**Optimization of the heat treatment of phosphate**

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**Abstract -**In this article, we studied the cold and hot mixtures sedimentary phosphates of Bouchane in order to optimize the expenditure related to energy by reducing the organic matter and carbonates. The cold mixture is done at the ambient temperature as the hot mixture is made at the calcination temperature. The experimental process of the mixtures is performed under the atmospheric air by the same phosphate source by mixing same manner in order to make a comparison between them. It appeared that the hot mixture using 33% of the same phosphate source can have an important outcome on the energy saving while preserving the environment and responding to indicators of quality demanded by users.

**Key words:** Phosphate **/** Energy**/** Mixture/ Cooling.

**Résume - Optimisation du traitement thermique du phosphate.** Dans cet article, nous avons étudié les mélanges à froid et à chaud du phosphate sédimentaire de Bouchane dans le but d’optimiser les dépenses liées à l’énergie en diminuant la matière organique et les carbonates. Le mélange à froid se fait à température ambiante quant au mélange à chaud il se fait à partir de la température de calcination. Les processus expérimentaux des mélanges sont effectués sous l’air atmosphérique par le phosphate de même source en malaxant de la même manière afin de faire une comparaison entre eux. Il apparaît que le mélange à chaud par ajout de 33% de phosphate de même source peut avoir d’importantes retombées sur l’économie de l’énergie tout en préservant l’environnement et répondant aux indices de qualité exigés par les utilisateurs.

**Mots Clés:** Phosphate / Energie / Mélange / Refroidissement

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**1. Introduction**

The Moroccan phosphate deposits constitute a family of very diverse products according to their origin, type of formation and geological history. Their agronomic effectiveness depends first on their inherent characteristics: mineralogy, crystallography, surface area, solubility etc… For that purpose, they undergo a various types of enrichment operations depending on the particles size and chemical characteristics. Among the special techniques of enrichment that can be applied is the calcination, which permits to remove organic matter and also affects the properties of use [1 – 7]. Time, temperature and physical-chemical proprieties of phosphates are the main parameters of the calcination [3; 4]. They have a direct impact during the industrial processes and hence on the overall outcome. In addition, the calcination treatment typically made at an elevated temperature followed by a cooling to ambient temperature corresponds to a loss of considerable energy [2; 8; 9]. We are, therefore, faced to the problem of the optimization of heat treatment which has known, in the recent years, a particular importance due to the high cost of energy and the economical imperatives that follow from it.

It is important to note that the presence of the organic matter and carbonates appears through many phenomena that occur within the various constituents of this matter: they affect the thermokinetic, thermoconvective and thermodiffusifs aspects which dependent on the thermophysical properties of the environment [10]. This coupling between the thermo-hydro-mechanical and chemical properties has a positive impact on a new hot mixing protocol.

In the present work, we will be interested in optimization of the energetic cost by recuperation of the energy lost during the cooling cycle. We propose to use this energy in the calcination of a given quantity of phosphate. Thus, it appeared interesting to determine firstly, calcination temperature and the time’s stay of phosphate, then to study mixtures of cold and hot phosphate.

**2. Raw material used and protocol of calcination**

**2.1. Phosphate ore**

The sedimentary layers of phosphates are made mainly by apatite. They contain the carbonated fluorapatite named francolite [11]. These sedimentary layers can contain apatite having a wide range of physical properties and very varied chemical and crystallographic characteristics, due to the geological conditions and after deposit’s deteriorations [12]. Apatite is a mineral of general formula: Me10(XO4)6Y2; Me has often a divalent cation,  has a trivalent grouping and Y- has a monovalent anion.

In addition to the matrix containing phosphorus, the phosphated layers contain also secondary minerals or impurities of gangue which become differentiated according to the conditions of sedimentation. These impurities are sometimes geologically well isolated in quite separate layers, or closely mixed with the phosphate ore. They include, in various combinations and concentrations, organic matter, silica, clayey minerals, calcite, dolomite and hydrated oxides of iron and aluminium [13; 14]. They have an influence on processes of phosphates valorising and on the efficiency of the natural phosphated rock used in a direct application [13; 14].

**2. 2. Geological data on the studied zone**

Morocco has the three quarters of the identified world phosphate reserves, and is the largest exporter country. The Moroccan sedimentary phosphate deposits contain relatively large quantities of associated minerals [15; 16]. The main facies concerned in this study are: sandy granular phosphate, limestones, dolomites, marls, clays and silicification-diagenétique-inserted. In term of microfacies, phosphorites are always a mixture of diversified origin (indigenous and/or immigrant) [17]. These general properties were described by L. Bilali and coll [10].

The studied phosphate samples were taken from the site of Bouchane, about 40 km East of Youssoufia town. The industrial exploitation of phosphate is in opencast (Fig. 1).



**Figure. 1.** Geographic location of the phosphate layers of the Ganntour Basin [18]

**2. 3. Physico-chemical characterization of the raw material**

The studies of phosphate samples characterization should provide data on: (i) composition of apatite, other phosphate and gangue’s minerals, (ii) the relative amounts of the existing mineral species (iii) the particle size of various minerals in the structure of phosphate ... etc.

Indeed, the general properties of the phosphate of Bouchane, located 40 km east of the Youssoufia town such as dimensional ranking, chemical analysis, mineralogical and thermal analysis made in previous work [3; 4; 7]. This new deposit, which has significant amounts of phosphates, is the subject of a particular attention because of its important granulochemical properties including a minimum of organic matter and carbonates and a decrease in the abundance of grains of phosphate of the lower and upper parts. In addition, the operating cost is low in that it is carried out in the open air.

**2. 3. 1. Granulometric analysis**

The granulometric distribution was carried out by manual sifting under dry way using a series of sieves (Nylon fabrics) of meshs with round holes in geometric progression. The present study showed that the most part of the overall masses concentrates in the section of 125µm - 800µm. The granulometric distribution of phosphates are indicated in figure 2.

**Figure 2.** Granulometric distribution of the crude phosphate sample.

In laboratory, the phosphate of a representative sample undergoes a mechanical treatment (crushing, homogenisation and quartering) in order to reduce the coarse grains by using a hammer mill in successive operations carrying on the refusal of the mesh 500µm and a sifting of fine particles lower than 40µm. Thus, we recover only the powder of granulometry between 40µm and 500µm rich in phosphorus [19]. The classification results are shown in figure 3.

Figure 3. Particale size by sievieng according to the classification

**2. 3. 2. Chemical analysis**

The chemical composition of the crude sample was determined by ICP and volumetric chemical analysis (grouped in Tables 1 and 2). We were interested in the following elements Corg, CO2, P2O5 and CaO.

**Table 1.** chemical composition of the Bouchane phosphate before the calcination by volumetric chemical analysis

|  |  |
| --- | --- |
| Elements | Weight (%) |
| P2O5 | 30.39 |
| CaO | 48.20 |
| H2O | 5.6 |
| Corg | 1.4 |
| CO2 | 6.60 |
| Others | 7.81 |

**Table 2.** chemical composition of the Bouchane phosphate before the calcination by ICP

|  |  |
| --- | --- |
| chemicals compositions | Phosphate rock (%) |
| P2O5 | 31.10 |
| CO2 | 6.5 |
| CaO | 49.1 |
| F- | 3.5 |
| SiO2 | 1.38 |
| H2O | 5.15 |
| Al2O3 | 0.42 |
| K2O | 0.07 |
| MgO | 0.65 |
| Na2O | 0.60 |
| SO3 | 1.52 |
| Cd | 16.21 ppm |

The quantities in P2O5 and CaO can be improved by calcination. Indeed, the heat treatment will allow the respective reduction of the contents of organic matter (%Corg) and carbonates (%CO2). These two types of impurities are responsible for the difficulties occurred at the time of the phosphates rock valorization especially for the synthesis of the phosphoric acid. In this respect, the presence of the organic components constitutes an awkward element reducing sulphide sulphates and involving thereafter an intense corrosion of the engines [20]. Moreover, the existence of these organic components causes the formation of foam which disadvantages the cooling of the exothermic reaction of attack by the sulphuric acid. Indeed, the latter causes an increase in the temperature and viscosity and consequently the formation of the phosphogypsums hemihydrates. Thus, a bad filtration rises which affects the quality of the phosphoric acid by decreasing the chemical outcome [21]. Moreover, the dioxide of carbon contaminates also the material by giving the black colour to the produced acid which contributes to the pollution of the environment.

**2. 3. 3. Mineralogical analysis**

The mineralogical analysis was carried out by using a diffractometer XPRT MPD Panalytical – Philips, with copper anticathode (K = 15.405 nm). We were interested in the crushed section of granulometry ranging between 40 µm and 500 µm. The diffractogram (figure 3), reveal the presence of the following phases: the fluoroapatite Ca10(PO4)6F2 (2θ : 32.173 ; 33.280 ; 49.786 ; 64.179 ; 40.227 ; 34.331 ; 25.879), the quartz SiO2 (2θ : 26.587 ; 67.861 ; 50.079 ; 20.885). The carbonates are in the form of dolomite CaMg(CO3)2 (2θ : 30.917 ; 50.674 ; 41.187) and the calcite CaCO3. (2θ : 45.790 ; 26.189 ; 48.376 ; 33.153 ; 38.101 ; 36.041 ; 27.081 ; 52.553).



**Figure. 4.** Diffractogram of X-ray of a rough sample (\* : Fluoroappatite, + : Quartz, ▲ : Calcite ● : Dolomite)

**2. 3. 4. Thermal analysis**

Thermal measurements (DTA-GTA) were carried out using a thermal apparatus of analysis Labsys TM type. They were completed under air with a speed of heating of 10°C/minute, ambient temperature until 1000°C, on the crushed section of 40 μm to 500μm. The substance of reference is alumina.

The results of the DTA and TGA thermic analysis, gathered on figure 5, present several phenomena:



**Figure. 5.** Curve DTA-GTA of a crude sample

\* Phenomenon of endermic ambient temperature to 120°C whose top is located towards 80°C, due to the departure of the humidity’s water;

\* Weak exothermic phenomenon which starts around 300°C and which is spread out until 700°C, due probably to the combustion of the organic matter;

\* Between 700°C and 900°C, an endothermic phenomenon which can be due to the decomposition of carbonates [calcite CaCO3 and the dolomite CaMg(CO3)2] according to the following reactions:

CaMg(CO3)2 CaO + MgO + 2CO2

H = 710kcal/kg

CaCO3  CaO + CO2

ΔH = 965kcal/kg

Let us note that the total loss at 1000°C is about 9.2%.

**3. Behavior of the principal constituents (Corg, CO2, P2O5 and CaO) of the calcination control**

**3. 1. Experimental procedure**

The optimization of the time’s stay and the calcination temperature was carried out according to the protocols “1”, while following the variation of the main contents of Corg, CO2, P2O5 and CaO, in the calcined samples. The tests were made in laboratory. Representative phosphate samples from the Ganntour basin with granulometry ranging between 40 μm and 500 μm are placed in a vertical cylindrical stainless enclosure (fixed bed), then calcined in an electric oven with adjustable temperature.

**Protocol “1”:** This protocol was to follow the evolution of the principal constituents of control during calcination enrichment. The tests were performed on representative samples classified as phosphate was placed in a vertical stainless steel cylindrical chamber (fixed bed), then in an electric oven with adjustable temperature. Every five minutes, a sample is taken to analyze the chemical compositions of apatite (Corg, CO2, P2O5 and CaO) of the ore at different temperatures (600°C, 650°C, 700°C, 750°C, 800°C, 850°C and 900°C) and the total time is 40 minutes.

Before the chemical analysis compositions Corg, CO2, P2O5 and CaO, we proceed to the extinction, by injection of the air and by closing the bed by a sieve of 40 μm diameter to remove the volatile matter adsorbed and the size fraction less than 40μm of which the phosphorus whose concentration is low.

**3. 2. Calcination, experimental results and discussions**

In this experimental study, we studied the time’s stay and the calcination’s temperature in order to optimize energy intended to the calcination without acting on the phosphate enrichment (fig 6).

**Figure. 6:** Curves of variations in Corg, CO2, P2O5 and CaO with time and temperature

The figure 6a shows that the percentage of organic carbon remains constant with its initial concentration (1.4%) when the temperature lies between 600°C and 700°C. Beyond 700°C, the combustion of the organic matter starts with times of maintenance which decrease with the temperature. This reaction of combustion reaches its stationary limit beyond 30min for the temperatures higher than 800°C. The content of Corg reached is 0.15%.

The figure 6b shows that the CO2 emission starts after a time’s stay which decrease with the calcination temperature while the speed of reduction in CO2 is accentuated. The CO2 content reaches a constant value (about 2%) beyond 800°C and from a time of maintenance of 30min.

The figures 6c and 6d show that the percentage in P2O5 and CaO varies respectively in the same way according to the temperature and the time of maintains. They reach constant maximum values between 850°C and 900°C with a stage of 30 min. As the total amount of material will be diminished with the departure of moisture and loss on ignition, the relative amounts of P2O5 and CaO compared to the remaining material, are increased accordingly. The stationary values reached of P2O5 and CaO are respectively 34.3% and 54.8%.

We conclude that starting from 800°C and with a time’s stay of 30 minutes, the contents of Corg, CO2, P2O5 and CaO become appreciably invariant under the effect of the calcination temperature.

The follow-up of the enrichment of the studied phosphate according to the calcination temperature and the time’s stay enabled us to note that:

- Between 600°C-700°C, there is a weak increase of the speed of enrichment following the release of the two types of chemical reactions as it was observed on the DTA and TGA curves (fig 5); the endothermic reaction of dehydration is followed by the exothermic reaction of combustion of the organic matter. The latter is responsible for the reduction in organic carbon (Corg). It seems that the phenomenon of dehydration observed between 80°C and 120°C on the DTA and TGA curves (fig 5) involves the departure of the water molecule. This phenomenon occurs brutally with 600°C during the enrichment, leads to the creation of the pores in the grains and contributes to the ventilation of phosphate during the calcination, which facilitates thereafter the release of the volatile matter.

From 700°C, the speed of enrichment increases considerably, following the endothermic reaction due to the decomposition of the carbonates (fig 5), which comes to be added to the reaction of oxidation of the organic matter. This endothermic phenomenon is responsible for the strong carbon dioxide emission.

Between 800°C and 900°C, the speed of enrichment remains almost constant; this is justified by contents of P2O5, Corg, CO2 and CaO which they have not underwent any variation. This appears obvious since, in this temperature interval, the loss of mass is very weak and the phenomenon of decarbonation is almost completed at 800°C with a stage of 30 min. The CO2 content measured in the calcined phosphate at 800°C with a stage of 30min can be explained only by the phenomenon of recarbonatation of the fluoroapatite already observed by Blazy and and Jdid [22]. These authors have explained this result by an increase in cell parameter of the fluoroapatite following the insertion of carbon in its crystal lattice.

**4. Behavior of the principal constituents (Corg, CO2, P2O5 CaO) during the treatment the phosphates by mixture**

**4. 1. Experimental procedure**

In this experimental study, we studied the mixture of cold and hot phosphate in order to optimize energy intended to the calcination without acting on the phosphate enrichment.

**Protocol “2”:** To study the cooling of phosphate by itself, a sample of 200 grams of phosphate is calcined under a temperature of 800°C and during time of stay of 30 minutes, then cooled in an atmospheric air [3; 4].

The sample is then mixed by cold (MC) with a quantity of phosphate of the same source and the same size classification.

The cooled mixture by hot (MH) is made by mixing under 800°C temperature, the calcined phosphate with a quantity of the same source and the same size classification.

The procedure is performed by adding different mass ma (ma = m×10%, m×20%, m×30%,…., m×100%).

Before the chemical analysis compositions Corg, CO2, P2O5 and CaO, we proceed to the extinction, by injection of the air and by closing the bed by a sieve of 40 μm diameter to remove the volatile matter adsorbed and the size fraction less than 40μm of which the phosphorus whose concentration is low.

**4. 2. Cooling of phosphate by itself under the standard conditions.**

The study of the effect of the temperature and time’s stay, enabled us to optimize the experimental conditions of the enrichment of these phosphates by calcination, while choosing a calcination temperature of 800°C and a time’s stay of 30min. Under these conditions, we propose to study certain physico-chemical characteristics of cold and hot phosphate mixtures in order to make a comparison with those of the calcined phosphate.

The figure 7 gives the evolution of the Corg, CO2, P2O5 and CaO content according to the added phosphate calcined both on the cold and hot. The contents variation of these two mixtures increases and reaches a maximum which remains invariant until to the addition of a quantity of 33% while keeping an acceptable content. For additions higher than 33%, this variation decreases in a remarkable way; the Corg, CO2, P2O5 and CaO content obtained becomes higher than the useful values [23].

**Figure. 7**. Variation of the Corg, CO2, P2O5 and CaO according to the mass of the added phosphate

The results obtained on the phosphate from the Ganntour basin, with properties listed above, which contains organic material and size fraction between 40 and 500 μm enriched by thermal and mechanical ways in a discontinuous manner, illustrate well the interest taken into account of the coupling between the process and the physical and chemical properties. We have described in this work an experimental protocol that allowed obtaining the optimum mixtures and their impact on the quality of phosphate.

During the cold mixture, the organic carbon content decreases from 1.4 to 0.15% and increases from 0.15 to 0.46% while the content of carbon dioxide decreases from 6.6 to 1.8% and increases of 1.8 to 3%. This combines a higher concentration of phosphate containing 30.39% of P2O5 in an amount of about 34.23% and decreases by 34.23% to 33%.

During the hot mixture, the organic carbon decreased from 1.4 to 0.15% and then grows from 0.15 to 0.3%, while the carbon dioxide decreases from 6.6 to 1.8% and then grows from 1.8 to 2.4%. This involves a higher concentration of phosphate containing 30.39% of P2O5 in an amount of about 34.23% and decreases slightly to a value of 33.45%.

The contents variation of these two mixtures increases and reaches a maximum which remains invariant until the addition of a quantity of 33% while keeping acceptable content (fig. 7). For additions higher than 33%, this variation decreases in a remarkable way; the Corg, CO2, P2O5content and CaO obtained become higher than the useful values [23]. The figure 8 shows the variation of the Corg, CO2, P2O5 and CaO contents between the hot (MC) and the cold (MF) mixtures according to the added phosphate.

**Figure 8.** Variation of the Corg (×), CO2 (▲), P2O5 (■) and CaO (●) contents between the hot (MC) and the cold (MF) mixtures according to the added phosphate.

**5. Characteristics of calcined phosphate and the mixtures of cold and hot phosphate**

In order to emphasize the calcination of phosphate during the cooling cycle of phosphate calcined at 800°C during 30min, we have compared the characteristics of the crude phosphate (A), calcined phosphate (B) and the phosphate obtained by cold (C) and hot (D) mixtures (Tables "3" until "8").

**Table 3.** Conditions of preparation of various phosphates

|  |  |
| --- | --- |
| Sample | Conditions of preparation |
| Crude (A) | Crude phosphate |
| Calcined phosphate (B) | Calcined phosphate at 800°C during 30 min |
| Cold mixture (C) | [67% (B) + 33% crude (A)] at ambient temperature |
| Hot mixture (D) | [(67% (B) + 33% crude (A)] at 800°C then cooled under the atmospheric air |

The obtained results are presented in tables 4 until 8.

**Table 4.** Average chemical composition of different types of the Bouchane phosphates by volumetric chemical analysis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Elements | A | B  | C | D |
| P2O5 (%) | 30,39 | 34,23 | 33 | 33,45 |
| CaO (%) | 48,20 | 54,77 | 52,88 | 53,45 |
| H2O (%) | 5,60 | 2,10 | 3,5 | 3,10 |
| Corg (%) | 1,4 | 0,15 | 0,46 | 0,30 |
| CO2 (%) | 6,6 | 1,8 | 3,00 | 2,4 |
| Others (%) | 7,81 | 6,95 | 7,16 | 7,30 |

**Table 5.** Average chemical composition of different types of the Bouchane phosphates by ICP

|  |  |  |  |
| --- | --- | --- | --- |
| Elements | A (%) | B (%) | D (%) |
| P2O5 | 31.10 | 33.90 | 33.70 |
| CO2 | 6.5 | 2.7 | 2.96 |
| CaO | 49.1 | 54.3 | 53.42 |
| SiO2 | 3.5 | 3.3 | 3.4 |
| H2O | 1.38 | 1.3 | 1.34 |
| Al2O | 5.15 | 1.6 | 2.1 |
| Si2O3 | 0.42 | 0.31 | 0.36 |
| K2O | 0.07 | 0.08 | 0.08 |
| MgO | 0.65 | 0.7 | 0.68 |
| MiO2 | 0.60 | 0.5 | 0.56 |
| SO3 | 1.52 | 1.30 | 1.39 |
| Cd | 16.21 ppm | 16.60 ppm | 17.0 ppm |

**Table 6.** Granulometric distribution (refusal (%)) different types of the Bouchane phosphate.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Net (μm) | A | B | C | D |
| 500< | 0 | 0 | 0 | 0 |
| 350 | 37.66 | 31.27 | 33.66 | 33.15 |
| 250 | 24.75 | 26.21 | 28.34 | 27.41 |
| 200 | 15.85 | 20.20 | 19.38 | 20.32 |
| 160 | 9.98 | 11.30 | 10.58 | 12.16 |
| 80 | 9.88 | 8.56 | 6.52 | 5.71 |
| 40 | 1.88 | 1.43 | 1.47 | 1.18 |
| < 40 | 0 | 0.03 | 0.05 | 0.07 |

**Table 7.** Specific surface of different types of the Bouchane phosphates

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type of phosphates | A | B | C | D |
| Specific surface (m2/g) | 10.30 | 10.20 | 10.26 | 10.60 |

**Table 8.** Densities of different types of the studied phosphates

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type of phosphates | A | B | C | D |
| Density (g/cm3) | 3.17 | 3.14 | 3.16 | 2.92 |

**6. Synthesis and discussions**

The different techniques of analysis applied to a series of representative samples of the phosphate from the studied area have demonstrated a close relationship between mineralogical phases, particle size distribution, density and the evolution of the main control parameters of the calcination according to the time and temperature [4; 7]. The mineralogical study revealed that the matrix is a carbonated fluorapatite highly substituted whose coating consists mainly of dolomite, calcite and quartz [7].

Indeed, the percentage by weight P2O5 and CaO are higher in the calcined phosphate (B) from the raw phosphate (A). Conversely, the percentages by weight in Corg and CO2 are reduced in the calcined phosphate (B) through decarbonatation reactions and oxidation of organic material during calcination. As a result, the main constituents of control (Corg, CO2, P2O5 and CaO) the calcination of phosphate with a chemical kinetics that increases with time and temperature until a time of 30 minutes and a temperature of 800°C. Apart, it follows an almost identical profile. By this, we were able to increase the weight of P2O5 30.39% to 34.23% and reduce levels of organic carbon (Corg) and carbon dioxide (CO2) by 1.4% to 0.15% and 6.6% to 1.8%.

From the point of view of the chemical composition, the contents of the phosphorus pentoxide (P2O5) and the lime (CaO) are higher in the hot mixture than the cold one. In contrast, the Corg and CO2 contents decreased in the hot mixture (Figure 7 and Table 4). This was caused by the dehydration and the decarbonation and the oxidation reactions of the organic matter during the cooling cycle when mixing hot. The phosphate’s chemical composition affects has an influence upon the kinetics of its thermic treatment because all components do not react at the same speed. The presence or absence of impurities on the grain would also change significantly the process of heat treatment at the granular level. The decrease in the organic matter and carbonates causes an increase in the responsiveness of a less rich phosphate. This phenomenon occurs in the calcined phosphate and the hot mixture.

As for the granulometry, we have noticed a reduction in the percentages of the mesh refusal of 350 μm for the two treated phosphate (B) and (D) (Table 6). This variation is due to the breaking of the coarse grains by the fast temperature raising within the particles, in the hot mixture, according to the dehydration and oxidation reactions of the organic matter and the carbonates decomposition which lead to the formation of water vapor and CO2. These volatile compounds create local overpressures causing cracking the reacting grains, a rapidity of their clearances and an increased porosity. Thus, the matrix becomes deformable under the influence of heat, and therefore, the granulometry effect is added.

Previous works [6; 24; 25; 26] have showed that the variation of the granulometric distribution improves physical properties especially the specific surface and the porosity (Table 7). Therefore, from the extensive exhibition of the organic matter and carbonates outward results a large specific surface of the finished product by the decrease in the density of the hot mixture (Table 8). This limits the rate of sedimentation of the pulp phosphate or the reaction boils during the production of phosphoric acid. Moreover, the solubility of the crude phosphate increases with the decrease of the size of its particles [27; 28].

The results obtained in this study show that there's an interaction between the thermo-physical and chemical parameters. Therefore, obtaining a better quality product depends largely on this coupling. Hence, heat treatment for hot mixture appears as an appropriate process.

**7. Conclusion**

In this work, we have been able to minimize the energy loss by recovering the lost energy during the cooling cycle of the calcined phosphate, and by using this energy for the calcination of the same crude phosphate.

The 800°C temperature calcination and a time’s stay of 30 min permit to obtain a phosphate rich in P2O5 and CAD with very weak CO2 and Corg contents.

The comparison of the Corg, CO2, P2O5 and CaO contents corresponding to the cold and hot phosphate mixtures with those of the calcined phosphate allows us to advance that the addition of a quantity of crude phosphate 33%, at the beginning of the cooling cycle at 800°C, provides a concentrate of phosphate of a better quality. Therefore, this process has a certain outcome on the energy saving and an increase in the productivity of a concentrate of phosphate of a better quality.

The extrapolation on an industrial scale of this protocol is possible by combining the two operations of drying and calcination existing. The process of heat treatment of hot mixtures will be based in a fluidized bed followed by a mixing rotary form.

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