Predicting the pressure drop of cyclones by combined application of computational fluid dynamics and chemometric methods

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Introduction

Cyclones are devices that employ a centrifugal force - generated by a spinning gas stream - to separate particles or drops from the carrier gas. The gas flow in cyclonic separators affects the collection efficiency and pressure drop. Since the cyclone pressure drop directly relates to the operating cost, efforts to minimize the friction losses are carried out. In this work the pressure drop of the investigated cyclonic droplet separators were lowered by about 50% using special internals below the exit pipe as applied by Vogelbusch GmbH for such cyclones.

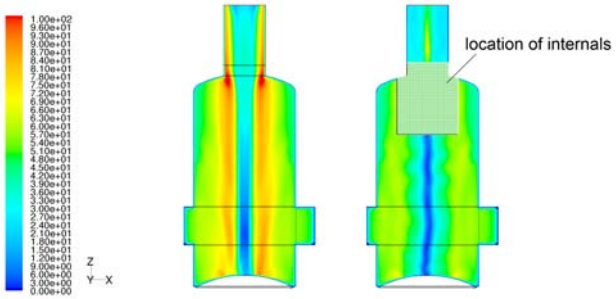
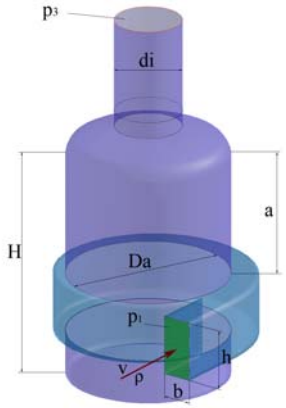


Figure 1: Typical velocity magnitude distributions of cyclonic separators without (left) and with (right) internals [m/s].

The flow field in the apparatus changes essentially by the application of the internals (see Figure 1). Known empirical correlations [1-4] overestimate the pressure drop of the treated geometry. However, for the proper design of plants an accurate prediction of the cyclone pressure drop is very important. Thus a new empirical correlation was developed using data from computational fluid dynamic simulations (CFD) and applying multivariate calibration methods [5].

CFD Simulation

To determine the influence of various geometry parameters on the pressure drop, 166 computational fluid dynamics (CFD) simulations were carried out using automated preprocessing. Scripts were written for the geometry generation.



di ..... outlet tube diameter
Da ..... diameter of vessel
H ..... height of cyclone
b ..... inlet width
h ..... inlet height
a ..... height of separating section
v ..... mean inlet velocity
ρ ..... gas density

p1 ..... inlet pressure
p2 ..... pressure at internals
p3 ..... outlet pressure

Figure 2: Cyclonic droplet separator geometry and geometry - parameters.

The calculations were done using the commercially available CFD code FLUENT and the pre-processor GAMBIT. Important simulation settings were: RSM-Turbulence model and QUICK (higher order) discretization.

The key results of the parameter variations (geometry parameters shown in Figure 2, the mean inlet velocity v and the gas density ρ) were partial pressure drops (Δp_{12} and Δp_{23}) of the device.

Chemometric Evaluation

Regression models for the pressure drop were built from geometric parameters. Additional features have been added as dimensionless ratios of the basic parameters. For theoretical reasons the pressure drop Δp can be expressed as

$$\mathrm{D}p = c_0 \times x_1^{c_1} \times x_2^{c_2} \times \ldots$$

where x_1, x_2, ... are geometric parameters or derived features and c_0, c_1, c_2, ... represent model parameters. Logarithmic transformation results in a linear relationship between log Δp and log x_1, log x_2, ... The regression coefficients c_1, c_2, ... have been estimated by PLS. Prediction errors have for instance been estimated by leave-one-out cross validation.

More than 75% of the predicted pressure drops differ less than 10% from the values calculated by CFD, 55% of the forecast values produce even less than 5% error.

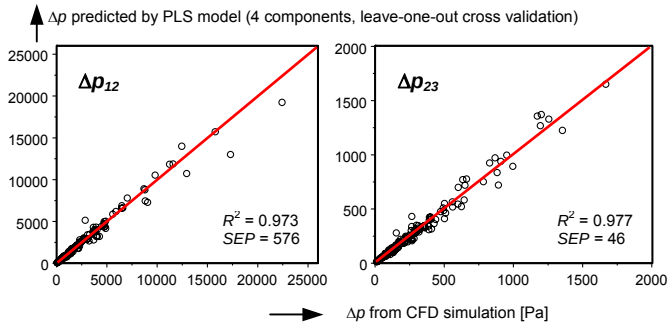


Figure 3: Δp predicted by PLS model.

Conclusions

The application of chemometric methods to results of CFD simulations is a promising approach for finding equations that predict the behavior of complex gas flows, and for investigating geometry – flow relationships. Such models allow a fast estimation of the pressure drop while a CFD simulation requires several hours of computer time. Applications are not limited to chemical engineering problems.

To improve applicability and reliability of the pressure drop models further geometry variations should be implemented to extend the database. Other pressure drop models will be analyzed in the future.

References

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