Combined application of computational fluid dynamics simulations and chemometric methods in cyclone design

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Introduction

Understanding gas flow in cyclonic separators is important for predicting pressure drop and separation efficiency [1-4]. Several types of flow structures in cyclones were reported in recent publications. The flow structures were split into arbitrary classes, each representing a certain type of axial velocity profile of the gas flow inside the cyclone. Class "V" are cyclones with a maximum of the axial velocity at the vortex core of the cyclone, whereas class "W" represents cyclones with an axial velocity profile that resembles an upside down character "W". This class has a local minimum of axial velocity at the vortex core or even displays backflow. The geometries belonging either to class "V" or class "W" showed only small relative differences.

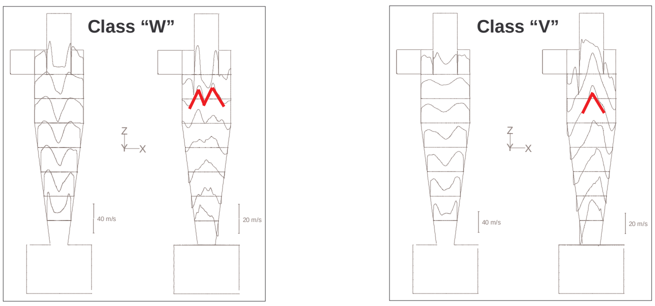

Figure 1: Examples of velocity profiles of tangential velocity (left) and axial velocity (right) of geometrically similar cyclones (constant volumetric flow rate).

CFD Simulation

To determine the influence of various geometric parameters on the internal flow structure and thus on the class membership, 144 computational fluid dynamics (CFD) simulations were carried out using automated pre- and postprocessing. Scripts were written for both geometry generation and control of simulation parameters.

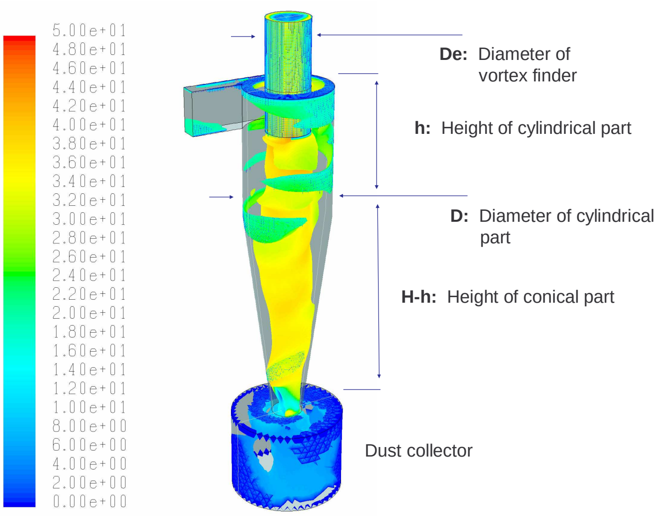

Figure 2: Typical flow structure inside a cyclone. Flow-regions with upward direction coloured by velocity magnitude [m/s].

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The calculations were done using the commercially available CFD code FLUENT and the preprocessor GAMBIT. Important simulation settings were: RSM-Turbulence model and 2nd order discretisation. The key results of the parameter variations (De, H-h, h and mean inlet velocity v) were the pressure drop of the device and axial velocity profiles like shown in Figure 1. Figure 2 shows an example of a typical swirling flow.

Chemometric Evaluation

A KNN classification was performed. The best results were achieved by using only the above mentioned geometry parameters as predictors. It yielded 85% correct assignment to classes "V" and "W". Including mean inlet velocity as predictor decreased correct classification to 60%. "X" was used to identify uncertain simulation results (neither conditions for class "V" nor "W" were fully met). Using results from KNN it was possible to improve definitions for class membership and locate not completely converged CFD-simulation runs.

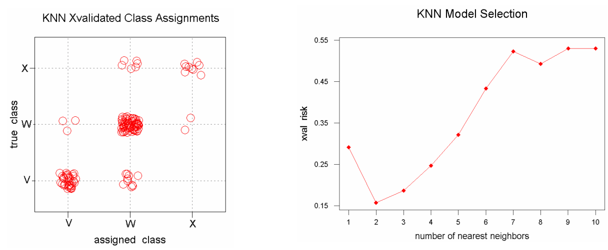

Figure 3: Results from KNN classification using De, H-h and h as predictors.

PLS was successful in modelling pressure drop using the following four (partly derived) parameters as predictors: $1/De^2$, v^2, H and H-h.

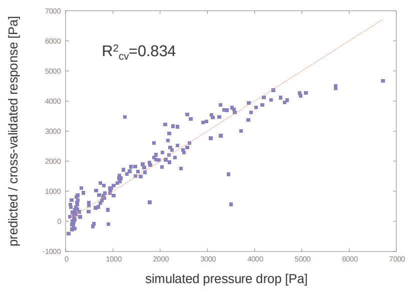

Figure 4: PLS using derived geometry parameters and square of inlet velocity (v^2) to predict pressure drop [Pa] for the unit

Future Work

The application of chemometric methods to the postprocessing of CFD results is a promising approach to classify flow behaviour of complex gas flows and to find geometry – flow relationships. Applications are not limited to chemical engineering problems. To improve the applicability and reliability of the models further investigations of the current problem are needed (calculation of other cyclone geometries, flow rates and fluid properties). Additional dependencies like grid structure and control volume size will be integrated into further classification studies. This is necessary to ensure minimal influence of the CFD solver settings on the simulation results.

References

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