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A.A. Negm*, A.-Z. M. Abouzeid*

UTILIZATION OF SOLID WASTES FROM PHOSPHATE PROCESSING PLANTS

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Most of the existing phosphate rocks are of low grade. For the production of marketable phosphate commodity, these low grade ores need upgrading before being utilized. Large quantities of solid-waste materials, with considerable amounts of P_2O_5 content are generated in phosphate processing plants. In addition of being environmental hazards and a source of pollution for air, water and soil, these waste materials add to the production cost for waste removal. The positive use of mineral processing plant tailings is becoming a common practice nowadays, to avoid pollution hazards and to improve the techno-economics of the mineral processing plants. In this paper, the solid-waste of Sebaeya phosphate washing plant, Upper Egypt, was successfully used to produce a high grade phosphate concentrate, to produce aggregates for road paving and for concrete mixes, in brick manufacturing, pottery making, and direct application for improving agriculture soils.

key words: phosphate, wastes, aggregates, road paving, concrete mixes, brick, pottery, agriculture soil

INTRODUCTION

Phosphate occurs in all igneous and sedimentary rocks in the form of phosphate minerals. However, most of the economic recovery of phosphate is of sedimentary origin. The world production of phosphate rock was 146 Tg in the year 2006. Most of the phosphate rock is produced by open-pit mining rather than underground mining.Most phosphate rocks as mined are of low-grade and need beneficiation. Beneficiation plants produce large quantities of waste materials relatively high in P_2O_5 content, which are considered as environmental hazard and a source of pollution of air, water and land. In addition, disposal of these materials represents a loss of valuable natural resource and adds additional cost to the production for waste removal. Dis-

* *Cairo University, Faculty of Engineering, Department of Mining. Giza 12613, Egypt*

posal of ore processing plant tailings is a major environmental problem, which is becoming more serious with increasing exploitation of low grade ores and deposits due to depletion of rich ones (Negm, 1997). The method used to dispose tailings have been developed due to the environmental pressures, changing milling practice and realization of profitable applications (Abouzeid, 2007). Early methods included discharge of tailings into rivers and streams which still practiced at some mines, and the dumping of coarse dewatered tailings on to land (Down, 1977). An alternative for the disposal of mineral processing tailings is the positive use of it, either in the raw state or after further processing (Down, 1977). Accordingly, utilization of waste mineral slimes discarded by ore milling plants is becoming a common practice to avoid pollution hazards and to improve the techno-economic feasibility of new mining projects. The concept of waste utilization is appealing because it offers two major advantages: 1- waste dispersal problem may be reduced or eliminated, 2- conservation of resources, by partly replacing natural material. There are three obvious positive uses for tailings. Firstly, they may be reprocessed to recover additional values, secondly, all or a portion of tailings may be used for backfill applications, and thirdly, the tailings may be used as one of the raw materials to manufacture higher values products (Michael, 1979)Processing of Sebaeya phosphate ore yields huge amounts of solid wastes and slime clayey fractions. It is estimated that approximately 1.5 megagrams (Mg) of coarse waste(-80mm) and about 1.0 Mg of slimes (–100 μm) are accumulated as stock piles or in tailing ponds. These wastes cause environmental and waste disposal problems. Therefore, this study is devoted to find some alternative uses for these wastes, to reduce their accumulated quantities as well as their enviromentals harms and change them into value-added products. These alternatives can be summarized as follows:

- obtaining a phosphate concentrate product
- manufacture of bricks suitable for non–load bearing walls
- pottery making
- aggregates for road bases and sub-bases
- aggregate for plain concrete
- direct application as natural fertilizer.

UTILIZATION OF PHOSPHATE WASTE

MINERAL PROCESSING OF PHOSPHATE WASTE

There is a large accumulation of waste material produced from the washing plant of Sebaeya phosphate company. The coarse waste dump produced by the crushing and screening section is estimated to be over 1.5 Tg assaying 18-24% P_2O_5. The fine tailings in the tailing pond is estimated to be over 1.0 million ton assaying 12-19% P_2O_5. These accumulated quantities of waste constitute an environmental hazard and must be reduced and removed. It is advantageous to change these wastes into useful product through mineral processing techniques in order to get high-grade marketable concentrate.

BRICK MAKING

Clay is one of the most abundant mineral material on earth. For production of brick, clay must, however, posses some specific properties. Clay must have plasticity, which permits them to be shaped or molded when mixed with water, and it must have sufficient wet and air-dried tensile strength to maintain their shape after forming. Also when subjected to raising temperatures, the clay particles must be fused together.

Clay bricks are used for an extremely wide range of applications in an equally extensive range of buildings and engineering structures (El-Wageeh, 1995). Among the most common applications are partition walls, party walls, claddings and facings, foundations, paving and floorings.

Bricks are classified according to their variety, quality, and type as follows:

1) varieties: common bricks, facing brick sand engineering bricks
2) quality: internal quality, ordinary quality and special quality
3) types: solid, perforated, hollow, and special shapes and standard.

The physical and mechanical properties of different types of bricks are mentioned in many texts (Nash, 1966). The most important properties are water absorption 20-32 %, compressive strength 30-40 kg/cm^2, and dimension 25x12x6 cm.

POTTERY MAKING

Phosphate slimes, which is a waste material produced from the beneficiation of phosphate ore, can be used in pottery making because it contains very fine clay and clay-like minerals suspended in water (Robertson, 1986). These slimes can be also used with kaolin, feldspar and quartz for the production of satisfactory ceramic tiles.

AGGREGATES FOR ROAD BASES AND SUB-BASES

Road structure today generally consists of four layers shown in Fig. 1, which are collectively termed the pavement. The type of aggregates and thickness of each layer depends on the type of the road and the use to which it is being put. The behavior of all four layers is crucial to the stability and safety of the road.

Unbound granular material is generally used as an important component in road payments as base and sub-base. The foundations as well as the surfaces of the roads can be constructed from these materials. As a base course, they play a structurally important role, especially in medium and low volume roads. As a sub-base, they protect the soil acting as a working platform and insulating layer against frost action.

The substantial benefits of using these waste materials for road building purpose can be summarized in the reduction of costs, in addition to the solution of the environmental problems.

Crushed rock, mine and mill refuse, and tailings can be used locally in low volume roads, where a lower quality aggregate is more appropriate. The solid wastes generated from the beneficiation of phosphate ores can be used as cheap local waste materials, for road and rail roadbeds. This positive use of wastes can be applied in the areas surrounding the mining zones in roads with less traffic.

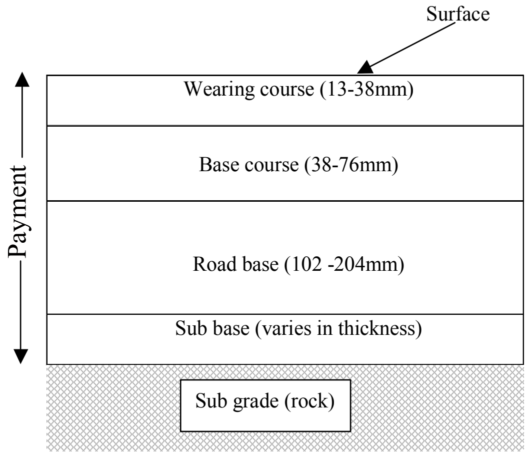

Fig.1. Structural layers in road construction.
Numbers refer to thickness of layers

SOLID WASTE AS CONCRETE AGGREGATES

The possibility of using solid wastes as aggregates in concrete received increasing attention in recent years as one of the promising solution to the escalating solid waste problems. The use of solid wastes for concrete has concentrated mostly on service as aggregates, since this provides the only real utilization of larger quantities of waste materials. The successful utilization of solid wastes in concrete will depend on anticipating potential problems and the ensuing properties of the concrete, and developing uses that comply with these restraints. The mining industry has traditionally made use of its own waste materials, either by reprocessing to recover additional minerals, or by using them for internal construction purposes. Portland cement concrete is made up of Portland cement, water and aggregates. Each of these must meet certain requirements in order that quality concrete is produced. Compressive strength is the simplest and easiest one of all the strength characteristics of concrete to be determined, and concrete design usually based on this property. Normal strength concrete of grades between 180 to 300 kg/cm^2 is widely used in usual building. Aggregates generally occupy about 70 to 80 % of the volume of concrete and can therefore be expected to have an important influence on its properties.

Aggregates must conform to certain standards for optimum engineering use: clean, hard, strong, durable, practically free of absorbed chemicals, coatings of clay, and other fine materials in amounts that could affect hydration and bond of the cement paste. It is generally advantageous to use as large size of aggregates as possible, although experimental investigations have indicated that the improvement in the properties of concrete with an increase in the size of aggregate does not extend beyond about 40 mm. The normal sizes of coarse aggregate used in concrete mix in Egypt are 40, 20 and 10 mm. Generally, the maximum nominal size of 40 mm is 15x15x15cm (Internet, 2003). They are made in a specified manner, allowed to set, and then cured in the laboratory in a humid room until a specified age. Proper curing requires water and a favorable temperature. Usually the strength is determined 28-day after casting because this is the design strength or common specified strength. However, 7-day strength may also be obtained either as an indication of the expected 28-day strength or as a specified strength.

The purpose of this study is to evaluate the possibility of using solid waste of mill tailings (over screen reject of Sebaeya phosphate company) as a substitution of natural coarse aggregate in a Portland cement concrete mix to produce concrete with compressive strength able to satisfy the construction purposes of small buildings.

DIRECT USE OF WASTE ROCK PHOSPHATE IN AGRICULTURE

Phosphorus is an essential element for the life of animals and plants. Animals get their phosphorus from eating plants and other animals, while plants get their phosphorus from soil.

Phosphorus is also essential in livestock nutrition. Some 80% of the phosphorus in the animal body is in the skeleton. Phosphorus also occurs in many proteins and is necessary for the utilization of carbohydrate. Although phosphorus is a major plant nutrient, its deficiency reduces animal productivity. Serious deficiencies can result in bone disorders and infertility.

In many respects the phosphorus cycle is analogous to the nitrogen cycle. Next to nitrogen, phosphorus is the most abundant nutrient contained in microbial tissue, making up as much as 2% of the dry weight. Partly for this reason phosphorus is the second most abundant nutrient in soil organic matter.

MATERIAL PREPARATION AND CHARACTERIZATION

Head samples of consolidated slimes and solid wastes of Sebaeya phosphate were used. In this investigation, each sample was crushed by jaw crusher followed by roll mill to minus 0.5mm. The particle size analyses of these prepared wastes are given in Table 1. For pottery making the phosphate slimes and shale were ground to minus 250 micrometers. Table 2 gives the chemical analysis of the used materials.

Table 1. Size analyses of slimes and coarse solid waste samples

Waste type	Slimes			Solid wastes		
Screen size, (μm)	Wt.%ret.	Cum.wt.% ret.	Cum.wt.% Passed	Wt.%ret	Cum.Wt.% ret.	Cum.wt.% passed
+500	00.00	00.00	100.0	00.00	00.00	100.0
-500+315	12.50	12.50	100.0	37.50	35.50	100.0
-315+250-	05.50	18.00	87.50	08.25	43.75	64.50
250+160	19.00	37.00	82.00	17.50	61.25	56.25
-160+125	12.25	49.25	63.00	05.50	66.75	38.75
-125+063	37.25	86.50	50.75	16.50	83.25	33.25
-063	13.50	100.0	13.50	16.75	100.0	16.75

Table 2. Chemical analyses of slimes, solid wastes, and El-Ballas shale

Component %	Slimes %	Solid wastes %	El-Ballas shale %	Component %	Slimes %	Solid wastes %	El-Ballas shale %
SiO_2	27.05	08.62	39.05	Na_2O	00.41	00.42	01.08
TiO_2	00.13	00.06	00.41	K_2O	00.17	<0.01	00.75
Al_2O_3	02.15	00.22	19.45	P_2O_5	16.90	24.45	00.40
Fe_2O_3	03.70	01.94	03.65	Cl	00.05	00.06	00.65
MnO	00.20	00.24	00.12	SO_3	00.51	02.80	00.32
MgO	01.10	00.28	01.18	L.O.I	09.33	07.94	19.06
CaO	36.45	48.95	12.85	-	-	-	-

EXPERIMENTAL RESULTS AND DISCUSSION

MINERAL PROCESSING OF PHOSPHATE WASTE

Phosphate waste rock contains certain value of P_2O_5. Due to the variation in composition of each particle according to its size, it was found that the most suitable way to release the phosphate particles from the associated gangue minerals by wet attrition scrubbing at high solid/liquid ratio. The classification of the products into different sizes is carried out by screening for coarse fractions and by hydraulic classification for fine and sub sieve fractions. Suitable sizes were used as feed to study the concentration of the proper feed by direct anionic froth flotation technique in a single stage. In these experiments the effect of the different flotation variables were studied. These variables were solid/liquid ratio, amount of collector, amount of frother, type of frother, and amount of kerosene. Pure oleic acid was used as a collector while pine oil, Aerofroth 70 and Aerofroth 65 were used as frothers. A sample of rice bran oil supplied by El-Nasr Mining Company was also used as a collector to compare with the oleic acid.

a) Effect of solid /liquid ratio(s/l)

Table 3. Effect of solid/liquid ratio on the grade and recovery

s/l, %	Product	Wt., %	P_2O_5, %	Insol.,	L.O.I	Recovery, %
5	Conc. Tail	80.2 19.8	29.0 ---	10.0 67.0	11.0 8.0	93.0 ---
10	Conc. Tail	81.9 18.1	31.2 ---	10.0 63.0	10.0 8.0	99.0 ---

b) Effect of collector amount

Table 4. Effect of collector consumption on grade and recovery

Collector, (kg/Mg)	Product	Wt, %	P_2O_5	Insol. %	L.O.I	Recovery %
2.8	Concentrate tailings	83.3 16.7	31.5 ---	17.0 44.0	--- ---	99.5
1.4	Concentrate tailings	80.2 19.8	29.5 ---	10.0 67.0	11.0 8.0	94.6
0.70	Concentrate tailings	81.9 18.1	31.2 ---	10.0 63.0	10.0 8.0	99.0

The 0.7 kg/Mg dose of collector gave a reasonable concentrate grade and recovery.

c) Effect of feed size

Table 5. Effect of feed size on flotation products

Feed size (μm)	Product	Wt %	P_2O_5 %	Insol. %	L.O.I %	Recovery %
-500+40	Concentrate Tailing	61.5 38.5	32.2 ---	7.0 36.	7.5 8.5	79.2
-250+40	Concentrate Tailing	77.0 23.0	30.7 ---	7.0 60.0	9.0 ---	94.6
-120+40	Concentrate Tailing	81.9 18.1	31.2 ---	10.0 63.0	10.0 8.0	99.0
-120+20	Concentrate Tailing	66.0 34.0	25.2 ---	30.0 29.0	--- ---	66.5

From the above table it can be seen that the suitable size for flotation was -250+40 μm with a higher weight recovery and concentrate assay of more than 30 per-cent P_2O_5.

d) Effect of frother type

Table 6. Effect of frother type

Frother	Product	Wt, %	P_2O_5	Insol., %	L.O.I, %	Recovery, %
Pine oil	Conc. Tailings	81.9 18.1	31.2 ---	10.0 63.0	10.0 8.0	99.0
Aero froth 70	Conc. Tailings	75.5 24.5	30.7 ---	9.0 58.0	7.5 7.0	95.0
Aero froth 65	Conc. Tailings	80.5 19.5	33.8 ---	8.0 65.0	10.0 7.0	99.0

It is seen from the above table that Aerofroth 65 is superior to other types of frothers.

e) Effect of collector type

Table 7. Effect of collector type on flotation

Collector	Product	Wt, %	P_2O_5	Insol., %	L.O.I, %	Recovery, %
Oleic acid	Conc. Tailings	80.5 19.5	33.8 ---	8.0 65.0	10.0 7.0	99.5
Rice bran oil	Conc. Tailings	80.5 19.0	31.85 ---	9.5 60.5	10.0 6.5	99.1

Oleic acid as a collector gave better results. However due to the low price of rice bran oil (as a by-product), we recommend its use in flotation.

f) Effect of the amount of kerosene

Table 8. Effect of amount of kerosene

Kerosene, cm^3	Product	Wt, %	P_2O_5	Insol., %	L.O.I, %	Recovery, %
without	Conc . Tailing	10.0 90.0	34.5 ---	--- ---	9.0 7.0	13.8
0.25	Conc . Tailing	80.5 19.0	29.5 ---	10.0 57.0	11.0 7.0	95.0
0.50	Conc . Tailing	80.5 19.0	31.9 ---	9.5 60.5	10.0 60.5	99.0

It is necessary to use kerosene as a collecting aid in the flotation of phosphate waste in order to minimize the use of collector.

g) Effect of grinding method

Table 9. Effect of grinding

Type of grinding	product	Wt%	P_2O_5	Insol. %	L.O.I%	Recovery %
Attrition scrub-bing	Conc . Tailings	91.1 8.9	30.2	7.5 52.0	11.0 9.0	99.5
Disc crusher	Conc . Tailings	51.5 48.5	26.5	8.5 33.0	8.5 9.5	52.5

Attrition scrubbing gave better grade and recovery than disc grinding.

The result of the present study of production of high grade concentrate from waste material of the phosphate washing plant of Sebaeya, the following remarks can be concluded:

1. for a successful flotation process using oleic acid as a collector, it is necessary to remove slime particles less than 40 μm as it has a bad effect on grade and recovery of the flotation process
2. it was possible to obtain a high-grade concentrate of more than 30 percent P_2O_5 at a 10 percent solids in a single stage flotation process
3. the optimum dosage of collector was 0.7 kg/Mg at P_2O_5 31.2 % and a recovery of 95 %. Rice bran oil was also successfully used as a collector
4. optimum results of flotation were obtained for feed size range of -250+40 μm. This fraction was about 35% of the original sample because the coarse and slime fractions were relatively low in P_2O_5
5. different types of frothers were used and Aerofroth 65 gave the best result
6. it is necessary to use sodium silicate to depress silica and kerosene as a collecting aid
7. attrition scrubbing of the feed is better than grinding in a ball mill or disc crusher
8. magnetic separation step prior to flotation reduced the iron content of the concentrate
9. a proposed flow sheet is suggested to obtain a high grade concentrate from this waste material.

USE OF PHOSPHATE WASTE IN BRICKS, POTTERY, ROAD PAVING AND PLAIN CONCRETE

Positive uses of phosphate tailings consume huge amounts of waste materials, which reduce their environmental harms, conserve the natural resources, and add to mining profits.

1. Bricks with acceptable qualities (average comp. strength 152 kg/cm^3 and slake durability index of 99.18%) are produced from a mixture of 90%phosphate slimes and 10% shale.
2. Pottery making is another alternative use of Sebaeya phosphate slimes. The mixture composed of 90% slimes and 10% shale gave pots and jars of reasonable quality. The produced potteries gave water seepage rate of about 0.0075 mm^3/sec·cm^2 without any defected products during firing process and its slake durability index was 99.3%.
3. Solid wastes of the over screen reject can be used in construction of low volume roads where a low quality aggregates is more appropriate.
4. Slime fraction of -40 μm generated from desliming phosphate tailings can be used in either potteries or brick making. For potteries it has a high workability

as it retains high percentage water. Bricks made from the slime fraction and shale show good qualities.

5. Coarse solid wastes can be used in concrete mix without seriously hindering its mechanical properties.
6. Concrete of about 240 kg/cm^2 compressive strength is obtained, which is suitable for the construction of small buildings.
7. The present study matches society's needs for safe and economic disposal of mill tailing of phosphate ores.

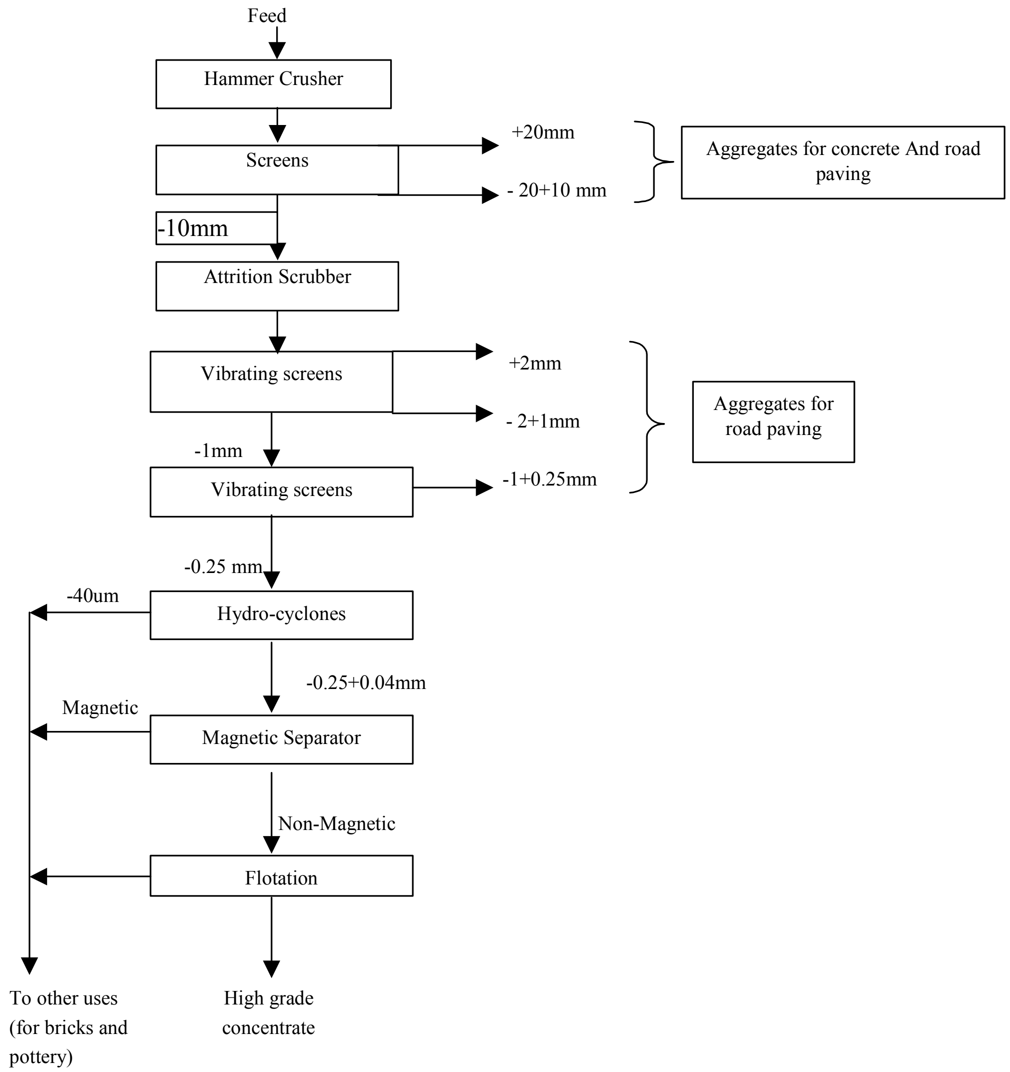

Fig.2. Proposed flow sheet for flotation of Sebaeya low grade phosphate

DIRECT USE OF PHOSPHATE WASTE IN AGRICULTURE

Egyptian soils are normally alkaline, therefore, the low availability of P to plants is common, especially in highly calcareous soils. Maximum phosphorus availability occurs at pH value of 6 to 7. Below this pH range, iron and aluminum phosphate were formed, but above this pH range, minimum solubility of calcium phosphate is formed.

Organic manures can increase the availability of P-forms for the growing crops, by rapid decomposition and liberation of large quantities of carbon dioxide, which dissolves in water to form carbonic and other acids. Organic manures can help to lower the pH of alkaline soil and increase the availability of phosphate to the succeeding crop. On the other hand, phosphate dissolving microbes solubilize insoluble P by producing various organic acids. This available P is taken up by plants.

SUMMARY

1. Approximately 1.5 megagrams (Mg) of coarse waste (-80 mm) and 1.0 Mg of slimes averaging 22 % and 15 % P_2O_5 respectively have been stock piled at El-Mahameed area (East Sebaeya) rejects from the phosphate processing plant.
2. Laboratory-scale tests revealed the technical feasibility of retreatment of the coarse waste to produce a concentrate of more than 30% P_2O_5 at over 90% recovery. The proposed flow-sheet comprises crushing, attrition scrubbing, desliming and direct flotation of phosphate using oleic acid or rice bran oil as collectors. Some equipment of the existing plant may be used in the proposed retreatment mill.
3. Full-scale tests proved the possibility to produce fired bricks from a blend of 90% phosphate slimes and 10% shale with acceptable properties concerning compressive strength, bulk density and slake durability. The same mix could be used for the production of pots and jars of reasonable quality.
4. The coarse phosphate waste can be utilized as aggregates in concrete mix to obtain concrete of more than 240 kg/cm^2 compressive strength as well as the construction of low volume roads.
5. The ultra-fine fraction (-40 micrometers) discarded from the flotation process feed proved to be a suitable raw material for pottery and brick making.
6. Green house experiments showed the possibility of direct application of phosphate tailings in both sandy and calcareous soils at high levels of phosphate uptake which is comparable to commercial super phosphate fertilizers.

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Negm A.A., Abouzeid A.-Z. M., *Wykorzystanie odpadów stałych po przeróbce fosforytów*, Physicochemical Problems of Mineral Processing, 42 (2008), 5-16 (w jęz. ang)

Większość skał fosforytowych ma niską zawartość fosforu i wymagają one wzbogacania prze wykorzystaniem. Dlatego duże ilości odpadów stałych o podwyższonej zawartości P_2O_5 są generowane w zakładach przerabiających fosforyty. Są one szkodliwe dla środowiska oraz źródłem zanieczyszczania powietrza, wody oraz gleby, a także generują koszty związane z usuwaniem odpadów. Wykorzystanie odpadów przeróbczych staje się więc obecnie codzienną praktyką dla uniknięcia zanieczyszczenia środowiska oraz dla zwiększenia ekonomiki zakładów przeróbczych. W pracy z powodzeniem wykorzystano odpady fosforytowe z zakładu przeróbczego Sebaeya w Górnym Egipcie do produkcji wysokiej jakości materiałów do produkcji kamieni stosowanych do utwardzania dróg oraz produkcji składników cementu, cegieł oraz fajansu, a także bezpośredniego wykorzystania do nawożenia gruntów rolniczych.

słowa kluczowe: fosforyty, odpady, kamienie drogowe, składniki cementu, cegły, fajans, grunty rolnicze