CHEMICAL ENGINEERING TRANSACTIONS

VOL. 53, 2016

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Valerio Cozzani, Eddy De Rademaeker, Davide Manca

ISBN 978-88-95608-44-0; **ISSN** 2283-9216

DOI: 10.3303/CET1653049

Effective Methods for Dust Collection and Separation of Aerosols on the Active Regimes of Phase Interaction

Kamila Bulekbayeva[a], Mayra Turalina[a], Ultugan Orynbayeva[a], Arnold M. Brener*[b]

[a]Taraz State Dulati University, Taraz, Kazakhstan
[b]State University of South Kazakhstan, Shymkent, Kazakhstan
amb_52@mail.ru

Necessity to achieve a high degree of gas mixtures separation and removal of dust and aerosols at the lowest possible energy cost makes it reasonable to use active hydrodynamic regimes. Such devices include scrubbers with contrary swirling flows. Apparatuses with described principle of action proved to be highly effective in pilot tests, but science-based engineering method of their calculation has not yet developed sufficiently. The goals of the submitted work are: to establish the regularities both of particles separation from the gas-aerosol flows in apparatuses with active hydrodynamic regimes of the new design; to determine the optimal design and regime parameters of their work; to develop the methods for calculating the hydrodynamic characteristics, parameters of gas purifying from dust.

The offered by authors design of the apparatus with active hydrodynamic regimes has passed the pilot tests in the system for collecting the dust generated during the phosphorites agglomeration process.

1. Introduction

Most of chemical and metallurgical industrial processes (De Nevers, 2010), processes of mechanical engineering, energy and agriculture (Omarbekuly & Bulekbayeva, 1998) are accompanied by intensive gas pollutions containing suspended solids and liquids (Schelle et al, 2015). For example, in the rough estimations, the amount of dispersed solid and liquid phases which are rejected into the atmosphere per year in the Zhambyl region of Kazakhstan is 18.4 thousand tonnes, since a lot of gas treatment devices do not meet modern environmental requirements (Bulekbayeva & Golubv, 2004). Not better things in other industrial regions of Kazakhstan (Bulekbayeva, Golubev, Omarbekuly, 2005). Therefore, to suppress dust emissions the more effective gas purifying devices with less specific quantities of metal and energy should be implemented in the industry (Wang et al, 2004). Besides the nature protection (Silverman, 2012) the dust collection devices provide also increasing the yield of the final product or raw material for subsequent processing, thereby increasing also production efficiency (Pilat & Prem, 1977). Apparatuses of the cyclone type for dust separation may be used also as main processing equipment (Viswanathan, 1997), as is the case for the separation of solid particles from dispersion in the production of the powders (Volnenko et al, 2015), in drying bulk material in the process of condensation (Golubev, Brener, 2002), in pneumatic systems in powder metallurgy etc (Park & Lee, 2009).

In this regard, the development of high-performance apparatuses for dust and aerosol collection that meet the latest international environmental standards is one of the urgent problem of contemporary science and technology (Lee et al, 2008). Unfortunately, despite a lot of various constructions offered as gas purifying devices, the problem is far from the solution as a whole (Couvert et al, 2008).

The objective of our work is to establish the regularities of particle separation from the gas-aerosol flow into the high-effective devices of new design with active hydrodynamic regimes (Bulekbayeva, 2004), the determination of optimal design and regime parameters of their work (Viswanathan et al, 2005), and the creation of the methods for calculating their hydrodynamic parameters and the rate of dust collection.

In order to reach these goals the special experimental and theoretic investigations have been carried out with applying to the cyclone type apparatus of new design. As the result of our work the set of recommendations for the calculation and operation of the high-performance industrial devices for trapping dust can be offered.

Please cite this article as: Bulekbayeva K., Turalina M., Orynbayeva U., Brener A., 2016, Effective methods for dust collection and separation of aerosols on the active regimes of phase interaction, Chemical Engineering Transactions, 53, 289-294 DOI: 10.3303/CET1653049

2. New design of the apparatuses with active hydrodynamic regimes

Currently used types of swirl scrubbers, which can be attributed to devices with active hydrodynamic regimes, are characterized by great variety (Bandyopadhyay & Manindra, 2007). However, a major drawback of most of these devices is low efficiency of finest fractions collection for polydisperse dusts and aerosols (Reither et al, 2000). This problem is noted by many researchers for cyclones (Kim & Lee, 1990), scrubbers (Bandyopadhyay & Biswasa, 2006) and for apparatuses of various types (Bandyopadhyay & Manindra, 2006). The main reason for this deficiency can be found in the fact that the fine particles which move co-current with the main gas flow have enough time to get into the central upward flow and to be carried along the apparatus axis (Austheim et al, 2008). In addition, the disadvantage of swirl scrubbers used for dust removal process is a relatively high specific power costs (Chang & Yongxin Zhao, 2008). These disadvantages reduce the overall effectiveness of particle collection (Costa et al, 2004). To overcome this limitation we have proposed a new design of a centrifugal dust separator with counter-current swirling flows (Omarbekov & Bulekbayeva, 1998). Figure 1 schematically illustrates a new design of this apparatus.

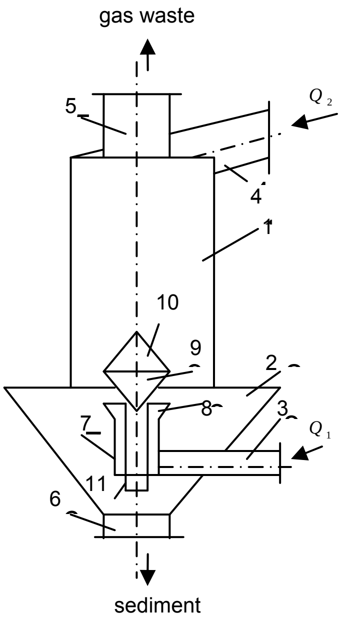

Figure 1: Swirl scrubber with counter-current flows

The device comprises a body with cylindrical part 1, truncated conical part 2 provided with tangential inlet fittings 3, 4. Union 3 is attached to the cylindrical portion and fitting 4 - to truncated conical part 2. Union 4 is provided with pneumatic fitting ring 5. Upper cylindrical body portion 1 has exhaust pipe 6, and the bottom - unloading pipe 7. Spiral ribs 8, which are enclosed into curly channel 9, are attached by the outer surface of the cylindrical part of body 1. Incidentally spiral channel 9 is provided with tangential inlet and outlet nozzles 10 and 11 respectively. The device operates as follows.

Dusty gases separated into two streams, the first Q_1 and the second Q_2, through tangential nozzles 3 and 4 come into the apparatus. The second stream is approximately 60-80% of the total flow. At the entrance to the scrubber both streams are swirled in the same direction and move further towards each other.

The first axial stream moves toward the second in direction to exhaust pipe 6. The second stream descending along the surface of cylindrical part 1, meets the first stream at baffle ring 5.

In rotating gas streams the particles caught by the centrifugal force move toward the apparatus walls and are conveyed by the second stream towards truncated conical part 2 under ring 5 to pipe 7.

Into spiral channel 9 the flow of cold air or water is fed counter currently to the second stream through tangential pipe 10 with the purpose for cooling the cylindrical part of body 1.

The preliminary laboratory studies and limited industrial testing confirmed the high performance characteristics of the described construction. In order to assess and verify the described ideas, the experimental investigations in a pilot plant which was installed in the Taraz State Dulati University have been carried out.

3. Experimental results

Each of the experiments was conducted at a fixed total air consumption, but at the changing value of flow ratio K. The experiments was repeated a few times, but at various values of the total air consumption. Values of the basic parameters of the experiments were as follows: total air consumption is of 800-4650 m / h; flow ratios K are from 1 to 3, the Stokes number ($Stk = \rho W d / 9\mu D$) are from 0.1 to 0.3 and particles sizes in various fractions are: 0.1 - 20 mkm. Altogether, 36 series of experiments were made under different environmental conditions. The main apparatus sizes are: body diameter $D =$ 0.4 m; body height $H = 1.2$ m. During experimental studies the following main parameters were measured: static pressures respectively of primary, secondary and outlet flows; the concentration of soda dust in the primary, secondary flows and at the output from the unit. The certain most significant results are shown in Figures 2, 3, 4, 5, 6.

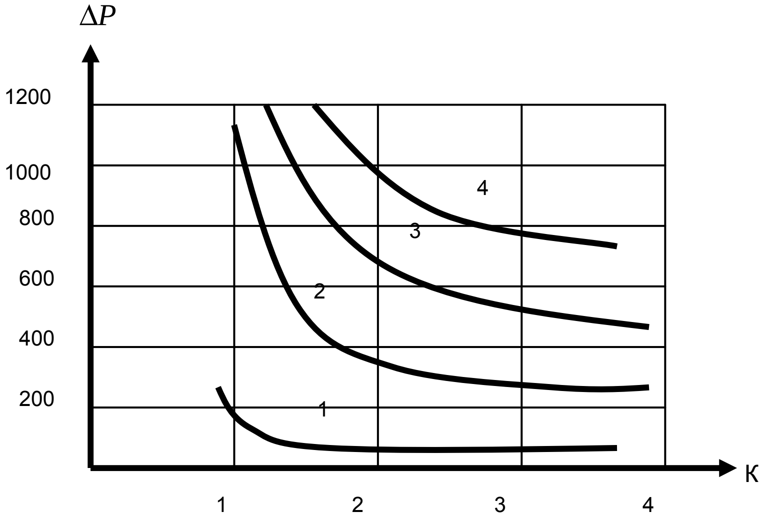

Figure 2: Total pressure drop ΔP (Pa) as a function of the flow ratio $K = Q_1/Q_2$. Average gas velocity W inside the apparatus: 1- 1.5 m/s; 2- 3 m/s; 3- 4 m/s; 4- 6 m/s.

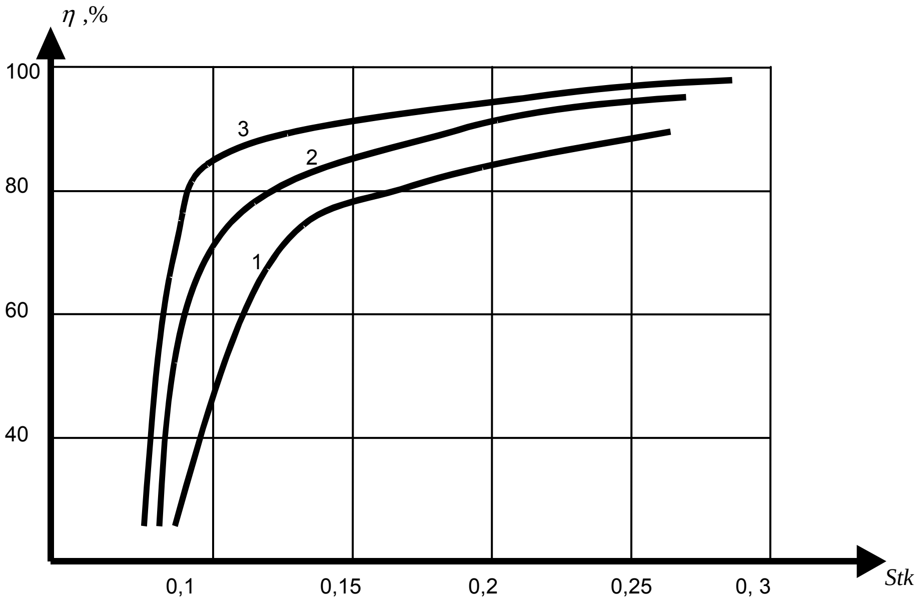

Figure 3: Degree of the dust collection (%) as a function of Stokes number Stk. Flows ratios: 1- 2; 2- 3; 3- 4

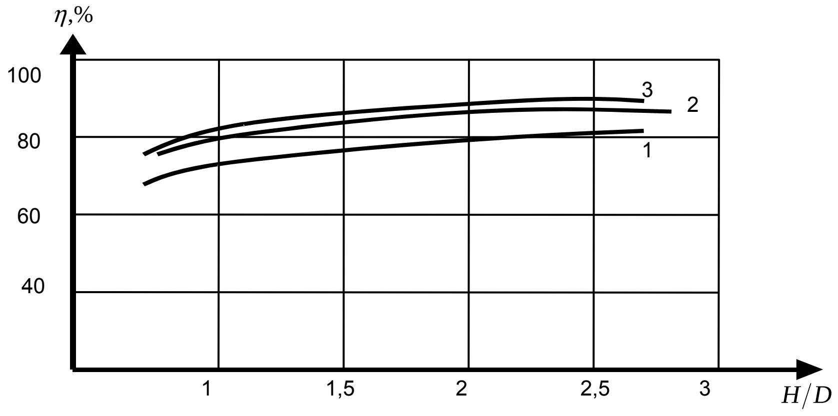

Figure 4: Degree of the dust collection (%) as a function of the apparatus scale H/D at the different flow twisting coefficients for the secondary flow - Φ , where Φ is a ratio between axial and tangential components of gas velocity. 1- $\Phi = 2$; 2- $\Phi = 2.5$; 3- $\Phi = 4$.

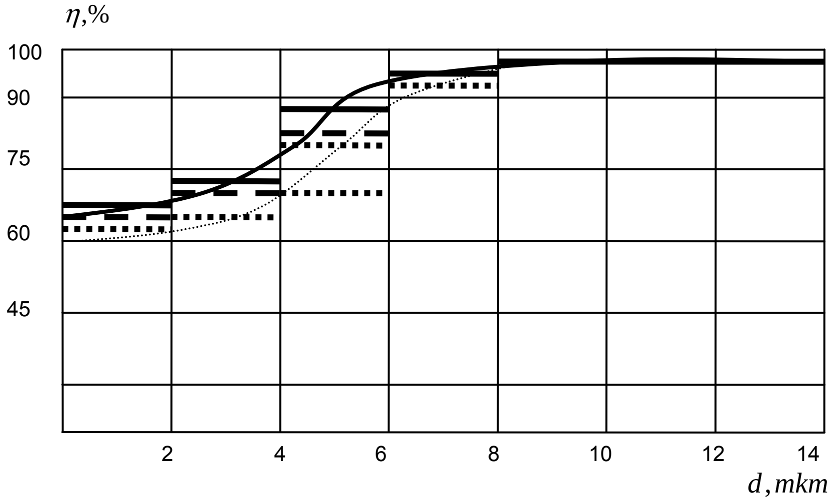

Figure 5: Degree of the dust collection (%) as a function of the dust fraction size d . at the different flows ratios K . Here: ▪▪▪▪▪▪ $K = 2$; ▬ ▬ ▬ ▬ $K = 2.5$; ▬▬▬ $K = 3$

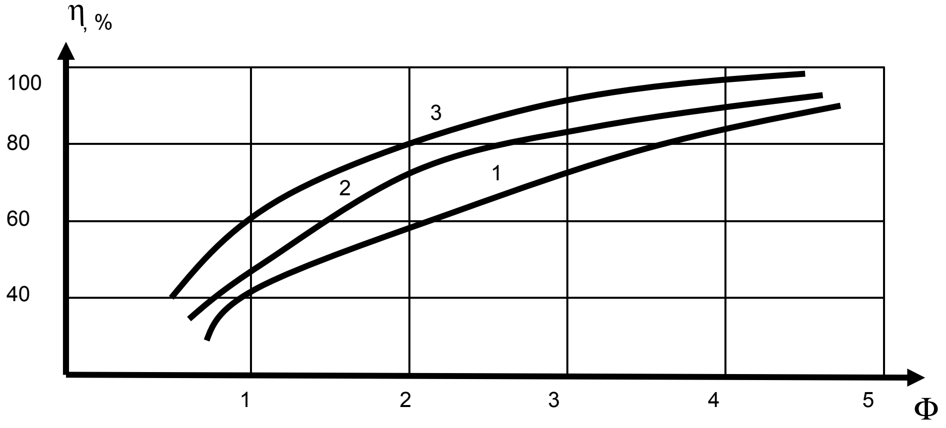

Figure 6: Degree of the dust collection (%) as a function of the twisting coefficients for the secondary flow - Φ. 1- $K = 2$; 2- $K = 2$; 3- $K = 3.5$.

The results of experimental investigations helped us to select the optimal values of main control parameters and to offer the certain expressions for engineering calculations.

4. Methods of engineering calculating the particles collection effectiveness

After generalizing the set of our experimental data and data of other researches (Austheim, 2006), as well on the base of theoretical reasons (Li et al, 2015), the following expressions for calculating the dust collection degrees were obtained as functions of the different control parameters .
The general form of the expression is

$$\eta = C(Stk)^{n_1} \Phi^{n_2} K^{n_3} \tag{1}$$

In the range of the Stokes number from 0.01 to 0.05:

$$\eta = 19{,}83(Stk)^{0,77} \Phi^{0,08} K^{0,23} \tag{2}$$

In the range of the Stokes number from 0.05 to 0.125:

$$\eta = 1{,}63(Stk)^{0,46} \Phi^{0,07} K^{0,21} \tag{3}$$

In the range of the Stokes number from 0.125 to 0.45:

$$\eta = 1{,}03(Stk)^{0,11} \Phi^{0,08} K^{0,22} \tag{4}$$

Industrial tests were carried out in the dust collection system for the dust formed during sintering the phosphorite fine fractions on LLP "Khimprom-2030" in Taraz city. These data support the conclusion that use of the swirl scrubber of the new design allows us achieving a more uniform cleaning of dust fractions with high degree of dust collection.

5. Conclusions

A new design of the apparatus with active hydrodynamic regimes, which is characterized by the high efficiency of the fine particles and dust aerosols capture has been worked out.

The main hydrodynamic regularities of the fine particles separation in the developed apparatus have been established, and the optimal ratios of primary and secondary streams, as well as optimal design and operating parameters, ensuring maximum efficiency of dust collection have been experimentally determined.

The dependences for calculating the effectiveness of dust collection in the apparatus with active hydrodynamic regimes of the new design have been obtained with the help of experimental data and modelling procedures. The industrial tests data confirm the expediency of using the new apparatuses for effective dust collection in dusty flows with wide range of fine particles sizes.

Reference

Austrheim T., 2006, Experimental characterization of high-pressure natural gas scrubbers. Dissertation for the degree philosophiae doctor (PhD), University of Bergen.

Austrheim T., Gjertsen L.T., Hoffmann A.C., 2008, Experimental investigation of the performance of a large-scale scrubber operating at elevated pressure on live natural gas, Fuel, 87.7, 1281-1288.

Bandyopadhyaya A., Biswasa M.N., 2006, Prediction of the Removal Efficiency of a Novel Two‐Stage Hybrid Scrubber for Flue Gas Desulfurization, Chemical engineering & technology, 29.1, 130-145.

Bandyopadhyay A., Manindra N.B., 2006, Particulate scrubbing in a novel two‐stage hybrid scrubber, AIChE Journal, 52.2, 850-854.

Bandyopadhyay A., Manindra N.B., 2007, Fly ash scrubbing in a novel dual flow scrubber, Waste management, 27.12, 1845-1859.

Bulekbayeva K.B., 2004, Mathematical model of aerosols separation in apparatuses with active hydrodynamic regimes, Industry of Kazakhstan, 4(25), 72-73 (in Russian).

Bulekbayeva K.B., Golubev V.G., 2004, Modeling the sedimentation of particles in apparatuses with active hydrodynamic regimes, Mechanics and modeling technology processes, 2, 224-229 (in Russian).

Bulekbayeva K.B., Golubev V.G., Omarbekuly T., 2005, Influence of phase transitions in dusty vapour-gas mixture on dust collection, Industry of Kazakhstan, 2(29), 84-85 (in Russian).

Chang J.S, Yongxin Zhao, 2008, Pilot plant testing of elemental mercury reemission from a wet scrubber, Energy & Fuels, 22.1, 338-342.

Costa, M. A. M., Henrique P.R., Gonsales J.A.S., Coury J.R., 2004, Droplet size in a rectangular Venturi scrubber, Brazilian Journal of Chemical Engineering, 21.2, 335-343.

Couvert, A., Sanchez C., Laplanche A., Renner C., Levasseur J.P., 2008, Design of a new compact scrubber for deodorisation, Chemical Engineering and Processing: Process Intensification, 47.9, 1793-1798.

Gabriel D., Cox H.H.J, Marc A. D., 2004, Conversion of full-scale wet scrubbers to biotrickling filters for H_2S control at publicly owned treatment works, Journal of environmental engineering, 130.10, 1110-1117.

Golubev V.G., Brener A.M., 2002, Film Condensation from a Dusty Vapor–Gas Mixture, Theor. Found. Of Chem. Eng., 36.2, 123-128.

De Nevers N., 2010, Air pollution control engineering. Waveland press.

Kim, J. C., Lee K.W., 1990, Experimental study of particle collection by small cyclones, Aerosol Science and Technology, 12.4, 1003-1015.

Lee Byeong-Kyu, Kwang-Ryun Jung, Sung-Hoon Park, 2008, Development and application of a novel swirl cyclone scrubber—(1) Experimental, Journal of Aerosol Science, 39.12, 1079-1088.

Li H., Gao B., Li B., 2015, Numerical analysis of flow dynamics of cyclone separator used for circulating fluidized bed boiler, Chemical Engineering Transactions (CET), 46, 991-996.

Omarbekov T.O., Bulekbayeva K.B., 1998, Apparatus with active hydrodynamic regimes for aerosols separation, in “Ecology problems for agro-industry systems and environmental protection”, Almaty, 118-120 (in Russian).

Park Sung-Hoon, Lee Byeong-Kyu, 2009, Development and application of a novel swirl cyclone scrubber:(2) Theoretical, Journal of hazardous materials, 164.1, 315-321.

Pilat M.J., Anil Prem, 1977, Effect of diffusiophoresis and thermophoresis on the overall particle collection efficiency of spray droplet scrubbers, Journal of the Air Pollution Control Association, 27.10, 982-988.

Reither K., Borger G.G., Listner U., Schweitzer M., 2000, Removal of fine dust in a venturi scrubber with hybrid jets, Chemie Ingenieur Technik, 72.5, 491-494.

Schnelle Jr., Karl B., Russell F. D., Ternes M.E., 2015, Air pollution control technology handbook. CRC press.

Silverman L., 2012, Particle size analysis in industrial hygiene. Elsevier, Amsterdam, The Netherlands.

Viswanathan S., 1997, Modeling of Venturi scrubber performance, Industrial & engineering chemistry research, 36.10, 4308-4317.

Viswanathan S., Ananthanarayanan N.V., Azzopardi B.J., 2005, Venturi scrubber modelling and optimization, The Canadian Journal of Chemical Engineering, 83.2, 194-203.

Volnenko A.A., Balabekov O.S., Korganbayev B.N., Sarsenbekuly D.S., 2015, Chemical Engineering Transactions (CET), 43, 1147-1152.

Wang L.K., Norman C.P. Yung-Tse Hung, Eds., 2004, Air pollution control engineering, Vol. 1. Totowa, NJ: Humana Press.