Synergetic CO2 Storage and gas/oil production from tight reservoirs

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Abstract

Tight reservoirs are currently not economically exploitable. This is due to the low permeability of the rock and consequently low values of production rate. Such reservoirs are good candidates for fracturing. The productivity of fractured tight-gas wells often does not reach its predicted value. Furthermore, this deficit in production often proves to be greater than expected, despite the existence of sufficient gas-filled porosity. The reasons for this lie in the configuration of the pore space and the negative impacts of the production process and production fluids.
At such sites CO2 can be used as stimulation and fracture fluid. The advantages of this method will be discussed. However, wettability effects on the shale and displacement efficiency of CO2 are some of the advantages.
The main aim of the investigations is to evaluate the creation of fractures by pressure and cold fluids, and the fracture porosity and fracture permeability.

This study has been focused on development of new fracture stimulation approach using CO2 based fracturing fluid that can cover a range of tight formations including shale play. In this approach, fracture will be created by pressure and cold CO2. Method has been developed to evaluate the relative permeability of supercritical CO2, brine/liquid CO2, and created fracture porosity and permeability. Emphases are given on the investigation and development of an appropriate technology for the coupling of hydraulic and CO2-Coldfrac. Numerical software has been developed to simulate the multiphase flow. In this software, the thermodynamic behaviour of CO2 evaporation has also been conducted. This paper also presents the technical and energetic evaluation of the field applications. The testability, adsorption effects on the shale, and displacement efficiency of CO2 and advantages of this method will also be discussed.

Keywords: Tight formations, fracturing, CO2-Storgae, CO2-Adsorption, Cold-fracturing

1 Introduction

Hydraulic fracture stimulation techniques have been widely used to enhance the production from low permeable tight gas reservoirs (Shehata, 2010). Success of this technique is, however substantially depend on fracturing fluids and it responses of fracturing fluid to the treated formations. Moreover this technology predominantly has been used to stimulate the tight sandstone reservoir. There are very limited applications for low permeable carbonate reservoirs due to complexities associated with the physical and mechanical properties of carbonate rocks and its interaction with fracturing fluid. In addition, the productivity of fractured tight-gas wells often does not reach its predicted value. This deficit in production often proves to be greater than expected, despite the existence of sufficient gas-filled porosity. The reasons for this lie in the configuration of the pore space and the negative impacts of the production process and production fluids.

The goal of fracture stimulation is to create artificial cracks or fractures through the formation by adding pressure in order to increase extraction rates and ultimate recovery of oil and natural gas （Class, et.al 2009, Xiaoxian Z. 2010). Especially in tight reservoir, where the permeability is already very low like in unconventional reservoirs such as shale rock or coal beds is it necessary to increase the area from which natural gas and liquids can be recovered.
To create such fractures a pressure have to be added by pumping a fluid which is higher than the formation break

down Pressure.

For this operation special treatment fluids have to be used. To hold the cracks open and achieve efficient drainage channel so-called proppants are used. After the stimulation process the treatment fluid and not fixed proppants have to be removed to avoid extensive formation damage.

2 CO2-Fracturing fluid

The main damaging process during fracturing is relative permeability loss due to the capillary effects between the treatment- and reservoir fluid. Another problem could be the swelling of clays which reduce the permeability as well. Especially in tight reservoir, where the permeability is already very low by nature capillary pressure damage becomes very critical. Because the capillary pressure increase as the pore size decrease and if the capillary pressure reach the reservoir pressure the pore fluid is trapped in the formation.
Hence, the goal is to find a treatment fluid which not interacts with the formation to avoid clay swelling and minimize capillary effects. One Fluid which achieves these requirements due to its thermodynamic properties is CO2.
CO2 has been used in fracture operation since the early 1960's. In the beginning it was used as an additive to hydraulic fracturing and acid treatments to improve recovery of treating fluid. It may exist as liquid, gas, or solid and the critical point is at 31°C and 7,4 MPa.
During fracturing operation CO2 is injected below the critical temperature as liquid. After enters the perforation, it will expand and change the state from liquid to gaseous. After the treatment CO2 flows back as gas, together with formation and fracture fluids. However the main goal was to get treatment liquid back to the surface.
Since the CO2 change its state of matter from liquid to gaseous in the formation any damage due to relative permeability and capillary pressure is eliminated. Figure 1 presents the development of fractures using CO2, while Figure 2 shows the p,T phase diagram of CO2.

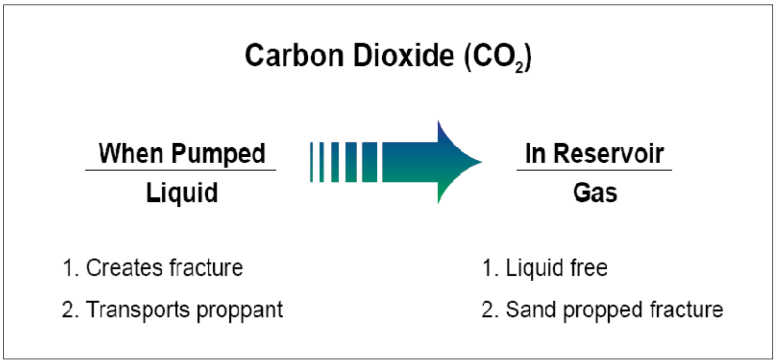

Figure 1: Schematic diagram of CO_2 using as fracturing fluid

2.1 CO2 as a proppant carrier fluid

A numbers of fracturing treatments have shown good results by using CO2 as treatment and proppant carrier fluid even if the viscosity is quite low compare to conventional fracturing fluids, where a good transport and placement is achieved by a high viscosity. The cause for this is that the carrier mechanism in low vicosity fluids is controlled by the turbulent flow caused by the high Reynolds's number because of low viscosity, also the high density of liquid CO2 (>1,1 g/cm³) support the proppants transport.

Especially tight gas reservoirs where a high in situ stress occurs have high requirements on the proppants due to the proppants strengh. Hence normally ceramics proppants have to be used because of the high compressive strength and the chemical resistance.
However, this proppants have a high density which makes a well placing of the proppants only by using CO2, due to the low viscosity, difficult. Hence polymers should be used to increase the viscosity of the CO2 to achieve a higher carrying capacity.

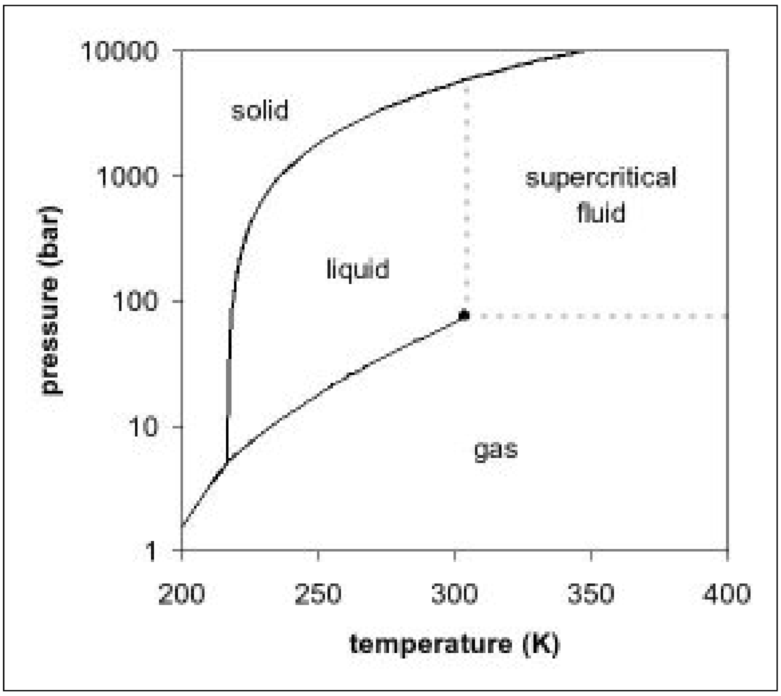

Figure 2: CO2 phase diagram

2.2 Requirements on CO2 as fracturing fluid

CO_2 is liquid at temperature lower than 31.1°C and high pressure, so it can properly be categorized as cold fluid which has strong thermal effect in creating fracture.
The use of liquid CO_2 as a fracturing fluid offers a viable method of stimulation. This review also showed the successful application of CO_2 fracturing to a variety of formations in USA. The process has proven be an economical alternative to conventional stimulation fluids with the following advantages:

- Reduction of permeability and capillary pressure damage by reverting to a gaseous phase.
- Better clean up of the residual fluid, so smaller mesh proppant can be used and supply adequate fracture conductivity in low permeability formations.
- The use of low viscosity fluid results in more controlled proppant placement and more amount proppant placement within the created fracture width.

2.2.1 Liquid CO_2 fracturing

Liquid CO_2 fracturing appears to be effective in providing immediate and significant improvements in gas storage well deliverability. It is apparent, however, that the ability to achieve high injection rate is a critical factor to proppant placement volume. This need may be particularly prevalent in high permeability settings where fluid leak-off is expected to be significant.
At stabilized reservoir pressure and temperature, CO_2 will vaporize to the gaseous state. The CO_2 is slightly soluble in water and very soluble in oil. CO_2 will support the recovery of oil as it is miscible with most crude and greatly reduces oil viscosity. The dissolving of CO_2 in water will form weak carbonic acid which has a pH of 3. There has been no indication that CO_2 or the resultant carbonic acid does any damage in sandstone reservoirs.
The process utilizes liquid carbon dioxide (CO_2) to both create hydraulic fractures and to transport proppants. Carbon dioxide is unique because it vaporizes at reservoir conditions and leaves only a liquid-free proppant pack.

2.2.2 CO2 thermal hydraulic fracturing

Reservoir fracturing using CO2 can be achieved through two scenarios:
The CO2 thermal hydraulic fracturing is a fracture technique which combines conventional hydraulic fracturing and fractures which are caused by thermal stresses by cooling down the formation due to the injection large quantity of CO2 (Gupta et. al. 2005, Haefner, 2009).
The thermal stress induced in a homogeneous, linearly elastic rock mass by cooling the formation can be given

as:

$$\sigma_T = \frac{E}{1-\mu} \cdot \beta \cdot \Delta T$$

σ_T	Thermal stress
β	Linear thermal-expansion coefficient
μ	Poisson's ratio
ΔT	Cooling of the rock

To create thermal stresses which lead to fractures in significant magnitude a large quantity of CO2 is needed. One promising sources could be power plants which have a CO2 emission up to 1 million t/a. The Transport could be realized by pipelines, from the plane site to the storages site.
During the transport the CO2 will cool down up to the ambient temperature of the ground. By the typical pipeline pressure of 80 bars and a soil temperature of 12°C, the CO2 is present in the liquid phase.
During the injection of CO2 under high pressure it will stay in this state, this will cool down the large area of the rocks and there are temperature reductions of 50-100 K. This effect will lead to enormous thermal stresses on the rock in which causes cracking along with the hydraulic pressure of the injection pump.
A rough estimate of the resulting fracture porosity from the thermal expansion coefficient of the rocks (of about $(2 - 5).10^{-5}\ K^{-1}$) leads to an increase of about 0.2-0.5 percent porosity, which to extend the cracks and increase permeability. As the cooling front with time further extended, a development of the cracking is also expected.

Together with the liquid CO_2 proppant should be injected in the fracture to keep the resulting fracture permanently open. These additives need to be developed and test with liquid CO_2 to give the necessary increase in viscosity and good capability of the proppant.

The large amounts of CO_2 which is required for the stimulation of the rock formation are only available from economic considerations in few locations,

- In a side which is also has the location for a CO_2 storage,
- Right on the CO_2 source (power plant, steel plant, cement factory, etc.)
- Situated in the vicinity of a CO_2 pipeline.

The injection of the cold CO2 for storage represents a priori a constant stimulation of the formation. In the first few months of the process, in which the temperature reduction has not yet produced, injection must take place in the so-called Frac regime, i.e. injection at high pressure on the well head (300-700 bar). After creation of a large crack in the formation, the well head pressure will decrease to an acceptable level. Initial simulations (Haefner, 2009) shows that this initial process will take 3-6 months (see Figure 3). In Figure 3 a relatively low injection rate was set at approximately 0.2 million t/a. At higher rates the temperature reduction will accelerate and the radial expansion will reach hundreds of meters.
The massive cap rock in the roof of the formation with its strong plastic behavior will assurance the sealing of the reservoir and prevents seismic impact on the overburden layers.

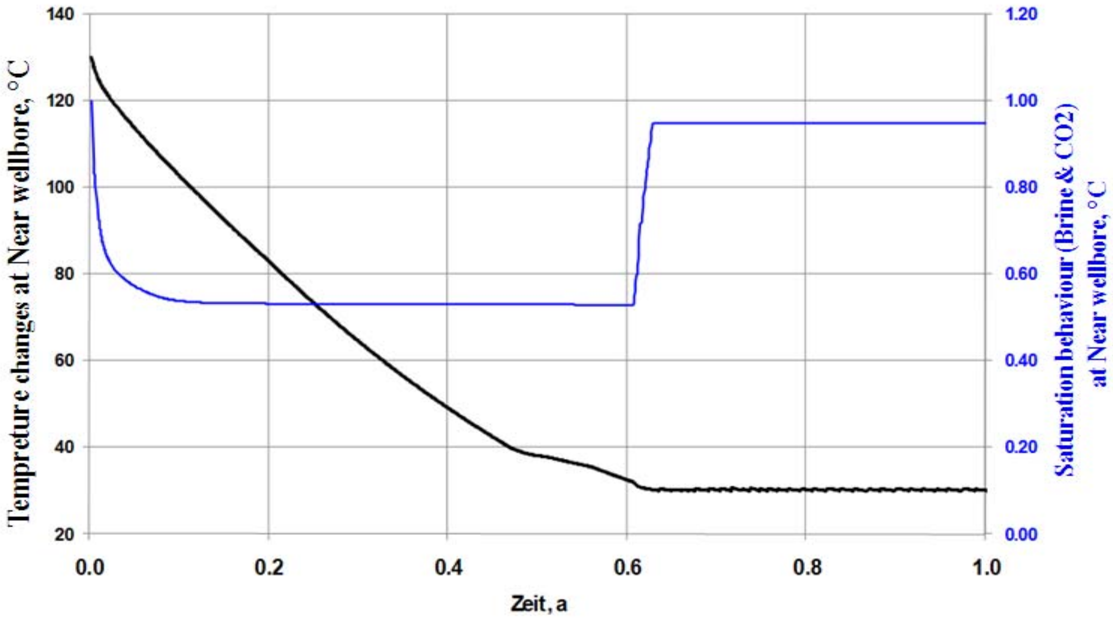

Figure 3: behavior of temperature and gas saturation in the vicinity of the injection well with CO_2-injection rate of 26.5 t/ h.

3 Conclusions

CO2 is liquid might be applied as fracturing fluid in tight reservoirs. This method would have several advantages in comparison to water fracturing. One of these advantages is the capillary pressure which is high in case of water and in tight reservoirs. In addition, the swelling of the clay in case of CO2 is not significant. Moreover and based on own simulation software the injection of liquid CO2 can lead to creating several fractures due to the thermal stresses which increase of porosity and which leads to increase in rock permeability. The amount of CO2 required to achieve an optimum fracturing should be determined. Additionally, the proppant required to keep the fractures open can be used in case of CO2.
Based on this study, CO2 is highly recommended in tight reservoirs.

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