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CYCLONE WITH SHUTTERS LATTICE MODELLING

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Summary. The performance of a new cyclone dust catcher is investigated using RANS-based single-phase computational fluid dynamics (CFD). The pressure drop across the cyclone dust catcher chamber is predicted. Possibility of further improvement of diesel engine air refinement processes by cyclone using is offered here.

Keywords: dust catcher, air refinement, cyclone separator, shutters lattice.

INTRODUCTION

In reliability of transport engines and other machines the important role is played by refinement of ingoing air [Woschni 1987, Johnson 1992, Painter 1992, Dzetsina 2010]. Due to that, the important problem is the development of effective dust-separating apparatuses for air systems of new engines [Gackey 1982, Povarkov 1999, Volodin 2002].

Mechanical dust catchers are apparatuses with gravitational, inertial and centrifugal mechanisms of precipitation. Centrifugal type of separators consists of single, group and battery cyclone separators, vortex and dynamic dust catchers.

Their basic advantages comparing to other gases refinement apparatuses are trapping of dust in a dry aspect, absence of moving parts, reliable activity in broad range of temperatures and pressures, stability of a flow friction, manufacturing and repair simplicity. Thus, they are widely used in air systems of internal-combustion engines, cooling systems of traction motors, in ventilation and compressor systems and in other engineering devices of railway transport due to their manufacturing and maintenance simplicity [Getzov 1999, Volodin 2002].

General weaknesses of cyclone separators are considerable pressure loss (1,2-1,5 kPa) and low effectiveness with dust particles size below 5 microns, that's why they are usually used for first stage air refining.

The recent researches in this field of science involve the development of centrifugal dust catchers that provide sufficient effectiveness at precipitation of superfine dust particles in conditions when other types of dust catchers cannot be

applied. Therefore, despite the peculiarities of application marked above, researches in the field of a centrifugal dust separation remain actual.

OBJECTS AND PROBLEMS

The dust separation effectiveness in centrifugal type apparatuses can be achieved by some improvements of classical cyclones: an intensification of a gas stream twisting at the apparatus input, decrease of secondary flow of a dust, the organization of efficient unloading of the dust, parallel use of other mechanisms of precipitation of suspended particles [Boysan 1983, Fraser 1997]. However, gained effectiveness is usually attained by increase of power and capital outlays, complication of design, increase of manufacturing and operation cost and can cause decrease of reliability. Therefore, the importance of technical service and control equipment of such apparatuses increases.

Many recent works are devoted to creation of new dust removal devices with two or more principles of action in separation process of dust and gas mixture. The apparatus investigated in [Hoekstra 1999] has a cylindrical body with a scroll type of inlet to introduce the fluid tangentially. At the base of the cyclone, a sudden reduction of the cross-sectional area occurs owing to the presence of a vortex stabilizer that also serves to reduce re-entrainment of particles from the collection hopper. The air is exhausted through the exit pipe, or vortex under, at the top of the cyclone.

In [Batluk 2005] principally new vortex dust catcher with shutter lattice is investigated. It is capable to effective separation of particles with pressure loss 1,5 times lower than conventional cyclones and also has 1,3 times smaller overall dimensions. In that direction it is necessary to improve such devices, so they would be able to decrease the discharge of fine-dispersed particles in technological processes.

In [Kutz 2005] hydraulic resistance of step-by-step solid phase extraction cyclone is estimated. The apparatus combines classical cyclone and shutter lattice. It improves effectiveness with decrease of particles concentration near housing walls, therefore, by way of gas stream suction of particles possibility minimization.

In [Syomin 2010] vortex executive devices application for regulation fluid streams in processes with hard working conditions of the equipment is analysed. On the example of industrial application with hydraulic cyclones the possibility of improving both technological and power parameters of such processes is approved.

A good understanding of the fluid dynamics is required to make further improvements to cyclone dust catcher designs. While analytical techniques do not allow changes in geometry to be readily assessed, computational fluid dynamics (CFD) models based on Reynolds-average Navier-Stokes (RANS) provide an economical means of understanding the complex fluid dynamics and how it can be influenced by changes in design and operating conditions. Still validation of results is required to establish confidence in the predictions.

A review of related papers revealed few researches involving simulation of cyclone dust catchers, but significant advances have been made in simulating cyclone separators. [Boysan 1983] who was early users of the CFD technology, applied the algebraic stress model (ASM) to simulations of a cyclone separator. Later [Zhou 1990, Hoekstra 1999, Modigell 2000] applied CFD to this problem with varying success.

Nevertheless, their works dealt only with two-dimensional prediction of the single-phase flow in the cyclones and treated the flow field as axisymmetric and steady.

Numerical simulations in three-dimensions are necessary to perform in order to get more details of the complicated flow field in cyclone devices. Following researchers dealt with numerical simulations of cyclone separators in three-dimensions: [Griffiths 1996, Witt 1999, Zhao 1999, Montavon 2000, Yoshida 2001, Derksen 2003, Schimdt 2003, Wang 2003]. They all tested several turbulence models: algebraic stress model [11], standard k-ε [Witt 1999, Montavon 2000, Yoshida 2001], RNG k-ε [Griffiths 1996], and a Reynolds stress model [Witt 1999, Wang 2003]. The conclusion of these studies is that CFD still cannot produce a very accurate description of the flow field due to difficulties in modeling the swirling flow. The pressure drop obtained experimentally was larger than the calculated one by 60%, 15%, and 16% for standard k-ε [Yoshida 2001], RNG k-ε [Griffiths 1996], and Reynolds stress model [Wang 2003], respectively. So pressure drop calculated results agree moderately well with the experimental data.

To predict the unsteady, spiral shape and vortex core characteristics of a cyclone separator, large eddy simulation (LES) was used [Derksen 2003, Schimdt 2003]. Both in terms of the average velocity and in terms of velocity fluctuations, good agreement with experimental data was obtained. The advantage of the LES approach as compared with the RANS was illustrated but computational cost increased greatly.

The objective of this paper is to present predictions of the gas-phase flow field and pressure drop through a cyclone dust catcher using RANS based CFD. A model developed is run for three-dimensional single-phase gas flow in the cyclone dust catcher. Simulation parameters such as mesh type, turbulence model, and level of mesh resolution are tested to find the best combination for flows of this type. The effects of orifice diameter and chamber height on the pressure drop are investigated. This is the first stage in the development of a computational method for cyclone dust catcher design.

In shutters lattice cyclone, centrifugal and shutter dust catchers mechanisms are united, gas flow is treated as superposition of two flows: flat outflow and flat vortex. Therefore, it is convenient to divide the computational geometry into zones, in which trajectories of particles with different sizes are defined. In addition, the end of previous area trajectory will be used at initial conditions setting for calculation of the following trajectory.

Unlike most calculation models of centrifugal-inertial dust catchers with shutter air outlet or shutter-vortex separators, the essence of step-by-step solid phase extraction cyclone separation effectiveness estimation is in checking that centrifugal force is equal to suction force of radial outflow. This is the second condition and the conception is that balanced particles are turning rotating in the stationary orbit and have the equal possibility to be drained through the clean gas outlet pipe or to be separated.

In step-by-step solid phase extraction cyclone the particles moving in gas stream to clean gas outlet are reflected with certain possibility by shutters lattice. So some of them are also separated with shutter principle from gas stream. Therefore, another way of cyclone performance improvement is connected with the shutters lattice design.

The geometry of the cyclone dust catcher used for the initial numerical investigation is shown in fig. 1, It is characterized by the principal diameter D, and the geometric ratios detailed in [Kutz 2005].

The diameter of the model cyclone dust catcher tested is 400 mm. Automatic initial conditions were set up with the and a required minimum RMS residual level of 10^{-6}. For standard k-ε turbulence model, the tangential velocity was under-predicted at both measurement planes when using the upwind differencing scheme.

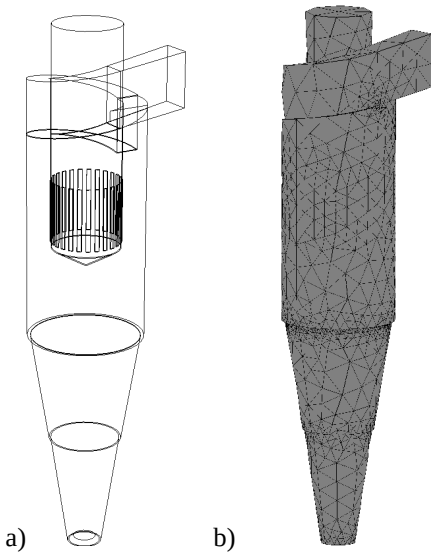


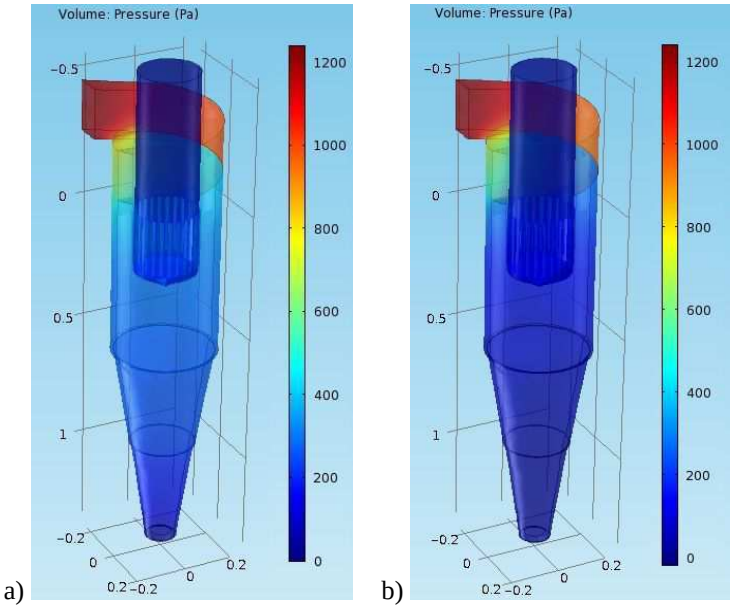
Fig. 1 The geometry of the cyclone dust catcher (a) and computational mesh (b)

The sharp gradient of axial velocity near the cyclone orifice cannot be captured due to the diffusive nature of this differencing scheme. The results below (fig. 2) show the results obtained using the upwind differencing scheme.

The results obtained with the high resolution and second order accurate advection schemes significantly improve the predicted tangential and axial velocity profiles. The second order accurate advection scheme clearly gives much better agreement than the other differencing schemes for both the magnitude and position of the maximum axial and tangential velocity. The pressure drop of the conventional cyclone dust catcher in conical part of cyclone is much higher than for step-by-step extraction type. Therefore, the reverse flow for the later cyclones is reduced. To predict the behavior of solid particles of dust present in gas, the modeling of their motion is done (fig.3).

As can be seen from fig.3, most solid particles leave the cyclone in first and second stage outlets and the rest keep moving down the sand nozzle. Still some of them can reach the clean gas outlet.

The application of investigated cyclone at first stage air refining of air system for transport engine of diesel locomotive leads to increase of air refinement level with moderate hydraulic loss, capital and maintenance costs.



a) b)

Fig. 2 The pressure drop three-dimensional plot of the conventional cyclone dust catcher (a) and for step-by-step extraction (b)

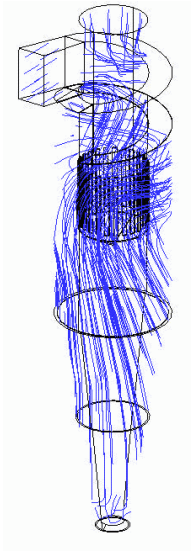


Fig.3 Trajectories of solid particles movement

Anyway, cyclone separator effectiveness changes at variable gas charge and irregular gas streams. This fault should be compensated with using of battery separators,

with the gas stream distributed between parallel cyclones united in one system. In addition, it is necessary to use automation devices for the support of nominal operation parameters, taking into account changes of the cyclone separator characteristics at gas unsteady flow parameters.

CONCLUSIONS

1. The advantage of the LES approach as compared with the RANS for cyclone dust catcher modeling is considerable but computational cost increases greatly.

2. The pressure drop in conical part of conventional cyclone is much higher than for step-by-step extraction type, the reverse flow for the later cyclones is reduced.

3. Most particles leave the cyclone in first and second stage outlets and the rest keep moving down the sand nozzle. Still some of them can reach the clean gas outlet.

3. The application of investigated cyclone at first stage air refining of air system for transport engine of diesel locomotive leads to increase of air refinement level, cyclone separator effectiveness changes at variable gas charge and irregular gas streams should be compensated with using of battery separators.

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МОДЕЛИРОВАНИЕ ЦИКЛОНА С ЖАЛЮЗИЙНОЙ РЕШЕТКОЙ

Дмитрий Дмитриенко

Аннотация. Исследована работа новых циклонных пылеуловителей методами вычислительной гидродинамики для однофазной среды в приближении Рейнольдса. Представлена картина падения давления в циклонах. Предложены пути дальнейшего улучшения процесса воздухоочистки для дизельных двигателей.

Ключевые слова: пылеуловитель, воздухоочистка, циклонный сепаратор, жалюзийная решетка.