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MINING AND BENEFICIATION OF PHOSPHATE ROCKS: PROSPECTS OF UNEXPLOITED PHOSPHATE DEPOSITS IN THE WESTERN DESERT, IRAQ

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ABSTRACT

Iraq has been producing phosphate since 1983 from the Akashat mine. Mining is being carried out by open cast strip mining method due to the stratiform nature of the phosphate beds and low stripping ratio. Phosphate beneficiation is carried out at the phosphate beneficiation Plant at Al-Qaim Fertilizer Complex to raise the content of P_2O_5 from 19 – 20 % to about 30% through the calcination process. Recent study has been carried out to beneficiate Akashat phosphate by froth floatation techniques, the results indicated the possibility of increasing the content P_2O_5 to the levels required for the fertilizer industry and other industrial uses. The massive discoveries of phosphate rock reserves in the Western Desert indicate that the deposit has a high variable stripping ratios and different content of P_2O_5 as well as different levels and contents of associated gangue minerals and compounds. Accordingly it became necessary to outline some of the mining problems and the best methods of beneficiation techniques in which the phosphate components can be increased. The results obtained in the research conducted on samples of phosphate rock from unexploited phosphate in the Western Desert showed the possibility of increasing the content of P_2O_5 up to 30% using the traditional calcination method and some deposits need only simple beneficiation processes.

آفاق استخراج وتركيز الصخور الفوسفاتية للرواسب غير المستغلة في الصحراء الغربية، العراق

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المستخلص

في العراق يتم استخراج الصخور الفوسفاتية منذ عام ١٩٨٣ من منجم عكاشات بطريقة المنجم السطحي المفتوح، ويتم تركيزها في معمل تركيز الصخور الفوسفاتية في مجمع القائم للأسمدة لرفع محتوى P_2O_5 من ١٩ – ٢٠ ٪ إلى حوالي ٣٠٪ من خلال عملية الكلسنة والغسل. كانت هناك دراسات قليلة عن استخدام طرق تركيز أخرى للاستفادة من فوسفات منجم عكاشات مثل طريقة التعويم الرغوي. أثبت بحث أجري مؤخرا إمكانية زيادة محتوى P_2O_5 إلى المستويات المطلوبة لصناعة الأسمدة وغيرها من الصناعات والاستخدامات. بعد الاكتشافات الضخمة لاحتياطيات الصخور الفوسفاتية في الصحراء الغربية والتي تتميز بظروف منجميه مختلفه وتحتوي على نسب متباينه من P_2O_5، فضلا عن محتويات

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المعادن الأخرى والمركبات المرتبطة بها، أصبح من الضروري القاء الضوء على التحديات التي يمكن أن تواجه العمليات الاستخراجيه مستقبلا ودراسة أفضل طرق المعالجة والتركيز والتي يمكن من خلالها زيادة تركيز الصخور الفوسفاتية.
أظهرت النتائج التي تم الحصول عليها من البحوث التي أجريت على عينات من الصخور الفوسفاتية من الرواسب غير المستغلة في الصحراء الغربية إمكانية زيادة نسبة P_2O_5 لتصل إلى ٣٠٪ باستخدام طريقة الكلسنة التقليدية وبعض الرواسب تحتاج إلى عملية تركيز بسيطة.

INTRODUCTION

Worldwide, the phosphate mining works classified the phosphate deposits into three and major groups; marine sedimentary, igneous and biogenic deposits. The most important volume and quality are the sedimentary deposits. Approximately 75 – 80 % of the marketable phosphate rocks are derived from these types (Mar and Okazaki, 2012; UND10, 1998). The phosphate deposits in Iraq, located in the Western Desert, are genetically of marine sedimentary origin (Al-Bassam *et al*., 1990a; Al-Bassam, 2007). This type of phosphate deposits are mostly mined by open cast strip mining (Patrick *et al*., 2015; Simandi *et al*., 2012). Several aspects should be taken in consideration before the phosphate ore is extracted, this include the geological condition with respect to the thickness of overburden (the layer of waste materials above the phosphate bed), morphology thickness and structural condition of the industrial bed. Strip mining (or open cast) is the cheapest and safest method, but it may have significant impact environmentally on the ground surface (Casey Research, 2015). Phosphate deposits contain a variety of mineral impurities, which vary considerably in the type, quality, and amount. Beneficiation or upgrading is therefore needed to produce a commercial grade phosphate of about 30% P_2O_5 (Kauwenbgh, 2010). Liberation of the phosphate minerals from the associated gangue is the first step in all beneficiation processes for any ore type, and consists mostly of crushing and grinding operations. The technique that are used to raise the phosphate grade depend on the type of the phosphate deposit (Sedimentary, igneous or, biogenic deposit) for some sedimentary rocks, suitable technique for economic ore beneficiation are crushing, screening or grinding followed by pneumatic particle size selection, washing or scrubbing and desliming by hydrocyclone or classifier (Abouzaid, 2008; Patrick *et al*., 2006). These techniques utilize the differences in differential friability between phosphate minerals and gangue and cementing matrix (carbonate, silica, clay, and silicates).

GEOLOGICAL AND MINING CONDITIONS

Phosphate-bearing rocks in Iraq are generally stratiform, bed thickness ranges from less than one meter to about 16 meters and extend over an area of hundreds of square kilometers. The overburden strata are generally marl, ranging in thickness from zero to about 70 m with highly variable stripping about 12: 1 with an average of 3: 1 (Al-Bassam *et al*., 1990a).

Table 1 shows the industrial bed thickness, overburden thickness and its main constituents as well as the stripping ratio of Swab, Dwaima, Marbat, Area 1 and Area 2 deposits, some of which were classified as high-grade deposits either for their natural high content of shelly limestone, lime- mudstone with chert nodules, nummulitic limestone and P_2O_5 content (Area-2 deposit) or due to their friable nature permitting simple beneficiation processes such as sizing, (Area-1 deposit) (Al-Bassam and Saeed, 1989; Al-Bassam *et al*., 1989; Al-Bassam, 1990; Al-Bassam *et al*., 1990b). Figure 1 show the location of Area 1 and Area 2 of Al-Hirri region.

As it can be seen in Table 1, the stripping ratio is highly variable with an average generally approaching (3: 1) for most deposits. The so-called “high-grade” deposits of Area-1 and Area-2 show higher stripping ratios due to their relatively thin phosphate layers. The stripping ratio in Area-1 varies from 3: 1 in the southern part to 6: 1 in the middle part and up to 12: 1 in the northern part, whereas the stripping ratio is 7: 1 in Area-2 (Al-Bassam and Saeed, 1989). The high stripping ratio generally involves high volume removal of waste overburden materials, and hence high mining costs. But this would be balanced by the high grade of the phosphates and its amenability for upgrading by simple methods, such as washing and screening, to the prevailing market grade of > 30% P_2O_5. The work of Al-Ajeel and Daykh, (1989) and Al-Ajeel and Hammody (1989) indicated that the phosphate deposit of Area-1 averaging 22% P_2O_5 and 4% MgO, can be upgraded by simple techniques arriving at a concentrate assaying of 30% P_2O_5 and 0.7% MgO; therefore 6 – 7 stripping ratio in the mining of Area-1 can work economically for the general phosphate production plant. The same is true for Area-2 deposit. On the other hand stripping ratio of 12: 1 in the northern part of the Area-1 deposit would not be profitable, as haulage cost and blasting (explosives), will be very high.

Table 1: Mining parameters of recently discovered unexploited phosphate deposits located in the Western Desert of Iraq (Al-Bassam *et al*., 1990a and 1990b)

Phosphate Deposits	Industrial bed thickness (average)	Overburden thickness (average)	Main constituent of overburden	Average stripping ratio
Swab	9 – 16 m (11.2 m)	0 – 70 m (37 m)	Shelly limestone, lime-mudstone, marl, nummulitic limestone, coprolitic limestone	3: 1
Dwaima	8.1 – 13.4 m (10.64 m)	0 – 65 m (34 m)	As above in addition of chert	3: 1
Marbat	Three beds of 6.4 m, 0.71 m and 2.2 m	31.5 m	Shelly limestone, lime-mudstones with chert nodules and marl, nummulitic limestone, limestone with bedded chert	3.4: 1
Area-1- High-grade phosphate (Al-Hirri ragion)	0.5 – 4.5 m (3 m)	0 – 55 m	Chert-bearing, lime-mudstone, marl and nummulitic limestone	3:1 – 12:1*
Area-2- High-grade phosphate (Al-Hirri region)	2 beds 0.8 – 3.2 m (1.6 m) 0.5 – 1.5 m (1.1 m)	Overburden 0 – 50 m (20 m) Innerburden 0.3 – 1 .3 m (0.7 m)	Shelly limestone, chert-bearing lime-mudstone, marl and coprolitic limestone	7: 1

* 3: 1 in the southern part of the deposit, 6: 1 in the middle part of the deposit, 12: 1 in the northern part of the deposit

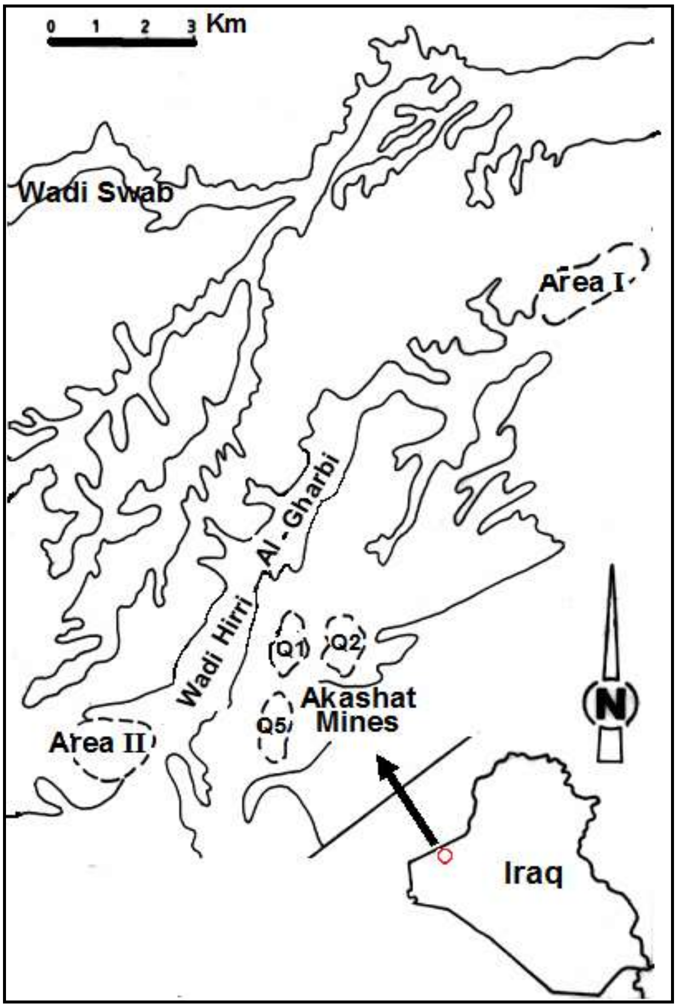

Fig.1: Location of Wadi Al-Hirri deposit, Area 1 and Area 2 at Western Desert of Iraq. (Modified from Hammodi, 2005)

UPGRADING OF AL-HIRRI PHOSPHATE DEPOSITS (AREA-1 AND AREA-2)

The phosphate deposits of Area-1 and Area-2 are located within the Akashat Formation, but they are of different stratigraphic position and vary in their mineral and textural constituents. The latter is the uppermost part of the Swab phosphate bed whereas the former is located at a higher stratigraphic level. Both deposits are friable in nature, but the former has dolomitic and calcareous impurities whereas the latter consists of loose phosphate peloids; consequently they differ in their P_2O_5 and MgO contents as shown in Table 2. The deposit of Area-2 shows a high grade P_2O_5 (29%) with very low MgO content (0.5%) which could be utilized directly in phosphoric acid production or it may need a very simple beneficiation work, therefore the upgrading of the phosphate deposits of Area-1 has received more attention.

Table 2: Average P_2O_5 and MgO contents of Area-1 and Area-2 high grade phosphate deposits

Location	P_2O_5	MgO
Area-1	21.94	4.12
Area-2	29	0.5

The chemical composition of major elements of a phosphate sample (300 Kg) collected from 70 boreholes of Area-1 for the purpose of the beneficiation tests showed: 22% P_2O_5; 45 – 28 % CaO; 4.5% MgO; 2.86% IR and 18.19% L.0.1. These results are quite analogues to the average chemical composition of the deposit reported by Al-Bassam *et al*. (1990b). Texturally, the ore is friable in nature, and the petrographical analysis revealed that it is dominated by phosphate ooids and apatite bone fragments. The cementing materials are dolomitic micrite and clay. Quartz and iron oxide are also present in trace amount. The phosphate ooids, however, are essentially spherical or elliptical in shape having a size range of (0.54 – 0.09 mm) but mostly at about 0.125 mm in size. These ooids are coated wholly or partially by clay and micritic dolomite. The apatitic bone fragments, on the other hand, are angular shape ranging in size from 0.9 mm to 0.01 mm. Dolomite and calcite are present commonly in a particle size of < 0.04 mm.

Based on the above information, the goal of the beneficiation tests was to raise the P_2O_5 content to the acceptable commercial level (> 30% P_20_5) and reduce the MgO content to < 1% MgO. High MgO content, however, affects the phosphoric acid production by increasing sulfuric acid consumption and greatly increases its viscosity (El-Midany, 2004; Safi *et al*., 2005). Because dolomite ($CaCO_3.MgCO_3$) is the most abundant impurity and the only source of MgO in the phosphate ore under test, beneficiation is conducted to separate dolomite and other impurities from the phosphate components. In this regard, the beneficiation techniques chosen are: **i)** size reduction, washing and screening (Al-Ajeel and Hammody, 1989) and **ii)** size reduction and attrition scrubbing followed by calcification (Al-Ajeel and Daykh, 1989).

By size reduction (crushing and grinding) the phosphate mineral (mostly francolite) can be liberated from the associated gangue and cementing matrix. Separation will then be accomplished by screening where the fine fraction (-0.125 mm) will be rich in the gangue material. The oversize +0.125 mm (or +0.106 mm) fraction, which contains most of the phosphate mineral grains, should be washed or scrubbed to remove fine material (clay and fine dolomite) adhered to the surface of the phosphate grains. Desliming is conducted then to remove the fine material generated from the operation. In both techniques, a phosphate concentrate having particle size of -2.36 + 0.125 (or +0.106 mm) and assaying 30 – 31.5 % P_2O_5 with 0.7 – 0.75 % MgO was achieved in the laboratory tests with a P_2O_5 recovery of 75 – 80 %. The fine fraction (-0.125 mm) was removed to waste as it contain a very low phosphate grade (about 9.5% P_2O_5) and significantly high MgO (10%). Nevertheless, further tests (bench-scale) are required to achieve more confidence in the result and to suggest the proper process flow diagram. An example of using the techniques above is the beneficiation plant of Nile Valley phosphate rocks at East Siba'eya area and Red sea coast phosphate rocks in Egypt (Abouzeid, 2008).

UPGRADING OF SWAB, DWAIMA, AND MARBAT DEPOSITS

Unfortunately no work has been previously done on the beneficiation of Swab, Dwaima, and Marbat phosphate rocks. These ores contain almost the same P_2O_5 grade (av. 21% P_2O_5) with calcite as the major impurity, but differ in their content of organic material, MgO, and silica (Al-Bassam *et al*., 1990). Swab deposit for example contains high organic (bituminous) mater, while that of Dwaima shows a high silica content, and Marbat phosphate deposit reveals slightly high MgO content (approximately 1.7% MgO as maximum level). As far as, calcite impurities are concerned, these recently assessed phosphate deposits are generally similar to that of Akashat phosphate, which is beneficiated by calcinations in Al-Qaim phosphate complex plant. This is because of the difficulty facing physical liberation of the phosphate components from the calcareous cement in these relatively well cemented and tough rocks (Abouzeid, 2008; Guo and Li, 2010).

Calcinations, however, was studied and recommended to treat Akashat phosphates in Iraq since the early 70s. Calcination is a process of heating the phosphate raw material at a high temperature (1000 °C) to eliminate organic matter and carbonate gangue. The CaO and MgO formed from the decomposition of calcite ($CaCO_3$) or Dolomite ($CaCO_3.MgCO_3$) are removed as hydroxide by quenching the calcined product in water. Under the best operational conditions, rock phosphate from Akashat containing 21% P_20_5 were beneficiated to 30% by this method (SCP, 1982). Treatment of Swab phosphates containing high organic matter by the calcination process can obviously come first. The phosphate rocks of the Marbat deposit can be also beneficiated by this method, whereas, that of Dwaima would need a pretreatment to eliminate or reduce the silica content.

Recent study (Wahaib *et al*., 2015) indicated that Akashat phosphate ore can be beneficiated by flotation. The process comprises milling the ore to -300 µ, washing and desliming to eliminate -75 µ size fraction and then subjecting the -300 + 75 µ fraction to flotation. Reverse flotation was used whereby the phosphate mineral was depressed and calcite gangue was floated as a reject. A concentrate containing 32% P_2O_5 and 0.5 MgO with a P_2O_5 recovery of 93% were achieved. However, the ore feed (-300 + 75 µ) introduced to the flotation cell constitute about 75% of the total P_2O_5 content in the ore. This work indicated that the phosphate mineral in Akashat phosphate rocks was liberated effectively from the associated calcite, and hence flotation technique was performed efficiently. Other workers (Haweel *et al*., 2013), claimed that the Akashat phosphates can be beneficiated by treatment with organic acid (acetic and lactic acid) to separate the calcite impurities, therefore its worth to do some beneficiation work other than calcinations before this method is suggested for the treatment of Dwaima and Marbat phosphate rocks.

CONCLUSIONS

The laboratory beneficiation tests carried out in this work on different phosphate deposits do not necessarily represent a comprehensive assessment of the best production technique but indicate that there is more than one method for the mining and processing of phosphate rocks according to the mineralogical and morphological characteristics of each deposit. Some of the beneficiation techniques studied showed more than one production path that can be developed in the future to suit the deposits explored in the Western Desert of Iraq.

The method currently used to beneficiate the Akashat phosphate rocks dates back to the 1980s, the date of establishment of the Akashat mine. It can be considered as a guide for planning of future exploitation of other phosphate deposits. However, during the period from the first phosphate beneficiation plant at Al-Qaim fertilizers complex, to the present time there has been a significant development in the beneficiation technologies that can be considered to use for new deposits.

There is a need to conduct technological and economic studies to investigate alternative technological concepts and ways to reduce costs to develop the phosphate industry considering the new phosphate deposits and a long-term sustainability of the beneficiation plants to be built in the future. Another thing to consider is the subsequent use of the beneficiated phosphates, whether for internal production of phosphoric acid and phosphate fertilizers, or for export as phosphate concentrates to the international market Strong competition in the market as a result of increased global supply capacity of phosphate rocks from strong producers may lead to stagnant demand in to choose modern technology the market; this provides an incentive and allocate resources to reduce costs and apply them to existing and future facilities.

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