

IMPLEMENTATION AND EVALUATION OF AHLERT-MCLAURY EROSION MODEL ON A CYCLONE PARTICLE SEPARATOR

NICOLA CASARI¹, CARLO BURATTO², NICOLA ALDI³, MICHELE PINELLI⁴, ALESSIO SUMAN⁵

¹Engineering Department in Ferrara (EnDiF), University of Ferrara, nicola.casari@unife.it

²Fluid-A s.r.l., carlo.buratto@fluid-a.it

³Engineering Department in Ferrara (EnDiF), University of Ferrara, nicola.aldi@unife.it

⁴Engineering Department in Ferrara (EnDiF), University of Ferrara, michele.pinelli@unife.it

⁵Engineering Department in Ferrara (EnDiF), University of Ferrara, alessio.suman@unife.it

Keywords: erosion, particle-laden fluids, Eulerian-Lagrangian approach

In this work the Ahlert-McLaury erosion model has been implemented in OpenFOAM (v. 3.0.0). This model provides the Erosion Rate (ER) for steel impacting by sand particles. In particular, the formulation adopted in this work is the same adopted by [1] and defined according to the Eq. (1). In the Eq. (1) ER depends on the shape of the particles and on the impact angle through the coefficients F_s and F_θ respectively. The shape coefficient F_s assumes different values: 1 for sand particles with sharp edges, 0.53 for semi-spherical particles and 0.2 for spherical particles. The angle coefficient F_θ refers to the Eqs (2) and (3):

$$ER = AF_s F_\theta V^n \quad (1)$$

$$F_\theta = b\theta + a\theta^2 \quad \text{if } \theta \leq \alpha \quad (2)$$

$$F_\theta = x \cos^2\theta \sin(w\theta) + y \sin^2\theta + z \quad \text{if } \theta > \alpha \quad (3)$$

where the impact angle θ is expressed in radians, the threshold values of angle α was set equal to $\pi/2$ and the model constant is defined as follow: $a = -33.4$, $b = 17.9$, $w = 1.0$, $x = 1.239$, $y = -0.1192$ and $z = 2.167$.

Since the erosion phenomena depends (i) on the materials of the particles and walls and on (ii) the particle velocity, the constant A was set equal to $15.59e^{-7}B^{-0.59}$ (where B is the Brinell hardness) in order to consider the sand and steel hardness while, the exponent n , is related to the relative impact velocity V of the particles and it was set equal to 1.73. It is well known that OpenFOAM deals with particle laden flows. The Lagrangian computation in openFOAM is widely investigated in the open literature, and the results are comparable with the ones obtained by ANSYS-FLUENT [2].

Test case. The validation of the model has been done using the test case of Eyer [3]: a pipe with a 90° bend traversed by a particle laden gas. The numerical model has been done by a trimmed mesh with 2 Million element with a standard κ - ϵ as a turbulence model. The numerical solution of the Eulerian and Lagrangian phase is compared to the experimental results obtained by Enayet [4] and Edwards [1] respectively. For the Eulerian phase the comparison refers to the velocity variation along the radius in correspondence of the outlet section of the bent tube while the sand erosion refers to the ER evaluated along the outer wall of the bend. Figure 1 reports the two numerical trend, with a continuous red line, superimposed with the literature data. The validation of the erosion phenomena due to the Lagrangian phase is carried out by using the results reported in [1]. Figure 1 shows good agreement between present results and literature ones confirming the validity of the implemented erosion model.

Cyclone particle separator. Starting from the validation reported above, the Ahlert-McLaury erosion model is applied to a vacuum-cleaner particles separator: an aluminum cyclone which separates particles from the air flow. The cyclone under examination has a conventional geometry with a tangential inlet of the contaminated airflow and an axial outlet of particles and clean air. Trimmed mesh with 18 Million elements was used coupled with a standard κ - ϵ turbulence model, with an average y^+ of 15. Figure 2 reports the cyclone separator geometry and the computational mesh.

The steady-state flow field (only Eulerian phase) has been validate comparing the results with the ones obtained from ANSYS-FLUENT in term of pressure losses and velocity pattern. The overall pressure loss obtained from the two CFD software differs about 1.7 % and it is considered reliable for the aim of the present study.

Once convergence for the single phase flow is reached, a certain particle distribution is injected at the inlet. The typical particles used for testing this kind of application is manly formed by mineral dust. The powder considered in this

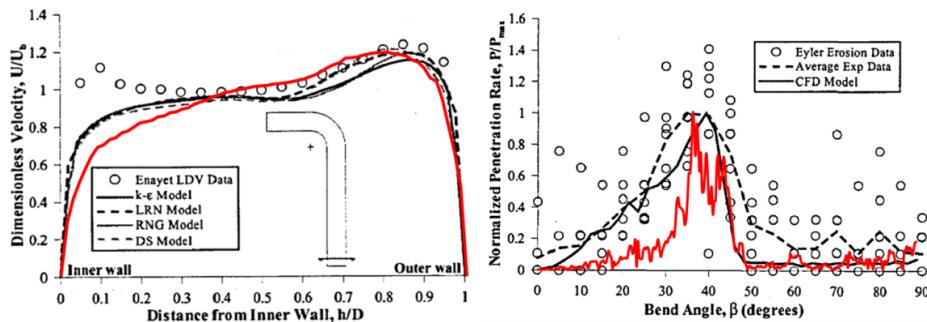


Figure 1: Eulerian and Lagrangian phase validation

analysis is defined in agreement with the standard ISO 12103-1 A2 [5] fine test dust modelled by using a Rosin-Rammler distribution with a minimum diameter equal to 0.97 μm , a maximum diameter equal to 176 μm , an average diameter equal to 13.97 μm and a spread equal to 0.85.

The particles are released uniformly from the inlet surface with the same velocity of the Eulerian phase equal to about 24.6 m/s. The cyclone separator operates in a full load condition corresponding to 180 g/m^3 as a powder concentration. At the walls, particles were reflected considering a perfectly elastic. This conditions are commonly used for this type of application [6,7]. For what concerns the effect of the turbulence on the particles, the *stochasticDispersion* model has been used. In this model the velocity is perturbed in a random direction, with a Gaussian random number distribution with a user defined variance.

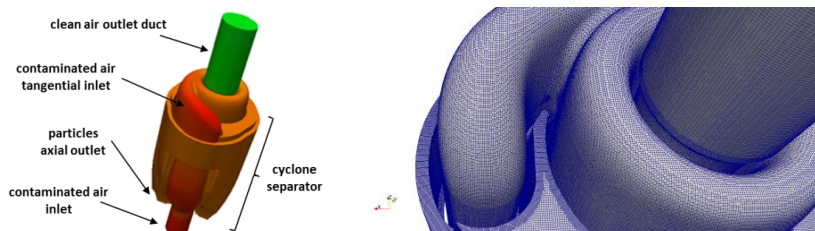


Figure 2: Cyclone dust separator: geometry and computational mesh

Results. The analysis reported in this work refers to separation efficiency and to erosion rate of the cyclone separators. Figure 3 reports velocity field, separation efficiency and erosion patterns. The velocity field is reported by means of a velocity contour plot with superimposed vectors highlight the eddy structure inside the cyclone separator. Move to the cyclone separator performance, in Fig. 3 the separation efficiency (η_r) trend as a function of the particle diameter is shown. It shows greater separation for the higher particle diameter. The threshold value (85 % of separation efficiency) corresponds to about 5 μm . Cyclone separator takes advantage of particle inertia and for this reason, smaller particles still flowing through the separators. In actual applications, manufacturer installs a fibers filters (sometimes HEPA filters) after the cyclone separators in order to increase the filtration efficiency.

The last analysis is devoted to the erosion phenomena that occurs inside the cyclone separator. The Ahlert-McLaury erosion model was implemented and set at the walls. Therefore, each solid surface was interested by erosion as a function of the particles sizes and trajectories. Figure 3 reports two erosion pattern for smaller and the bigger particle involved in this analysis. The erosion provided by smaller particle ($d_p = 1.5 \mu\text{m}$) is almost negligible but is widespread and some erosion trace could be find in the clean air outlet duct (for this particle size the separation efficiency is too scarce). Bigger particles ($d_p = 88.0 \mu\text{m}$) damage especially the contaminated air inlet and in the region of the tangential inlet in correspondence of the 90° bend.

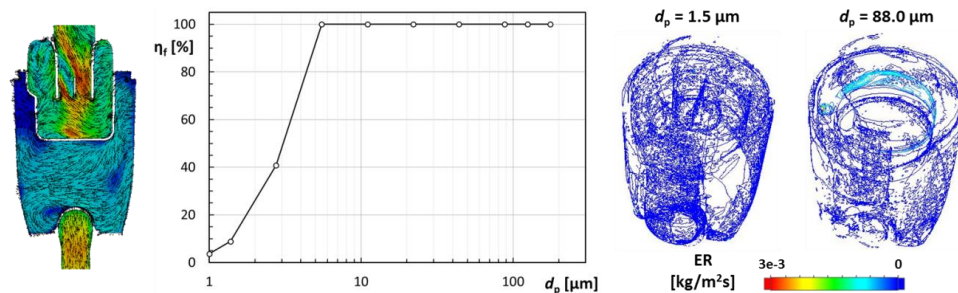


Figure 3: Cyclone performance: velocity field, separation efficiency and erosion pattern

References

- [1] J. Edwards et al., “Evaluation of alternative pipe bend fittings in erosive service,” *Proc. FEDSM*, vol. 2, pp. 959-966, 2000.
- [2] A. López *et al.*, CFD study of Jet Impingement Test erosion using Ansys Fluent® and OpenFOAM®, Computer Physics Communications, vol. 197, pp 88-95 , 2015.
- [3] R. Eyler, Design and Analysis of a Pneumatic Flow Loop, 1987.
- [4] M. M. Enayet et al., “Laser-Doppler measurements of laminar and turbulent flow in a pipe bend,” *Int. J. Heat Fluid Flow*, vol. 3, no. 4, pp. 213-219, 1982.
- [5] ISO 12103-1:2016, “Road vehicles -- Test contaminants for filter evaluation -- Part 1: Arizona test dust”
- [6] J. Oh et al., “Numerical simulation of an internal flow field in a uniflow cyclone separator,” *Powder Technol.*, vol. 274, pp. 135-145, 2015.
- [7] F. J. de Souza et al., “Simulation of the performance of small cyclone separators through the use of Post Cyclones (PoC) and annular overflow ducts,” *Sep. Purif. Technol.*, vol. 142, pp. 71-82, 2015.