INVESTIGATION OF AEROSOL SYSTEM EVOLUTION IN LIMITED VOLUME VIA LASER LIGHT SCATTERING

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Abstract

This paper discusses some possibilities of studying the evolution of concentrated aerosol systems (i.e. systems with eigen volume), formed in a limited volume, (i.e. in a measurement chamber), via laser light scattering. The changes of their density with the course of time are followed. Density measurements are carried out according to the method of free outflow. Experimental results concerning the smoke from different cigarette trademarks are presented. A new characteristic of the aerosol system – ***"state spectrum",*** *is introduced. The latter is used to characterize the aerosol systems under investigation.*

1. INTRODUCTION

An aerosol system with an eigen volume of its own is a special state of the aerodispersion systems. This state can be observed in natural phenomena (fog, clouds, smoke from forest fires) as well as in laboratory conditions [1-5]. Because of the similarity of this state to a liquid one, i.e. the existence of a horizontal upper boundary, when the system is formed in a closed vessel and of hydrostatic pressure, in [3, 4] it was defined as a "quasi-liquid" state. In essence this state is a non-equilibrium one, since the system is open, i.e. the latter loses the substance held in it as a result of diffusion, evaporation via the upper boundary, sedimentation, deposition on the vessel walls, etc.

In some of our previous works [5-8] we offered a method of measuring the kinematics viscosity based on the aerosol outflow through a horizontal tube over the bottom of the vessel due to the action of the eigen aerosol hydrostatic pressure. In our papers [9, 10] we modified the method to measure the mass density of an aerosol

system with eigen volume. The following expression for the mass density was obtained

$$\rho_i = \frac{\eta_i}{v_i} = \frac{1}{b}\frac{\Delta H_i}{\bar{H}_i}\frac{\eta_0}{\Delta t_i} \quad , \qquad (1)$$

where $b = \pi r^4 g / 8 l S$, r is the radius of the horizontal tube, l - its length, g - earth acceleration, S – the cross-section of the vessel with aerosol, η_i - the dynamic viscosity, ρ_i - the density of the aerosol phase as referred to the interval ΔH_i, which is crossed by the diminishing upper boundary for time interval Δt_i, $\bar{H}_i$ is its average height with reference to the outlet tube. Formula (1) makes it possible to define the density of the aerosol phase ρ_i, after measuring Δt_i and $\bar{H}_i$.

In the present paper the modified method for determining the mass density is applied to investigate the evolution of the aerosol system after its formation. For this purpose before conducting the experiment to determine the mass density, the aerosol is left for some time t_z to stay in the chamber. We define that time as **"detention time"**. Then the tube at the lower end of the measurement chamber is opened and the aerosol is left to flow out through it. For each value of t_z from 0 to 10 minutes, 21 experiments were conducted to determine the mass density. An increase in t_z leads to a decrease in the aerosol density and in its hydrostatic pressure, respectively. There comes a moment after which the outflow is impeded. This moment depends on the type of aerosol and on the surrounding factors. The aerosols we studied had a steady outflow until the tenth minute /under room conditions/.

2. EXPERIMENTAL RESULTS

2.1 Measurement of the change of aerosol phase density with the time

Fig.1 illustrates the change in the mean density of the aerosol phase of the smoke of Arda cigarettes as a function of the detention time t_z. Each point of the graph, corresponding to a definite detention time is determined on the basis of 21 values. The same figure presents also approximation with a straight line /thick line/ and approximation with an exponent /dotted line of the dependence studied/. The

coefficients of linear regression - R^2, for both cases are as follows /using statistical computer processing/:

-for the straight line approximation – 0.8368 ,

-for the exponent approximation – 0.8514 .

It can be seen that the two approximations are close. This gives us ground to consider the dependence as approximately linear, with real density fluctuations, exceeding the corresponding mean quadratic errors. The latter are presented graphically with triangles /closely over the OX axis/.

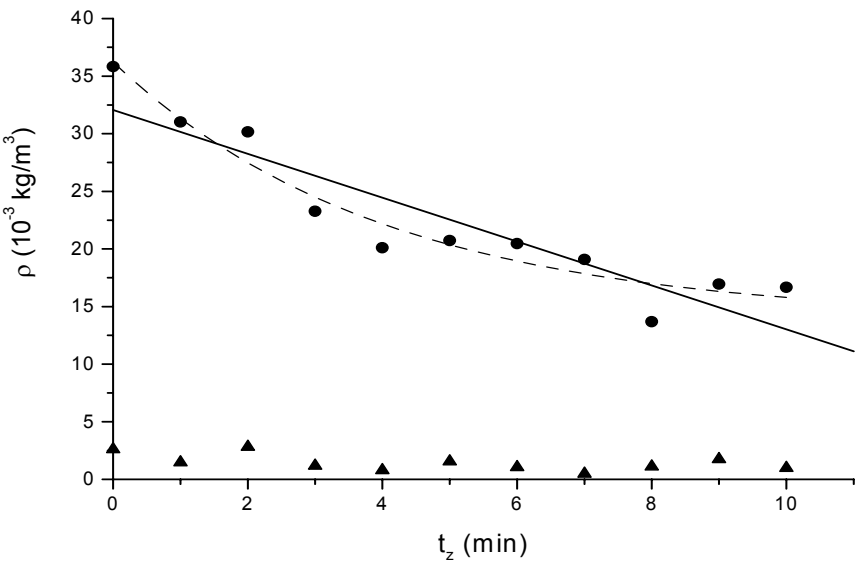

Fig. 1. Mean density of the aerosol phase of smoke of Arda cigarettes as a function of detention time t_z .

Fig.2 presents analogous results, this time obtained from Stuyvesant cigarette smoke. It can be seen that the initial density is twice smaller than the density in the previous experiment. It is a typical parameter for the different cigarette trade marks. Its value is obtained when t_z=0. The corresponding mean quadratic errors are illustrated as before with triangles.

Obviously, here too, during the detention time the density undergoes fluctuations which are beyond the error limits. Analogous results have been obtained in our papers [5-8] when determining the values of the kinematics viscosity of the aerosol system. The detention times t_z were the same – from zero to ten minutes.

That should be expected, since $\nu_i = \frac{\eta_i}{\rho_i}$ and η_i is practically equal to the dynamic viscosity of air η_0 = 1.81 10^{-5} (Ns/m^2).

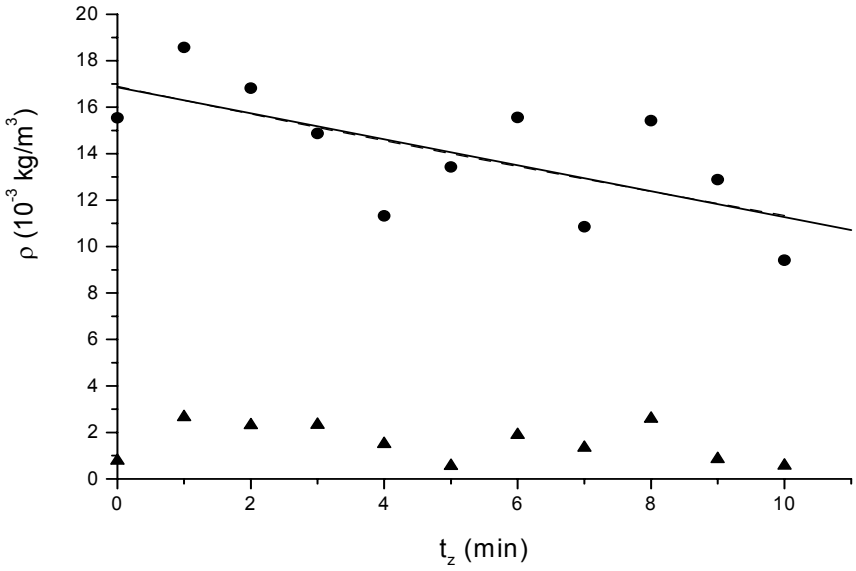

Fig. 2. Mean density of the aerosol phase of smoke from Stuyvesant cigarettes as a function of the detention time t_z .

Fig.3 illustrates the changes in the mean density of three different volumes of the aerosol phase of smoke from Arda cigarettes as a function of the detention time t_z . The heights of the aerosol limit in relation to the outlet tube are accepted as a measure of the volume of the aerosol. Dependence 1 refers to the height of the upper limit – 0.285 (m), and dependence 2 – for 0.195 (m), dependence 3 – for 0.105 (m). Three experiments are conducted for each detention time. The results are too close to each other which shows that an aerosol with different volumes /smoke from Arda cigarettes/ evolves practically in the same way.

Fig. 4 depicts the change in the density of an aerosol system /smoke from Arda cigarettes/ as a function of the volume, i.e. at different heights of the upper aerosol limit in relation to the outlet tube. For each volume /for each point of the graph/ 33 experiments are conducted which include all detention times. The straight line approximation is also presented. The linear regression coefficient is R^2=0.0322 , i.e.

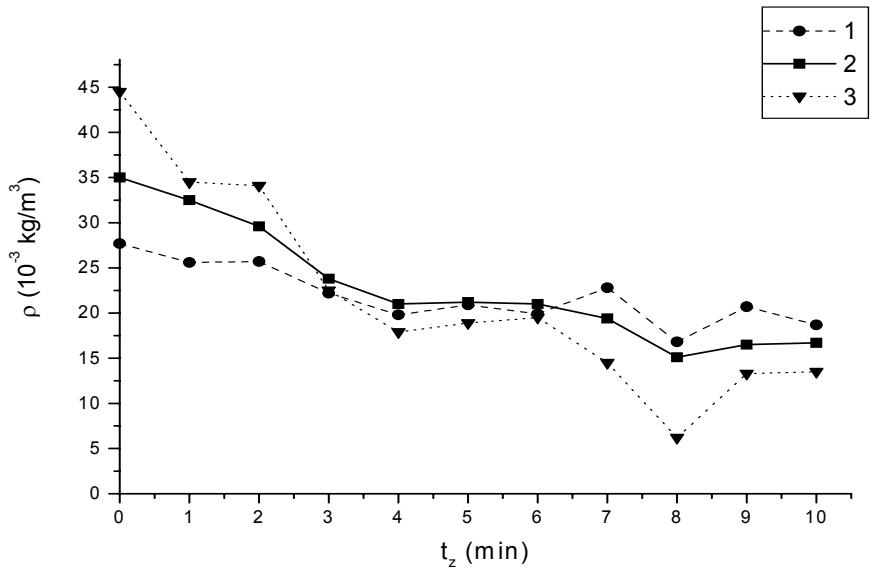

Fig. 3. Change in the mean density of three different volumes of the aerosol phase of smoke from Arda cigarettes as a function of the detention time t_z .

the points are very close to the straight line. The corresponding mean quadratic errors are also presented /with triangles/. The graphic shown /the points are close to the straight line/ is a proof of the general volume homogeneity of the system.

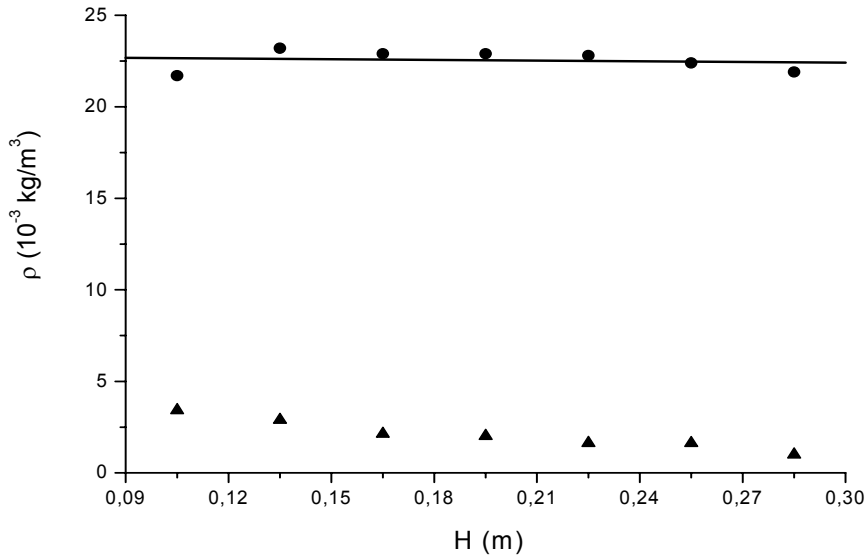

Fig. 4. Mean density of the aerosol phase of smoke from Arda cigarettes as a function of the volume /the height of the upper aerosol limit/.

2.2 Spectrum of the state of aerosol system with eigen volume

We offer to characterize the change in the aerosol system density, depending on the detention time t_z, at different heights from the vessel bottom can be characterized by means of the function of density distribution, defined via the following formula :

$$f_i = \frac{W_i}{\Delta\rho_i} = \frac{N_i}{\sum N_i}\frac{1}{\Delta\rho_i} \quad , \qquad (2)$$

where N_i is the number of the values obtained experimentally in the interval $\Delta\rho_i$, $\sum N_i$ is the total sum of the values. $\Delta\rho_i = \Delta\rho = const$ are the steps in the change of the density, which is a constant in our experiment. We call this function **"spectrum of the state of the aerosol system".** It is a general characteristic of the aerosol system and includes the set of all density values /in our case they are 231 in number/. They are obtained in the course of its time evolution at different heights of the upper level with respect to the vessel bottom.

Fig. 5 illustrates the spectrum of the state of smoke from Arda cigarettes. The thick line /AV/ presents the average spectrum of the whole set /231 values/. The smoke of one cigarette can fill up the measurement chamber three times. Therefore

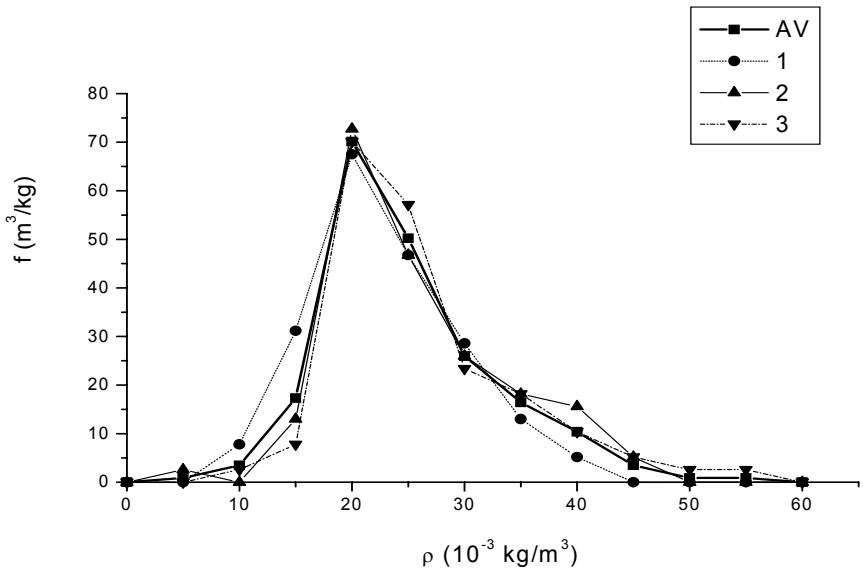

Fig. 5. Spectra of the state of Arda cigarette smoke:Average spectrum - dependence AV. Spectra of the state of the smoke from the separate thirds of the cigarette – dependences 1-3.

the cigarette is relatively divided in three parts. Dependence 1 illustrates the spectrum of the smoke, released from the beginning of the cigarette, and dependence 3 from the end, respectively /the part nearest the filter/. The shift of the spectra of the separate thirds is insignificant. This is a proof of the poor filtering quality of the tobacco in this brand of cigarettes /coarsely ground, poorly stamped, etc./.

Fig.6 illustrates the same dependences but for Stuyvesant cigarettes . The shift of the spectra of the separate thirds /dependences 1 – 3/ is obvious. This is a proof of the better filtering quality of the tobacco in this kind of cigarettes.

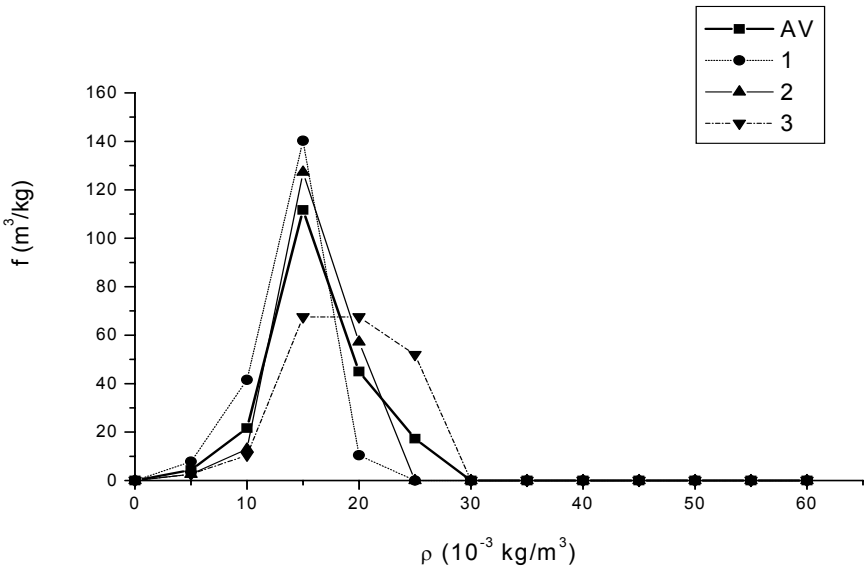

Fig. 6. Spectra of the state Stuyvesant cigarette smoke: Average spectrum - dependence AV. Spectra of the state of the smoke from the separate thirds of the cigarette – dependences 1-3.

The mean arithmetic density values $\bar{\rho}$, the corresponding mean quadratic errors σ_ρ, the minimum $\rho_{\min}$ and maximum $\rho_{\max}$ values in the sets for smoke from different cigarette trademarks are quoted in **Table 1.** The last two lines illustrate the maximum of the density distribution function $f_{i\text{-}max}$ /formula (2)/ from the corresponding spectra and its respective semi-widths $\rho_{0.5}$. These parameters can help to qualify and compare different aerosol systems, in particular, cigarette articles /cigarettes, cigars, tobacco for pipes/.

Table 1. Parameters of the smoke obtained from different cigarette trademarks.

		Cigarette				
№		Arda	Stuyvesant	Gauloises	Gitanes	Vega
1	$\bar{\rho}\ (10^{-3}\ kg/m^3)$	22.54	14.06	24.15	19.31	24.00
2	$\sigma_\rho\ (10^{-3}\ kg/m^3)$	0.498	0.261	0.422	0.336	0.470
3	$\rho_{\min}\ (10^{-3}\ kg/m^3)$	4.28	2.79	12.36	7.09	6.05
4	$\rho_{\max}\ (10^{-3}\ kg/m^3)$	50.57	24.72	44.50	38.37	57.69
5	$f_{i-\max}\ (m^3/kg)$	80	130	66	118	64
6	$\rho_{0.5}\ (10^{-3}\ kg/m^3)$	11	6	18	8	17

4. CONCLUSIONS AND DISCUSSIONS

The present paper applies the previously developed method for measuring the mass density of aerosol systems with limited volume for studying their volume homogeneity and time evolution. It is established that the aerosol systems under study /cigarette smoke from different cigarette trademarks/ differ in density outside the limit of the experimental error. The density distribution function /or **spectrum of the state**/ is introduced and it can be utilized as one new characteristic of the aerosol systems, in particular – for comparison and qualification of cigarette products.

What impresses, is that the spectra of the state of the different aerosol systems have a characteristic peak with a definite amplitude $f_{i\text{-max}}$ and semi-width $\rho_{0.5}$. This shows that the concentrated aerosol systems in a limited volume have a most probable density, coinciding with the peak position. Supposedly, this is a basic regularity of these aerosol systems.

The range between the minimum $\rho_{\min}$ and the maximum $\rho_{\max}$ mass densities measured by us for the investigated aerosol systems /cf. Table 1/ is too narrow – from 2.79- to 57.69 10^{-3} ($kg.m^{-3}$) /or in approximately 20-fold relationship/. The relationship between the mass densities for the well-established liquids is similar –

about 4, which is of the same order. In the case of gases, the mass density depends on the pressure and it changes within very broad limits. For the atmospheric air, for instance, at an altitude of 10 (km), the density diminishes about 10^6 times. In view of this characteristic, the concentrated aerosol systems in limited volume resemble rather liquids than gases, although in view of the absolute mass density value, they come closer to gases.

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