Value Added Usage of Anthropogenic Carbon Dioxide in Oilfield Operations – New Applications in Unconventional Reservoirs

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Summary

In this paper, a number of carbon capture, utilization and storage (CCUS) techniques will be outlined which create economic benefit while at the same time sequestering a portion of the anthropogenic carbon dioxide (CO_2) used in the operation. These techniques, while not necessarily new to the oilfield, represent new applications to unconventional sandstone and shale reservoirs. These are examples of 'green technologies' and developed 'in Canada' solutions to greenhouse gas (GHG) emissions.

Introduction

Carbon dioxide and other greenhouse gas emissions have become a major challenge globally, and particularly for the oil and gas industry. Carbon capture, utilization and storage is one of the options to reduce the amount of anthropogenic CO_2 entering the atmosphere. This option creates economic benefit from the waste CO_2 vs. pure disposal for sequestration. Organic rich shale reservoirs are an attractive target for carbon storage, due to their adsorptive abilities and multiple mechanisms for gas storage.

CO_2 has been widely used in oilfield operations since the 1950's. The unique physical properties of CO_2 allow for easy transport in pipelines as a gas, or by transport truck as a cold liquid. Oilfield uses include: A gaseous agent to assist in fluid recovery from the wellbore / reservoir, a component in hydraulic fracturing fluids, an enhanced oil recovery (EOR) agent, a fluid blockage removal agent, etc. CO_2 is at least partially soluble in water and is a strong hydrocarbon solvent.

This paper will outline new oilfield applications for CO_2 usage, as well as identify the storage or sequestration mechanisms which retain a portion of the CO_2 injected. An example estimation of the volume of CO_2 sequestered will be shown.

Carbon Dioxide Storage Mechanisms in Shales and Sedimentary Rock

Organic rich shale reservoirs are an attractive target for carbon storage, due to their adsorptive abilities and multiple mechanisms for gas storage. It has been fairly accepted that carbon capture utilization and storage (CCUS) occurs through different mechanisms during EOR procedures. It is expected that similar mechanisms are at play during hydraulic fracturing in similar rock types. It would be difficult to predict what mechanism dominates or what percentage of CO_2 is trapped by each one of those mechanisms, but this study corroborates what many researchers have found about CO_2 sequestration. During EOR operations, large quantities of CO_2 are injected and will become sequestered (Sobers 2011). While the CO_2 volumes are much less, the same trapping mechanisms are at play during hydraulic fracturing operations.

It is known that high quality CO_2 based fluids used for hydraulic fracturing can significantly increase production by to up to 20% (Reynolds, 2015; Kong 2016). It is worth investigating the correlation between incremental production, organic content, pore distribution/permeability and CO_2 sequestration and how some of the same mechanisms could increase productivity while also having a CO_2 storage effect.

The literature has described three main mechanisms that affect CO_2 storage (Benson 2008, Clarkson 2013): structural trapping, adsorptive and capillary trapping, and solution trapping. The trapping is classified depending on the type of interactions: such as fluid/fluid or fluid/solid interactions in porous media, physical adsorption, homogeneous and heterogeneous reactions, or flow of CO_2 until geological seal is reached (Kang 2010).

New Applications of CO_2 in Unconventional Reservoirs

1) Hydraulic Fracturing

CO_2 has been used as an energizing agent in hydraulic fracturing fluids in Canada for many years. This is because many of the Deep Basin type reservoirs are under-pressured to a water gradient and may contain variable amounts of water sensitive clays. There are three important types of water induced damage mechanisms (Davis 2004), including: 1) Clay expansion; 2) Clay dispersion; 3) Aqueous phase trapping. Many of the tight shales being developed with multi-stage fractured horizontal wells have very low water saturations (sub-irreducible) and are subject to water imbibition and phase trapping. It has been estimated that in nano-Darcy shales, the threshold capillary pressure to remove water from the tight pore spaces may be as high as 10,000 psig (Penny 2012).

With the development of unconventional reservoirs using multi-stage fractured horizontal wells, there are many successful examples of CO_2 based fracture fluids used in completions. A search of the public data bases showed that from January 2005 to June 2016, CO_2 had been used in the completion of 997 multi-stage fractured horizontal wells in 27 formations across western Canada (Source: Canadian Discovery Fracture Database Oct. 2016).

New research into CO_2 fracturing of gas shales (Middleton 2015) suggests that CO_2 has distinct advantages over fracturing with water. The paper states that CO_2 will dramatically increase production through the following physical mechanism:

- Low viscosity and thermal fracturing will create more complex fractures;
- Miscibility with hydrocarbons and preferential adsorption of CO_2 vs. methane in organic rich shales;
- Physical blockage of tight pores and flow channels does not occur with CO_2 the way it does with water (capillary trapping);
- CO_2 sequestration during the fracturing phase (through adsorption in organics, dissolution into connate waters).

The following figure shows the physical storage sites in a gas shale, and how CO_2 interacts to release additional methane:

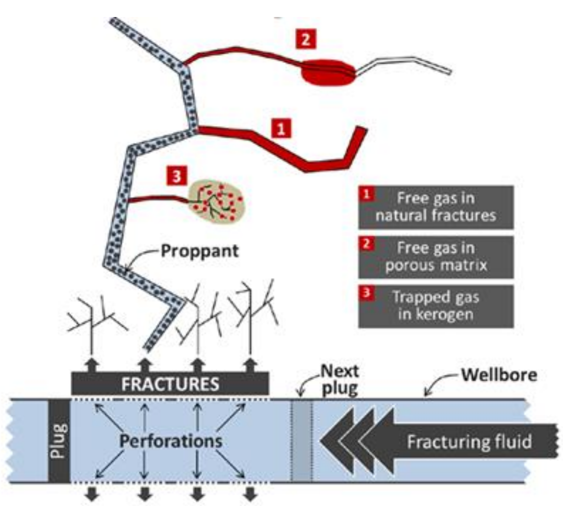
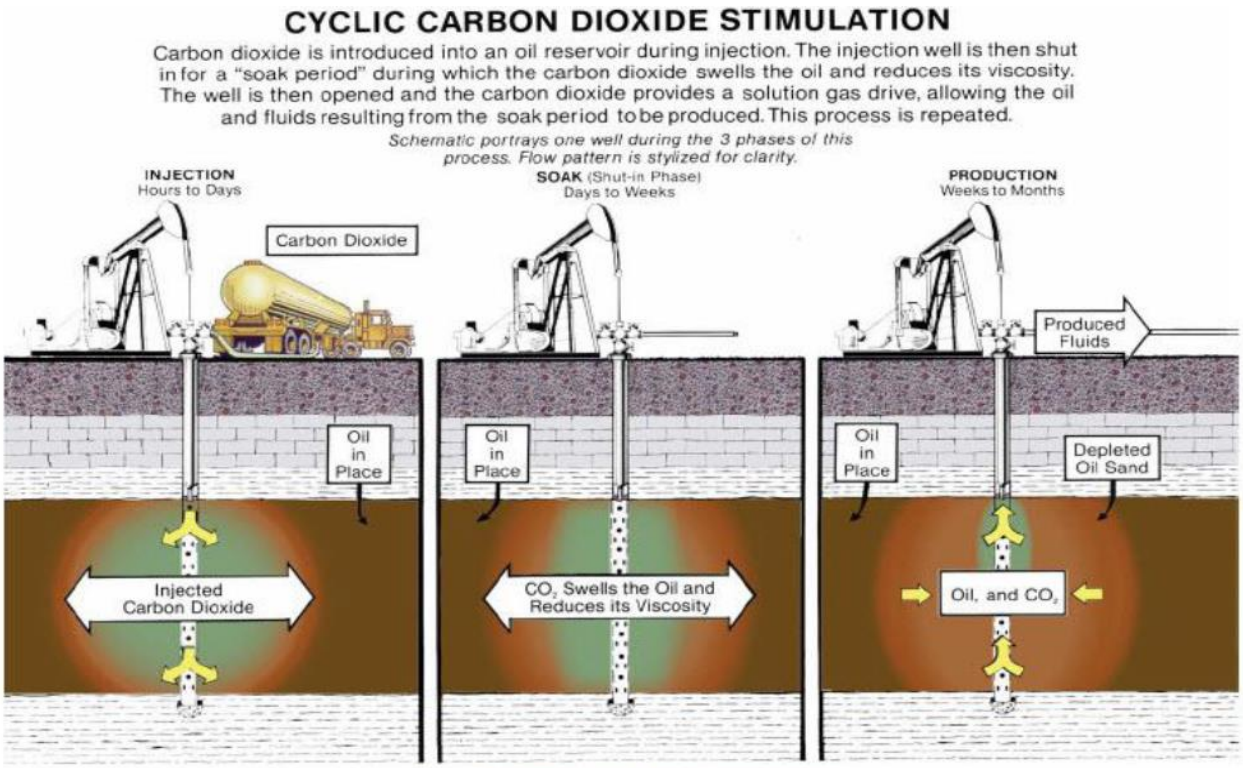


Figure 1 (Middleton 2015) – CO_2 may more efficiently extract gas from (1) and (2) since CO_2 is miscible with hydrocarbon thereby preventing multi-phase flow blocking, and from (3) since CO_2 can preferentially displace methane that is sorbed onto the kerogen.

2) Cyclic Solvent Injection (CSI)

Cyclic solvent injection (CSI) (sometimes called huff'n'puff) using CO_2 as the solvent is an EOR process which has been applied successfully for many years in both conventional light oil and heavy oil (Haskin 1989, Olenick 1992). A schematic diagram of how the process works is shown in Figure 2. More recently, there has been significant interest in applying this technology to tight oil and unconventional liquid reservoirs (Yu 2014, Wan 2013, Sun 2016, Jacobs 2016, Meng 2015).



SOURCE: http://decarboni.se/publications/technical-aspects-co2-enhanced-oil-recovery-and-associated-carbon-storage/13-recovery-methods-and-processes

Figure 2 – Three Steps of the CO_2 Huff'n'Puff Process

A huff'n'puff cycle consists of three phases: injection of the CO_2, a soak period where the well is shut-in, and a production period (Figure 2). Early in the injection phase, the injected gas is immiscible and some by-passing of the oil is desirable to get deeper penetration into the reservoir of live CO_2. Moveable water saturation is cleared from the near-wellbore area, resulting in more favorable relative permeability to oil during the production phase. At the end of the injection phase, the CO_2 is dispersed into the reservoir, the reservoir pressure is increased significantly. During the soak phase, mass transfer begins to occur between the CO_2 and the crude oil, where the oil swells in volume and lighter hydrocarbons are extracted. Depending on pressures, the CO_2 may become miscible with the oil, increasing the mixing with the crude. During the production phase, incremental production occurs as a result of oil swelling throughout the contacted region, viscosity reduction, etc. (Murray 2001). These steps are repeated for an economically optimum number of cycles. The second or third cycles often produce the maximum oil volumes, due to delayed diffusion and penetration of the solvent into the reservoir.

Cyclic solvent injection offers a number of advantages over other EOR techniques. A major advantage in times of low oil prices is: little or no capital investment in equipment is required. The process is also attractive because: 1) shorter project life so economics are better; 2) uses a smaller amount of CO_2 compared to a flood; 3) with tight zones, or poor inter-well communication this may be the only feasible process for incremental recovery (Bassioumi 2005).

Example – CO_2 Volumes Sequestered During Hydraulic Fracturing

Completion reports are publically available in Canada, so exact volumes of pumped CO_2 were available from the stimulation operations. Flowback information, including detailed recovered volumes of CO_2 and reservoir fluids were usually available in the same completion reports. A simple Cartesian plot of CO_2 Wellhead Content (%) vs. CO_2 Recovered (% of Injected) was found to yield a straight line – with the x-axis intercept indicating the total amount of CO_2 recovered during flowback and early production testing.

An example plot from the Montney formation is shown in Figure 3 below:

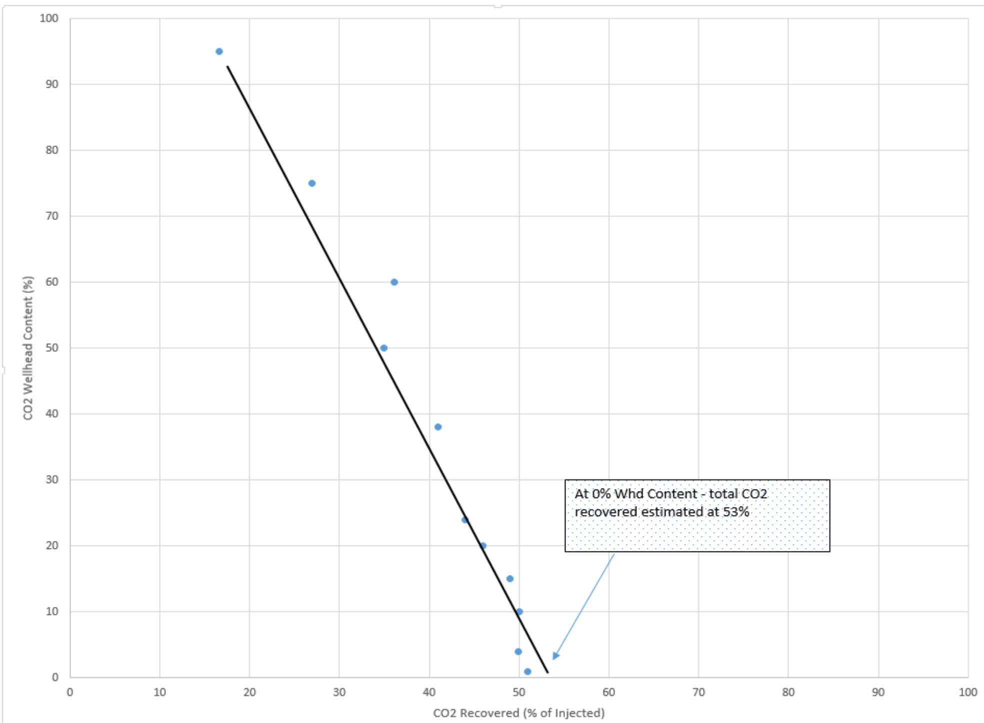


Figure 3 – CO_2 Recovered Volumes for a Montney Well, Glacier Field, AB

Conclusions

Carbon capture, utilization and storage is an economically viable technique to sequester a portion of the ever increasing volumes of anthropogenic CO_2. Information gathered from the literature has defined the many trapping mechanisms making organic rich shale and sandstone reservoirs an attractive target for CO_2 storage.

Multi-stage fractured horizontal wells in shales and tight sands provide a unique form of CCUS, involving the sequestration of a portion of the CO_2 during the fracture stimulation treatment using CO_2 based fracture fluids.

Cyclic solvent injection using CO_2 as the solvent offers an economical and technically feasible EOR technique for tight oil and unconventional liquid reservoirs. A portion of the CO_2 becomes trapped in the reservoir by the same reservoir mechanisms identified in this paper.

Both of these techniques offer value added ways to sequester CO_2 while enhancing well productivity and economics.

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