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Economic Analysis of Polymer Flooding Materials During Enhanced Oil Recovery

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ABSTRACT
Cost-benefit analysis was used to ascertain the most cost-effective polymer material for polymer flooding using sixteen sand packs. Various combinations of polymer were used for the flooding each of the sand packs. In this analysis key variables such as capital expenditure, price of oil, and operating expenditures were considered. The cost-benefit ratio was used to evaluate the various polymer flooding. The results obtained for sand packs without polymer flooding had a cost of benefit ratio of 3.53 while the enhanced sand packs had varying degrees of profitability as indicated by the benefit cost ratio. The most economically viable is the use of the biopolymer gotten from caladium bicolor with a benefit cost ratio of 5.52.
Keywords: Polymer flooding, benefit-cost ratio, Enhanced, Oil Recovery

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I. INTRODUCTION

Economic analysis is a very important aspect of all engineering projects because the cost of an investment in the oil and gas industry is highly capital intensive and involves very high risks and uncertainties. Therefore, every technique or technology to be used in the field must be economically analyzed on its profitability, for investment decision to be taken for subsequent field implementation. Hence, the need arises to successfully evaluate the cost effectiveness of different enhanced oil recovery (EOR) materials used in polymer flooding.

It is speculated that world gross domestic product (GDP) will increase by 200% from 2016 to 2040 due to rapid economic growth and development for non-organization for Economic Cooperation and for developing countries (ExxonMobil, 2018). It is reported that, energy utilization will increase in every area of transportation, industry and electricity generation. With steady decline in oil supply due to the increasing demands there is a need to increase oil production which necessitated the importance of enhanced oil recovery.

Enhanced oil recovery is a process used to recover oil that was by-passed during primary and secondary recovery technique (Ihekoronye *et al*.,2019).

Polymer fooding is an enhanced oil recovery (EOR) method that uses high molecular weight polymers to increase the viscosity of the displacing water in bid to reducing water mobility to improve sweep efficiency and hence to improve oil recovery (Seright and Wang, 2023).

Polymer is one of the major material needed in polymer flooding project hence the keen interest in cost effective polymers.

To embark on an EOR project, decision must be taken whether to invest on a prospect, the incremental cost to execute the prospect must be compared with the future net revenue expected to be benefited from the future prospect. If the cost of executing a prospect is higher than the expected benefit, such prospect a should be abandoned (Sampson *et al*.,2020). So, in making a definite decision on whether to enhance a well or not, a thorough economic analysis must be done.

Cost-benefit analysis compares the total cost of an investment prospect and expected benefit or profit from the investment outcome (Eleni and Konstantinos, 2016).

There are several economic tools used in project analysis, they include the following:

I. **Net Present Value (NPV)**: NPV compares the value of a dollar today to the value of the same dollar in the future, taking inflation and returns on investment into account. If the NPV of a prospect is positive. it should be accepted and rejected if negative.

P (1)

Where,

P = present value, F = Future value, I = interest rate, n = number of years

2. **Internal Rate of Return (IRR):** Is a rate of return on an investment. The IRR on an investment is the interest rate that gives it a present value of zero (Gernot, 2009). On the basis of the definition of IRR, it is calculated as follows:

(2)

3. **Profitability Index (PI):** This is the extent of the proportion of the present value of dollars return to dollars invested. If the profitability index is greater than 1, accept project. If less than 1 reject project.

4. **Cost-Benefit Analysis:** It is an economic tool for determining the benefits and costs of a project discounted over a period of time using a basic monetary value, (Boardman et al., 2015).

The economic tool used in this study is the cost-benefit analysis

II. MATERIALS AND METHODS

Different polymer materials were used singly and in combinations to ascertain the effect on oil recovery. An experimental analysis of polymer flooding was done with the following materials: Hydrolyzed polyacrylamide (HPAM), Polypropylene, guar gum, and biopolymer obtained from caladium bicolor tuber, *bacillus sp* and *pseudomonas sp*.

Sixteen sand packs were used for the various polymer combination of polymer flooding. The combination used in this work is shown in Table 1.

Table 1: Polymer Flooding Combination

S/N	Experimental set- up
1	OP_1
2	OP_2
3	MP_1
4	MP_2
5	CP_1
6	CP_2
7	MP_1+MP_2
8	CP_1+OP_2
9	OP_1+OP_2
10	OP_1+MP_2
11	OP_2+MP_2
12	$OP_1+OP_2+CP_2$
13	$MP_1+MP_2+CP_2$
14	$OP_1+OP_2+CP_1$
15	$OP_1+OP_2+MP_1+MP_2$
16	$OP_1+OP_2+MP_1+MP_2+CP_2$

Key:

OP_1 = Guar gum
OP_2 = Caladium bicolor
MP_1 = *Pseudomonas*
MP_2 = *Bacillus*
CP_1 = Polypropylene
CP_2 = HPAM.

The economic analysis adopted in this study is the cost benefit analysis. Cost benefit is a systematic approach that compares the magnitude of the costs and benefits of a form of investment in order to ascertain its economic profitability, (Woodhall, 2004). For this project the cost benefit analysis model used is the benefit – cost ratio, which is defined as:

(3)

Where,

Assumptions

The following assumptions were made for simulated field economic analysis and the cost incurred is stated below:

a. If EOR of the wells was done for a period of 60 days and each of the three personnels was paid \$28.285 per day for a period of 60 days.
b. A total of sixteen wells were enhanced with different EOR materials. The cost of materials includes the cost each sand pack (well), EOR materials, water, industrial sodium chloride and antibiotics.
c. 1 ml of crude oil in the laboratory represents 1000 bbl. in the field.
d. 1 ml of other fluids (water and chemical) represents 1000 bbl. in the field.

e. Crude oil price at $100.420 per barrel was used. (Central bank of Nigeria, 29th of September,2023 Daily Report).
f. HPAM at $2.5/kg
g. Guar gum at $2.50 /kg
h. Caladium bicolor tuber at $1/kg
i. Polypropylene at $2.8/kg
j. Bacillus at $2.5/ kg.
k. Pseudomonas $2.8/kg.
l. corporate income tax (CIT) 10% was charged as assessable profit.
m. Royalty of 8.5% was adopted
n. 10% Discount rate was adopted.
   o. 1g is equivalent to 1000kg.

The following cost was incurred before Flooding:

i. Cost of manpower = $ 5091.3
ii. Cost of machine = $ 20000
iii. Cost of Material (well, water, salt, chemical and other cost) = $100000
iv. Fixed cost = $25000

Total cost before Flooding = $150091.3

The calculations on the economic analysis, Cost of production before EOR, Cost of production after EOR and the Benefit cost analysis are stated in Tables 2 and 3 respectively.

III. RESULTS AND DISCUSSION

Table 2: Benefit-Cost Ratio Analysis Before Polymer flooding

core label	Total cost before ($)	Cost of oil Recovered before Flooding ($)	profit before tax ($)	Royalty ($)	CIT ($)	Benefit before ($)	BCR
A	150910	805520	654610	55641.85	65461	533507.2	3.535267
B	150910	805520	654610	55641.85	65461	533507.2	3.535267
C	150910	805520	654610	55641.85	65461	533507.2	3.535267
D	150910	805520	654610	55641.85	65461	533507.2	3.535267
E	150910	805520	654610	55641.85	65461	533507.2	3.535267
F	150910	805520	654610	55641.85	65461	533507.2	3.535267
G	150910	805520	654610	55641.85	65461	533507.2	3.535267
H	150910	805520	654610	55641.85	65461	533507.2	3.535267
I	150910	805520	654610	55641.85	65461	533507.2	3.535267
J	150910	805520	654610	55641.85	65461	533507.2	3.535267
K	150910	805520	654610	55641.85	65461	533507.2	3.535267
L	150910	805520	654610	55641.85	65461	533507.2	3.535267
M	150910	805520					
N	1509	805520	6546	55	6	533	3.

	10		10	641.85	5461	507.2	535267
O	150910	805520	654610	55641.85	65461	533507.2	3.535267
P	150910	805520	654610	55641.85	65461	533507.2	3.535267

Table 3: Benefit-Cost Ratio Analysis After Polymer flooding

core label	Cost of operation, $	Total cost of Flooding mat ($)	Total cost of Flooding ($)	Cost of oil Recovered ($)	Profit before tax ($)	Royalty, ($)	CIT, $	Benefit, $	BCR
CP2	150910	4571.42	155481.4	1107590	952108.6	80929.23	95210.86	775968.5	4.990747
MP1	150910	44800	195710	1006900	811190	68951.15	81119	661119.9	3.378059
MP2	150910	40000	190910	906210	715300	60800.5	71530	582969.5	3.053635
OP1	150910	163.43	151073.4	1006900	855826.6	72745.26	85582.66	697498.7	4.616951
OP2	150910	4571.428	155481.4	1208280	1052799	89487.88	105279.9	858030.8	5.518542
OP1+MP2	150910	10081.73	160991.7	1107590	946598.3	80460.85	94659.83	771477.6	4.792033
CP1+OP1	150910	18214.28	169124.3	1006900	837775.7	71210.94	83777.57	682787.2	4.037192
CP1+CP2	150910	17071.42	167981.4	855865	687883.6	58470.1	68788.36	560625.1	3.337423
OP1+OP2	150910	390.295	151300.3	986762	835461.7	71014.24	83546.17	680901.3	4.50033
MP1+MP2	150910	21200	172110	906210	734100	62398.5	73410	598291.5	3.476216
OP1+MP1	150910	22797.86	173707.9	1107590	933882.1	79379.98	93388.21	761113.9	4.381575
OP2+MP2	150910	9428.564	160338.6	1006900	846561.4	71957.72	84656.14	689947.6	4.303067
OP1+OP2+CP2	150910	3471.435	154381.4	936417	782035.6	66473.02	78203.56	637359	4.128469

MP1+MP2+CP2	150910	73478.58	224388.6	1006900	782511.4	66513.47	78251.14	637746.8	2.842154
OP1+OP2+MP1+MP2	150910	22797.86	173707.9	1107590	933882.1	79379.98	93388.21	761113.9	4.381575
OP1+OP2+MP1+MP2+CP2	150910	44800	195710	805520	609810	51833.85	60981995.2	496995.2	2.5394

4.1 Effect of Different Polymers on Oil Recovery

Figure 1 shows the different flooding materials and their effect on the volume of oil recovered.

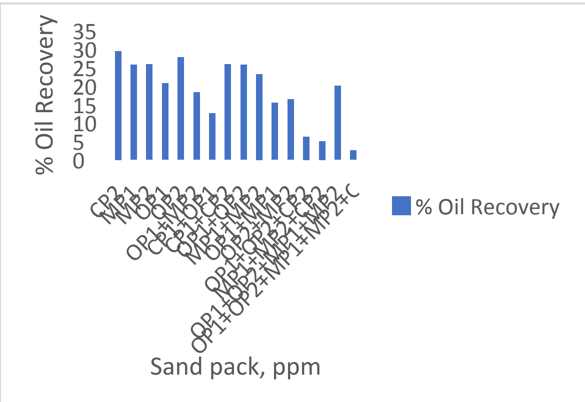

Figure 1: A Plot of Different Combination of Polymers Vs Volume of Produced Oil before and After Flooding

From Figure 1, the various combination of polymer flooding showed varying volume of oil recovered. OP_1 + OP_2 had oil recovery of 20.4%, MP +MP_2 produced 18.8%. OP_1 +MP_1 produced 12.8%, while, OP_2 +MP_2 produced 13.5%, the combination of OP_1 +OP_2 +CP_2 produced 5.9%, MP_1 + MP_2 + CP_2 produced 4.2%. The least production of oil was gotten from MP_1+MP_2+OP_1+OP_2+CP_2 with oil production of 2.4%.

CP_2 had the maximum oil recovery of 29.3% after flooding. It is expensive because it is not locally available. According to Gbadamosi *et al.*, (2019), HPAM is very soluble in water, and provides good mobility control; good mobility control indicates that the polymer solution will be able to sweep through the entire reservoir and effectively displace the oil. Additionally, the anions on the carboxyl groups in HPAM promote polyelectrolyte behavior, which increases viscosity and controls adsorption within the reservoir. This is in agreement with the result obtained in this study.

OP_1 has great potentials for oil recovery too, but also expensive because it is massively used in oil, food and pharmaceutical industries. OP_1 is susceptible to shear degradation from 40^{o}C upward resulting decrease in its viscosity. Even though it is biodegradable, is not readily available locally.

OP_2 exhibited significant oil recovery. It is at a close range with OP_1 in the volume of oil recovered and they are both plant-based bio-polymer. OP_2 has ability to withstand higher temperature as its viscosity increases with increasing temperature. It is biodegradable, locally available in this part of the world and very cheap because it is not edible. Hence will not posed food scarcity if used by the oil and gas industry.

MP_2 also shows remarkable oil recovery, they are both environment friendly but prone to corrode production facility due to the secretion acidic gas by their microbial activities. MP_1 like MP_2 is a bacterial that readily available in the soil. It produces acidic gas as one of its by product that may likely corrode some down hole facilities. The use of microbial flooding requires additional cost of anti-corrosion agent which will pose an additional cost on production.

The combination of CP_1+CP_2 gives an appreciable oil recovery, indicating they are effective in oil recovery. They are both synthetic and not environment friendly. CP_2 is expensive because it is not readily available locally.

4.2 Cost Benefit Analysis for the Different EOR Materials

The benefit-cost ratio for the sixteen sand packs obtained from polymer flooding is presented in Figure 2. This result shows the economic analysis of various combinations of polymer flooding used in this study.

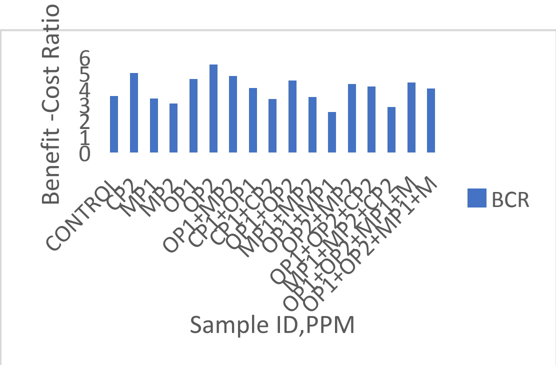

Figure 2: Benefit-Cost Ratio Before and After Polymer Flooding

As shown in Figure 2, is the benefit-cost ratio analysis of a well without EOR (control) and sixteen wells with polymer flooding. From result obtained from the control well, the cost benefit ratio obtained was 3.5352, indicating that for every that for every \$1 costs of investment, \$3.5352 dollar benefit will be generated. For the wells flooded with different polymers, varying degree of benefit- cost ratio was gotten. $0P_2$ had the highest benefit- cost ratio of 5.5185. The benefit cost ratio of OP_2 implies that for each \$1-dollar cost of EOR project, the expected dollar benefit generated is \$5.5185. This well ranked 3rd in oil recovery but is more cost effective in the flooding because it is a locally available biopolymer, therefore , it is cheaper compared to others. Next is CP_2 with a benefit cost ratio of 4.9907, which implies that for each \$1-dollar cost of EOR project, the expected dollar benefit generated is \$4.9907. The least benefit-cost ratio was obtained from OP_1+OP_2+MP_1+MP_2+CP_2 with a benefit- cost ratio of 2.5394, it is the least economical in this analysis. Both prospects without polymer flooding and with polymer flooding all had a positive benefit- cost ratio.

IV. CONCLUSION

In conclusion, the results obtained for both polymer flooding and non- flooding prospects will be profitable ventures because the benefit-cost ratio is positive for all prospects. The economic analysis showed that the polymer flooded wells had varying degree of profitability. The most cost- effective enhanced oil recovery material from the benefit-cost ratio analysis was Caladium bicolor (OP_2), with the highest benefit-cost ratio of 5.5. Caladium bicolor is the most cost effective because it is a locally available and cheaper to produce compared to other materials that will be imported. Some of the flooding combinations are less economical compared to the sand packs without polymer flooding.

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