Ways to Raise Recovery Potential of NFe Metals from MSWI Bottom Ash

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Abstract NFe metal fraction in bottom ash from waste-to-energy plants comprises a small but valuable part compared to glass, ceramics, magnetic fraction and ferrous scrap. Therefore, attempts to raise non-ferrous separability efficiency are economically reasonable. This paper wants to discuss not only basic parameters influencing the efficiency of non-ferromagnetic separation method based on eddy currents, especially the size, shape and conductivity of the separated material, properties of other fractions including humidity and their mutual interaction, but also the type and arrangement of the separator. On the basis of detailed analysis, still commonly unused approaches and advances will be proposed.

Keywords: waste-to-energy, metal recovery, eddy currents, separation

1. Introduction

Separation of non-ferromagnetic (NFe) metals is usually performed on the basis of eddy currents (EC), induced in the separated particle by the changing magnetic field. Most commonly used EC separators use a rotating drum with a series of oppositely polarized strong magnets on its circumference located under a belt carrying the mixture of particles. The drum rotation generates a strong alternating magnetic field, which separates the conducting particles from other non-conducting material. In this contribution we will consider alternative realizations of an EC separator, often met obstacles to EC separation and how to avoid them.

2. EC separation fundamentals

Separation of NFe metals is based on the fact that the forces and torques acting on conductive particles differ from those acting upon non-conducting ones, just changing their trajectories primarily given by gravitation field.

For the force $\vec{F}$ with components F_k acting on a conductive non-ferromagnetic body moving in a magnetic field we can write (in component notation)

$$F_k = -K_{ij} \cdot \left(v_l \cdot \partial_l B_i + \varepsilon_{ilm} B_l \omega_m + \frac{\partial B_i}{\partial t} \right) \cdot \partial_k B_j \qquad (1)$$

and for the torque T_k

$$T_k = -K_{ij} \cdot \left(v_l \cdot \partial_l B_i + \varepsilon_{ilm} B_l \omega_m + \frac{\partial B_i}{\partial t} \right) \cdot \varepsilon_{kjn} B_n \qquad (2)$$

with ε denoting Levi-Civita symbol. The interaction of separated particle with electromagnetic field is given by the product of the induced magnetic moment with the magnetic field or with its gradient. The last derivative in (1) is the field gradient, while the rest of the expression on the right hand side represents the magnetic moment of the particle due to induced eddy currents. The first term in parentheses is the magnetic field change due to translation motion of the object with respect to the field with relative velocity v_l, the second term is due to rotation of the object with respect to magnetic field with relative angular velocity ω_m and the last term accounts for the change of the field.

The tensor quantity K_{ij} is connected with the polarizability of the separated particle. If we model the object like closed planar current loop with resistance R and inductance L, then for a harmonic field B_j with angular frequency ω its value will be

$$K_{ij} = \frac{S_i S_j}{R + i\omega L} \qquad (3)$$

where the vector S_k is perpendicular to the loop plane and absolute value of S_k is the loop area.

Calculations of K_{ij} for real geometrical forms of objects may be rather complicated. For further estimations we restrict ourselves to low frequencies when the inductance term $i\omega L$ in the denominator can be neglected. This corresponds approximately to the case with negligible skin effect in the particle, the quantity K_{ij} is then real. Further simplification may be introduced for the case of the spherical shape of the particle by assuming that it is described by isotropic tensor

$$K_{ij} = K_s \delta_{ij} \,. \tag{4}$$

For this case, we obtain K_s by simple integration

$$K_s = \frac{2\pi}{15}\sigma r^5 = \frac{1}{10}\sigma r^2 V \tag{5}$$

where σ is the object conductivity, r its radius and V its volume.

3. EC separation problems encountered

3.1. Small particles

Formula (5) explains both the linear dependence of the forces and torques acting upon a metal particle on its conductivity value and the well-known fact that the separating force falls with the object dimensions much quicker than its mass. Therefore, the standard method of EC separation becomes ineffective for very small particles because frictional forces dominate the separation.

One possible way to solve the problem is to construct specialized rotors with many small poles to increase the frequency and the gradient of the magnetic field. Such experiments were carried out by Fuhrmann (1999) who recovered aluminum particles down to 1mm in diameter but at a relatively low throughput of about 1 t/h per meter width of the rotor.

Another known way is to use the torque that the magnetic drum exerts on the metal particles to introduce a selective separation effect. The torque given by equation (2) also scales as the fifth power of the particle size, but so does the particle moment of inertia. Settimo *et al*. (2004) show that the torque can break the adhesive forces that make wet particles stick to the conveyor belt and liberate them from the belt whereas non-metal particles remain stuck to the belt.

3.2. Changing the shape of particles

It can be seen from equation (3) that the magnetic moment induced in a conducting particle by the time-dependent magnetic field is shape-dependent. Experiments with different particle shapes (e.g. Zhang *et al*., 1998) show, that the EC separation efficiency is higher for flat particles than for spherical particles of the same volume and material. It suggests that, when using EC separators to recover NFe metals, the particles in the material stream should be as flat as possible.

This theoretical and experimental finding brings us to a conclusion that the separability efficiency of NFe metal fraction in bottom ash from waste-to-energy plants could be raised by incorporating particle-shape changing equipment in front of the EC separator. We propose to use a double drum crusher for a small particles fraction that will press the malleable metal particles to flatter shapes but crush the fragile ones. As shown in Fig. 1, metal spheres will be pressed to rotational ellipsoids with better separation trajectories.

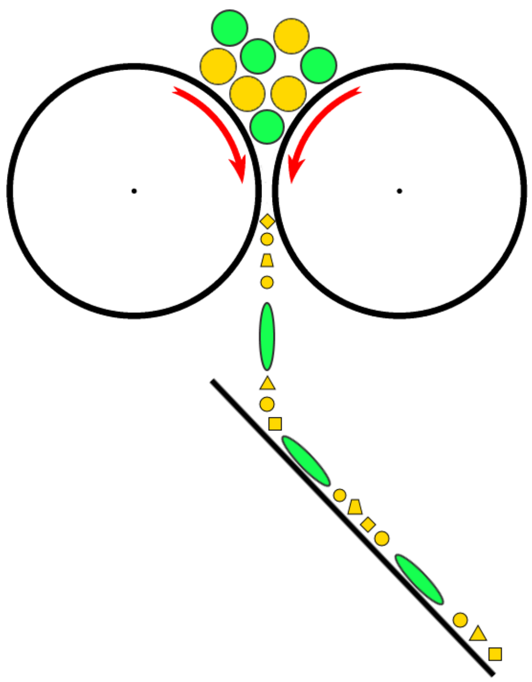

Figure 1. A double drum crusher optimizing the shape of metal particles

3.3. Electromagnetic double grate

EC separation drums have two important practical limitations – size of single magnets on its circumference and the permissible angular frequency.

These disadvantages for the small particles fraction can be surpassed by creating the changing magnetic field with a set of fixed coils. In order to obtain a non-zero force acting on the particle even in the low-frequency limit (K real!), we have to use several coils with different phases of the currents.

Without going to detailed reasoning that will be a subject of another contribution (Fähnrich *et al*. 2017) we propose to use rectangular coils the longer sides of which lie all in the same plane and are oriented parallel to each other. Thus these conductors are forming a grate-like configuration with different phases of the currents. Two such parallel grates can be combined with the space between them available for an effective separation.

To verify the calculations, a simple physical experimental realization was built with coils fed by two independent generators with phases shifted by $\pi/2$. In order to obtain the highest currents at the frequency as high as possible, the coils were completed with proper capacitors to form resonant circuits. In this set-up the coupling between the coils due to their mutual inductance is of enormous importance. It was necessary to set the configuration so that this inductance became effectively zero. Only then the mutual influencing between the generators was avoided and stable operation was achieved.

Comparing calculated and experimentally observed force acting on an aluminum sphere, a satisfactory agreement was found. A simple program was written displaying the map of force acting on a separated particle for any given configuration of conductors. As an illustration, in Fig. 2 we can see the force acting on an aluminum sphere with diameter 4 mm at the frequency 1 kHz.

Strictly speaking, for the frequency 1 kHz the quantity K_s is no more real and has been calculated according to a more complicated formula, its argument – the phase angle – is about 0.1 rad.

From Fig. 2, the advantages of the proposed double grate configuration are evident. The field of the force between the grates is almost homogeneous and with conductors oriented vertically can be used effectively for separation of particles falling down through this space from a funnel. This is in contrast with single grate or single drum separator, where the separating force decreases strongly with the distance from the surface.

3.4. Humidity of the bottom ash

Apart from the shape and conductivity of separated particles an important role plays water contents in bottom ash during EC separation of NFe metals in waste-to-energy plants.

In order to discuss the humidity influence on the separation, it must be emphasized that the conductivity σ of most non-metal components of the waste is by several orders of magnitude lower than that of metals. The same is valid concerning the effect of moisture – conductivity of water solutions depend on the concentration of the ionic solute, but even for rather concentrated solutions the difference is great (for seawater – more than 6 orders).

Thus the eddy currents in the non-metallic waste can hardly change the magnetic fields in the separator and influence the principal electromagnetic mechanism of separation. However, separation efficiency may be deteriorated by other, non-electric effects, e.g. capillary forces, binding the particles together in the waste with noticeable content of liquid phase. The cohesion of particles, of course, may depend distinctly on the specific character of the waste, but, in general, separating dry waste should be preferred.

4. Conclusions

After discussing basic parameters influencing the efficiency of non-ferromagnetic EC separation method, especially the size, shape and conductivity of the separated

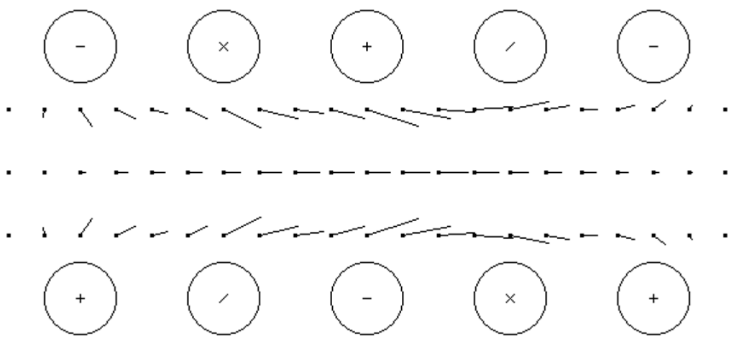

Figure 2. Configuration of a double grate separator with calculated field of the separating force acting to an aluminum ball (Phases: + ≅ 0; x ≅ $\pi/2$; - ≅ π; / ≅ $3\pi/2$)

material, we offered two different solutions for small particles separation. The first solution consists in modification of separation waste by means of a double drum crusher. Small malleable metal particles will be pressed to better separable flatter shapes while the fragile ones will be crushed.

The second solution comes with an idea of using an electromagnetic double grate as a new EC separator. This conception needs to carry out further development and testing of the double grate to confirm its theoretical expectations.

We have discussed an effect of humidity with a conclusion that the water content influences the separability not by shielding the magnetic field but by creating agglomerates of conducting and non-conducting particles, thus diminishing the separation efficiency.

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References

Fähnrich J., Neubert M., Nedbal J. (2017), Electromagnetic double grate for EC separation, to be published

Fuhrmann J. (1999), Wirbelstromscheidung von feinkoernigen metallhaltigen Stoffgemischen, In: Schubert G. and Schoene C. (Eds.), *Proc. 50. Berg- und Hüttenmännischen Tag 1999*, Freiberg, Freiberger Forschungshefte **A 850**, Technische Universität Bergakademie Freiberg, 190–202.

Settimo F., Bevilacqua P. and Rem P. (2004), Eddy current separation of fine non-ferrous particles from bulk streams, Physical Separation in Science and Engineering, **13**, 15-23

Zhang S., Forssberg E., Arvidson B. and Moss W. (1998), Aluminum recovery from electronic scrap by High-Force® eddy-current separators, *Resources, Conservation and Recycling*, **23**, 225–241