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Heat exchange and separation efficiency in a cluster of gas-solid separators in a complex cement production plant.

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Abstract

This work presents a study on a gas-solid cyclone separator used in a complex cement production plant. The main objective of the study consists on the performance evaluation and optimization of the cyclone separator in terms of particle separation and heat transfer efficiencies, while keeping pressure losses under control. The thermal interaction is between two gas-solid mixtures, one at 850 °C and the other at 600 °C, respectively. The solid phase consists mostly of calcium carbonate subsequently intended to the so-called baking process for the production of clinker and ultimately cement. A first model has been setup using experimental data as boundary conditions to assess the physical model behavior and the CFD solver parameters. After that, five additional models with different geometries have been analysed to evaluate the influence of the *vortex finder* (*vf*) length on the separation efficiency and on the heat exchange performance. Increasing the length of the *vf*, the results show a global improvement in the separation efficiency of up to 5% if compared to the geometry without the *vf*. Further, the increasing of the *vf* length determines a monotonic decrease of temperature at the exit but a monotonic increase of pressure losses. In the second part of this work, using one of the previous models with *vf*, a study of the influence of the particle diameter on the separation efficiency has been performed. The increaseof particle diameter causes an increase of the separation and thermal exchange performance, decreasing at the same time the pressure drop. The numerical approach for all the cases is based on implicit unsteady simulations using the Eulerian Multiphase model

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Keywords: cyclone; Eulerian multiphase; gas-solid heat exchange; computational fluid dynamics; geometrical optimization.

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1. Introduction

The present studyis a step of a longer activity aimed to optimizethe heat exchange betweena flow of gasat high temperature (about 900°C) and the raw materialpowder(consistinglargelyof calcium carbonate), to be submitted to thecooking processfor the productionof"clinker", and then of cement.Much of thisheat exchange takes placein apreheating towerconstituted bycyclones andconnection pipes: the flow ofhot air from theovenmeets, in countercurrent,the raw materialto be preheated. The dried raw meal is preheated and even partially calcined (dry/semi-wet processes) while is held in suspension with the hot gases coming from the rotary kiln. At least in theory, a wider contact surface allows a heat exchange nearly complete. These systemsusually have fromfour tosix stagesofcyclones, which are arranged one over the otherto forma tower with a height varying from 50 to 120m. The stadiumon topcan beconstituted by twoparallelcyclonesfora better separationof the powder.In general, the task of a cyclone is the removal of solid particles from a gas with a consequent beneficial effect on the air pollution control. At this aim, a lot of studies available in literature [1-15], developed by many authors, have been widely studied both numerically and experimentally with the main goal of increasing the separation efficiency. Multiple studies [1-8] demonstrated the decisive influence of both operating parameters and design on the separation efficiency and pressure drop.

The CFD-3D analysis is an efficient and economical approach of understanding the fluid dynamics process in complex plants, providing a precious way to evaluate how it is affected by changes of operating conditions and geometric shapes. At this aim, the *CFD* approach has been used by many authors [1, 8-15]; the papers deal with issues relative to the flow of gas-solid suspensions predicting solid separation efficiency, at different operating conditions, in good agreement with the experimental evidences. Furthermore, in [13-15] the authors proved as the Reynolds Stress Model is the suitable turbulent model for cyclone with strong swirling flow.

In this work, the authors used the *CFD* approach to evaluate numerically the thermal exchange, the separation efficiency and the influence of the grain size on the cyclone performance.

The complex plant studied in the present paper is an assembly of cyclones as a part of a process whose industrial goal is the production of the cement. This type of problem can be classified as a multiphase system with heat exchange where the air is the continuous phase, at a temperature of 850 °C and the dispersed phase at 600 °C consisting, mostly, of *Calcium Carbonate* (density equal to 2063 kg/m^3), subsequently intended to the so-called baking process, in order to produce clinker and then cement.

In the first phase, some simulations were carried out with the aim of obtaining results in agreement with the available experimental data; these simulations were executed on the reference case #1, characterized by the *vf* length equal to zero.

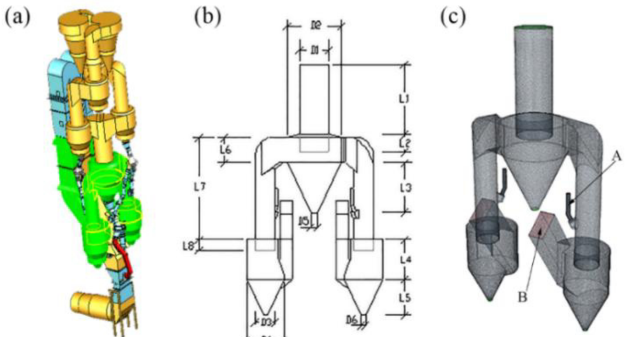

Figure 1: geometry (a,b) and mesh representation (c) of the cyclone system

2. Model

2.1. Cyclone separator

Together with the table 1, fig. 1(b) shows the geometrical dimensions of the cyclone separator model. Fig. 1(c) shows the volumetric model where A and B represent the main and secondary feed respectively; the same figure shows the mesh constituted by about 500000 polyhedral volumetric cells with a base size of 10 cm, a minimum cell size of 2 cm and 2 prism layers at the walls. The transparent visualization enables to see the presence of the vortex finders, the lengthof whichcharacterizesthe sixsimulated models.

Table 1: Geometry of the cyclone

Parameter	Symbol	Size [mm]	Parameter	Symbol	Size [mm]
Diameter of upper vortex finder	D1	3370	Length of upper vortex finder	L2	*
Diameter of upper cylindrical part	D2	6250	Length of upper conical part	L3	5670
Diameter of lower vortex finder	D3	2320	Length of lower cylindrical part	L4	4583
Diameter of lower cylindrical part	D4	4330	Length of lower conical part	L5	4119
Diameter of upper spigot	D5	780	Length of upper cylindrical part	L6	2891
Diameter of lower spigot	D6	500	Length of lower outlet tube	L7	11700
Length of upper outlet tube	L1	8014	Length of lower vortex finder	L8	*

2.2. Numerical model

For incompressible, unsteady and non-isothermal flow in cyclone separator, the eulerian-multiphase model has been used. This model treats a dispersed multiphase flow as two (or more) fully interpenetrating quasi-fluid and also considers the interpenetrating effect of each phase by using drag model. The volume fraction of each phase is defined on the basis of the distribution of each phase and the size of computational volume. The difficulty solvingthis model is twofold:first, the equations are difficult from a numerical point of view, since there are many coupled equations with one shared pressure;secondly, to solve the equations, closure models are required for τ and F_k , which represent respectively the rheology of the phase and the interaction force with the other phases.

A 2-Layer Realizable K-ε model has been applied to the gas phase and a Modified Johnson Frictional model was used to evaluate the stresses in granular medium.

The CCM+ 9.6 packagewas used to solve the equations by the finite volume method. The boundary conditions concerning the feed of the cyclone (A and B in fig. 1(c)) are summarized in table 2

Table 2: Boundary conditions

Inlet port	Gas mass flow [kg/s]	Solid mass flow rate [kg/s]	Gas/solid temp [°C]
A	31	25.5	850
B	36	23.5	600

3. Results and discussions

Tables 3 summarize the various length of the vf used in 18 different simulation. To analyse the influence of the top and bottom stage, each section was singly analysed. The first 6 simulation was performed varying only the length of upper vf, after that other 6 simulation was performed varying only the bottom vf length, and, at last 6 simulation was performed varying all the vf length.

Table 3: Variation of the vf length of all cyclones

case	upper vf length [m]	lower vf length [m]
#1	0	0
#2	0.44	0.37
#3	0.87	0.75
#4	1.31	1.12
#5	1.73	1.50
#6	2.60	2.25

The simulation #1 (with vf=0), reproduces exactly the systemcurrently in operation; the experimental values of temperature at the exit, pressure drop and separation efficiency differ, from the simulated one no more than 1.5%.

The greater is the vortex finder length the greater is the number of particles that bumps against its wall. The frictions and collisions are the basis of decrease of particles velocity, then promoting their collection. The slight decrease of temperature at the exit, is due to the simultaneous increase of the contact time of the two feeds caused by a greateraverage particlepath, before their expulsion (Figure 2). It is also obvious the reason of the modest increase of the pressure drop that it is the effect due to the increasing intrusiveness of the vortex finder.

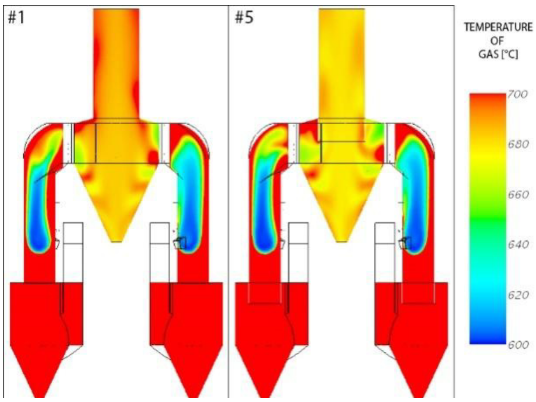

Figure 2: 2D representation of gas temperature concerning the cases #1 and described in Table 3

In the previous figure, it is possible to observe the positive effect of the vortex finder on the separation efficiency mainly due to the barrier effect while, to the other site, there is a negative effect on the pressure drop whose increase is due to the vf intrusiveness.

Figure 3 represent the value of separation efficiency (left) and gas outlet temperature for the 16 cases. Taking into account the simulation #5, the introduction of vf, produces an increment of the separation efficiency of about 1% and a reduction of gas outlet temperature of about 1.7%; respect to the case #1.

The simulations #5A and #5B (Table 4) implement another parametric study developed by varying the particle grain size. Table 6 compares the two simulations with the previous case #5. As well known in literature [1-3, 5, 6, 10, 14], it highlights that, increasing the grain size, the separation efficiency increases while the temperature at the exit and the pressure drop, decreases. Gravity, centrifugal forces and friction play a fundamental role on the decrease of kinetic energy of particles and then on the increasing of the efficiency.

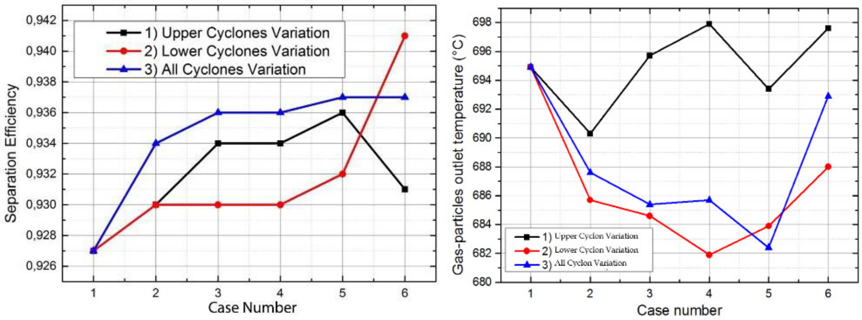

Figure 3: Separation efficiency (left) and gas outlet temperature (right) trend for the 18 simulation, grouper by geometry type.

Table 4: Effect of the particle diameter on the separation efficiency on the temperature at the exit and on the pressure drop

Case	Particle diameter [μm]	Separation efficiency [σ]	Gas outlet temperature [°C]	Pressure drop [Pa]
#5A	30	0.722	722	785
#5	63	0.937	682	659
#5B	120	0.984	678	476

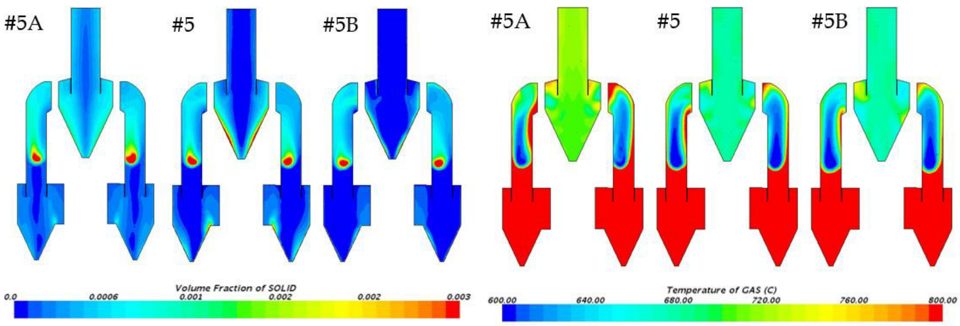

Figure 4: Influence of grain size variation on particle volume fraction (left) and gas temperature (right).

4. Conclusions

The present study is a parametric study that considers, as parameters, the vortex finder length and the particle grain size, alternatively. The experimental values of temperature at the exit, pressure drop and separation efficiency differ, from the simulated case #1 (vf length=0), no more than 1.5%. Case #1 reproduces the geometry of the systemcurrently in operation. In all simulated cases, the greater is the vf length the greater is the solid separation efficiency, while the pressure drop constantly increases of a few Pascals and the exit temperature decreases until a certain value of the vf length and then inverts its trend.

The last part of the work evaluates the effect of the particle grain size on the main performance parameters of the cyclone. To this aim, three cases were simulated with particle diameter equal to 30μ, 63μ and 120μ, corresponding to the cases #5A, #5 and #5B respectively. 63μ is the mean particle diameter value in the operating system. The increase of the particle diameter, results in a better separation efficiency up to 9%, in the case # 5B, with a consequent low variation percent of the exit temperature and a considerable decrease of the pressure drop.It is in progress an activity of simulation,of the same plant, that considers the simultaneous presenceof particles with different diameters according to asuitabledistribution function.

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Biography

Francesco Risi Born in Tarquinia (VT) on 11/06/1984. Graduate in Mechanical Engineering in Perugia in 2012; currently enrolled at the second year of PhD school in Industrial Engineering. He focused his research activity in numerical analysis of internal and external flow of machines using CFD/3D analysis.