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Economic Evaluation of Beneficiating Nigerian Bentonite Using Periwinkle Shell and Mucuna Solannie

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Abstract: According to past studies, Nigerian Bentonites are found to be deficient in both fluid loss and rheological properties. Due to the deficiency of the Nigerian bentonite (NB), a good majority of bentonites used within Nigeria are imported. This research work seeks to evaluate the economic profitability of beneficiating the fluid loss and rheological properties of NB using periwinkle shell (PWS) and Mucuna Solannie (MS) as additives. The economic evaluation of this research seeks to point out the best possible action, based on available evidence. Two parameters—cost and outcome, are measured by the economic evaluation. From this measurement, an economic evaluation's results will not exactly point out the better alternative, the way that an experimental trial would. If the most effective option from the evaluation is the cheapest, then it is the most cost effective option. In such a scenario, the most cost effective option is said to be the dominant alternative. From the economic evaluation of the PWS and MS additives performed during the course of this research, it can be said that these additives are economically profitable when added to local bentonite (LB), compared to the cost of using imported bentonite (IB) clay. Estimation of required equipment and facility for processing of additives (PWS and MS), calculation of discounted cash flow rate of return (DCF – ROR) for the investment and sensitivity analysis on the cash flow assumptions were carried out for the achievement of optimum results.

Keywords: Bentonite, Mucuna Solannie, Periwinkle Shell, Economic Evaluation, Sensitivity Analysis

1. Introduction

Activities involving gas and oil exploration as well as (AWA) production exist virtually every part of the globe where hydrocarbon deposits are deemed to occur. In order to produce these hydrocarbons (HCs), the industry relies on a number of oilfield chemical formulations; one of such chemical formulations is the drilling fluid (DF). If the research findings on the market demand for DF are anything to go by, then it would be safe to infer that as DF demand increases, bentonite clay demand (one of the essential components of most DFs) would correspondingly increase. With this foreseen increase in demand, pressure would pile on the existing bentonite clay reserve sources; hence depleting it at a rate faster than hitherto anticipated. It must be noted that bentonite when added to fresh water to make a DF, plays a number of invaluable roles namely: to improve the hole cleaning properties of the fluid, reduce fluid loss to thief zones, create a thin and low permeability filter cake, cause stabilization of the borehole in formations that are poorly cemented [1, 2]. Current bentonite clay consumption in drilling operations across Nigeria is put at estimation of above 50 thousand tons/year. However, the Nigerian oil industry spends a lot of money importing these foreign bentonite (FB) because her LB reserve doesn't meet the specifications required by API and hence, is a less preferred option to the expensive FB [3].

1.1. Nigerian Bentonite and Its Characterization

Nigeria has been blessed with an abundance of bentonite reserves and this would greatly reduce the importation of specialized DFs and ingredients, if properly harnessed. It has been reported that all regions in Nigeria possess a significant bentonite clay deposit and the country's bentonite reserves are put at the region of 700MM metric tons and above [4] with Edo State (Mid-Western Nigeria) being the largest shareholder and boasting a reserve of about 70–80MM metric tons of bentonite clay [5, 6]. In 2003, the Federal Government placed a restriction on FB importation so as to promote the use of the large local deposits [7]. Irrespective of this restriction, the gas and oil industry has failed to utilize the LB clay deposits as there are no current reports of its use in drilling operations. Previous studies on DFs produced from strictly NB have demonstrated that such DFs have high fluid loss and poor rheological properties. This is likely due to poor quality of NB and hence the need for beneficiation [8]. As bentonite clay demand rises and with the movement of the activities of gas and oil exploration to deep offshore locations, it has become imperative for NB clays' properties to be enhanced so as to meet up with the API standard. The NB clays can be graded as Oil Company Material Association (OCMA) grade bentonite; thus requires a lot of beneficiation to make them meet the API bentonite standard [9, 10]. The use of local materials [11] and sodium salt for the beneficiation of these clays has been largely employed [12] by various researchers in the conversion of montmorillonite clays that are calcium based into montmorillonite clays that are sodium based, with rheological properties that can be compared to API standard bentonite clays [9, 10]. The mechanism occurs through the route of ion exchange that involves substituting calcium ions with those of sodium ions. Despite diverse studies on beneficiation of LB in the literature, there has not been any evaluation on the profitability of using PWS and MS for LB beneficiation. In this work, investigation on the economic evaluation of beneficiating NB using PWS and MS as local materials was conducted. This was necessary to ascertain the profitability of the project.

1.2. Periwinkle Shell and Mucuna Solannie (PWS and MS)

Periwinkle (Littorinalittorea) is a robust intertidal species of small edible sea snail with shells that are darkened and sometimes banded. Periwinkles originated in the northeastern rocky shores and later had their introduction to the northwestern part of the Atlantic Ocean. They can also be found in the Niger Delta region, Calabar and Badagry, located in the Southern and Western part of Nigeria respectively. PWSs are mostly regarded as waste and disposal has proved difficult over time, therefore leading to an accumulation of large shell deposits at various locations. Bringing this waste into the oil industry will be great as its shell contains elements that are viable for improving our local bentonite.

Mucuna as a genus consists of about a hundred species of the fabaceae family, a family of shrubs AWA climbing vines found in tropical woodlands of Asian and African countries [13]. The leaves has3-palmate, alternate or spiraledshape, with pea-like flowers AWA petals and distinctive curve. Mucuna seeds are toasted before grinding and flowering, and are mostly used as thickeners in soups, sauce, beverages as well as other local delicacies, by the Igbo in Southern Nigeria [14, 15]. Also, research by Uwazuoke *et al.,* (2016) has discovered that MS has the ability and elemental constituents to improve the quality of DFs [16].

1.3. Principles of Economic Evaluation

1.3.1. Cost Benefit Analysis (CBA)

Cost and decision making ties are essential to the analysis of strategy and important in understanding cost position and competitiveness in the long run [17]. CBA is an approach that systematically studies alternatives, estimates their strengths AWA weaknesses and determines or selects options which will provide a combination of achieving benefits and preserving savings. Opportunity cost is the guiding principle, and it refers to the sacrifice of alternatives foregone in the production of goods and services. There are two major applications of CBA [18]; to determine the soundness of an investment or decision AWA provision the basis for investments' comparison (comparing each option's total expected cost with its expected total benefits).

1.3.2. Net Present Value (NPV)

NPV is used for the evaluation of a number of alternatives. For cases involving a single alternative, the alternative is said to be viable if the Minimum Acceptable Rate of Return (MARR) is met or exceeded and this occurs when an investment's NPV at the MARR is greater than or equal to zero [16]. For cases involving two or more alternatives, the NPV at the MARR is calculated and compared, and the alternative which has the highest numerical NPV is selected. If all NPV's are negative, the negative NPV that is least is chosen. However, if all NPV's are positive, the most positive is chosen. In cases where there are both positive and negative NPV's, the more positive alternative is chosen.

Present Value, $PV = \frac{FV}{(1+i)^n}$, where FV=Future Value, i=interest rate and n=number of periods. Note that the NPV is the total sum of all the PVs.

1.3.3. DCF-ROR

This is the interest rate made by the bank on an investment in a project. This evaluation technique is used on one alternative or to select between two or more alternatives [19], as soon as a MARR is stated. Accordingly, discounting at any rate in CBA simplifies the enormous future effects [20]. 'Discount rate' is usually used for PV and FV comparison. The DCF-ROR can also be described as the rate of interest that brings the NPV to zero. This means that if the DCF-ROR is calculated and its application made on the cash flow series, the NPV should be $0.00. In the case of incremental analysis, DCF-ROR can also be used on two alternatives to check if the extra investment is profitable. If the calculated DCF-ROR from the increment in cash flow is greater than or equal to the MARR, the extra investment alternative is then selected [21], and if otherwise, it is rejected. For scenarios involving more than two alternatives, it can be used as an elimination tool to screen out all alternatives that have a DCF-ROR value which is less than the MARR.

1.3.4. Sensitivity Analysis (SA)

SA is a technique that calculates the amount of impacts that uncertainty in one or higher input variables will have on those of output variable [22]. SA helps improve or reduce the model prediction by quantitatively and/or by understanding the studied phenomenon by variable interactions analysis or qualitatively studying the response of the model to input variables changes. However, we must not necessarily focus on the model output, but on the questions to be answered by the model. That is, the robustness of the model can be evaluated using the expected values of the parameters involved, and then, the values beyond which the output variable changes significantly, will be identified. SA helps improve knowledge by identifying priority needs.

2. Materials and Methods

2.1. Purchasing and Processing of Locally-Sourced Materials and Additives

The locally sourced materials are local (Nigerian) bentonite, PWSs and MS plant. IB was also used in the analysis. After local sourcing of the materials and additives, the additives (PWS and MS) were processed to enable usage. The PWS was washed to remove dirt particles, sun-dried to remove moisture and then grinded in a mill to powdered form. For MS, the seeds were removed, washed and dried to remove moisture, and then grinded to powder form.

2.2. Determination of Elemental and Oxide Composition of Additives Using X-ray Diffraction Test

To achieve an optimum level of accuracy and reliability, the elemental and oxide composition of the additives (PWS and MS) had to be known as it would indicate the major constituent element and also a good overview of the elemental and oxide distribution in the additives. This is important because, since we are trying to beneficiate LB, we need to know the elemental or oxide properties of the additives that will be responsible for the beneficiation process. Also, research has proven that NB is predominantly calcium-based and needs elements like sodium for beneficiation. This test was carried out in a spectral laboratory.

After the X-ray diffraction test was conducted on the additives, rheology and LTLP test (For fluid loss determination) were conducted on the three samples of bentonite (local, imported and beneficiated NB).

2.3. Economic Evaluation of Beneficiation Process

Since this is an alternative approach, it needs to be compared with the current system of using IB in terms of quality and cost-benefit.

The cost-benefit method used for economic evaluation of this beneficiation process involved the following steps:

1. The costs of purchasing and processing PWS and MS were recorded.
2. The costs of purchasing LB were recorded. Also, the costs of every needed equipment and facility were duly estimated.
3. The costs were projected over a period of five (5) years.
4. Discount rates were applied and the NPV was estimated.
5. The DCF-ROR was calculated.
6. SA was performed primarily to check the implications of variations in the factors affecting the proposed alternative (beneficiation process). These factors are revenue, investment and expenditure.

3. Results and Discussions

3.1. Compositions of PWS and MS

Tables 1 and 2 depict the composition of the elements of both PWS and MS obtained with the use of SEM. Table 3 depicts the composition of the oxides gotten with XRD technique. From the results, PWS had calcium (Ca) of 77.67%, which is in agreement with the work of [23], CaO of 57.61%, Al_2O_3 of 9.99% and SiO_2 of 14.05% in elemental AWA composition of the oxides while MS had potassium (K) of 28.86%, SiO_2 of 4.82% andAl_2O_3 of 1.82%. The Ca and K high content conveys to a great degree shale inhibition characteristics of PWS and MS during well drilling operations. Also, SiO_2 and Al_2O_3 presence are among NPs which are known for effectively stabilizing the wellbore. The results revealed that PWS is primarily constituted of Ca (77.67%) with little quantity of Na of 0.23% which basically is what constitutes the FB while MS is primarily constituted of C (35.27%) and K (28.86%). This indicates that the main elements of MS that aided the process of beneficiation were C and K

Table 1. *Elemental composition of PWS.*

Elements Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	77.67	79.48
14	Si	Silicon	12.31	8.83
47	Ag	Silver	0.77	2.13
39	Y	Yttrium	0.94	2.13
41	Nb	Niobium	0.65	1.55
26	Fe	Iron	0.78	1.11
19	K	Potassium	1.04	1.04
17	Cl	Chlorine	1.05	0.95
16	S	Sulfur	1.05	0.86
13	Al	Aluminium	0.85	0.58

Elements Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	1.02	0.42
6	C	Carbon	1.08	0.33
15	P	Phosphorus	0.27	0.21
11	Na	Sodium	0.23	0.13
12	Mg	Magnesium	0.20	0.13
22	Ti	Titanium	0.10	0.13
	Thj			

Table 2. *Elemental composition of MS.*

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
19	K	Potassium	28.86	39.18
6	C	Carbon	35.27	14.71
15	P	Phosphorus	7.34	7.89
30	Zn	Zinc	2.81	6.37
26	Fe	Iron	2.63	5.11
16	S	Sulfur	4.54	5.05
20	Ca	Calcium	3.27	4.55
39	Y	Yttrium	1.15	3.54
22	Ti	Titanium	1.84	3.06
17	Cl	Chlorine	2.19	2.70
8	O	Oxygen	3.74	2.08
14	Si	Silicon	2.00	1.95
13	Al	Aluminium	1.89	1.77
12	Mg	Magnesium	1.39	1.17
11	Na	Sodium	1.08	0.86

Table 3. *Oxide composition of PWS and MS.*

OXIDE	PWS	MS
CuO	0.002	0
NiO	0	0
Fe_2O_3	0.982	0
MnO	0.037	0
Cr_2O_3	0	0
TiO_2	0.167	0.029
CaO	57.608	0.583
Al_2O_3	9.99	1.828
MgO	0	0.243
ZnO	0.01	0.003
SiO_2	14.047	4.816

3.2. Fluid Loss and Rheological Properties

Table 4 depicts the fluid loss AWA rheological properties of FB, LB and BB. From the result, there was significant reduction of filtrate volume with the utilization of PWS and MS as additive for the control of fluid loss. 15g of FB at 600rpm gave dial reading of 27 while15g of LB at 600rpm gave dial reading of 18. 5g concentration and below at 600rpm, the dial reading was 26, which is lower than 27 and as such lower than that approved by API. Thus, PWS and MS as DF additives for improvement of the fluid's rheological properties are unviable prospects at concentrations that are not above 5g. Nigerian LB therefore do not have the satisfaction of API standard for dial reading of 600-rpm of above 30. Hence the need for rheological properties improvement is therefore necessary through beneficiation by increasing the additives' concentration. If the concentration of beneficiating agents is increased from 7-8g, the dial reading will definitely meet the API standard [24, 25]. From table 4 also, with the increase in the additives, the obtained filtrate volume decreased from 27ml to 12ml which meets the API standard in accordance with [24] which states that the acceptance of DF as additive for fluid loss is only when the used additives gives below 15mL volume of filtrate loss over 30minutes time. Thus at higher concentration of 7-8g of the additives, volume of filtrate loss will be much lower which is excellent and again in agreement with API standard.

Table 4. *Results for fluid loss and rheological tests conducted.*

	FB (15g)	LB (15g)	FB (30g)	LB (30g)	LB (15g) +MS (1g) +PWS (1g)	LB (15g) +MS (2g) +PWS (2g)	LB (15g) +MS (3g) +PWS (3g)	LB (15g) +MS (4g) +PWS (4g)	LB (15g) +MS (5g) +PWS (5g)
Fluid loss (ml)	13	27	5	11	24	22	16	14	12
600rpm	27	18	52	34	18	19	22	23	26
300rpm	21	13	43	28	13	14	14	15	16
200rpm	15	8	32	21	9	9	9	9	10
100rpm	11	6	25	16	6	6	6	7	8
6rpm	8	4	17	10	4	4	4	4	5
3rpm	5	3	14	8	3	3	3	3	3

3.3. Economic Evaluation of Beneficiation Process

Table 5 depicts series of cashflows for the process of beneficiation. From table 5, the cash flow for the local BB was obtained by subtracting the expenses which includes the costs of PWS, MS, LB, and machine maintenance and vehicle petrol from the revenue. From Table 6, The initial cash flow with NPV of 110.4 was discounted at the rates of 10%, 15% and 30% which gave NPVs of $47.16934, $24.22991 and -$23.72884 respectively. The various discount rates were plotted against the obtained cash flows in figure 1 and the DCF-ROR was obtained at the rate of 22% which brings the NPV to zero (ORR). It can be seen that the DCF-ROR of 22% is very good compared to the normal standard 10-15% required by oil companies. This implies that this alternative is reasonably efficient in returning the profits on investment.

Table 5. *Cash Flow of Base Case for Beneficiation Process Alternative.*

Years From Start	Revenue ($1,000)	Investment ($1,000)	Expenditure Breakdown ($1000) Periwinkle shells	Mucuna Solannie	Local Bentonite	Machine Maintenance	Expenses Vehicle Petrol		Cash Flow ($1,000)
0	0	150.6						0	-150.6
1	150	0	18	16	35	20	10	99	51
2	150	0	18	16	35	20	10	99	51
3	150	0	18	16	35	15	10	94	56
4	150	0	18	16	35	20	9	98	52
5	150	0	18	16	35	20	10	99	51

Table 6. *Incremental Analysis of beneficiation process alternative.*

Years From Start	Cash Flow	DR @ 10%	PV @ 10%	DR @ 15%	PV @ 15%	DR @ 30%	PV @ 30%
0	-150.6	1	-150.6	1	-150.6	1	-150.6
1	51	0.90909	46.36359	0.86957	44.34807	0.76923	39.23073
2	51	0.82645	42.14895	0.75614	38.56314	0.59172	30.17772
3	56	0.75131	42.07336	0.65752	36.82112	0.45517	25.48952
4	52	0.68301	35.51652	0.57195	29.7414	0.35013	18.20676
5	51	0.62092	31.66692	0.49718	25.35618	0.26993	13.76643
TOTAL	110.4		47.16934		24.22991		-23.72884

Where: DR=Discount Rate.
PV=Present Value.

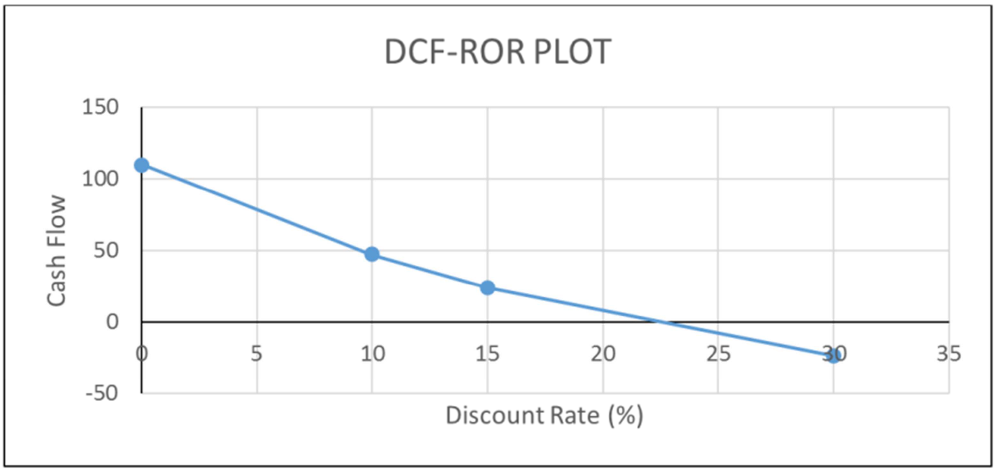

Figure 1. *DCF-ROR plot.*

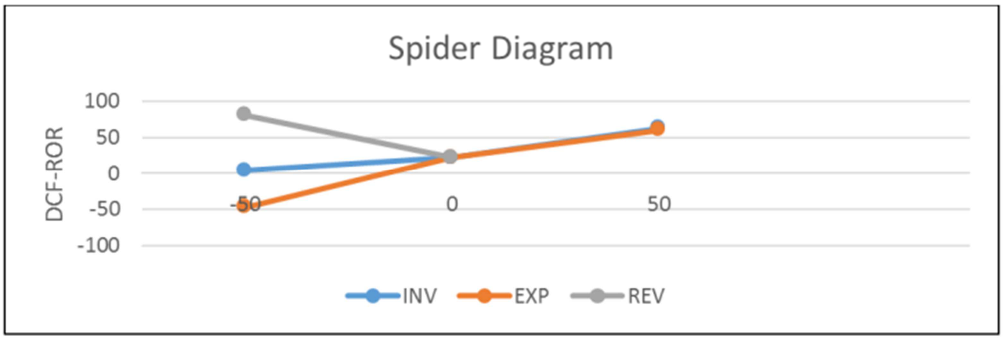

Figure 2. *Spider Diagram on SA.*

Table 7. *Sensitivity Analysis on Variations in Cash Flow Assumptions.*

Years From Start	Revenue	Expenses	Investment	Tax	Base Case	INV + 50%	INV - 50%	EXP + 50%	EXP - 50%	REV+ 50%	REV - 50%
0	0	0	150.6	0	-150.6	-225.9	-75.3	-150.6	-150.6	-150.6	-150.6
1	150	99	0	1	51	50	50	1.5	100.5	126	-24
2	150	99	0	1	51	50	50	1.5	100.5	126	-24
3	150	94	0	1	56	55	55	9	103	131	-19
4	150	98	0	1	52	51	51	3	101	127	-23
5	150	99	0	1	51	50	50	1.5	100.5	126	-24
DCF - ROR					22%	4%	61%	-48%	61%	80%	N/A

It can be seen from the spider diagram, that for the base case shown in Figure 2 and Table 7, the DCF-ROR is 22%. It is quite above the criteria of 10-20% rate acceptable in most companies. With a 50% increase in the value of investment, the DCF-ROR is 4%. However, if there is a 50% reduction while maintaining same projected revenue, expenses and tax, as depicted in Table 7, the DCF-ROR is 61%. Similarly, if there is a 50% increase in expenses, the DCF-ROR is negative with a value of -48%, but if there is a 50% reduction, the DCF-ROR is 61%. Also, if there is a 50% increase in revenue, the DCF-ROR is 80%, and if there is a 50% reduction in same, the table shows that there are extreme losses over the 5-year period. The NCR which is the cumulative cash-flow for a period of 5 years is $110,400. The PO is about 2.9 years and the DCF-ROR is 22%.

3.4. FB and Local BB Cost Comparison

Table 8 depicts the cost estimates of materials and ICF series respectively for the process of beneficiation. From table 8, the sum total of the purchase of items for the local BB is quite cheaper than that of FB. Therefore beneficiation of LB as an alternative to the FB is a reasonable and better option. Developing an ICFs between the two alternatives is the most preferred way to compare the foreign IB and the local BB by subtracting the cash flows of the FB (Case A) from the cash flows of the local BB (Case B) as shown in table 9. The ICF with a NPV of $453.4 as depicted in table 10 was discounted at the rate of 10% which gave a NPV of $307.326224 which did not give an ORR. The ICF was further discounted at the rates of 15% with a NPV of $254.365088. Again, the incremental cash was discounted at the rate of 30% with a NPV of 143.690544 which did not give an ORR. Furthermore, the ICF was discounted at the rate of 60% and 100% with NPVs of 31.526536 and -33.575 respectively. The DCF-ROR plot depicted in Figure 3 intersected the discount rate at 75% which gave an ORR. The intersection at the rate of 75% shows that the local BB will reduce the cost spent on drilling mud by 75% compared to the foreign IB. This implies that this alternative (local BB) is reasonably efficient in returning the profits on investment.

Table 8. *Cost estimates of materials.*

S/N	Item description	Size (metric tons)	Unit Price ($)
1	Foreign bentonite	1	305.4
2	Local bentonite	1	150.6
3	Periwinkle shell	1	18
4	Mucuna solannie	1	16

Table 9. *Incremental Cash flow Series.*

Years	Case A	Case B	Incremental (case B - case A)
0	0	-150.6	-150.6
1	-305.4	-184.6	120.8
2	-305.4	-184.6	120.8
3	-305.4	-184.6	120.8
4	-305.4	-184.6	120.8
5	-305.4	-184.6	120.8
TOTAL	-1527	-1073.6	453.4

Case A=FB.
Case B=Local BB.

Table 10. *Incremental Analysis of beneficiation process alternative.*

Years From Start	Cash Flow	DR @ 10%	PV @ 10%	DR @ 15%	PV @ 15%
0	-150.6	1	-150.6	1	-150.6
1	120.8	0.90909	109.818072	0.86957	105.044056
2	120.8	0.82645	99.83516	0.75614	91.341712
3	120.8	0.75131	90.758248	0.65752	79.428416
4	120.8	0.68301	82.507608	0.57195	69.09156
5	120.8	0.62092	75.007136	0.49718	60.059344
TOTAL	453.4		307.326224		254.365088
DCF-ROR	75%				

Table 10. *Continued.*

Years From Start	DR @ 30%	PV @ 30%	DR @60%	PV @ 60%	DR @ 100%	PV @ 100%
0	1	-150.6	1	-150.6	1	-150.6
1	0.76923	92.922984	0.625	75.5	0.5	60.4
2	0.59172	71.479776	0.39063	47.188104	0.25	30.2
3	0.45517	54.984536	0.24414	29.492112	0.125	15.1
4	0.35013	42.295704	0.15259	18.432872	0.0625	7.55
5	0.26993	32.607544	0.09531	11.513448	0.03125	3.775
TOTAL		143.690544		31.526536		-33.575
DCF-ROR						

4. Conclusion and Recommendation

4.1. Conclusion

From the results gotten and analysis made, it can be inferred that:

(a) The beneficiation process is very economically beneficial and a good potential for the oil industry.
(b) The additives (PWS and MS) have proven to contain and provide enough properties to be able to enhance our local bentonite if added in substantial amounts.
(c) With the DCF-ROR of 22%, the Nigerian oil industry has a lot to benefit from this approach.
(d) Also, considering that drilling and production operations are long term processes, this process will be beneficial at the long-run as investment is made only once and annual cash flows are positive indicating profits.

4.2. Recommendation

While conducting the tests, evaluating the cost benefit and also analyzing the results, it was noticed that the additives were not sodium based but still yielded profitable results. Therefore, we would recommend that more research should be conducted with a combination of snail shells as additives.

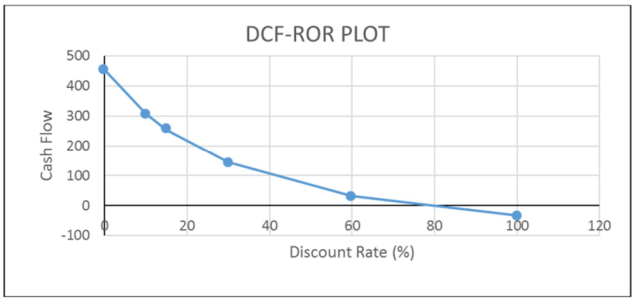

Figure 3. *DCF-ROR plot.*

Nomenclature

AWA - As well as
DF - Drilling fluid
HC – Hydrocarbon
HCs – Hydrocarbons
DFs - Drilling fluids
API - American Petroleum Institute
LB – Local Bentonite
FB – Foreign Bentonite
NB – Nigerian bentonite
BB – Beneficiated Bentonite,
OCMA - Oil Company Material Association
MARR - Minimum Acceptable Rate of Return
PV – Present value
PVs – Present values
PO - Payout
LTLP – Low temperature low pressure
YP – Yield Point
PV – Plastic Viscosity
IB – Imported Bentonite
MS – MucunaSolannie
PWS – Periwinkle Shell
PWSs – Periwinkle Shells
NPV - Net Present Value
DCF – ROR - Discounted Cash Flow Rate of Return
CBA - Cost–Benefit Analysis
ICF - Incremental cash flow
ICFs - Incremental cash flows
SEM - Scanning Electron Microscope
NPs –Nanoparticles
ORR – Optimum return rate
CMC - Carboxymethyl cellulose

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