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A REVIEW OF PIT LIMIT OF ITAKPE IRON ORE DEPOSIT, NORTH CENTRAL NIGERIA

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Abstract:

The National Iron Ore Mining Company Ltd, Itakpe, Kogi state Nigeria, operates two pits: the East Pit and West Pit. While exploitation work is currently going on the East pit, the process has temporarily been stopped on the west pit waiting for a review of the pit limit and other techno-economic parameters. This research project is meant to ascertain the optimum pit limit for the West pit of the company. In order to do this, the initial pit limit of 250m established on cross-sections in 1976 using stripping ratio method were used as a baseline pit limits. Thereafter, a preliminary three dimensional pit was designed using the cross sections. Using this preliminary three dimensional pit as a baseline, four variants of pit limit were ear-marked for economic analysis. For each variant, ore reserve and production rate were estimated followed by cash flow analysis. Finally the net present value (NPV) was ascertained for each of these variants. Analysis shows that the maximum net present value was generated in variant 3 with a net present value (NPV) of USD374million. This variant therefore becomes the optimum pit limit of the west pit of Itakpe mine. On cross-section 36, this pit limit is depicted at a depth of 200m.

Keywords —Net present value, Pit limit,capital outlay.

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I. INTRODUCTION

The National Iron ore mining company Itakpe, is an organization saddled with the responsibility of mining Itakpe iron ore deposit in Nigeria. The deposit consists of 25 ore layers varying in grade from 14%Fe – 41%Fe. It is made up of two limbs: east limb and west limb. Analysis by Nwosu and Irene (2018) shows that the cut-off grade is 23%Fe. The ore layers of Itakpe deposit are displayed in cross-section 36 of the deposit (Fig. 1). The mine design for the deposit was done in 1976 and proposes that the two limbs of Itakpe Iron ore deposit be mined in separate pits; the east and west pit. Mining of the east pit has progressed to extraction of several benches while extraction on the west pit has been temporarily stopped waiting a review of the pit limit and other techno-economic

indicators of the pit. This research reviews the pit limit of the west pit for the extraction of the western limb of the deposit.

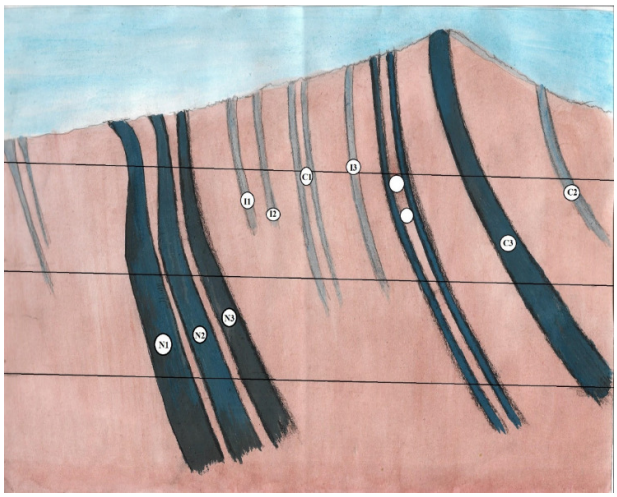

Fig 1: Cross-section 36 of Itakpe iron ore deposit

Mine limit can be defined as economic boundary of any mine (Arsentiev 1970). Economic boundary is often seen on two perspectives.

i) The boundary below which the pit can no longer break-even
ii) The boundary below which the net present value is no longer maximum.

The break-even approach of pit limit is often sought for through the economic limit stripping ratio, which is the maximum stripping ratio above which the pit cannot break-even. But the use of economic limit stripping ratio does not accommodate the consideration of royalty and tax payment in pit limit analysis. This means that NPV can turn negative in a mine designed using the limiting stripping ratio. Therefore the limiting stripping ratio can only be used in a preliminary assessment of pit limits.

However, the use of net present value (NPV) in pit limit analysis optimizes the value of the deposit. The advantage of the use of NPV in pit limit estimation have been emphasized by several researchers; Hahrikov (1980); Nwosu (1994) in which several variants of pit limits were suggested and the variant with maximum net present value was recommended as optimum. In our consideration of the new pit limit of the west pit of Itakpe iron ore deposit, we apply the use of the net present value criterion on the project.

2. METHODOLOGY

The method applied in the review of pit limit of west pit is the variant method in which several variants of pit limit are considered and the NPV for each variant is established. The pit limit that generates maximum NPV becomes the chosen pit limit. The following steps were applied to achieve the above method.

1. The initial pit limit which was established in 1976 i.e pit depth of 250m was used as a baseline pit limit on the cross-sections for further optimization of the pit limit using NPV approach.
2. Using the preliminary pit limits on the cross-sections, three dimensional pit limit was established.
3. From the above preliminary three dimensional pit limit, variants of pit limit were ear-marked upward (in decreasing order of pit depth).
4. For each three dimensional pit boundary, ore reserve of the pit was estimated along with the balanced stripping ratio.
5. Then, the production scheduling was done establishing the production rate in ore, concentrate and waste.
6. The production rate in ore was established using Taylor's formular in the form.

$$A = 4.88T^{0.75} \text{ (Taylor 1987)} \quad (1)$$

Where; T = reserve of ore on the pit.

7. Cash flow was developed showing annual cost of mining, processing and waste removal. The cash flow also shows cash inflow, royalty, tax and net profit.
8. The capital outlay required for mine development for each variant of pit limit was estimated and presented in table 3.
9. Finally the NPV for each variant was estimated using formula (2) and the variant with the highest NPV becomes the chosen pit limit.

$$NPV = \sum_{i=1}^{t} N_p - T_c \quad (2)$$

NPV = net present value of the project
$\sum_{i=1}^{n} N_p$ = sum of discounted annual net profits
n = Lifespan of the project (1,2,3…… n)
T_c = capital outlay on the development of the pit limit.

3. RESULTS AND DISCUSSION

The table below shows the current cost of mining, mineral processing and waste removal at Itakpe iron ore deposit and other techno-economic parameters as updated by Brian (2021). In the analysis below, 150USD was adopted as the price per ton of concentrate as against the current price of 120USD in the International market.

Table 1: Techno-economic parameters of Itakpe deposit

Techno-Economic Parameters						
Unit cost of mining per ton of ore USD	Unit cost of waste removal per ton of waste USD	Unit cost of processing per ton of ore USD	Yield per ton of ore	Discount rate	Royalty	Tax
3.5	2	4	0.35	10%	40%	20%

This is because of expected rise in price per ton of concentrate in the near future. Fig 1 is a cross section of west pit of Itakpe iron ore deposit with the 4 variants of pit limits while Fig. 2 is the three dimensional model of the same pit. The 4 variants were subjected to net present value analysis. The respective variants of pit depths in relation to cross-section 36 (profile IV) are 100m, 150m, 200m and 250m. Tables 2 to 5 shows the cash flow for net present value estimation.
The ore reserve estimated from the 4 variants of pit limits are displayed in table 2.

Table 2: west pit

Variants of pit depth (m)	100m	150m	200m	250m
Reserve estimated (mt)	27.9	46.3	70.4	91.6
Balanced stripping ratio (t/t)	0.86	2.56	4.31	6.59

For annual production rate we apply Taylors's formula in the form
$A = 4.88T^{0.75}$
For variant 1: Production rate
$A = 4.88\ (27{,}900{,}000)^{0.75} = 1.8\text{mt}$
$\text{Lifespan} = \frac{27.9\text{mt}}{1.8\text{mt}} = 16\text{yrs}$

Following similar steps, production rate for other variants have been estimated and used in tables 4 – 7. The lifespan and production rate were used to schedule production and develop the cash flow table for variant (1) using the techno-economic data in tables 1 & 2.

Table (4) shows the discounted values of net profit for variant 1.

Capital outlay required for the development of each variant of the pit was estimated and presented in table (3).

Table 3: Capital outlay required for various variants

Variant	1	2	3	4
Capital outlay required (million USD)	43.28	91.11	166.31	264.09

Using the capital outlay for each variant in table (3) above, and the sum of the discounted net profit for each variant, NPVs were estimated for variants 1 – 4 using formula (2).

For variant 1: NPV = 292.56 – 43.28 = US$249.28million

NPVs for other variants were similarly calculated and presented in table 8.

The variant of pit limit with maximum NPV is variant 3 with NPV of USD374.16million. This pit limit therefore becomes the optimum pit limit for the west pit of Itakpe mine. The graph of NPVs versus pit variant is shown in Fig. 3

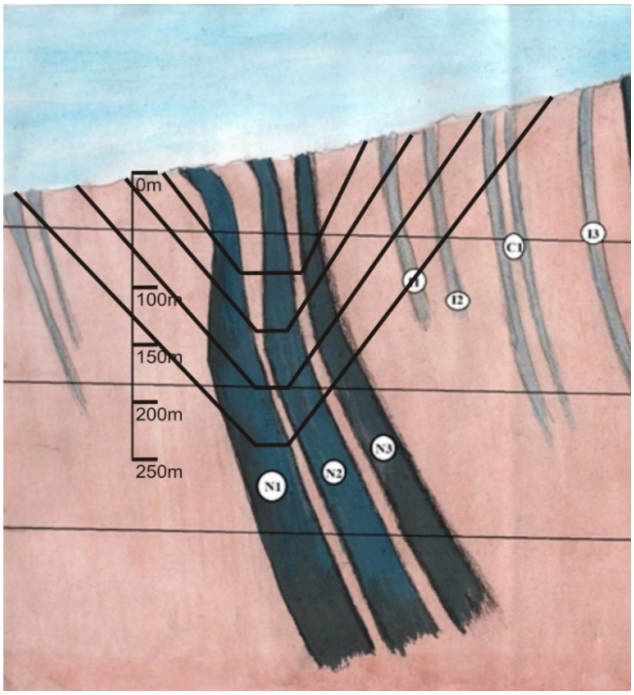

Fig 2: variants of pit limit on cross-section 36

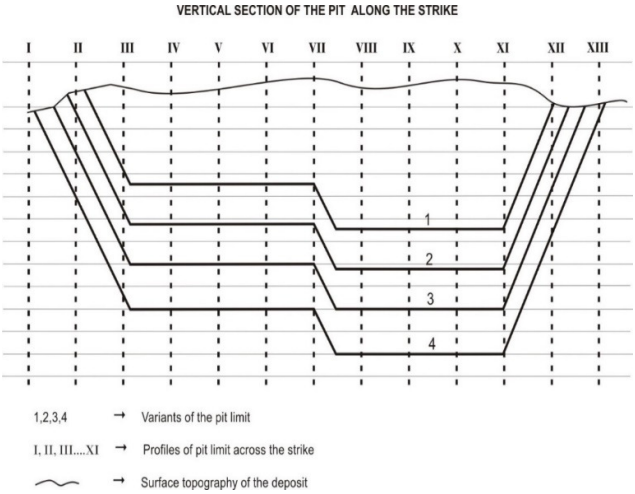

Fig. 3: Vertical section of the pit along the strike

Table 4: Variant 1

years of production	Production Rate	Annual prod of concentrate (mt)	annual waste removal	Annual mining cost (million USD)	annual cost of processing (million USD)	annual cost of waste removal (million USD)	Cash outflow (million USD)	Cash inflow (million USD)	Gross Profit (million USD)	Royalty (million USD)	Profit before tax (million USD)	Taxation (million USD)	Net profit (million USD)	Discounted cash outflow (million USD)	Discounted net profit (million USD)
1	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	15.087	33.994
2	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	13.716	30.904
3	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	12.469	28.095
4	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	11.335	25.541
5	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	10.305	23.219
6	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	9.368	21.108
7	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	8.516	19.189
8	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	7.742	17.445
9	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	7.038	15.859
10	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	6.398	14.417
11	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	5.817	13.106
12	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	5.288	11.915
13	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	4.807	10.832
14	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	4.370	9.847
15	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	3.973	8.952
16	1.80	0.63	1.55	6.3	7.2	3.10	16.60	94.5	77.90	31.16	46.74	9.348	37.394	3.612	8.138
SUM														**129.842**	**292.559**

Table 5: Variant 2

years of production	Production Rate	Annual prod of concentrate (mt)	annual waste removal	Annual mining cost (million USD)	annual cost of processing (million USD)	annual cost of waste removal (million USD)	Cash outflow (million USD)	Cash inflow (million USD)	Gross Profit (million USD)	Royalty (million USD)	Profit before tax (million USD)	Taxation (million USD)	Net profit (million USD)	Discounted cash outflow (million USD)	Discounted net profit (million USD)
1	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	30.976	46.986
2	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	28.160	42.714
3	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	25.600	38.831
4	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	23.273	35.301
5	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	21.157	32.092
6	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	19.234	29.175
7	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	17.485	26.522
8	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	15.896	24.111
9	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	14.451	21.919
10	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	13.137	19.927
11	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	11.943	18.115
12	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	10.857	16.468
13	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	9.870	14.971
14	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	8.973	13.610
15	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	8.157	12.373
16	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	7.415	11.248
17	2.70	0.95	6.91	9.45	10.8	13.82	34.07	141.75	107.68	43.07	64.61	12.921	51.684	6.741	10.225
SUM														**273.326**	**414.590**

Table 6: Variant 3

years of production	Production Rate	Annual prod of concentrate (mt)	annual waste removal	Annual mining cost (million USD)	annual cost of processing (million USD)	annual cost of waste removal (million USD)	Cash outflow (million USD)	Cash inflow (million USD)	Gross Profit (million USD)	Royalty (million USD)	Profit before tax (million USD)	Taxation (million USD)	Net profit (million USD)	Discounted cash outflow (million USD)	Discounted net profit (million USD)
1	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	54.222	58.737
2	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	49.293	53.397
3	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	44.811	48.543
4	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	40.738	44.130
5	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	37.034	40.118
6	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	33.667	36.471
7	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	30.607	33.156
8	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	27.824	30.141
9	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	25.295	27.401
10	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	22.995	24.910
11	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	20.905	22.646
12	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	19.004	20.587
13	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	17.277	18.715
14	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	15.706	17.014
15	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	14.278	15.467
16	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	12.980	14.061
17	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	11.800	12.783
18	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	10.727	11.621
19	3.70	1.30	15.95	12.95	14.8	31.89	59.64	194.25	134.61	53.84	80.76	16.153	64.611	9.752	10.564
SUM														**498.917**	**540.465**

Table 7: Variant 4

years of production	Production Rate	Annual prod of concentrate (mt)	annual waste removal	Annual mining cost (million USD)	annual cost of processing (million USD)	annual cost of waste removal (million USD)	Cash outflow (million USD)	Cash inflow (million USD)	Gross Profit (million USD)	Royalty (million USD)	Profit before tax (million USD)	Taxation (million USD)	Net profit (million USD)	Discounted cash outflow (million USD)	Discounted net profit (million USD)
1	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	84.600	62.483
2	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	76.909	56.803
3	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	69.917	51.639
4	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	63.561	46.944
5	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	57.783	42.677
6	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	52.530	38.797
7	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	47.754	35.270
8	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	43.413	32.064
9	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	39.467	29.149
10	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	35.879	26.499
11	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	32.617	24.090
12	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	29.652	21.900
13	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	26.956	19.909
14	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	24.506	18.099
15	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	22.278	16.454
16	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	20.253	14.958
17	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	18.411	13.598
18	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	16.738	12.362
19	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	15.216	11.238
20	4.50	1.58	29.66	15.75	18	59.31	93.06	236.25	143.19	57.28	85.91	17.183	68.731	13.833	10.216
SUM														**792.272**	**585.147**

Table 8: Pit depth versus NPV

PIT DEPTH	100	150	200	250
NPV (mt)	249.28	323.48	374.16	321.06

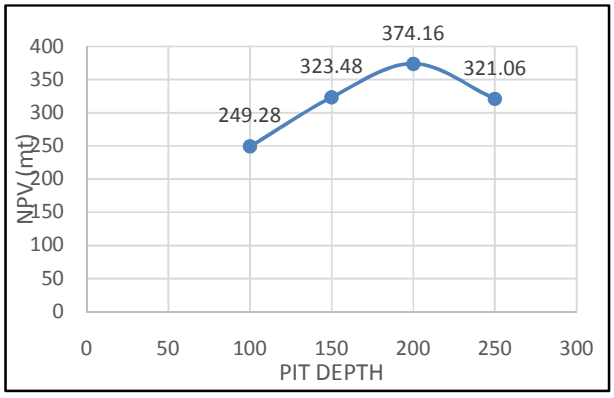

Fig 4: Pit depth versus NPV

4. CONCLUSIONS

i. Analysis has shown that the pit limit that generates the highest value of the west pit is variant 3 (tables 8 and Fig. 3) with pit depth of 200m on cross-section 36 as against the previous pit depth of 250m earlier estimated in 1976. This shows the advantage of application of net present value criterion over the break-even stripping ratio criterion.

ii. Consequently, the lifespan of the west pit of Itakpe is 19years with an average production of 3.7million tons per annum. This will generate a net present value of USD374.16million.

iii. Adjustment of surface intercept of the pit limit to reflect the 200m pit depth will improve the techno-economic indicators of west pit of Itakpe open-pit mine.

REFERENCES

[1] Nwosu, J.I. and Benard, I.U. (2020). Influence of Sub-Grade Ores on the Cut-Off Grade and Ore Reserve of Itakpe Iron Ore Deposit, North-Central, Nigeria. Journal of Mining and Geology Vol. 56(1) 2020. pp. 105 – 111.

[2] Arsentiev A.I (1970) Pit Limit and Production Rate Estimation. Nedra Publishers Moscow.

[3] Arsentiev A.I, Halodnikov GA (1990) Open Pit Mine Limit Estimation of Complex ore Deposit. Quaterly of Department of Surface Mining. St. Petersburg Mining Institute Russia.

[4] Nwosu J.I. (1994) Optimum Pit Limit Design and Production Rate Estimation for Complex Ore Deposits. Unpublished Ph.D thesis, St. Petersburg Mining Institute (Technical University) St. Petersburg, Russia.

[5] Taylor, H.K. (1986) "Rate of Working of Mines -A simple Rule of Thumb" Transactions, Institution of Mining and metallurgy, No. 95.

[6] Nwosu J.I. and Onwualu-John, J.N. (2019). Techno-Economic Evaluation of Ajabanoko Deposit, Kogi State, Nigeria. Journal of Mining and Geology Vol. 55(2) 2019. pp. 253 – 259.

