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INTEGRATED STUDY OF HYDRODYNAMICS CHARACTERISTICS OF THE SCRUBBER

Keywords: dynamic spray scrubber, mathematical model, experiment, water resistance, air swirler, process flowsheet of clearing of gas emissions, specific irrigation.

The numerical model of process of clearing of gas emissions in program Ansys CFX is devised. Presence of swirling motions and distribution of speed and pressure of a gas-dispersed stream is revealed. Experimental researches of a water resistance of the irrigated apparatus are observed. Pressure change on phases is investigated at a compulsory twisting of a stream, and also in terms of angular speed of twirl of a rotor and veering of twirl of guide vanes of an air swirler. Calculation of a twirled air swirler is offered for spending, being based on the theory of centrifugal blowers, in terms of quantities and directions of rotation of guide vanes. Steel intensity of the industrial apparatus and expense of energy for gas clearing has been reduced.

Ключевые слова: динамический газопромыватель, математическая модель, эксперимент, гидравлическое сопротивление, завихритель, технологическая схема газоочистки, удельное орошение.

Построена численная модель процесса газоочистки в программе Ansys CFX. Выявлено наличие вихревых движений и получено распределение скорости и давления газодисперсного потока. Проведены экспериментальные исследования гидравлического сопротивления орошаемого аппарата при изменении нагрузок по фазам, а также, при принудительной закрутке потока, с учетом угловой скорости вращения ротора и изменении направления вращения лопастей завихрителя. Расчет вращающегося завихрителя предложено проводить, основываясь на теории центробежных вентиляторов, с учетом количества и направления вращения лопастей. Проведенные исследование позволили снизить металлоемкость промышленного аппарата и энергозатраты на очистку газа.

1. Introduction

From the very beginning of emersion of scrubbers before engineers there was a problem - to predict parametres of work of the apparatus before drawings will be given to manufacture. In apparatuses of rotational act the problem became complicated that critical parametres of their work (resistance, efficiency, an input, etc.) are defined by a picture of a current of streams in the setting. The current of a stream of multiphase Wednesday so difficult that a unique reliable method of research in hydrodynamics remains till now experiment. Only last years essential progress in creation of simulars and calculation of currents of multiphase Wednesdays has been attained. Modelling allows to carry out calculation with high reliability of the results, therefore the necessary volume of experiments in many cases is reduced to a minimum.

The purposes of the given work:

1. To devise algorithm of modelling of process of separation of firm corpuscles in a dynamic spray scrubber, allowing to define potential possibilities of apparatuses of clearing of gas emissions.

2. To carry out the analysis of the numerical circuit design, to build numerical model in the program of computing hydrodynamics *Ansys CFX*. To reveal presence of whirling motions and to have distribution of speed and pressure of a gas-dispersed stream.

3. To execute numerical research of a flow pattern of a current of a stream in bundled software *Ansys CFX*. To compare results of calculations for various flows. To make verification of design data with the data which has been had in experiment.

4. On the basis of experimental researches to devise a design procedure of a hydraulic resistance of the apparatus at change of loadings on phases, and also, at a compulsory twisting of a stream, in terms of angular speed of twirl of an air swirler.

5. To solve a practical problem on perfection of complex system of clearing of an aerosphere from gas emissions. To devise a flowchart of process of clearing of gas emissions of baking ovens for the purpose of betterment of hygienic and sanitary working conditions.

2. Geometrical Model Making

The first stage of preparation of initial data for current calculation - creation of the solid-state geometrical model simulating volume in which there is an investigated current [1-5]. 3D the apparatus model has been executed in a package of solid-state modelling *Solid Works* (**fig. 1**), and then imported in *Ansys Design Modeler*.

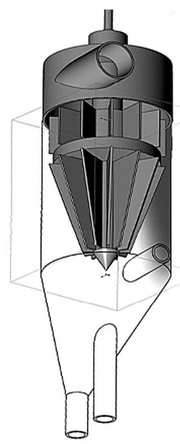

Fig. 1 - A scrubber geometrical model in *Solid Works*

The circuit design of the grid used for the solution of the given problem, is presented in drawings (**fig. 2**). In our problem the right-angled in-process was applied to the solution of the equations of mathematical model, adaptive, locally comminuted finite-dimensional a grid.

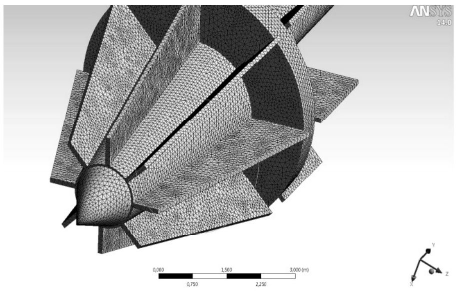

Fig. 2 - Rated operating conditions, desing grid and surface of the interface of a twirled air swirler

Actuating medium sampling

In a dynamic scrubber in the capacity of operating fluid water viscosity $\mu_l = 1\square10^3$ newton · second/m^2 was used; dusty gas with ρ_g=1,291 density of dusty gas, kg/m^3; for a corpuscle of a quartz dust (ρ = 2600 kg/m^3) diameter d=1÷150 a micron, moving in air stream (V = 5,1÷35$\square$10^{-6} m^2/s). In entry conditions for calculation magnitude of an ambient pressure and ambient temperature is set. Magnitude of external (surrounding) pressure makes 1atm., temperature of ambient air 25^0 C.

It is necessary that on lateral walls the attachment condition is satisfied

$U_{wall} = 0$,

On upper bound and in the field of a flow values of speed are set:

$$\begin{cases} U_{inlet} = u_{axial}\bar{i} + u_{radial}\bar{j} + u_{swirl}\bar{k} \\ u_{axial} = -u_1 \\ u_{radial} = 0 \\ u_{swirl} = 0 \end{cases}, \qquad (1)$$

$$\begin{cases} U_{inlet} = u_{axial}\bar{i} + u_{radial}\bar{j} + u_{swirl}\bar{k} \\ u_{axial} = -u_2 \\ u_{radial} = 0 \\ u_{swirl} = 0 \end{cases}$$

Investigated problems are solved in axisymmetric statement (dependence on azimuthal co-ordinate φ is not considered), the liquid current is supposed turbulent and is presented by system of the operating equations in the dimensional formulation.

Model choice

The mathematical model of motion of gas in the apparatus is based on the solution of system of Nave-Stoks equations for an axisymmetric problem (2) and continuity equations (3).

$$\frac{1}{r}\left[\frac{\partial}{\partial r}(r\rho\upsilon_r\upsilon_r) + \frac{\partial}{\partial r}(r\rho\upsilon_r\upsilon_z)\right] = $$
$$= \frac{1}{r}\left[\frac{\partial}{\partial r}\left(r\mu_T\frac{\partial\upsilon_r}{\partial r}\right) + \frac{\partial}{\partial z}\left(r\mu_T\frac{\partial\upsilon r}{\partial z}\right)\right] - $$
$$-\frac{\partial P}{\partial r} - \mu_T\frac{\rho\upsilon_r}{r^2} + \frac{\rho\upsilon^2\varphi}{r}$$

$$\frac{1}{r}\left[\frac{\partial}{\partial r}(r\rho\upsilon_r\upsilon_\varphi) + \frac{\partial}{\partial z}(r\rho\upsilon_z\upsilon_\varphi)\right] = $$
$$= \frac{1}{r}\left[\frac{\partial}{\partial r}\left(r\mu_T\frac{\partial\upsilon_\varphi}{\partial r}\right) + \frac{\partial}{\partial z}\left(r\mu_T\frac{\partial\upsilon_\varphi}{\partial z}\right)\right] - $$
$$-\mu_T\frac{\rho\upsilon_\varphi}{r^2} - \frac{\rho\upsilon_\varphi\upsilon_r}{r} \qquad (2)$$

$$\frac{1}{r}\left[\frac{\partial}{\partial r}(r\rho\upsilon_r\upsilon_z) + \frac{\partial}{\partial z}(r\rho\upsilon_z\upsilon_z)\right] = $$
$$= \frac{1}{r}\left[\frac{\partial}{\partial r}\left(r\mu_T\frac{\partial\upsilon_z}{\partial r}\right) + \frac{\partial}{\partial z}\left(r\mu_T\frac{\partial\upsilon_z}{\partial z}\right)\right] - \frac{\partial P}{\partial z} \qquad (3)$$

$$div\rho\bar{\upsilon} = 0$$

where υ_z - speed of a stream along an axis; υ_g - speed of a stream in the radial direction; υ_φ - tangential speed of a stream; p - mix density; μ - factor of turbulent viscosity; P - pressure; ύ - *a* vector of speed.

For short circuit of system of the equations the two-parametric model of turbulence k - ε, as one of the most well proved models for calculation of currents such is used. At turbulence modelling it was used k - ε model, for it dares two additional transport equations for the purpose of definition k - a turbulent kinetic energy and ε - turbulent energy of a dissipation.

Model turbulence:

$$\frac{\partial\rho_c k_c}{\partial t}\alpha_c + \frac{\partial\rho_c u_c k_c}{\partial x_j}\alpha_c = \tau_{ij}\frac{\partial u_c}{\partial x_j}\alpha_c - \alpha_c\cdot\rho_c\cdot\varepsilon_c + $$
$$+\frac{\partial}{\partial x_j}\left[\alpha_c\left(\mu_c + \frac{\mu_c^t}{\sigma_k}\right)\frac{\partial k_c}{\partial x_j}\right]$$

$$\frac{\partial\rho_c\varepsilon_c}{\partial t}\alpha_c + \frac{\partial\rho_c u_c\varepsilon_c}{\partial x_j}\alpha_c = C_{\varepsilon 1}\frac{\varepsilon_c}{k_c}\tau_{ij}\frac{\partial u_c}{\partial x_j} - \qquad (4)$$
$$-C_{\varepsilon 1}\frac{\varepsilon_c}{k_c}^2 + \frac{\partial}{\partial x_j}\left[\alpha_c\left(\mu_c + \frac{\mu_c^t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon_c}{\partial x_j}\right]$$
$$\mu_c^t = C_\mu\cdot\rho_c\cdot\frac{k_c^2}{\varepsilon}.$$

where κ_c - a turbulent kinetic energy of a gas phase; σ_κ - a turbulent Prandtl number for the kinetic energy equation; μ_c and μ - molecular and turbulent viscosity of a gas phase; ε_c - speed of a dissipation of a turbulent kinetic energy; σ_ε - *a* turbulent Prandtl number for the equation of a dissipation of a kinetic energy; τ_{ij} - the Cartesian components of tensor of voltage: μ = 0.09, ε_1 = 1.44, ε_2 = 1.92, σ_k = 1.0, σ_ε = 1.3.

Calculations show that near to firm walls there is a change of parametres k and ε. For the appropriate permission of these changes it is necessary to use rather dense desing grid.

Results of numerical experiment

As a result of numerical experiment distributions of static pressure of a gas stream in all cross-sections of desing space that has allowed to size up an apparatus hydraulic resistance are had.

It is necessary to pay attention that in separated flows the underpressure both in comparison with a main stream, and in a zone of guide vanes of an air swirler is observed. Irregularity of static making pressures in a scrubber has reducing an effect on efficiency of clearing. By comparison to empirical data on separation efficiency it is revealed that decrease in efficiency of separation does not exceed 1 %, though on level of irregularity of a pressure pattern a difference more appreciable. It is possible to explain it to that irregularity of pressure is compensated by positive effect of presence of the separated flows promoting branch of small corpuscles of a dust from a main stream in zones of a rarefaction and their removal on a helicoid path from working space, and further on walls of a conic part of the apparatus in the sludge remover. On apparatus altitude high enough energy of turbulent pulsations remains, it leads to the best dispersion of corpuscles in a stream and to increase in efficiency of separation.

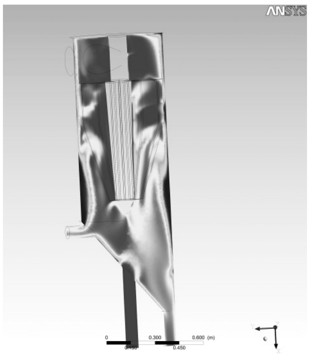

Fig. 3- Static component of pressure

The total pressure of a gas-dispersed stream in the apparatus body increases to periphery (**fig. 3**). On discharge connections pressure drops to the atmospheric.

3. Dynamic Spray Scrubber Experimental Researches

On the basis of the analysis of builds of modern apparatuses for gas clearing the dynamic spray scrubber build is devised. The apparatus is supplied by twirled air swirler and the central pipe for irrigation water supply. A centrifugal force originating at twirl of a rotor, secures with liquid crushing on microfogs that causes intensive contact of gases and trapped corpuscles to a liquid. Thanks to act of a centrifugal force, intensive mixing of gas and a liquid and presence of the big interface of contact, there is an effective clearing of gas in a bubble column [9].

Researches of a hydraulic resistance of a scrubber with an air swirler in altitude 0,25 metre were studied on experimental installation (**fig. 4**). Magnitude of hydraulic losses was defined on a difference of static pressure of a gas stream before and after a rotor.

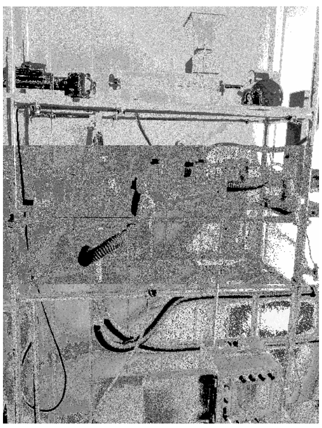

Fig. 4 - Experimental installation

In the course of research following parametres varied:

- Speed of gas on an entry in an air swirler υ =1÷20 mps;
- Angular speed of twirl of a rotor ω = 0÷100 c^{-1};
- Direction of rotation α <90 ° or α> 90 where α - an angle between a vector of relative speed ω and a peripheral velocity vector υ;
- An angle of installation of blades α = 0÷65 °

The analysis of results of experiment

The analysis of the gained results has allowed to install that growth of magnitude of a specific irrigation in the apparatus at the expense of increase in altitude of a torch of a sprayed liquid does not render considerable effect on a water resistance. This results from the fact that essential impact makes on head losses speed of a gas stream and extent of overlapping by a liquid of a contact zone of the apparatus, thus generated in a zone of an air swirler the formation of a stream does not undergo change at its current along angular co-ordinate. Liquid phase effect on a scrubber water resistance was investigated at speed of gas in the twisting device 5÷20 mps, relations of mass flow rates of water and gas *L/G*=0,1÷1,5. The altitude of a spray of a liquid is equal 0,15 m.

The essential contribution to the total head losses originating at increase of altitude of a spray of the irrigating liquid is brought in by the losses connected with expenses of energy of a gas stream on transport of a liquid in a zone of twirled guide vanes. Thus with growth of area of an irrigation these losses will increase. The analysis of results of the experiment, presented on (**fig. 5**), has shown that the water resistance of the irrigated apparatus at low relative loadings *L/G* drops in comparison with a water resistance of the dry apparatus. Water resistance decrease speaks decrease of tangential making speed of gas. At the maximum relative loadings *L/G* water resistance growth that is connected with expenses originating in the course of work for liquid phase transport is observed.

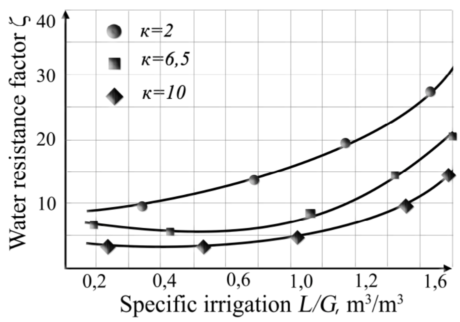

Fig. 5 - Dependence of factor of a water resistance on magnitude of a specific irrigation

During experiments it is installed that at a stopping delivery of an irrigating liquid the water resistance gets not at once value of the dry apparatus, and adopts a value 0,8 · ΔP, and only at disposal of water of a midwall of the apparatus and air swirler guide vanes, the water resistance accepts values of the dry apparatus. Water resistance decrease can be proved salutary affecting of a drop layer on a surface of guide vanes of an air swirler, friction decrease about apparatus walls, and as suppression of turbulent pulsations of a gas stream by drops of liquid [6].

4. Method Preparation Of Calculation Of The Hydraulic Resistance

In terms of liquid phase effects

The hydraulic resistance in terms of liquid phase effects can be expressed the pressure differential sum. Such differences will develop of the resistance originating at motion of gas in the dry apparatus and a pressure, which is necessary for informing a gas stream to compensate resistance on transport of a fluid-flow stream, i.e.:

$$\Delta P = \Delta P_{\text{dry}} + \Delta P_{ir} \qquad (5)$$

Or on the equation of Darsi:

$$\Delta P = \Sigma\xi \cdot \frac{\rho v^2}{2}$$

$$\Sigma\xi = \xi_{\text{dry}} + \xi_{ir}$$

ζ_{dry} - factor of resistance of not irrigated apparatus; ζ_{ir} - coefficient of resistance, in terms of the changes which are brought in by an irrigation.

The gained expressions for definition of hydraulic losses of the dry apparatus and losses on liquid phase transport allow to design a water resistance in an investigated range of loadings on phases.

In terms of rotor twirls

At rotor twirl the investigated air swirler represents the centrifugal fan vane wheel rotor.

The formula of theoretical pressure (6), in terms of (7), will register as [8, 10]

$$H_T\infty = \rho u(u - W_2 \cos\beta_2) \qquad (8)$$

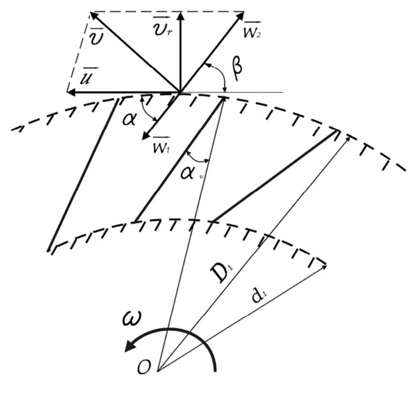

Fig. 6 - Roll forming of guide vanes of an air swirler

The gas stream in a dynamic spray scrubber air swirler moves from periphery to its centre. Therefore the gas stream should overcome except a hydraulic resistance of motionless feeding, also the pressure created by twirled air swirler in the assumption of a return current of gas through it. At such assumption, considering following relationships (**fig. 6**).

$$u = \omega\frac{D_1}{2}$$

$$\beta_2 = \alpha$$

For calculation of the third summanded (5) it is possible to use the formula (8) in a following aspect

$$\Delta\rho_{\omega>0} = \frac{0{,}5\rho\omega D_1(0{,}5\omega D_1 - W_1\cos\alpha)}{1 + \dfrac{1{,}5 + 1{,}1\alpha/90^\circ}{z(1-d_1{}^2)}} \qquad (9)$$

where d_1 - *a* relative root diameter of an air swirler. Considering (5) and (9), magnitude of a hydraulic resistance of a dynamic spray scrubber is designed under the semiempirical formula:

$$\Delta P = \Delta P_{dry} + \Delta P_{ir} + \Delta\rho_{\omega>0} \qquad (10)$$

5. Clearing Of Gases Of A Dust In The Industry

The had results hardware in manufacture of roasting of limestone at conducting of redesign of system of an aspiration of smoke gases of baking ovens. The devised scrubber is applied to clearing of smoke gases of baking ovens of limestone in the capacity of a closing stage of clearing.

Temperature of gases of baking ovens in main flue gas breeching before a copper-utilizatorom 500-600°C, after exhaust-heat boiler 250 °C. An average chemical compound of smoke gases (by volume): 17%$C0_2$; 16%N_2; 67 % CO. Besides, in gas contains to 70 mg/m^3 $S0_2$; 30 mg/m^3 H_2S; 200 mg/m^3 F and 20 mg/m^3 CI. The gas dustiness on an exit from the converter reaches to 200/m^3 the Dust, as well as at a fume extraction with carbonic oxide after-burning, consists of the same components, but has the different maintenance of oxides of iron. In it than 1 micron, than in the dusty gas formed at after-burning of carbonic oxide contains less corpuscles a size less. It is possible to explain it to that at after-burning CO raises temperatures of gas and there is an additional excess in steam of oxides. Carbonic oxide before a gas heading on clearing burn in the special chamber. The dustiness of the cleared blast-furnace gas should be no more than 4 mg/m^3.

The following circuit design (**fig. 7**) is applied to clearing of the blast-furnace gas of a dust.

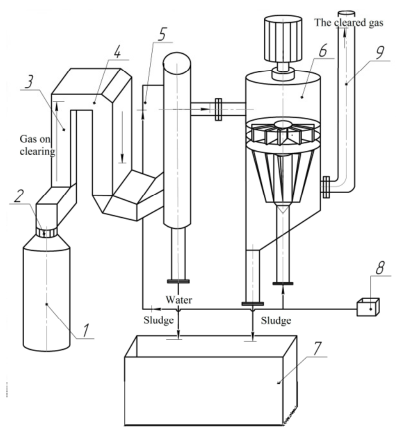

Fig. 7 - Process flowsheet of clearing of gas emissions: 1 - bake roasting; 2 - water block; 3 - raiser; 4 - downtaking duct, 5 - centrifugal scrubber; 6-scrubber dynamic; 7 - forecastle of gathering of sludge, 8 - hydraulic hitch, 9 - chimney

Gas from a furnace mouth of a baking oven 1 on gas pipes 3 and 4 is taken away in the gas-cleaning plant. In raiser and downtaking duct gas is chilled, and the largest corpuscles of a dust which in the form of sludge are trapped in the inertia sludge remover are inferred from it. In a centrifugal scrubber 5 blast-furnace gas is cleared of a coarse dust to final dust content 5÷10/m^3 the Dust drained from the deduster loading pocket periodically from a feeding system of water or steam for dust moistening. The final cleaning of the blast-furnace gas is carried out in a dynamic spray scrubber where there is an integration of a finely divided dust. Most the coarse dust and drops of liquid are inferred from gas in the inertia mist eliminator. The cleared gas is taken away in a collecting channel of pure gas 9, whence is fed in an aerosphere. The clarified sludge from a gravitation filter is fed again on irrigation of apparatuses. The closed cycle of supply of an irrigation water to what in the capacity of irrigations the lime milk close on the physical and chemical properties to composition of dusty gas is applied is implemented. As a result of implementation of trial installation clearings of gas emissions the maximum dustiness of the gases which are thrown out in an aerosphere, has decreased with 3950 mg/m^3 to 840 mg/m^3, and total emissions of a dust from sources of limy manufacture were scaled down about 4800 to/a to 1300 to/a. Such method gives the chance to make gas clearing in much smaller quantity, demands smaller capital and operational expenses, reduces an atmospheric pollution and allows to use water recycling system.

6. Conclusion

1. In the given work the algorithm of modelling of process of separation of a dispersoid in a gas stream has been devised. The devised model helps is rapid and visually to model motion of a dusty gas stream.

2. Experimental researches of hydrodynamics of a scrubber with twirled лопастным an air swirler are studied. The research problem made definition of a hydraulic resistance of the irrigated apparatus at change of loadings on phases.

3. Calculation of a twirled air swirler is based on the theory of centrifugal fans, in terms of quantities and directions of rotation of guide vanes.

4. Research of these factors and creation of a design procedure of a hydraulic resistance is the momentous problem in decrease in metal consumption of apparatuses and power inputs on gas clearing.

5. Designs on modernisation of system of an aspiration of smoke gases of baking ovens of limestone with use of the new scrubber which novelty is confirmed with the patent for the invention are devised. Efficiency of clearing of gas emissions is raised. Power inputs of spent processes of clearing of gas emissions and power savings at the expense of modernisation of a flowchart of installation of clearing of gas emissions are lowered.

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