DESTRUCTION OF MICROPARTICLES RELATED TO DUSTY PLASMA PROCESSES AND POSSIBLE TECHNOLOGICAL APPLICATIONS

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A method of destruction of microparticles related to dusty plasma processes is discussed. The method includes the achievement of anomalously high dust particle charges, for which the destruction process of the particles starts. Technological applications of dust particle destruction can be associated with the separation of nano- and microscale monomineral fractions from polymineral microparticles, that is of practical interest for enhancement of the efficiency of development of low-grade deposits and reprocessing of ore dumps and tailings which contain a definite amount of noble metals in the form of fine-dispersed fractions.

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INTRODUCTION

Dust particles are found in interstellar medium, in magnetospheres and ionospheres of planets, in cometary atmospheres, etc. Influence of dust on the properties of the matter is often significant and sometimes determinative. Laboratory experiments on dusty plasmas are carried out beginning from 1990s. Since then understanding of the processes in dusty plasmas is improved significantly. An important topic of investigations related to dusty plasmas is the consideration of possible technological applications of dusty plasma methods. In this paper we discuss a possibility of the use of dusty plasma methods for destruction of dust particles, which can be utilized for processing of noble metal ore from particular deposits.

The exhaustion of high-grade deposits in the process of mining and production of noble metals demands enhancement of the efficiency of development of low-grade deposits and reprocessing of ore dumps and tailings, which contain a certain amount of noble metals in the form of finely disseminated fractions. The recovery of disseminated metals from fractions which are less than 100 μm in size is a complicated problem. Here, we present an attempt to solve this problem using dusty plasma methods.

1. ELECTROSTATIC PRESSURE

In a plasma dust particles acquire often high electric charges $q_d = eZ_d$. Here, $-e$ is the electron charge. In experiments [1] the charges of about $5{\cdot}10^7 e$ are observed. Under the assumption of spherical form of a dust particle of the size a and homogeneous distribution of the charge over its surface, the electrostatic pressure which acts on the dust particle surface is

$$P = \frac{1}{8\pi}\frac{e^2}{a^4}Z_d^2 . \tag{1}$$

When the electrostatic pressure (1) is higher than the strength σ of the particle, then the particle destroys. Furthermore, in the case of polymineral particles [2] their separation to monomineral fractions is possible.

The conditions for the dust particle destruction can be satisfied when dusty plasma is formed by the action of high-powered ultraviolet radiation or X-rays. In this case the photoelectric effect plays an important role in the dust particle charging process resulting in positive charges of dusts. Possible sources of such hard radiation are synchrotron radiation, laser-electron generators, etc.

2. BASIC EQUATIONS

Dynamics of dust particle charge in plasma medium is described by the equation

$$\frac{\partial q_d}{\partial t} = I\left(q_d\right), \tag{2}$$

where $I(q_d)$ is the total current which is represented by a sum of microscopic electron and ion currents, as well as the photoelectron current. Photoelectrons are generated as a result of photoelectric effect when electromagnetic radiation interacts with the surface of the particle.

For simplicity, we consider a situation when the plasma consists of positively charged dust particles and photoelectrons. Such a situation can be realized in vacuum chamber (Fig. 1) where dust particles are injected by means of dispenser. Walls of vacuum chamber are supposed to be transparent for UV-radiation and X-rays.

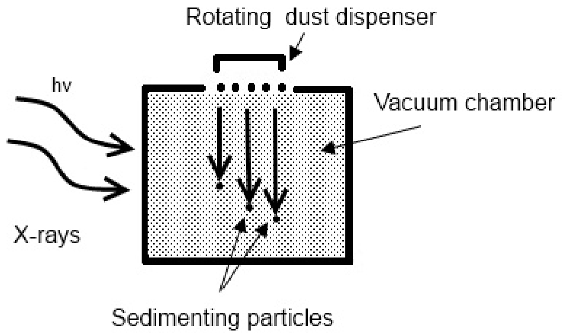

Fig. 1. Installation for destruction of microparticles by dusty plasma methods

Dust particles sediment under the action of the gravity, are irradiated by hard photons which knock out electrons from the surfaces of dust particles, and finally acquire positive charges due to the action of hard electromagnetic (UV and X-ray) radiation.

In this situation the steady-state charge on the particle surface is defined by the equation

$$I_{ph}\left(q_d\right)+I_{eph}\left(q_d\right)=0, \qquad (3)$$

where photoelectron current to dust particle (return current) is

$$I_{eph}(q_d)=-n_d e Z_d \pi a^2 \sqrt{\frac{8T_e}{\pi m_e}}\left(1+\frac{Z_d e^2}{aT_e}\right), \qquad (4)$$

while the current of the photoelectrons which leave particle surface is

$$I_{ph}\left(q_d\right)=\beta\pi a^2 e \int\limits_{\max\{\omega_R+(eq_d/a\hbar),\ \omega_{\min}\}}^{\omega_{\max}} j_{ph}\left(\omega\right)d\omega \cdot \qquad (5)$$

Here, n_d is the number density of dust particles, T_e is the electron temperature, m_e is the electron mass, $j_{ph}(\omega)$ is the spectral density of electromagnetic radiation flux, $\omega_{\max}$ ($\omega_{\min}$) is the upper (lower) boundary of the spectrum of electromagnetic radiation, ω_R is the work function of dust matter, β is the probability to knock out electron by photon from particle surface, $\hbar$ is the Plank's constant.

Taking in the consideration Eqs. (4) and (5) we rewrite Eq. (3) in the form

$$\frac{\partial Z_d}{\partial t}=\pi a^2\left[<j_{ph}>\beta-n_d Z_d\sqrt{\frac{8T_e}{\pi m_e}}\left(1+\frac{Z_d e^2}{aT_e}\right)\right]=0. \qquad (6)$$

Here, $\left\langle j_{ph}\right\rangle=\int\limits_{\max\{\omega_R+(eq_d/a\hbar),\ \omega_{\min}\}}^{\omega_{\max}} j_{ph}\left(\omega\right)d\omega$.

Finally, we find a solution of Eq. (6) which corresponds to positive particle charge

$$Z_d=\frac{1}{2}\left(\frac{aT_e}{e^2}\right)\left(\sqrt{1+\frac{4\left(e^2/aT_e\right)<j_{ph}>\beta}{n_d\sqrt{8T_e/\pi m_e}}}-1\right). \qquad (7)$$

3. DUST PARTICLE DESTRUCTION

Condition for dust particle destruction (coincident with the condition of polymineral particle separation to monomineral fractions) can be found from Eqs. (1) and (7). It takes the form

$$a^3 n_d<\frac{<j_{ph}>\beta\sqrt{T_e m_e}}{16\sqrt{2\pi\sigma}}. \qquad (8)$$

Further calculations are performed under the assumption that the main dust particle component part is quartz. This assumption presents a practical interest for gold-bearing ores of concrete deposits [2]. For such particles the strength σ is equal approximately to 90 kbar.

Fig. 2 shows the minimum density of electromagnetic radiation flux required for dust particle destruction in dependence on particle radius. The typical parameters are chosen to be $T_e = 1$ eV, $\beta = 0.1$, $\sigma \approx$ 90 kbar.

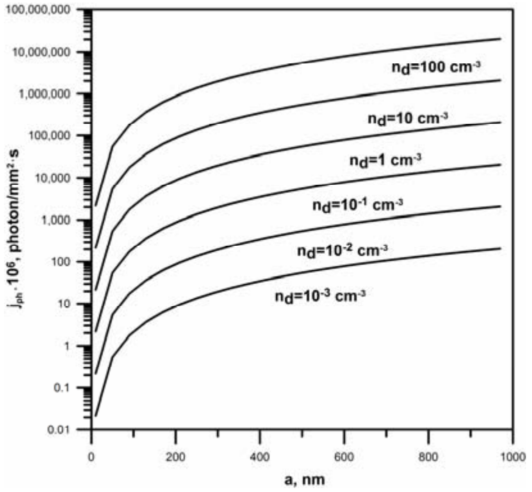

Fig. 2. Minimum radiation flux density required for particle destruction vs particle radius for different values of dust number density

A possibility of polymineral particle destruction and its separation to monomineral fractions is estimated on the basis of Eq. (8). For the estimates we use the parameters of synchrotron radiation generated on VEPP-3 electron-positron storage ring at the Budker Institute of Nuclear Physics, where the flux density of synchrotron radiation from viggler with the magnetic field 2 T, electron energy 2 GeV, and current 100 mA at the distance of 20 m from the source is higher than 10^{12} photon/mm$^2\cdot$s [3]. The average energy of radiation is close to 20 keV. Correspondingly, at less distances from the source one can expect much more intensive electromagnetic radiation flux. For instance, at the distance of 20 cm from the source the flux density of synchrotron radiation reaches the magnitudes higher than 10^{16} photon/mm$^2\cdot$s. This value is used in further calculations. The other parameters are T_e = 1 eV, $\beta = 0.1$, $\sigma \approx 90$ kbar.

Using Eq. (8) one can find that the destruction of quartz particles with sizes less or equal to 1 μm occurs for $n_d < 10^{-3}$ cm^{-3}, with sizes less or equal to 100 nm for $n_d < 1$ cm^{-3}, and with sizes less or equal to10 nm for $n_d < 10^3$ cm^{-3}. Thus we show a possibility of dust particle destruction (and its possible separation to monomineral fractions in the case of polymineral dust particles) by dusty plasma methods.

Fig. 3 illustrates charges of dust particles for different values of dust number densities in the presence of synchrotron radiation flux with the density of 10^{16} photon/mm$^2\cdot$s. It is seen that the charges of micron-sized particles can reach the magnitudes exceeding 10^7 elementary charges. Such large dust particle charges can be achieved only for small dust number densitites. For larger dust number densities the effect of strong dust particle charging can be achieved if a method of removal of electrons from the vacuum chamber will be proposed. The electrons formed in the vacuum chamber due to the photoelectric effect on dust particle surfaces prevent strong dust particle charging, because they tend to return to the dust particle surfaces in the form of microscopic electron currents.

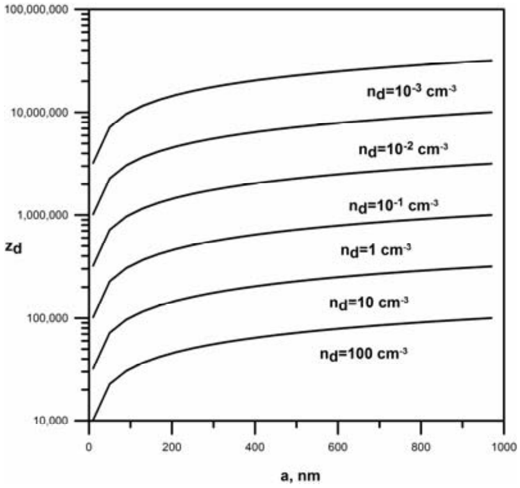

Fig. 3. Charge number Z_d vs dust particle radius. Radiation flux density is equal to 10^{16} photon/mm^2·s

CONCLUSIONS

Thus, we have considered a possibility of destruction of dust particles and their separation to monomineral fractions by dusty plasma methods. These processes can be accomplished in vacuum chamber where dust particles are injected.

The destruction effect can be achieved with anomalously high dust particle charging due to irradiation of dusts by hard and intensive electromagnetic radiation (UV and X-rays) performed with the aid of modern installations. This problem and its further technological elaboration present practical interest for enhancement of the efficiency of development of low-grade deposits and reprocessing of ore dumps and tailings.

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ДРОБЛЕНИЕ МИКРОЧАСТИЦ В ПЛАЗМЕННО-ПЫЛЕВЫХ ПРОЦЕССАХ И ВОЗМОЖНЫЕ ТЕХНОЛОГИЧЕСКИЕ ПРИМЕНЕНИЯ

Т.И. Морозова, С.И. Копнин, С.И. Попель

Обсуждается метод дробления микрочастиц в плазменно-пылевых процессах. Метод включает достижение аномально высоких зарядов пылевых частиц, при которых начинается их разрушение. Технологическое применение разрушения частиц может быть связано с разделением полиминеральных частиц на нано- и микромасштабные мономинеральные фракции, что представляет практический интерес с точки зрения повышения эффективности разработки рудных месторождений и переработки рудных отвалов и хвостохранилищ, содержащих определенное количество благородных металлов в виде тонковкрапленных фракций.

ДРОБЛЕННЯ МІКРОЧАСТИНОК У ПЛАЗМОВО-ПИЛОВИХ ПРОЦЕСАХ І МОЖЛИВІ ТЕХНОЛОГІЧНІ ЗАСТОСУВАННЯ

Т.І. Морозова, С.І. Копнін, С.І. Попель

Обговорюється метод дроблення мікрочастинок в плазмово-пилових процесах. Метод включає досягнення аномально високих зарядів пилових частинок, при яких починається їх руйнування. Технологічне застосування руйнування частинок може бути пов'язано з поділом полімінеральних частинок на нано- і мікромасштабні мономінеральні фракції, що представляє практичний інтерес з точки зору підвищення ефективності розробки рудних родовищ і переробки рудних відвалів і хвостосховищ, що містять певну кількість благородних металів у вигляді тонковкраплених фракцій.