Phenomenon of Tribo-Electricity in Drying Technology

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ABSTRACT: *The aim of the research in our scientific work is to reduce the negative points that may be present during the drying process. These negative points could include ignite product and even explosion. Therefore, in this article there're published studies on the phenomenon of Tribo-electricity particularly the effect in the form of physical process named as "Tribo-charge" in technical literature has been investigated in this article. The process of Tribo-charge occurs in the process of drying manufacturing line operation comprising different elements in the form of cyclones, pneumatic conveyers, instantizers, storage hoppers, etc. in this system. Experimental results for analysis of some elements of this Phenomenon on the laboratory equipment are presented. The food product – Skim milk powder has been taken as the basis of our scientific studies. The results of Skim milk powder particles Tribo-charge depending on experimental tasks and conditions have been shown.*

KEYWORDS: Drying Technology, Skim milk powder, Adhesion, Tribo-charges, Faraday.

INTRODUCTION

Now in Russia operates about 270 spray-dryers of various types and designs. Safe operation of these installations is complex task. Part of this task is to reduce of negative reasons[13].

In practice, the conditions at which Powder milk products produced by spray-drying method are kept can be very different: static, dynamic, differ by character of particles packing, adhesive and cohesive interaction between them.

The phenomenon itself under the term of "Tribo-electricity" has been known long ago, in principle, from the time when the first information about electricity appeared. 3Thus, in turn, the important role in the mentioned above interactions plays the physical processes connected with "Tribo-electricity" and namely with Tribo-charge of particles. Tribo-charge is complicated and volumetric process, which occurs during friction of different uniform particles or particles contacting with different materials such as metal or materials relating to conductors.

For example, Tribo-charge physical process occurs during the technological equipment operation providing spry-drying influencing the efficiency and in some cases nonexplosiveness of this process in the whole[3].

THE STATUS OF THE ISSUE

Upon Condensed milk, spraying and drying in spray Drier drying chamber aero-suspension of Powder milk particles can stick on inner surfaces of the Drying process equipment or repeatedly contact between each other and walls of transporting air ducts.

Within these processes, static charges accumulate in the product (Powder milk) that requires drying unit circuit grounding[7, 10] or improving surface characteristics of the drying chamber and air ducts walls[19].

The data relating to electric potential of Powder milk particles are rather scanty and require further systematization.

Japanese scientist Shin'ichi Taneya from the research laboratory Snow Brand Milk Products Ltd. published his investigations in the famous magazine "Japan Journal Applied Physics"[17].

In his experiments fixed in detail in the form of pictures and texts he stated that electrification of spraying drops of condensed Skim milk and other products manufactured by spray-drying can be studied on the basis of electric potential investigation inside the flow of these droplets.

Shin'ichi Taneya concluded that the largest volume of spraying drops dried into particles less than in a radius of 100 (μ) microns are positively charged while bigger drops are negatively charged.

This author studied electrization of Skim milk powder particles in the pneumatic path by the similar method.

Afterwards he (Taneya) found out that the higher the particles concentration according to their increasing velocity in the flow is the higher are the total charge of these particles, i.e. the charge potential is increasing. Herewith the powder particles supply positive charge.

He determined the net charge of the electrified powder particle in the process of drying by V-shaped tray after which (particles) in the stage of the free fall get into a.c. (alternating current) field which produce sinusoidal tracks (vibrations) of these particles.

He determined as well that powdered particles of such products as Skim-milk powder, powdered butter, flour, dry lactose and others dry products of low-sized classes are approximately less within a radius of 10 (μ) microns, and mainly charged positively; at that relatively some amount of particles which are charged positively, "loss" this charge (i.e. become neutral particles) with the change of these particles size.

The particles, which are bigger or equal within a radius of 40 (μ) microns, are electrically neutral. Such a big particles are in reality composite particles consisting of big particles and smaller ones.

In the other research the scientists report that at friction with each other or inner size of the equipment, e.g. in pneumatic or aerosol transport, the product particles obtain electric charges stipulating appearance of Electric forces of Adhesion.

Electric forces of Adhesion inherent to powdered milk products particles influence the operation of drying unit, pneumatic transport systems, nonexplosiveness, efficiency of the particles agglomeration process and dried milk reconstitution[4, 20].

These forces arise at particles contact with the equipment surface. Electric forces of Adhesion depend on the volume and composition of powdered product particles and material surface contacting with it. The smaller the particle size, the greater the charge has dry milk[6].

Under particle approaching to the surface Electric Coulombic forces of Adhesion arise. Electric Coulombic forces of Adhesion are sharply reduced at the particle contact with the surface.

The residual Coulombic forces depend on the particle moisture and the equipment surface Electric conductivity. Depending on the amount of particles adhered to the solid surface they can settle on it without interaction among themselves or forming the layer of interacting particles.

German scientist-researcher Simon [12] concluded that such layer firmness depends not only on its adhesion to the surface but on the number of interacting particles.

Particles can be placed on the hard surface of the equipment, depending on the number of these particles, or if no contact among themselves, or forming a layer of contact between particles.

He (Simon) concludes that the strength of this layer depends not only on the Adhesive forces of the surface equipment, but also from the forces of particle interactions amongst themselves.

It should be considered that adhesive interaction of particles and adhesion electric forces do not just only limit surface.

In the whole adhesion of particles to hard surface is realized mainly due to molecular forces, capillary forces of the liquid contacting in the gap between contacting bodied as well as under the action of double electric layer forming in the contact zone and coulomb interaction.

Under certain conditions, the forces of one type can predominate over the others. So, for example, at the relative humidity over 70% or moisture content in milk powder over 7% capillary forces begin to exert dominating effect on adhesion magnification[5].

As for the particles electric potential Tanaka Tatsuo from Japan Powder technology handbook CRC Press proved that humidity reduces explosive situation decreasing the period of charge disintegration (if the powder is in hydrophobic condition)[16].

In present time known many works on Adhesion of powdery material. Questions have on the theory and practice of this phenomenon (Adhesion) as it relates to dry dairy products.

Adhesion of dry milk studied insufficiently and not reached beyond individual experimental research. However, in the food industry, in particular the process of drying milk, these works insufficiently[14, 15].

THE OBJECT OF RESEARCH AND METHODOLOGY OF EXPERIMENTS

In our investigations, the basic food product is Skim milk powder. Studies relating to Tribo-electricity of Skim milk powder particles are necessary for investigation of manufacturing processes connected with different materials drying including milk drying.

Faraday Cylinder method was used for determination of electric charge of dried milk particles mass[11].

The laboratory equipment presented in Figure 1 was constructed for Tribo-electricity measurement.

"Tribo-charge" was determined on wafers manufactured from metal grade Ch18N10T and dielectric (polyethylene terephthalate)[22].

Length of the slanted tray (rectangle form) was 300 mm. The slanted tray was two kinds from metal and dielectric.

The metal stainless wafer finish on mean square deviation of the surface asperity was at the level of $H_{sq} = 0,2$ (μ) micron.
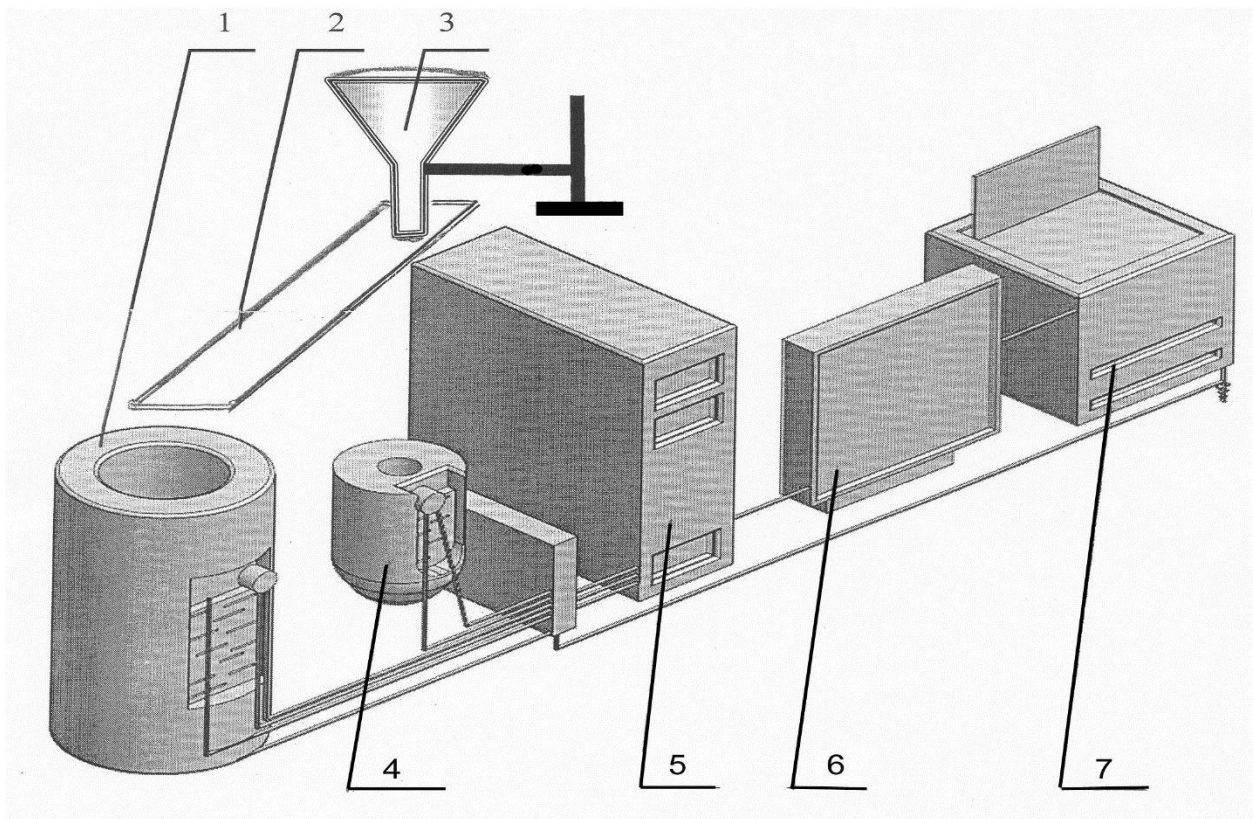

Fig 1. Experimental laboratory equipment for measurement of Tribo-electricity of Skim milk powder particles:

1 - Faraday Cylinder; 2 - Slanted tray; 3 - Feed hopper-receiver; 4 - Adapter;
5 - Processor on IBM base with integrated Electrostatic Voltmeter and Electro-
Meter; 6 - Monitor; 7 - Printer

Measurement was realized as follows: particles in the form of Skim milk powder were fed into loading hopper (receiver) **3**. After receiver **3** Skim milk powder particles by smooth flow at free fall from a height of H=150 mm are delivered to Slanted tray **2**.

The Slanted tray **2** angle of slope to horizontal plane made up 45º. A part of Skim-milk powder particles due to Adhesion forces stipulated by Coulombic forces (Electric forces) was fixed on the Slanted tray surface. Meanwhile the metal Slanted tray was grounded.

Another, basic part of the particles in the form of Skim milk powder was delivered to Faraday Cylinder **1**.

After each experiment, the amount of Skim milk powder got directly into Faraday Cylinder was weighed.

Faraday cylinder is shielded device fully protected against the effects of an external electric field

Capacity of measuring circuit "**C**" comprises the device capacity, particles receiver and wires, **C= 1,72–10^{-10}** Fa - const.

The acquired potential and Skim milk powder particles polarity got into Faraday Cylinder were measured in the form of specified frequency signal.

This signal is modulated through Adapter **4** and analyzed by Processor **5** on IBM base.

Processor **5** is the unit, which besides the basic functions of conventional computer executes the tasks connected with determination of potential, and polarity of Skim milk powder particles got into Faraday Cylinder.

That is through the specified electronic board Electrostatic Voltmeter and Electro-meter are integrated into Processor **5**.

The readings were analyzed at the Monitor (display) **6** of the mentioned device and as needed were transferred to paper media by means of printer **7**.

Mass of Skim milk powder got into receiver was measured at electronic balance with accuracy (+/-) 0,01 g.

Potential of Skim milk powder particles was determines at T = 20°C and relative air humidity 75 – 80 %.

The particles rate of motion from receiver **2** to Faraday Cylinder was changed in the range from 0,1 to 2 m/sec. depending on the change of specific electric charge of Skim milk powder particles.

Specific electric charge of particles (Coulomb/kg) was determined according to the formula:

$$q_{sp} = CU/m$$

(1)

Where   **C** – capacity of measuring circuit, Faraday;
                 U – voltage, Volt;

                 m – mass of Skim milk powder particles, kg.

RESEARCH RESULTS

Table 1: Parameter of Specific electric charges of Skim milk powder at Tribo-charge

Variable parameter	Dependence of Specific electric charges from Slanted tray length						
q_{sp}, x10^8 C/kg at U = 100 V – metal grade Chr18N10T	0	4,5	6,0	9,0	15,0	25,0	40,0
q_{sp}, x10^8 C/kg at U = 100 V dielectric polyethylentephtalat	27	18	6,0	2,3	1,8	1,6	1,6
q_{sp}, x10^8 C/kg at U = 0 V - dielectric polyethylentephtalat	18	12	6,0	3,4	2,9	2,8	2,8
q_{sp}, x10^8 C/kg at U = 150 V dielectric polyethylentephtalat	45	24	6,0	1,6	1,0	0,8	0,8
L - slanted tray, mm.	0	50	100	150	200	250	300

It is natural that when the length of the pass traversed by Powder milk particles is increased the specific contacting area of particles with metal slanted tray 2 surface has been considerable increased promoting the increase of Specific electric charge quantity.

It was stated that all Skim milk powder particles get positive polarity of the charge since forming on them free electrons are easily rendered to metallic wafer i.e. conductor which was grounded.

Under replacing metallic slanted tray for dielectric (polyethylentephtalat) in the process of Tribo-electrization opposite polarity charges were accumulated on the Slanted tray as well as on Skim milk powder particle surfaces.

Whereupon potential difference between the wafer surface and particles was increased that was registered at monitor **6** promoting the particles attraction to the Slanted tray.

Due to a great meaning of Skim milk powder particles contact area (direct accumulation of particles on the Slanted tray) Tribo-charge process and the following process of discharging (particles "drop" into Faraday Cylinder) is accelerated.

On application of metallic slanted tray, the increase of specific charges of Skim milk powder particles depending on velocity occurs negligible.

However, on application of dielectric slanted tray (rectangle form) the particles Specific electric charges are increased significantly depending on these particles velocity (Fig 2.).
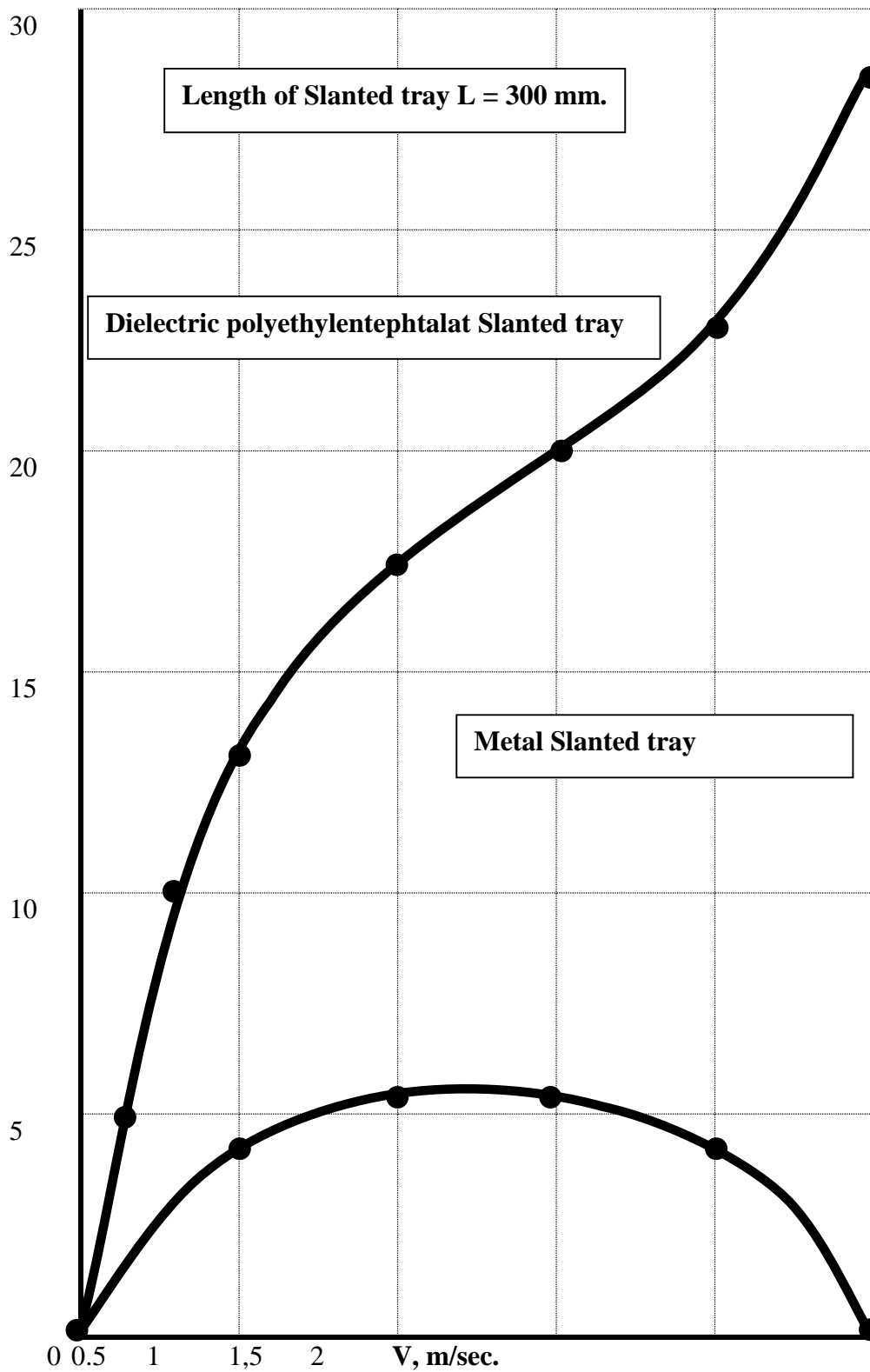
$q_{sk} \times 10^8$, **Coulomb/kg**

Fig. 2. Change of Specific electric charge of particles of Skim milk powder in Tribo-charge depending on the speed of movement of particles

Moreover it was stated that drop of electric potential supplied to metallic Slanted tray promotes increase of specific electric charges obtained by Skim milk powder particles. Table 2.

Table 2: Specific electrical charges of Skim milk powder at Tribo-charge

Variable parameter	Dependence of Specific electric charges from Electrical potential						
U, Volts.	0	25	50	75	100	125	150
q x 10^8 C/kg	5,2	4,2	3,5	2,8	2,5	2,2	1,8

DISCUSSION OF EXPERIMENT RESULTS

Effect of Tribo-electrization is the result of exchange between contacting surfaces of particles and as some scientists consider in their manuscripts[8] is connected with formation of general in contact area double electric layer, which is the source of static charges.

Energy state of surfaces prior their contact is characterized by definite equilibrium state. Under surfaces contact their energy state is violated since surfaces having different level of surface energy[9] come in contact.

Newly formed double electric layer equal to several micrometers is characterized by new energy state.

Under the contact break on each particle of the dried product uncompensative electric charges of reversed sign are formed quantity of which is determined by kinetics of the processes occurring during formation and break of double electric layer in the place of these particles contact.

For each instance, kinetics of electric charges report depends on a number of factors connected with electro-physical characteristic of contacting phases and specific conditions at which Tribo-electrization occurs[2].

Mathematical Model Tribocharging of Particles

In this section, the mathematical model of inner and outer electric charge transfer for separate particle of Skim milk powder is presented[1].

Inner and outer electric charge transfer of Skim milk powder separate particle depends on electric field and the potential inside and outside of the particle which can be conditionally taken for sphere in radius $R = A$ and charged current with volume density p_v, C/m^3, (Fig 3)[21].

Let us consider the voltage of field inside the sphere $(R < A)$, on spherical particle surface $(R = A)$ and out of it $(R > A)$ according to Gauss theorem[18].

Quantity of electrical charge in a spherical particle:

$$q = V\,p_v = (4/3)\,\pi\,A^3\,p_v.) \qquad (2)$$

Electric field, created out of spherical particle coincides with the field created by equivalent to point charge. According to Coulomb law the voltage of such field $(R > A)$ make up:

$$E_{EX} = k\, q\, /\, R^2 = q\, /(4\, \pi\, \varepsilon_0\, R^2) = A^3\, p_v\, /(3\, \varepsilon_0\, R^2) \qquad (3)$$
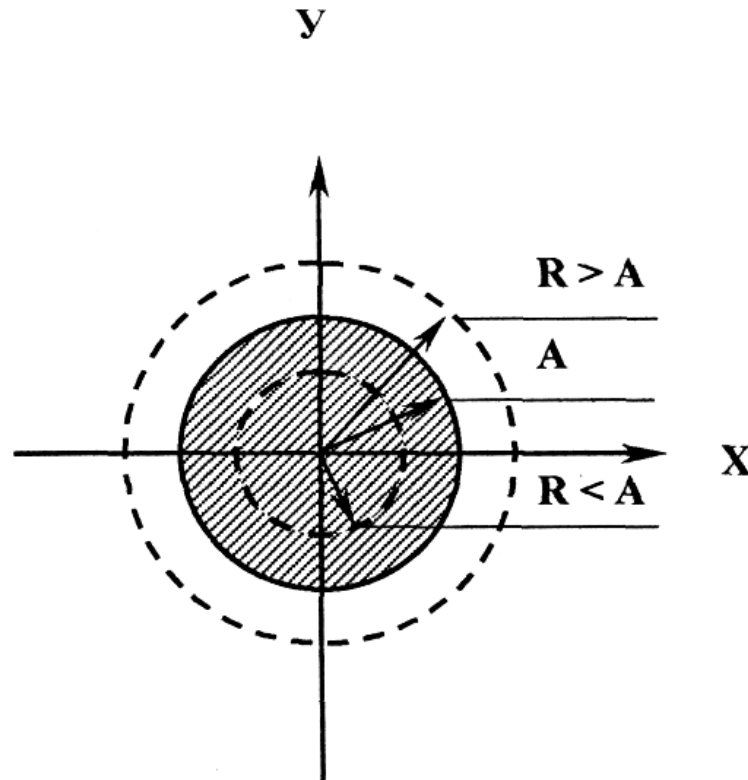

Fig. 3. Spherical particle of Skim milk powder in radius R = A

The voltage of electric field on the surface $(R = A)$ of spherical particle make up:

$$E_{SF} = A^3\, p_v\, /(3\, \varepsilon_0\, A^2) = A\, p_v\, /(3\, \varepsilon_0) \qquad (4)$$

The voltage of electric field inside of spherical particle $(R < A)$ is changer linearly from zero in the center to peak value on the surface:

$$E_{IN} = R\, p_v\, /(3\, \varepsilon_0) \qquad (5)$$

$$\varepsilon_0 = 8{,}85\ 10^{-12}\ C^2/(H\, m^2)\ \text{- electric constant.}$$

Difference of potentials in the inside field of spherical particle between spherical shell of radiuses R_1 and R_2 make up:

$$U_{R1} - U_{R2} = \int_{R2}^{R1} E_{IN}\, dR = (R^2_1 - R^2_2)\, p_v\, /(6\, \varepsilon_0) \qquad (6)$$

So, in particular, difference of potentials between center of the particle and its surface make

up:

$$U_A - U_0 = A^2\, p_v\, /(6\, \varepsilon_0) \tag{7}$$

The difference of potentials in external field particle between spherical shells of radiuses R_1 and R_2 make up:

$$U_{R1} - U_{R2} = \int_{R2}^{R1} E_{EX}\, dR = (1/R_2 - 1/R_1)\, A^3 p_v\, /(3\, \varepsilon_0) \tag{8}$$

Therefore, in particular, the difference of potentials between spherical particle surface and infinity make up:

$$U_A - U_\infty = A^2\, p_v\, /(3\, \varepsilon_0) \tag{9}$$

If we take the potential at infinitely, remote point equals zero: $U_\infty = 0$

Then potentials on surface U_A and in center U_0 of spherical particle are:

$$U_A = A^2\, p_v\, /(3\, \varepsilon_0) \tag{10}$$

$$U_0 = A^2\, p_v\, /(6\, \varepsilon_0) \tag{11}$$

The Numerical Values of The Potential Electric Field

According to the mentioned above formulas we can calculate electric field and potential inside and outside of Skim milk particle $d = 60\,\mu$ charged by electric current with specific density per mass unit: $\rho_m = 6 \cdot 10^{-8}\ Кл/кг$

Since powder milk bulk density makes up **560-580 kg/m³**, so specific volume will make up **$1,7 \cdot 10^{-3}\,m^3/kg$**; so specific density of electric charge per volume unit will make up: $\rho_v = 3,53 \cdot 10^{-5}\ C/m^3$

Then the voltage of electric field on the surface of particle Skim milk powder will make up: $E_{SF} = A\, p_v\, /(3\, \varepsilon_0) = 40\ V/m$

$$\tag{12}$$

The voltage of electric field on the external of the spherical particle

E_{EX} at $R = 1\ 10^{-4}m$ will make up: $E_{EX} = A^3\, p_v\, /(3\, \varepsilon_0\, R^2) = 3,6\ V/m \tag{13}$

for $R = 1 \cdot 10^{-3}\,m,\ \ E_{EX} = A^3\, p_v\, /(3\, \varepsilon_0\, R^2) = 3,6\ 10^{-4}\ V/m \tag{14}$

for $R = 1 \cdot 10^{-2}\,m,\ \ E_{EX} = A^3 p_v /(3\varepsilon_0 R^2) = 3,6\ 10^{-6}\,V/m \tag{15}$

Quantity of electricity in spherical particle: $q = (4/3)\pi A^3 p_v = 4 \cdot 10^{-18}\ C \tag{16}$

Difference of potentials relative to infinity for the center of the spherical particles make up:

$$U_0 = A^2 p_v /(6\varepsilon_0) = 6 \cdot 10^{-5}\ V$$

$$\tag{17}$$

Difference of potentials relative to infinity for the surface of the spherical particle make up:

$$U_A = A^2 p_v/(3\varepsilon_0) = 12 \cdot 10^{-5}\, V \qquad (18)$$

The diagrams of the voltage electric field E and difference of potentials U with infinity point as function R distance from the center of remote spherical Skim milk particle are presented at Fig 4.
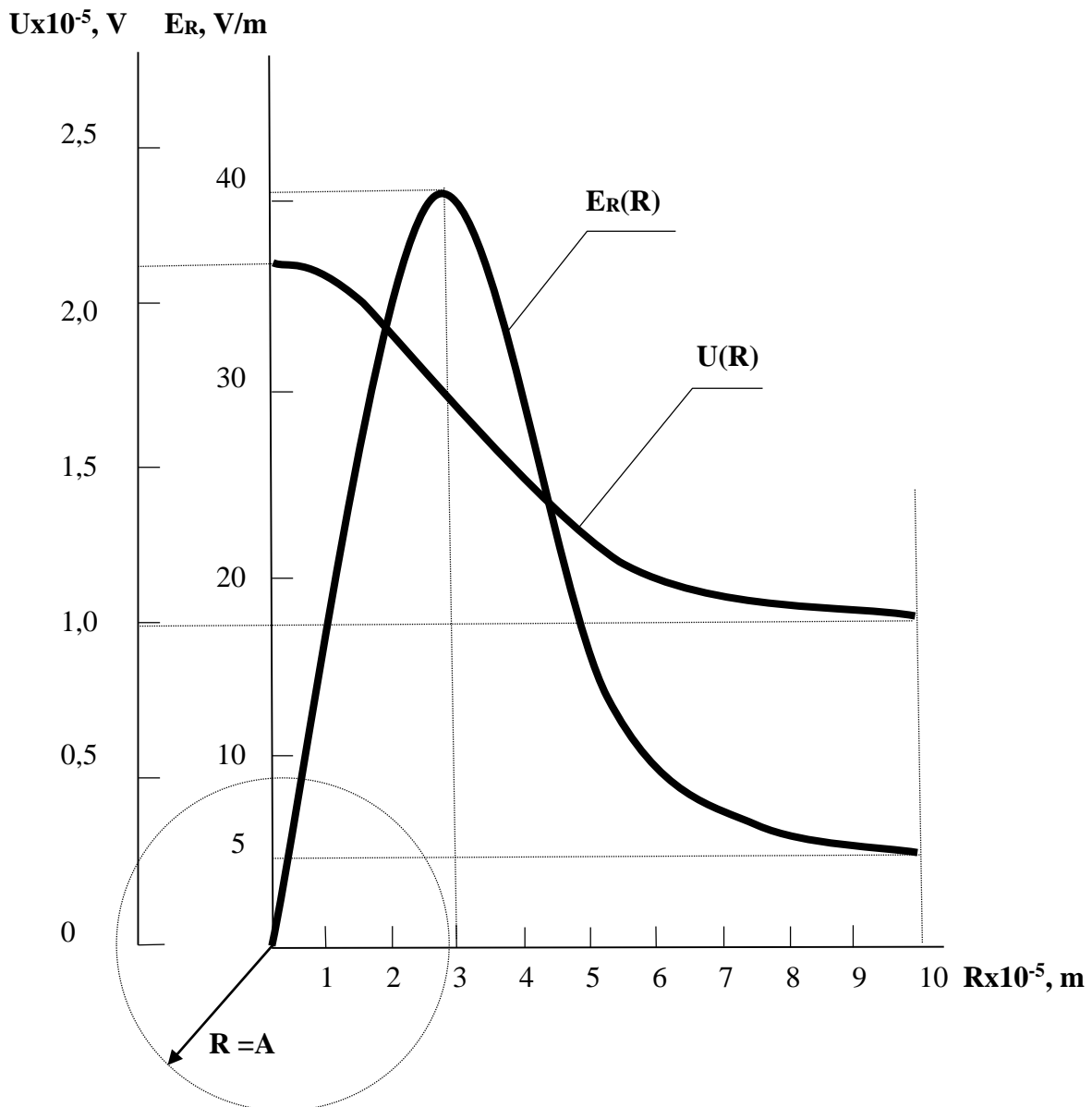

Fig. 4.   Distribution of voltage E (R) and difference potentials U (R) electric field inside and outside of the single spherical particles of Skim milk

    The presented mathematical model is to be considered, as the first stage in solving the very complicated task relating to modelling of triboelectric phenomenon underlying the process of drying by the example of Skim milk powder.

CONCLUSION

During transportation as the result of technological equipment inner surfaces friction, powder milk particles get electric charge. Removal of static electricity is very important task in the process of drying equipment operation.

Thus the investigations in such field is multipronged task which requires complex technical solutions aimed at creation of safety processes of transportation and storage of powder milk manufactured by spray-drying process.

In our experiments, we tried to study and research Tribo-electric phenomenon not only on the laboratory equipment, but also during production process connected with Skim milk powder drying[2]. Our work resulted in receiving of additional experimental material charactering the specific peculiarities of Tribo-charging of Skim milk powder particles.

The mathematical model of inner and external transfer of electric charge for separate Skim milk powder particles are presented. The algorithm of determination of inner and external electric charge transfer in the separate Skim milk powder particle, which depends on electric field and potential inside and outside of the particle, has been proposed. The numerical values of electric field intensity outside and on the particle surface had been determined as well as intensity (potential) in the center, inside and on the surface of Skim milk powder particle.

REFERENCES

[1] Burlev, M.Ya. Mathematical model of drying milk particles with using the weak electric impulses. / M. Ya. Burlev, V.V. Ilyukhin // Theoretical and practical bases of development processes and devices of food manufactures: scientific papers. 100 years Fedorov N.E. Moscow: MSUAT, 2001. p. 32-39.

[2] Burlev, M.Ya. Intensivierung des Prozesses von dehydratisierung in elektrischem Feld schwaches Impulse / M. Ya. Burlev, N. S. Nikolaev //. Materials of the III intern. research and practice conf. V. 1. Publish office Vela Verlag Waldkraiburg. – Munich, Germany. April 25th - 26th, 2013. - S. 88-91.

[3] Hayashi, H. Cohesion in dry whole milk / H. Hayashi, M. Honda. // XIX Int. Congress on the Dairy. - Moscow, 1978. - pp. 131-132.

[4] Kazi Aurnob. Analysis of Factors Affecting Dust Explosion / Duluth Journal of Undergraduate Research // Sweson College of Science and Engineering University of Minnesota Duluth. USA. 2014. pp 48-63.

[5] Kharitonov V.D. Two-stager drying of Dairy products. - Moscow: Agro Publish. 1986. - 104 p.

[6] Lipatov, N.N. Milk Powder. / N.N. Lipatov, V.D. Kharitonov // Moscow: Publish Food Industry. 1981. - pp. 209-210.

[7] Masters, K. / Spray Drying Handbook // George Godwin. London. Great Britain. 1985. - pp. 696-701.

[8] Molchanov, V.I. Physical and chemical properties of finely dispersed materials. / V.I. Molchanov, T.S. Yusupov. - Moscow: Subsoil. 1981. - 162 p.

[9] Muchnick, V.M. Electrization coarse particles / V.M. Muchnick, B.E. Fishman. - Leningrad: Gidro-meteo Publish, 1982. - 205 p.

[10] Nikolaev, N. S. The process of Tribo charging particles by spray drying. / N.S. Nikolaev, M.Ya Burlev. // IX International Academic-Practical Conference. Molecular Physics. Vol. 15. Poland. 7 - 15 January 2013. - pp. 20-24.

[11] Payel Bagga, Measurement of Electrostatic Dipoles and Net Charge on Air Dispersed Particles. / A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Chemical and Process Engineering at the University of Canterbury, New Zeeland. May 2009.

[12] Simon, A.D. Adhesion of Dust and Powders / Chemistry, 1978. - 372 p.

[13] Smokotin, E.V. Study of aerodynamic interactions of the product with air and improving the design of spray dryers. / Dissertation Moscow 2014. - 25 p.

[14] Supuk, Enes Tribo-electrification of active pharmaceutical ingredients and excipients. / Enes Supuk, Afsheen Zarrebini, Jay P. Reddy, Helen Hughes, Michael M. Leane, Mike J. Tobyn, University of Particle Science and Engineering, Journal Powder Technology. UK. No. 217. - 2012. pp. 427-434.

[15] Svinschtov V.Ya. Theoretical and practical aspects study methods of physical characteristics food products and the mechanism the processes of interaction electric fields with matter: D. Ph. of Science theses. - Moscow: 1993. - 46 p.

[16] Tanaka, Tatsuo. Spontaneous ignition and dust explosion. In Hiroaki Masuda, Ko Higashitani, & Hideto Yoshida (Eds.), *Powder technology handbook* CRC Press. 2006. Vol. 3, pp. 849-878.

[17] Taneya Shin'ichi, Japan Journal Applied Physics, vol. 2, No. 12, December 1983. - pp. 798-804.

[18] Tenesesku, F. Electrostatics in technology. / F. Tenesesku, P. Kramaruk. - Moscow: Energy, 1980. - 295 p.

[19] Timothy G. Walmsley. An experimentally validated criterion for skim milk powder deposition on stainless steel surfaces. / Timothy G. Walmsley, Michael R.W. Walmsley, Martin J. Atkins, James R. // University of Waikato, New Zeeland, Journal of Food Engineering, No. 127. - 2014. pp 111-119.

[20] U.S. Department of Labor. Occupational Safety and Health Administration. (2008). *Hazard alert: Combustible dust explosions.* OSHA Fact Sheet. URL: https://www.osha.gov/OshDoc/data_General_Facts/OSHAcombustibledust.

[21] Volobuev, A.N. Biophysics. - Moscow. - Samara: Print House, 1999. - 143 p.

[22] Zimon, A.D. Autogesion bulk materials. / Zimon A.D., Andrianov E.I. - Moscow: Metallurgy. 1978 - pp. 48-55.