New methodology for design of moving bed filters

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Abstract

Combustion of fossil fuels and waste results in generation of gases that are harmful from an environmental point of view. This fact leads to the development of new types of filters with specific properties. In order to achieve the high quality of design together with efficient use of these filters a new design methodology should be developed. This paper deals with the description of such a new methodology together with the practical results achieved. The new approach is based on concurrent use of the simulation model and physical model of the filter designed.
Keywords: moving bed filter, simulation model, fluid flow dynamic.

1 Introduction

Production of electrical energy in the Czech Republic is mainly based on the utilization of coal. The usage of coal has two main negative aspects: the coal belongs to resources that are not renewable and during combustion of coal CO2 is generated. The share of electrical energy produced in the Czech Republic by means of coal is about 60%. Other energetic resources are also used in the Czech Republic – mainly nuclear energy and water energy. The potential for the usage of water energy has already been exhausted and the use of nuclear energy has also limits of various kinds that have been already reached in the Czech Republic.

A main strategy of the EU (and Czech Republic as well) is increasing efficiency of fossil fuels utilization (mainly coal), increasing the share of renewable energy resources (in CR at first biomass) and higher energetic usage

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of combustible wastes. All of these trends are connected with resolving the problems of the environmental impact of the energy technologies.

2 Environmental strategy

For ecological reasons it is necessary to develop strategy that will allow the electrical energy producers to reduce the amount of production of polluting gases. There are two ways how to cope with this goal:
- To use new methods for transformation of coal or biomass into electrical energy – a promising way is to use gasification of these fuels.
- To develop new technologies that will perform cleaning of gases generated as a result of coal and biomass combustion and municipal and industrial waste combustion.

Both approaches require development of new devices for cleaning up technologies [3, 5] (flue gas in the first case and removal of CO2 in the second case). There is extensive research around the world that results in the design of new devices for cleaning up of gases of various kinds. The goal is to design an optimal configuration of a filter by means of which the gas is cleaned. The optimization of filter configurations should comply with two main requirements:
- The use of a filtration medium with maximum efficiency (which means with low costs of filter exploitation).
- The most effective removal of dangerous gases from the gas cleaned [2].

3 Design of moving bed filter

Most of the research is performed on physical models of these devices. Measurements on physical models allow the designers to establish optimal configurations of single parts of filters.

The main disadvantage of these physical models is the possibility of limited modification of parameters of such a model. Only a 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 to the problem are not considered. In advance you cannot predict the results of such modifications. From the results a new problem could be released, which has not been 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 sorts of problems can be solved with a 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 a physical model are easy to handle.

Intensive research in the field has been conducted at CTU Prague that resulted in the development of methodology for the filter design. The methodology is

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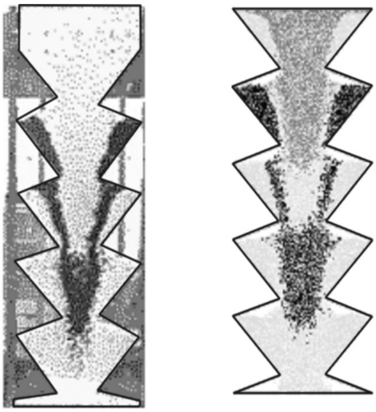
based both on experiments with real devices and on the use of sophisticated computer models of filters [1, 4, 6].

In Fig. 1 is an example presenting the comparison of computer simulation and the physical model of particle flow in the filter.



10 min **7,5 s**

Figure 1: An example presenting the comparison of computer simulation and physical model of particle flow in the filter.

The results obtained corresponded with data acquired from the producer of the filter (EVECO Ltd. Prague). Based on the results of simulations a physical model of a louvered moving bed filter has been designed. The realization has been performed in the CTU laboratories. This filter is shown in Fig. 2.

The combination of the use of a simulation model and a physical model gives the possibility to develop new sophisticated computer models of filters that are verified on physical models of filters (Fig. 2). The main advantage is that it is possible to perform a large number of simulations by means of computer models of filters where behavior of the particular design of the filter is tested. Only some critical parts of design should be verified on the real model. This methodology of the filter design allows the designer to combine advantages of both approaches:

- Flexibility of simulation of filter behavior (easy configuration of design) and the large number of experiments that may be performed.
- Verification of particular design on physical model.

The computer models covered two decisive parts of the filter design:

- Dynamic behavior of granules the cleaning medium consists of
- Dynamics of adsorption processes in granules.

The first problem was the subject of intensive research [1] and resulted in a computer model that has been thoroughly verified in a number of experiments. These experiments dealt mainly with handling situations in critical areas of filter, where filter blocking can occur. In this case, the calculation of a trajectory in 3D

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has been performed. From the shape of the trajectory, it is possible to derive which part of the filter could generate some problems, and therefore needs some reconfiguration.

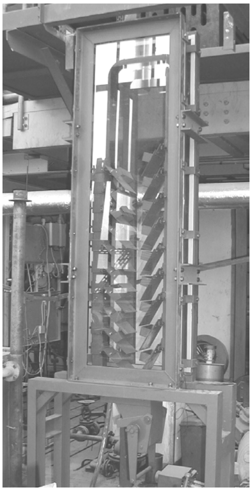

Figure 2: The physical model of filter.

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. In this case, the match was also extremely good (Fig. 3). It is possible to see the correspondence between simulated behavior of the filter and experiments on a physical model.

The combination of simulations and measurements resulted in determination of critical angles of louvers from the point of creation of stagnant zones where granules are concentrated without movement. The experiments (both physical and computer simulation) were concentrated (after a set of other experiments) on three angles that are a sort of representation of typical behavior of dynamic properties of filters. These angles were 10, 20 and 30 degrees. When using 30 degrees we could see that the creation of stagnant zones is very intensive and they disappear only in the case when the filtration medium (granules, represented by sand or active coke) is fully removed from the filter body (this means when the experiment terminates). Better results have been achieved in the case of 20 degrees. In the 10 degrees case, there were no stagnant zones and there was apparent flow of granules between double louvers. By the angle 30 degrees there was no movement of the particles in full cross-section between double louvers (see Fig. 3).

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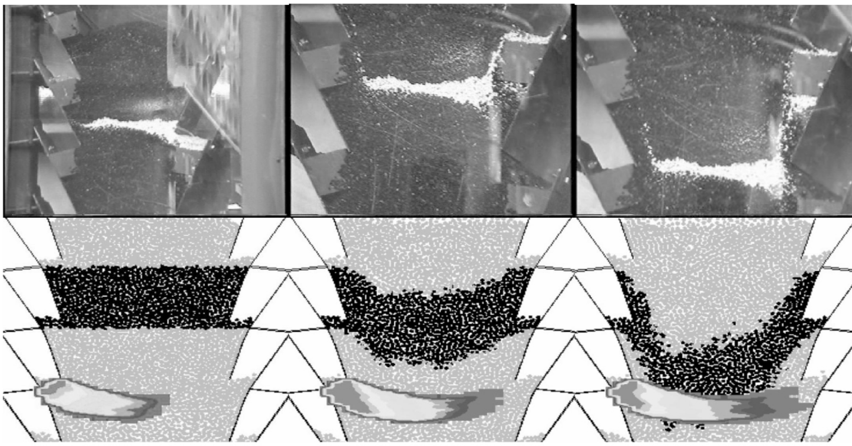
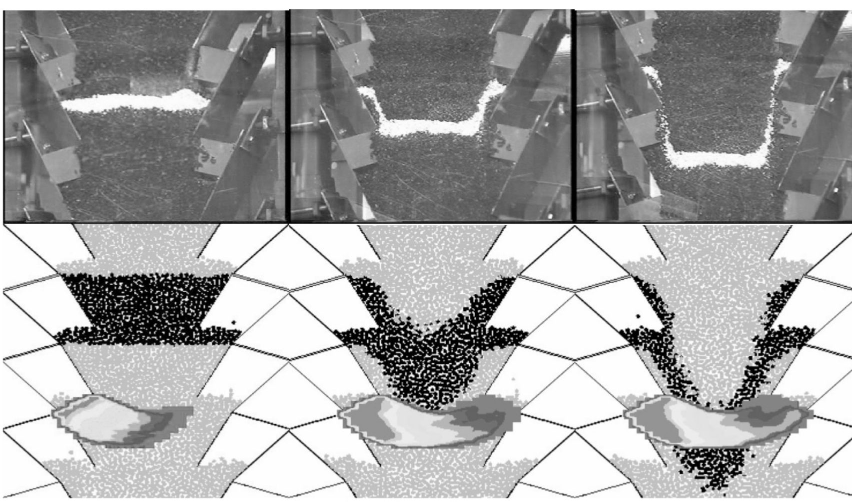


Angle of inner louvres 10°



Angle of inner louvres 30°

Figure 3: Comparison of granule flow in the filter physical model and computer simulation among double louvers with different angle of the louvers.

The other part of the problem was simulation of adsorption processes in the filter. The simulation was based on the Dubinin formula where the adsorption properties are described in a formal way [4, 6].

The model used for simulation of the movement of granules has been based on the partition of the filter volume into a finite set of volume elements. The volume elements have cubical form and are of the same size. This approach allowed us to deal uniformly with all elements in the filter volume which simplified the computational process. The state of a volume element is given by

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several parameters like the number and positions of granules in the element. From the point of view of the adsorption process we are interested in the parameter characterizing concentration of pollutants that is assigned to each element.

Besides simulation of adsorption processes it was also necessary to simulate the dynamic behavior of gas flow in the filter. Especially critical was the case when the gas flows in the filter through one inlet and leaves the filter through several outlets. The problem is rather complex and its solution required development of a new approach. The problem has two important aspects:

- Distribution of gas between two or more outlets.
- Shape of trajectory that describes the gas flow in the filter (taking into account the gas distribution between outlets).

4 New methodology of filter design

Both problems can be solved in a traditional way as a problem of a fluid dynamics type. The solution is obtained by means of a system of differential equations describing the flow dynamics. The main drawback of this approach is that obtaining a solution is very time consuming. This might impose serious limitations on the number and quality of experiments performed by means of a computer model. It was necessary to develop an alternative approach that will not be so time consuming.

We have used the fact that the gas flow takes place in a dense environment (granules that are used as filtration medium). There are vectors of an input velocity and the output velocity of the gas flow. In the dense environment we cannot expect (for the application under investigation) dramatic changes of the gas flow. This assumption allows us to describe the gas flow trajectory by means of Fergusson curves. The calculation of such a trajectory is very fast and has been verified by means of calculations based on a traditional approach. The verification was done by means of a Fluent system (Fig. 4).

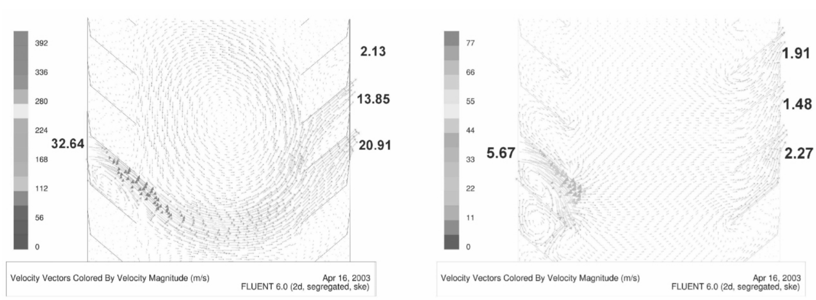

Figure 4: The calculation of the trajectory by means of Fluent system.

The following approach to simulation of the gas flow has been designed and implemented:

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- In the inlets and outlets there will be created N corresponding nodes (this means that N will influence both the accuracy of calculation and time required for calculation),
- The corresponding nodes in inlets and outlets will be connected by Fergusson curves,
- From the accuracy and time requirements the length step (trajectory corresponding to delta t) will be determined.
- It is necessary to determine the relation between distances between the set of Fergusson curves (see Fig. 5) and the number of control points on Fergusson curves (see Fig. 5).

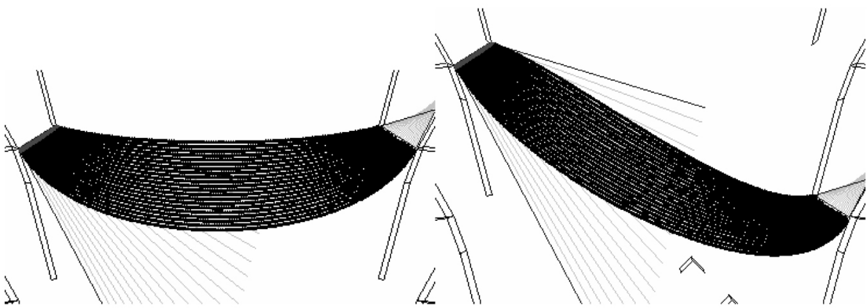

Figure 5: Inlets and outlets will be connected by Fergusson curves.

- The data acquired in previous steps will be used for construction of mesh where the gas flow represented by single volume elements will be calculated (Fig. 6).
The detailed description of trajectory of the gas flow allowed us to simulate adsorption process in its full complexity (it was clear which granules will participate in the adsorption process).

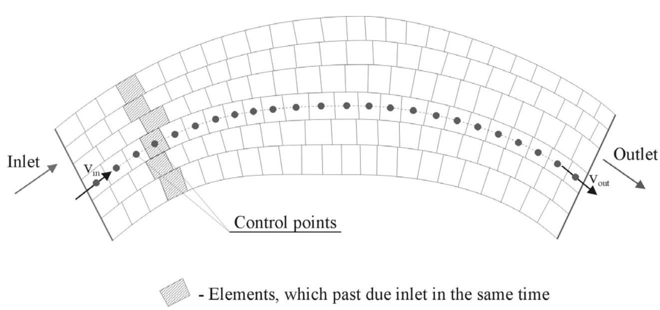

Figure 6: The mesh where the gas flow represented by single volume elements will be calculated.

5 Application of new design methodology

The problem investigated in this particular case concerned the behavior of granules on louvers in filters equipped with retarders. The retarders are slowing

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down (see Fig. 7) the movement of cleaning granules on the side of filtered gas outflow. Fast removal of fully adsorbed granules is necessary on the side of gas inlet.

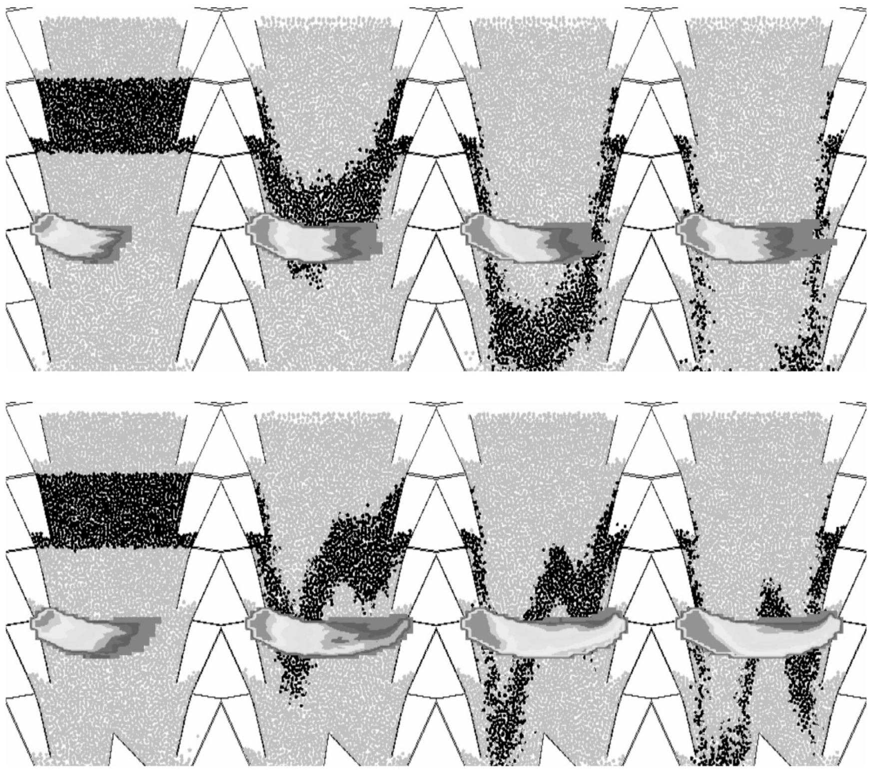

Figure 7: Comparison of granule flow between usually filter and filter with retarder.

Furthermore, cleaned gas contains particles that are filling the gaps between granules and they increase flow resistance of the filter, in consequence they decrease filter capacity.

The advantage of different flows on the inlet and outlet is the better utilization of active particle adsorption capacity and in consequence saving of expensive filtration filling.

Simultaneously, full capacity of the filter is kept with lowered consumption of filling granules.

The methodology described was used for the design and production of a filter for waste incinerator in Leciva Prague (large pharmaceutical factory in the Czech Republic).

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6 Conclusion

In the paper a new methodology for filter design has been described. This new methodology is based on a combination of simulation of filter behavior and experiments on physical devices.

The main advantage of this method is that the physical model is designed on the basis of analyses made by computer simulations of different filter set-ups. On this designed physical model are verified possible critical points of a real filter. After that it is easy to make simple changes according to best results of computer simulations and verify them very quickly.

Such a combination allows the designer to perform a large number of experiments and verification of some crucial experiments in the critical part of the filter design. Such a combination leads to a much higher quality of design. Another contribution of the research described was development of new formal models for modeling of some processes that are part of the filter behavior. An example of these new models is the model for description of dynamics of flow of granules in the filter body (where a finite element approach has been used) and the use of Fergusson curves to replace time consuming calculations of gas flow traditionally based on fluid dynamics.

The new methodology was used for the design of a real filter where this new methodology has proved its efficiency. The study clearly indicates advantages, limitations and possible applications.

Acknowledgement

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