The Dependence between the Ignition Value of Air Suspension and the Size of the Reaction Chamber

1st Alexander I. Sechin
School of Non-Destructive Testing
Tomsk Polytechnic University
Tomsk, Russia
email: auct-68@yandex.ru

2nd Andrey A. Sechin
School of Basic Engineering
Tomsk Polytechnic University
Tomsk, Russia
email: seanal@yandex.ru

3rd Yuri F. Patrakov
Federal Research Center of Coal and Coal Chemistry
Russian Academy of Sciences, Siberian Branch
Kemerovo, Russia
email: yupat@icc.kemsc.ru

4th Irina L. Mezenceva
School of Basic Engineering
Tomsk Polytechnic University
Tomsk, Russia
email: mezenceva@tpu.ru

5th Yuliya A. Amelkovich
School of Non-Destructive Testing
Tomsk Polytechnic University
Tomsk, Russia
email: amely@tpu.ru

***Abstract*— The influence of the geometric factor of the reaction chamber on the limit value of the air suspension ignition is studied. It is found that in determining the lower concentration limit of the flame propagation (LCLFP), it is most promising to use an installation with a cylindrical reaction chamber whose height is equal to the diameter. The dependence of the determination of the LCLFP value on the geometric factor of the reaction chamber is proposed, tested on metal powders and organic dust-forming materials. The expression allowing to carry out the comparative analysis of scientific results received on other technical devices with the results received on the installations executed according to the requirements of normative and technical documentation is received that significantly reduces the volume of experimental works.**

Keywords*— *reaction chamber, lower concentration limit of flame propagation, air suspension, geometric factor, ignition.

I. INTRODUCTION

The properties of industrial dust determine the level of fire and explosion hazard of many technological processes: crushing and grinding, drying, pneumatic transportation, grinding, grain processing, etc. Annually dust explosions and fires cause significant damage to the national economy [1-3].

It is known [4] that a considerable amount of dust-forming substances and materials in the state of air suspension become explosive. The literature provides a large amount of experimental data [5] on the critical conditions of combustion propagation in air suspensions, which are not always consistent with each other since they are obtained on reaction chambers with different geometric dimensions and at different time periods. The introduction of the normative document [6], led to the ordering of the research results and nevertheless a large layer of experimental data obtained outside the framework of the normative document, is of great scientific interest. The solution of the problem covering of these data, the influence of the geometric factor of the reaction chamber on the limit value of the ignition of the air suspension and is devoted to this work.

Practical observations of the processes of production, storage, transportation and processing of combustible dust-forming materials formed the basis of the principles of ensuring their fire and explosion safety. Development of M.G. Godzhillo formed the basis of the national system of assessment of fire and inflammation of industrial dusts. In the future, this system was improved by V.T. Monakhov, which was included in the state standard regulating the nomenclature of indicators of fire and explosion hazard of oil products and chemical organic products [6-8].

The researchers noted that the value of the lower concentration limit of flame propagation in air suspension is significantly affected by the method of creating an air suspension, the shape of the reaction chamber and its volume, the source of initiation of combustion, etc.

Great difficulties in the comparative analysis of scientific results cause a variety of experimental facilities and techniques to determine the critical conditions of flame propagation.

From the list of factors influencing the result of the experiment, the geometric factor is of interest – the ratio of the reaction chamber volume to its surface. The researchers note that heat losses are crucial in the study of critical conditions of flame propagation in the air suspension.

II. RESULTS AND DISCUSSIONS

Let us analyze the case of ignition of an air suspension in the center of a volume of arbitrary shape, the concentration of particles is uniformly distributed. It should be assumed that the ignition of the air suspension is more expedient to make as far as possible from the walls of the reaction vessel in order to minimize the breakage of the reaction chains of combustion on it. Assuming that the flame front has a cellular structure [9], heat transfer in the form of a stream of parallel rays from the moving front is most effective when located in the center of the reaction volume.

Consider the case in which the radiation energy f is completely absorbed by the particles and the flux, which is described by the following equation [10, 12]:

$$\Phi = \Phi_0 e^{-N\sigma x} = \Phi_0 e^{\frac{-x}{L}} \qquad (1)$$

where Φ_0 is the total radiation energy of the source, Joule; x is the thickness of the air suspension as an absorption layer, m; σ is the current absorption area, m^2; N is the number of air suspension particles per unit of elementary volume; L is the free path of radiation, m.

For the case when σ and N are constant, the absorbed part of the radiation will be characterized by the value of x, and, consequently, part of the freely transmitted radiation flux. But it should be borne in mind that the value of the absorption layer depends on the geometry and dimensions of the reaction volume. In this case, the value x is the distance from the heat

978-1-7281-2896-2/19/$31.00 ©2019 IEEE

source located in the center of some volume of arbitrary shape to the limiting surface of this volume, then from the expression (1) it follows that the direction of the heat flow with less x will be accompanied by a smaller result of absorption of radiation. Since the reaction volume is characterized by a certain surface, the net losses that do not affect the parameters of the air suspension will be minimal.

Thus, in order to establish the ratio between the amount of heat absorbed by the air suspension and the amount of heat loss by radiation in the reaction chamber of a particular experimental installation, it is necessary to substitute a certain value of the current x_{ef} coordinate in formula (1). As a first approximation, the value of the x_{ef} can be determined on the basis of the following considerations (without taking into account the volume occupied by the particles and the particle shadow area). The geometric place of all distances is the volume of the reaction chamber of the experimental setup taken by us. The geometric location of the points of exit of the rays from any volume is a surface that limits this volume, this will be the surface of the reaction chamber of the experimental setup (or the surface of the technological volume). Therefore:

$$x_{ef} = \frac{V}{S} \tag{2}$$

where V is the volume occupied by the air suspension, m^3; S is the surface limiting the cloud of the air suspension, m^2.

In this case, the formula (1) takes the form:

$$\Phi = \Phi_0 e^{-\sigma N x_{ef}} = \Phi_0 e^{-\frac{V}{SL}} \tag{3}$$

From the formula (3) it follows that the larger the reaction volume of the experimental setup, the greater the probability of absorption of radiation, the less heat loss by radiation. Conversely, the larger the surface, the greater the probability of free release of radiation beyond the cloud of air suspension, the greater the heat loss by radiation.

The solution of the variational problem of finding a geometric figure with a maximum volume at a minimum surface is a sphere. Consequently, the reaction chamber of the experimental setup in the form of a spherical vessel has the lowest probability of free radiation output, that is, has a minimum amount of heat loss. Taking into account the fact that in a spherical chamber the creation of a uniform concentration of the air suspension meets technical difficulties, it is necessary to choose the geometric parameters of the reaction chamber of the experimental setup of another type. The solution of the variation problem leads to the conclusion that of all the figures (cube, cylinder, cone, etc.), the cylinder has a maximum volume-to-surface ratio, and the extremum is reached when its height is approximately equal to the diameter. In this case we have:

$$x_{ef} = \frac{1}{3} R \tag{4}$$

where R is the radius of the cylinder base, m.

In an experimental setup with a reaction chamber of cylindrical shape (pipe type), the possibility of creating an air suspension of controlled concentration is much wider (pulsed, gravitational, etc.) than a spherical vessel.

Thus, when determining the lower concentration limit of the flame propagation (LCLFP), an installation with a reaction chamber of cylindrical shape, the height of which is equal to the diameter, should be used.

For this case, the equation of radiation absorption in the volume of the air suspension will be as follows:

$$\Phi = \Phi_0 \exp\left(-\frac{R}{3L}\right) \tag{5}$$

Formula (5) allows us to draw the following conclusions: the increase in the size of the reaction chamber of the experimental setup (R) leads to a decrease in heat loss by radiation and, as a consequence, to a decrease in the LCLFP. The latter is not difficult to prove, based on the results of [11, 12]. It is shown that the limiting conditions of ignition of the air suspension are such conditions under which a constant share of heat loss by radiation is realized, determined by L = const. Therefore

$$\frac{N\sigma V}{S} = const$$

and for a strictly fixed value of the particle size we have:

$$\frac{NV}{S} = const \tag{6}$$

It follows that as the dimensions of the reaction chamber of the installation increase, the concentration of particles N can be reduced, that is, the LCLFP decreases. Transformations (6) lead to the dependence of the LCLFP value on the geometric factor of the reaction chamber of the experimental setup:

$$M = \frac{M_0 S V_0}{V S_0} \tag{7}$$

where M – the value of the LCLFP for installation with variable dimensions V and S, $\mathrm{g/m}^3$; M_0 – the value of the LCLFP in the installation with dimensions V_0 and S_0, $\mathrm{g/m}^3$.

Calculation according to the formula (7) finds not only qualitative, but also quantitative confirmation in [8, 11].

In the work [12] on the example of air suspension of titanium powder with dispersion of 50-56 microns, it is shown that with an increase in the volume of the chamber from 0.33 to 21.6 liter LCLFP decreases, and the explosion pressure increases, the most dramatic change in these values occurs in the range of reaction volumes from 1 to 4 liter. In this case, the authors used sealed metal chambers with pulsed powder spraying.

In work [10, 12] influence of diameter of a pipe on a limit of ignition of air suspensions was studied. The researchers used glass pipes with diameters of 0.055, 0.105, 0.14 m and a height of 2 m. At the upper end of the pipes there was a screw dust generator, which almost closed the end of the pipe; at the bottom, at the open end of the pipe, there was a source of ignition – a nichrome spiral. Particular attention is drawn to the significant methodological differences in the determination of experimental values of the LCLFP in [10, 12]. Comparative data on the calculated and experimental values of the LCLFP are given in table I and II.

Thus, the expression (7) shows that when comparing various experimental studies on the LCLFP, it is necessary to pay attention to the geometric factor of the reaction chambers of the installations in which it is determined.

TABLE I. THE DEPENDENCE OF THE LEL TITANIUM DISPERSION 50-56 μM FROM THE GEOMETRICAL FACTOR OF THE INSTALLATION

The diameter of the chamber [m]	Height [m]	V/S [m]	LCLFP [g/m^3]	
			The experiment	*Calculation*
0.05	0.175	0.011	80	80.0
0.10	0.345	0.021	35	40.0
0.11	0.390	0.024	30	36.2
0.20	0.200	0.033	25	26.4
0.20	0.692	0.044	23	20.0

Note: In table I the experimental values of the lower explosive limit of titanium is taken from [10].

TABLE II. EXPERIMENTAL [13] AND CALCULATED VALUES OF LCLFP DEPENDING ON THE DIAMETER OF THE REACTION CHAMBER

Name of air suspension substance	The diameter of the reaction chambe [mm]					
	55		105		140	
	The results of the determination of the LCLFP [g/m^3]					
	Experiment	*Calculation*	*Experiment*	*Calculation*	*Experiment*	*Calculation*
Alumomagnesium PAM - 4	123.00	106.40	56.00	56.00	36.00	42.00
Magnesium MPF - 4	68.00	70.60	37.00	37.00	26.00	27.75

Analyzing tables I and II, it should be noted a satisfactory coincidence of the calculated values of the LCLFP according to the formula (7) with the experimental data obtained in various methodological conditions: the pressure, the material of the reaction chambers of the plants, the method of spraying powders. However, it should be borne in mind that the formula (7) is limited due to the approximate value of x_{ef}, the calculation of which did not take into account the volume occupied by the particles and the shadow area of the particles. However, this expression allows for a comparative analysis of the scientific results obtained on other technical devices with the results obtained on the installations performed in accordance with the requirements of normative and technical documentation, which significantly reduces the amount of experimental work.

This regularity (7), obtained on metal powders, is applicable for organic dust-forming materials, and in particular, for fine-crystalline powders of drugs and their intermediates. The uniformity factor of the dust phase distribution in the volume can now be considered as the main one.

Based on experimental data [13], we found $10^3 \geq P \geq 0.1$ kPa. Where it was determined that the optimum diameter of the reaction chamber 0.1-0.11 m. Considering the dependence of the final flow rate on the second air flow rate in the chambers of different diameters as a family of linear equations $y=Kx$, and it was observed that they all have one difference – a dimensionless ratio K (fig. 1). K shows that the increase in the flow rate, structurally means a decrease in the diameter of the chamber. The analysis shows that the diameter of the reactor vessel d is not less than 0.08 m K varies slightly, which indicates the difficulties in creating uniform flows at shorter distances. More than 0.12-0.14 m – ratio K also varies slightly, which indicates the difficulties of creating a uniform velocity field in the flow of small pulses, there is a need to increase the V_C to obtain the most stable distribution. It should be noted that this reduces the area of distribution of the dust cloud, its height decreases, which will introduce a systematic error in the processing of the results.

Based on the above, it follows that the most important is the interval of values of the site from $0.15 > K > 0.08$. In the chambers of this range, it is most easy to adjust the V_C and the speed distribution should be the most uniform.

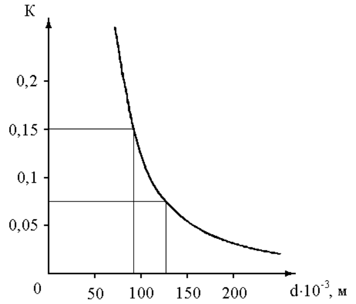

Fig. 1. The change in the value of the dimensionless ratio K from the final flow rate V_C in chambers of different diameters

Thus, it can be stated that the closer the geometric dimensions of the experimental volumes are to the established values, the greater the accuracy of the recalculated value.

After analyzing the design dimensions of the reaction chamber, it is necessary to analyze its experimental capabilities to create a uniformly distributed dust cloud.

Based on the conditions of uniform particle concentration at a flow rate close to the weighing rate, we conclude that the weighing rate for most organic substances does not exceed 10 m/s. Therefore, the height of the reaction chamber from the nozzle to the ignition source should be such as to provide a flow rate of not more than 10 m/s. From the analysis [13] it is clear that the height should be within 0.4-0.8 m. In this case, a minimum velocity difference in the granulometric dispersion of a certain fraction is provided.

III. CONCLUSION

As a result of the study, the influence of the geometric factor of the reaction chamber on the limit value of the ignition of the air suspension was studied. It is found that in determining the lower concentration limit of the flame propagation, it is most promising to use an installation with a cylindrical reaction chamber whose height is equal to the diameter. The dependence of the determination of the LCLFP value on the geometric factor of the reaction chamber is proposed, tested on metal powders and organic dust-forming materials. The expression allowing to carry out the comparative analysis of scientific results with the results received on the installations executed according to the shown requirements of normative and technical documentation is received.

ACKNOWLEDGEMENT

The research is carried out at Tomsk Polytechnic University within the framework of Tomsk Polytechnic University Competitiveness Enhancement Program grant.

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