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Cost-Efficient Physicochemical Techniques for the Beneficiation of Abu-Tartur Phosphate Utilizing the Existing Classification Method

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Abstract

In this study, we focus on enhancing the quality of Abu Tartur phosphate ore from the Western Desert of Egypt through physical concentration methods. This involves treating the metal surface by utilizing the surface differences among various metals that are made up of a single raw material, regardless of the type of charge applied to it, or the variations in specific density, magnetic properties, or through electrostatic separation using a variety of techniques and devices. We enhance the upgrading process through multiple stages, including gravimetric separation, hydrolytic separation, and magnetic separation, to achieve optimal results in upgrading. Extensive experimentation and analysis have determined the chemical composition of the phosphate sample using XRD analysis, which reveals the presence of insoluble P_2O_5, CaO, SiO_2, SO_2, and Fe_2O_3, leading to an increase in P_2O_5 content from 21% to 34%, allowing its application across various fields and industries.

Keywords: Physicochemical Techniques;the Existing Classification Method;Abu-Tartur Phosphate

Introduction

Phosphate rock or pre-concentrated phosphate ore plays a very important role as a principal raw material for the Egyptian economy; it comes in eighth place worldwide with regard to the production of phosphate rocks in 2020 [1]. In Egypt, there are three primary phosphate mineral mining zones: (1) the area between El-Kharga and El-Dakhla Oases in the western desert, (2) the Nile valley near Idfu, and (3) the area along the Red Sea between Safaga and Quesir. The estimated total phosphate resource reserves in Egypt are as high as 2.8 billion t[2,3]. Egypt now holds the third-largest phosphate ore reserves in the world, following Morocco (50 billion t) and China (3.2 billion t). Abu Tartur phosphate deposit is one of the largest phosphate deposits in the Middle East [3]. Relatively high concentrations up to 0.05-0.20 wt. % REEs are found in sedimentary Abu Tartur phosphate ore of Egypt [4,5,6and7] which are approximately 0.05% in comparison to those found in other sedimentary phosphate ores [8]. In sedimentary deposits of marine origin, the phosphate material is present in admixtures with detritus materials, such as silica, mica, and clay. It is frequently found in the presence of limestone and, on rare occasions, dolomite. Additional contaminants that are not frequently observed in sedimentary deposits may be present in igneous apatite's. This apatite crystallized from other components of the magma, which are the source of these impurities[9]. Industrial chemistry and agriculture are significantly influenced by phosphate minerals. It is evident that the examination of phosphate minerals is significant from the perspectives of economic, agricultural, environmental, human and animal health [10]. The fertilization of soils with phosphate has always been crucial, as a deficiency of phosphate (p) can result in the malnutrition of vast areas of agricultural land. The term "available phosphate" is employed due to the fact that phosphate is the most immobile of the major plant nutrients, and if it is not in a soluble form, it is difficult, if not impossible, for plants to obtain it [11], in general, the composition of phosphate rocks is primarily determined by their form and origin. Approximately 90% of the rocks are utilized in the production of phosphate fertilizers, while the remaining 10% are utilized as a source of phosphorus for the chemical and culinary industries [12]. Abu Tartur is a substantial mine situated in the New Valley Government. It is estimated to contain 980 million tons of ore, with a 30% P_2O_5 content. Abu Tartur is one of Egypt's largest phosphate reserves [13]. The annual consumption about 150 million tons of phosphate rock in a year. Phosphorus has important role in many industries. Phosphorous is the most required nutrient of plants, but its availability in Egypt I s relatively low [14]. It also used in food and medical industries.

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Fatty Acid flotation of High -Phosphorous Iron Ore Using Enzymes for Selective Separation. The reserves in Egypt are 100 mmt [15]. EQ It would appear that the following reserves and resources are under the control of the Nasr Mining Company - ENMC: all the reserves and resources in Sabaiya area east and west, the Eastern Desert, and the Red Sea coastal area. West Sabaiya reserves would amount to 24 mmt of ore. In the East Sabaiya, there is a mineral deposit of approximately 55 million metric tons. The ore is inspected either dry or moist, contingent upon the region. The average ore product ratio is 1.6. The West Sabaiya area's content reserves are 15 mmt and comprise approximately 27% P_2O_5. The East Sabaiya area has concentrate reserves of 34 mmt and approximately 29–30% P_2O_5. The Red Sea region's phosphate rock reserves are virtually depleted. ENMC specifies a minimum of 27% P_2O_5 and 1.6 mmt as reserves. The content from the Red Sea has been marketed for direct application. In southern Egypt, there are seven quarries that have the capacity to generate 1,000,000 mt/year of the highest quality rock phosphate. The current cargo capacity is 8000 tons per day.

[16]Stated that in recent years, in an effort to render phosphate rock concentrate an appropriate substrate for the production of phosphoric acid and other affiliated industries, research has been conducted to decrease its magnesium content. The bioprocessing technique is one of these endeavors. Conversely, this investigation is dedicated to the examination of the use of an enzyme, which was extracted from Aspergillus Niger fungi that were cultivated on a coffee residue that was provided by the National Research Center Microbiology Laboratory, as a surface modifier during the fatty acid flotation of calcareous phosphate rock. A concentrate product with a P_2O_5 recovery of over 86.14% was obtained from the Abu-Tartur feed (2.88%MgO) under the appropriate conditions, containing less than 0.70% MgO. The Abu Tartur phosphate minerals are distinguished by their high concentration of rare earth elements (REEs) (736 $mg\ kg^{-1}$). The production of phosphoric acid and fertilizer industries could be used to extract the REEs. The heavy metal and uranium content of the phosphate fertilizers collected from Abu Zaabal and Abu Tartur in Egypt, which are used for fertilizer production, varies significantly [17,1].8The findings supported the assertion that the heavy metal content of Abu Tartur phosphate was lower than that of imported rock and was below the permissible limits, with the exception of lead, which was higher in local phosphate deposits than in the imported rock samples. Prior to its direct application in agriculture, it is imperative to eliminate heavy metals from phosphate rock, as it is a source of contamination in the food chain, water, soil, and air.

The aim of this work is to search for new, innovative and simple ways to reach high purity phosphate concentrates of up to 32 percent phosphorous oxide P_2O_5% with consideration further, using conventional physical beneficiation techniques, such as magnetic separation and gravity separation, it can be challenging to produce a concentrate product with a low phosphorus content and a high iron grade. and by studying the different factors for each traditional method of physical concentration, then combining them with each other and testing them in the laboratory, then at Higher semi-industrial levels, to reach the highest concentration of phosphorous oxide.

Experimental Techniques:

Materials:

Ore Preparation:

A representative ore sample was obtained, a low-grade calcareous phosphate rock from the Abu-Tartur deposits in the Western Desert of Egypt, weighing 1000 KG, was employed for this investigation.

Pulverization and Sampling:

The solid sample was initially crushed in a laboratory Denver Jaw crusher with a capacity of 2.25x3.5 and an IH.P. motor. 20 kg sample was obtained for granulometric analysis by yard sampling the completely mixed ore aggregate using the coning and quartering method. The entire quantity was subsequently secondary pulverized in a Wedage roller measuring 12x12 until it reached a particle size of 100 percent - 1mm. The "(Denver)" Jones riffler was used to sample the crushed product from approximately 100kg quantities that were stored in sealed sacks. One of these quantities was finely pulverized to 200 mesh. An analytical sampler was employed to divide the fine product into approximately 250 g samples. Figure (1) demonstrates generalized flowsheet for the preparation of the ore samples to prepare as concentrate from froth flotation.

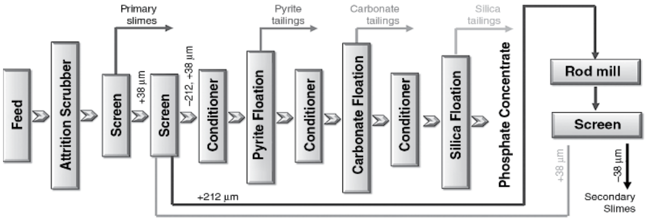


Figure1: Beneficiation of phosphate rock containing carbonates, silica and pyrite as the main gangue materials [14].

Granulometric Analysis of the sample:

Utilizing the German "Din" set sieves 11.2, 8, 4, 2, 1,0.84, 0.5, 0.35, 0.211, 0.125, and 0.105, a laboratory "Wedag" Ro-tap sieve agitator was implemented for the dry sifting of the ore material, 0.074mm. The weight sample was chosen to represent about two particles layers on the screen and the screening time was usually fixed at twenty minutes.

Ore Petrography:

Scanning electron microscope (SEM), petrographic microscope, and X-ray diffraction (XRD) were implemented to evaluate the samples that were furnished in terms of petrography and mineralogy. The particle size, texture, and microstructure of various samples were analyzed using a petrographical microscope to witness a thin section. At the Geological Survey of Egypt, samples were examined for dolomite morphology on the fractured surface using a Scanning Electron Microscope (SEM) (Hitachi 2400s) and associated minerals.

Additionally, the mineral composition of the samples was analyzed using X-ray power diffraction. The Philips PW-1730 X-ray diffractometer, which is furnished with a Cu ka tube and monochrometer, was employed to X-ray pulverized samples from 2 for a duration of 20 minutes. The samples were affixed to a glass receptacle. The voltage and current of the tube are 40 kV and 20 mA, respectively. The mineralogical examination of hand-picked samples was conducted to investigate the mineral association and characteristics, as well as particle size. The minerals were identified by analyzing the reflected light from polished sections. Selected samples, one inch piece was primarily ground on emery paper of increasing fineness, placed pn 30 cm disc rotated at 240 to 825 r.p.m. The ground samples were the mounted in araldite resin, reground then polished on a rotating polished head with alumina of increasing fineness. Ultimately, the refined sections were examined under an Ortholux Leitz microscope.

Overall Chemical Analysis of Samples:

The standard methods for phosphate analysis were employed to conduct routine chemical analysis of the samples. Additionally, the X-ray fluorescence (XRF) and scanning electron microscope (SEM) techniques were employed to analyze the main oxides.

The Perkin-Elmer Atomic Absorption 2380 was employed to ascertain magnetism and iron oxides. A Perkin-Elmer spectrophotometer model 3B UV/VIS’S spectrophotometer was employed to determine phosphorus. XRF was employed to conduct a comprehensive chemical analysis of the original sample.

Methodology by mixed simple beneficiation experimental

The techniques beneficiation the low grade of calcareous phosphate rock of Abu-Tartur deposits involving:

- Acetic acid was employed in the leaching process to eradicate the carbonate content of Abu-Tartur phosphate rock, thereby reducing acid consumption and enhancing the composition of P_2O_5, U, and Ln.
- Physical processes which the methods used to concentrate a low calcareous phosphate rock of Abu-Tartur deposits (Western Desert of Egypt) are physical methods of ore dressing, which are contingent upon the physical characteristics of the materials and other constituents. Such physical properties are coherence, surface properties, hydrolytic, Specific gravity and magnetic susceptibility.

Froth flotation

Froth flotation is a process that selectively separates materials based upon whether they are water repelling (hydrophobic) or have an affinity for water (hydrophilic). In this technique, particles of interest are physically separated from a liquid phase as a result of differences in the ability of air bubbles to selectively adhere to the surface of the particles, based upon their hydrophobicity. The hydrophobic particles with the air bubbles attached are carried to the surface, thereby forming a froth which can be removed, while hydrophilic materials stay in the liquid phase [19] Figure (2).

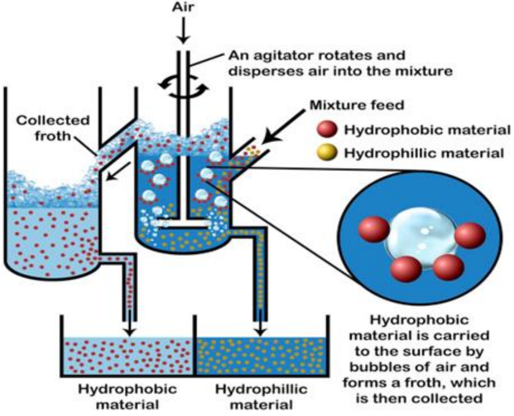


Figure 2: The process of froth flotation.

Up Current Classifiers

The sample is mechanically cleaned, and all slimes (Kaolinite) and fine quartz are removed using up current classifiers, which are predicated on the variations in the density and size of mineral particles. The perforated spray pipelines were used to inject an appropriate amount of water, and the mechanical agitator, the stirring speed of 200 rpm and the horsepower of 1 HP are both adjustable as in Figure (3). The purified sample was subsequently desiccated and concentrated using gravimetric separation. The tailing, the sample, which consisted of slimes and low-density mineral particles, was filtered, desiccated, weighed, and bagged for analysis.

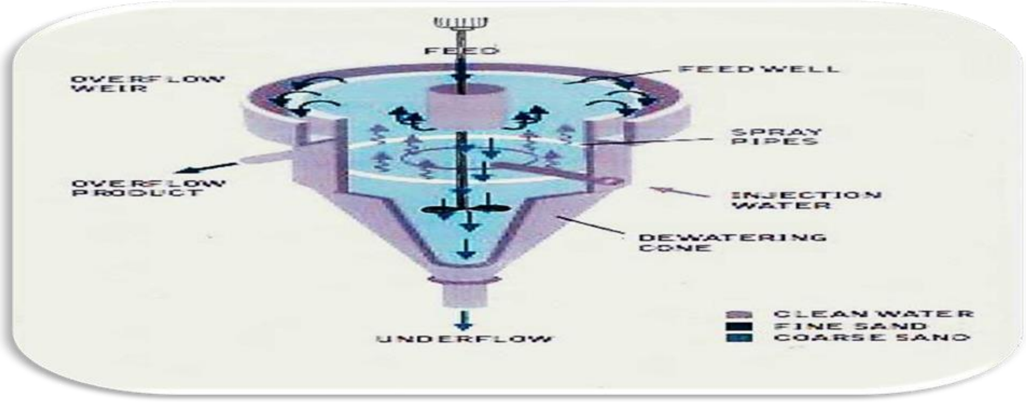


Figure 3: **Shows that the Longitudinal section of up-current classifiers.**

Results and Discussion

Granulometric analysis of sample

The size and chemical distributions of the secondary crushed ore, Table (1), show a predominance of phosphorous bearing minerals in the fine fractions, while iron minerals; silicates and magnesium bearing minerals prevail in the coarse fractions. This indicates that selective grinding occurs due to the different in grind ability between phosphate and other associated minerals.

Table 1: Typical Cumulative Size and Chemical Distribution of the Secondary CrushedOre (Sieve Analysis).

Size, mm	Wt.%	Wt. % retained	Wt.% passed	% P_2O_5	% MgO	% Fe_2O_3	% SiO_2
+11.2	10.92	0	100	11.58	5.35	7.52	26.60
-11.2+8	4.95	15.88	88.67	12.91	3.22	13.47	35.48
-8+4	4.28	20.16	83.72	13.74	3.22	13.41	38.16
-4+2	16.13	36.29	79.44	18.82	2.76	11.89	27.74
-2+1	13.24	49.53	63.31	20.89	1.76	8.29	11.84
-1+0.84	3.74	53.27	50.07	25.15	1.03	11.95	6.82
-0.84+0.5	11.22	64.45	46.33	26.23	1.59	11.87	5.42
-0.5+0.32	7.96	72.45	35.11	27.46	1.13	10.58	4.16
-0.32+0.211	12.11	84.56	27.15	27.08	1.43	10.85	5.00
-0.211+0.125	8.76	93.32	15.04	23.63	1.76	10.38	7.92
-.125+0.105	1.18	94.50	6.28	20.31	3.78	7.15	8.76
-.105+0.074	1.41	95.91	5.10	19.98	4.35	7.38	8.26
-0.074+0.044	3.69	100	0	17.73	4.25	11.41	11.2
Calc. Head assay				20.88	2.46	10.49	15.47
Original sample				22.14	2.88	7.98	15.32

Characterization of Abu- Tartur phosphorites

Geological outlines of Abu Tartur phosphorites:

The Abu-Tartur plateau is located in the Western Desert, approximately 600 kilometers southwest of Cairo. The plateau's southern border provides a view of the Nubia plain to the south, while the general surface of the northwestern desert is formed by a gentle northward inclination. The plateau's surface elevations range from 540m to 570m above sea level. The Eocene Garra Formation limestone covers the plateau surface in the northern and western regions of the region, forming the primary limestone plateau through a higher step. Black shale and dolostone alternate with coarse-grained phosphorites and phosphatic sandstone in the phosphate-bearing formation (Duwi formation). It uncomfortably overlies the Qusseir formation, which is covered with pooly-sorted pebbly phosphatic sandstone and an undulated erosional contact. The lower surfaces of phosphatic bedes are typically severely bioturbated, with branched and y-shaped cavities that measure 2 to 5 cm in diameter. The Qusseir formation is a layer of varicolored shales that is approximately 75 meters thick and is interspersed with sandstone and siltstone strata. The Dakhla formation, which is approximately 150m thick and consists of gray, foraminifera-rich, laminated shales intercalated with marl and chalk layers, conformably overlies the Duwi formation.

Sample Varieties:

Samples are classified based on their lithology mineralogy into three categories namely phosphorites and phosphatic variety, dolostone and black shales. Following are a detail description of these varieties.

Mineralogy

Phosphorites:

XRD analysis of bulk phosphorite samples Figure (4) indicated six mineral phases, namely francolite, ankerite, quartz, gypsum, anhydrite and some smectite. Francolite is present in both phosphatic mudclasts and phosphatic bioclasts, as indicated by the XRD analysis of individual phosphatic granules. The X-ray diffraction patterns of both grains exhibit francolite peaks that are comparatively broad and weakly resolved, which indicates that the francolite has a low crystallinity. The peak position of francolite in the Duwi formation exhibits minor deviations from the position of typical francolite, indicating that the cell parameters have been altered as a consequence of the isomorphous substitutions.

Dolostone:

The XRD results indicated that dolostones are composed of dolomite with minor amounts of smectite, pyrite and quartz. Figure (5), A straightforward approach to ascertaining the solid solution between ankerite (ferroan dolomite) and normal dolomite is XRD. The d-space ratio of 2.89Aº/2.19Aº increases from 3.5 for non-ferrous dolomite to 17 for ferrous dolomite. In the present investigation, the dolomite is exclusively of the ferroan type, with a ratio of approximately 19 to 2.89Aº/2.19Aº. Using XRD data, calcium ranges from 55% to57% with an average of about 54%. Therefore, the studied dolomite is non-stoichiometric or calcium and the structural formula can be written as, $Ca_{0.56}Mg_{0.44}CO_3$.

Black Shales:

XRD analysis of black shales samples Figure (6) indicated four mineralphases, namely smectite, ankerite, quartz, and some pyrite.

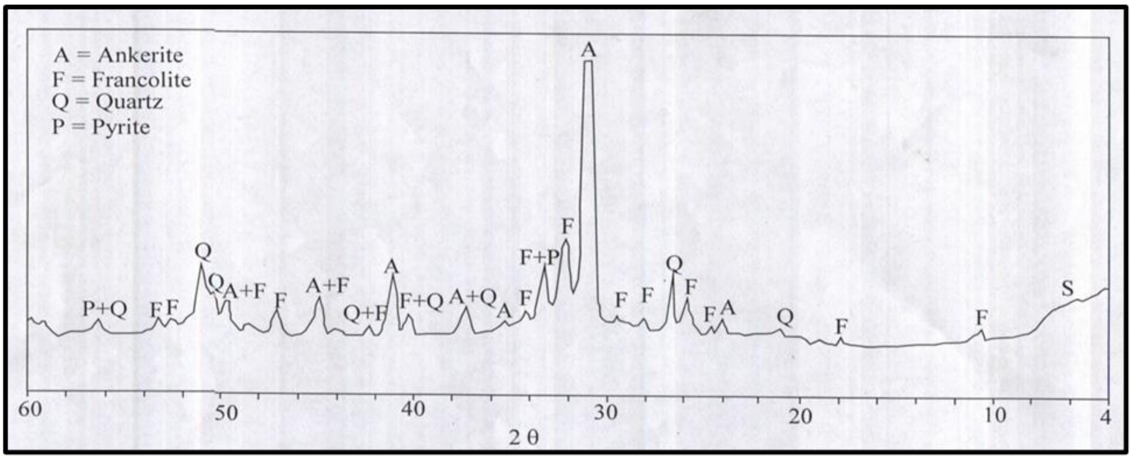


Figure 4: XRD of phosphorite sample.

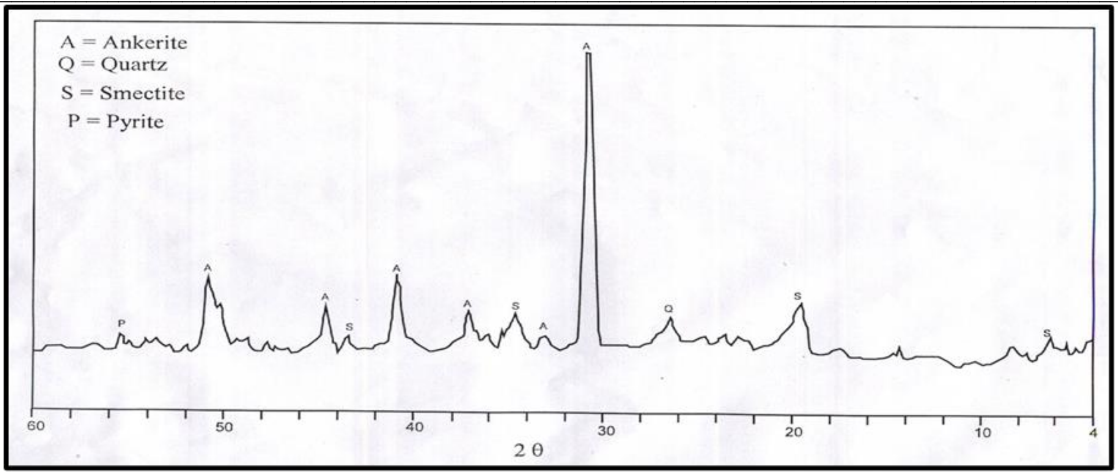


Figure 5: XRD of Dolostone Sample.

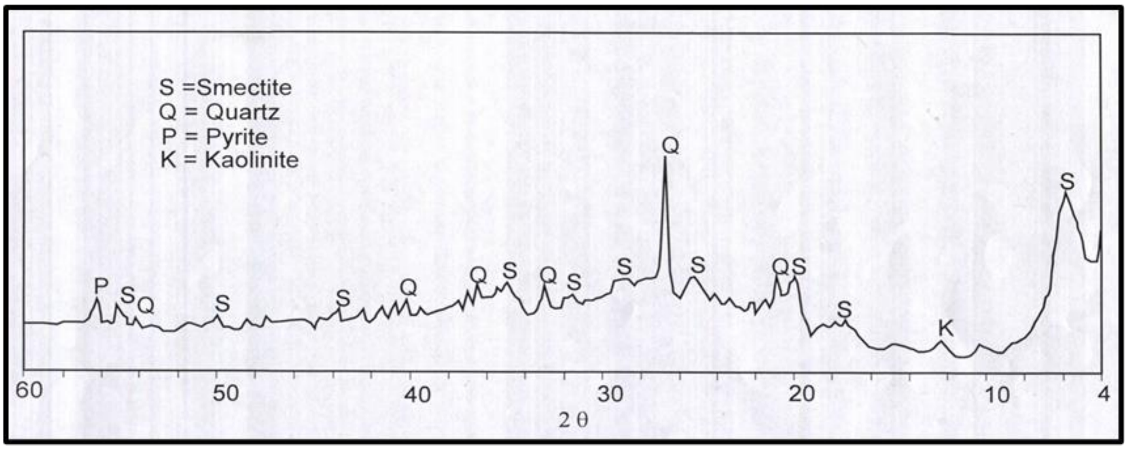


Figure 6: of Black shale sample.

Overall Chemical Analysis of Samples:

The standard methods for phosphate analysis were employed to conduct routine chemical analysis of the samples. Additionally, the X-ray fluorescence (XRF) and were employed to analyze the main oxides.

Magnesium and iron oxides were analyzed using the Perkin-Elmer Atomic Absorption 2380, while phosphorus was determined using the Perkin-Elmer spectrophotometer model 3B UV/VIS spectrophotometer. The original sample's complete chemical analysis was conducted using XRF.

Samples chemical analyses were done at the chemical laboratories of the Nuclear Materials Authority. The Scanning Electron Microscope (SEM) and X-ray fluorescence (XRF) techniques were employed to analyze the major oxides, as illustrated in Table (2). Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) was employed to analyze trace elements as shown in Table (3). The main mineral constituents of the original sample were analyzed using X-Ray Diffraction (XRD) as shown in Table (4). In order to analyze P_2O_5 and CaO after digestion with $HClO_4$-HCl, colorimetry was implemented (Technic on Auto-analyzer, Bran-Lubbe, SPX Process Equipment, Norderstedt, Germany). The atomic adsorption spectroscopy (Perkin Elmer-A Analyst 800, Norwalk, CT, USA) was implemented to analyze MgO, Fe_2O_3, Al_2O_3, Cu, Zn, Mn, and Ni after digestion by $HClO_4$-HF-HNO_3, SiO_2 after digestion by HCl-HF, and Cd after digestion by HNO_3. Flame spectrometry was employed to analyze Na_2O and K_2O after digestion with $HClO_4$-HF-HNO_3. Following its hydrolysis by HCl and the subsequent precipitate of SO^{4-} ions as $BaSO_4$, the SO_3 was analyzed by gravimetry using a $BaCl_2$ assay. For the establishment of the loss-on-ignition (LOI), a muffle furnace was employed at $1050^{\circ C}$. The same protocol that was employed to analyze the phosphate material in this study was employed to decompose and analyze the standard reference phosphate material SRM694 (Western phosphate rock) and SRM120C (Florida phosphate rock). This was done to ensure the accuracy of the results. Less than 5% experimental errors were observed in all chemical analyses.

Table 2: Results of major oxides of phosphate rock of Abu-Tartur deposits

Component	Wt.%
Al_2O_3	2.53
SiO_2	6.69
P_2O_5	21.27
MgO	1.16
CaO	46.06
Na_2O	0.76
K_2O	0.46
TiO_2	0.39
Fe_2O_3	7.23
MnO	0.34
Cl	0.23
F	0.97
SO_3	3.32
L.O.I	8.55
Total	99.96

Table 3: Results of trace elements of phosphate rock of Abu-Tartur deposits

Element	Ppm	Element	Ppm
Sc	69	La	209
V	114	Ca	229
Cr	72	Nd	170
Co	59	Sm	48
Ni	48	Yb	10
Cu	32	Y	292
Zn	81	U	39
As	35	Th	13
Cd	4		
Sr	1486		

Table 4: Results of the main mineral constituents of phosphate rock of Abu- Tartur deposits

Component	Wt.%	Component	Wt.%
Apatite	48.91	**Ironoxides**	7.23
Calcite	22.79	**Clay**	5.31
Dolomite	4.46	**Quartz**	3.91
Gypsum	7.36		
		Total	**99.97**

The results have shown that phosphate ore contains P_2O_5(21.27%), the CaO content (46.06%) and while U assays 39 ppm. Characterization showed that sample is not imperative to meeting market requirement. After characterization of the raw material, it was subjected to the following leaching and physical processes.

Preparation of the Feed

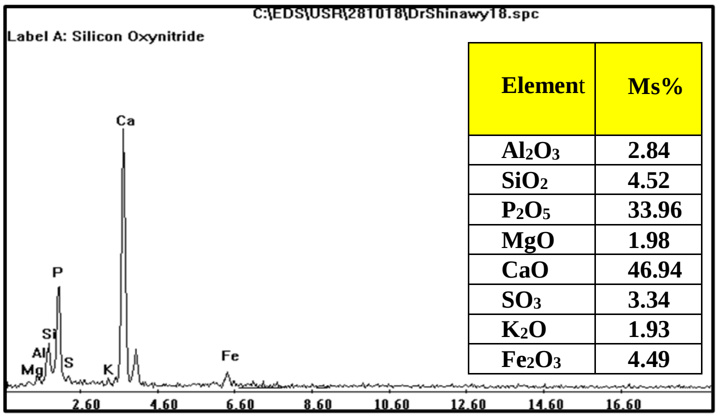
The phosphate ore sample was pulverized in a 5x6" Denver Jaw crusher and subsequently processed in a Wedge roller mill. The laboratory where the pulverized sample was ground to a fineness of less than 0.25 mm in a closed circuit using a wedge rod mill, using a 0.25 mm sieve. The flotation process was adversely affected by the thin character of the – 0.074 mm fraction, which was eliminated using a 0.074 mm sieve. Magnetic separation results, using Dings cross belt separator, of the (- 0.25 + 0.074) mm sample are shown in Table (5). The nonmagnetic fraction was used as a flotation feed for this study.

Table 5: Results of The Magnetic Separation for Size (- 0.25 + 0.074) mm.

Product	Wt. %	P_2O_5 %	MgO %	Fe_2O_3 %	SiO_2 %
Magnetic fraction	20	10.94	3.20	12.38	14.73
Non-Magnetic fraction	80	25.25	2.80	6.88	15.88
Feed	100	22.38	2.88	7.98	15.65

The cleaned sample by mean of up current classifiers was dried for analysis by means of Scanning Electron Microscope (SEM) technique. The results are shown in Figures (7,8). and it appear that the sample contains Al_2O_3(2.84), SiO_2 (4.52%),

P_2O_5 (31.96%), MgO (1.98%), CaO (48.94%), K_2O (1.93%), Fe_2O_3(4.49%). Also, the chemical analysis of the cleaned sample was done and shown in Table (5). The results of the up current classifiers process test Table (6) showed that the phosphate ore sample from Abu-Tartur locality (Western Desert of Egypt) that was delivered uncrushed was pulverized in a 5x6" Denver Jaw crusher and subsequently processed in a Wedge roller mill. In the laboratory A closed circuit was employed to grind the pulverized sample to a fineness of less than 0.25 mm using a wedge rod mill, using a 0.25 mm sieve. The flotation process was adversely affected by the thin character of the – 0.074 mm fraction, which was eliminated using a 0.074 mm sieve.



Element	Ms%
Al_2O_3	2.84
SiO_2	4.52
P_2O_5	33.96
MgO	1.98
CaO	46.94
SO_3	3.34
K_2O	1.93
Fe_2O_3	4.49

Figure 7: Scanning electron microscope EDAX and semi quantitative analysis of the cleaned phosphate sample by the up current classifiers process.

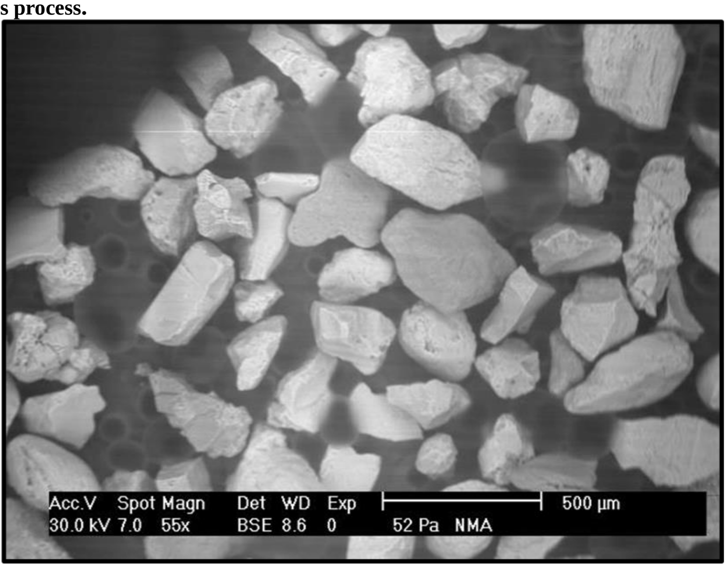


Figure 8: Photo shows the cleaned phosphate sample by the u current classifiers process.

Table 6: Chemical analysis of the cleaned phosphate sample by the up current classifiers process.

Oxides	**Content%**
P_2O_5	33.15
CaO	43.71
MgO	0.91
SiO_2	2.94
Na_2O	0.47
K_2O	0.29
SO_3	2.30
Al_2O_3	2.29
Fe_2O_3	3.45
Mn	0.13
Cl	0.16
F	1.14
L.O.I	10.03

Which we compare to the froth flotation yields as in Table No. 7

Table 7: Results of major oxides of phosphate concentate of Abu-Tartur deposits by using the froth flotation [15].

Component	Wt.%
Al_2O_3	2.53
SiO_2	4.69
P_2O_5	29.27
MgO	0.16
CaO	43.06
Na_2O	0.76
K_2O	0.46
TiO_2	0.39
Fe_2O_3	5.23
MnO	0.34
Cl	0.23
F	0.97
SO_3	3.32
L.O.I	8.55
Total	99.96

Summary and conclusions

The aim of this work is to search for new, innovative and simple ways to reach high purity phosphate concentrates of up to 32 percent phosphorous oxide P_2O_5% with consideration further, using conventional physical beneficiation techniques, such as magnetic separation and gravity separation, it can be challenging to produce a concentrate product with a low phosphorus content and a high iron grade. and by studying the different factors for each traditional method of physical concentration, then combining them with each other and testing them in the laboratory, then at Higher semi-industrial levels, to reach the highest concentration of phosphorous oxide.

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