

# Heat engineering problems of phosphogypsum utilization during its processing into construction gypsum

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**Abstract.** The shortcomings of common equipment for utilization of phosphogypsum when processing it into semi-aqueous gypsum have been analyzed. Specific energy consumption per ton of produced construction gypsum in different equipment is shown. Calcination duration is compared. The reasons for the uncompetitiveness of the process of production of construction gypsum compared to the production of natural gypsum stone are analyzed. Two problems are considered. The first - common equipment for burning construction gypsum is energy-intensive. The second is the established practice of washing impurities in phosphogypsum with water. At the same time, energy consumption increases several times due to the need for energy consumption for moisture evaporation. It is theoretically reasonable to carry out the firing in a suspended state. The firing time is a few seconds. The experimental studies show the possibility of producing construction gypsum by firing in a suspended state.

## 1. Introduction

In the modern mechanical engineering a significant number of parts are fabricated from lead-tin-base bronzes. They include a series of parts which should possess sufficiently advanced strength characteristics (sealings and piston rings, oil-seal and expander rings). In order to enhance tribotechnical characteristics, lead is introduced into these materials. Lead reduces friction coefficient, enhances tribotechnical characteristics, however, it reduces strength significantly.

Phosphogypsum is one of the multi-ton solid wastes of mineral fertilizer production. It is produced by sulphuric acid processing of natural apatites and phosphorites into phosphoric acid, superphosphate, precipitate and other phosphoric fertilizers.

At present, phosphogypsum wastes are accumulated in the dumps of different countries of the world hundreds of millions of tons [1-2]. The problem of creating technologies and equipment for transfer of phosphogypsum into construction gypsum is dealt with by many firms. There are about a hundred technologies to convert phosphogypsum into building gypsum. However, almost all of them are unprofitable or environmentally impractical due to the high energy intensity of the proposed technologies [3].

The relevance of phosphogypsum recycling is due to the following factors:

- Dumps occupy huge territories of the earth,



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- In dry weather phosphogypsum is dusty and this leads to air pollution,
- Rains wash soluble phosphoric acid residues into groundwater and they contaminate water basins in storage areas,
- There is a need for maintenance costs for these dumps.

As for the equipment in which two-water calcium sulfate is converted into semi-water calcium sulfate - construction gypsum - there is no consensus among producers and workers on the issue of the most expedient machine.

The most common current gypsum binder machines are rotary furnaces (drums), gypsum cookers, dampers and autoclaves. In the production of construction gypsum from phosphogypsum, the same machines are currently used in which calcium sulfate hemihydrate is produced from natural gypsum stone.

V. V. Ivanitsky and other researchers [4-5] believe that the optimal technology for making gypsum binders has not yet been found.

Phosphogypsum is disposed of in all countries of the world [6-10], but the volume of recycling is very small and does not allow reducing accumulation of waste.

## 2. Materials and methods

A common disadvantage of lines using dampers and autoclaves is the considerable duration of the cooking cycle. This fact provides a significant amount of specific heat consumption per unit of finished reduction.

The firing (cooking) time in all existing technologies is from one to six hours. Table 1 shows the firing time and energy consumption for the production of gypsum binder in known machines [11].

**Table 1.** Firing time and specific energy consumption [3]

Equipment	Duration of thermal treatment	Specific consumption		Plaster cementitious matter
		conditional fuel, tons/hour	electric power, kW • hour/ton	
Gypsum cooking boiler	1 - 3 hours	45...52	26...30	( $\beta$ -CaSO <sub>4</sub> ·0,5H <sub>2</sub> O)
Rotating drum	45 - 60 minutes	48...56	30	( $\beta$ -CaSO <sub>4</sub> ·0,5H <sub>2</sub> O)
Damper	4 - 5 hours	110...120	20	( $\alpha$ -CaSO <sub>4</sub> ·0,5H <sub>2</sub> O)
Autoclave	4 - 6 hours	259...282	30...32	( $\alpha$ -CaSO <sub>4</sub> ·0,5H <sub>2</sub> O)

A gypsum-cooking boiler is two vessels (pipe in pipe) with a spherical bottom. Inside the inner vessel, a stirrer is rotated to stir the gypsum powder. Heat is transferred to the material layer through the wall separating the inner vessel from the outer vessel. Fuel combustion products, which are a source of thermal energy, are supplied to the external vessel [11]. Heat transfer through the wall is not effective.

In rotating drums [11] heat from gas flow is transferred to pieces of material - crushed stone. In dampers heat is also transferred to pieces of material, but in drums the heat transfer efficiency is higher as the drum rotates. In autoclaves, the heat is perceived by the shaped bricks, and therefore the heat exchange surface is small. Energy consumption in these machines leaves much to be desired (Table 1).

Thus, **the first problem** is the absence of a generally recognized rational method and equipment for dehydration of calcium sulfate dihydrate.

However, this problem is solved. The authors consider the theoretical component of the firing process.

It is known that the amount of heat transferred is determined by Fourier law:

$$Q = \alpha F \Delta t \quad (1)$$

where  $\alpha$  – coefficient of heat transfer,  $\text{kJ/m}^2\cdot\text{K}$ ;  $F$  – a surface which accepts heat,  $\text{m}^2$ ;  $\Delta t$  – is a difference of temperatures between the heat carrier and material.

It follows from Fourier law that, all other things being equal, in order to increase the efficiency of heat transfer, it is necessary to strive to increase the area of contact between the material and the heat carrier.

In order to determine how to intensify the process of producing construction gypsum by firing calcium sulfate dihydrate, an attempt has been made to theoretically determine the firing time. The parameters of moving heat carrier and characteristics of material to be fired were taken into account during reasoning.

Firing time was determined by formula, seconds:

$$\tau = \frac{(Q_1 + Q_2 + Q_3) \cdot d^2 \cdot \rho}{6 \cdot \text{Nu} \cdot \lambda \cdot G \cdot \eta \cdot \Delta t} \quad (2)$$

where  $Q_1$  – the heat flux used to evaporate the physical moisture of the starting gypsum,  $\text{J/kg}$ ;  $Q_2$  – heat flow spent on gypsum heating,  $\text{J/kg}$ ;  $Q_3$  – the heat flux used to dehydrate gypsum,  $\text{J/kg}$ ;  $D$  – equivalent particle diameter,  $\text{m}$ ;  $\rho$  – density of plaster,  $\text{kg/m}^3$ ;  $\text{Nu} = f(\text{Re}, \text{Pr})$  – Nusselt criterion;  $\text{Re}$  – Reynolds criterion;  $\text{Pr}$  – Prandtl criterion;  $\lambda$  – heat conductivity of gases of the heat carrier,  $\text{W/m} \cdot \text{g}$ ;  $G$  – consumption of initial material on end production unit,  $\text{kg/kg}$ ;  $\eta$  – the coefficient considering losses of heat;  $\Delta t$  – average the logarithmic difference of temperatures between the heat carrier and material, degree celsius.

### 3. Results and considerations

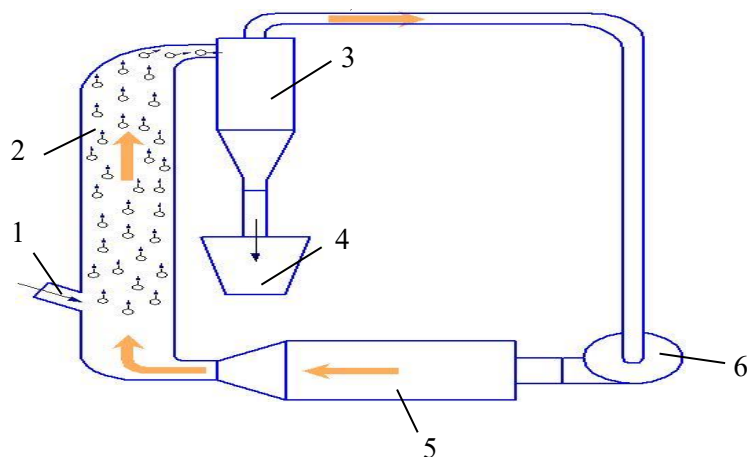
In order to check the theoretical prerequisites, a plant for burning phosphogypsum in suspended state has been created, the diagram of which is presented in Figure 1.

The principle of operation is as follows. Raw material in the form of ground powder is supplied to vertical pipe, along which heat carrier moves. The heat carrier may be heated air or fuel combustion products. The heat carrier picks up the material and takes it to the cyclone. During movement along the ascending pipe in a few seconds in the material it is possible to undergo a dehydration reaction of calcium sulfate dihydrate with its conversion into calcium sulfate hemihydrate – construction gypsum. Gases are separated from material in cyclone. The material is lowered down the walls into the hopper and the exhaust gases can be recycled or discharged into the atmosphere.

The design of the plant allows quickly adjusting the parameters of the coolant and, therefore, changing the conditions for obtaining the final product of sufficiently good quality. This is also facilitated by the uniform heating of the material due to the direct contact of the fine particles of the material with the heat carrier moving in the turbulent mode. As a result of experiments, construction plaster of G- 5 and G- 6 grades was obtained 2 hours after flooding with water. After 7 days of storage of samples in air, their compression strength was 15 MPa. The obtained gypsum binder meets the current standards by quality indicators. The installation is installed at the Kharkov National University of Construction and Architecture. The results of the experiments confirmed the correctness of the theoretical prerequisites.

**A second problem** is that existing methods of neutralizing impurities in phosphogypsum using water result in increased phosphogypsum humidity. Natural gypsum stone contains (3-5)% moisture and phosphogypsum (30-40)%. This leads to an increase in thermal energy consumption of several times, as evaporation of moisture is a very energy-intensive process. Therefore, wet purification of phosphogypsum is energy-efficient and makes existing technologies uncompetitive compared to technologies for producing construction gypsum from natural gypsum stone. For this reason, phosphogypsum still lies in the dumps and is disposed of in small quantities worldwide. Although, scientists proved the feasibility of the production of gypsum binder and gypsum construction materials and products. Julian Hilton quote from article «...the risk of use is substantially lower than the risk of containment...»

More effective is the direction of binding soluble harmful compounds to insoluble harmless compounds without adding water.



**Figure 1.** Suspended Material Firing Scheme: 1- shows a feed hopper; 2 - roasting pipe; 3 - cyclone; 4 - finished product bin; 5 - heat generator; 6 - fan.

#### 4. Conclusion

The reasons for uncompetitiveness of construction gypsum production from phosphogypsum compared to production from natural gypsum stone were analyzed.

The thermal engineering causes are shown to be two:

- Production of construction gypsum in energy-intensive equipment,
- High humidity of phosphogypsum.

The directions of solving said problems are disclosed: burning of construction gypsum in suspended state and conversion of impurities in phosphogypsum into insoluble free compounds without addition of water.

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