Optimization of Geometric Parameters of the Cyclone Apparatus Based on its Numerical Modeling

V V Biryuk, A A Gorshkalev, A B Tsapkova, A A Shimanov, E V Blagin

Samara National Research University, 34, Moskovskoye shosse, Samara, 443086, Russia

E-mail: tema444st@mail.ru

Abstract. This article deals with a cyclone cleaner which separates solid particles from the gas. The influence of the input duct angle and the relation of the conical part of the apparatus to a cylindrical one on the cleaning degree were investigated. 3-d models of the flow channel of the opposite-flow cyclone with input duct angles varied from 0 to 40° and conical and cylindrical parts relation from 2:3 to 4:1 were considered. Numerical modelling of a soot clearing process in the opposite-flow cyclone was carried out in the ANSYS Fluent software. The results of 25 different models are presented.

1. Introduction

Presence of the soot particles is a well known problem in diesel and other engines. Particles are usually deleted from the gas flow by a soot filter which is often pluged and requires frequent substitution. Authors suggested using a cyclone cleaning apparatus instead of a soot filter. The cyclone apparatus utilizes a vortex where solid particles are moved to the sides of the apparatus by centrifugal force and then they are delivered to a soot-catching storage due to its motion along the conical surface. It is necessary to know the part of particles which will be delivered in the soot-catching storage and the part of particles which will remain in the flow, which are different due to various configuration of the apparatus [1,2]. Previous researches show that the opposite-flow cyclone separates solid particles from the flow better. Given research presents an investigation of the input duct angle, and a relation of the conical part to a cylindrical one influencing the cleaning degree. For this purpose, a numerical modeling of a different configuration of cyclones was carried out in the ANSYS Fluent software. [3,4]

The opposite-flow cyclone, presented in [5], was selected as a prototype.

2. Formulation of the problem

From the result of the research [5], the number of particles which pass through the apparatus per 200 seconds is equal to 629677. 78,3% of them (492893) were delivered to a soot-catching storage, 21,3% (134209) of them were still inside the flow channel and 0,4% (2575) were not separated from the flow and left the cyclone with cleaned gas. Particles which are still in the flow channel are primarily located near the walls.

Investigation of the geometric characteristic change influence on the cyclone cleaning degree was carried out. Common dimensions and dimensions of input and output ducts must be retained due to limitation of mass-dimensional and technological limitation. Thus, the following parameters were selected as varying: an input duct angle and a relation of the cylindrical and conical part of the lengths

(figure 1)

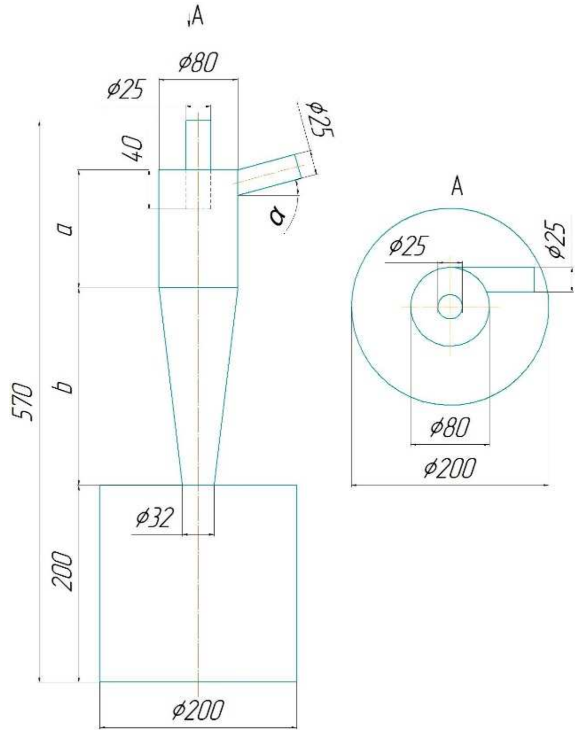


Figure 1. Geometric parameters of the opposite-flow cyclone

Input duct angle α varied from 0 to 40˚ with a step equal to 10˚. Relation of conical part *b* to cylindrical part *a* varies from 2:3 to 4:1. Parameters of calculation models are presented in table 1.

Table 1. Parameters of calculated models

Input duct angle α, ˚	Relation of a conical part to a cylindrical one *b/a*
0	2/3
10	1/1
20	3/2
30	7/3
40	4/1

Numerical modeling was carried out for every angle of the input duct angle with different relations of the conical part to a cylindrical one. This results in 25 different calculations.

3. Numerical simulation

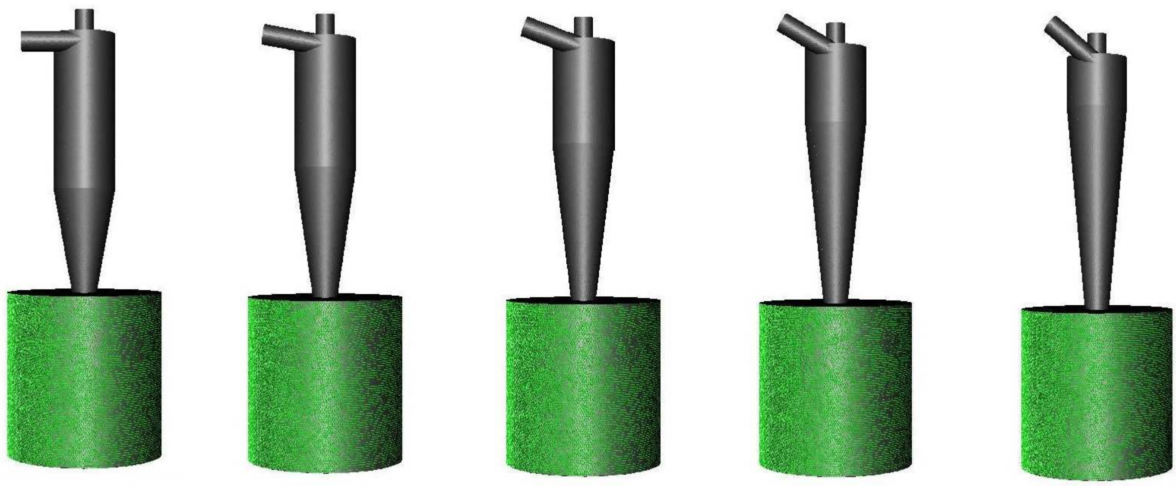
25 three-dimensional models of the opposite-flow cyclone flow channel were created for numerical modeling of the soot-cleaning process. Then, these models were exported to ANSYS DesignModeler, where inlet, outlet and soot-catching storage boundaries were set. Later, they were separated in a finite-element mesh. Helium was selected as a working fluid.

The pressure inlet condition was set at the entrance of the cyclone and the pressure outlet – at the exit of the cyclone. Discrete Phase Model (DPM) [6,7,8] was used to model soot particles. This model calculates a trajectory of a discrete particle by integration of total force acting on the partcile. This force is fixed in Langrangian coordinate system. The impulse conservation law has the following form:

$$\frac{du_p}{dt} = F_D(\vec{u} - \vec{u}_p) + \frac{\vec{g}(\rho_p - \rho)}{\rho_p} + \vec{F}$$

where $F_D(\vec{u} - \vec{u}_p)$ – specific resistance force per a mass unit of the particle, $\vec{u}$ – fluid flow velocity, $\vec{u}_p$– particle velocity, $\frac{\vec{g}(\rho_p-\rho)}{\rho_p}$ – gravitation forces, $\vec{g}$ – gravity acceleration, ρ – fluid density, ρ_p – particle density, $\vec{F}$ –additional force caused by another reasons.

A spherical form was selected for particles. The particles material is carbon with the particle diameter from 5 μm to 1.5 mm. Diameter distribution was made by a rosin-rammler distribution mechanism.



a b c d e

Figure 2. Calculation models of the cyclone apparatus:
a – α=0°, b/a=40/60; b – α=10°, b/a=50/50; c – α=20°, b/a=60/40; d – α=30°, b/a=70/30;
e – α=40°, b/a=80/20.

Carbon particles are injected normally to an entrance plane. The mass of the injected particles is uniformly distributed along the whole injection period. The trap model was used during setting of soot-catching storage boundary conditions. This condition is characterized by the fact that if the particle contacts with the storage wall, it is considered stucked and is not considered in further calculation. A reflection boundary condition was set on other walls of the model. An escape boundary condition was added to an exit section to calculate the number of particles which leave the cyclone. The time step of the calculation is equal to 0.1 sec, calculation duration is 200 sec.

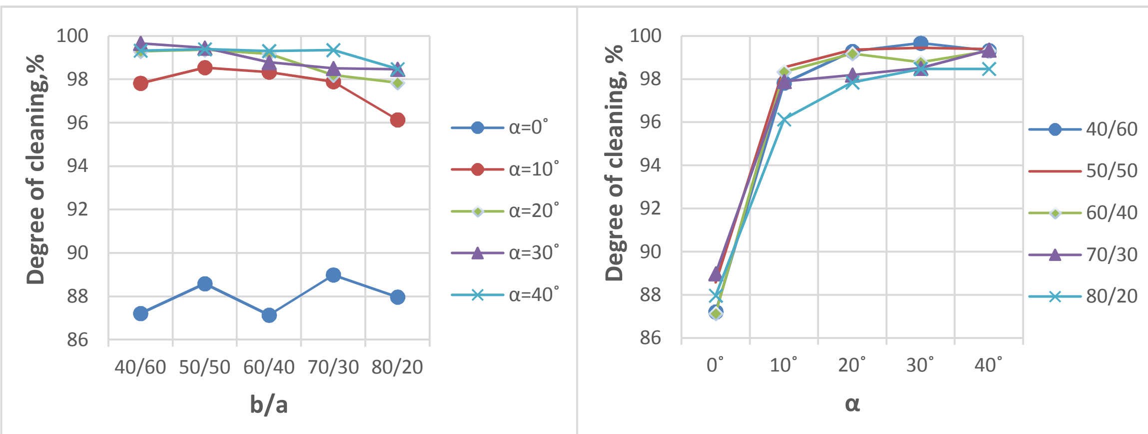
4. Results and discussions

The result of the numerical modeling is presented in table 2. As it can be seen, the number of particles varies from calculation to calculation, so the percentage relation was considered.

Dependencies of the cleaning degree for every model on relation *b/a* and angle α are represented in figure 3. The cleaning degree was calculated as a relation of the soot mass which was “trapped” by the soot-catching storage to a total mass of particles which was ejected into the cyclone. The mass of particles which remains inside the cyclone at the end of calculation (marked as “incomplete”) was ignored. As it can be seen from the plots, the cleaning degree in case the input duct angle equal to 0° is significantly smaller than in other cases. It caused by the fact that, if the angle is wider than 0°, particle motion receives a spiral direction to a soot-catching storage. Model №16 has the highest cleaning degree. Its value reaches 99.7% which is by 11.6% higher than the similar value of the prototype. Analysis of results shows that the input duct angle has the most significant impact on the cleaning degree. For the whole *b/a* range and for angle range α=20-40°, a cleaning degree is higher than 97.8%. Relation of a conical to cylindrical part has a smaller influence on the cleaning degree.

Table 2. Results of numerical modeling

Calculated model	α, °	b/a	Incomplete		Trapped		Escaped	
			Number of particles	Mass, kg	Number of particles	Mass, kg	Number of particles	Mass, kg
1	0	2/3	99702	0.4348	460234	2.993	3145	0.00391
2	0	1/1	85304	0.3791	460262	2.992	3337	0.00639
3	0	3/2	93241	0.4288	459807	2.986	3780	0.01192
4	0	7/3	82221	0.3660	461179	2.994	2526	0.00439
5	0	4/1	96367	0.4049	460530	2.994	3004	0.00450
6	10	2/3	40109	0.0629	492781	2.994	3008	0.00388
7	10	1/1	27221	0.0412	492914	2.996	2939	0.00317
8	10	3/2	35577	0.0475	493321	2.996	2411	0.00325
9	10	7/3	45069	0.0601	492946	2.995	2779	0.00435
10	10	4/1	66956	0.1172	461724	2.996	2068	0.00327
11	20	2/3	16199	0.0188	493123	2.996	2704	0.00287
12	20	1/1	6297	0.0177	493592	2.998	2313	0.00170
13	20	3/2	10500	0.0216	493422	2.996	2361	0.00336
14	20	7/3	25121	0.0523	493601	2.997	2167	0.00284
15	20	4/1	46491	0.0639	461655	2.997	1993	0.00226
16	30	2/3	10065	0.0075	493475	2.996	2375	0.00262
17	30	1/1	8756	0.0146	493575	2.998	2274	0.00202
18	30	3/2	15773	0.0343	493148	2.997	2680	0.00265
19	30	7/3	24873	0.0441	493780	2.998	1998	0.00134
20	30	4/1	33857	0.0442	493785	2.997	2013	0.00244
21	40	2/3	11371	0.0159	492842	2.995	2939	0.00461
22	40	1/1	12246	0.0154	493451	2.996	2255	0.00305
23	40	3/2	6924	0.0166	493324	2.995	2504	0.00440
24	40	7/3	14357	0.0179	493999	2.997	1827	0.00184
25	40	4/1	12320	0.0446	495397	2.999	2302	0.00202



a b

Figure 3. Dependency of the cleaning degree on the input duct angle and the relation of the conical

part to the cylindrical one.

5. Conclusion

A method for numerical modeling of a soot cleaning process by the cyclone apparatus was developed. The developed model allows one to calculate a cleaning degree of the cyclone apparatus, which is equal to a relation of the soot mass which was trapped in the soot-catching storage to a total mass which was ejected in the apparatus. An influence of two geometric parameters was investigated. These parameters are an input duct angle and a relation of a conical part of the cyclone to a cylindrical one. Results shows that the presence of even a small positive duct angle significantly increases the cleaning degree. The highest cleaning degree was reached in the configuration of the input duct angle equal to 30 ° and parts ratio equal to 2/3. The value of the highest cleaning degree is equal to 99.44%. This value allows making a conclusion that this apparatus can be effectively used for exhaust gases cleaning in diesel or other engines as a substitution of the soot filter.

6. Acknowledgments

Work was supported by the Ministry of Education and Science of the Russian Federation in the framework of the implementation of the Program ‘‘Research and development on priority directions of the scientific-technological complex of Russia for 2014–2020”

References

[1] Aslamova V S 2008 *Uniflow cyclone. Theory, calculation, practice* p 233
[2] Vetoshkin A G 2005 *Processes and devices of dedusting* p 210
[3] Zubanov V Egorychev V Shabliy L 2014 *Research Journal of Applied Sciences* **9** 660-663
[4] Biryuk V V Gorshkalev A A Kayukov S S Uglanov D A *Open Mechanical Engineering Journal* **8** 441-444
[5] Biryuk V V Tsapkova A A Shimanov A A 2016 *Key Engineering Materials* **685** 153-157
[6] Demir S Karadeniz A Aksel M *Powder Technology* **295** 209-217
[7] De Silva M S M Narayana M 2016 *2nd International Moratuwa Engineering Research Conference* MERCon 2016 pp 204-209
[8] Azadi M Azadi M Mohebbi A *Journal of Hazardous Materials* **182** 835-841