Sensitivity analysis for the stripping ratio in a phosphate mine

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This research aimed at identifying the profitable stripping ratio for orebody number 8 at Jordan Phosphate Mines Company. Currently, the stripping ratio used by the company is 1:20, however, due to changes in operating costs and selling prices this ratio should be changed to reflect current conditions. Analysis revealed that the new ratio must be less than 1: 10.92 to be profitable. Sensitivity analysis was conducted to outline the effect of price and cost changes and the effect of skipping the benefaction stage on the profitable stripping ratio. This analysis concluded that every one USD increase in price would increase the ratio by 0.79 and every one USD increase in operating cost will decrease the stripping ratio by 1. 198. Also, skipping benefaction lowers this ratio to 1: 7.

هدف البحث لتحديد معامل إزاحة الردم المربح للخام رقم ٨ في شركة مناجم الفوسفات الأردنية. القيمة المعتمدة الحالية لهذا المعامل من قبل الشركة تبلغ (١:٢٠)، ونتيجة للتغيرات في الكلف الإنتاجية وأسعار البيع فان هذا المعامل يجب ان يتغير ليعكس تأثير الواقع الحالي. أظهر التحليل أن المعامل الجديد يجب ان يكون أقل من (١٠,٩٢ : ١) ليكون مربحا. تم استخدام تحليل الحساسية لبيان تأثير تغيير الكلف والأسعار وتأثير الاستغناء عن الغسيل على معامل إزاحة الردم. واستنتج البحث أن زيادة سعر الفوسفات بمقدار دولار أمريكي واحد يزيد معامل الإزاحة بمقدار (٠,٧٩) وكذلك زيادة دولار أمريكي واحد في كلفة التشغيل يخفض معامل الإزاحة بمقدار (١,١٩٧). كما ان الاستغناء عن عملية الغسيل كمرحلة لرفع نسبة الفوسفات يخفض معامل الإزاحة ليصبح (١:٧).

Keywords: Phosphate mines, Stripping ratio, Orebody, Sensitivity analysis, Jordan

1. Introduction

AI-Abiad phosphate Mine is located 1 10 km south of the capital Amman and 70 km east of Karak City. AI-Ablad Mine complex consists of 10 orebodies numbered 3 west, 3 east, 6, 7, 8, 10, 21, 22, 23, and 24. Numbers 3 west, 10, 24 has been exploited, while numbers 3 east, 6, and 7 are under exploitation to feed the mine mill site with the rock necessary for production. Orebodies number 21, 22, 23 are under more detailed evaluation. Orebody number 8 has been explored at the end of 1997 and ready for mining exploitation, it is situated 15 km northeast of AI-Abiad mine site. Site elevation is 841 meters above see level with dessert climate and annual rainfall of 50 mm. However, heavy shower with more than the average rainfall might occurs in one hour. The relative humidity is very low and the weather conditions are dry. In 1999, the Jordan Phosphate Mines Company (JPMC) general management decided to start exploitations of orebody number 8, which is divided to 5 mining sections: A, B, B 1, C, and D [1], see fig. 1.

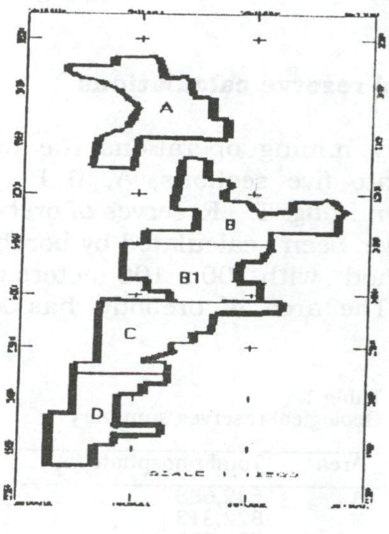

Fig. 1. Map of orebody number 8.

A report prepared by JPMC Exploration Department revealed that the reserve calculation of orebody number 8, one of the ten orebodies at Al-Abiad Mine, is equal to 2.6 million m^3. for any open pit mine, there is a strong correlation between mine economics and waste amount that has to be moved for each ton of ore, which is expressed in Stripping Ratio (SR). Stripping ratio is considered as an indicator of economic value. In its simple form, the SR number suggests that mine costs are a function of the waste amount and that mine revenues are a function of ore amount. A low SR means lower costs in relation to revenue and, therefore, it could be used as an indicator of relevant profit [2]. The borders and reserves of the orebody were determined on criteria basis were Tricalcium Phosphate Percentage (TCP) considered at least 65% and at most 1:20 as stripping ratio [3].

This research aims at determining the breakeven SR considering the latest operation costs and ore prices. A spreadsheet model will be built and applied to evaluate the change effect of the above-mentioned criterion and the effect of change on reserves and ore borders. Lavel [4] considered spreadsheets as a method of enhancing engineering economy principles and as a tool for engineering problem analysis. Sensitivity analysis will be conducted to present conclusions concerning the effect of change in ore prices and stripping cost parameters.

2. Geology and reserve calculations

To simplify mining operations the mine was divided into five sections, A, B, B 1, C, and D as shown in fig. 1. Reserves of orebody number 8 have been calculated by borehole influence method with 100 x 100 meters grid of boreholes. The area of orebody has been covered with a total of 350 boreholes. The results are summarized in table 1.

From table 1, the total mining reserve equals to 2.64 million m^3 covered by 30.84 million m^3 of overburden. Section A is considered to be the best in quality due to relatively higher TCP equal to 65.42% and relatively lower overburden volume of 3.6 million m^3. The lowest TCP relatively 63.07% is in section D that is covered by 3.8 million m^3 of overburden. The geological averages of the TCP and SR are 64.1% and 11.68, respectively, which will play a major role on decisions made from this study. In section A there is an increase of ore thickness to the northwest direction of about 3.95m, TCP is 65.42%. In section B the TCP is increasingly moving to the, west and southwest directions with average TCP of 64.01 %. Section B 1 has a stable TCP change with a slight decrease in the southwest section with average TCP of 63.5%. Section C has an average TCP of 63.69% the ore in this section have medium soft and medium hard form in general. The average TCP of section D is 63.07% [5].

3. Phosphate upgrading process description

3.1. Mining

Phosphate up-grading process starts by separating high from low percentage layers, and by cleaning the ore layers of any overburden and inter waste materials. This stage of upgrading process is accomplished by layer separation using bulldozers and experienced mining tasks. After extracting, the ore is transported to the mill site by hauling trucks. The cost of mining phosphate rock is 0.56 JD/m^3, while transportation cost is 0.0454 JD/m^3 for each kilometer [6].

Table 1
Geological reserves summary

Area	Total phosphate (m^3)	Total overburden (m^3)	SR	TCP%
A	642,688	3,595,059	5.59	65.42
B	822,313	1,0367,734	12.61	64.01
B1	555,331	8,941,278	16.10	63.50
C	316,339	4,130,731	13.06	63.69
D	303,987	3,804,583	12.52	63.07
Total	2,640,658	30,839,385	11.68	64.10

3.2. Screening and crushing

Phosphate ore after extracting and transporting is processed through the screening and crashing unit where it is screened on 6 mm screens. The phosphate ore with less than 6 mm fragments is convoyed to the open storage facility while the over 6 mm fragments is transported to the crusher head where it is liberated from hard fragments. The crushed materials are transported to secondary screen with 6 mm size, which separates fragments again over than 6 mm and less than 6 mm, material above 6 mm is convoyed to reject banker and sent away by trucks. Phosphate below 6 mm is convoyed to the open storage facility. The screening and crushing unit has two identical lines the first line is specialized in producing phosphate below 67% TCP, while the second line is specialized in above 67%. Each of these lines have it is own storing facility, according to JPMC's Research Department experiment report for orebody number 8 specific gravity is 2.2 ton/m^3 with 75% and weight recovery. The crusher feed from orebody number 8 is going through line number one due to low-grade characteristic [7].

3.3. Beneficiation plant

This unit is designed only for low-grade phosphate rock less than 66%. In this unit washing technique is used to upgrade the ore by agitating, wet screening, and hydro sizing. The overflow considered being concentrated grade. Lower flow considered being rejects. This plant is able to upgrade from 65% to 73% TCP, with weight recovery up to 70%. The cost of this operation is 1.9 17 JD, see table 2.

3.4. Drying

This unit is designed to reduce water content in phosphate rock from 13% to 3% by processing wet phosphate through rotating dryer cylinder that is heated up to 900°C using fuel burner. According to table 2, the cost of this operation is 2.229 JD/Ton, with recovery of 95% [8].

4. Sensitivity analysis

Sensitivity and breakeven analysis are used as a decision making tool to aid in solving and making decisions among alternatives. Before conducting any analysis for JPMC, capitals, initial costs, salvage values and other variables were converted to time period-related equivalence talking into account the time value of money. Then, all these variables were integrated in a spreadsheet model, which was used for sensitivity analysis. Pack [9] presented the theory of traditional breakeven analysis and applied it to profit considerations for profitable construction company. Also, Hawes and D'Amico [10] used breakeven method to determine breakeven production output, were they considered price and variable costs as a function of product unit. Next, the data and assumptions used in the model are presented.

The following assumptions are used in the model building and analysis:

1. Capital and initial principles of upgrading equipment's, infrastructure facilities and exploration costs have been recovered by previous mining tasks and not included in the analysis. Therefore only operating tasks, which includes upgrading processes and extraction by the contractor is considered. Salvage values in this case are zero.
2. Revenues are only limited to ore selling operations with no other revenue drivers, these revenues are related to world phosphate markets.
3. Costs are limited to the items mentioned in table 2, which are not affected by time due to short project life, which is less than one year.
4. Time value of money concepts is not considered in the analysis due to the absence of initial principles and the short project life.
5. Tax is paid according to Jordanian income tax law, which consider 15% of incomes from mining tasks as tax rate [11].

The paper aimed at determining the profitable SR, which will enable the mining management to determine areas with no economical potentials using break even analysis, based on data from JPMC cost report and current selling prices of phosphate.

Table 2
Al-Abiad manufacturing cost (JD)* - concentrated grade

Cost Item	Variable costs		Fixed costs		Total costs	
	Total (100 JD)	Unit cost (JD/ton)	Total (1000 JD)	Unit cost (JD/Ton)	Total (1000 JD)	Unit cost (JD/Ton)
Total current beneficiation	975	0.990	913	0.927	1,889	1.917
Current dryer	530	1.329	359	0.90	889	2.229
Handing & storing	8	0.021	108	0.272	116	0.293
Mine overhead	93	0.233	654	1.639	747	1.872
Cost of deliveries t Aqaba	4,267	12.409	1,570	4.568	4,838	16.977
Cost by railway	57	3.693	0	0.000	57	3.693
Cost by trucks	290	3.367	0	0.000	290	3.367
Total transport	347	3.416	0	0.000	347	3.416
Aqaba branch expendiure	0	0.000	42	0.419	42	0.419
General overhead	0	0.000	197	2.099	197	2.099
Financial expnditure	0	0.000	204	2.171	204	2.171
Other marketing expenditure	85	0.911	0	0.000	85	0.911
Aqaba port charges	165	1.750	0	0.000	165	1.750
Exporting fees	471	5.000	0	0.000	471	5.000

*1 USD = 0.71 JD

According to Cranford [12] these calculations are performed using the following equation;

$$\text{Max SR} = \frac{(S_r - C_o)}{C_s}. \quad (1)$$

Where, Maximum SR (Max SR) is where the cost equals revenue from ore selling,
S_r is the sale revenue of phosphate before stripping (JD),
C_o is the cost of phosphate mining, upgrading, transporting, and marketing before stripping (JD), and
C_s is the stripping cost (JD).

Using eq. (1), the spreadsheet model shown in fig. 2 was constructed to calculate the maximum profitable SR and conduct sensitivity analysis using actual cost data, market prices of phosphate, and technical parameters from JPMC files. Fig. 2 consists of four tables; table (a) summarizes the orebody technical data; table (b) presents the financial data needed for SR calculation; table (c) describes each production stage cost and recovery factors; and table (d) shows the calculation results.

By conducting sensitivity analysis, it was determined that the SR where the cost equals the revenue is equal to 10.92 which can be interpreted that mining operation can be profitable in orebody number 8 only if the volume over one cubic meter of phosphate is less than 10.92 m^3. In addition, one cubic meter of ore rock will produce 0.9096 ton of ore delivered to Aqaba. The researchers noticed that beneficiation-upgrading process could be skipped to produce phosphate ore with 66% TCP avoiding its unit cost share. Result says that the SR will equal 7.08 if the assumed upgrading sequence is realized.

Also, sensitivity analysis was conducted to test the effect of changes in selling price of concentrated ore and the effect of operating cost on the SR. Results say that every one USD increase in selling prices increases the maximum SR by 0.79. Fig. 3 shows the relationship between the change in price and SR.

The change in cost of manufacturing phosphate ore and SR is demonstrated by changing the model's total cost inputs. Results are illustrated in fig. 4; every one USD increase in cost will decrease SR by 1.193.

5. Conclusions

Research findings are different from previous studies results in which less than a SR of 1:20 was considered profitable. Due to current conditions, it was concluded that less than 1:10.92 is the profitable SR. Sensitivity analysis results showed that one USD increase in phosphate price would increase SR by 0.79. The analysis also showed that every one USD increase in operating cost would decrease SR by 1.198. If the beneficiation process was skipped, the SR will drop to.

Table (a): Orebody technical data.

Grade %	1
Density ton/m³	2.2
Hauling distance (km)	15
Ore volume (mln cm)	2.64
Overburden volume (mln m³)	30.84
Stripping ratio	11.68

Table (b): Financial data.

Selling price usd	49.3200
Exchange rate	0.7100
Selling price (jd)	35.0172
Stripping jd/bcm	0.7100
Mining jd/m3	0.5600
Trans.ore jd/t*km	0.0434

Table (c): Production stage and recovery factors

Concentrate	Unit	Feed	Weight recovery	Product	Cost/unit	Total cost
Stripping	m³				0.71	
Mining	m³	1.00	1.00	1	0.56	0.56
Ore transport	Ton	2.20	1.00	2.20	0.04	1.43
Crushing & screening	Ton	2.20	0.75	1.65	0.29	0.47
Internal transport	Ton	1.65	0.98	1.62	0.02	0.04
Benificiation	Ton	1.62	0.70	1.13	1.91	2.16
Drying	Ton	1.13	0.82	0.93	2.23	2.07
Handling & storing	Ton	0.93	1.00	0.93	0.29	0.27
Mine overhead	Ton	0.93	1.00	0.93	1.87	1.74
External transport	Ton	0.93	1.00	0.93	3.42	3.17
Aqaba office	Ton	0.93	1.00	0.93	0.42	0.39
Port charges	Ton	0.93	1.00	0.93	1.75	1.62
General overhead	Ton	0.93	1.00	0.93	2.10	1.95
Marketing expenses	Ton	0.93	1.00	0.93	0.91	0.85
Financial expenses	Ton	0.93	1.00	0.93	2.17	2.02
Export feez	Ton	0.93	1.0000	0.93	5.00	4.64
Total cost before stripping						23.38

Table (d): Calculation results.

Dry phosphate output t/m³	0.93
Sales revenue (jd).	32.50
Total cost before stripping	23.38
Tax (jd)	1.37
Net profit (before stripping)	7.76
Breakeven stripping ratio	10.92

Fig. 2. Spreadsheet model output for orebody number 8 profitable SR.

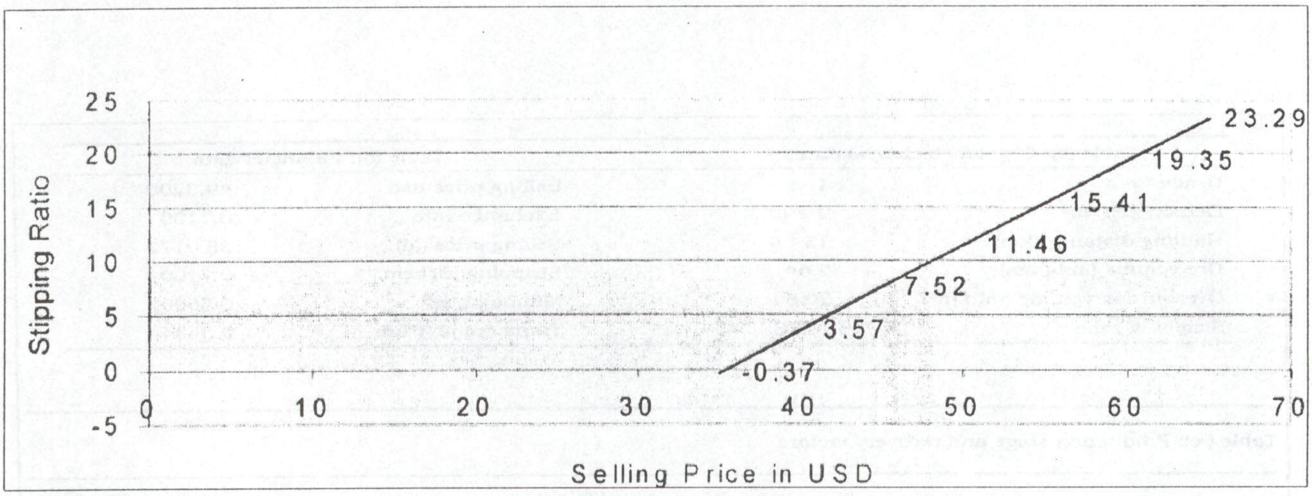

Fig. 3. Selling price change effect.

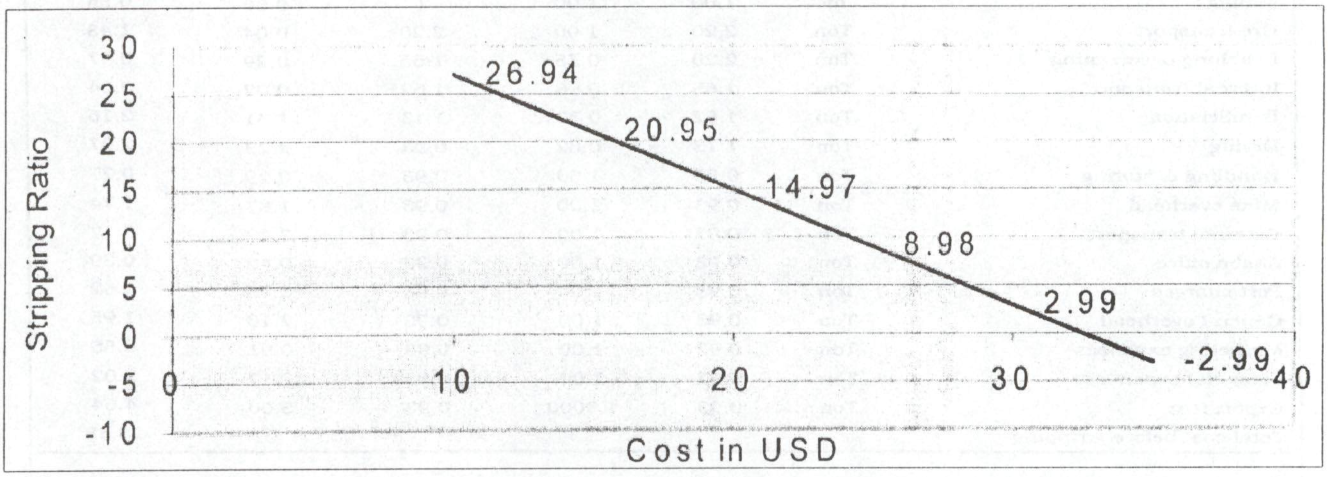

Fig. 4. Cost change effect.

seven. Another approach to mining operation in orebody number 8 is recommended.

Due to higher SR in sections B, B 1, C and D, which are equal to 12.61, 16.1, 13.06 and 12.52, respectively, a decision should be made to avoid exploitation in these sections, which will save 7 million USD according to the model analysis. Beneficiation shouldn't be skipped and further studies on operating cost reductions and better marketing strategies must be conducted.

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