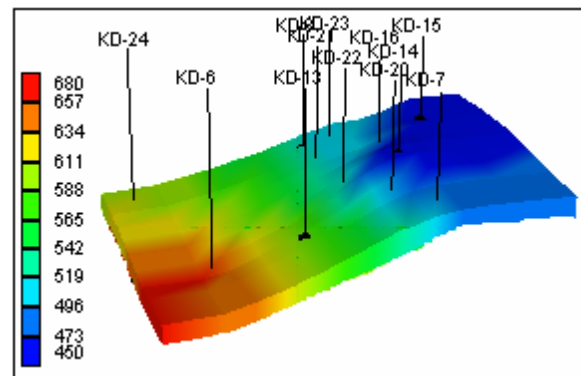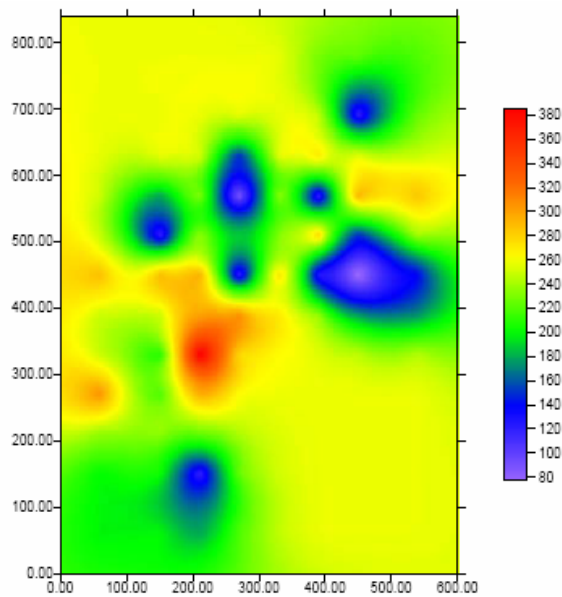

Figure 1: Grid block orientation and production well locations.
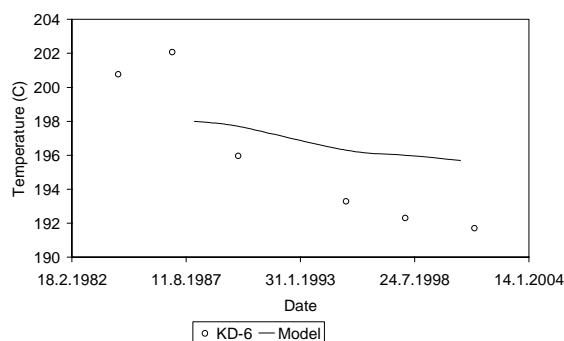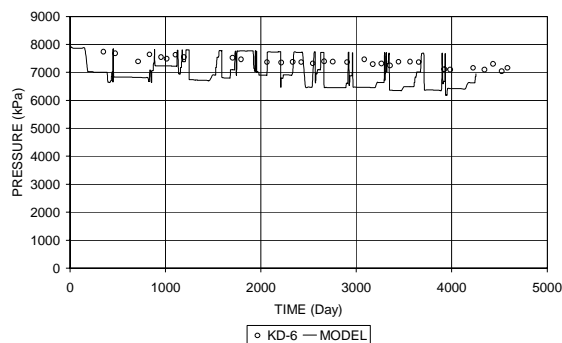

Figure 2: Depths (m) of the top grids.

Figure 3: Permeability (md) distribution (Akin et al., 2003)

Table 1. Simulation model properties

Property	Value
Fracture spacing	5 x 5 x 10 m.
Shape factor	Gilman – Kazemi
Fracture relative permeability	Power law n = 2.8
Matrix permeability	1 md.
Fracture porosity	0.08

Figure 4: Pressure (top) and temperature (bottom) match for well KD-6 (After Uraz and Akin, 2003).
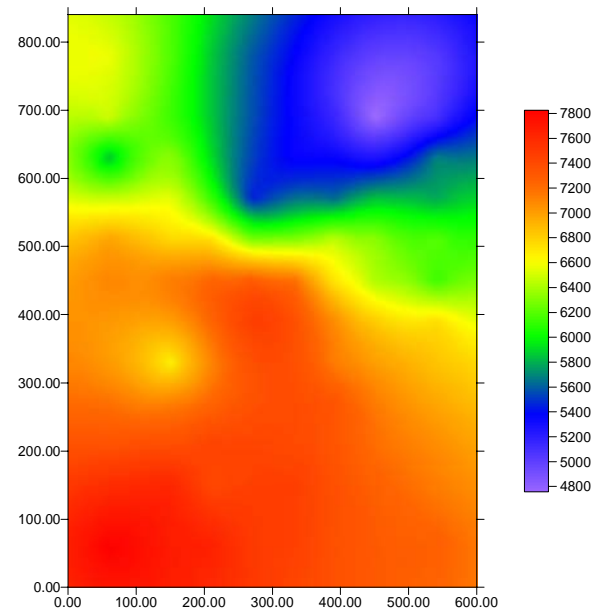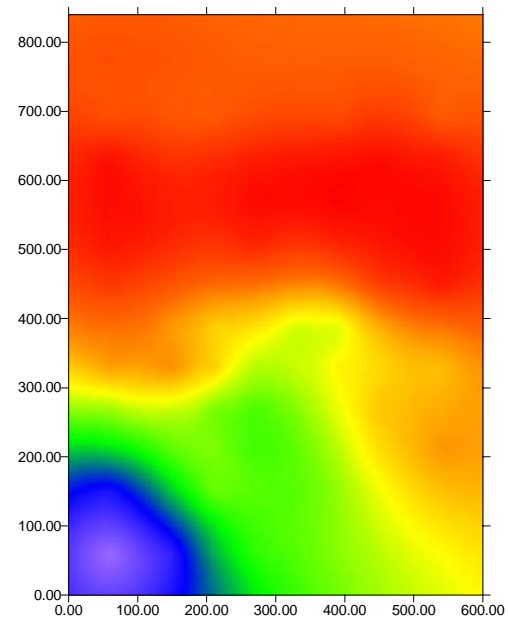
Figure 5: Temperature, (top) and pressure, kPa (bottom) distribution.

3. RESULTS & DISCUSSIONS

3.1. Injection Location Analysis

Reinjection location selection has always been a contraversial subject in geothermal engineering. While some studies suggested injecting from outside of the field (Einarsson et al., 1975), some preferred to inject from the center of the field (Bodvarsson and Stefansson, 1988). Yet another injection strategy is to consider injection and production wells are interchangable and distributed evenly in the reservoir (James, 1979). Peripheral injection is suggested in cases where maximum thermal sweep is of greater importance than the pressure maintenance (Sigurdsson et al., 1995).

Carbon sequestration in a geothermal reservoir aims at maintaining CO_2 in the field, which will retain a high amount of gas while keeping the pressure and temperature as

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high and long as possible. This is desired because as the residence time of CO_2 increases, CO_2 reactions with the water and rock matrix increases. Thus more CO_2 could be stored. In order to increase the amount of sequestered gas and to keep the reservoir temperature at desired levels, it is necessary to take into account injection well pressure, injection rate, and injection well location. Thus several simulations were conducted to find the optimum location of the CO_2 injection well. Injection temperature, pressure and the rate of CO_2 were of 25 ^{o}C, 9000 kPa, and 50m^3/d respectively that correspond to supercritical injection conditions. It was further assumed that CO_2 and water formed ideal solutions. Furthermore, the reactions that would lead to solution of rock matrix and mineralization of CO_2 were neglected. Locations IWL-7 through IWL-9 represented meteoric recharge zone, whereas locations IWL-1 through IWL-6 together with IWL-10 represented peripheral injection locations. Injection locations IWL-11 and IWL-12 correspond to injection from the center of the reservoir (Fig 6). It was observed that as the injection location gets closer to meteoric feed zone and the corners of the field CO_2 residence time increased (Table 2). It was also observed that these injection locations are at the deeper sections of the reservoir compared to other cases. It was reported by (Uraz and Akin, 2003) that the overall temperature decrease was less pronounced with corner injections of cool processed water; however, pressure drop was highest. On the other hand central injection of water resulted in higher pressure support with more cooling.
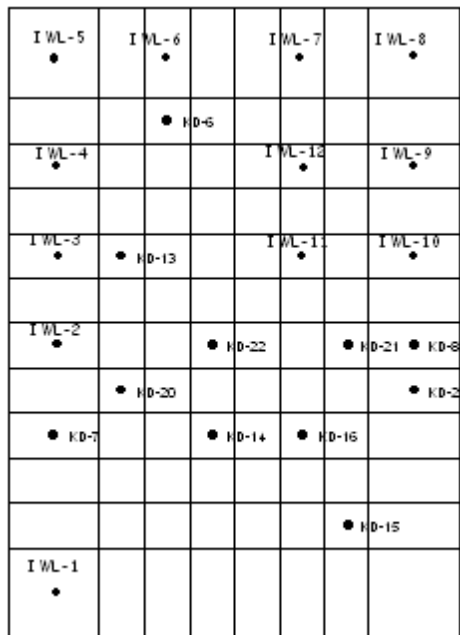

Figure 6: Different injection well locations (IWL) at the bottom of the reservoir.

3.2. Relative Permeability Analysis

The effect of fracture relative permeability was analyzed by using two different relative permeability curves (Fig 7). Both of the figures were power law type as opposed to linear or x-type relative permeability curves. It is believed that power law relative permeability curves describe the nature of fracture flow better compared to linear relative permeability curves (Akin, 2001b). It was observed that with the use of a relatively higher irreducible gas saturation (i.e. 0.3), the simulation prematurely ended with an unphysical block relative permeability error. Apart from

that no significant difference was observed in terms of CO_2 residence time and average temperature and pressure of the geothermal reservoir.
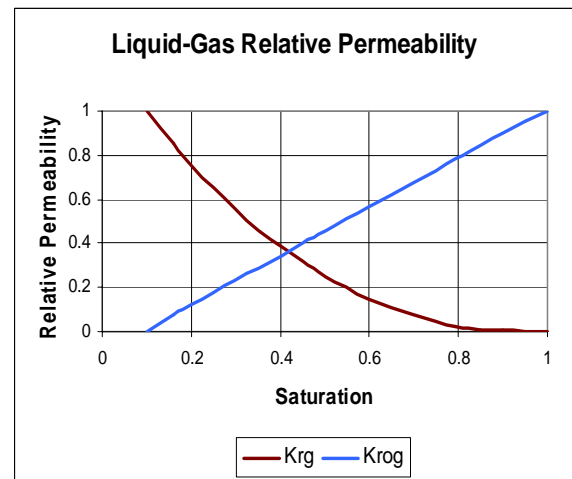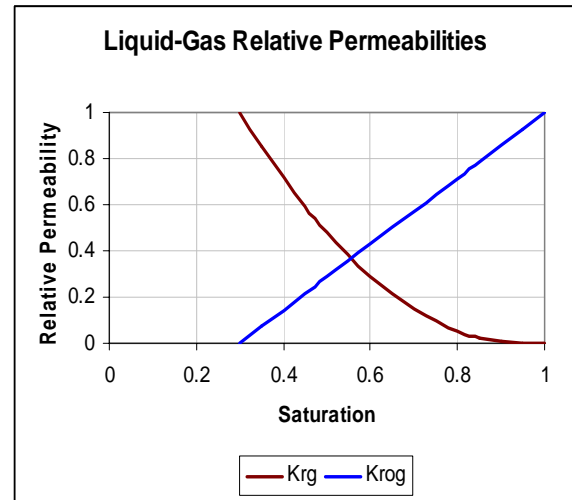

Figure 7: Liquid-gas relative permeability with high (top) and low (bottom) irreducible water saturation.

Table 2. Cumulative amount of sequestrated CO_2 for each injection well.

Location	Breakthrough time, days	Cum. CO_2 sequestrated (m^3)
IWL-1	212	10600
IWL-2	59	2950
IWL-3	31	1550
IWL-4	50	4500
IWL-5	151	7550
IWL-6	50	1550
IWL-7	268	13400
IWL-8	311	15550
IWL-9	250	12500
IWL-10	212	10600
IWL-11	50	4500
IWL-12	151	7550

3.3. Injection Rate Analysis:

CO_2 injection rate affected CO_2 residence time as well as the pressure drop. It was observed that the reservoir temperature has not been affected significantly. As the injection rate increased breakthrough time decreased logarithmically (Fig 8). On the other hand, the amount of CO_2 increased significantly.
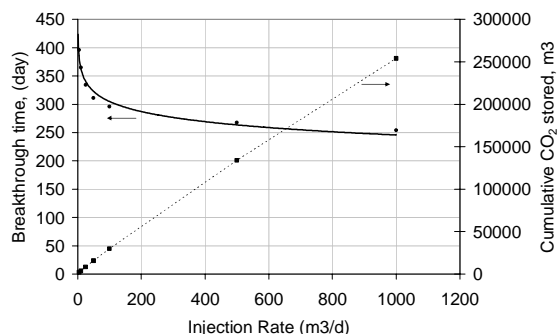
Figure 8: Effect of injection rate on breakthrough time and total CO_2 sequestered.

3.4. Injection Temperature and Pressure

Injection temperature and pressure are other crucial parameters that might affect carbon sequestration. As the injection temperature increased from 25 to 40 °C the final average reservoir pressure drop increased (Table 3). Note that injection at 9000 kPa and 40 °C represents injection at supercritical conditions compared to near critical injection at 10 and 25 °C. Thus it was concluded that at subcritical injection conditions even though the amount of carbon sequestered is lower the pressure drop is somewhat better than that of the supercritical cases.

As the injection pressure changed from supercritical to subcritical the average temperature drop did not change significantly. It was observed that the temperature drop was more near the top of the formation compared to deeper sections of the reservoir.

Table 3: Average reservoir pressures for different injection tempeatures.

Temperature, °C	Pressure, initial, kPa	Pressure, final, kPa
10	5075.774	3713.79
25	5075.774	3711.638
40	5075.774	3702.956

3.5. Fracture Spacing

Fracture spacing is a major parameter that could affect CO_2 sequestration efficiency. A sensitivity analysis was carried out to analyze the effect of fracture spacing. Three different cases were considered: base case (5 x 5 x 10 m), horizontal fracture dominant case (1 x 1 x 20 m) and vertical fracture dominant case (20 x 20 x 1 m). In both comparisons note

that there are more fractures compared to the base case. It was observed that when vertical fractures dominated the system the pressure drop was higher compared to horizontal fracture dominant case. In both cases the overall pressure drop was higher compared to less fractured case. The temperature drop was again insignificant. The highest temperature drops occurred at the shallower sections of the reservoir followed by deeper sections. The overall carbon sequestered and the breakthrough time followed the same trends presented earlier.

Table 6: Reservoir pressure analysis for different fracture orientation.

Fracture	Initial Ave. Pressure, kPa	Ave. Pressure at B.T.T., kPa	Final Ave. Pressure, kPa
homogeneous case	5075.77	5016.46	3711.64
vertical case	5001.78	4951.04	3534.01
horizontal case	5025.43	4972.95	3604.57

4. CONCLUSIONS

Possibility of CO_2 sequestration in high temperature liquid dominated geothermal reservoirs was investigated by means of reservoir simulations. The breakthrough time of CO_2 was evaluated as a function of injection location, injection temperature, injection rate, and fracture analysis. It was observed that it is possible to sequester very limited amounts of carbon dioxide for short periods of time (i.e. less than a year). Sensitivity analyses showed that at subcritical injection conditions even though the amount of carbon sequestered is lower the pressure drop is somewhat better than that of the supercritical injection. Moreover, it was found that fracture spacing is a very important parameter. As the fracture intensity increased total amount of CO_2 sequestered and the breakthrough time decreased. The results indicate that long term CO_2 sequestration is not feasible in high temperature liquid dominated highly fractured geothermal systems.

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