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Simulation model of the moving granular bed gas cleanup filter

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Abstract

In the last few years there have been many attempts to improve efficiency of electricity production. This is mostly achieved by introducing technologies (e.g. IGCC) that have not been used before in industrial scale. These new technologies require high level of purification of produced gas. To solve this type of problems, it is necessary to use new methods for the hot flue gas (or high pressure, respectively) clean-up. The investigation of these processes is the topic of intensive research around the world. This paper analyzes the possibility of a simulation model of the moving granular bed gas cleanup filter, for the real design of this filter type.

Introduction

There are several new technologies that are suitable for the hot flue gas cleanup. One of these technologies are the use of granular moving bed filters [1, 2, 4]. This technology is one of the most promising developments in particle collection technologies in the last couple of years. In moving bed cross-flow operations, the filter bed is a vertical layer of granular material held in place by retaining grids or louvered walls. The gas passes horizontally through the granular layer, while the filter granules move downwards, and are removed from the bottom of the moving bed filters.

The aim of the performed research was to investigate the possibility of occurrence of quasi-stagnant zones – especially near the louvered walls. The existence of these zones significantly decrease the efficiency of the flue gas cleaning process. To avoid these situations, it is necessary to design the geometry of the filter in such a way, that the velocity field will have certain properties.

The traditional approach is to build an experimental device, where the velocity field is studied under various conditions. These devices are mostly in a form of a 2D model, where the flow of granules is investigated [2]. The

Air Pollution VIII, C.A. Brebbia, H. Power & J.W.S Longhurst (Editors)

experiments performed, allowed the configuration of the filter in various ways and the study of the detailed the behavior of the velocity field in the filter. In order to obtain relevant results in the course of experiment, it was necessary to use special experimental techniques (like coloring granules etc.) which allowed the experimenter to trace groups of granules during the course of experiment. In such a way it was possible to generate pictures that represented the velocity fields in the filter.

This type of approach requires to build a special device modification, of the consuming time. The main disadvantage of these physical models, is the possibility of limited modification of parameters of such a model. Only few parameters (diameter of granules, velocity of removed granules, etc.) can be modified in a flexible way. In the case when more extensive modification is required, it is necessary to build a new filter model. As it is not clear in advance that the modification will meet the expectations, the result is that some marginal solutions that could bring a new insight in the problem, are not considered. This means in general, that the efficiency of this approach is not as good as the nature of the problem that might be required.

These sort of problems can be solved with much higher degree of efficiency by means of a computer model, by which it would be possible to perform simulations of various situations in the filter investigated. Also situations that would be difficult to handle in physical model are easy to handle.

The usual type of numerical simulation of the flow patterns takes into account the mechanical behavior of granular assemblies. The concrete types of the calculation get the discrete element method (DEM). The calculations of concrete Dorfan Impigo type of moving bed filters are described in [5]. The numerical calculation performed in the DEM alternates between the application of Newton second law, to the particles and force - displacement law at the contacts advocated in [2].

In order to develop a reliable model, it was necessary to compare the results of a model developed with real results obtained by means of the physical model. On this paper a model is described, which meets requirements for intensive experiments with such a model. The results achieved are original results, as the essence of the problem is very specific that can not be satisfactorily covered by some existing software of general nature.

Design of a discrete model

The model developed was a 2D model, in order to be able to compare results obtained from this model with the resultats obtained from the physical model [6]. Another reason for choosing the 2D case was the fact, that the implementation of this model is considerably less demanding than the 3D one. Such an approach considerably reduces the computational time and thus allows the user to perform much more experiments within given period of time. The model consists of two parts:

- the filling phase where the filter is filled with granules in the required extent
- the simulation phase where the flow of granules in the filter is simulated and visualized.

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The granules have a form of spheres with typical diameter from 1 to 10 mm. These granules are able to adsorb dust and gas pollutants from the polluted gas that flows through the filter. Each granule was represented by an element in the filter bed. The principal assumption was the movement of granules in the bed, as a result of forces acting on each granule in the lower part of the filter. The nature of these forces is simply the weight of the granules in the layers above the granule in the question. The solution to the problem (creating a satisfactory model) was to deal with distribution of forces (caused by weight of granules) in the filter bed. Due to the large number of granules, the calculation of forces distribution was rather a time consuming process.

This fact resulted in some simplifications that reduced the computational time. In the principle, there were two assumptions:

- the granules do not move continuously but in a discrete way (between specific positions)
- the filter is always full.

Especially the second assumption was very important, as it allowed us to make some precalculations at the beginning of each simulation, concerning the global distribution of forces in the filter bed. Due to the fact that the filter is always full, this distribution of forces remains constant during the course of experiment. From both assumptions, it is possible to calculate in advance the positions where the granules will reside. From these positions, it is possible to derive prospective trajectories of granules during the simulation.

The knowledge about positions of granules removes the necessity to calculate the collisions between granules and the walls of the filter. This fact significantly reduces the computational time. The main idea is to create a list of all the potential positions where granules could be located during the simulation process. An initial position of a granule is selected, and the next position is calculated. Such a position is the position with the smallest (nearest) distance in the y-direction. In the case where there are more positions of this kind, the new position is randomly chosen from the set of candidate positions. Each internal position has six neighbours. The potential positions located near the filter walls are evaluated by a special algorithm: " whether they meet requirements for being at such a position".

Some inaccuracies may be easily removed when using granules with smaller diameter in comparison with the size of the filter – which is the real case.

After performing the initial calculations mentioned above, we will deal with the simulation of the flow of granules. This simulation is based on three basic operations:

- removal of a granule from the given location in the filter on the outlet from the filter
- moving a granule into vacant position (after a granule was removed)
- filling granules into vacant positions at the outlet of the filter.

In general, it is possible to say that vacant positions generated by granules removal from the filter outlet propagate upwards until the top of the filter filling has been reached. Due to the fact that there are usually more candidates for removal of granule, or moving granule into a new position, a statistical approach has been used what creates certain randomness in the process simulated.

Air Pollution VIII, C.A. Brebbia, H. Power & J.W.S Longhurst (Editors)

The algorithm has been tested – mainly the point of view of correspondence with resultants of physical tests. The resultants were non corrected in the area of the louvers in the filter (Fig. 1).

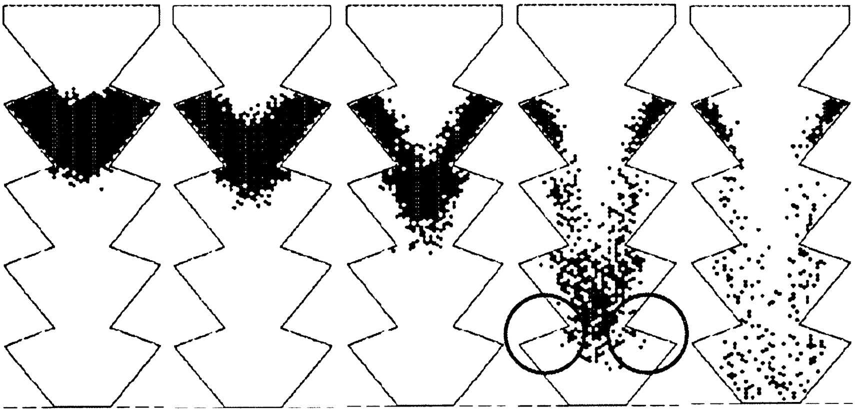

Figure 1: Simulation of granule flow – the circled areas do not correspond with reality

Design of a continuous model

From the simulation point of the view, the main disadvantage of the discrete model was the fact, that granules moved along predefined trajectories. In the new model (continuous one) the granules are specified by their position, velocity vector, density, diameter and absorption capability. The flow of the filter bed is influenced by the density of granules, and by mutual interaction between granules and walls of the filter. As the new model is more complicated, it was necessary to use different theoretical basis for the simulation description. The first improvement was the switch from the 2D model into 3D model as it will allow the user to investigate the process in much broader context. This approach also allows the user to investigate the properties of the gas flowing through the volume element.

Investigation of the situations in each single volume element reduces substantially the computational time as only the granules in the volume element (resp. in close neighbourhood defined by the trajectory of a granule) are considered for calculation of potential collisions (Fig.2).

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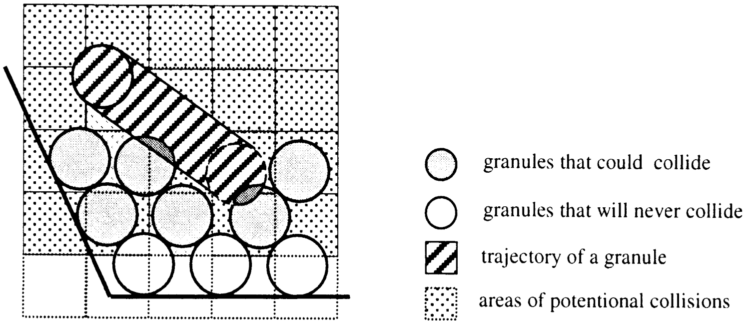

Figure 2: Trajectory of a granule

A special algorithm has been developed, that calculates potential collisions of granules with the wall of the filter (Fig.3). The approach is used on calculation of critical areas of filter, where filter blocking can occur. In this case, the calculation of trajectory in 3D has been performed. From the shape of the trajectory, it is possible to derive which part of filter could generate some problems, and therefore needs some reconfiguration.

The results of simulations performed were very encouraging. The match with results obtained by means of physical models was extremely good. In order to get a better feeling about the dynamics of the process investigated, we generated a set of animated sequences where a comparison has been made between the simulated results, and the real ones. Even in this case, the match was extremely good (Fig.4).

Development of testing methodology

The tests have been performed both with the discrete and continuous model. Results were in both cases compared with the results obtained at National Taiwan University [5,6]. The main purpose of tests was to investigate conditions for creation of dangerous zones in the filter, where blocking may occur. The results of testing of the discrete model led to the development of a more successful continuous model.

In the case of a discrete model, two types of tests were performed. The first test dealt with the dependency of the flow of granules on the filter geometry. The tests were performed for three different geometries of the filter. The diameter of granules was 5 mm for all three experiments (see Fig.1 – example). In some cases (Fig.1) the results did not match with the results obtained by the physical test. This was caused by simplifying the assumption mentioned above.

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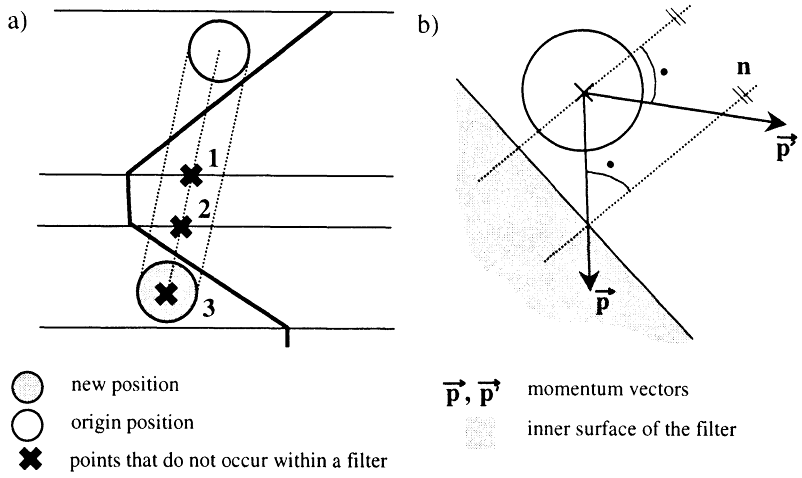

Figure 3: a) detection of granule collision with the surface of the filter (granule positions creating the trajectory)
b) change of granule momentum during the collision with the surface of the filter

The second test (Tab.1) investigated dependency between the granule flow and the diameter of granules (Fig.5). The course of simulation was controlled by means of number of removed granules from the outlet of the filter. In order to be able to follow the behavior of the filter (flow of granules), the selected granules (mostly on the top of the filter) were colored. In this way, it was possible to follow the behavior of these selected granules.

The experiments (Tab.1) with the size of granules (Fig.5) and its influence on the flow have shown, that the regeneration capability of the filter increases with the growing diameter of granules. On the other hand the absorption capability of the filter grows with the decreasing diameter of granules.

Also the experiments with a continuous model were of two kinds. The first one was the same as the one in the previous case – experiments with three geometries of the filter. These experiments served as a verification of the model (comparison with real data – Fig.6). This part of testing was successful, which allowed us to perform experiments with some input parameters of the filter:

- dependence of the flow on the speed of the conveyer (that takes the granules out of filter)
- dependence of the flow on the diameter of granules

The first test had to discover critical areas in filter. The purpose of the second test was the same but the parameters of the process were different (geometry of the filter).

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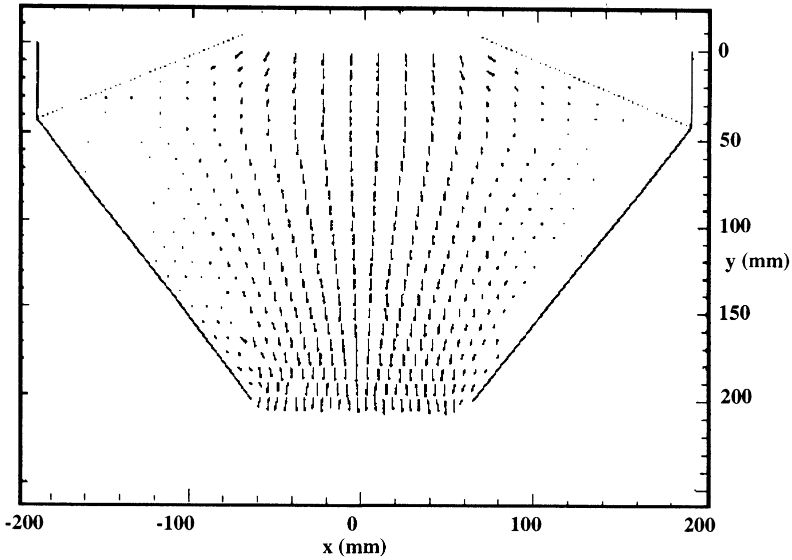
velocity field – real tests



velocity field – computer simulation

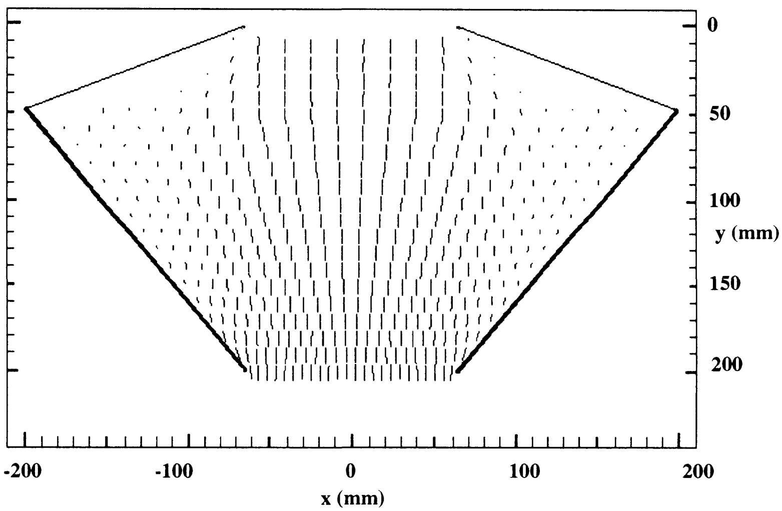


Figure 4: velocity fields – comparsion between reality and computer simulation

The system that consists of the simulation and visualization part was implemented for Windows9X/NT platform in programming language C++. The graphical output was realized by means of the standard graphical library OpenGL.

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Table 1: Test parameters for Fig.5

test d2:				
simulation	α	B_T [mm]	B_B [mm]	r [mm]
d2b	45°	200	100	5
d2c	45°	200	100	10

α ... angle of louvers
r ... diameter of granules
B_T,B_B ... filter width – upper and lower outlet

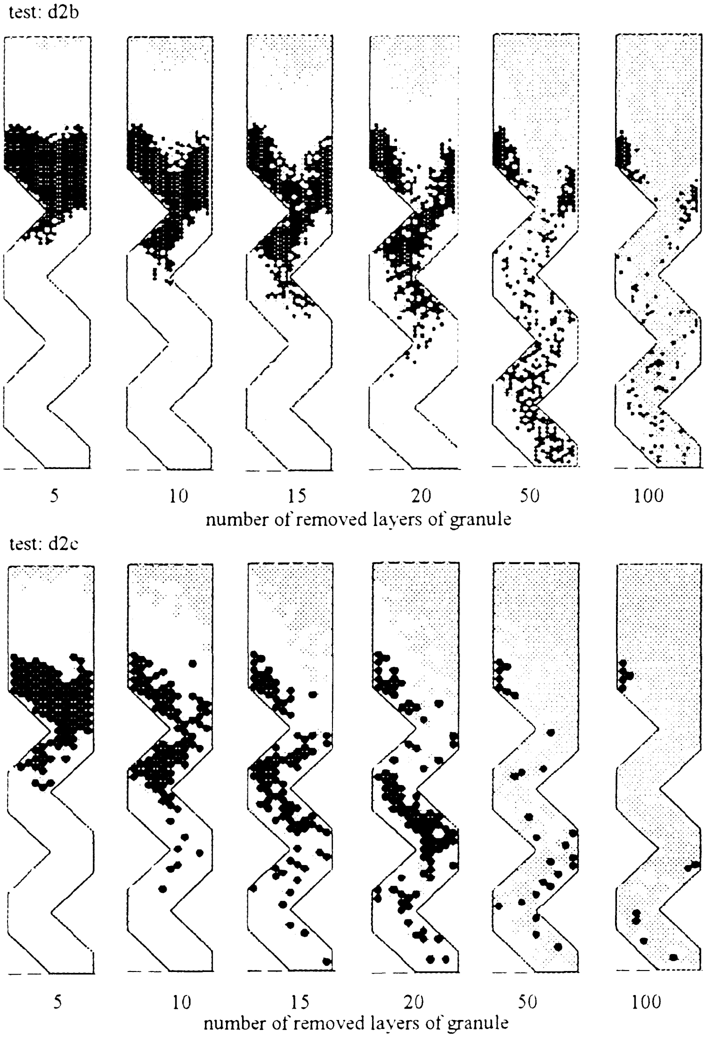

Figure 5: Simulation for various granule diameters

Parameters of the tests performed with the model, were the same as in the case of tests with physical model [4]. The experiments were performed with the same filter geometries. The results shown in the Fig.6 were obtained for one of the geometries, and for the diameter of granules (6 mm), and the speed of the conveyer belt 20 mm/s.

Conclusion and future work

The system designed and implemented makes it possible to investigate very deeply the behavior of filters of specific type. The main contribution of this work is the possibility to perform a large number of experiments within a short period of time. Also the change of the geometry of the filter is very easy. The tests performed have shown a very good match with the reality. The approach selected for the design and implementation of continuous model – the use of volume elements allows us to continue in research where the main target will be the simulation of absorption capability of filters under various conditions. This parameter of the filter is influenced both by the speed the granules flow in the filter, and by the degree of saturation of active granules. From these experiments, it would be easy to determine an optimum set up of filter parameters during filter exploitation. The data acquired from these simulations will allow us to use these filters in an efficient way, with a high degree of filtering effect.

Acknowledgement

This research has been subsidised by the Research Projects of MSMT of the Czech Republic J04/98 : 212200009 and J04/98:212300014 and by the Research Project of GACR of the Czech Republic 101/99/0647.

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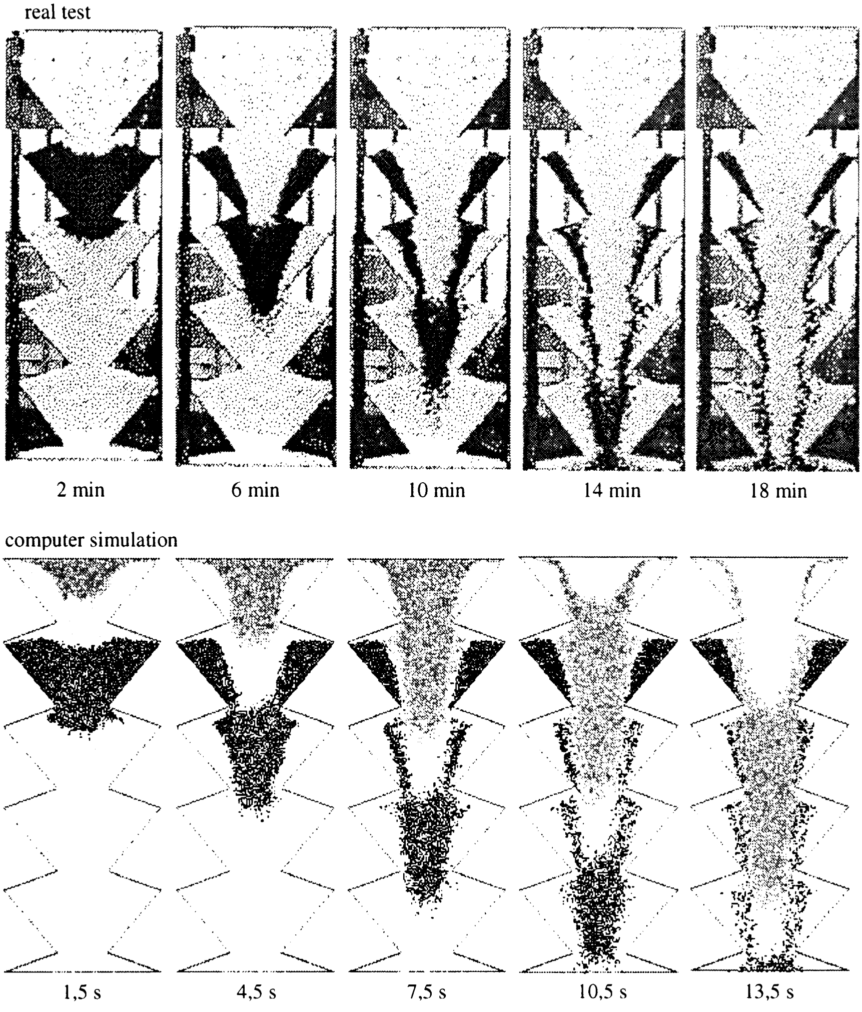

Fig.6: Verification of the continuous model

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