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Investigation of separation of fine materials in strong magnetic fields

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ABSTRACT

The aim of the present study is to choose process parameters for separation of fine ceramic materials. Authors investigated regularity of separation of fine particles and showed a possibility to extract weakly magnetic particles with diameter 1-5 micron using magnetic methods.

Key words *: Magnetic separation, ceramic materials, ferromagnetic collector, mathematical modeling*

INTRODUCTION

During past years requirements for quality ceramic materials essentially increased all over the world. It concerns both chemical and grading composition of porcelain mass.

The most important requirement for raw materials that are used in fine ceramics (porcelain mass contenting feldspar (25-30%), kaolin (30-35%), quartz sand (30-35%) and glue) production is low content (less than 0,2%) of harmful impurity (iron and titanium oxides). Iron and titanium oxides give undesirable color to fine ceramic goods and decrease transparency of porcelain. Increasing thermal conductivity of electrotechnical porcelain, the impurity decreases quality and dependability of insulation. Iron and titanium oxides also decrease acid resistance of equipment.

In world practice chemical and mechanical methods are usually used to remove impurity. During past years many patents for chemical methods of kaolin (used in porcelain production) whiten had appeared. Whiten is compound and expensive method and is often used to process the finest fraction for production of the highest sorts of pigmental kaolin.

Chemical whiten is usually used after using of cheaper and easier methods of iron and titanium oxides removal; the most popular of them are flotation and its varieties, magnetic separation and, in some degree, hydrocycling. Sometimes, if impurity is combined mainly with coarser sizes, it's possible to decrease content of iron and titanium oxides using classification.

Investigation of mineralogical composition of porcelain mass impurity, and particular of kaolin, shows that iron and titanium may contain in the form of separate minerals (ilmenite, goethite, hydrogeothite, rutile, leucoxene) or form crystal lattice of silicate, mica, for example.

Impurity content in grain-size fractions differs for raw material from different deposits. Iron and titanium minerals are to be found in material of all fractions, but in the coarsest fractions there is usually maximal content of them. Nevertheless, sometimes iron oxides may concentrate in the finest fractions (less then 1 micron).

That's why last 10-15 years electromagnetic methods of beneficiation of the raw material were so attended. Designers and technicians bent every effort to create electromagnetic separators for fine weakly magnetic impurity picking out from porcelain mass, in particular from kaolin. Johns & Forer's poly-gradient separator (was proposed in 50s to that end) let pick out mineral impurity particles (30-50 micron) from ceramic raw material for the first time. But if iron and titanium compounds content in the form of micron inclusions or form silicate crystal lattice, one can't succeed in separation.

Further perfection of electromagnetic methods of ceramic raw material benefication trends toward creating of more powerful magnetic field, using of different formed ferromagnetic collectors as a poligradient medium, using of special methods of suspension processing to increase extractive material magnetic properties before separation and also using of another forces to extract impurity minerals.

. First poligradient separators' magnetic field intensity was $16\text{-}18*10^3$ oersted and they had intensity gradient of $1*107$ $A*m^2$. But only stronger magnetic forces let extract mineral particles less than 10 micron in diameter and ironed kaolin particles (magnetic susceptibility about $10*10^6\text{-}20*10^6$ cm^3/g). They can be achieved at magnetic field intensity more than 20-30 thousand oersted and field gradient about $1*10^9$ $A*m^2$.

In spite of great advances in the domain of fine materials magnetic separation, question about extraction of weakly magnetic particles less than 10 micron in diameter becomes more and more important. It is the main problem in the area of particularly clean concentrates receiving.

In view of it investigation of superconductive magnetic separators use becomes topical, because it lets solve two problems at the same time: to decrease power expense and to increase the efficiency of fine weakly magnetic materials benefication. Such systems give a possibility to decrease power expense essentially while producing magnetic field and to increase induction in working area up to 3-5 T.

Theoretical model

Theoretical investigation aim was to estimate possibilities of fine particles extraction in high-gradient magnetic separators working zones with strong magnetic fields. Investigation of fine weakly magnetic particles extraction based on mathematic modeling of particles motion near single ferromagnetic collector.

To carry out calculations we accepted a simplified physical model of the real object (the magnetic separator and the pulp). The simplifications concern to following factors:

1) ferromagnetic collector configuration and spatial structure: we considered the real collector as a system consisting of cylindrical ferromagnetic collectors considering that their axes are perpendicular to the flow velocity vector;
2) the pulp dilution degree: we accept that the pulp is diluted good enough to let us ignore solid phase's influence upon the pulp flow velocities vf(x,y) distribution and use a simple theoretical model of hydrodynamic influence upon a particle and consider each particle as separate;
3) magnetic particles form, diameter and physical properties: we considered spherical haematite particles in all cases.

Let's consider capture cross-section (yc) and capture probability values' (p) dependence on magnetic field intensity and particle diameter if cylindrical ferromagnetic collector is separate. Capture cross-section value yc is the maximal value of distance between the starting point of particle moving and the collector axis under conditions that capture is still possible in magnetic field with given characteristics and at given hydrodynamic regime. Capture probability value p=yc/L is the capture cross-section to distance between neighboring collectors axes ratio.

So, to determine capture cross-section and capture probability values we need to find numerical solution of particle motion equations (1) and (2) for the given particle diameter dp, pulp flow velocity vf and external magnetic field intensity H0 values. Wire diameter dw is always 0,5 mm. The system of equations, unlike equations from[1,2], considers influence of particle weight (inertial and gravitation forces) and changing of the particle motion hydrodynamic regime on its path.

Besides, we considered changing of the particle magnetic susceptibility depending on the external magnetic field induction. We used the following empirical formula for the particles of substantially haematite composition:

$$æ_p = 0.0014 + \frac{1.62.10^3}{H}$$

$$\frac{d^2 r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 = \frac{1}{r}\left[-\frac{\upsilon_m}{\widetilde{r}^3}\left[\frac{A}{\widetilde{r}^2} + \cos 2\theta\right] - N_d(\upsilon_{p,r} - \upsilon_{f,r})\right] + g\left(1 - \frac{\rho_f}{\rho_p}\right)\cos(\theta - \beta); \quad (1)$$

$$r\frac{d^2\theta}{dt^2} + 2\frac{dr}{dt}\frac{d\theta}{dt} = \frac{1}{r}\left[-\frac{\upsilon_m}{\widetilde{r}^3}\sin 2\theta - N_d(\upsilon_{p,\theta} - \upsilon_{f,\theta})\right] - g\left[1 - \frac{\rho_f}{\rho_p}\right]\sin(\theta - \beta). \quad (2)$$

where m_p – particle mass ;

$\vec{\upsilon}_{f,r}(r,\theta)$ - fluid velocity vector;

r, θ - coordinate axes;

r_w - collector radius;

$$\widetilde{r} = \frac{r}{r_w};$$

ρ_P – particle density;

$M = 2AH0$ - collector magnetization;

$$A = \frac{\mu_w - \mu_f}{\mu_w + \mu_f};$$

μ_w, μ_f - collector material and fluid magnetic

$(\mu_f \approx \mu_0)$;

$N_d = C_d / C_d / C_{d,0}$

The equations of particle motion near a separate ferromagnetic collector are [3] :

d,0, d gidrodinamic resistance factors by Stoke formula and by more common formula;

$$\tau = \frac{\rho_p d_p^2}{18\eta}$$

For numeric solution we used Runge-Cutta method.

EXPERIMENTAL INVESTIGATIONS

The regularity of fine weakly magnetic particles capture was investigated using superconducting separator designed by research officers from Magnetic Beneficiation Laboratory, National mining academy of Ukraine, on the basis of the cryomagnet devised by Physical & Engineering Institute of Donetsk.

The device is designed for investigation of ore magnetic benefication and non-metallic material cleaning and for processing of industrial superconducting separators working zones constructional and operating parameters. Cryomagnetic system allows producing magnetic field induction upto 9 T.

The device consists of a cryostat, a magnetic system, a cryomagnet power supplying system, a system of cryoprovision, technological highway and a zone of separation, feeding system, unloading system and an operating unit. In connection with a high value of magnetic induction and to supply the device automatical operation mode for all delevels of the working cycle, the device was equipped with a system of automatic control containing a remote-control station.

We used porcelain mass samples as experimental objects at external magnetic field induction of 1T, 2,5T and 7 T.

RESULTS AND DISCUSSION

Analytical Investigations

Calculations of particles motion trajectory and estimation of cylindrical collector capture cross-section value, made for weakly magnetic particles of 0,5-20 micron in diameter, showed that the particle diameter and magnetic susceptibility, the pulp flow velocity and the magnetic field characteristics in the working zone are the main factors determining the capture cross-section value and therefore the capture probability value.

The results of calculations are shown in Figs. 1 and 2. In Fig. 1 one can see the capture probability value's dependence on the external magnetic field induction for particles of different sizes at pulp flow velocity values of 0.01 m per s and 0.05 m per s.

The results are evidence of the dependence's approximation to linear in most cases. Pulp flow velocity decrease from 0.05 down to 0.01 m/s causes great increase of the capture probability value. For example, if induction is equal to 7T, the value increases from 0.012 up to 0.05 for particles of 1 micron in diameter and from 0.046 up to 0.21 for ones of 2 micron in diameter. When

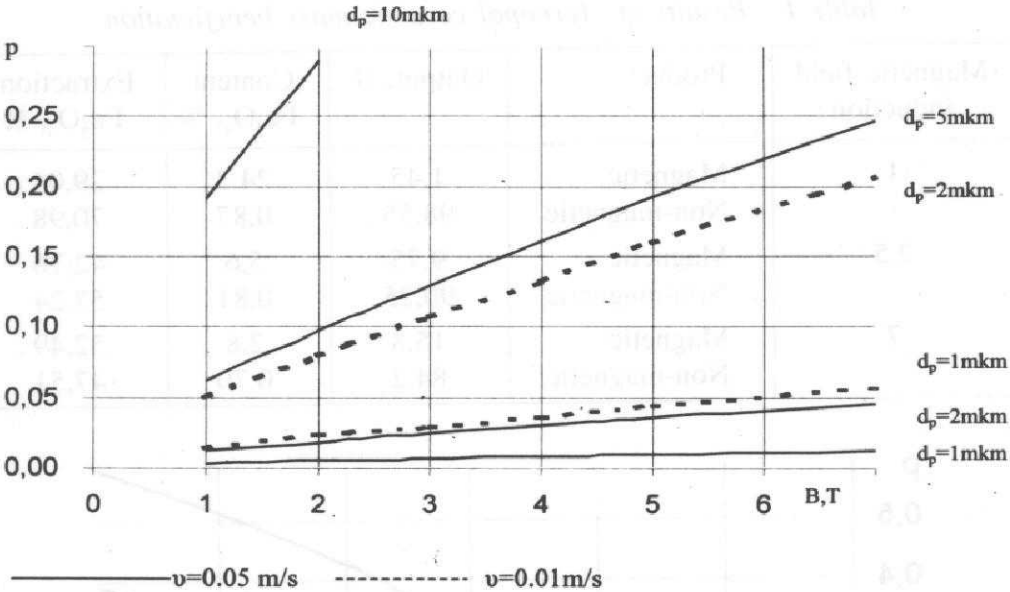

Fig. 1 : Capture probability value as function of magneti fild induction

particle diameter increases from 1 up to 10 micron, the capture probability value increases in 41.6 times, if induction is equal to 1T, and in 43.3 times, if induction is equal to 7T.

From Fig. 2, one can see the capture probability value's dependence on the particles diameter if the external field induction is 1T, 2.5T, 7T.

Experimental

We carried out experimental researches using a cryomagnetic separator and ceramic mass samples from the Ternopolskiy ceramic plant. Starting material contained 1.18% of iron.

Results of the material beneficiation are shown in Table 1.

To examine granulometric composition of the starting sample and of the separated material we used a laboratory electronic granulometer. Granulometric composition of the starting sample is shown in Figure 3.

As you can see, particle sizes of the sample change from 0.5 up to 20 micron. Most of particles have 1.5-8 micron in diameter.

In Fig. 4, curve of extraction value as a function of particle diameter is

Table 1 : Results of Ternopol ceramic mass beneficiation

Magnetic field induction	Product	Output, %	Content Fe_2O_3, %	Extraction Fe_2O_3, %
1	Magnetic	1,45	24,2	29,04
	Non-magnetic	98,55	0,87	70,98
2,5	Magnetic	9,75	5,6	42,76
	Non-magnetic	90,25	0,81	57,24
7	Magnetic	15,8	2,8	52,49
	Non-magnetic	84,2	0,70	47,51

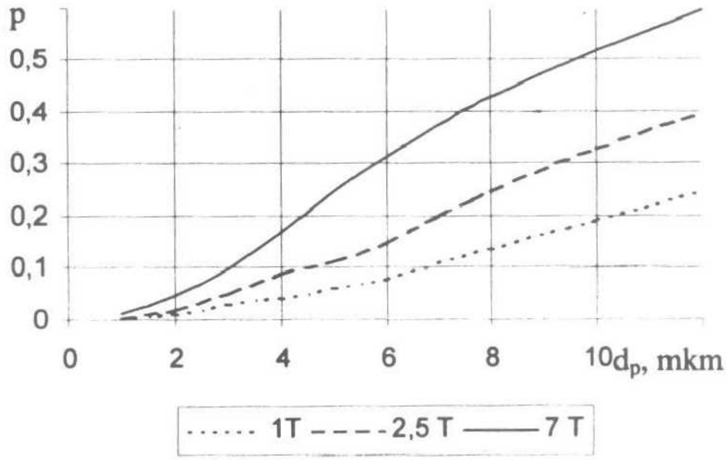

Fig. 2 : Capture probability value as function of particle diameter

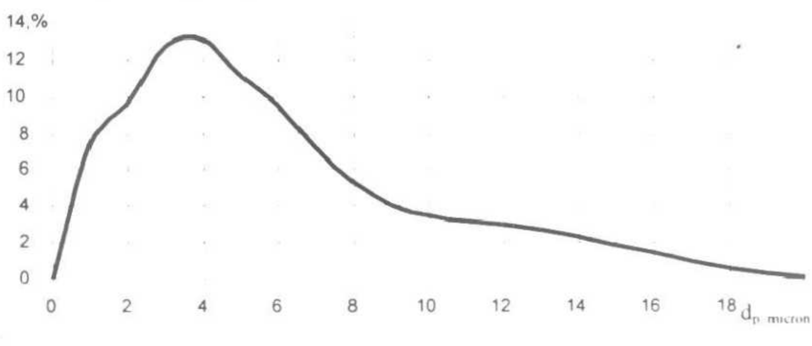

Fig. 3 : Granulometric composition of ceramic mass

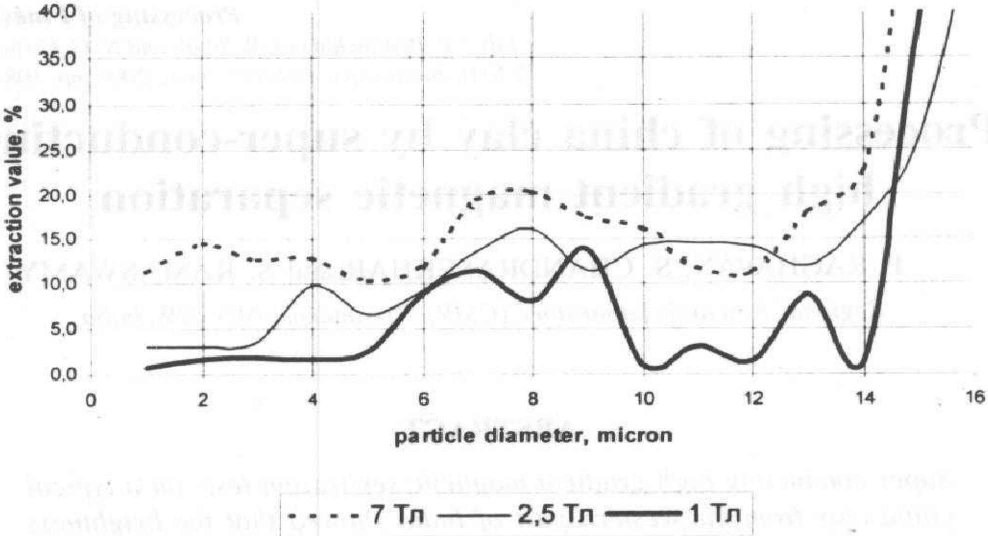

Fig. 4 : Extraction value as function of particle diameter (experimental data)

shown. Our data are evidence of the fact that induction increase from 1 to 7 T leads to substantial increase of extraction value for the particle of 1-15 micron. If particle diameter are more than 15 micron we do not see extraction value increase at higher values of induction.

CONCLUSION

Results of the experiments are evidence of efficiency of using of superconducting high gradient magnetic separators and of increasing of magnetic induction value up to 7T for the purpose of extracting of particles less than 10-15 micron in diameter.

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