Magnetically controlled systems for CO_2 absorption

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Abstract. In this paper is presented a conceptual model of magnetically controlled system for CO_2 absorption. A design of magnetic air contactor is considered and internal magnetic field in its channels is modelled. It is a closed domain contactor design with controllable internal thermodynamic conditions, additionally influenced by magnetic field. Considered design is providing huge specific surface for dynamic interaction with the processed airflow. Results on magnetic field distribution inside air channels are calculated in order to estimate field homogeneity and force directions on used particles.

1 Introduction

Ferrofluids and free magnetic particles systems have been the subject of intense research for more than 50 years [1, 2]. Most commonly, they are bulk-dispersed suspensions of micro- and nano-sized particles with ferromagnetic properties in or without a viscous fluid carrier with surfactants, forming a nonlinear multiphase composite material. Modeling of the properties and behaviour of such materials in a complex electromagnetic-thermodynamic environment remains a completely unresolved task. The difficulties arise from observable thermodynamic features, partially contrary against the law of system increasing entropy, in the presence of an externally applied magnetic field or an internal magnetic field source problem, as described and secondary electrical effects in the viscous carrier (volumetric Lorentz force and Kelvin force) [1-5].

These features make the existing thermodynamic, mass-transfer, acoustic, fluid, etc. models to produce inaccurate results when dealing with ferrite particles [3-6]. Theoretical and computational models of ferromagnetic materials and systems in which such materials are used are hardly needed. Due to the peculiarities in the properties of ferromagnetic materials, they are considered as a key for innovative technological applications in magnetic cooling technologies; intensification and management of chemical reactions in technological processes [1-4]; thermodynamic transducers; solid, liquid and gas separators of various material phases, etc.

In order to intensify industrial volumetric chemical processes, technologies involving bulk dispersed ferromagnetic with nanosized particles are considered. They stimulate the process on three main levels: a) they create an isothermal magnetically controlled convection process, with relatively low energy consumption, compared to thermodynamic convection

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with the same intensity; b) increase the incredibly active surface of interaction; (c) create conditions for magnetically controlled transport, concentration and segregation of active substances. We emphasize the magnetic and electromagnetic controllability of the processes.

2 Magnetically controlled systems

Nowadays, some of the most interesting technical challenges are related to CO_2 absorption systems, as their peculiarity can be noted the relatively low concentration of the absorbed substance (CO_2), the need to stimulate the process without additional energy consumption, the need for greater compactness of the equipment. All three technical challenges can be solved by applying ferromagnetic dispersed systems with magnetic control. A general scheme of such technology with dispersed ferromagnetic materials for CO_2 absorption with magnetic control is shown in Figure 1.

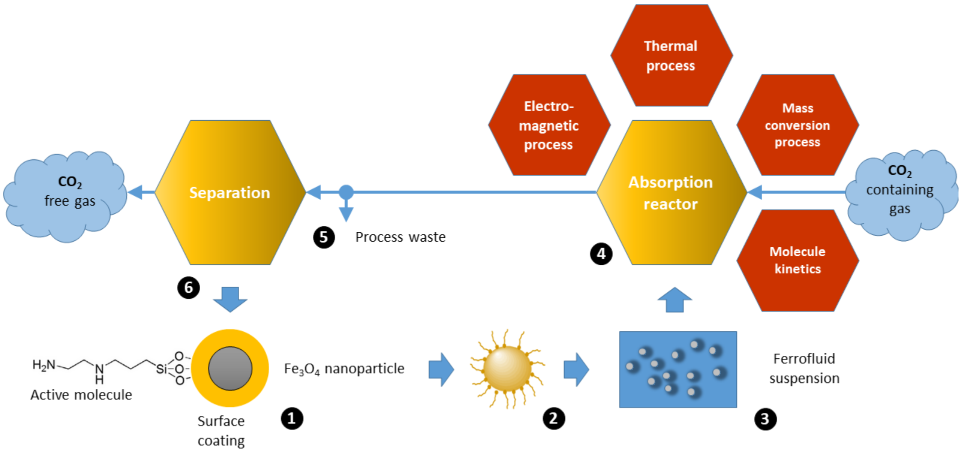

Fig. 1. Absorption and separation processes of dispersed magnetic material in a continuous cycle for CO_2 absorption and separation. Air contactor is denoted as absorption reactor.

A ferrite (Fe_3O_4, Fe_2O_3) large number micro and nano sized particle are used as a carrier of a surfactant molecule (1), a composition of particles (2) in the phase of ferromagnetic particles (3) is injected into an absorption chemical reactor called air-contactor (4), forming a dispersed system with bulk ferromagnetic properties, the process is electromagnetically controllable, and after the completion of the reaction between the active substances and separation of the starting components (5), magnetic separation of the ferrite particles (6) and their "re-charging" with new surface active molecules. This cycle, with controlled magnetic, electromagnetic and thermo-magnetic convection, is applicable to various technological processes and different active substances [1-3].

Electromagnetic control of the state of dispersed magnetic particles is a highly efficient volumetric process with significant intensity compared to the gravitational and thermodynamic segregation of chemical mass systems. Such electromagnetic control of particle kinetics and mass transfer will give a significant increase in the energy density of equipment built with such technology.

The interconnection of the thermo-magnetic processes in magnetic particle, in electromagnetic process control, is an extremely complex, multi-connected, multiscale task for theoretical and numerical modeling. Classical fluid, thermodynamic, electromagnetic models do not give an adequate idea of the ongoing processes, due to the fact that these are field macro models in continuous media, are ignoring the micro and nano compositional nature of the ferrofluid material. Molecularly dynamics models, in turn, are characterized by extreme computational complexity and are unsuitable for modeling macro-technological systems, at least for the foreseeable future. The problem of complete modeling of processes in dispersed ferrofluid systems remains open. Similarly, there is the problem of the material properties of ferrofluid compositions, the contradiction between the molecular properties and the integral macro characteristics of the solvent is a known problem, making it difficult to solve multi-connected and multiscale problems. Last but not least is the issue of harmonizing the different and contradictory minimization criteria for multi-related tasks. A material system has, for example, different magnetic and thermodynamic relacsation optimum and strives for different equilibrium states, making the minimization of multiconnected problems computationally complex and with significant uncertainties in the achieved results [7]. Here is presented a conceptual model of magnetically controlled system for CO_2 absorption. A design of magnetic air contactor is considered and internal magnetic field in its channels is modelled. It is a closed domain contactor with controllable internal thermodynamic conditions additionally influenced by magnetic field. Considered design is providing huge specific surface for dynamic interaction with the treated air flow. Results on magnetic field distribution inside air channels are calculated in order to estimate field homogeneity and force directions on used particles.

3 Magnetic contactor

Air contactor for CO_2 absorption [5-7], or other chemical process, is a close unit that must provide huge specific surface and ability to support intense internal conditions as high temperature or pressure to faster the internal process. Here it must be also magnetic to trap free magnetic particles in the airflow [8, 9]. The design under consideration is closed domain with internal magnetic field created by contactor main material (Figure 2). Magnetic material used is ferrite composition with H_C = 190 kA/m, magnetized in Z direction. This design provides huge specific surface for dynamic interaction with the treated airflow.

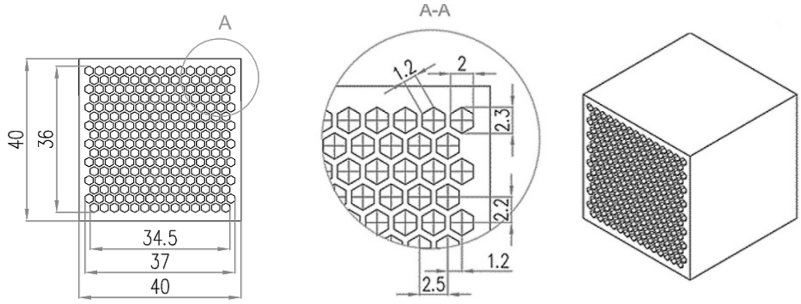

Fig. 2. Dimensions of the magnetic air contactor with honeycomb cross-sectioned channels.

4 Modelling formulation

3D static Ω formulation is used for contactor design modeling. Ω formulation where Ω is nodal-based magnetic scalar potential, defined in the entire solution domain.

$$\nabla \cdot \mu(\mathbf{H}_S - \nabla\Omega) = 0 \,, \tag{1}$$

where μ, and H_S are magnetic permeability, and field intensity of sources respectively. Here magnetic field source is the remanent intensity of contactor enclosure.

Ansys-Maxwell magnetostatic solver is used for Ω formulation implementation. It computes the static magnetic field that exists in a contactor structure magnetized as a ferrite permanent magnet in Z-axial direction. The magnetic field may be computed in structures with both nonlinear and linear materials. A force matrix is computed from the magnetic field energy.

Magnetic force $\mathbf{F}_M$ acting on ferromagnetic particle with magnetic momentum M can be expressed as

$$\mathbf{F}_M = \mu_0 \mathbf{M} \nabla \mathbf{H}, \tag{2}$$

where μ_0 is the free space permeability of the particle dispersion domain.

5 Modelling Results

Modelling results of magnetic field distribution of air contactor block are presented in Figure 3. Field looks consistent and homogenous, but its influence on particle dynamics depends on close range interaction alongside directional movement, here it is the Z vertical direction.

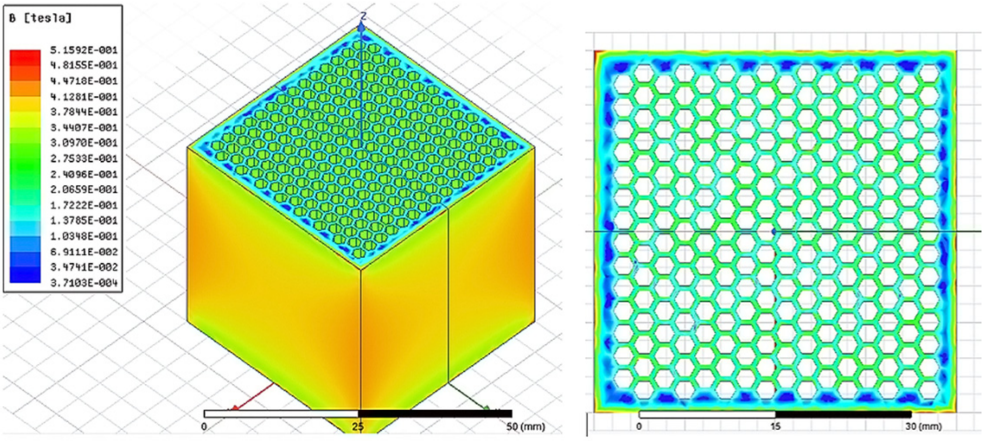

Fig. 3. Magnetic flux density of closed domain magnetic air contactor.

Three lines situated alongside internal channels are selected to trace magnetic fields that determines particle forces inside the contactor. These [L_1, L_2, L_3] channels are depicted in Figure 4.

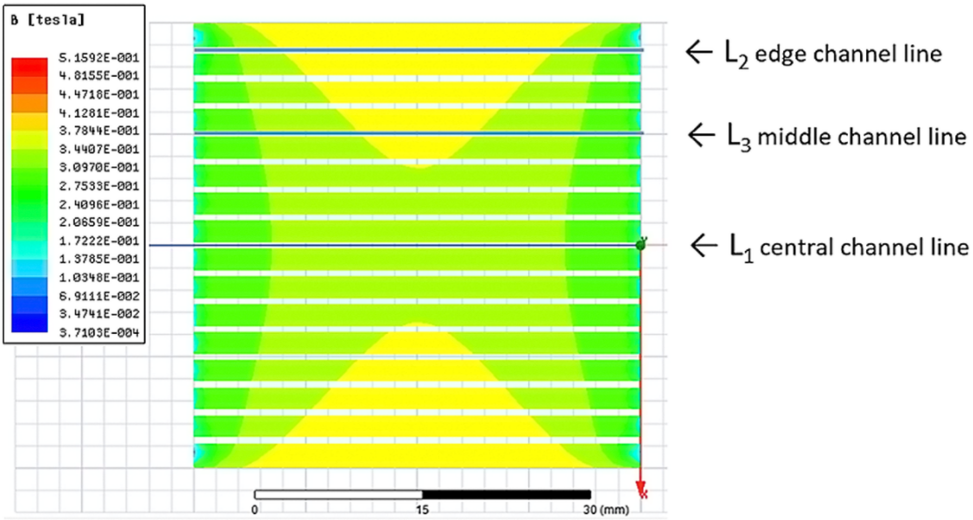

Fig. 4. Z-channels representation, used for internal magnetic field estimation.

Magnetic field intensity alongside channels is presented in Figure 5. It shows difference in field intensity which is more significant close to the channel ends, mostly visible for L_2 result. This can be explained with L_2 proximity to outer contactor edge.

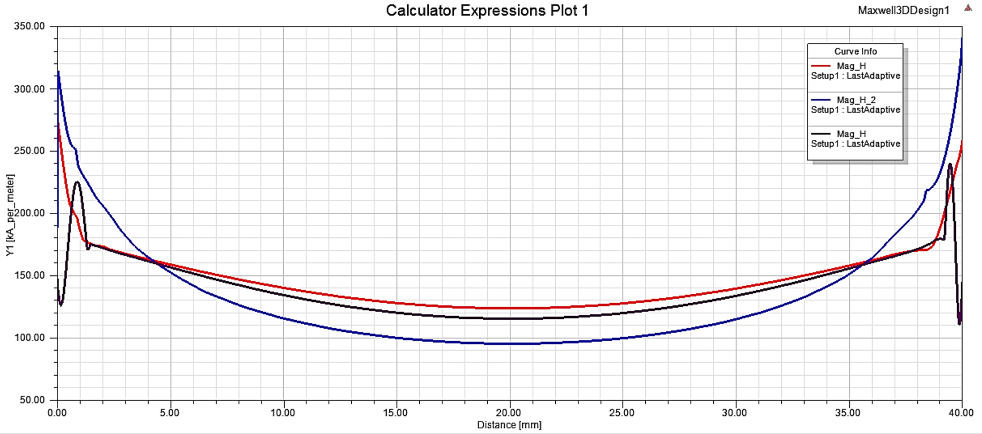

Fig. 5. Magnetic field intensity alongside channels. Red line is L_1, brown L_2, and blue L_3 as marked in Figure 4.

Magnetic flux density alongside channels is presented in Figure 6. Here picture again shows difference for L_2 line. These results are very important for estimating contactor efficiency of particle trapping inside the channels. The trapping ability, determined by magnetic force, shows deviations for outer channels, close to outer edge as L_2. Flux density drop is significant, from 370 mT to less than 50 mT. In that case outer contactor shape is important for its operation.

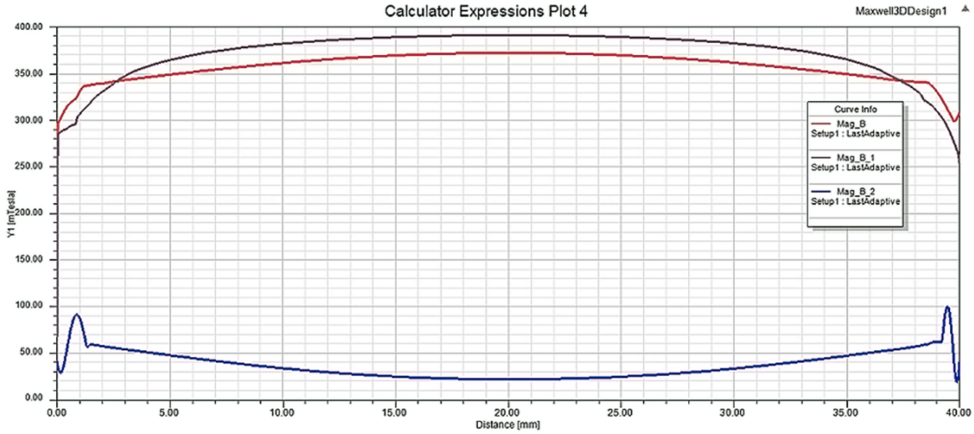

Fig. 6. Magnetic flux density alongside channels. Red line is L_1, brown L_3, and blue L_2.

Internal magnetic field distribution is dependent from channel cross-section, alongside length and outer block geometry. For optimal operation all these must be adjusted in a proper way that provides max flux density interaction for each moving particle. 3D metal printing can provide complex shape channels with advanced fluid flow control options. The magnetic field results must be coupled with particle dynamics model for complete process definition.

Magnetic field control can be applied by specially designed block or by a system of electric coils with controllable current. Coils are providing huge options for dynamic field control during operation and real-time process sensing.

6 Conclusion

Current work is focused on computer modelling of magnetic effects in conceptual air contactor for dispersed ferromagnetic particles. Presented conceptual design and magnetic model can be used for process optimization and attempts to provide magnetically controlled system operation by changing magnetization intensity and direction. Internal magnetic field distribution is dependent from channel cross-section, alongside length and outer block geometry. For optimal operation all design variables must be adjusted in a proper way to regulate magnetic field responsible for particle kinetics. Future work on new material appliance and new process control strategies will be beneficial for further system implementation.

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