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Production and Economic Analysis of Enhanced Oil Recovery (EOR) by Water Flooding: A Case Study of Reservoir OD-48 in The Niger Delta

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Abstract

Water flooding aids in the recovery of a large volume of oil that would have been dissipated in a depleted oil reservoir. In this paper, the production and economic potentials of Niger delta Reservoir OD-48 have been used to depict it. Reservoir OD-48 had oil originally in place as 9.7457 MMSTB. The oil remaining in the reservoir as at the period that the reservoir innate energy was not sufficient enough to produce oil was 3.51 MMSTB. The reservoir is currently considered as an abandoned reservoir with the left-over oil inside. From the current investigation, it is observed that if a second oil recovery activity is carried out on the reservoir, part of the left over oil will be retrieved. Following the conditions given, about 1.77 MMSTB of the 3.51 MMSTB of oil in Reservoir OD-48 would be produced during the breakthrough time of 760 days. Furthermore, acknowledging the economical facet of the project, Reservoir OD-48 is acceptable for investment. The NPV analysis carried out showed that the NPV of Reservoir OD-48 at an interest rate of 10% is $10.52 million. Considering that the NPV at a breakthrough time is greater than zero, the project is economically beneficial.

***Keywords**: Water flooding; Water injection; Enhanced oil recovery; Economic analysis.*

1. Introduction

Enhanced Oil Recovery (EOR) can be defined as the recovery of oil through the introduction of a fluid that might be original to the reservoir [1]. EOR is a process used to enhance the constructive life of an un-commercial oil-field. It is commonly adopted after recovery by alternative, less uncertain, and more typical approaches i.e. pressure depletion and waterflooding [2]. Few reservoirs are susceptible to EOR. Adequate screening systems must be used to analyse appropriate candidates. As integrals of the screening, depreciated cash-flow forecasts are customarily performed to appraise profitability. At the basis of this projection is an evaluation of oil recovery achievement or performance. All of the currently feasible EOR is established on one or more of two assumptions: developing capillary amount means and decreasing the mobility ratio as regards to their water flood estimates [1]. Developing the capillary amount means, radically speaking, decreasing the oil-water interfacial tension. The fluid mobility may be decreased by developing the viscosity of water, decreasing the viscosity of the oil, decreasing the permeability of water or all inclusive [3].

The migration of reservoir streams to the surface via the wellbore needs the mechanism of natural dynamic phenomena. In the initial production life of a well, the dynamic force is innately arising from the coalescence of gas expansion deliquesced in the oil, supposing is at the pressure below the bubble point; Gas cap expansion; The enlargement of an aquifer under build-up; The lone-phase expansions of the subsurface rock and of the streams: under-saturated oil, gas or water following a decline in pressure (compaction drive). The artificial lift has dominant adverse circumstances in conditions of recovery supposing the reservoir is acquiesced to become drained. A fluid introduction into the reservoir enables the pressure to be sustained. It is achieved by introducing gas or water into the reservoir by means of a single wellbore and generation of oil or gas through a different wellbore. Without a doubt, the most basic fluid introduced is water due to its availability, little cost and immense specific gravity which aids injection. By introducing the water into the producing structure, an operation known as water flood, a product of flow and well bore pressure is sustained by expelling the generated oil [4]. The process of water injection produces approximately 80-85% of the surplus oil generated [1].

Several recent studies have been conducted in line with this current investigation. Aghaeifar *et al.* [5] investigated smart water injection as an EOR technique in a high temperature offshore oil reservoir. Huang *et al.* [3] investigated the use of waterflooding for the recovery of gas from glutenite resersoirs. Wang *et al.* [6] conducted an experimental investigation on water flooding and continued EOR techniques in buried-hill metamorphic fractured reservoirs. The current study is focused on a reservoir in the Niger delta region of Nigeria. The aim of this study is to evaluate the production and economic potentials of Niger delta Reservoir OD-48. This study is important as it comes at a time when the concerned effort is being channelled towards financial sustainability in the country.

2. Methodology

2.1. Analysis of oil recovery

2.1.1. The efficiency of the overall recovery

The overall or total recovery factor efficiency RF, either secondary or tertiary oil recovery approach, is defined as the product of the consolidation of threes singular efficiency constituents as denoted by the ensuing theorised expressions which are shown in Equation 1.

$RF = E_D E_A E_V$ (Eqn. 1)

The cumulative or aggregate production, Np is given as Equation 2

$N_p = N_S E_D E_A E_V$ (Eqn. 2)

where RF = overall or total recovery factor; N_S = original oil in place at the beginning of the flood, STB; N_P =cumulative or aggregate oil produced, STB; E_D = the displacement or expelling efficiency; E_A = areal sweep efficiency; E_V = vertical sweep efficiency.

E_D, which is the displacement efficiency, is the part of the movable oil that has been moved from the swept zone at a given period or pore volume introduced. Considering the fact that an immiscible gas introduction or waterflood will constantly leave surplus oil, therefore E_D will consistently be lower than 1.0. A segmented area of the arrangement that is swept by an expelling/displacing fluid is known as Areal Sweep Efficiency E_A.

2.1.2. Oil recovery

The oil produced, prior or subsequent to breakthrough = $N_S E_D E_A E_V$.

When the prior saturation of gas;

$S_{gi} = 0,\ E_D = (S_w - S_{wi})/(1 - S_w)$ (Eqn. 3)

At the point of Breakthrough,

$E_{DBT} = (Sw_{BT} - S_{wi})/(1 - S_{wi})$ (Eqn. 4)

$(N_p)_{BT} = N_S E_{DBT} E_{ABT} E_{VBT}$ (Eqn. 5)

Supposing E_A & E_V amounts to 100%

$(N_p)_{BT} = N_S E_{DBT}$ (Eqn. 6)

Prior to Breakthrough, $S_{gi} = 0$, production of water, $W_p = 0$, and water flow rate, $Q_w = 0$

Subsequent to Breakthrough $S_{gi} = 0$, E_A , E_V = 100%

$E_D = [(PV)(S_{oi}/B_{oi}) - (PV) S_o (S_o/B_o)] / [(PV)(S_{oi}/B_{oi})]$ (Eqn. 7)

$E_D = [(S_{oi}/B_{oi}) - (S_o/B_o)] / (S_{oi}/B_{oi})]$ (Eqn. 8)

where B_{oi} = the formation volume factor of the oil at the commencement of the oil, bbl/STB; S_{oi} = initial saturation of the oil at the commencement of the flood; S_o = the average/mean saturation of the oil in the flood pattern at a given position whilst in flood.

At a consistent Formation Volume Factor of Oil

$E_D = (S_{oi} - S_o) / S_o$ (Eqn. 9)

Original Saturation of Oil

$S_{oi} = 1 - S_{gi} - S_{wi}$ (Eqn. 10)

For the swept area, the saturation of gas is taken to be zero.

$S_o = 1 - S_w$ (Eqn. 11)

Substituting the derived equations into Equation 9,

$E_D = (S_w - S_{wi} - S_{gi})/(1 - S_{gi} - S_{wi})$

S_w = average or mean saturation of water in the swept region/area, S_{gi} = initial saturation of gas at the commencement of the flood. S_{wi} = initial saturation of water at the commencement of the flood; assuming there is no prior gas at the beginning of the flood.

$E_D = (S_w - S_{wi})/(1 - S_{wi})$ (Eqn. 12)

Just as the value of S_w rises at various phases of the flood, E_D increases also up till the point where it approaches its peak when the mean saturation of oil in the region of the flood sequence/pattern is decreased to the remaining oil saturation S_{or} or equitably when $1 - S_{or} = S_w$. The value of E_D will gradually boost with the amount of water saturation in the reservoir increasing. The hindrance definitely lies with establishing a method for arbitrating the increase in the amount of average water saturation in the swept region/area as a function of the aggregate water introduction (or introduction time/period). The Fractional Flow equation was developed to provide the fundamentals for such a relationship by Buckley and Leverett [7].

2.1.3. The areal sweep efficiency

The fraction of the absolute flood pattern or arrangement that is interfaced with the displacing fluid is known as Areal Sweep Efficiency. It gradually increases with an injection at level zero at the beginning of the flood up to the time of breakthrough; subsequently, E_A maintains an increase at a reduced rate. These are the basic factors upon which the areal sweep efficiency depends:

I. The pattern of the flood
II. Mobility ratio denoted as M
III. The total cumulative or aggregate water injected, W_{inj}

2.1.4. The fluid mobility ratio

The ratio of the mobility of the expelling fluid to the mobility of the expelled fluid is called the Mobility ratio (M).

Mobility of the oil $= K_o/ \mu_o = KK_{ro}/ \mu_o$ (Eqn. 13)

Mobility of the water $= K_w/ \mu_w = KK_{rw}/ \mu_w$ (Eqn. 14)

Mobility ratio = mobility of expelling of displacing fluid/ mobility of expelled or displaced fluid $= (K_w/ \mu_w)/(K_o/ \mu_o)$ (Eqn. 15)

2.1.5. Mechanism of areal sweep prediction

The mechanisms of predicting the areal sweep efficiency are basically divided into 3 stages of the Flood: Prior to Breakthrough; At the Point of Breakthrough; Subsequent to Breakthrough.

Stage 1: Areal sweep efficiency prior to the breakthrough

The areal sweep efficiency prior to the time of breakthrough is proportional to the amount of water introduced and is denoted by:

Prior to Breakthrough,

$E_A = W_{inj}/[(PV)(Sw_{BT} - S_{wi})]$ (Eqn. 16)

W_{inj} = the cumulative of aggregate water injected bbl; (PV) = the pore volume of the flood pattern, bbl.

Stage 2: Areal sweep efficiency at the point of breakthrough

An illustrative relationship that prelates the areal sweep efficiency at the point of breakthrough E_{ABT} along with the mobility ratio for a pattern having 5 spots was proposed by Craig and Geffen [8]. The graphical interpretation of areal sweep efficiency as an important dependent of mobility ratio illustrates that a modification in the values of mobility ratio from 0.15 to 10.0 would alter the breakthrough areal sweep efficiency from 100 to 50%. Willhite gave the preceding numerical correlation,

$E_{ABT} = 0.54602036 + 0.03170817/M + 0.30222997/e^M - 0.00509693M$ (Eqn. 17)

where E_{ABT} denotes the areal sweep efficiency at the point of breakthrough, M stands for Mobility ratio.

Stage 3: Areal sweep efficiency subsequent to breakthrough

In the equivalence that the displacement efficiency $E_{D,}$ significantly increases after the time of breakthrough, the areal sweep efficiency increases also as a result of the constant rise in the absolute swept area is constant injection. The gradual increase in the areal sweep efficiency after the point of breakthrough along with the ratio of the volume of water that is injected at any given time period after breakthrough (W_{inj}) to the volume of water at breakthrough, (W_{IBT}) was correlated by Dyes and Caudle [9] and is denoted by:

$$E_A = E_{ABT} + 0.633 \log(W_{inj}/Wi_{BT}) \quad \text{(Eqn. 18)}$$

2.1.6. The vertical sweep efficiency

The region of the vertical section of the pay zone in which the injection fluid is contained is known as the vertical sweep efficiency (E_v). This specific sweep efficiency reckons basically on a) the mobility ratio & b) absolute volume introduced. As a result of the non-homogenous permeability, any introduced fluid will aim to move over the reservoir with an intermittent front. In the fractions that are more permeable, the introduced water will move more quickly than in the zone that is less permeable. Perchance, the region of the considerable ambiguity in developing a waterflood is the significant observation of the permeability disparity in the reservoir. The extent of permeability ab-normally is seen as the maximum variable affecting the vertical sweep efficiency.

2.2. Installation and development of waterflood mechanisms

2.2.1. The drilling of wells for water injection and production

As soon as the water source has been accepted and declared suitable for use acquiesced to engineering regulations for waterflooding. The well for water injection is drilled into the sunk hole close to the oil reservoir via which water can be introduced into the reservoir in order to expel the oil contained in the reservoir, including the drilling of the oil production well. For unique results, the wells are drilled to the accorded arrangement.

2.2.2. The design of waterflood plants

Subsequently, on the index is the process of installing the waterflood plants and pumps. The waterflooding pumps are intended for the introduction of the water into the reservoir and the plants and pumps for waterflooding are situated quite near to the water injection annular tubes on the project site. The process of selection and evaluation of waterflood operation equipment are commonly exclusive to separate waterflood as a result of several changing specifications. The basic specifications might be the pressure and volume, whilst secondary specifications might comprise of the treating criteria and the fiscal position of the capitalist. A difference in any specific variable might extremely modify or totally change the process of selecting and evaluating a waterflood plant. The amount of water injected to be operated will definitely be the essential primary piece of data to learn for arbitrating the plant size; in this state, there are different variables on which the analysis is based. Importantly, the volume of water is a function of the aggregate amount of the reservoir expected to be flooded, the reservoir rock porosity, the expected conformity or productivity of the flood, and the remaining oil saturation at both the commencement and finalization of the flood. This information will be attributed to the definite reservoir analysis, and only the eventual aggregate volume and the recommended regular rate of injection should be known by the plant engineer. To enable the transmission of water from the water-well or source of water to the water flooding pumps on the project site, water lines are installed.

3. Results and discussion

A Niger delta Reservoir: Reservoir OD-48, which is located at the Niger delta Region of Nigeria, is being considered for waterflooding. The relative permeability analysis and the correlative water cut are tabulated in table A.1 contained in the appendix. The reservoir and fluid data/analysis process for the solution drive reservoir is given in table A.2. The waterflood data that is proposed for the project can be found in table A.3 contained in the Appendix. The oil recovery performance is to be interpreted with the given information at a constant rate of water injection.

3.1. Production computations

Process 1: The Basic Calculations
Stage 1: The Pore Volume and the Oil Volume at the beginning of the Flood
PV = 7758 * Flood Area * Formation thickness * Porosity = 7758 * 50acres * 70ft * 0.25 =$6.79 * 10^6$ bbl
The volume of the oil at the beginning of the Flood, Ns
Ns = $PV(1 - S_{wc})/B_o$ = $[6.79 * 10^6$ bbl * (1-0.20)]/1.549 = 3.51MMSTB
Stage 2: Plot a graph of f_w against S_w to determine $S_{wf} = Sw_{BT}$ = 0.56
Given that $f_{wf} = fw_{BT}$ = 0.82; Sw_{BT} = 0.778; fw_{BT} = 1.0
Stage 3: Let the value of K_{ro} at S_{wi} and K_{rw} at Sw_{BT} be determined from the given permeability data.
K_{ro} at S_{wi}, 0.20 = 0.9; K_{rw} at $Sw_{BT,}$ 0.778 = 0.426
Stage 4: Determine the Mobility ratio, (M)
$K_{rw}\mu_o / K_{ro}\mu_o$; M = (0.426 * 1.0)/(0.9 * 0.55); M = 0.861
Stage 5: Determine the value of the areal sweep efficiency at the point of breakthrough,
$E_{ABT} = 0.54602036 + 0.03170817/M + 0.30222997/e^M - 0.00509693M$
$E_{ABT} = 0.54602036 + 0.03682714286 + 0.1277643511 - 0.00438845673$
$E_{ABT} = 0.70$
Process 2: The Calculation of the Recovery Performance at the point of breakthrough
Stage 1: The cumulative or the aggregate pore volume of water introduced at the point of breakthrough, Qi_{BT}
$Qi_{BT} = Sw_{BT} - S_{wi} = 0.778 - 0.20 = 0.578$
Stage 2: The cumulative or the aggregate water introduced at the point of breakthrough, Wi_{BT}
Wi_{BT} = (PV) Qi_{BT} E_{ABT} = $6.79 * 10^6$ bbl * 0.578 * 0.70= 2.75MMbbl
Stage 3: The time to breakthrough, t_{BT}
$t_{BT} = Wi_{BT}/ i_w$
i_w = rate of injection = 3620bbl/day; t_{BT} = 2.75MM bbl / 3620 bbl/day; t_{BT} = 760 days
Stage 4: The displacement efficiency at the point of breakthrough, E_{DBT}
$E_{DBT} = [Sw_{BT} - S_{wi}]/(1 - S_{wi})$ = [0.778 – 0.20]/(1-0.20) = 0.7225
Stage 5: The cumulative or aggregate oil production at the point of breakthrough, $[N_P]_{BT}$
$[N_P]_{BT} = N_S E_{DBT} E_{ABT}$ = $3.51 * 10^6$ bbl * 0.7225 * 0.70 = 1.77 MM STB

Table 1. The data for the Oil Recovery Process showing the variables for the Waterflooding Project of Reservoir OD-48

Variable	Value	Variable	Value
Viscosity of Water	0.55cP	The Areal Sweep Efficiency at the Point of Breakthrough, EABT	0.70
Flood area Proposed, (A)	50 acres	The cumulative PV of water introduced at the point of breakthrough, QiBT	0.578
Flood pattern/sequence Proposed	5 spot	The cumulative volume of water introduced at the point of breakthrough, WiBT	2.75 MMbbl
Rate of Water Injection Proposed	3620 bbl/day	The time to break through, tBT	760 days
The Pore Volume at the beginning of the Flood	6.79 * 106 bbl	Expelling or Displacement efficiency at the point of breakthrough, EDBT	0.7225
The Oil Volume at the Beginning of the Flood, Ns	3.5 MMSTB	The cumulative or aggregate production of oil at the point of breakthrough, [Np]BT	1.77 MMSTB
Mobility Ratio, (M)	0.861		

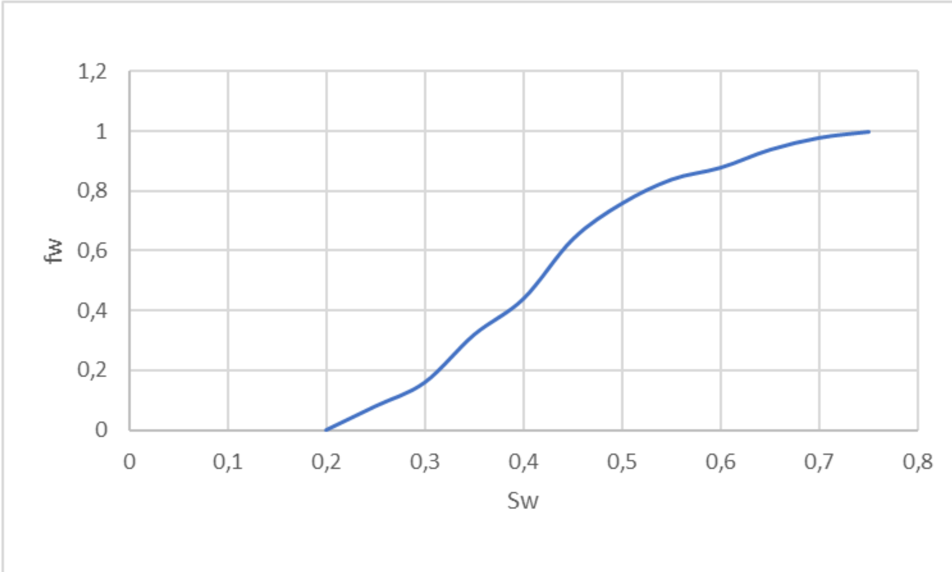


Figure 1. The graph of f_w against S_w of reservoir OD-48

It can be observed from the Table 1 that the cumulative or aggregate oil production at the point of breakthrough is approximately 760 days of waterflooding is 1.77 MMSTB encompassing about 43% of the original volume of oil at the beginning of the flood which is commendable. The displacement efficiency and the areal sweep efficiency at the point of breakthrough are 0.7225 and 0.70, respectively. Assuming the waterflooding project wasn't carried out, as much a volume as 1.77 MMSTB of oil would be trapped in the reservoir formation. Although 43% of oil recovery can be accepted, there are some important specifications can be varied in order to produce additional oil.

For example, the water intended to be used for the introduction has a viscosity of 0.55cP, there are some surface operative agents that can be used to increase the water viscosity which will amount to a decrease in the mobility ratio and would also increase the areal sweep efficiency and the total oil production during the breakthrough. Consider this example, supposing the viscosity of water is increased with surface operative agents to about 0.65cp; the ratio will decrease from 0.861 to 0.728; also the areal sweep efficiency will alter 0.70 to 0.7318 and the total oil production at the breakthrough would then be 2.75 MMSTB instead of 1.77 MMSTB. The parameters are given below.

Table 2. The outcome of a modification in viscosity for the oil recovery from Reservoir OD-48

Parameters	0.5cp of Water	0.65cp of Water
Mobility ratio, M	0.861	0.728
Areal Sweep Efficiency at the point of breakthrough	0.7	0.7318
Total oil Production at the point of breakthrough	1.77 MMSTB	2.75 MMSTB
$[N_P]_{BT}$ as a percentage of N_S	43%	47%

3.2. The economic evaluation of secondary oil recovery

3.2.1. The cost of investments

The cost implications comprise of the charge for the installation of the operation facilities and the operation of the equipment. The cost in this context incorporates the prior costs of investments and also the cost of the operations. For example, supposing a five-spot pattern is considered as the preferred waterflood pattern; money would be needed for the drilling and completion of the wells for the purpose of injection and production. Equipment costs also to be considered are the costs are the costs of the injectors and water pumps i.e. water-flooding plants. Assuming the location of the water source is distant from the site, the costs incurred by the provision of the water and water lines are also considered in this case. Another important factor that is put into consideration is the cost of water treatment, assuming the water requires treatment. The drilling and completing cost for a water injection wells for a 5-spot pattern is simplified below:

I. The drilling and Completion process of a well costs $165 per foot
II. The process of drilling and completing a well of a depth of about 11000ft costs $165 * 11000ft = $1.82 million
III. The process of installing well head facilities is $15000

The cumulative cost of one well is $1.82million + $15000 = $1.835million
Hence, the total cost of the 5 wells drilled is $1.835million * 5 = 9.175 million, [10].

i. The process of installing a water injection pump, for instance, an Elmar water/grease injection control module costs $308000
ii. The costs of the injection comprise of the costs of the water, and the water lines are broken down to:
iii. The process of drilling a water well to approximately 1500ft cost $4000 [10].
iv. The process of installing a water system for the purpose of water gathering costs $80000
v. The process of installing water lines for the purpose of transporting the water from a distant of approximately 10 miles to the oil well, in the region of the water well, and the process of execution of related civil works and also the maintenance of water equipment costs about $966600 for about 2 years

The aggregate costs of water lines and the water is $4000 + $60000 +$966600 = $1030600. The cumulative investment cost is the sum total of the costs incurred in the drilling of the water injection wells, costs incurred in the installation of a water injection pump, and the cost of the water lines and water. The cumulative investment cost is therefore: $9.175 million +$308000 + $1030600 = $10.52 million.

3.2.2. Costs of operation

i. Costs of Operation = Costs of Labour + Costs of Maintenances + Costs of Management.
ii. Costs of Labour = Assuming that the number of employees is 50, and each employee is paid $5000 per month. For 50 employees, the costs if labour per month would amount to 50 * $5000 = $250000. Therefore, the costs of labour on an annual basis would amount to $250000 * 12 = $3000000.
iii. Costs of Maintenance = These comprise of the usage of spare parts in value of $2.54million annually, the repair of fixed assets in value of $956000/year, operating services that are outsourced in value of $5.37million/year. The Cumulative cost of maintenance per year is $2.54 million + $956000 + $5.37 million = $8.866 million.
iv. Costs of Management = $905000

Annual Operating Cost = $3000000 + $8.866million + $905000 = $12.78 million.

3.2.3. The profitability analysis of reservoir OD-48

For the profitability analysis of reservoir OD-48, the gross profit of the operation is put into consideration, the gross profit of the project is determined by estimating the cumulative value of the volume of oil that is recovered during the process of the project. The cumulative value of the oil is estimated using the value of crude oil in the market. For the purpose of this work, the crude oil price is assumed to be $60 per barrel. The cumulative oil production of reservoir OD-48 $[N_P]_{BT}$ of approximately 760 days is 1.77 MMSTB, the cumulative value of the oil is, therefore, $60 * 1.77 MMSTB = $106.2 million. For this project, a 1-year period is taken to comprise of about 330 days of work with the remainder days used for the servicing of the equipment and also for maintenance purposes. In order to achieve an authentic appraisal of the project work, the volume of oil recovered after a period of 30 days is assumed to be 761100 STB.

3.2.4. The net present value analysis of reservoir OD-48

An important deciding factor of any project is its Net Present Value. The Net Present Value (NPV) can be defined as the value of cash flows that have been projected. The net present value criteria enable the evaluation or either current or potential investments and also gives room for the calculation of expected return on investment (ROI). The NPV makes a comparison between the value of a dollar today and its value in the future, putting into consideration inflation and returns. Assuming a prospective project has a positive NPV, it is then approved. But, if the NPV of the project is negative, then it is advised not to proceed with the project because it will yield a negative cash flow. In Table 3, it is deduced that the Net Present Value at a discount rate of 10% is -$10.52M +$29.9M +$27.2M + $1.6M = $48.18 million. The project can be approved because its NPV is greater than zero.

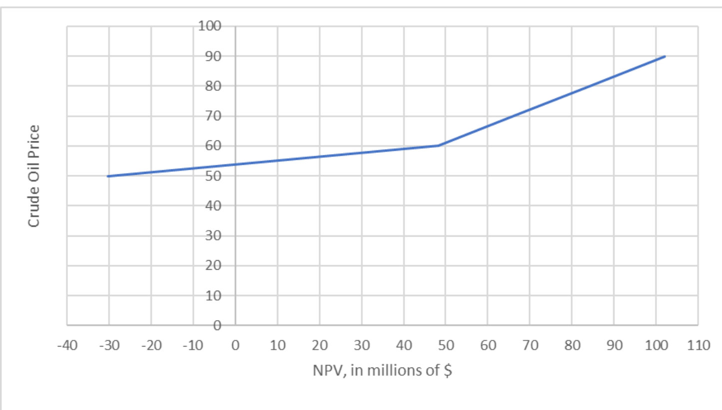
Table 3. The Cash Flows for the waterflooding operation, Reservoir OD-48

Year	Investment	Revenue	Expenses	Ncr	Cumm NCR	PV @ 10%
0	$10.52	-	-	-10.52	($10.52)	-10.52
1 [330 days of work]	-	$45.7	$12.78	$32.90	$22.40	$29.90
2 [660 days of work]	-	$45.7	$12.78	$32.90	$22.40	$27.20
Breakthrough [760 days]	-	$14.9	$12.78	$2.10	$57.40	$1.60

3.2.5. The NPV for the waterflooding operation at different crude oil prices

Table 4. Net Present Value at different prices of crude oil, reservoir OD-48

Crude oil price	NPV @ Various Crude Oil Prices
$50	($30.2)
$60	$48.18
$70	$66.16
$80	$84.14
$90	$102.12



From Figure 2 and Table 4, it can be observed that the Net Present Value turns negative at the Point where the crude oil prices decline below $53. Hence, it can be concluded that for the waterflood project on reservoir OD-48 to be economically feasible, the crude oil price shouldn't decline below $53.

Figure 2. Crude oil price against NPV at various Prices for reservoir OD-48

3.2.6. The NPVs for the waterflooding operation at different interest rates

Table 5. Net Present Value at different interest rates at a crude oil price of $60/bbl, reservoir OD-48

The interest rates	Net Present Value at interest rate
10	48.15
20	36.15
40	17.28
60	5.78

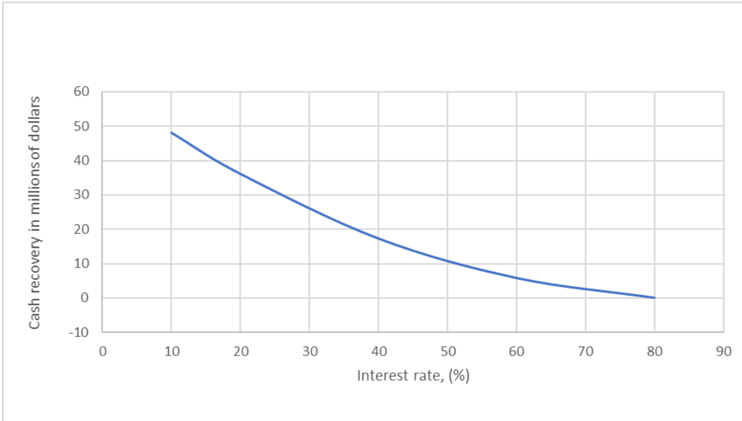


Figure 3. The graphical illustration of the cash recovery against the interest rates, reservoir OD-48.

From Figure 3 and Table 5, it can be observed that DCF-ROR is 80%. The discounted cash flow rate of return is a method of evaluation (i.e., profit indicator) that is used to predict the value or worth of investment on the basis of its projected cash-flows. It discounts all future revenue margins to equal all incurred future costs. It is the tool that discounts the NPV of a project to zero.

4. Conclusion

The evaluation of reservoir OD-48 for waterflooding was carried out in this project. The results determined from the investigation were given to illustrate that an equivalent type of reservoir is compatible with the waterflooding project if managed accurately, may be productive from both an economic and technical perspective. Some equations were used for the evaluation of the pay-off reservoir capacities, the volume of water to be introduced into the reservoir at specific conditions inaugurating the sweep efficiencies. In order to determine the Net Present Value for the purpose of predicting the feasibility of investing in the project work, the profitability analysis was undergone. The efficient administration of any required waterflood project, particularly in stratified or composite reservoirs, depends mostly on understanding what takes place in each well in the field. The moment the installation of a water flood is completed, adequate operations are needed to achieve the best outcome. An efficient waterflood process is a more lucrative substitute for the depletion of the reservoir where convenient.

Disclosure statement

No potential conflict of interest was reported by the authors.

List of symbols

a	*inclination angle/angle of dip, degrees*	N_S	*Original oil in place at the beginning of the flood*
A	*cross-sectional area responsive to flow, sq ft*	*Pc*	*Capillary pressure*
bbl	*barrel*	*ppm*	*parts per million*
bbl/day	*barrel per day*	*Psi/ft*	*pounds per square inch per foot*
Bbl/ft	*barrel per foot*	*PV*	*pore volume*
B_{oi}	*the formation volume factor of the oil at the commencement of the oil, bbl/STB.*	P_{wf}	*bottom-hole flowing injection pressure*
E_A	*areal sweep efficiency*	*Pe*	*pressure at re distance from injection well*
E_{ABT}	*areal sweep efficiency at the point of breakthrough*	q_o	*Flowrate of oil, RB/day*
E_D	*displacement efficiency*	q_w	*Flowrate of water, RB/day*
EOR	*enhanced oil recovery*	*qt*	*total flow rate, bbl/day*
E_V	*vertical sweep efficiency*	*RF*	*overall oil recovery factor*
ft	*foot*	R_{OS}	*residual saturation of o*
FVF	*formation volume factor.*	S_{gi}	*initial saturation of gas*
F_w	*fractional flow of water*	S_{oi}	*initial saturation of oil at beginning of the flood*
in	*inch*	S_o	*the average/mean saturation of the oil in the flood pattern at a given position whilst in flood.*
I	*Initial investment*	S_w	*average or mean saturation of water in the swept region/area*
K_o	*Effective permeability to oil, md*	S_{gi}	*initial saturation of gas at the commencement of the flood.*

K_w	*Effective permeability to water, md*	S_{wi}	*initial saturation of water at the commencement of the flood*
K_{rw}	*relative permeability to water at S_{or}*	S_g	*gas saturation*
K_{ro}	*relative permeability to oil at S_{wi}*	S_{wc}	*connate water saturation*
M	*mobility ratio*	t_{bt}	*time to break through*
M	*Million*	Wi_{BT}	*Water injection at the point of breakthrough*
mD	*milli-darcy*	W_{inj}	*cumulative water injected, bbl*
m	*metre*	*Wi*	*the cumulative water injected, bbl.*
MMSTB	*million stock tank barrel*	*μo*	*viscosity of oil, cP*
n	*number of days to accomplish the project*	*μw*	*viscosity of water, cP*
NCR	*net cash recovery*	*γ*	*Specific gravity of the fluids, in fraction*
NPV	*Net Present value*	*α*	*Angle of dip, degrees*
N_P	*cumulative or aggregate oil produced, STB*	*Ø*	*porosity*

Supplementary material

A.1 Relative permeability data and water cut of reservoir OD-48

Sw	0.2	0.35	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
Kr	0.9	0.433	0.259	0.195	0.143	0.082	0.067	0.042	0.025	0
Krw	0	0.05	0.115	0.14	0.199	0.249	0.315	0.396	0.485	0.495
Fw	0	0.1582	0.4473	0.752	0.6011	0.8284	0.9135	0.9524	0.9743	1

A.2 Fluid and reservoir data

Discovery presure	3765 psig
Reservoir temperature	218°F
Stock tank oil	9.6346 mmSTB
Initial oil formation volume factor, B_o	1.549
API gravity	27°API
Viscosity of oil	1.0 cP
Initial saturation of water	20%
Connate water saturation, S_{wc}	10
Current saturation of gas, S_g	20%
Permeability, K	40 MD
Wel depth	11000 ft
Thickness, h	70 ft
Porosity,Ø	0.25
Radius of Wellbore	1.0 ft

A.3 Water flood Data for the project

Proposed Flood Area, A	50 acres
Proposed Flood Pattern/Sequence	5 spots
Proposed rate of Water Injection	3500 bbl/day

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