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# Magnetic field enhanced press-filtration

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**Abstract**

The proposed hybrid process represents a new application of a magnetic field which directly influences a classical press filtration. The new technology offers high potential in the field of magnetic pigment production and iron oxide processing as well as bio-separation with functionalized magnetic particles. Especially in the field of fine-scale particulate product systems high specific cake resistances result in slow cake building and dewatering kinetics, which leads to economic inefficiency.

Experimental and theoretical investigations show that the magnetic field has strong influence on cake building. Two major effects were observed: (I) In inhomogeneous magnetic fields magnetic particles experience a magnetic force counter directed to the pressure force, that results in slow down of cake formation; (II) Interparticle magnetic forces lead to structured cake formation.

This gives on one hand the possibility to uncouple fluid and magnetic particle motion to force a cake built-up in designated location of the filter chamber. The result is a big increase of the overall filtrate mass flow and therefore an improvement of filtration kinetics. On the other hand due to the particle's magnetization including the formation of an attracting north and south-pole chainlike agglomerates can be observed. This leads to a "structured" cake building and therefore higher permeability.

This work will show the effect of a superposed magnetic field on press filtration of ferromagnetic iron oxide particles ($Fe_3O_4$) in a lab-scale filter press.


*Keywords:* Cake filtration; Filtration; Field enhanced separation; Magnetic structuring; Magnetic field; Particle formation

## 1. Introduction

In most traditional and current industrial production processes, products accumulate in form of slurry. Due to the long historical development, modern mechanical separation processes are developed on high technical level. Increasing demands on the efficiency of production processes and the quality of their products require a continuous improvement of existing processes and the development of new process concepts. Especially in classical unit operations as solid–liquid separation the development of hybrid processes is of major interest. To extend the field of application for mechanical separation processes, new concepts have been developed. Important milestones of the development of hybrid solid–liquid separation processes are represented by steam-pressure-filtration (Gerl and Stahl, 1997), steam-pressure-centrifugation (Peuker and Stahl, 2001), "hot" chamber press filtration (Ruf and Stahl, 1997) and electro-press filtration (Weber and Stahl, 2002).

However on the way to nano- and biotechnology even harder requirements have to be fulfilled. A new approach to face these challenges and utilize synergetic effects lies in the superposition of magnetic fields. By taking advantage of the different magnetic properties of materials, additional and new parameters for the manipulation of separation processes can be developed. This enables the separation of submicron till nano-scale magnetic particles. Apart from classical applications of magnetic fields e.g. in the minerals industry for sorting, there are many more opportunities for field enhanced separation processes. One example for this advance is the high-gradient-magnetic-separation

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(Oberteuffer, 1974; Franzreb and Höll, 2000) which emerged in industry-scale filtration for the separation of low concentrated suspensions e.g. in the wastewater industry. The magnetic particles are separated by a non-remanent ferromagnetic matrix in an external homogeneous magnetic field. Due to the development of high gradients around the matrix, high magnetic forces in direction of the filter matrix act upon the particles (Gerber and Birss, 1983; Tsouris and Yiacoumi, 1997). As the matrix has a limited capacity the HGMS separation is only applicable to low concentrated feed streams. To improve filtration kinetics also for high concentrated slurries a novel application of magnetic fields, the magnetic field enhanced cake filtration (Fuchs et al., 2004) has been developed. It was shown that not only an external magnetic force on the particles but also an interparticle force that causes a self-assembled structure of the filter cake lead to improved filtration kinetics. Especially in magnetically stabilized fluidized beds these structural modifications reduce back mixing effects of solids and fluids (Rosensweig et al., 1981). While applying an external magnetic field the particles form chains with discrete flow channels in between. Due to the attractive magnetic forces the particle motion is reduced and the streaming velocity can be increased beyond the discharge velocity. Bolto et al. (1975) uses the chain-formation within a magnetic field as a switchable degree of freedom to vary the permeability of a filtermedia. By using granular magnetic particles as filter aid Bolto induced the formation of highly porous structures on top of the filtermedia by magnetization. This on one hand led to a reduction of turbidity of the filtrate and on the other hand to an acceleration of the filtration process. By a magnetic sorting step of the filter cake including the magnetic filter aid the particles can be recycled.

In combination with highly functionalized magnetic particles also an application of field enhanced filtration in specific bioseparation (Safarik et al., 2001) is easily possible and currently transferred to large scale production processes.

In the presented work, a new hybrid filtration process, the kinetics of dewatering is significantly influenced by magnetophoresis and magnetic self-assembly in the filter cake. Magnetophoresis hereby decreases the rate of cake formation and magnetic self-assembly increases the permeability of the cake by structural changes. In this paper both effects are experimentally investigated.

## 2. Theory

### 2.1. Magnetic properties of materials

Usually materials are classified according to their irritability by an external magnetic field. The quantitative measure of this irritability is the so called susceptibility $\chi$. Depending on the magnitude of the susceptibility materials are coarsely grouped in diamagnetics, paramagnetics and ferromagnetics.

Diamagnetism ($\chi < 0$) is the weakest magnetic phenomenon. Although every substance is indeed diamagnetic, the phenomenon itself can only be observed when it is not superposed by the stronger paramagnetism ($\chi > 0$) or ferromagnetism ($\chi \gg 0$). Due to counter directed magnetic moments diamagnetic materials locally weaken the magnetic field and experience a magnetic force in direction of decreasing field gradient. The opposite effect can be observed in paramagnetic and ferromagnetic samples. They experience a force in the direction of the magnetic field gradient. This external magnetic force is indeed the bottom line of magnetic separation processes and represents to be an additional degree of freedom.

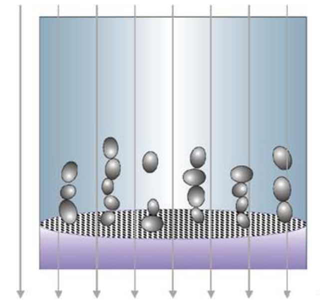

Fig. 1. Agglomerate chains.

Apart from external magnetic forces another important and up to now underrated role play interparticle magnetic forces, which are generated between particles. Due to the superposition of an external magnetic field the magnetic moments of the material are aligned according to the external field direction. The magnetized samples or particles hereby act as microscopic permanent magnets with North and South poles. Two approaching particles in an external magnetic field attract each other in direction of the magnetic field and repel each other perpendicular to the external field direction (Charles, 1988). This causes the formation of chainlike agglomerates as shown schematically in Fig. 1. The macroscopic dipole moment per volume unit of the sample is defined to be the magnetization $M$.

### 2.2. Forces acting on the particles

During filtration the interaction of different forces like gravitational, drag, external magnetic, interparticle and buoyancy forces are ruling the filtration process.

Gravitational and buoyancy forces shall be negligible in comparison to the magnetic and hydrodynamic forces represented by the drag force. The drag force can be calculated by the following equation:

$$F_D = \frac{\pi}{4} \cdot d_P^2 \cdot c_W(Re) \cdot \frac{\rho_f}{2} \cdot u_r^2. \quad (1)$$

For $Re < 0.25$, which is the case within the region of differential pressures used in this work, laminar flow can be assumed and Eq. (1) simplifies to the Stokes drag force.

$$F_D = 3\pi \cdot \eta_f \cdot d_P \cdot u_r. \quad (2)$$

The magnetic force on a particle depends on the magnetization, the volume of the particle, but also on the magnitude of the external field and its gradient $\nabla H$ as can be seen in Eq. (3),

$$F_m = \mu_0 \cdot V_p \cdot \rho_P \cdot M_p \cdot \nabla H. \quad (3)$$