archives
of thermodynamics
Vol. **34**(2013), No. 4, 247–256
DOI: 10.2478/aoter-2013-0041

Experimental investigations of additional gas extraction inside a cyclone

ARKADIUSZ KĘPA*

Czestochowa University of Technology, Institute of Thermal Machinery,
Armii Krajowej 21, 42-200 Częstochowa, Poland

Abstract The paper presents the results of investigations on a cyclone with additional gas extraction. The experiments were performed in the cyclone with a diameter of 0.2 m equipped with a truncated counter-cone situated in the dust bin inlet. The gas stream flowing through the counter-cone was 10 and 20% of the gas supplied to the cyclone. The separation efficiencies and pressure loss were measured. The experiment showed that the extraction of gas by the counter-cone deteriorated the cyclone efficiency and forcing the outflow of gas through the counter-cone requires the use of an additional outlet fan.

Keywords: Gas cyclone; Particle separation; Dust collection; Additional gas extraction (bleed flow)

1 Introduction

Cyclone as a device for separating the dispersed phase from the transporting continuous phase is widely used and is still the subject of many studies. In Poland cyclones are used very often at small municipal and industrial heat-generating plants where hard coal is burnt. Also in small stoker-fired boilers alternative fuels are more often burnt [1]. The challenge in describing the performance of a cyclone lies in the fact that the construction of a cyclone is simple whereas the phenomena occurring in cyclones are complex. The

*E-mail: a_kepa@imc.pcz.czest.pl

flow is three-dimensional, rotational (outer swirl directed downwards, inner swirl directed upwards) and two-phase (the concentration of dispersed phase changes in the wide range – from the dispersion (inlet and vortex) through material slipping down the walls to static layer of particles in the bin). This complexity of phenomena occurring in cyclones makes the description of the cyclone performance difficult. During the century-old history of cyclones, a great number of models have been developed so far. The majority of these models are based on the experiment that comprises the effects of several basic geometrical dimensions. Many studies have been conducted in Poland and worldwide aimed at construction of the most efficient cyclone (i.e., with the maximum separation efficiency at minimum pressure loss). The majority of these studies were orientated at determining the optimal ratios for the main dimensions (i.e., body part, conical part and vortex finder). On the other hand some researchers aimed at improving the performance of the cyclone by installing new elements such as a filter in a vortex finder, a swirl separator (i.e., a pipe on the extension of the vortex finder which separates the inner swirl from the outer swirl), a vortex breaker (i.e., metal sheet placed in the bin perpendicular to the axis of the device) or a swirl stabilizer (a counter-cone in the outlet from the cyclone to the bin). For these cases, the mathematical description of the effects of the applied elements is rather poor. One of the above mentioned elements – a counter-cone – deserves a special attention. For many practical applications, cyclones are equipped with a counter-cone that may be placed over the inlet to the bin as well as under the bin (i.e., in the dust bin). Despite the fact that the literature provides some guidelines [2–5], until now there is no comprehensive theory and mathematical description that shows the effect of a counter-cone on the cyclone performance.

In [6], based on well-known relationships, it was shown that there is an optimal location of the counter-cone in cyclone (its distance from the inlet to the vortex finder), for which the separation efficiency can be maximized. Another way of improving the performance of the cyclone may be additional gas extraction. Gas extraction has been analysed by very few researchers. Crane *et al.* [7] analysed the secondary gas extraction through a central nozzle in the common collection bin of a nine-cell multicyclone with an axial inlet. Their findings showed that the extraction gave the reduction in particulate emission, and thus the increase in the efficiency calculated from the amount of material which is not retained in the cyclone (remained in the exhaust gas). Other researchers have added elements after the vortex finder. Ray *et al.* [8–10] tested an auxiliary device called the post cyclone (PoC) which was situated above the vortex finder of the cyclone. The PoC utilizes the swirl present in the vortex finder but its efficiency may be improved by the gas extraction (bleed flow). The overall efficiency of the PoC improved with the increase in bleed flow from 10% to 36% (increase in bleed flow from 5% to 25% was considered) [8]. Sadighi *et al.* [11] divided the outlet stream from the cyclone into two streams in a device called the RDC (recycle dividing chamber). The RDC is joined to the vortex finder and uses the swirl present in the vortex finder like the PoC. Sadighi *et al.* used the recycle ratio from 19% to 89% and obtained the increase of overall efficiency of the system from 97% to 99.2%. Kepa [12] divided the outlet flow in a cyclone by means of a doubled vortex finder. In (outer) vortex finder an additional tube (an inner vortex finder) was placed. Calculations showed that gas extraction (up to 57%) by the outer vortex finder did not significantly change the cyclone efficiency. In [12] a commercial CFD software was used. Lately, apart from the experimental and theoretical investigations, the computational fluid dynamics is very often employed. This provides a fantastic opportunity to 'glimpse into' the device but should be pointed out, that computer simulations require experimental validation. In another work, Kepa [13] has analyzed additional gas extraction which took place by the truncated counter-cone located in the lower part of 0.4 m diameter cyclone. In calculations 20% and 40% of bleed flow was considered (velocity inlet of gas was equal to 11 m/s). A slight improvement, up to 5.6% for certain particle sizes has been achieved.

The paper presents the results of measurement of separation efficiency and pressure loses for a cyclone with additional gas extraction through a counter-cone.

2 Apparatus and procedure

A scheme of the experimental setup is presented in Fig. 1. Air flow through the cyclone (1) is forced by two adjustable exhaust fans (8) – the main fan ensuring the flow through the vortex finder and auxiliary fan ensuring additional extraction of gas through the counter-cone. Both of connecting ducts (9) were equipped with rotameters (7) measuring volumetric flow and pressure sensors (5). Static pressure measurements allowed to determine the pressure loss. The bulk material (fly ash) of known mass and particle size distribution was fed by the feeder ejector system (4). Based on the mass of the sample introduced into the cyclone and retained in the dust bin (3) the overall collection efficiency was determined for each turn. The measurement of the feeding time allowed to determine the mass loading (i.e., ratio of mass flowrate of dust to mass flowrate of gas) which ranged from 0.0009 to 0.0269, with the average value of 0.0081. For A, B and C cases, 41 attempts have been done in total. Analysis of particle size distribution (used Mastersizer by Malvern [15]) allowed calculation of the fractional efficiency. The dust not retained in the cyclone was separated from the gas by the bag filters (6). Measurements were carried out at an inlet gas velocity of 8.9 m/s for all three cases. Case A – without additional gas extraction, case B – 10% and case C – 20% of additional extraction by counter-cone. The geometry of the tested cyclone is described in Fig. 2. The counter-cone (basic dimensions are shown in Fig. 3) was mounted in the dust outlet of the cyclone. The basis of the counter-cone coincided with the basis of the cyclone cone (with the upper plane of the cylinder separating cyclone from the dust bin).

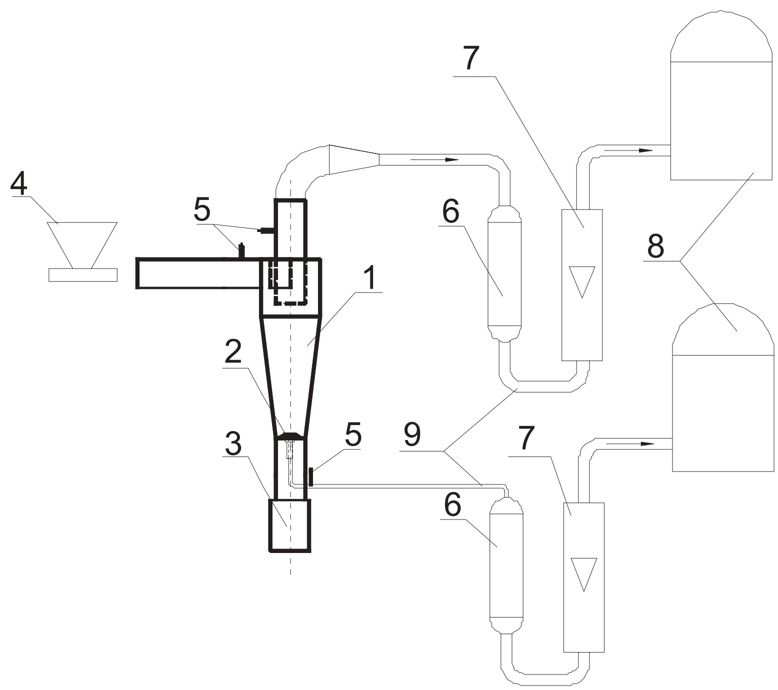

Figure 1. Schematic diagram of the experimental setup: 1 – cyclone, 2 – counter-cone, 3 – container of collected material, 4 – feeding system, 5 – pressure sensors, 6 – bag filters, 7 – rotameters, 8 – air exhaust fans, 9 – connecting ducts.

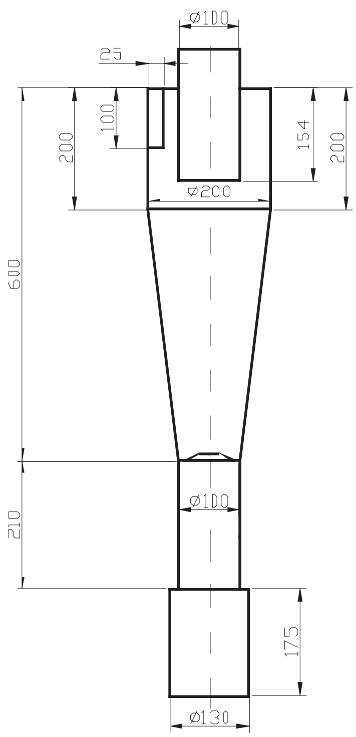

Figure 2. Geometry of the cyclone, in mm.

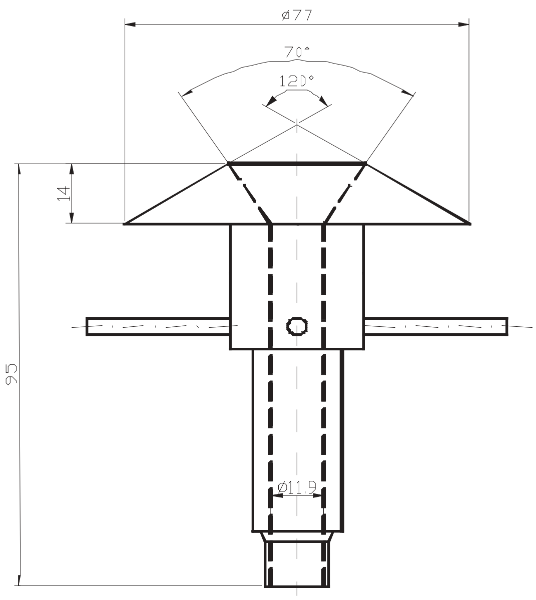

Figure 3. Geometry of the counter-cone, in mm.

3 Results

The measured total efficiencies as a function of extracted gas flow fraction (in percent of inlet flow) are presented in Fig. 4. It may be seen that the gas extraction impairs the total efficiency of the cyclone. It should be noted that the efficiency is calculated by dividing the mass retained in the cyclone by the mass fed into the cyclone. Undoubtedly, some mass of dust is leaving the cyclone with the extracted gas. If the dust was retained (e.g., in the fabric filter), the efficiency of the unit cyclone with the filter would be higher.

Three samples for each case were drawn for the analysis of particle size distribution. The samples were indicated by successive numbers with increasing mass loading. The obtained (measured) total efficiencies as a function of the mass loading for these samples are shown in Fig. 5. The

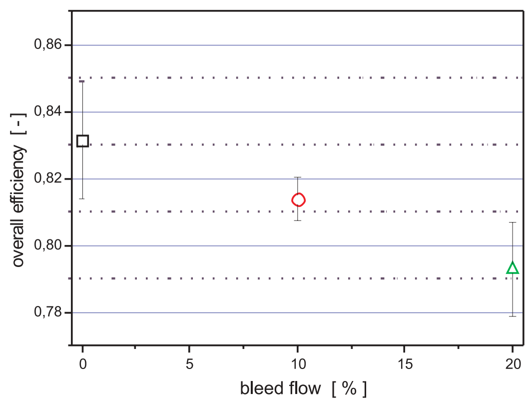

Figure 4. The overall efficiency versus additional extraction (average mass loading 0.0081).

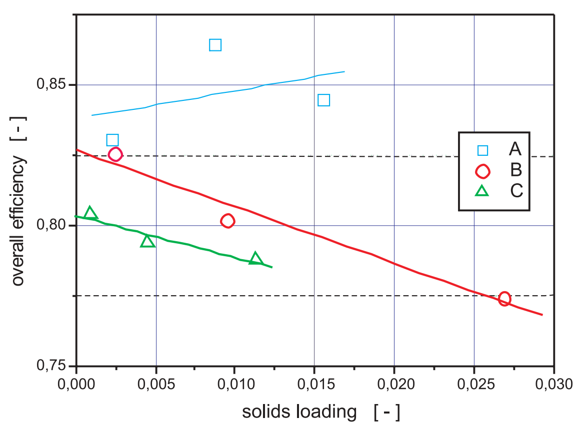

Figure 5. The overall efficiency for the analysed samples.

fractional efficiencies determined from the particle size distributions (of the materials fed and retained in the cyclone) are shown in Fig. 6. The mean (for three samples) fractional efficiencies are shown in Fig. 7. As it can be seen, the deterioration of separation with increasing gas extraction occurs over the entire range of particle diameters (for the tested geometry and flow conditions).

The measured vacuum pressures for the analyzed samples are provided in Tab. 1. The pressure sensors S1 and S2 (see Fig. 1) were placed in the

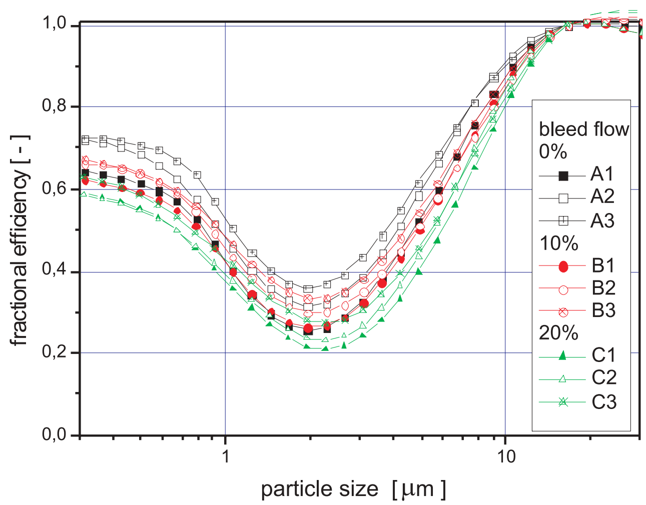

Figure 6. The fractional efficiency for the analysed samples.

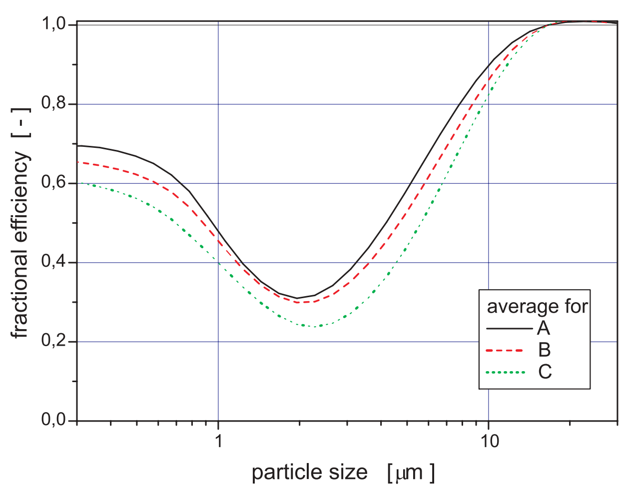

Figure 7. Average values of fractional efficiencies (for the analysed samples).

inlet and the outlet channels of the cyclone, respectively, S3 sensor in the channel through which the bleed flow takes place. If there is no gas flow through the bleed flow channel (case A) the indication of the sensor should be interpreted as a vacuum pressure at the counter-cone inlet. As seen, in order to force the flow of gas through the counter-cone, the pressure behind it (S3 sensor) must be much lower than in the exhaust duct of the cyclone (S2 sensor). In industrial applications, such as in the experiment, it would be necessary to apply an additional fan.

Table 1. The measured pressure.

Case	Denotation of measurement	The sensor readings [Pa]		
		S1	S2	S3
A	A1	-34.2	-161.5	-242.2
	A2	-32.4	-148.9	-219.5
	A3	-31.5	-146.7	-212.3
B	B1	-35.9	-181.0	-966.0
	B2	-35.5	-164.5	-1034.4
	B3	-34.7	-154.5	-1056.4
C	C1	-34.7	-170.1	-2475.4
	C2	-32.4	-147.9	-2564.0
	C3	-32.9	-147.6	-2590.0

Table 2. The measured pressure differences.

Case	Denotation of measurement	Pressure difference [Pa]			
		S1-S2	S1-S3	Average S1-S2	Average S1-S3
A	A1	127.3	208	119.7	192.0
	A2	116.5	187.1		
	A3	115.2	180.8		
B	B1	145.1	930.1	131.3	983.6
	B2	129	998.9		
	B3	119.8	1021.7		
C	C1	135.4	2440.7	121.9	2509.8
	C2	115.5	2531.6		
	C3	114.7	2557.1		

The pressure differences (drops) are given in Tab. 2. Gas extraction impairs the flow conditions and generates higher pressure losses in both cases (B and C). The pressure drop (loss of energy) in the device is affected by both differences: S1-S2 and S1-S3 and pressure drop is greater than the difference S1-S2. Figure 8 shows the pressure difference S1-S2 as a function of the mass loading. The vast majority of theories recognize (e.g., [14]) that with increasing mass loading cyclone efficiency increases and pressure drop decreases. The same pattern was also observed in the experiment for case A (without extraction). For cases B and C the efficiency decreases (and pressure drop decreases too) with increasing mass loading.

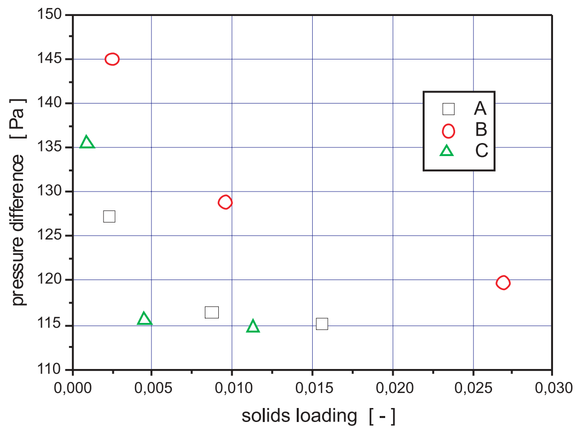

Figure 8. Pressure differences (cyclone inlet and outlet: S1-S2).

4 Conclusions

The measurements of the cyclone performance with additional gas extraction through the counter-cone have shown that:

- gas extraction deteriorated the work of the cyclone,
- for all diameters of used particles the measured efficiency with extraction was lower than without,
- extraction increased the pressure drop in cyclone.

Received 14 October 2013

References

[1] Orszulik E., Jachyra J., Wasylewicz A.: *The concept of energy production on the basis of modern alternative fuels*. Arch. Thermodyn. **34**(2013), 1, 19–39.

[2] Krambrock W.: *Die Berechnung des Zyklonabscheiders und praktische Gesichtspunkte zur Auslegung-Teil 2*. Aufbereitungs-Technik **10**(1971) 643–649.

[3] Muschelknautz E., Greif V.: *Cyclones and other gas-solids separators*. In: Circulating Fluidized Beds (J.R. Grace, A.A.Avidan, T.M. Knowlton, Eds.), Blackie Academic & Professional, 1997.

[4] Yoshida H., Kwan-Sik Y., Fukui K., Akiyama S., Taniguchi S.: *Effect of apex cone height on particle classification performance of a cyclone separator*. Adv. Power Technol. **14**(2003), 3, 263–278.

[5] Yoshida H., Nishimura Y., Fukui K., Yamamoto T.: *Effect of apex cone shape on fine particle classification of gas-cyclone*. Powder Technol. **204**(2010), 54–62.

[6] Kępa A.: *The effect of a counter-cone position on cyclone performance*. Separ. Sci. Technol. **47**(2012), 2250–2255.

[7] Crane R.I., Barbaris L.N., Behrouzi P.: *Particulate behaviour in cyclone separators with secondary gas extraction*. J. Aerosol Sci. **23**(1992), Suppl. 1, S765–S768.

[8] Ray M.B., Luning P.E., Hoffamnn A.C., Plomp A., Beumer M.I.L.: *Improving the removal efficiency of industrial-scale cyclones for particles smaller than five micrometres*. Int. J. Miner. Process. **53**(1998), 39–47.

[9] Zhao W., Mujumdar A.S., Ray M.B.: *Collection Efficiencies of Various Designs of Post-Cyclone*. Can. J. Chem. Eng. **79**(2001) 708–716.

[10] Jo Y., Tien C., Ray M.B.: *Development of a post cyclone to improve the efficiency of reverse flow cyclones*. Powder Technol. **113**(2000), 97–108.

[11] Sadighi S., Shirvani M., Esmaeli M., Farzami R.: *Improving the removal efficiency of cyclones by recycle stream*. Chem. Eng. Technol. **29**(2006), 10, 1242–1246.

[12] Kępa A.: *Division of outlet flow in a cyclone vortex finder — The CFD calculations*, Separ. Purif. Technol. **75**(2010), 127–131.

[13] Kępa A.: *CFD investigation of a flow inside a cyclone with additional gas extraction*. Chem. Process Eng. **29**(2008), 1027–1035.

[14] Hoffmann A.C., Stein L.E.: *Gas Cyclones and Swirl Tubes*. Springer-Verlag, 2002.

[15] Malvern: *Mastersizer 2000 user manual (MAN0247-2.0)*.