CB09 - Active Dust Aspiration During Packing Coke Filling

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Abstract

Active dust aspiration during packing coke filling is a new solution developed by Fives. It concerns the anode baking process dedicated to production of primary Aluminum. The invention relates to the packing coke filling which leads to dust emissions in the anode baking furnaces pits. This suction system extracts the fine particles of dust before petroleum coke gets out of the filling pipe. Thus, the packing coke is conditioned before being poured into the pit of the baking furnace. This new type of solution has demonstrated that petroleum coke no longer generates mist due to fine particles, as suction inside the filling pipe is much more efficient than out of it.
Benefits are:

- Environmental: Less dust emissions inside the baking furnace,
- Improvement of working conditions: less exposure for floor operators,
- Economical: carbon savings in the process,
- Quality: participates to a better baking homogeneity.

Keywords: Anode baking furnace, Dust reduction, Carbon saving, Packing coke filling, Furnace tending assembly.

1. Context

The primary aluminum industry is facing relatively unprecedented challenges. Its impact in terms of greenhouse gas emissions is focusing attention on the conditions under which it conducts its operations, particularly among the new generations of operators and engineers. In other words, it will have to produce "cleanly" if it is to remain attractive to its stakeholders. In fact, most of the industry's major players include waste reduction and environmental impact targets in their sustainability roadmaps.

Carbon dust emissions coming from the anode baking furnaces are just one of the issues to be improved if we are to adhere to this new objective of cleaner production. This objective will be more relevant if it also has a positive impact on the quality of operations, and ultimately on operating expenses. Indeed, it is generally accepted that the packing coke quality is a key factor for the right functioning of the furnace firewalls and ultimately for the anode baking quality [1]; as an example, Zhaohui Wang et al. [2] cite the fine coke as a factor contributing to the carbon build-up on the refractory walls.

1.1 General Information about Anode Fabrication

Primary aluminum smelters produce metal using the Hall-Héroult process which, in its modern application, involves positive electrodes made of pre-baked carbon blocks [3]: the anodes. Given that the consumption of anodes is roughly around 55 wt. of the smelter's metal production - gross carbon consumption being around 550 kg per ton of primary aluminum - the anode manufacturing process is an important activity, whether it is carried out within the foundry or in specialized plants that produce only anodes. There are two main stages in the manufacturing process of anodes: the formation of raw anodes, performed in green anode plant (GAP), where a paste is prepared by mixing solid coke and liquid pitch and then is put in shape and baking of the green anode in a furnace, generally referred to as an anode baking furnace (ABF).

Carbon dust generation in the smelter is due to dry material handling, so it should occur mainly upstream in the GAP where dry solid material is processed (handling - crushing – screening – milling – storing – dosing, etc.). A dust collection system, made of various extracting hoods located in fixed judicious places, connected to a ductwork and finally a to an extraction fan with a filter bag, avoids excessive emissions. The other area in the smelter where carbon dust is generated is in the ABF; where the dust emission is not due to the handling of the anodes, but rather to the use of a packing material made of coke (packing coke), which is handled at time an anode batch is put in or remove from the furnace. The present paper will focus on the circumstances where dust in generated in the ABF with packing coke handling. To better visualize the problem, Figure 1 shows a typical aerial view of an aluminum plant, where dark zones correspond to carbon material processing.

Figure 1. Bird's-eye view of an aluminum smelter.

1.2 Role of the Packing Coke

During the anode baking process, part of its pitch constituent is burned while another part is coked, thus ensuring increased cohesion of the material with all the desirable characteristics for good performance in use on the electrolytic cell. This baking process lasts several days; in the initial phase, the anode passes through a relatively soft phase before the coking of the pitch gives it more cohesion, so it needs to be constrained like in a mold. On the other hand, the anode material cannot be directly exposed to the flame of a heating system, nor to the air that would oxidize it - it must therefore be insulated in some way. That is the purpose of the packing coke: 1) to maintain anodes within the pit and 2) to prevent the burning of the anode material during the firing process.

In practice, as it can be seen in Figure 2, the baking furnace comprises of a series of cells, called pits, where several layers of anodes are loaded, separated by double-walled partitions – the firewalls - in which gases are burned to provide the necessary energy. The packing coke is put around the anode blocks, between the external faces of the firewalls. The flames of the burning gases have no contact with the anodes to bake so the protective packing coke will conduct the heat towards the anode. During the firing, gases emitted by the heated anode material are sucked by the firewall cavity which is maintained with a certain vacuum.

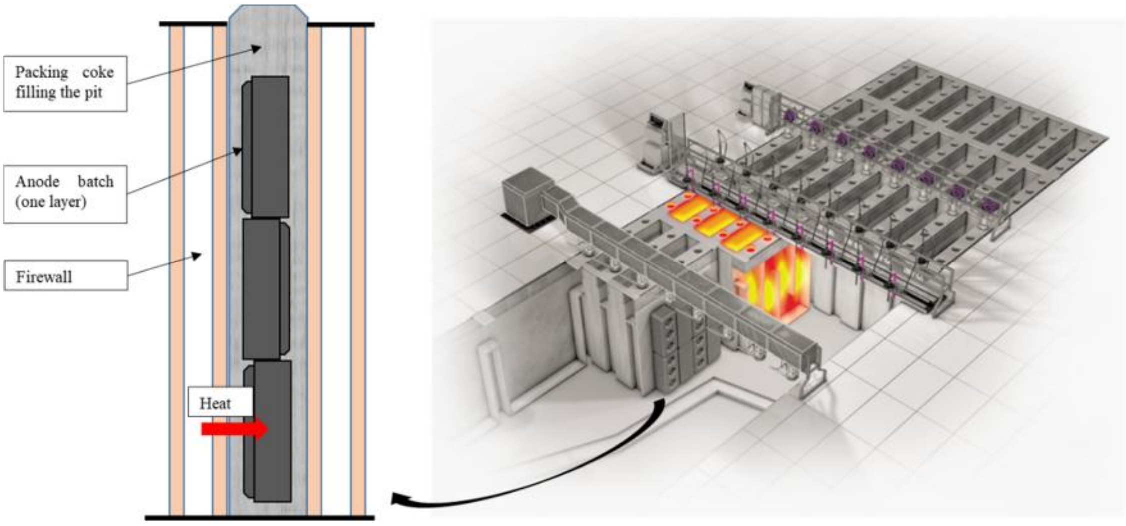

Figure 2. Right: View of a series of pits with firing ramps, Left: Cross section of a pit and its next firewalls.

Green anodes are placed in several layers into chambers and are surrounded and covered by a granular packing material in order to achieve the following:

- Protection of anodes against air burn from oxidizing gases
- Prevention of anode deformation during heat up
- Efficient heat transfer from flue walls to anodes

After baking, the packing material is removed by vacuum and the anodes are taken out; the packing coke is then reused for packing new batches of green anodes. The typical grain size range of the packing coke is 1 to 20 mm. So the packing coke must have special characteristics to both protect and maintain the anodes, to carry efficiently the heat, meanwhile it must allow the transfer of volatile gases and it must not facilitate the build-up of carbon deposits on the walls.

The typical packing coke grain size distribution (GSD) is shown on Figure 3. This GSD is the result of the coke characteristics as supplied, of the attrition effect due to the alternative deposit/removal cycles, of the partial burning and aggregation during the firing cycle and finally of the elimination of a fraction of the finest particles by the dedusting system located in the pneumatic handling circuit.

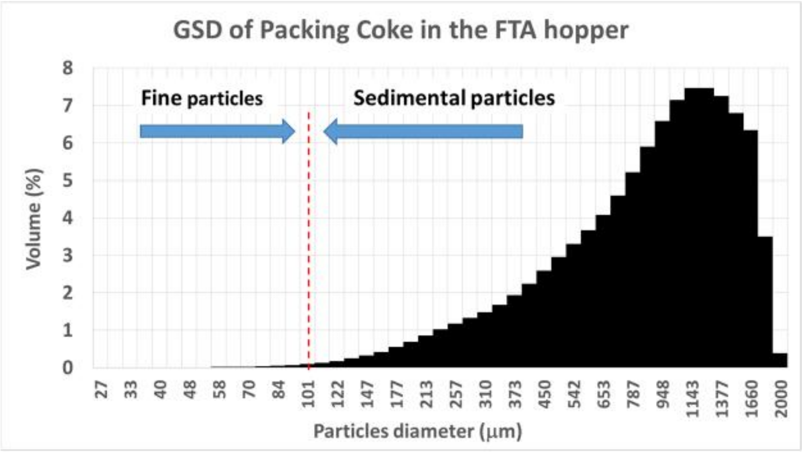

Figure 3. Grain Size Distribution of a packing coke in use.

1.3 Anode Batch Operation in ABF

The anodes are put in and removed from the ABF pits by layers of several units, one layer at a time, using a special grab embedded in the furnace tending assembly (FTA), the special crane in charge of that operation. Figure 4 shows such a crane handling a batch of anodes on top of the ABF pits.

Figure 4. View of an FTA crane handling a batch of anodes.

The operations are carried out as follow:
- Spreading out a first layer of packing coke on the bottom of the empty pit; the aim is to get a horizontal plane as much as possible,
- Picking of an anode batch from the conveyor – located usually in the axis of the ABF,
- Lifting of the grab and translation to the target pit,
- Laying of the batch within the pit,
- Filling of the gaps around the batch with packing coke, using a special tool embedded on the FTA (the filling pipe),
- Repetition of the sequence for each anode layer,
- Covering of the last layer with packing coke on top of it,
- Baking of the anode batches (20 days approximately),
- Removal of the packing coke using a special tool embedded o the FTA (the suction pipe);
- Unloading of the baked anodes from the pits, using the FTA grab,
- Translation and deposit of the anode batch on the conveyor,
- Anodes are then cleaned from their adhering packing coke, before to be sent to the anode storage area or to the anode rodding shop.

The packing coke material is stored in a hopper embedded on the FTA between the suction and filling phases. These operations (filling and sucking only, excluding the anode batch handling with the grab) represent 40 % of the total daily open time for a standard furnace crane. This is during the pit filling, either at the bottom of the pit, or around the anodes, or on top of the last layer, that large amounts of dust are generated in the ABF shop. The removal being done by suction, dusts are naturally captured during that packing coke handling phase.

1.4 Packing Coke Filling

The FTA crane, which is operated in the ABF, is generally equipped with a main hopper with a capacity of 30 to 40 m^3, which is used to store the packing coke, after its removal from the pits or before its deposit around the anodes in other pits. This storage is therefore located several meters higher than the top surface of the pits.

The pit filling is made using a telescopic pipe fixed under the hopper outlet where a valve allows or prevent the flow of the material. Figure 5 shows such a general arrangement of the tools embedded under an FTA cane.

The packing coke is spread:

- At the bottom pit to get a layer of 10 cm approximately. This is to stabilize the packets when they are loaded;
- All around the packets to prevent burning anode during baking. The packing coke distributes the heat evenly;
- on top of the anodes to avoid anode oxidation during baking;
- finally, a plastic film cover is laid down to partially seal the pits from air inlet.

2. Current Practice Performance and Room for Improvement

Depending on the ABF design, the quantity of packing coke per pit is around 10 m^3. That means for a set of 7 parallel pits (a section) that 70 m^3 of packing coke must be handled for each filling or emptying operation when a fire is moved (the firing systems progress by one section each on a regular base – the said firing cycle – approximately 24 h).

Taking into account the organisation of the operations in the ABF, where several firing systems are progressing simultaneously, one can consider that during one day (3 times 8 hour-shifts), the crane is filling and removing 210 m^3 of packing coke from the hopper. Even if only a small fraction of that quantity is lost through dusting, this leads to significant emissions and deposits.

Figure 5. Embedded tools on a FTA.

During filling operation (30 % of the operation time of the crane), the packing coke which includes fine particles and is stored in the main hopper, follows down by its own weight inside the telescopic tubes to reach the pit. This chute of several meters, as shown on Figure 6, gives a rather high speed to the material and so generates some turbulences at the outlet of the pipe where a dusty black cloud is formed.

2.1 Order of Magnitude for Such Dust Generation

A suction system is usually integrated to the filling pipe tool in order to mitigate such effect. It can be for instance a de-dusting sleeve around the telescopic pipe. But this way of de-dusting is not efficient enough and creates a lot of dust in the air. Figure 7 shows such a device and the usual efficiency one can observe.

From the GSD of Figure 3, it can be estimated that 1 % (vol.) of the packing coke is less than 100 micrometers. This is that fraction which generates suspension particles during the operations. This fraction is built because of the attrition between coke grains and their collision against the tubes and elbows of the filling pipe tool.

- Volume of packing coke filling = 210 m^3/day
- Quantity of fine particles in the distributed packing coke: 210 × 0,01 = 2,1 m^3/day
- Packing coke flow density = 900 kg/m^3

A fraction of that dust is spread out in the workshop, probably equivalent of several dozens of kilograms per day.

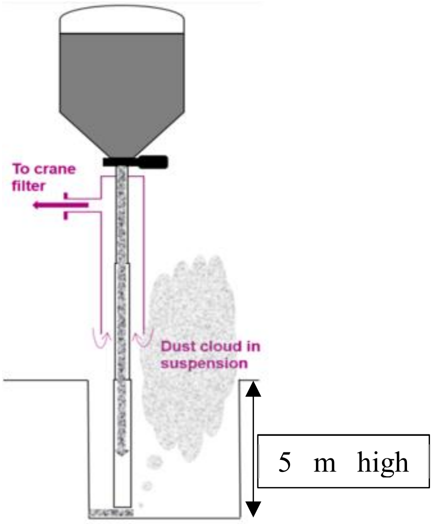

Figure 6. Schematic cross section of the filling pipe under operation.

Figure 7. Present dust suction system. Left: local suction device, Right: Dust emissions as observed.

2.2 Health and Environmental Impacts

The implementation of powdery materials and the associated operations such as weighing, mixing, transfer, etc. are likely to suspend dust in the air which can be inhaled by the operators as well as by all the employees present in the workplace. Such dusts spread also outside the ABF building. Exposure to these dusts can lead to the development of pathologies. So personal protective equipment is usually required in the dusty areas. To significantly reduce the level of airborne dust, it is recommended to capture the dust at the source.

For instance, the France's regulation relating to the ventilation and sanitation of work premises takes the airborne dust into account, in particular by setting concentrations not to be exceeded for premises with specific pollution. These concentrations have evolved recently. From July 1, 2023, they have been set at 4 mg/m^3 instead of 7 mg/m^3 in 2022. Before 2022, the rate was commonly set at 10 mg/m^3.

In addition, carbon dust is conductive and a layer of fine particles in electronic components or power panels can create short cuts or even arc flashes which can lead to serious incidents.

The FTA is using a sleeve fitted on the filling pipe to collect the fine dust in the air, but this solution is not efficient enough to reach the new expectations. The solution which has been investigated consists of removing the dust in a close box located upstream the flow material just under the chute of the hopper, it reduces significantly the dust scattering in the air.

3. New Device for Enhancing the Dust Collection during the Pit Filling

3.1 Description

As shown on Figure 8, the dust is captured before it spreads in the workshop by creating an air counter-flow through the packing coke stream, the one on the top of the filling pipe, close to the hopper chute. The air counter-flow removes the fine particles from the falling material, leading to a grain size segregation in the 200 micrometers range.

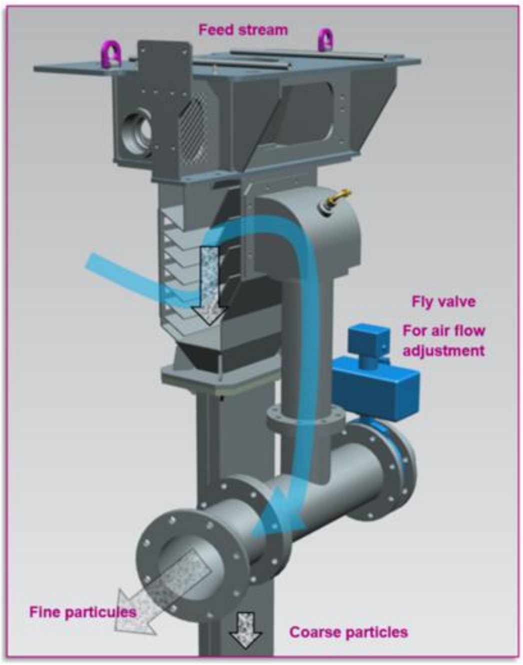

Figure 8. New air separator fitted on top of the filling pipe.

The cross-air flow is generated with the existing vacuum circuit which is used for the suction pipe, as seen on the Process Flow Diagram of Figure 9. So, the dust is carried through the existing filtering chain of the FTA. The dust is collected and screened the same way as for the packing coke is during its removal from the pit.

This active dust collection can be installed in new cranes as well as on existing ones as in a modernization project. For that latter case, only a room of about one meter height between the main hopper bottom and the filling pipes must be allocated. This is easily adaptable.

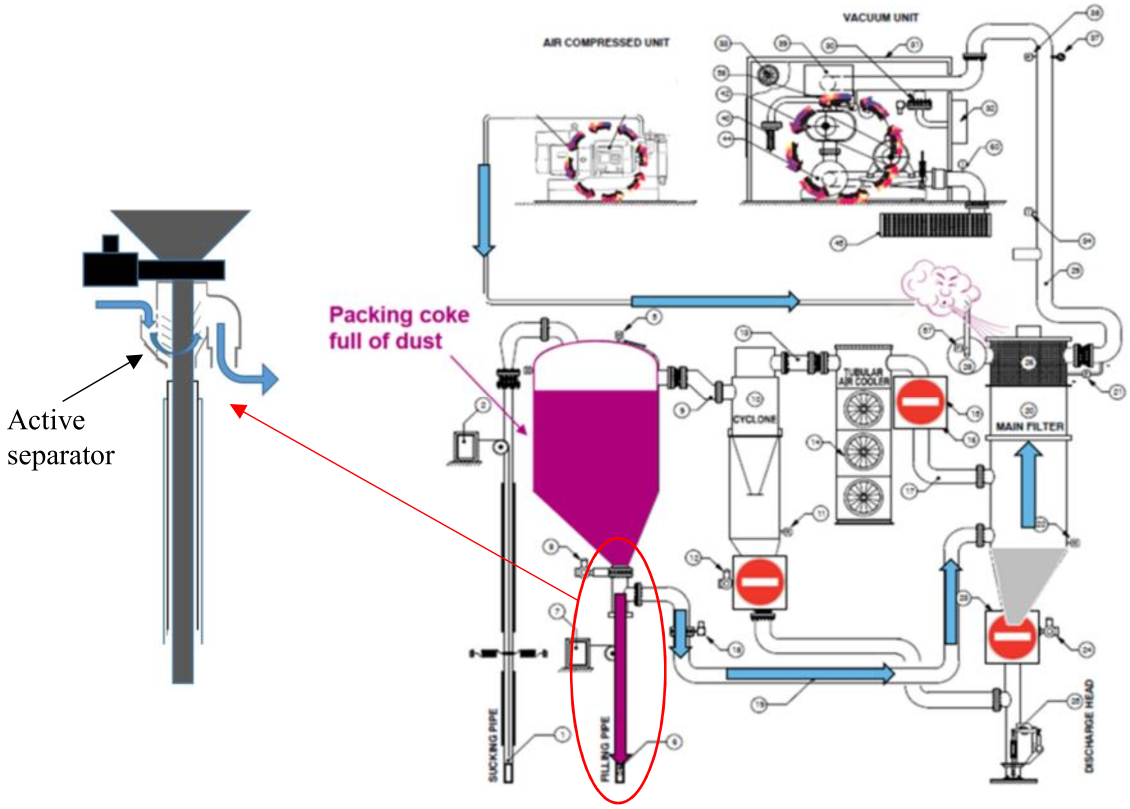

Figure 9. Process Flow Diagram of the vacuum chain of an FTA.

3.2 Modelling

In order to optimize the design, we numerically simulated the distribution of particles in the body of the dust separator. The objective of this simulation is to study the efficiency of the device for sorting particles with a diameter less than 200 µm.

For that purpose, we used the Ansys & Fluent software suit by combining two analysis: a finite volume method to solve the equations of fluid mechanics and a discrete element method for solving the particle motion. The simulation has been simplified by considering a 15 mm-thick slice located in the middle of the separator, which is representative of the air and particle flow.

Two distinct geometric models have been built, one for each analysis, as illustrated in Figure 10. A first model constitutes the so-called "Fluid" model and represents the volume of air in the separator. A second model constitutes the so-called "Solid" model and represents the boundaries of the dust separator.

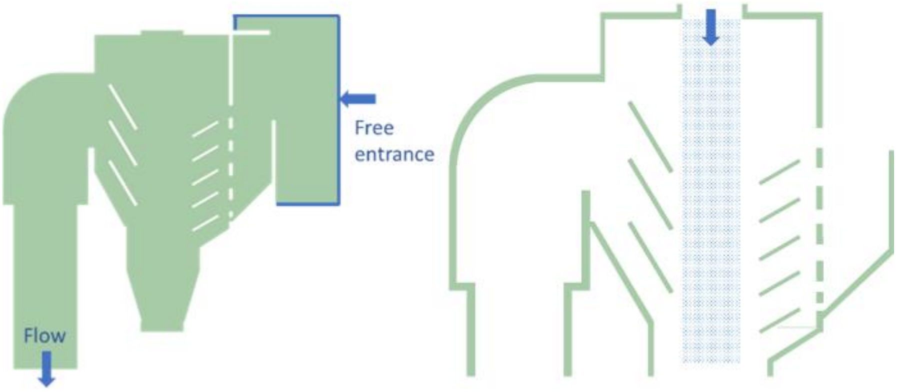

Figure 10. Left: Domain for fluid resolution. Right: Boundaries for discrete resolution and area of initial location of dropping particles in the central area.

The computing sequence is the following: 1) analysis for initial air flow distribution; 2) evolution of the same flow distribution with the presence of the solid material in the central area; 3) discrete analysis of the particle trajectories. Each step taking into account the results of the previous one.

Assumptions for the fluid flow modelling are the following: non symmetrical conditions in a turbulent and non-stationary flow; thermal transfers are neglected; the fluid is considered as incompressible and has the properties of the air which are maintained constant.

For the discrete modelling, only particles with a diameter greater than 92 µm in diameter have been simulated to alleviate the model; that nevertheless represents 99.77 % of the total packing coke particles. It is considered that if almost all particles with a diameter slightly larger than 92 µm are sucked in by the airflow, particles with a smaller diameter will also be sucked in.

The initial state for the fluid analysis is an established flow in the separator (Figure 11 – Left). The air flow at the outlet frontier has been adapted to get equivalent average speeds for the whole device:

- In the middle of the separator (area where the particles left the main flow),
- At the air intake (area where particles are sucked out of the device).

Then a porous medium in simulated in the central area to get the final air flow speed distribution (Figure 11 – Right). One can observe that the speed distribution through the inlet and outlet fins is slightly evened, this is due to the additional pressure drop created in the central area by the dropping material.

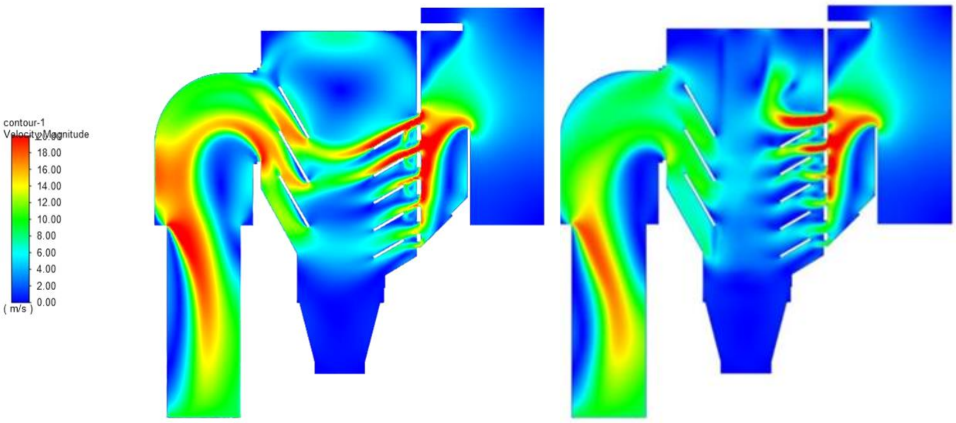

Figure 11. Left: Initial air flow speeds. Right: Final air flow speeds with the presence of porous medium in the central area (scale 0–20 m/s).

The initial state for the solid discrete analysis is a dense flow of free-falling particles in the central area of the separator (Figure 12). The inlet mass flow rate of such particles has been adapted to the slice thickness of the simulated model, assuming that the material is evenly distributed over the width of the separator.

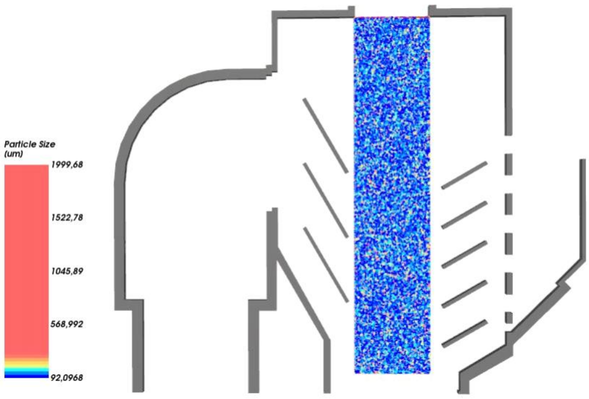

Figure 12. Initial particle distribution for the discrete analysis (color scale is set according to the particle size, but each particle is plotted as a single point: Blue 92–124 μm; Green 124–155 μm; Orange 155–187 μm; Red 187–2000 μm).

Figure 13 presents the kind of visualization of the results obtained after this last discrete analysis. The left figure shows the trajectories of the finest particles, which are removed from the main falling flow. More precisely, one can see that the selective effect occurs on the side of the main flow close to the crossing air outlet, but it is estimated sufficient; a better design would be to distribute the product in a finer and wider way, but it is poorly achievable in terms of engineering integration between the hopper chute end the filling pipe which has a section imposed by the ABF pit design. The right picture represents the particles distribution according to their size and it confirms that a selective effect is achieved on the expected range, close to 200 mm approximately: the “red” coarser particles flowing the normal vertical path, a great part of the “blue” finest ones being lifted and then dragged with the crossing air.

In terms of result quantification, the technique consists of getting from the simulating software the GSD in volumes set at the device outlets (one for the fines and air outlet; the other one for the main product flow), by considering a full cross section and a significant thick layer – such volumes are represented as V1 and V2 on the Figure 13 – Right picture.

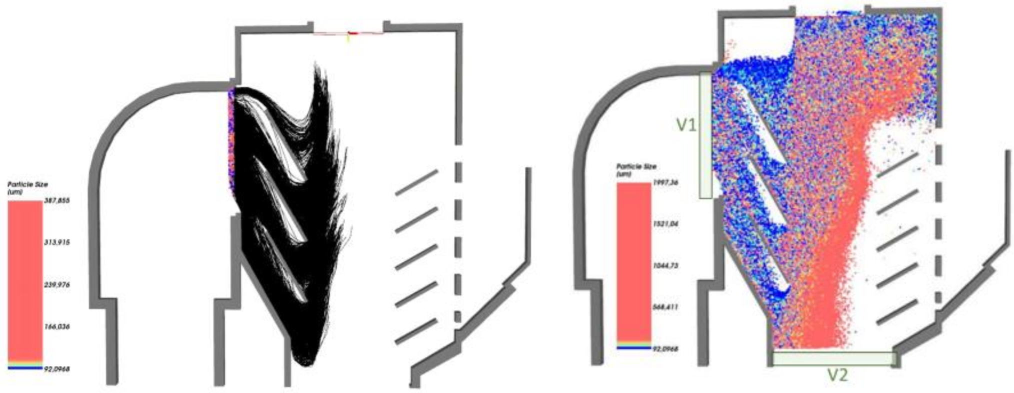

Figure 13. Left: Trajectories in the flow for 92–100 μm particles. Right: Spatial particle size distribution in the stabilized flow after the last computing step (same color scale as plotted in Figure 12).

The simulation also confirmed that the classifying value is depending on the counter airflow velocity, this last can be adjusted roughly with a derivative fly valve on the outlet duct and then precisely by a louvered damper at the inlet side.

Fins located at the inlet of the separator orientate the cross airflow downwards meanwhile the fins located at the outlet side do it upwards. This fast change of direction improves the classifying effect. This numerical model not only confirms the efficiency of such selector, but allows to adjust design details not explicated here.

3.3 Simulated GSD for Extracted Dust

Table 1 data show that only fine particles are extracted, as 90% of the dust is composed of particles smaller than 175 μm without any particle greater than 387 μm.

Table 1. GSD of dusts at the crossing airflow outlet.

Particle size (μm)	Cumulated percentage (units)
100	50%
135	75%
175	90%
387	100%

The calculated volume of fine particles selected by the separator is 1.5 m^3 per day, this amount is directed to the fine particle hopper fitted under the bag-filter casing and at a later stage (for instance each end of shift) redirected to the fine collection unit installed in the building.

3.4 Advantages

The main advantages of this new device are the following ones:

- The dust extracted this way is no more lost and can be reused in the past plant,
- The packing coke is cleaner. There is no more excess of fines, its characteristics are maintained constant during the repetitive filling-removal cycles, for instance porosity,
- Pneumatic transport of the packing coke during unloading is easier,
- The classification set point can be adjusted by the inlet and outlet valves,
- The device has no mechanical part in the flow of the packing coke so it can be neutralized very easily in case of malfunctioning.

4. Conclusion

The active dust removal system has positive aspect regarding the environment.

It has been designed and validated by numerical calculations. It performs better than an external dust extraction sleeve because it extracts dust at the source, within the circuit. Daily use of this system gradually evacuates the excess dust and thus guarantees a better quality of the packing coke.

In addition, the advantages of implementing this system are numerous. There is much less dust generated which contributes to better working conditions for the floor operators.

Another advantage induced by this solution is a contribution to the cleanliness of the site. Finally, the system permanently eliminates the dust removal sleeves, which highly improve the crane cabin operator's vision during the pit filling.

The next step is to test the system as a pilot in a shop to confirm its performance in real conditions. It should be noted that the implementation of the active dust removal system is simple to set up, accessible financially and reversible. A patent application for such a solution has been filed.

5. References

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