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Review of Enhanced Oil Recovery Methods and the way Forward

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ABSTRACT
The majority of studies and reviews show that primary drive mechanisms can extract about 20–30 percent of oil, while secondary recovery can reach up to 40 percent. However, modern enhanced oil recovery (EOR) techniques can recover up to 60–65 percent of oil. These enhanced oil recovery (EOR) strategies are basically made to recover oil are referred to as "**residual oil.**" This is the oil that can't be extracted with conventional methods (Primary and secondary recovery methods). The Quantity of oil recovered is determined by the quantity of oil produced as a result of the initial recovery [1]. According to the United States Department of Energy, the Quantity of oil available is only a third of the total oil accessible on the planet is produced. So, by employing EOR techniques, we will be able to produce more oil as demand rises while supply falls. The project is a research and experiment focused on developments in enhanced oil recovery techniques, with the goal of analyzing current procedures and determining what advancements have occurred in these approaches that have resulted in increased oil output.Experimenting and comparing (two of these techniques: direct carbon dioxide infusion and WAG injection) the recovery laboratory data from a series of core flooding laboratory trials, and finally the collected results are discussed.

Keywords: Enhanced Oil Recovery (EOR), CO2, WAG, and oil productivity.

I. BACKGROUND

According to the United States Department of Energy, global oil production accounts for only one-third of overall oil supply. As a result, we will be able to produce more oil utilizing EOR technology as demand rises. We are currently experiencing a supply shortage. A lot of study has been done in the field over the previous three decades. Since then, Enhanced oil recovery (EOR) systems have been developed. EOR strategies were used and compared to primary and secondary recovery, its efficiency on mature and depleted reservoirs was improved after the main recovery. Enhanced oil recovery is the process of increasing the oil recovery after primary recovery(the recovery carried out by the primary drive mechanisms) and secondary recovery done by water flooding. Many approaches, such as gas injection, chemical injection, ultrasonic stimulation, microbiological injection, or thermal recovery, can be used to improve oil recovery.

The research portion of this study aids in the review of all enhanced oil recovery approaches. And the experimental part aims at calculating the carbon dioxide and WAG injection recovery % on medium light oil.

II. PROBLEM STATEMENT

It is common knowledge that the term "easy oil" refers to oil that can be retrieved easily in populated areas, and that the Quantity of oil produced by primary recovery from these locations represents for just 20 to 30 percent of total available oil. [2] Petroleum companies are looking for oil in very remote areas, such as deep waters and areas where the temperature is below zero, and developing fields in these areas is very expensive. Instead, we can still produce the remaining Quantity of oil in existing fields by introducing enhanced oil recovery techniques and applying new technologies to increase the recovery factor. It is very expensive; instead, we may continue to produce the remaining oil in existing fields by implementing enhanced oil recovery techniques and employing new technology to maximize the recovery factor. Enhanced oil recovery techniques can extract millions of barrels of oil from existing fields, as they increase recovery up to 60% of the oil in the reservoir. Billions of dollars are invested

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in enhanced oil recovery research to get the most Quantity of recovery for the least Quantity of money from existing fields before moving to remote areas.

III. LITERATURE REVIEW

"Using enhanced oil recovery EOR technologies, the United States produced around 707,000 barrels of oil per day (BOPD) in 1998, accounting for nearly 12% of total national crude oil production."

Thermal EOR accounts for about 393,000 BOPD, or about 7% of the state's total output . The Quantity of oil recovered by carbon dioxide (CO2) EOR is roughly 196,000 BOPD, or about 3% of total output in the United States. Hydrocarbon miscible EOR (mainly natural gas injection) recovers around 86,000 BOPD, or about 1.5 percent of US production, while nitrogen miscible/immiscible EOR recovers about 32,000 BOPD, or about 0.5 percent of US production. Chemical EOR and microbiological EOR, which are still in the research stage, contribute for less than 1% of all EOR generation in the United States." [2]

Enhanced oil recovery techniques now account for nearly a third of Alberta's recoverable conventional oil reserves. As exploration opportunities deplete over time, the capacity to extract more from what has already been discovered has become more important as a source of increased oil supply. [3]

"EOR has gained popularity and the Oil & Gas Journal (Moriti) publishes a large survey every couple of years that shows that EOR output in Canada and the United States accounts for around 25% and 10% of total oil production, respectively, and is expanding." [4]

Oil prices are rising, and concerns about future oil availability have prompted a renewed focus in Enhanced Oil Recovery. Techniques for increasing the recovery factor from reservoirs by injecting some fluids into the reservoir to sweep out the residual oil. Some of these EOR techniques are now being used to produce significant additional oil. Other techniques, such as the MRI, have yet to have a commercial impact like microbial method. [5]

In general, EOR approaches are divided into two categories: (increasing the volumetric sweep efficiency and improving displacement efficiency). Poor sweep efficiency can be caused by reservoir heterogeneity or poor mobility. Mobility can be controlled by controlling the mobility of the injected fluid, which can be accomplished through polymer flooding, or by controlling the mobility of the desired fluid, which can be accomplished through thermal methods. The capillary force has a significant impact on displacement efficiency because it holds the oil in the reservoir matrix, so chemical surfactants, caustic alkaline flooding, miscible gases, nitrogen flooding, and microbial processes are used to reduce this action. However, many factors and answers to some questions must be considered before choosing the right technique. For miscible processes, use the following formula: What will the phase behavior of the reservoir fluid and the injected fluid be like? What is the projected phase(s) mobility? Will it be a first-contact miscible or an evolved miscible process?

What is the remaining oil saturation after water flooding for immiscible gas injection processes? What is the difference between residual and immiscible gas? What method will be used to drain fault blocks or strata with low permeability?

For chemical operations, how should the chemical slug be designed to provide the ultra-low interfacial tension required for effective displacement? What degree of adsorption will the chemical have with the clays in the reservoir rock? What is the salinity of the reservoir water, and how will it affect the chemical slug's activity during the process? How can the mobility of the oil and chemical bank be controlled?

What polymer concentration is required for mobility control in polymer processes? What percentage of the polymer slug will be absorbed by the reservoir rock's clays?

In the case of thermal processes, What are the expected thermal losses in the wellbore, cap and base rock, and formation water? Is it possible to manage the thermal front in the reservoir? Is it possible to adjust the reservoir pressure in the range required for efficient reservoir fluid heating? Can microbes that can be supported in the reservoir, use in-situ nutrients and/or oxidants,

create surfactants and polymers that will help the project achieve its aims be identified?

How will bacteria and/or their products be carried across the reservoir in a stable manner? Can the selected EOR method be implemented in the selected reservoir, given the reservoir rock and fluid environment already in place? Is it possible to implement this procedure in such a way that it produces a financially viable project?

Because other parts of these projects, such as geological, laboratory analysis, economic analysis, and project design, are included in these projects, answering the aforementioned questions is not enough to determine the proper technique. [5]

"The solvent and improved gas drive method," which may be separated into three

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approaches, such as Solventflooding, is one of the other strategies utilized for enhanced oil recovery.

i. Solventflooding.
ii. Enriched gasdrive.
iii. High pressure gasdrive.

Some of the factors responsible for increasing the carbon dioxide recovery factor are:

a. It promotes swelling.
b. Reduce viscosity.
c. Reduce oil density.
d. Vaporize and thus remove parts of the oil.

Here are the features that improve recovery:

a. Carbon dioxide is very soluble in water.
b. There is an acidic effect on the oil.
c. Carbon dioxide is transported.

In addition to the above:

i. Remove swabbing.
ii. Provides quick silt cleaning.
iii. It prevents and removes emulsion blocks.
iv. Increase the maturation of carbonate formations.
v. It prevents swelling of the clay as well as rainwater and aluminum hydroxides.

Carbon dioxide is used in EOR processes due to the combination of driving gas solution, fat burning, viscosity reduction, and mixed effects caused by hydrocarbon emissions.Carbon dioxide is highly soluble in hydrocarbons, causing the oil to swell; however, in methane-bearing reservoirs, less carbon dioxide dissolves in the crude oil, resulting in less oil swelling.

When reservoir oil is saturated with carbon dioxide at high pressures, the viscosity of the oil in the reservoir decreases significantly. The water in the formation is also affected by carbon dioxide, and some expansion occurs for the water, causing the density to decrease. As a result, both oil and water densities decline after carbon dioxide injection, bringing their values closer together and lowering the effect of gravity segregation.

As shown in Figure 1, a water alternating gas can be made up of a mixture of CO2 and water (WAG). This technique, which will be used later in this project, may be able to provide more favorable mobility ratios. [6]

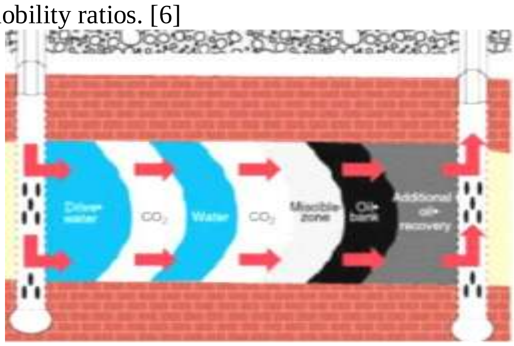

Fig.1: Water Alternating Gas WAG [7]

The following are the most common EOR approaches utilized today, as listed below:

GAS INJECTION

Gas injection is the most widely employed technique in the world; in the United States alone, gas injection techniques account for about half of all EOR production, and it has proven successful in a wide range of oil reservoir types. [9]

The following are the objectives of the gas injection: [8]

Ensure that the reservoir pressure is restored.
Increase output of oil.
Reduce your operating costs.
Gases used in injections include: [8]
Carbon dioxide (CO2) (the most popular).
Air / Nitrogen
Hydrogen.

Types of gas injection: [8]

a. Gas injection into a gas cap: In order for this to happen, there must first be a gas cap, or a gas cap that has formed during primary recovery when oil and gas are separated, generating a gas cap. Gas is injected into the gas cap above the oil zone in this kind of injection, which serves to maintain reservoir pressure and force the oil to flow towards the producing wells.
b. Gas injection in an oil zone: Because there is no gas cap in an oilzone, the injected gas is injected radially into the oil phase, sweeping the oil from the injector in the direction of the producer.

The degree of success of a gas injection project is determined by the following factors:

The mechanism by which the gas displaces the oil (displacement efficiency).

The interaction of the injected fluid with the reservoir volume (sweep efficiency).

The displacement process of gas injection can be miscible or immiscible. The temperature and pressure conditions of the injection determine this. It can also be mixed with water to form a water alternating gas (WAG)

CARBON DIOXIDE INJECTION

The displacement of oil by CO2 injection is dependent on some mechanisms related to the gas behavior of the CO2 and the crude mixture, the most important of which is the reservoir temperature and pressure. We have four phases, but only phase one (below the miscibility pressure) will be discussed, as shown in figure 2. [10]

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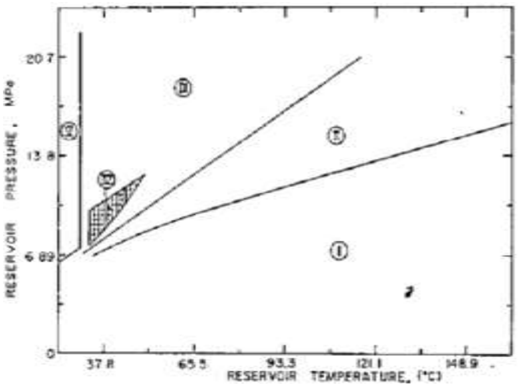

Fig. 2: The effect of reservoir temperature and pressure on carbon dioxide injection recovery mechanism. [10]

Recovery Mechanism

The following factors help in increasing oil recoveryin the immiscible CO_2injection [10]

A. Swelling of oil.
B. Reduced viscosity
C. Blowdown recovery .
D. Increasedinjectivity

Swelling of oil: Carbon dioxide is soluble in hydrocarbons, but the amount depends on the saturation pressure, crude composition, and reservoir temperature. The dissolution of CO2 in the crude will increase the volume of oil by up to 40%, lowering the value of the residual oil and increasing recovery.

Reduced viscosity: The reduction in crude oil viscosity occurs when carbon dioxide gas saturates the crude, so crudes saturated with carbon dioxide are easier to sweep than crudes not saturated with carbon dioxide gas; this is for miscible injection.

Blowdown recovery: This mechanism is somewhat complicated because the pressure decreases with production (flooding termination). While sweeping the oil to the wellbore, carbon dioxide gas will be released from the solution.

Increased injectivity (increased permeability): When carbon dioxide and water react, acidic content is formed, which reacts with carbonate portions in the reservoir, causing some of the formation's matrix to dissolve, increasing the permeability of the rocks. However, these acids may also react with the asphaltene, causing it to precipitate and plug the pore spaces, causing a significant reduction in permeability, so a thorough study is required.

WAG (Water Alternating Gas)

Almost all gas injection projects use the WAG method; it is reported that the US has the largest share of WAG application, followed by Canada, and it can be applied to various reservoir types such as sandstone and chalk. In the WAG processes, CO2gas is used 47 percent of the time, followed by hydrocarbon 42 percent of the time. [11]

WAG is a combination of water flooding and gas flooding; it was first used in the field by Exxon Mobil in Alberta in 1959 to increase recovery by injecting miscible gas after water flooding; it works by dissolving the injected gas in the residual oil, increasing the Quantity of oil that can be recovered.[11]

IMMISCIBLE WATER ALTERNATING GAS (IWAG)

The efficiency of IWAG oil acquisition can be higher than that of floods due to one or more of the following methods [12]:

- Improved volume sweep with gas following gas. The presence of free gas in the perforated area makes it possible for water to enter three-dimensional areas less than water and oil reservoirs only allowing diversion of water to unsweptarea previously.
- Reducing the viscosity of the oil due to the melting of the gas makes the flow rate of the oil evaporation better in the state (initially) under saturated oil.
- Inflammation of the molten oil causes the remaining oil to contain less oil in the stock market and thus increase recovery even when there is no other way to reduce the excess oil residue (Sor).
- Reduction of Interfacial tension (IFT) (gas-oil IFT is lower than water-oil IFT) in principle allows gas to remove oil through small passages that cannot be reached by water alone under the existing pressuregradient.
- Reduction of residual oil loss due to three stages and effects of hysteresis. In wet rock, gas trapping during mbibition cycles can lead to oil accumulation at low concentrations and effective reduction of the remaining oil saturation of the three phases.

THERMAL TECHNIQUES

Thermal techniques are mostly used for heavy oil reservoirs; heat is introduced into the reservoir via steam, and the heat applied is used to reduce the viscosity of highly viscous fluids, allowing the oil to flow more easily and be produced more easily. According to Dolberry Oil, steam accounts for 52 percent of the market methods used for EOR. In comparison to gas injection, carbon dioxide is at 31% and nitrogen is at 17%. Steam adds pressure, which increases oil

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production because the extra heat aids in the loss of crude oil in the "pay zone" surrounding the well.
The following are the various types of thermal recovery [6]:

a) Hot fluid Injection: Hot fluids, such as hot water and steam in their saturated or superheated forms, are injected into the reservoir, which should reduce the viscosity of the heavy oil and increase recovery.
b) In-situ combustion :It is accomplished by injecting air or oxygen-containing gas into the reservoir and burning a portion of the crude in the formation, thereby increasing the Quantity of residual oil produced. It is recommended for reservoirs with high oil saturation, high porosity, good permeability, and oil with a viscosity of less than 1.0.
c) Cyclicsteam :Cyclic steam injection is a single well process that involves injecting steams for 2 to 6 weeks into a producing well after a short soak period of 3 to 6 days, after which the well produces at a higher rate for several months to a year, also known as the huff and puff method (Figure 3).

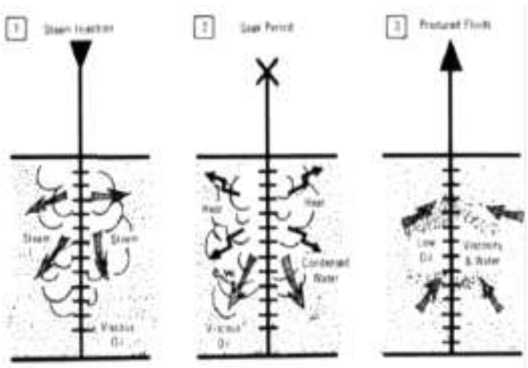

Fig 3.cyclic steam injection (huff and puff) method

Microbial Enhanced Oil Recovery (MEOR)
It is a new technology being developed in the oil and gas industries to improve oil recovery. It is accomplished by modifying the function and structure of the oil reservoir.
The following are some of the benefits of this technique:

i. Increase in oil output.
ii. It doesn't necessitate a lot of changes to the facilities.
iii. Environmentally friendly
iv. When compared to other techniques, it is regarded as inexpensive.

Research Methodology
To achieve the goals of this research, research and study were conducted while reviewing technical papers from the Society of Petroleum Engineers (SPE), reference books, the internet, and, finally, laboratory experiments at Rivers State University Petroleum Laboratory.

The apparatus used in the experiment
The following tools are used to conduct this research:

1. Porperm (Porosity - permeability testing device).
2. 800 RPS (Relative Permeability System).

IV. EXPERIMENT

For Porperm
The POROPERM tool is a permeameter and porosimeter used to determine the characteristics of the main plug-sized samples at a closed pressure of 400 psi. In addition to direct property measurement, the instrument's user-friendly Windows-based software provides reporting and calculation capabilities. Measurements:

i. Pore volume Vp(cc).
ii. Sample Porosity(%).
iii. Sample bulk volume Vb(cc).
iv. Grain volume Vg(cc).
v. Graindensity(g/cc).
vi. Gas permeability Kg(mD).
vii. Liquid permeability K(mD).
viii. Slip factor “b”(psi).
ix. Inertial resistivity(ft-1).
x. Turbulent factor(μm).

The measurement is based on the unsteady state method (pressure falloff), and the pore volume is calculated using Boyle's law.
Table 1 lists the specifications of poroperm equipment .[13]

Table.1: Specifications of the Poroperm device.

Item	Type / model / specification
Confining Pressure:	400 psi
Pore Pressure	250 psi
Core diameter	1" or 1.5"
Core length:	1" to 3"
Permeability Range	0.1 to 5000 mD
Porosity Range	0.01 to 60%
Power	110 / 240 VAC, 50 or 60 Hz
Air	125 psi (dry)
Gas supply	400 psi nitrogen or helium

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RPS 800

The TEMCO RPS-800-10000 HTHP Relative Permeability Test System is intended for determining the permeability and relative permeability of core samples under in-situ pressure and temperature conditions.. The system can perform initial oil saturation, secondary water flooding, tertiary water flooding, permeability, and relative permeability tests. Brine, oil, or water can be injected into and through the core sample. Refer to the D-1558-2/PLUMB flow/plumbing diagram for more information. This system's core holder can also be installed in an X-ray core scanner for in-situ measurement. Test conditions at 177°C (350°F) can include up to 10,000 psig flowing pressure and up to 10,000 psig overburden (confining) pressure. Individual pressure transducers are used to measure the pressure at the core sample's inlet/outlet as well as the overburden (confining) pressure. A differential-pressure transmitter, on the other hand, is used to measure the differential pressure across the core. After the back pressure regulator, fluids produced by the core sample are collected in a beaker, or the fluids are injected into a two phase separator for pressure and temperature production measurement.

The system can also be used to measure gas or liquid permeability. A single phase of gas can be injected through the core sample. Two fluids can be injected at the same time to determine relative permeability.

Fig. 4: A Poroperm device

V. DATA

The laboratory Experiment

In this laboratory experiment, two cores were used; one for the direct CO_2 injection and the other one for WAG injection, both of the cores are barite sandstone (Table. 2)

Core-1

Weight	188.032 g
Diameter	37.85 mm
Height	77.12 mm
Permeability	125.3 mD
Pore volume	14.394 cc
Porosity	16.588 %

Core-2

Weight	188.834 g
Diameter	37.87 mm
Height	77.75 mm
Permeability	35.579 mD
Pore volume	15.171 cc
Porosity	17.323 %

Core-3

Weight	178.113 g
Diameter	37.95 mm
Height	75.32 mm
Permeability	201.842 mD
Pore volume	17.344 cc
Porosity	20.363 %

VI. DISCUSSIONS AND OUTCOMES

Table 2 displays the Poroperm device's results for core-1, 2, and 3. However, because this experiment compares two EOR techniques, core-2 was replaced by core-3, so the permeability value should be close. The difference in permeability between core-1 and core-2 is enormous in this case, and it will undoubtedly affect the results. The core was replaced by core-3, which has a permeability value comparable to core-1, yielding a more comprehensive result.

THE EXPERIMENT OF THE RPS

Failure of Core-1 (CO_2injection)

The core was plugged into the RPS machine; all valves were tested and checked; the cylinders were charged with the injected fluids; The injection parameters (Table.3) were set, inlet pressure 800 psi, over burden pressure 1200 psi, water (brine) was injected at 800 psi and 2 ml/min, until the core was fully flooded with water, then the oil valves were opened. So we calculate the Quantity of water extracted, which is how we know how much oil is in the core; the Quantity of brine recovered 5.03 ml should be subtracted from it (the tubing size from the core to the beaker), and then the CO_2 injection begins.

Table.3: Parameters for injection

Inlet pressure	800 psi
Overburden pressure	1200 psi
Injection rate	2 ml/min

CALCULATIONS
Brine Recovered = 12.80 ml
Oil in place = 12.80 - 5.03 = 7.77 ml
Water Injection (secondary recovery)
Quantity of oil recovered = 7.4 - 5.03 = 2.37
Water injection percentage recovery (secondary recovery) = 2.37/7.77 = 30.5 percent of oil recovered using the water injection technique
Quantity of oil remaining after the water injection = 7.77-2.37 = 5.04 ml
CO_2Injection
Quantity of oil recovered = 1.3 ml

During the experiment, the carbon dioxide gas cooled and plugged the tubings, resulting in fictitious results; the experiment was repeated to obtain the correct results.
SUCCESS OF CORE-3 (CO2INJECTION)
The same procedures as in the first run were repeated, but with different core parameters; the results will be slightly different but still within the same range, as expected.
Quantity of waterrecovered= 14.8 ml
The Quantity of oil in place= 14.8- 5.03= 9.77 ml
Total PV= 17.344

Water Injection (secondary recovery)
Quantity of oil recovered by water inj. = 4.28 ml
Recovered percentage = 4.28/9.77 = 43 % of oil has been recovered using the water injection technique.
Oil remaining after the secondary recovery = 9.77-4.28 = 5.49 ml
CO2 injection
To avoid cooling of the gas and plugging the tubings time heaters are used which gives the results mentioned below;
Quantity of oil recovered = 3.4 ml
The percentage recovered = 3.4/5.49 = 61.9 % of oil has been recovered using CO2 injection technique
CORE-1 (WAG) SUCCESS
Following the water flooding, the core was alternately flooded with CO2gas and water. The experiment was carried out at a 9 ml/min injection rate and pressures ranging from 800-900 psi, the WAG process was carried out at a ratio of 1:1, with a slug volume of 0.6 PV, and 6 cycles were carried out due to time constraints (Table.4)

Table.4: Ratio, slug size and Injection parameters

Inlet pressure	800 – 900 Psi
Overburden pressure	1200 Psi
Injection Rate	9 ml/min
Injection Ratio	1:1
Slug size	0.6 PV

Water displaced due to oil injection = 13– 5.03 = 7.97 ml is also the Quantity of oil in place.
Water injection (secondary recovery)
Early water break through occurred during the brine injection, resulting in a high water cut and a low recovery. considerably
Quantity of oil recovered = 6.8 – 5.03= 1.77
Percentage recovery = 1.77 / 7.97 = 22.2 % of oil has been recovered due to the water injection, it is considered low as compared to the first core but this maybe as a result of the uncleanness of the core from the first failed run due to the time constraint in the lab time.
Water alternating gas injection (WAG)
Quantity of oil in place before WAG injection = 7.97 – 1.77 = 6.2 ml
Quantity of oil recovered using WAG injection = 3.30 ml
Percentage recovery = 3.3 / 6.2 = 53.2 % of oil has been recovered using the WAG technique

DISCUSSIONS (COMPARING THE OUTCOMES)
The two techniques employed in this study are now widely used in the oil and gas industry. The experiment was designed to put both techniques to the test and compare them in terms of oil recovery. Water was injected into the experiment to simulate the real case, but it is not for discussion. The direct carbon dioxide injection performed better in terms of oil recovery, recovering approximately 62 percent of the oil that was originally in place, whereas the WAG injection recovered approximately 54 percent of the oil that was originally in place (Figure.5). Table.5 displays the results.

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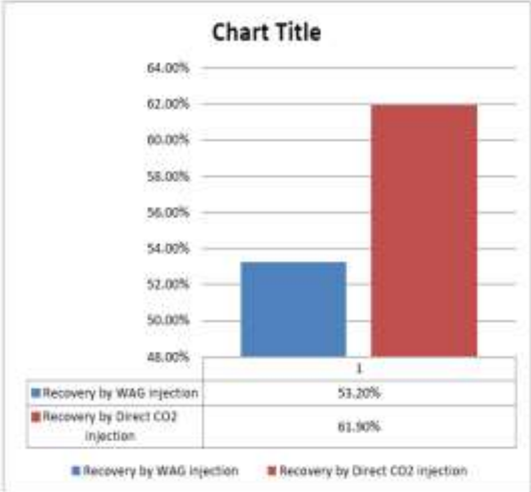
Table.5: Recovery percentage from different core samples

Exp	Core 1	Core 3
Recovery by Water injection	22.3 %	43 %
Recovery by Direct CO2 injection	-	61.9 %
Recovery by WAG injection	53.2 %	



VII. CONCLUSIONS

Enhanced oil recovery techniques research is critical these days because it will help us produce unrecovered oil to aid in the advancement of humanity. EOR techniques have the potential to produce 50–60% of the oil that is currently in place, providing us with fuel for the next several decades. The recovery from direct CO_2 injection is greater than the recovery from WAG injection.

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