CONTROL SYSTEM ELABORATION FOR PHOSPHORITE CHARGE PELLETIZING PROCESS

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Abstract. *Regular granulation of fine materials requires appropriate density and humidity fluctuations. The control system of pelletizing process that assures optimal modes was proposed. The combined control algorithm was realized with fuzzy model based disturbance-stimulated control at the upper level, and the deviation control at the lower level.*

Keywords: pelletizing process, optimal control, fuzzy logic

PROJEKTOWANIE SYSTEMU STEROWANIA PROCESEM PALETYZACJI FOSFORYTÓW

Streszczenie. *Regularna granulacja drobnych materiałów wymaga odpowiedniej gęstości i wilgotności. W artykule zaproponowano system sterowania procesem peltyzacji, zapewniający optymalne tryby pracy. Złożony algorytm sterowania został zrealizowany z uwzględnieniem modelu rozmytego w ramach sterowania stymulowanych zaburzeń na górnym poziomie, natomiast na niższym poziomie (wykonawczym) funkcjonują układy automatycznej regulacji.*

Słowa kluczowe: granulacji proces, sterowanie optymalne, logika rozmyta

Introduction

The main problem of Karatau basin phosphorites processing is the fact that during the cycle of ore mine-plant, up to 55-60% of phosphorite fines are formed, with coarseness (10mm), during ore extraction, transportation and processing [3]. The ore of such fraction cannot be exposed to processing in electric furnaces.

To provide the required gas permeability of a stock column and the reduction in likelihood of its sintering in a phosphorus furnace, it has to be preliminarily turned into a lump material with a grain size at least 5-10 mm. The agglomerate should have sufficient mechanical strength, should not form fines during transportation, while loading into the furnace and in the course of melting [4, 9].

At NDFZ, sintering is performed by agglomeration using the charge baking on the dedicated sintering machines [5]. However, for successful agglomeration sintering, stock column should have sufficient gas permeability on the sintering belt. The phosphatiferous fines are intermixed with the amount of fuel and flux necessary for sintering to achieve the required gas permeability. After that the derived charge is subjected to pelletizing in drum granulators.

1. Pelletizing process description

For normal granulation of fine materials, they should have density and humidity fluctuations, i.e. nucleation centers are needed. During pelletizing of fine-grained materials, separate lumps are used as nucleation centers. Lump voids are filled with water. Lumps, having sufficient mass (several grams), while pouring in the granulator, receive such kinetic energy margin, which is enough for rearranging the pellet structure. Moreover, granular material, moistened to the state of maximum capillary moisture, possesses lowered cohesive strength, which facilitates mutual migration of individual particles and attainment of dense lump structure.

In practical conditions the preset amount of water assuring optimal humidity is divided into two parts. The greater part is fed to the dry materials layer to form nucleating seeds, and the smaller part – to large-size lumps interspersion section.

In [2] theoretical and experimental analysis has been conducted to assess granular material behavior in the rotary drum. It was found out that the nature of material movement in the rotary drum depends on the degree of its fill-up, rotation speed and the state of drum internal surface. Authors [2] have determined three modes of material movement in the drum cross-section: roll mode, tumbling mode and cyclic mode. In this regard the most optimal mode is the roll mode.

In roll mode, once the tilt of load surface exceeds the angle of natural slope, excess material will start pouring downward. In this mode the loaded material sort of rolls over along the drum internal surface, simultaneously "rotating" around the unique center – material movement is carried out in so called roll mode. Characteristic feature of material movement in the roll mode is the absence of particles' parabolic section of trajectory – after the circular section, material particles instantly shift to the pouring section. Volume of material while moving under this mode is approximately only 10% higher than load volume at rest.

However in researches [2] the material pelletability was not taken into account, experiments were conducted using polystyrene as granular material. Polystyrene allowed the author [2] to check the accuracy of formulas as per capacity calculation, stay time and trail. However he could not describe the pelletizing itself using these relationships.

Material pelletability can be assessed with the help of granulation coefficient [2], numerically it can be estimated in the following way. It is known that due to the insufficient amount of coarse grains (nucleation centers) in base charge, pelletizing runs unstably, respectively the granulation of fines rolling onto the coarse grains is disrupted. Then the pelletizer starts to make regular intermixing of the material. In accordance with this, granulated pelletizing capability of the material might be estimated using the coefficient, which presents the ratio of pelletizing fractions surface to the volume of fine (pelletized) fractions. The greater this value, apparently, the faster the fines will be rolled onto the coarse grains.

For pelletizing, NDFZ uses phosphorite fines and flux, which is fed to silos of sinter shop charging section. To the same silos the sinter siftings as well as quartzite, having coarseness 6-0 mm, are fed. [9].

From silos the phosphorite ore and coke breeze are transported by means of conveyor system to the primary intermixing section. On this track, primary (cooled) return, resulted from grizzly screening of the hot sinter, is added to the charge as well as the secondary return, extracted during sinter separation in the grizzly screening section. In the course of primary intermixing, charge humidity is brought to 3-4%. The charge, intermixed in the drum mixers, is fed to four storage bunkers, out of which the charge from two bunkers is fed for pelletizing in parallel by two streams.

Sequential operation of two pairs of storage bunkers complicates the control over the process, but at the same time allows calculating the optimal modes of pelletizing for each pair of storage bunkers separately. Sequential startup of storage bunkers leads to the natural control reserve – time. In other words, while the next pair of bunkers becomes depleted, there is a time reserve for an analysis of physicochemical properties of charge to be oaded into the nonworking bunkers. This allows correcting the pelletizing modes beforehand at the moment of startup of this pair of storage bunkers.

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Availability of two pairs of sequentially working bunkers allows implementing, perhaps, one of the most advantageous laws of control – combined law. At that the disturbance-stimulated control is calculated as per the data derived from the analysis of charge physicochemical properties, and the deviation control is performed as per the conventional ways: ratio of “charge-water”, “capacity – drum rotation speed”.

2. Control system structure elaboration

Based on the features of pelletizing process as a control object we suggest the control system structure for the given process, which assures optimal running of modes.

The major difficulty in pelletizing process control is in severe conditions in terms of finished pelletized material quality under non-stationary qualitative and quantitative composition of loaded components. The following items are considered while calculating the pelletizing modes, which are used as input variables:

- grain composition of phosphorite fines, coke, flux, dust, secondary and primary returns;
- percent composition of charge components.

Control variables can be:

- “charge-water” ratio;
- drum rotation speed;
- drum load (capacity).

It is also necessary to maintain the most optimal “roll mode” of material movement in the drum for providing finished product quality.

With regard to input and output variables we suggest control system structure, which allows changing tasks for regulators (control devices) at regular times – with depletion of next “working” pair of bunkers, and shifting to the new pair with other but already known charge qualitative properties.

Optimal control system represents a double-level hierarchical structure. At the upper level, calculation is performed regarding optimal modes of the process running for next pair of bunkers, ready for operation. At the lower level there are control devices of the existing automation system, for which optimal tasks are computed. That is, the most effective control principle is realized - combined control: at the upper level - disturbance-stimulated control, and at the lower level the deviation control.

3. Elaboration of mathematical description of various factors impact on pelletizing quality

The correlation between the capacity (G), drum rotation speed and material bulk weight is more fully given in [2]:

$$G = \frac{\pi^2 \gamma_N}{360} n D^3 \lambda (0{,}00087\lambda - 0{,}011) tg\gamma \qquad (1)$$

where n – number of drum rotations; D – drum diameter; γ – material lifting angle in the rotary drum relating to the generant of the drum cylinder; γ_N – material bulk weight; λ – angle depending on the pouring angle ω, where

$$\lambda = 180 - 2\omega \qquad (2)$$

It is highly important to point out that under drum continuous running, there automatically such dependence is set, at which equation (1) becomes justified.

Equation (2) determines the limit degree of drum fill-up, up to which the material will be moving in the roll mode. In the equation (2) angle ω primarily is determined by the angle of material internal friction (natural slope angle), strongly depends on the drum rotation speed. Other things being equal, pouring angle ω increases with the rise in drum fill-up degree.

As it was already noted, granulation effectiveness is characterized to a great extent by the coefficient of granulation speed [2]:

$$K_{гр} = \frac{6\left[\dfrac{P_1(\%)}{d_1\gamma_1} + \dfrac{P_2(\%)}{d_2\gamma_2} + ... + \dfrac{P_n(\%)}{d_n\gamma_n}\right]}{\dfrac{P_n}{\gamma_N}} \qquad (3)$$

where g_i – specific density of charge components; P_i – i - component content in the charge (pelletizing fractions); P_n – fine (pelletized) fractions content; g_N - bulk weight of pelletized fractions.

Formula (3) represents the ratio of pelletizing fractions surface to the volume of fine (pelletized) fractions. However, equation (3) determines the granulation effectiveness coefficient, which is not connected with equations (1-2). That is, equation (3) determines the granulation quality only as an indicator of its effectiveness; its numerical value is not used in calculation of output variables.

However equations (1-3) allow identifying the major correlations between input and output variables. This gives possibility to overcome the marked uncertainties using modern mathematical tool - methods of artificial intelligence. Unlike conventional mathematical modeling of physico-chemical processes, running in the drum pelletizer, new tool enables modeling of the control process. In other words, omitting the stages of building of model structure, its identification and elaboration of optimal control algorithm, intelligent technologies enable, based on the long experience of technologist-operators, proceeding with control algorithm elaboration instantly.

4. Fuzzy control model elaboration

Intelligent or fuzzy systems while controlling the complex objects considerably reduce the impact of so called human factor [1, 8]. Advantage of such systems consists in the fact that in initial stages of training, experienced operator-experts can enter information to the systems, and after the training the data collected by the fuzzy system can be used for model refinement by experts. Fuzzy control systems consider information about disturbing actions, which can be measured, but cannot be used in analytic formulas for reasons of complex nature of their impact on the object, as well as take into account information, which cannot be measured by tools. However they might be approximately estimated by a man [7].

However, from our point of view, the most effective way is to use the methods of artificial intelligence theory jointly with classic methods of engineering process control. This being the case, it is attainable to combine the advantages of conventional methods, techniques and algorithms (such as: mathematical modeling, optimal control algorithms, synthesis of local control systems and etc.) with mathematical tool of fuzzy sets theory[6].

While elaborating the fuzzy model for pelletizing control the following assumptions have been made:

In connection with the fact that during the primary intermix, a rather good intermixing of charge components takes place, process properties: g_N, g_i and w adopt constant values, and are determined by an experimental approach;

Pelletizing effectiveness depends mainly on the value of granulation coefficient (formula 3);

Pelletizing effectiveness depends not only on grain composition of charge, but also on percent composition of charge components (phosphorite fines, return, coke breeze, dust and etc.). In connection with the fact that the charge consists for over 90% out of phosphorite fines and return, in the model we will consider only these two charge components;

Optimal ratio of “charge-water” primarily depends on the ratio of coarse and fine fractions – the greater the amount of fine fractions, the more moist will be required for “adherence” of charge particles. The best estimation of such ratio might e the granulation speed coefficient, computed using formula (3).

The lower the value of this coefficient, the greater amount of fine fractions is contained in the charge – the greater amount of moist will be required for assuring a good "adherence" of charge lumps (i.e. the lower value will the "charge-water" ratio have);

- moreover, amount of moist required for quality "adherence" of charge particles depends also on percent composition of charge components (phosphorite fines and return);
- it is considered that the humidity of base material is constant.

Input and output (controlling) variables have been determined above. In doing so, the principal task of fuzzy model is the estimation of pelletizer capacity, which would be providing high quality of derived lumps and optimal "charge-water" ratio for charge lumps to "adhere" with each other. As it becomes clear from such control task definition, the major goal of this model is providing high quality finished products, on which the sinter quality is dependent.

The next stage of fuzzy model building is the formation of rule database (knowledge base), by way of polling of experienced operator-technologists, who have been working on drum pelletizers for a long period of time. With regard to the accepted assumptions, the poll allowed drawing up the rules as follows:
RULE-1: IF "granulation coefficient is high" and "phosphorite fines content is high" and "return content is low", then the "capacity is high" and ""charge-water" ratio is high".

RULE-2: IF "granulation coefficient is low" and "phosphorite fines content is high" and "return content is low", then the "capacity is low" and ""charge-water" ratio is low".

… and so forth.

Overall, 27 rules have been compiled, which comprise intelligent system knowledge base. Further, using "Matlab" tool, the fuzzy, neuron network and hybrid models of control have been researched. The most adequate model turned out to be the hybrid model, which combines advantages of fuzzy algorithms and neuron networks.

After the granulator (G) optimal capacity has been found, according to equation (1), drum rotation numbers (n) are estimated, which assure the most favorable mode of material movement in the drum – roll type.

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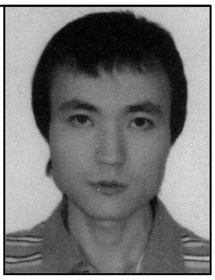

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