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Development and Testing of a Moving Granular Bed Filter at the Taiwan Industrial Technology Research Institute

Key Words
Moving Granular Bed Filter, Flow Pattern, BIGCC, Cold Flow Test, and High Temperature Gas Cleanup

Introduction

The main purpose of developing high temperature gas cleaning technologies are to clean the gas under high temperature in order to be cost effective and to improve energy efficiency.

Moving granular bed filters are technically and economically applicable for high temperature cleaning system because of low cost, possible to keep operation at a constant pressure drop, simple structure, easy in operation and maintenance, no high risk internals, and more tolerant to process thermal flow.

Energy and Resource Laboratories, Taiwan Industrial Technology Research Institute (ERL/ITRI) has been developing a moving granular bed filter (MGBF) for BIGCC(Biomass Integrated Gasification Combined Cycle) high temperature gas cleanup. The filter granules move downwards directed by louver-like guide plates and the hot gases penetrate the MGBF horizontally. Filtration mechanisms include collection of the dust cake over the bed media surface and deep bed filtration. Stagnant zones of filter granules combining with the dusts always exist along the louver walls. Such stagnant zones often corrode the louver-like guide plates, increase the system pressure drop and decrease the total reaction efficiency that may endanger MGBF operation. Series louver and inert structure research that modify the granular flow pattern have been designed to eliminate the formation of these stagnant zones. By connecting to an auxiliary dust/bed media separation system, MGBF can be operated continuously at a stable pressure drop with a stable high efficiency.

There are several MGBF R&D activities in progress: (1) a 3-dimensional cold flow system for testing the MGBF filtration efficiency; (2) a high temperature gas cleanup experimental system that has been designed and installed; (3) a 2-dimensional flow pattern experimental system for approving design concepts.

Objectives

The formation of stagnant zones usually is the majoy challenge of MGBF design. Figure 1 shows the earlier design of MGBF (moving granular bed filter). The granular material **2** is packed and held by a pair of louver-like guide plates, an inlet louver-like guide plate **1i** and an outlet louver-like guide plate **1o**, arranged vertically and is moved downward to form a moving bed, while gas **3** is introduced into a reactor **4**, passed transversally through the moving bed via inlet louver-like guide plate **1i** to effect dust removal and reactions, and then discharged from outlet louver-like guide plate **1o** on the opposite side. However, such a MGBF has hitherto met with the following problems.

The first problem is that the quasi-stagnant zone **2i-qs** and the stagnant zone **2i-s** of granular material **2** are formed on louver-like guide plate **1i** and the quasi-stagnant zone **2o-qs** and the stagnant zone **2o-s** of granular material **2** are formed on louver-like guide plate **1o** as shown in Figure 2 (Kuo et al. 1998, Hsiau et al. 1999, 2001). Accordingly, in the case of feeding a gas with a high dust concentration, a layer of dust grows at the gas inlet side of stagnant zone **2i-s** and quasi-stagnant zone **2i-qs**, resulting in the increase of the gas pressure drop. In addition, the quasi-stagnant zones **2i-qs** and **2o-qs** and the stagnant zones **2i-s** and **2o-s** of granular material **2** reach a saturation in chemical reactions and particles of chemical products or adsorbents leave zones **2i-qs** and **2o-qs** and zones **2i-s** and **2o-s** slowly, if any, which often corrode the louver-like guide plates and increase the system pressure drop that may endanger the MGBF operation. In addition the total filtration efficiency drops. More or less, the uniform velocity field of granular material **2** exists only in the area of central flowing core **2c**.

Secondly, the central flowing core **2c** of granular material **2** in the GM-B filter or reactor **4** is ordinary expanded from the gap of louvers **1i** and **1o** as shown in Figure 3 (Hsiau et al. 1999). When operated the moving granular bed or reactor **4** as such, the velocity distribution of the granular material **2** in the converging channel of louver-like guide plate **1i** and louver-like guide plate **1o** becomes as shown by curves of vertical velocity **v** profiles in Figure 4. Thus, there have been proposed methods wherein various flow regulations are provided so as to make the velocity distribution in the moving beds as uniform as possible. Series of flow pattern modification R/D activities has been made by way of a 2-dimensional experimental system. 3-dimensional cold flow and high temperature gas cleanup experimental system have been designed and installed for testing the MGBF filtration efficiency and operation.

Approach

The present design seeks to provide a moving granular bed apparatus comprising at least one container for a downwardly moving granular bed, through which the gas flows transversely, which container has louvered walls on the inflow and outflow sides and will function even when dust-laden gas is used. Furthermore it is desirable if possible that a substantially uniform sliding speed of the particles in the moving bed should be achieved over the whole cross-section of the moving bed with a consequent uniform residence time of particles in moving bed and a uniform dust loading of particles, for example, in the case of filtration or a uniform adsorbent, active carbon or catalyst loading in case of moving bed adsorption apparatus is accomplished.

According to the new design there is provided granular moving bed apparatus comprising at least one container for a downwardly sliding particles of moving bed through which the gas mixture flows transversely, said container having a louvered wall on the inflow side and on the outflow side, wherein at least one of said louvered walls consists of a series of louver-like guide plates inclined downwardly from the outside to the inside and positioned one above the other and a series of flow-corrective elements in the middle of the container shaped like a saddle roof of vertex angle that is a double value of the angle of louver-like guide plate and shifted vertically against the louver-like guide plate nearby.

ITRI corporate with the National Central University processed a series of two-dimensional tests using a moving bed as experimental apparatus, as shown in Figure 5. It consists of a narrow layer of particulate material sandwiched between two transparent panels with louver-like side walls. The height of the channel is 1000 mm. The channel width W is adjustable (maximum width is 400 mm) and is fixed at the value of 380 mm. The channel depth is 48 mm. The front and the rear walls were cleaned carefully before each experiment in order to reduce the wall friction effect on the granular flows. The configuration of the louvers can be changed (louver spacing, louver angle and length). In this paper, the louver angle ¯of 40° is used and the louver spacing d is fixed as 350 mm. The length of the vertical part of the louver is 40 mm and the length of the inclined part l is 200 mm. Three are louver sections exist in the moving bed. Two 210-mm-length steel plates with an internal angle of 60 form the flow corrective element°. The three flow corrective elements were connected by a thin steal rod and placed in the central bed. Johanson (1966, 1967/68) and Johanson and Kleysteuber (1969) found the right placement of inserts can improve the granular flow in bins. According to their results, each of the current flow corrective elements should be placed at 105 mm above the lower tip of the corresponding louver. The above placement is noted as Position 1 in this paper. Position 2 and Position 3 represent the tests with the flow corrective element shifting upwards by 20 mm and 40 mm. Figures 6(i) to (iii) show the three configurations of the louver sections in the three tests.

The flow of granular solids is induced and controlled by a moving belt underneath the granular bed. Granules are fed into the vertical channel from a top hopper, which has a rectangular discharge slot of the same cross-section as the vertical channel. Nevertheless, from the observation of the inlet and the outlet granules positions along the path of 1 m (the total channel height), it was found that the granules close to the front wall were about 4 cm behind the granules in the center of the moving bed. We can roughly say that the wall friction effect was limited within 4% of the granule path.

We have selected 6-mm diameter PE spheres with a density of 964 kg/m^3 as granular solids for the experiments. Packing of the spheres was characterized by the bulk density measurements. Two bulk densities were measured: a poured bulk density of 582 kg/m^3 (porosity 0.396) and a tapped bulk density of 600.5 kg/m^3 (porosity 0.377). Both densities were measured in a graduated glass cylinder. The mass flow rate measurements were made by continuous collection of the discharged granules in a tarred bucket. Weighing of full buckets was made with an electronic balance.

There were two parts of experimental tests. The first is the observations on the flow patterns of filter granules in the whole moving bed channel (Hsiau et al., 2001). The moving bed was circulated for two hours to reach the steady state conditions (meaning the steady bulk density distribution and flow patterns). Then the space between the second pair of louvers under the top hopper was filled with colored granules to observe the flow patterns of the moving bed. A JVC video camera was used to record the development of the flow of colored granules until the colored granules left the granular bed completely. The camera was supported on a sturdy tripod and activated several seconds before the flow of granules was started. A Depict P360F power grabber was used to grab the flow images from the recorded tape.

The second part of experiments was the velocity measurement. For the velocity measurements, a volume of 20% differentially colored granules uniformly dispersed in the moving bed were used as tracers (Hsiau et al., 2000, 2002). The JVC camcorder was used to record the steady flow of the colored granules in one louver section for about one hour. It was believed that the moving bed had reached the steady state conditions. The flow images were grabbed by the power grabber and stored in a personal computer. By identifying the positions of every tracer in the consecutive images, the granule displacements could be measured. Dividing the displacements by the time between two images, the individual granule velocities could be found. The flow region was divided into approximate 500 to 600 subregions depending on the louver configurations. The mean velocity in each subregion was calculated from averaging the whole tracer velocities found within the subregion. Hence the velocity field of the granular flow could be plotted.

Figure 7 shows the flow history of the colored granules in eighteen frames under Position 3 conditions. Frame 1 shows the beginning of the experiment. The time interval for frames 1 to 15 is 120 seconds. The frames following frame 13 have progressively longer time intervals. Figure 8 show the velocity field of the filter granules under Positions 3 conditions. The symbols of X and Y represent the horizontal and vertical coordinates. From Figures 7 and 8, there existed three different flow regions in the louver section, as shown in Figure 9, schematically:

(1) Zone of granular deceleration: This zone is located beyond the exit of the upper louver section. Since the granules move out from the louver section and the sectional area of the flow expands with free surfaces, the filter granules decrease their speed.

(2) Zone of granular acceleration: Opposite of the deceleration zone, the flow accelerates when the sectional area of the flow decreases. There are two locations of the granular acceleration zones: the region between the flow corrective element and the louver section near the bottom of the flow corrective element; and the exit convergent region of the louver section.

(3) Zone of steady flow: This zone is located between the zone of granular deceleration and the zone of granular acceleration. The velocities are comparatively uniform in this zone.

The corresponding flow history and velocity field of filter granules in the same moving bed without the placement of flow corrective elements can be found from the papers by Kuo et al. (1998) and Hsiau et al. (1999). From the histories of flow development in the moving bed, the times for the whole colored particles leaving the bed are 40, 38 and 37 min for flow corrective elements placed at Positions 1 to 3. Correspondingly, the time for the case without flow corrective element placement (with the louver angle of 40°) was 209 min (Kuo et al. 1998). It shows that the placement of flow corrective elements helps the flow of filter granules and diminishes the quasi-stagnant zone. The vertical upward shift of the flow corrective elements in this study also help the flow and decrease the time of colored particles to leave the bed. In the moving bed, the dirty filter granules are removed and cleaned. Then they can be used again. This circulation process is called refreshing of filter granules. For the filter operation, the granules refreshing rate is an important design parameter. Kuo et al. (1998) and Hsiau et al. (1999, 2001) defined the refreshing rate as the mass of the filter granules packing in the bed divided by the time required to completely replacing the whole moving granular bed with a new batch of circulated particles. The refreshing rates are 1.58, 1.62 and 1.71 g/s. The refreshing rate of the case without flow corrective element is 0.4 g/s (Kuo et al., 1998).

Project Description

We then process a lot of experiments. The real filter granules (sands) were also tested. The best configuration of the louver and flow corrective elements was found. A three-dimensional cold test model was designed and installed. The coal ashes were transported from a hopper to a screw feeder to mix with the air to form a modeled flue gas. The dust concentration of the flue gas was controlled by the speed of the screw feeder and the airflow rate was controlled by an air pump. A belt conveyer underneath the moving bed controlled the flow rate of the filter granules. A particulate material collecting system collected the dust concentrations in the inlet and the outlet. The schematic drawing of this apparatus is shown in Figure 10.

According to the cold test results and conclusions, a high temperature MGBF test model will be designed and tested in Industrial Technology and Research Institute. There is a high temperature gas cleanup experimental system has been designed to operate at 800°C. The high temperature test system was characterized into four subsystems: (1) a dust laden hot gas generation system; (2) an on-line analysis system which can measure the concentration and the size distribution of the dust particulate as well as the gas velocities; (3) an independent MGBF system which is exchangeable within the high temperature test system; (4) an energy saving system where the clean hot gas energy can be recovered by heat exchangers to preheat. The schematic drawing of high temperature gas cleanup experimental system is shown in Figure 11.

Results

The parameters controlled in the 3-dimension cold flow test were: (1) gas flow velocity across the bed media ranging from 10 cm/sec to 45 cm/sec; (2) bed media particle size ranging from 2mm to 4 mm; (3) dust laden gas concentration ranges from 5,000 to10,000 ppmw. Figure 12 reveal the MGBF filtration efficiency and the dust concentrations of the outlet gas in the same figure that the efficiency is always better than 99.3% when gas flow velocity across the bed media is lower than 30 cm/sec, however, when the gas velocity is higher than 30 cm/sec, the efficiency decreases seriously.

Figure 13 shows the filtration efficiency of the cold test using flue gas inlet velocity of 30 cm/sec. The dust concentrations of the outlet gas were also shown in the same figure. The filtration efficiency increases with the mass flow rate of the filter media, after reaching the best efficiency, then decreases with the mass flow rate of filter media. For the lower sand mass flow rate, the sands are not quick enough to bring the collected dusts out from the bed; therefore the performance is not good enough. However, for the higher flow rate greater than the critical vale, the sands are too fast to destroy the cake formed in the region close to the gas inlet, and the good filter efficiency cannot be reached. More cold tests and experiments are currently processing to investigate the apparatus.

Though the MGBF can achieve good filtration efficiency. New designs based on the stagnant free zone concept, which can enhance the filtration mechanism, will be soon designed and built up for cold/ high-temperature model filtration test.

About the high temperature gas cleanup experimental system, subsystem (1), (2) and (4) have been installed completely. The subsystem (3) currently is under design and construction based on results and conclusions of the MGBF cold test model. Cold and hot flow dust laden gas trial runs of the other subsystems have been completed. The whole system filtration tests will be soon follow.

Application

Moving granular bed filters are technically and economically applicable for advanced power generation systems such as Integrated Gasification Combined Cycle (IGCC) and Pressurized Fluidized Bed Combustion (PFBC), incineration, calcination, and precious material recovery processes. In addition, MGBF is capable of multi-contaminants such as sulfur; alkali; halide and particulate removal.

Since the subsystem (3) of the high temperature gas cleanup experimental system is designed independently and exchangeable, it is applicable to install any other high temperature technologies in the hot gas test system for testing and comparison.

Future Activities

The MGBF is favorable for high temperature gas cleanup from an economic viewpoint. Advantages are also evident for the MGBF system to removed derived pollutants such as SOx, alkali and halogens. Currently, the ITRI’s MGBF dust removal test achieves good filtration efficiency. The research and testing for improving the filtration efficiency are continually being developed. The multi-contaminant control study will be tested at the ITRI’s MGBF soon.

Acknowledgement

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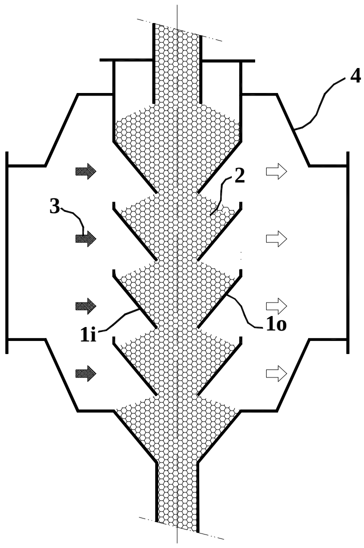


Figure 1. The cross-sectional view of a granular moving-bed apparatus in which a granular material is held by prior art louver-like guide plates.

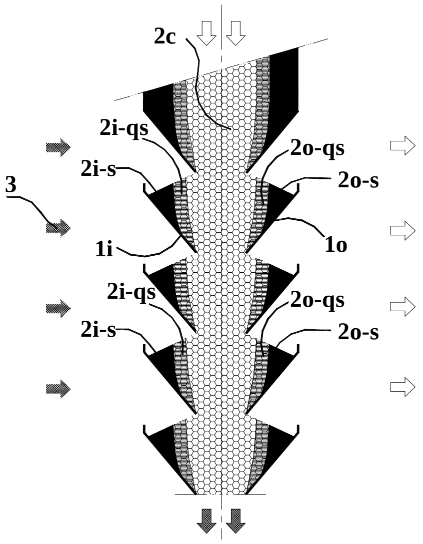


Figure 2. a partially enlarged view of the stagnant and quasi-stagnant zones in the granular-moving bed apparatus of the prior art shown in Figure 1.

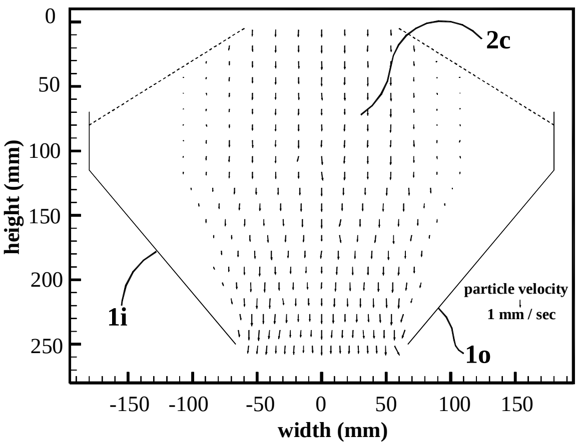


Figure 3. The view of velocity field in granular moving bed with stagnant zones in vicinity of louver-like guide plates of the prior art shown in Figure 1. (Hsiau et al. 1999)

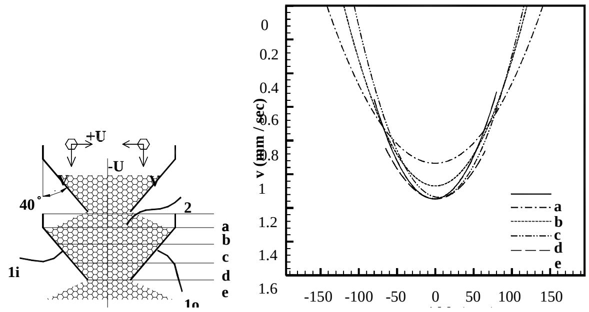


Figure 4. The view of vertical velocity profiles of moving granular bed between louver-like guide plates o the prior art shown in Figure 1. (Hsiau et al. 1999)

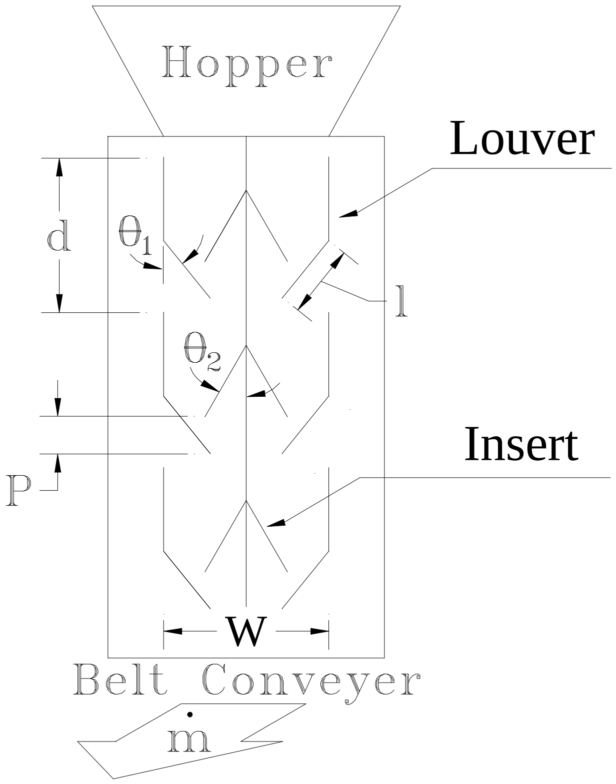


Figure 5. The schematic drawing of the 2D experimental test apparatus.

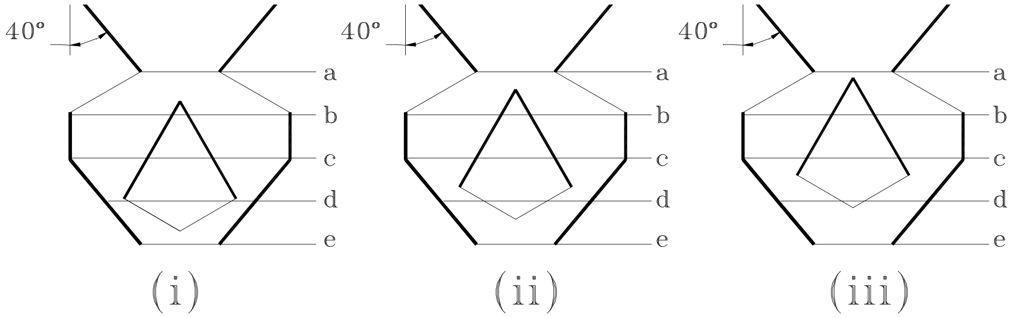


Figure 6. The configuration of the louver geometry and the flow corrective elements for Positions 1 to 3..

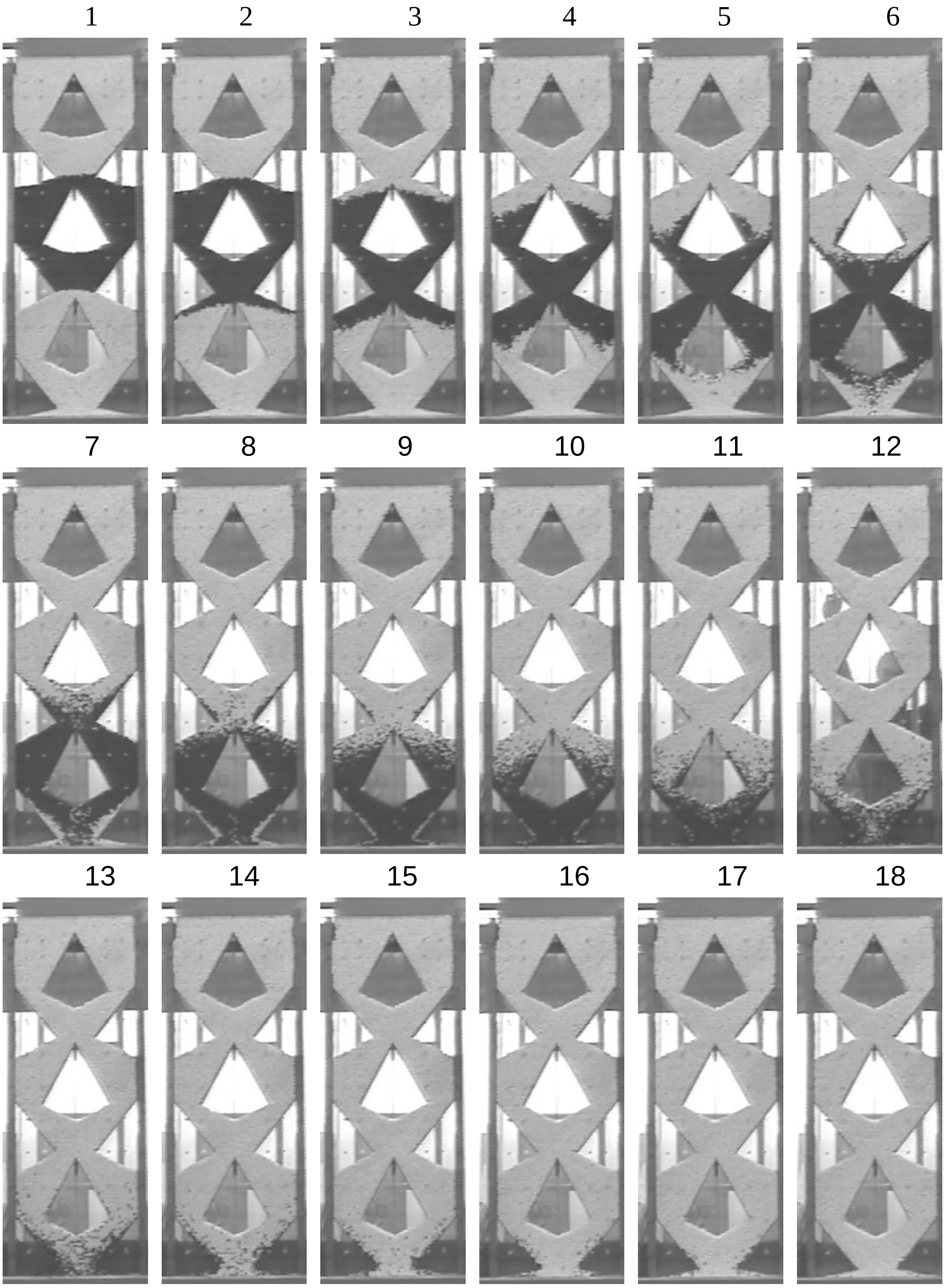
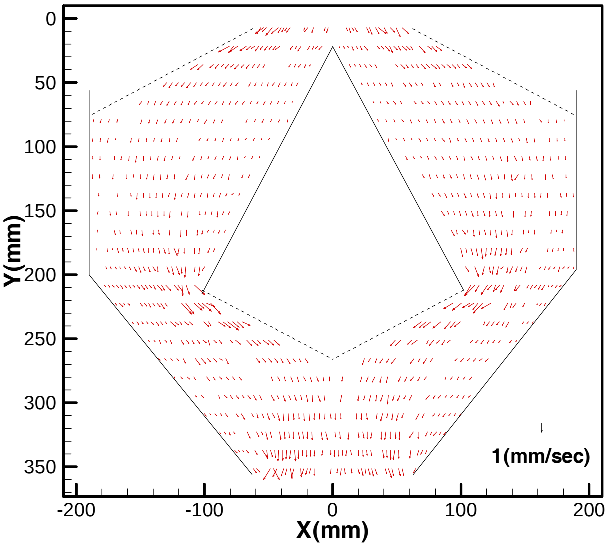


Figure 7. Flow patterns of granules in the louvered channel with obstacles. (Position 3) Frames 1-15, time interval 2 min; frame 16, time 30 min.; frame 17, time 33 min.; frame 18, time 37 min.



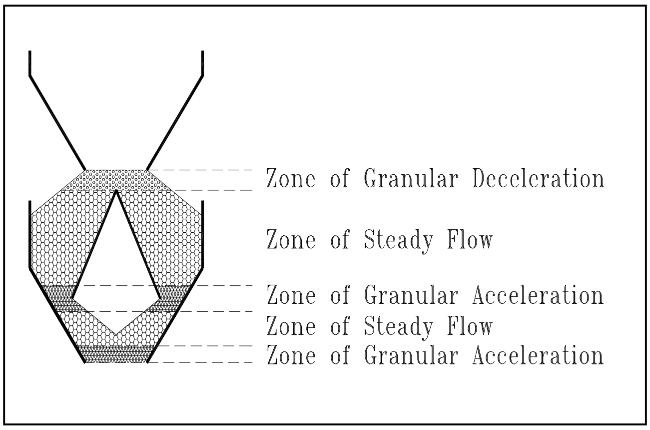


Figure 9. The flow regimes in the channel

Figure 8. The velocity field of a louver section for the test of Position 3.

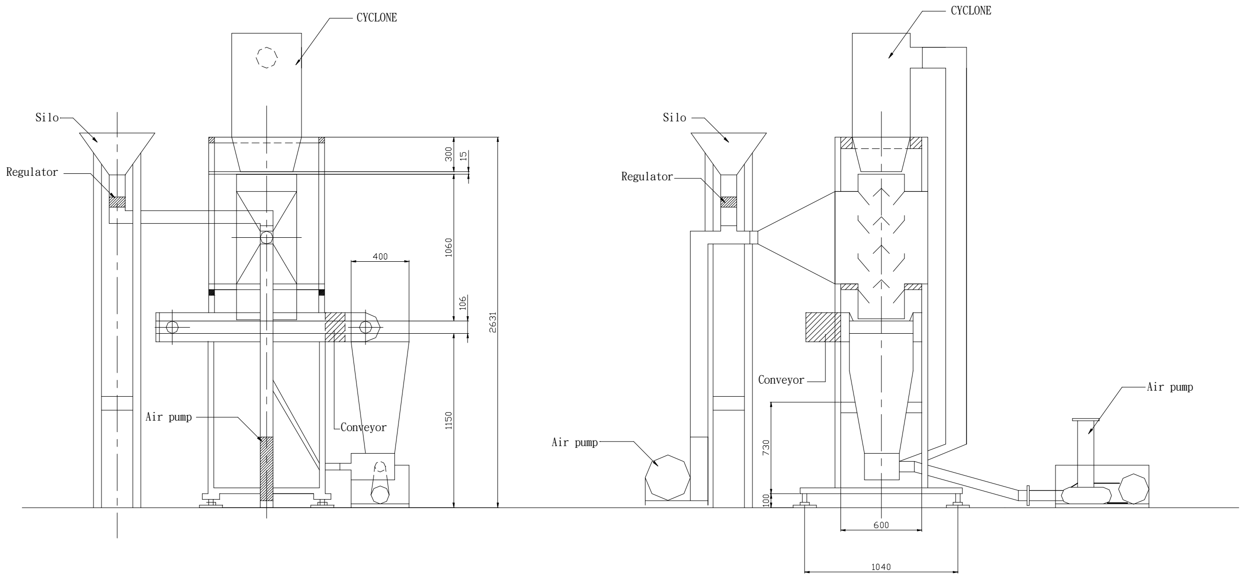


Figure 10. The schematic drawing of our cold test model.

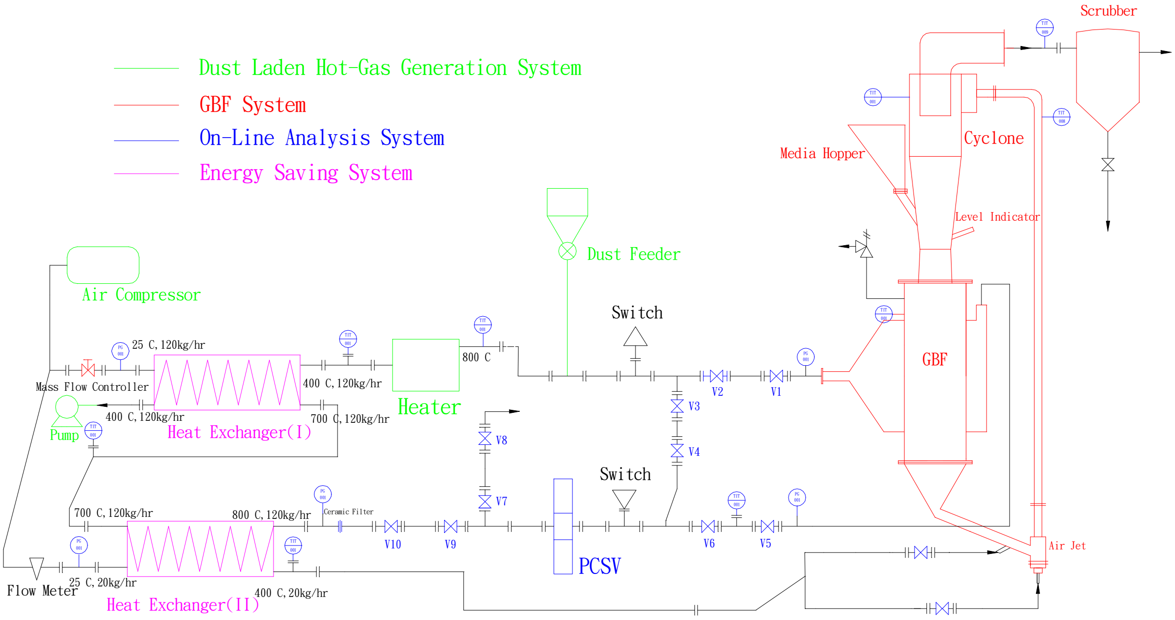


Figure11. high temperature gas cleanup experimental system

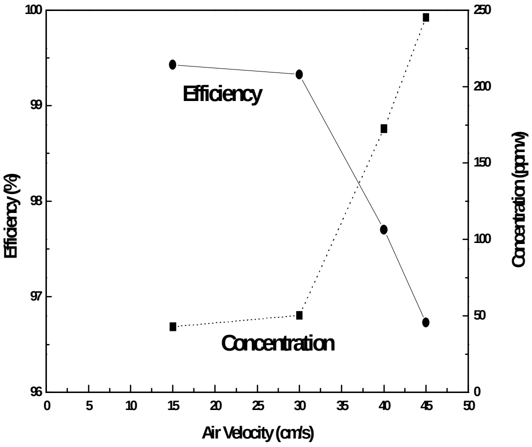


Figure12. The filtration efficiency of the cold model test vs. flue gas inlet velocities

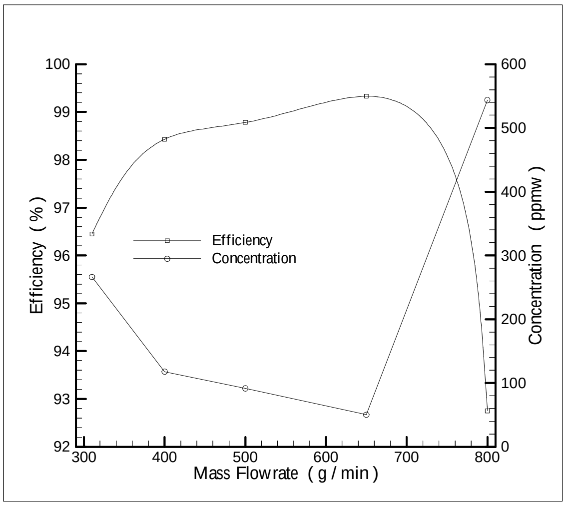


Figure13. The filtration efficiency of cold model test using flue gas inlet velocity of 30 cm/sec.