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The influence of the riser outlet geometry on erosion of a FCC using dense discrete phase model

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***Abstract*— The erosion caused by solid particles is a major problem in catalytic cracking units. The riser outlet is the most vulnerable region to this process because a change in direction of the biphasic flow of gas and catalyst particles occurs. In this work, different configurations for a riser outlet were studied aiming at minimizing erosion. Computational Fluid Dynamics (CFD) with Dense Discrete Phase Model (DDPM) approach was used to simulate the gas-solid flow in a riser. The k-ε turbulence model was used to model the turbulence. It was observed that an abrupt L outlet produced the same average erosion rate as a soft outlet, while an abrupt T outlet provided an average erosion rate two times larger than the abrupt L outlet. Additionally, new riser outlet geometry was proposed in order to minimize erosion on top of risers. However it was found that this geometry presented disadvantages when compared to the other outlet geometries studied.**

***Keywords*—riser, FCC, CFD, DDPM**

I. Introduction

Fluid catalytic cracking (FCC) is one of the most important units used in a refinery to produce gasoline from heavy oil fractions. The reactions occur inside a long pipe called riser. At its base, pulverized load and catalyst particles are introduced, rise toward the top and move on to the separator vessel.

A change in the direction of the multiphase flow promotes the separation of particles and gas flow resulting in a particle impact on the wall at the top of the riser. As a consequence, the energy of the particles is transferred to the wall and the impact zone starts to wear off in a process called erosion. Erosion causes damages in the region and requires a constant pipe exchange in the area of wear. Erosion is a complex phenomenon because it depends on operating conditions (such as fluid velocity and particle flow), properties of the fluid and particle, material of the pipe wall, pipe geometry, etc.

In order to minimize the effects of erosion on top of risers, changes in output geometry are widely used to modify the trajectory of the catalyst particles and, consequently, change the dynamics of the impact of the particles on the surface.

Soft and abrupt outlet configurations are commonly used in top of the risers. In abrupt L outlet, the direction of the multiphase flow is changed by a right angled exit; and in abrupt T outlet, a right angled with extension is used. In soft outlet, the change in direction is made by a bend exit.

Outlet configurations influence the axial volume fraction profile of the particles along the riser. Bai et al. (1992) found an increase in solids concentration at the top of the riser for an abrupt T outlet while the region below the top suffers no effect in the distribution of solids. That results a C volume fraction profile for an abrupt outlet. For a soft outlet, it was concluded an exponential volume fraction profile with a higher concentration of solids only at the bottom of the riser.

In addition to experiments, the use of Computational Fluid Dynamics (CFD) has been widely used to analyze in detail the behavior of particles in risers. Wilde, J., Marin, G. B., Heynderickx, G. J. (2003) found that in abrupt T outlet, part of particles does not follow the gas stream to the exit of the riser. Due to inertia, the solids reach the top wall of the riser and are reflected, forming a vortex in this region. With the formation of the vortex, it was noted a downward flow of both solid and gas on the opposite side of the outlet of the riser, which increases the resistance of the gas-solid mixture that is rising in the riser and, thereby, generates an increase in concentration of solids in that region. Van Engelandt et al. (2011) also observed the formation of a vortex for the abrupt L outlet, though to a lesser extent.

The objective of this work is to analyze the behavior of particles in different outlets configurations of risers and study the erosion of the pipe in this region. It also proposes a new configuration outlet to minimize erosion.

II. Mathematical Modeling

Dense Discrete Phase Model (DDPM) approach was used to simulate the gas-solid flow in a riser (Gidaspow et al, 1992 Schaeffer, 1987and 1994; Syamlal-O'Brien, 1989; Dalla Vale, 1948; Syamlal et al., 1993; Lun et al., 1984; Ogawa et al, 1980; Haugen et al., 1995).

This approach considers the trajectory of individual particles using Newton's laws, but the interaction between particles is not simulated directly. The particle-particle interaction is estimated by the granular kinetic theory that considers the random motion similar to the thermal motion of molecules in a gas. The granular temperature is introduced as a way of quantifying the energy contained in the random motion of the particles, and then is used to estimate the viscosity and pressure of the particle phase. The gas phase is modeled as a continuous phase in which the characteristics are determined by solving transport equations.

The effects of turbulence were simulated using κ-ε Dispersion Model (ANSYS FLUENT 13.0, 2011). The dispersion of particles due to turbulence of the gas phase was predicted by the stochastic tracking model.

Near wall Launder and Spalding (1972) semi-empirical equations were used.

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III. Numerical Simulations

The simulations were performed using ANSYS 13.0.

The geometry of the riser simulated was the same as the riser used in Pärssinen and Zhu (2001) with a 76 millimeters diameter and total height of 10 meters. Above 0.17 to 0.25 meters of the base, there is an intake side of the same diameter of the main pipe. Four different output configurations were evaluated: soft outlet, abrupt L outlet, abrupt T outlet (with 65 millimeters extension) and a new geometry.

Knowing that erosion is strongly influenced by the particle velocity, a pipe with a larger diameter (0.2 meters interconnected with the main riser pipe by a conic section 0.1 meters height) was created at the top of the riser with the objective to reduce the particle velocity and therefore reduce the erosion in this region.

The properties of the phases were taken from Pärssinen and Zhu (2001) work and are shown in Table 1. The particles were considered inert with same diameter. The interaction between particles was measured as the coefficient of restitution particle-particle equal to 0.9.

The boundary conditions are presented in Table 2.

TABLE 1 – PHASES PROPERTIES.

Air Density	1.23 kg m^{-3}
Air Viscosity	1.79×10^{-5} kg m^{-1} s^{-1}
Particle Diameter	67 µm
Particle Density	1500 kg m^{-3}

TABLE 2 – BONDARY CONDITIONS.

Bottom Inlet	*Velocity-Inlet* Gas Phase: 8 m/s	
Side Inlet	*Mass-Flow-Inlet* Gas Phase 0.245 kg $m^{-2}s^{-1}$	Particle Phase Particle injection 1.6 kg s^{-1}
Outlet	*Outflow*	

The mesh applied consists of approximately 944,000 control volumes. The finite volume method described in more detail by Maliska (2004) was used.

The Phase Coupled SIMPLE algorithm was used for pressure-velocity coupling. The cell-based least squares method was applied to the development of diffusion gradients. The other pressure terms were discretized using the second order upwind, except for the volume fraction which was discretized using QUICK method. Second order was used for temporal discretization. The flow was transient with 20 seconds duration and time step equal to 0.005 seconds.

IV. Results and Discussion

As in DDPM the particulate phase approach is described by the trajectory of particles individually, it is possible to analyze the effect of the exit geometry and erosion.

Figure 1 shows the trajectory of the particles at the top of the riser for different geometries investigated. For the soft outlet, most particles collides the top wall and go to the exit of the riser through the horizontal pipe.

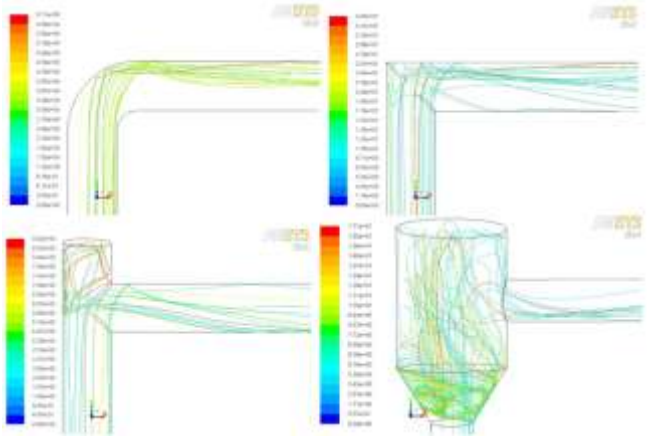

Figure 1 – Trajectory of the particles colored by residence time in seconds, for the soft L, abrupt L, abrupt T and new type of outlets, respectively.

For the abrupt L outlet, part of the particles collide the top wall and moves to the exit of the riser, and the other part of the particles collides on the wall falls a short distance on the opposite side of the outlet and then proceeds to the exit of the riser. The downward flow of solids at the opposite side of the exit can explain the increase in volume fraction of solids in this area as found by Bai et al. (1992) and a small vortex at the top of the riser.

For the abrupt T outlet, part of the particles collide the wall of the extension, falls a short distance on the opposite side of the outlet and follows to the exit of the riser with the gas flow or is again carried to the extension of the riser. This cyclical movement of ascent and descent of the particles leads to the formation of the vortex in the riser extension as seen in Van Engelandt et al. (2011). Another part of the particles collide directly in the region between the extension and the horizontal pipe and follows to the exit of the riser.

For the new geometry, particles run through a long path until reach the exit of the riser. Part of particles collide the top wall and return to the conic section; the other part cannot reach the top wall and returns from the middle of the large tube to the conic section. In the conic section, the particles descend the wall in spirals movement until they are taken by the upward flow of gas-solid mixture to the exit of the riser.

In order to compare the erosion in different geometries studied in this work, Figure 2 shows the particle erosion rate caused at the top of the riser.

It is observed that the soft outlet and abrupt L outlet show the highest values of erosion rate on the wall which is projected from the inlet region. This region of higher erosion suffers the impacts of particles directly as shown in Figure 1.

The abrupt T outlet has the highest values of erosion rate on the extension (side and end of extension) and in the region between the extension and the horizontal pipe. From Figure 1, it is noted that these regions are the more prone to the impacts of particles and therefore present the highest erosion rate. In the side of the extension, the main reason for the increased erosion rate can be given by the movement of particles with repeated motion in extension.

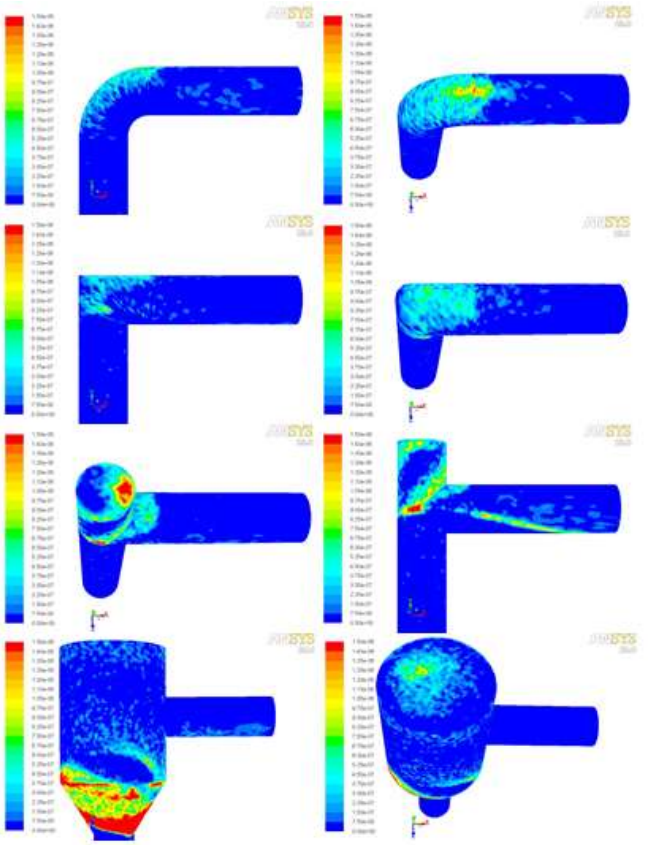

Figure 2 – Particle erosion rate, for the soft L, abrupt L, abrupt T and new type of outlets, respectively.

The new geometry has two main regions that suffer the effects of erosion: the end of the larger riser pipe and the conic region. The end of the pipe has high rate of erosion due to the direct impact of the particles, as is also observed on top of the other geometries. However, erosion generated in the conic region is influenced by the spiral movement of the particles as shown in Figure 1. Comparing with other geometries, the new geometry presents a larger area of intense erosion rate, especially in the conic region.

In order to obtain the influence of geometry on the erosion of the top risers in a quantitative manner, Table 3 shows the average area erosion rate at the top of the riser (mean erosion). The mean erosion rate values were calculated in the surface above the height of 9.7 meters from the riser.

The results indicate that the soft outlet and the abrupt L outlet present average erosion rate value in the same order of magnitude, however the abrupt L outlet has the lowest value of 4.8e-8 kg m^{-2} s^{-1}. Additionally, the abrupt T outlet provides an average erosion rate around 9.5e-8 kg m^{-2} s^{-1}, 2 times larger than the abrupt L outlet.

On the other hand, it is noted that the new geometry provided the highest average erosion rate, equal to 1.1e-6 kg m^{-2} s^{-1}, approximately 22 times greater than the abrupt L outlet.

Erosion is a major problem in the riser outlet of catalytic cracking units. It was observed that an abrupt L outlet produced the same average erosion rate as a soft outlet, while an abrupt T outlet provided an average erosion rate two times larger than the abrupt L outlet

TABLE 3 –AVERAGE EROSION RATE OF DIFFERENT GEOMETRY OUTLETS.

Top of the riser	Soft Outlet	Abrupt L Outlet	Abrupt T Outlet	New Geometry
Erosion Rate (kg m^{-2} s^{-1})	5,7e-8	4,8e-8	9,5e-8	1,1e-6
Erosion Rate (mm/year)	1,2	1,0	2,0	22,1
Erosion ratio between a given geometry and the abrupt L outlet	1	1	2	22

V. Conclusions

The study of the behavior of the catalyst particles and the influence of the geometry for different outlet configurations of the riser was evaluated for an FCC unit through the ANSYS 13.0.

For the soft outlet, the highest values of erosion rate were observed in the wall that is projection of the inlet riser. This region suffers the direct impact of particles on the wall.

For the abrupt L outlet and the abrupt T outlet, it was noted a downward flow of solids on the opposite side of the exit riser. It was observed the formation of a vortex for these outlets due to the backflow of solids, besides the abrupt T outlet presented a larger vortex. The erosion profile for the abrupt L outlet was similar to that found for the soft outlet. But, for the abrupt T outlet two regions of highest erosion were identified: the extension of the riser and the region between the extension and the horizontal pipe

The new geometry showed the highest erosion rate in the region of the conical section, where a spiral movement of particles occurs.

Comparison between the outlets commonly used for risers in FCC unit, the soft outlet and abrupt L outlet presented the lowest average erosion rate, equal to 1.2 and 1.0 mm/year, respectively. However, the abrupt T presented 2 times more average erosion rate in relation to the abrupt L outlet. The new geometry proposed in this work showed the highest average erosion rate, about 22 times greater than the abrupt L outlet, and thus its use has disadvantages for the prevention of erosion when compared to the commonly used geometries.

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