Potential of CO_2 Flooding in the Appalachian Basin

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INTRODUCTION

The Appalachian basin has had a long history of drilling for oil and gas. It has been the center of oil production for more than a century. Widespread and unrestrained drilling over the initial years after discovery has depleted the reservoir pressure of the region making it a suitable candidate for enhanced recovery processes because about 60-90% of the oil has been left stranded in the ground. The Appalachian basin has an estimated 10 billion barrels of oil still in place[1]. Although conventional methods have been exhaustively used, there is great potential in the basin in terms of enhanced oil recovery processes. According to the US Energy Information Administration, annual crude oil production in the Appalachian Basin, which includes the states of New York, Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, Tennessee, and Alabama, in the year 2008 stood at 22 million barrels of oil. Reservoir simulation that used data from the major oilfields throughout the region indicated that using advanced CO_2 EOR technology can recover about 1.23 billion barrels of the original 10 billion barrels still in place[1].

One method of EOR is CO_2 flooding. Injection of CO_2 into oil reservoirs may initiate oil displacement by a number of mechanisms. It consists mainly of two mechanisms. They are miscible and immiscible processes.

The miscible CO_2 process is a multiple contact process whereby the injected CO_2 mixes with the formation crude and forms a mobile fluid with low viscosity and low interfacial tension. Although CO_2 is not usually miscible with reservoir oil upon initial contact, it may create a miscible front similar to the lean gas process. Thus miscibility is initiated by the extraction of significant amounts of heavier hydrocarbons (C5 to C30).

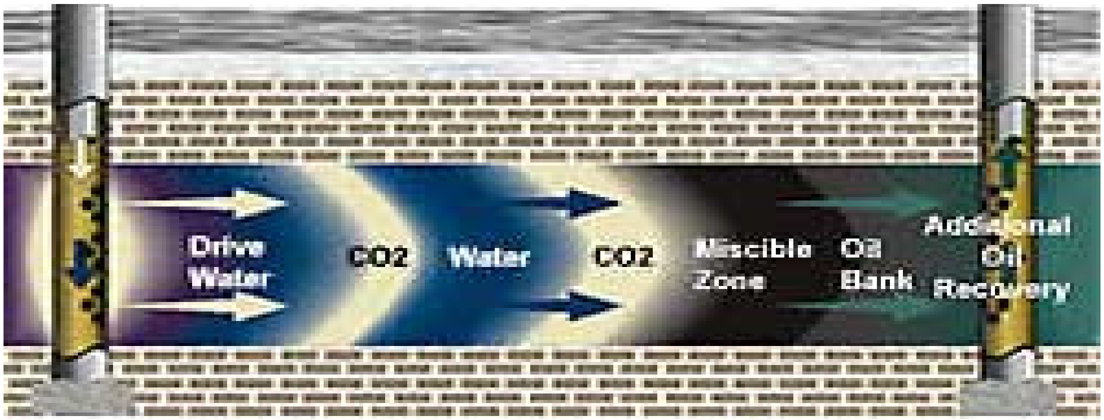
The other process is immiscible CO_2 flooding. At different reservoir conditions, CO_2 displacement may resemble enriched gas drive, i.e., CO_2 may saturate the reservoir fluids to such an extent that the in situ swollen crude is miscible with the trailing CO_2. The injected CO_2 does not does not mix with the crude but saturates it, thereby contributing to the swelling of the oil phase and an increase in the pressure drive in the reservoir[1].

There are advantages to CO_2 flooding over the other enhanced recovery methods such as polymer recovery, steam flooding etc. The main advantage is that the displacement efficiency is high in miscible cases and the process is aided by solution gas drive mechanism. Also it is useful over a wider range of crude oils than other hydrocarbon injection methods. Another advantage is that the miscibility can be regenerated if it is lost[2].

The primary purpose of EOR processes is to decrease the effective viscosity of the displaced fluid relative to the displacing fluid either by increasing the injected fluids viscosity (polymer flooding) or by decreasing the oil viscosity (thermal processes and immiscible CO_2 injection). CO_2 is highly soluble in hydrocarbon fluids and depending on the PVT conditions, a large amount of CO_2 will dissolve in 1 barrel of oil. For example, for a 17° API oil, over 700 scf of CO_2 will dissolve in 1 bbl of oil giving a 10-30% increase in its volume. This swelling of the oil results in less residual oil being left behind in the reservoir. Also as CO_2 dissolves into the crude, there is a large reduction in its viscosity. The CO_2 saturated oil can have viscosities $1/10^{th}$ to $1/100^{th}$ of the original viscosity. This makes it easier for the mobilization of the oil in the reservoir as well as increases the efficiency of the sweeping effect[2].

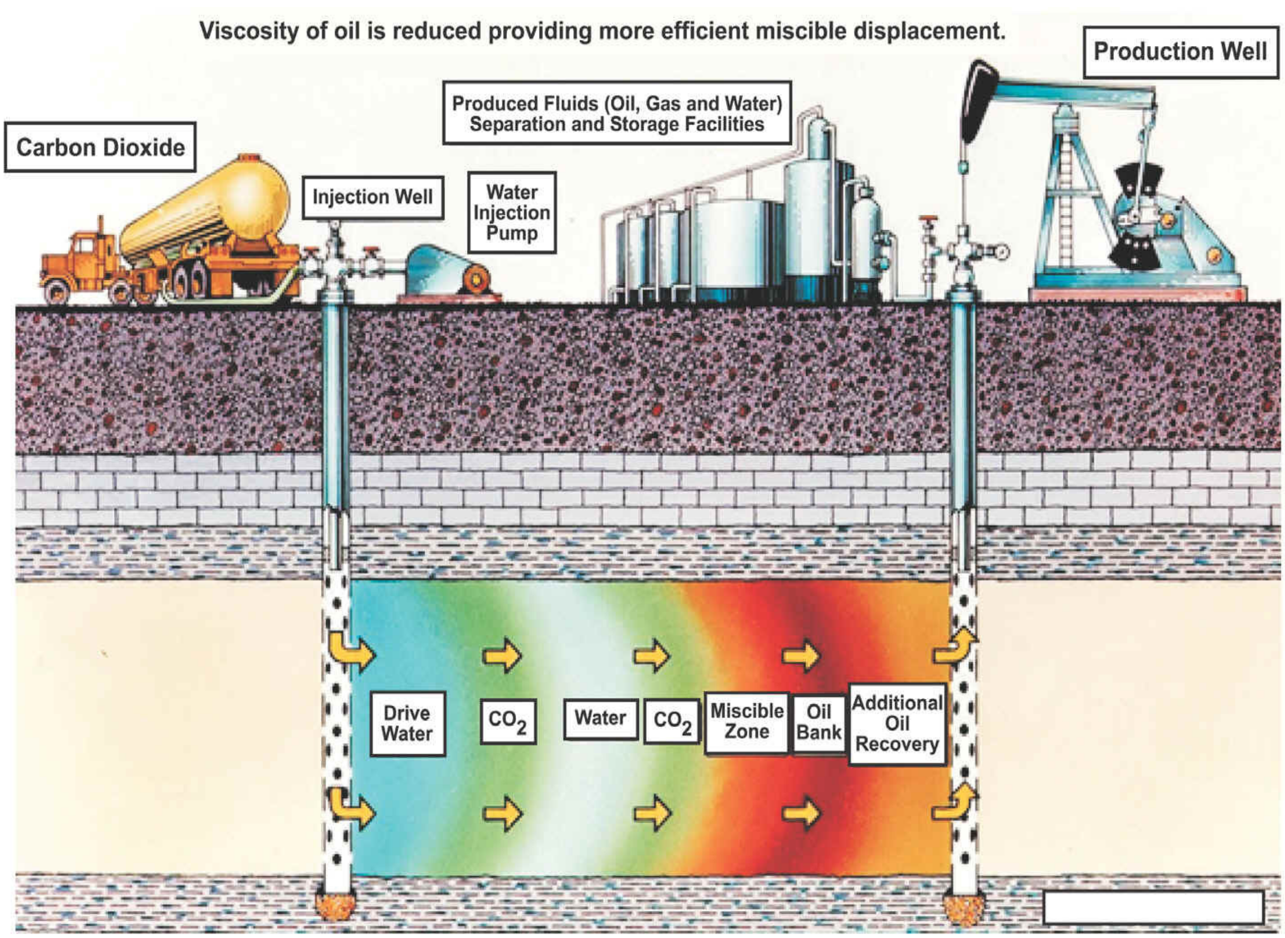
The following figures show the process of CO2 flooding in an oil reservoir. Carbon dioxide is injected along with water following a WAG strategy (water alternating gas) to increase oil production.

Figure 1: Process of Miscible CO_2 flooding



(Courtesy: www.enhancedoilrecovery.com)

Figure 2: Process of CO_2 flooding with surface equipment



(Courtesy: www.enhancedoilrecovery.com)

REQUIRED RESERVOIR PROPERTIES FOR CO_2 FLOODING

The oilfields have to be screened for different technological aspects before the process of CO_2 injection can be applied. Not all reservoirs are amenable to CO_2 flooding and require certain oil and reservoir properties. There are various criteria which have to be applied for the proper selection of the reservoir for CO_2 flooding and can be found in the oilfield literature. The screening parameters help us to efficiently eliminate reservoirs that are not suitable and thus provide a comprehensive list to work with. The parameters for the reservoir in question provide an approximate idea of applicable design and therefore each reservoir should be considered on an individual basis given its previous production and reservoir data.

The screening parameters have been divided based on the oil properties and the reservoir characteristics. Under the oil properties, the API gravity, the viscosity and the composition of the oil will be considered. Under the reservoir properties, the oil saturation, the formation type, net thickness and depth, average permeability and the temperature will be considered.

The first parameter in the screening of the reservoir under the oil properties is the viscosity at the reservoir conditions. For CO_2 flooding the viscosity of the fluid has to be less than 12 cp in case of miscible flooding and between 100-1000 cp in case of immiscible flooding. In case of viscosity for miscible flooding, the lower the value, the better it is. Less viscous crude increases mobility and helps to achieve higher sweep efficiency. The average value from current field projects is 1.5 cp. The second parameter is API gravity of the oil. It has to be greater than 30 API in case of miscible CO_2 process and greater than 22 API in case of immiscible CO_2 process. Higher gravity oil is better as the higher the value of this number, the more efficient the process will be. This is because a higher API gravity indicates that the crude contains lighter carbon molecules. This will help CO_2 to become easily miscible and the already light oils will have easily reduced viscosities. The average for current field projects is 36 API. Another parameter under oil properties is the composition of the oil. For CO_2 flooding, it needs to have a high percent of C5-C12 hydrocarbons[3].

Under the reservoir characteristics, the first parameter is the oil saturation as a percent of the pore volume. The value has to be greater than 20. The higher the value of this parameter, the better it is for CO_2 flooding. Current field estimates have the average value of 55. Another factor to consider would be the lithology of the formation. CO_2 flooding is well applicable in a carbonate or sandstone formation. The depth of the formation has to be greater than 3000 ft in case of miscible CO_2 flooding and greater than 2300 ft in case of immiscible CO_2. Another parameter is the original bottomhole flowing pressure. It has to be greater than 1500 psi for miscible CO_2 and greater than 1000 psi for immiscible CO_2 flooding. The net pay thickness and the permeability of the formation are not critical parameters in screening the reservoir for potential CO_2 flooding[3].

Given the reservoir properties, the question of miscible vs. immiscible process arises. Miscible CO_2 flooding is generally preferred over immiscible flooding. However, immiscible process is used and is advantageous in shallow formations, because it will not be possible to achieve the miscibility pressure required for miscible flooding at shallow depths. Thus miscible flooding is preferred but immiscible flooding is useful in reservoirs restricted by shallow depth.

The above technical parameters give us an approximation of the screening criteria. If the given reservoir or formation does not meet all the criteria, it cannot be considered for potential CO_2 flooding of the reservoir. It is interesting to note that the values of the porosity and the permeability of a given formation are not a critical factor in determining the potential of that reservoir to be considered for CO_2 flooding. The porosity is somewhat accounted for when we take oil saturation into consideration but permeability has no role to play when it comes to the screening criteria.

SCREENING SOME FIELDS OF THE APPALACHIAN BASIN

The Appalachian basin has a large number of oil and gas fields. According to the SPE paper 111282 by Bank, Reistenberg and Koperna, which contained a database of 190 oil reservoirs, 22 reservoirs were found as potential candidates for miscible CO_2 flooding and 46 candidates for immiscible CO_2 flooding. This research paper will examine at three major oil fields in each of the major producing Appalachian states. The Bremen oil field of Ohio, the Bradford field of Pennsylvania and the Cabin Creek field of West Virginia will be screened for potential CO_2 flooding. The data found for the above three oilfields was the most comprehensive and therefore used for the screening against the given criteria.

The Bremen Oil Field, OH

The Bremen oilfield includes parts of Rush Creek and Richland townships and extends from Bremen to New Lexington in Ohio. The Clinton sand formation is the source of oil and gas for this oilfield. According to the Geological Survey of Ohio and the SPE paper 14513, the Clinton sandstone is a low porosity, low permeability fine grained interbedded sandstone and siltstone with an average height of 35 feet in this field. The permeability is as low as 0.1 md and the average porosity is 8%. Against the given criteria, the average oil saturation of the field is 55% which meets the requirement. The viscosity of the crude is 3.92 cp at 110°F which again meets our criterion of being below 12cp. The depths of the Clinton sands range from 3000'-6000'. This depth provides enough hydrostatic to reach the miscibility pressure required for the process of flooding. The oil gravity of was found to be 40° API[9]. This is very suitable for CO_2 flooding because we want the oil to have an API higher than 26. This also shows that the crude contains lighter hydrocarbons which will aid in miscible displacement.

The Bradford Oil Field, PA

The Bradford oil field lies mainly in the north central part of the McKean County, PA and most of its production comes from the Bradford Third sand. The Bradford pool extends over an area of about 84,000 acres. Against the given criterion, the average oil saturation of the field from cores is 38%. This meets our criterion of being above 20%. Although the saturation value is a little low compared to the other fields, this field is a mature one with successful water flooding operations already conducted. This makes the Bradford field a good candidate for the tertiary recovery process of CO_2 flooding. The average depth of wells in the Bradford field range from 1800 feet to 2500 feet and this depth provides the required miscibility pressure. This again meets the given criterion. As for the oil properties, the viscosity of the crude is 42 cp at 100°F and the API gravity is 40°API. The higher values of the field again reassure us that it is suitable for CO_2 flooding either miscible or immiscible. The Bradford field has been providing a large part of the Pennsylvania crude. After the primary recovery mechanism and the water flooding projects, more than 120 million barrels of oil have already been produced covering about 40% of the production[4]. Therefore 60% of the original oil remains stranded in place and a considerable portion of it can be recovered using advanced CO_2 recovery technology.

The Cabin Creek Oil Field, WV

The third field under consideration is the Cabin Creek field in West Virginia. The Cabin Creek field is located about 20 miles southeast of Charleston, WV. The Berea sandstone is the oil bearing formation in the field. The Cabin Creek has had gas injection wells for increasing production, so it has had some experience in enhanced recovery process. The Bureau of Mines analysis states that the "cabin creek crude is a clear, light amber colored oil with an average gravity of 47°API at 60°F". Also the viscosity of the crude is 2.7 cp at 100°F [5]. The average depth of the formation is about 3000 feet. Also the oil saturation is found to be 54.9 % at the time of the end of primary and secondary production. Given the properties, this field is suitable for miscible CO_2 flooding. The oil recovered from CO_2 flooding in this field will be significant. Estimated cumulative production after primary and secondary production at the end of 1970 was equivalent to 25.6 % of the original oil in place. Although the Cabin Creek is a smaller field compared to the Bradford field, previous gas injection projects have recovered about 1 million barrels of oil which represents 8% of the original oil in place in this field. This leaves room for a lot more production from the field.

Table 1: Required Properties and the Screened fields

Property	Bremen	Bradford	Cabin Creek
Oil Saturation	55%	38%	54.9%
Viscosity	3.92 @ 110°F	42 @ 100°F	2.7 @ 100°F
API Gravity	40	40	47
Depth of Formation	3000'-6000'	1800'-2500'	3000'
High % of C5-C12	Yes	Yes	Yes

CO_2 SOURCES NEAR THE FIELDS

Carbon dioxide flooding has evolved as a technology and as a process with the industry getting more data, more experience and better technology. Currently, there are 86 CO2 EOR projects underway in the US with the bulk of them in the Permian Basin. The Midwest region of US has only three CO_2 EOR projects producing oil in the state of Michigan[6]. This leaves a large potential for implementation of CO_2 EOR in the Appalachian Basin. Using state of the art technology which includes injecting larger volumes of CO_2 (1 HCPV compared to 0.4 HCPV), using the WAG strategy for increased sweep efficiency and mobility and effective management and monitoring practices, it is possible to produce 1.23 billion barrels of additional oil[6]. This would require 5.6 Tcf of CO_2[1]. Therefore it is very important to identify sources of CO_2 that will provide the large volumes of the gas.

The Appalachian Basin and the US in general does not have a wide network of CO_2 pipelines that can be used to transport the gas. There is some infrastructure in the Permian Basin which provides EOR ready CO_2 but there is lack of it in other regions. The Appalachian Basin however has a large number of stationary sources of CO_2 such as coal burning power plants, chemical plants etc that can provide carbon dioxide to be used for injection.

The Appalachian Basin has a large number of coal fired power plants which emit millions of tons of CO_2. This carbon dioxide can be captured and supplied to the oil fields to be used for injection and oil recovery. For the three fields under consideration, there are many sources of CO_2 that can sufficiently provide the gas for injection. However the gas from these sources needs to be captured first and then transported to the fields. The Department of Energy/Energy Fossils is currently working on developing and implementing the carbon capture technology in the Michigan and Illinois basin and assuming it can be applied to the Appalachian basin, we can possibly get affordable cost CO_2 from the power plant sources[7]. This will help not only in getting large volumes of CO_2 but will considerably reduce emissions from large power plants thereby providing a boost to both industries. It will also bolster more research and investment in the carbon sequestration program.

The state of Ohio where Bremen oil field is located has 36 coal fired power plants. There are a couple of power plants located near Bremen and New Lexington. The most suitable, however are the Conesville Power Plant and Picway Power plant owned by American Electric Power. The Conesville plant has a capacity to provide 9.5 million tons of CO_2 which it emits every year. The Picway Power plant can provide about 500,000 tons of CO_2 to be used for injection[8].

The Bradford oil field located in Pennsylvania also has plenty of sources which can support injection requirements. The state has 78 coal fired generated units at 40 locations accounting for 40% of the state's electric generating capacity. The plants near the field includes the Bruce Mansfield Power station which emits about 17 million tones of CO_2, the Shawville Generating station with a capacity of 3.6 million tons and the Scrubgrass Generating plant which can provide about 1 million ton of carbon dioxide to be used for injection[8].

The state of West Virginia where the third field, the Cabin Creek field is located has about 20 locations of power plants. Two major plants located near the field are the Amos Plant and the Kanawha River plant. The Amos plant is capable of providing about 15 million tons of CO_2 and the Kanawha River plant has a capacity of about 2 million tons. This CO_2 which otherwise would have been emitted into the air can be used for flooding and enhanced oil recovery[8].

CONCLUSION

The Appalachian Basin has had the longest history of oil and gas drilling. The fact that the fields are mature and several of them have undergone waterflooding operations makes them promising candidates for carbon dioxide EOR. With 10 billion barrels of oil still remaining in place and the possibility of recovering 1.23 billion barrels of oil requiring approximately 5.6 Tcf of CO_2, it is important that the industry start looking into this area of oil recovery. The results from the fields screened above show that the basin does have potential for CO_2 flooding. Although only three fields were screened, the given properties are derived from the source formation and they can be assumed to extend homogeneously over the same formation. This shows that various other fields under the same formation can be possibly amenable to CO_2 flooding.

The CO_2-EOR process has been successfully applied to the Permian Basin in West Texas and has significantly improved production in that area. It is also being applied to fields in Colorado, Michigan and even Canada. Technical knowhow and experience from these fields can help to start the process of CO_2 recovery in the basin. There is also a great need for more comprehensive research that will look at all major fields in the region to determine the true potential of the region. In addition, studies that look into the economic feasibility of the process need to be conducted once the technical analysis is done. Given that the Appalachian region does not have a wide existing pipeline network for CO_2, initial capital costs may be high for CO_2 EOR. However, these costs can be offset by the large volumes of recovery. Also the investment in state of the art CO_2 technology will depend on the price of the oil at the given time. With low oil prices, these investments tend to take a backseat.

CO_2 EOR is a highly effective tertiary recovery process and the Appalachian Basin has great potential for it. Not only will the process provide a way to recover large volumes of stranded oil, it will also help in the capture of CO_2 emissions from highly polluting environments thus contributing to the overall effort of reducing gas emissions.

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