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Inductively heated fluidized beds and their potential for energy savings and efficient process control

V. V. Idakiev[1, 2*], L. Mörl[3]

[1]*University of Chemical Technology and Metallurgy, St. Kliment Ohridski Blvd. 8, 1756 Sofia, Bulgaria*
[2]*Institute of Catalysis, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl. 11, 1113 Sofia, Bulgaria*
[3]*Otto von Guericke University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany*

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This article presents a novel method with the necessary equipment for introducing contactless energy into heated fluidized beds, enabling improved energy utilization and consistent quality of the manufactured product. Inductive energy input serves as an alternative to convective heating. In contrast to conventional heat supply, where the heated fluidization gas acts as the energy carrier, electrically conductive particles are used here. These electrically conductive, yet chemically inert particles, are introduced into the fluidized bed and fluidized together with the substrate to be treated. An integrated inductor within the system applies an electromagnetic alternating field to the fluidized bed, thus inductively heating it.

The heated inert particles are intended to release their heat from the interior of the fluidized bed over a very large surface area to the material being treated. This results in a high energy density and, ultimately, highly efficient heat transfer. This is especially relevant for batch processes that are evaluated for efficiency and cost-effectiveness. The fast and precise temperature control in inductively heated fluidized beds is also particularly beneficial for thermolabile materials.

Keywords: Fluidized bed; inductive heating; contactless energy input; heat exchange; precise temperature control

INTRODUCTION

The phenomenon of solid fluidization exhibits distinct characteristics and manifestations that can be strategically leveraged across various processes. Notably, the heightened intensity of heat and mass transport processes in fluidized beds renders them advantageous in numerous industrial applications. The intensified processes often permit substantial reductions in apparatus constructions. Fluidized beds are increasingly utilized in diverse economic sectors for processes such as solid heating, drying, particle granulation and coating, as well as the combustion of solid, liquid, or gaseous substances. They play a role in the pyrolysis or gasification of solids and in the classification or sorting of particle mixtures. In recent years, fluidized beds have become prevalent in environmental technology processes, including adsorptive or absorptive gas purification within a fluidized bed, and the fluidization of immobilized microorganisms in a liquid phase for the preparation of active compounds or wastewater purification.

Alongside the manifold application processes in fluidized beds, a multitude of apparatus-specific solutions have been developed for their implementation. Extensive literature and patent research indicate that the number of publications and patents related to fluidized beds has already surpassed five figures. It is no longer feasible for a single expert to encompass all developments in this field. Nevertheless, we have yet to explore all the potential applications of fluidized bed technology, and ongoing innovations are anticipated [1, 2].

The customary approach to heat a fluidized medium within a fluidized bed involves indirect convective heating through an upstream heater. Another commonly employed strategy to augment heat transfer to the fluidized bed involves contact heating through the utilization of vapor-heated pipes within the chamber or by heating the walls of the apparatus. Energy conservation plays a pivotal role in facilitating the economic and ecologically sustainable design of fluidized bed processes. Nevertheless, an alternative method for heating the fluidized medium may be necessary to achieve this objective. Alternatively, inductive heating utilizing electro-conductive and chemically inert particles or other electro-conductive elements provides a means for energy input into a fluidized bed. In inductive heating, the primary heat source does not stem from a fluid or heated surfaces, it arises from the interaction of electro-conductive objects within an electromagnetic field, leading to the contactless heating of these objects. These electro-conductive objects can be, for example, moving iron hollow

* To whom all correspondence should be sent:
E-mail: idakiev@uctm.edu
idakiev86@ic.bas.bg

balls (IHB) or other stationary iron tubes inside the fluidized bed chamber. In this scenario, as the heat is directly and contactless transmitted into the electro-conductive fluidized particles (for example, IHB) across a significantly expanded heat transfer surface, it enables achieving a high energy density and more efficient heat transfer in comparison to conventional heating methods.

The concept of contactless energy transfer using iron hollow balls (IHB) within a magnetic field was first experimentally validated on a fluidized bed by Stresing *et al*. in 2011 [3]. The results confirmed the feasibility of energy input into the fluidized bed through an induction coil and IHB. Subsequently, Idakiev *et al.* delved deeper into the fluidization behavior of beds, incorporating additional inert particles. Non-conductive particles such as glass, alumina, or plastic were mixed with the IHB, and experiments were conducted with inductive energy input. Experimental findings indicate that an increase in the proportion of inert particles correlates with a rise in process temperature [4, 5].

Generally, the use of induction technology enables rapid heating and cooling of the fluidized bed. Additionally, it facilitates targeted heating of the fluidized bed, allowing for precise adjustment of gas temperature. This capability is particularly crucial for temperature-sensitive materials.

EXPERIMENTAL

For the implementation of the above-mentioned process or objective, several fluidized bed systems were developed and tested. However, all of them operate in the same way. In Figure 1, the functioning of such a fluidized bed with inductive heating is illustrated. The figure shows a cylindrical fluidized bed apparatus with direct non-contact heating of electro-conductive particles fluidized together with the substrate to be treated in the fluidized bed chamber. This fluidized bed chamber is surrounded by three induction coils switched in parallel, each with three windings, so that the electro-conductive material inside the chamber can be subjected to an alternating electromagnetic field, whereby this material should be inductively heated directly and contactless. The building material (copper) used for the induction coil has a high purity and also very good electrical conductivity. In order to avoid heating or overheating of this building material, the coils are continuously cooled with cold water. In this way, the electrical conductivity of the copper used is kept stable.

For the inductive energy input into the apparatus, an alternating current induction generator TruHeat MF3040, TRUMPF Hüttinger Elektronik GmbH, with a maximum power of 40 kW, is used.

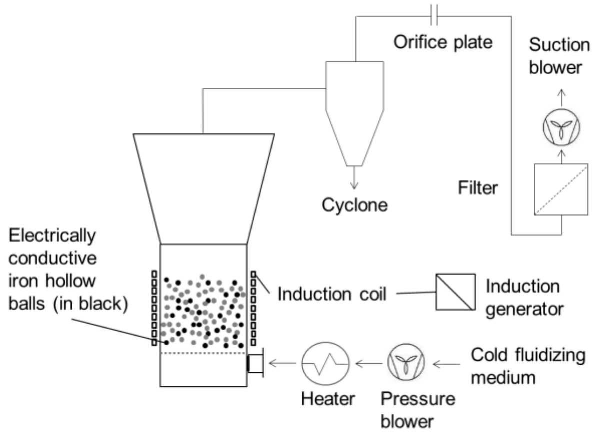

Figure 1. Graphic illustration of a cylindrical fluidized bed with direct contactless inductive heating of the electro-conductive particles inside the fluidized bed chamber.

Figure 2 shows a real picture of the cylindrical fluidized bed apparatus shown in Figure 1. This picture depicts the chamber surrounded by three parallel switched induction coils, each with three windings. The copper coil generates an electromagnetic field, leading to the inductive heating of the electro-conductive particles inside the apparatus chamber.

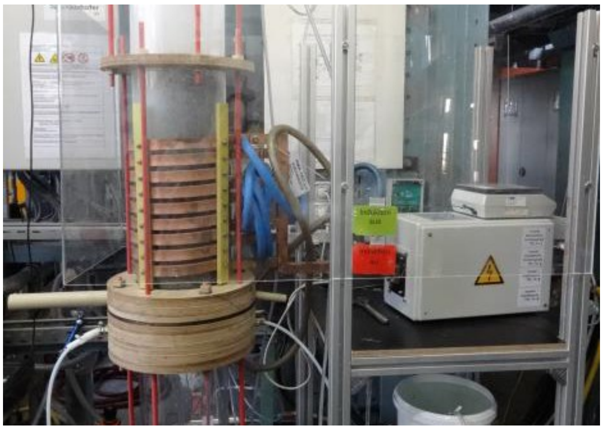

Figure 2. Picture of the cylindrical fluidized bed apparatus from Figure 1. Shows the fluidized bed chamber surrounded with the copper induction coil.

For a direct comparison between the novel energy input into the fluidized bed and the conventional method (*via* preheated fluidization gas), this system is equipped with a convective heater, installed at the gas inlet before the fluidized bed chamber. The plant can be operated in both suction and pressure modes, as well as with the simultaneous use of the suction and pressure fan, however, this has no effect on the energy input discussed in this paper.

For the realization of particle formulation processes in the inductively heated fluidized bed, a two-fluid nozzle Mod. 940 from the company Schlick is mounted as a bottom spray. This nozzle allows the injection of different liquids and their fine distribution thanks to the second channel with compressed air atomization. During the development phase of the process involving inductive heating of fluidized beds, typical fluidized bed processes such as drying, granulation, coating, agglomeration, and roasting were implemented in fluidized beds with inductive heating and compared with convective heating. For the cleaning of the fluidization medium in particle formulation processes in this fluidized bed apparatus with inductive heating, cyclones and filters are available [6].

RESULTS AND DISCUSSION

The most significant advantage of the inductively heated fluidized bed is the precise control of gas temperature, particularly crucial for temperature-sensitive materials. The utilization of induction technology allows for extremely short heating and cooling durations in the fluidized bed, leading to a notable reduction in energy consumption. For a better representation of these advantages and of the actual temperature profile of a induction fluidized bed apparatus, Figure 3 displays an experimental image captured with a thermal camera.

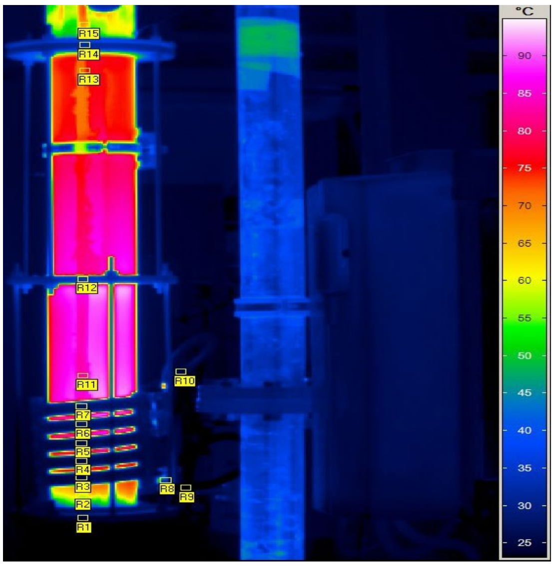

Figure 3. Picture taken with a thermal camera depicting the heat concentration in the chamber of the induction fluidized bed, external view of the apparatus.

In this case, it concerns a different fluidized bed system with inductive heating. In comparison with the apparatus shown in Figure 2, the induction coil here has 5 turns. The functionality of this presented induction fluidized bed is the same. As seen in this image, cold air enters the fluidized bed chamber from below, where the electro-conductive elements (for example iron hollow balls) in a fluidized state are exposed to an external electromagnetic field, resulting in heat generation directly within the fluidized bed chamber. Thus, non-contact energy input is achieved, and heat is generated precisely where it is needed – directly in the chamber of the fluidized bed.

By precisely controlling the supplied energy (in kW, up to a maximum of 40 kW) through the connected induction generator TruHeat MF3040, only the amount of energy necessary for the processes occurring in the fluidized bed is provided.

The following pictures (Figures 4, 5, and 6), taken with a thermal camera, directly depict the heat profile of the fluidized bed in comparison to picture 3, where the induction fluidized bed apparatus is shown from the outside. In these specific experiments, the thermal camera was carefully mounted directly within the fluidized bed reactor above the fluidized electro-conductive iron hollow balls. The left window in each image displays the color representing the heat directly generated within the fluidized bed. The right window correlates 1 to 1 with the left window and graphically displays the corresponding temperature of the non-contact and inductively heated fluidized bed of iron hollow balls. Both windows are scaled up to 220 °C. Picture 4 illustrates the cold fluidized bed (about 20 °C) in an initial state, prior to the input of energy and serves as a benchmark. Figure 5 indicates a warming of the layer and the corresponding rapidly increasing temperature. The layer reaches a temperature of approximately 170 °C for only about 15 seconds. The supplied power is 5 kW in this case.

By using cold fluidization medium, in this example ambient air with a temperature of approximately 20 °C, the layer can also cool down very rapidly when the induction is turned off, what is shown in Figure 6. This rapid temperature adjustment in inductively heated fluidized beds can be of significant importance for temperature-sensitive products.

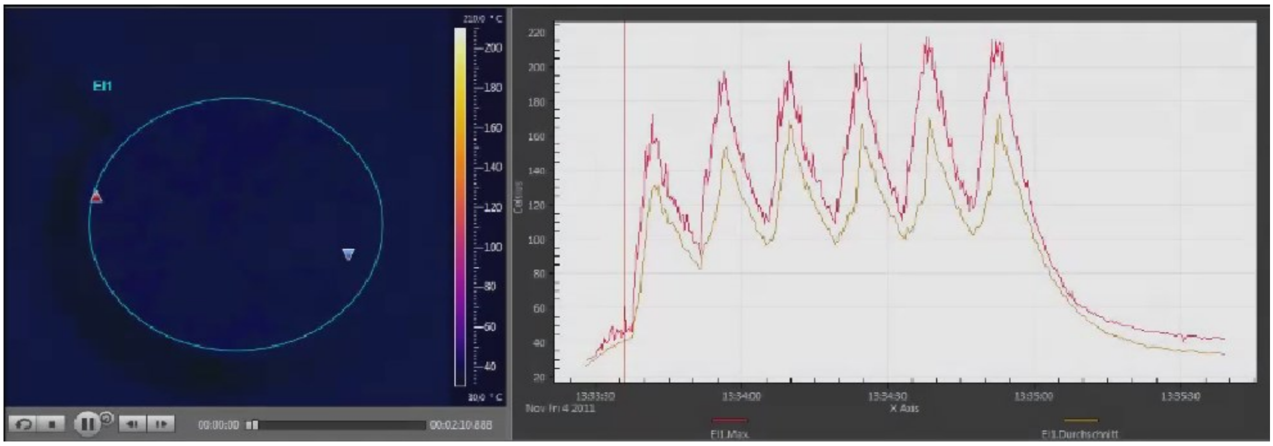

Figure 4. Picture taken with a thermal camera. Top internal view of the fluidized bed chamber, 0 kW input power

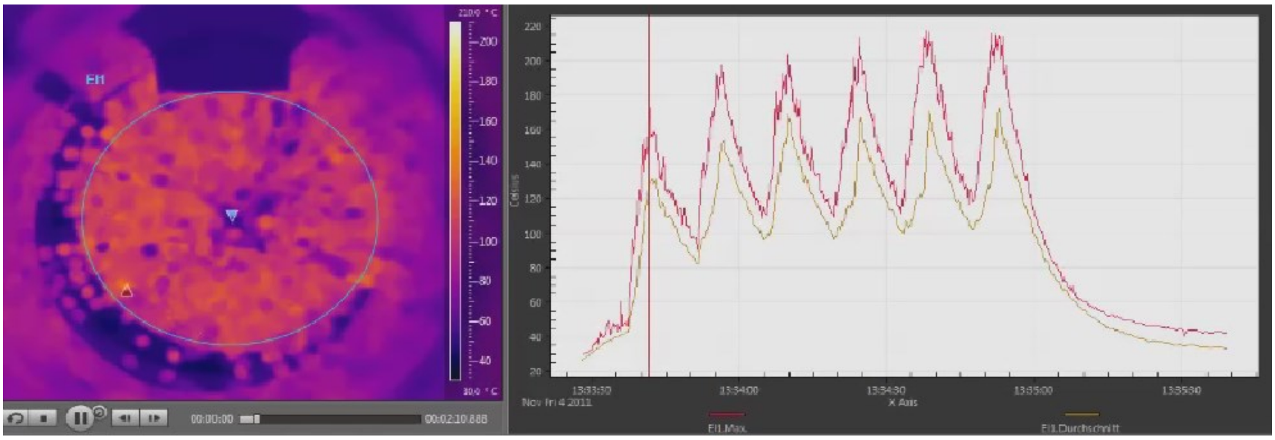

Figure 5. Picture taken with a thermal camera. Top internal view of the fluidized bed chamber, 5 kW input power

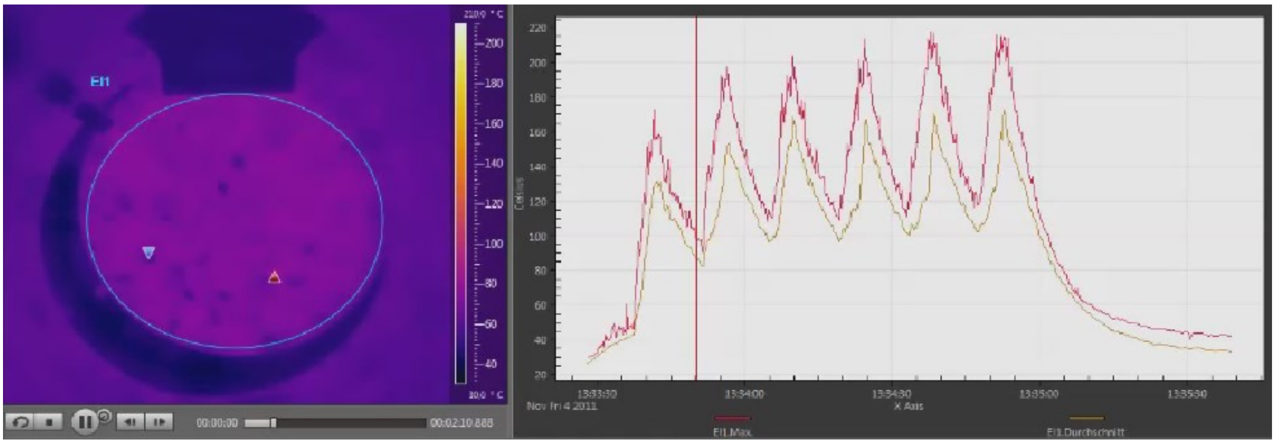

Figure 6. Picture taken with a thermal camera. Top internal view of the fluidized bed chamber, 0 kW input power

It should be noted that the purpose here is to illustrate the speed and precise control of the heating process in induction fluidized beds. The induction fluidized beds shown here are deliberately not insulated to gain a better understanding of the heating process. The introduction of insulation is mandatory for safety reasons and energy conservation, and it was implemented in later research.

CONCLUSIONS

The main focus of this research was the introduction of an alternative method for conventional energy supply in fluidized beds. The research conducted within the framework of these extensive investigations encompassed the implementation of all common fluidized bed processes, such as drying, coating, granulation, agglomeration, or roasting, using fluidized beds with inductive, non-contact heating. This innovative method allows for non-contact energy input directly into the fluidized bed chamber through the use of ferromagnetic objects (such as iron hollow balls) located in the fluidized bed chamber along with the substrate to be treated. The electrically conductive, ferromagnetic iron hollow balls fluidize together with the substrate to be treated. In this case, the iron hollow balls serve as a movable (mobile) heat exchanger directly in the fluidized bed chamber. Since they release heat directly through contact and convection in the fluidized bed chamber, the heating process can be additionally intensified. Additionally, instead of iron hollow balls, a securely fixed, stationary object (for example, a securely fixed ferromagnetic iron tube) in the center of the fluidized bed chamber can be used as a stationary heat exchanger.

It can be summarized that the conducted research using fluidized beds with inductive heating shows a significant reduction in heating and cooling phases, resulting in precisely controlled temperature profiles for fluidized bed processes. This allows for the shortening of costly and time-consuming startup procedures in a batch process design within the fluidized bed.

The presented work confirms the potential of the inductive energy input in fluidized beds. The use of fluidized beds with inductive heating opens up new possibilities for the treatment of industrial products that require rapid and precise adjustment of the temperature profile or are thermolabile.

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