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Modeling of Classification Process in a Continuous Trommel Screen

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Abstract

Mechanical classification of bulk materials is quite widely used in various industries. Modeling of the process is complicated due to the fact that in a continuous mode the bulk material moves not only in axial, but also in longitudinal section of the classifier. To describe the classification process, deterministic and stochastic models can be used. When modeling the process of mixing-separation in a continuous drum classifier it is impossible to consider the process which takes place in the fixed circulation contour. It is necessary to take into account the material movement along the axis of the drum, and also the reduction in the area occupied by the material in the cross-section of the trommel screen. The process of movement in the continuous drum classifier can be presented as discrete in space and time. Thereby the process of mixing-separation can be considered similar to the periodic one, but the transition to each successive section along the length of the classifier must take into consideration changes in configuration of the circulation contour associated with a decrease in the area occupied by the material in the cross-section of the drum. To describe the process of mixing taking place simultaneously with the process of classification, the mechanism that determines the sequence of phases for a three-component mixture can be used. While describing the mechanism of separating small and product fractions from the mixture composition, constant coefficients defining the intensity of separation of these particles from the mixture are used. The presented mathematical description of the process considers both the mechanism of components segregation and the mechanism of separating the mixture into individual fractions. Options of practical use of the mathematical description for designing new equipment and optimizing the operating one are presented in the conclusion.

Keywords

Bulk material; classification; drum; modeling.

Introduction

Mechanical classification of bulk materials is commonly used in chemical and related industries, particularly, in the production of fertilizers. Two most frequently used versions of process hardware design are screening from the fine material to the large one and from the large material to the fine one [1].

At high rates of filling the drum the movement of the material has circulation nature in its cross-section. The nature of the movement in the cross-section of the drum is described in a large number of scientific papers [2–4].

In industry screening is used to separate material into two or three fractions: fine, product and large fractions. Depending on the process hardware design there occurs either simultaneous separation of fine fractions from product fractions or successive separation first of fine, then of product fractions. In both cases, to describe the process the mathematical models of the mixing process in a periodic mode can be adapted [5–7], including those based on Markov random chains [4, 8], as applied to the classification process. In the drum classifier two oppositely directed processes are carried out simultaneously: mixing of different-sized particles and their separation into separate fractions. The most promising models to describe the processes implemented in a trommel screen, in our opinion, are deterministic-stochastic mathematical models [9].

Modeling of classification process in a continuous trommel screen is associated with a number of difficulties due to the fact that material moves not only in the cross-section of the mixer, but also along its axis. The nature of this movement depends on both the mixer design and its mode parameters. At the same time it is possible to identify a number of general regularities: more intensive mixing-separation in the radial direction of the trommel screen at a quite clearly marked circulation movement of the material; decrease in the extent of cross-sectional filling of a trommel screen with the material when moving from the loading area to the unloading area, along with an increase in the axial velocity.

The above said leads to the assumption that a single mathematical model of the process can be developed for continuous drum classifiers.

Methods and Materials

Despite the fact that deterministic-stochastic models for periodic processes do not take into account the movement of the components along the axis of the drum, they can be used as a basis for describing the process of continuous screening, since axial movement of the bulk material has a fairly pronounced deterministic and stochastic nature.

Let us consider briefly the basics of the strategy of the modeling of mixing-separation process of dispersed materials. According to [4] in circulation movement all the material in cross-section can be divided into rising ($ACBM$ zone) and rolling down ($ACBN$ zone) layers (Fig. 1). In the rising layer the material moves as a continuous stream and mixing of the particles is not observed, but there occurs a process of separation of particles of different fractions. Mixing process is most active mainly in the rolling down layer.

When layer-by-layer or cell-like mathematical models based on Markov chains are used [4] in the cross-section of a trommel screen at the beginning the circulation contour is divided into sub-layers. The volumes of sublayers moving from the drum shell to the center of circulation decrease.

Knowing the thickness of the rolling down layer CN all the material can be divided into n sub-layers:

$$n = CN / d_{\max}, \quad (1)$$

where $d_{\max}$ – maximum diameter of the components of the mixture.

In practice, the application of this formula, in most cases gives a fractional result. However, in subsequent calculations a fractional number of sublayers involved in the mixing-separation process cannot be used, so the integer part of the obtained expression is used as the number of sublayers and the remaining fractional part (which is less than $d_{\max}$) is evenly distributed between all the sublayers. The thickness of each sublayer appears to be greater than $d_{\max}$.

Time τ_C needed for a particle to make a complete circulation cycle can be defined as the sum of the time of the particle residence in the rising layer τ_{Ris} and the time of the particle residence in the rolling down layer τ_{Rol}

$$\tau_C = \tau_{Ris} + \tau_{Rol}. \quad (2)$$

For a continuous drum classifier the longitudinal cross-section of the drum partially filled with mixture components is shown in Fig. 2. The dotted line in it characterizes the position of the center of circulation along the length of the classifier. As can be seen from Fig. 2, the amount of material decreases in the

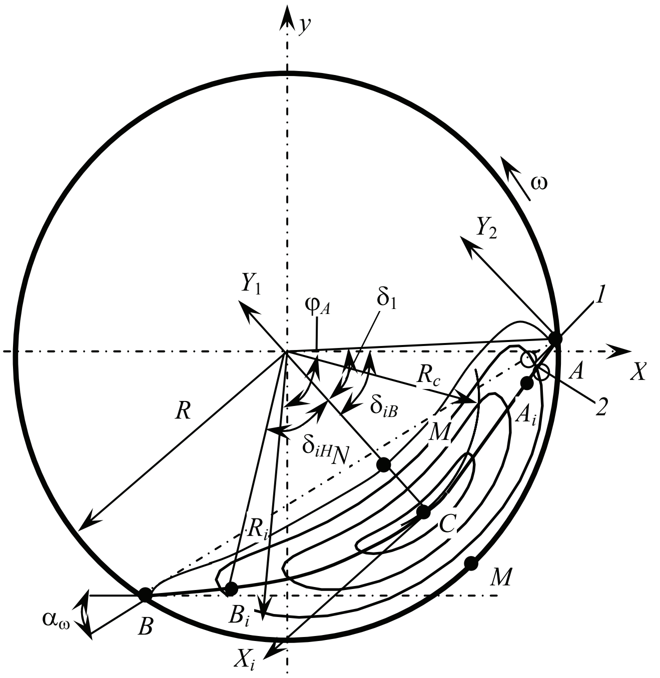

Fig. 1. Scheme for determining the character of movement of bulk material in the cross-section of the drum

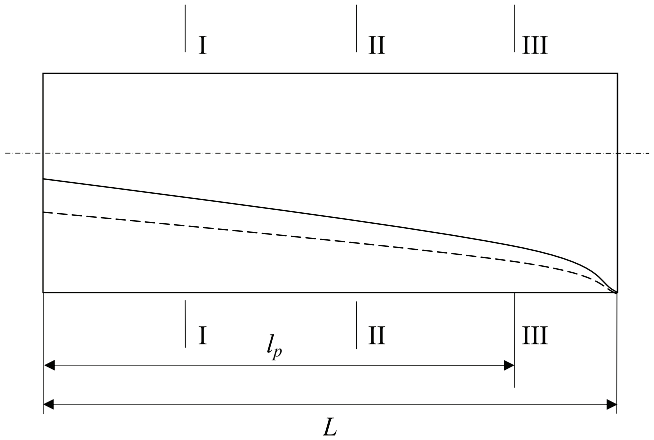

Fig. 2. The distribution of bulk material in the longitudinal section of the drum mixer of continuous operation

direction from the loading area of the drum (on the left) to the unloading area (on the right). If three cross-sections I – I, II – II, III – III are made, it is evident that the area occupied by the circulation contour of the material in section I – I will be the greatest and the area in cross-section III – III – the lowest. Taking into account the above said when modeling the process of mixing-separation in a continuous drum classifier it is impossible to consider the process which takes place in the fixed circulation contour. It is necessary to take into account the fact of material movement along the axis of the drum, and also the fact of the reduction in the area occupied with material in the cross-section of the trommel screen [10].

Experiments on the nature of distribution of bulk material along the axis of the drum are widely presented in [10]. However, theoretical dependence describing the nature of the distribution of bulk material along the length of the trommel screen has not been studied yet. Fig. 2 shows that the line describing this nature of distribution has the maximum curvature in the area located to the right of section III – III, i.e. close to the pouring edge of the structure. With accuracy sufficient for engineering calculations, we can assume that in the section with length l_p this dependence is linear.

The section which has the greatest curvature near the pouring edge of the drum classifier is negligible, so we can make an assumption about the linear nature of the distribution of the material over its entire length.

Taking into account that when moving away from the loading area of the drum, the amount of material in the cross sections decreases, the rate of material feed in the axial direction will increase as the condition of continuity of flow holds true. Thus, there is a strong relationship between the amount of bulk material in the cross-section of the drum and its rate of feed in the axial direction.

Movement of the bulk material particles in the axial direction occurs in the rolling down layer, but as the material moves in the direction of the pouring edge, the area occupied with mixed particles in the cross-section of the drum decreases. As a result, the thickness of the rolling down and rising layers decreases. In accordance with dependence (2) the value of the cycle time in each successive section is lower than in the previous one.

The process of movement in a continuous drum classifier can be presented as discrete in time and space [10]. Therefore, mixing-separation process can be considered similar to the periodic one, but the transition to each successive section must take into account changes in configuration of circulation contour due to a decrease in the area occupied with the material in the cross-section of the drum.

The existing structure of components distribution by sublayers of the circulation contour must be retained when the area at each transition decreases [10]. Herewith there are two possibilities.

1. The number of sublayers has not decreased, but their thickness has changed. This variant is implemented by dividing the rolling down layer into sublayers according to dependence (1), when the integer part is used as the number of sublayers, and the remaining fractional part is distributed uniformly between the sublayers. The value of the fractional part can be small, and, in this case, a very small value is added to the volume of each of the sublayes. If the fractional part of the value is large enough, then when it is distributed among the sublayers, quite a large volume is added to each of them. Note that the volume added in each of the sublayers will be proportional to the volume of the sublayer. If the fractional part is large enough, then when the area occupied by the material changes in the cross-section of the drum, the separation of circulation contour into sublayers can reduce the value of the fractional part rather than the number of sublayers. Taking into account that volumes of sublayers, as mentioned above, change proportionally, it is sufficient to preserve the structure of distribution of key components by sublayers of the circulation contour existing before the recalculation.

2. As a result of changes in the area occupied by bulk material in the cross-section of the drum, the number of sublayers has decreased. In this case, it is necessary to revaluate the concentrations of key components of the newly formed sublayers of the circulation contour while retaining the available distribution structure. Since the area occupied by the circulation contour along the axis of the drum changes monotonically and can be described by a straight line with a small angle of inclination, and the cycle time is much less than the residence time of the particles in the drum, the maximum decrease in the number of sublayers can not be greater than a unit. Suppose before the recalculation of parameters of the circulation contour there were q sublayers and after the recalculation – $q-1$ sub-layers. Then the key components of the “lost” sublayer should be distributed between the remaining sublayers retaining the existing distribution structure. Each newly formed sublayer must contain the particles of the layer of the same name (before the recalculation), as well as some of the particles of the successive sublayer. The excess of the particle concentration in the new layer will be:

$$r = q/(q-1)\,. \qquad (3)$$

For a three-component mixture the concentration of fine and product fractions in any sublayer after reducing the number of sublayers will be:

$$C_1^{(i,m)} = (CO_1^{(i,m)}(r+i(1-r)) + CO_1^{(i+1,m)}i(r-1))/r\,; \quad (4)$$

$$C_2^{(i,m)} = (CO_2^{(i,m)}(r+i(1-r)) + CO_2^{(i+1,m)}i(r-1))/r\,, \quad (5)$$

where i is a sublayer number, $i = 1, ..., q-1$; $CO_1^{(i,m)}$ and $CO_2^{(i,m)}$ – the concentrations of fine and product fractions in i sublayer before a change in the number of sublayers; m – transition number. One transition means a time interval within which the smallest sublayer makes a complete revolution around the center of circulation.

To describe the mixing process taking place simultaneously with the separation process, we use the mechanism of the mixing process [11], which determines the sequence of phases for a three-component mixture consisting of basic material, as well as fine and product fractions.

Let the probability coefficients of the transition of the peripheral sublayers to the area of circulation center of the components 1, 2, 3 be arranged according to the inequality $P0_{13} > P0_{23} > P0_{12}$. The main component is designated by digit 3, the components of fine and product fractions are designated by digits 1 and 2. There are three variants of the process of particles exchange between contiguous sublayers: 1) the particle of the component that is involved in the metabolism in this transition phase moved to the adjacent volume of the overlying sublayer; 2) the particle moved into the adjacent volume of the underlying sub-layer; 3) the particle remained in the same sublayer.

Exceptions are the first and last sublayers, for which there are only two options.

Let us consider the first transition phase for two adjacent sublayers.

In the first transition phase we consider the transition of the first component into the sublayer lying closer to the center of the circulation, followed by displacement of the third component from it. The probability of transition of the first component from subrlayer i into sublayer $i+1$ in this transition phase at time $T = m\Delta T$ equals $P_{13}^{(i,i+1,m)}$

$$P_{13}^{(i,i+1,m)} = P0_{13}\left(1-\left(C_1^{(i+1,m-1)} + C_2^{(i+1,m-1)}\right)\right), \quad (6)$$

where $P0_{13}$ – probability coefficient of the transition of the first component into the sublayer containing the third component; $C_1^{(i+1,m-1)}$, $C_2^{(i+1,m-1)}$ – concentrations of components 1, 2, respectively, in sublayer $i+1$ at time $T = (m-1)\Delta T$; $m = 1, 2, ..., k$.

The probability of transition of the first component from sublayer i into sublayer $i+1$ depends on the probability $P0_{13}$ – the value which is constant for a particular mixture determined by the properties of components 1, 3, and on the concentration of component 3 involved in the mixing in sublayer $i+1$ (the expression of the right part of the dependence (6) in parentheses). Then the concentration of the first component in sublayer i, after the first transition phase will be determined by the dependence

$$C_1^{(i,m)} = \frac{C_1^{(i,m-1)}V^{(i)} - C_1^{(i,m-1)}P_{13}^{(i,i+1,m)}V^{(N)}}{V^{(i)}} + \frac{+C_1^{(i-1,m-1)}P_{13}^{(i-1,i,m)}V^{(N)}}{V^{(i)}}, \quad (7)$$

where $V^{(i)}$ is the volume of sublayer i; value $C_1^{(i,m-1)}V^{(i)}$ presents the volume of the first component contained in sublayer i before this transition phase, and value $C_1^{(i-1,m-1)}P_{13}^{(i-1,i,m)}V^{(N)}$ presents the volume of the first component which moved into sublayer i in this transition phase from sublayer $i-1$, which is directly adjacent to sublayer i and closer to the drum shell. This volume of the first component does not take part in the exchange with sublayer $i+1$, because it is known that during one transition phase the component can move only from one sublayer into another, and this component has already taken part in this transition phase having moved from sublayer $i-1$ into sublayer i. Value $C_1^{(i,m-1)}P_{13}^{(i,i+1,m)}V^{(N)}$ characterizes the amount of the first component which moved from sublayer i into sublayer $i+1$ in this transition phase.

Calculation based on the presented dependences should be started from defining the probability of transition and concentration of the component involved in this transition phase in the first sublayer. In the first phase the probability of the transition of the component from the first sublayer into the second one can be defined from dependence (6), but at $i = 1$. In this case the concentration of the first component after this transition phase in the first sublayer can be defined as

$$C_1^{(1,m)} = \left(C_1^{(1,m-1)}V^{(1)} - C_1^{(1,m-1)}P_{13}^{(1,2,m)}V^{(N)}\right)/V^{(1)}. \quad (8)$$

Here the most distant from the circulation centre sublayer is absent and therefore in this transition phase the first component is not transferred from this sublayer.

After the calculation of the concentration of the first component in the first sublayer you can use dependence (8) for all the sublayers except the last one since for each successive sublayer value $C_1^{(i-1,m-1)}P_{13}^{(i-1,i,m)}V^{(N)}$ is known. For example, in the calculation of the concentration in the second sublayer this value will be equal to the volume of the first component which moved from the first sublayer into the second one in this transition phase, i.e. $C_1^{(1,m-1)}P_{13}^{(1,2,m)}V^{(N)}$.

While calculating the concentration of the first component in the last sublayer you can use expression

$$C_1^{(N,m)} = C_1^{(N,m-1)} + P_{13}^{(N-1,N,m)}C_1^{(N-1,m-1)}. \quad (9)$$

According to this expression, concentration of the first component in this transition phase in sublayer N increases. In this case, if the concentration of the third component in sublayer N is close to zero, probability $P_{13}^{(N-1,N,m)}$ tends to zero, since there is no component to be replaced. As a result, in this transition phase the first component stops its penetration in sublayer N. Thus, there starts stronger displacement of the third component from sublayer $N-1$, followed by its replacement by the first component.

Hence, segregation mechanism with subsequent accumulation of components more prone to segregation around the center of circulation becomes evident.

In the mathematical description of the screening process in the drum self-grinding and agglomeration of particles can be ignored. This is due to the fact that, for example, during the processing of fertilizers the percentage of self-grinding did not exceed 2–3 %. The formation of only single agglomerates was also recorded [12].

Let us consider the case of screening process from the large material to the fine one. Herewith the simultaneous separation of the particles of fine and product fractions occurs [1].

While considering the mechanism of separation of the product fraction from the mixture composition, the probability of separation of these particles from the mixture

$$P_{\text{ot}_2}^{(i,m)} = ER_2(R^{(i,m)} - RC^{(m)})/(RB - RC^{(m)}), \quad (10)$$

where $P_{\text{ot}_2}^{(i,m)}$ is the probability of separation of particles of product fraction from i sublayer at time moment $T=(m-1)\Delta T$; $m=1,2,...,k$; ER_2 is constant coefficient, the numeral value of which is defined when parameters of the mathematical model are identified in real process; $R^{(i,m)}$ is radius of i sublayer of the drum classifier at time moment $T=(m-1)\Delta T$; $m=1,2,...,k$; RB is the drum radius; $RC^{(m)}$ is radius of the center of circulation contour formed by the particles of bulk material in the cross-section of the drum classifier at time moment $T=(m-1)\Delta T$; $m=1,2,...,k$. As the amount of bulk material decreases when it moves to the pouring edge of the classifier, the radius of the center of circulation increases. At the same time the number of sublayers of circulation contour decreases.

From the analysis of dependence (10) it follows that as the distance from the drum shell increases, factor $(R^{(i,m)} - RC^{(m)})/(RB - RC^{(m)})$ decreases and, consequently, the probability of separation of product fraction particles from the mixture decreases.

Simultaneously, the separation of particles of fine fraction occurs. The probability of separating particles of fine fraction from the mixture

$$P_{\text{ot}_1}^{(i,m)} = ER_1(R^{(i,m)} - RC^{(m)})/(RB - RC^{(m)}), \quad (11)$$

where ER_1 is constant coefficient defining the intensity of the separation of particles of fine fraction from the mixture.

The number of fine and product fractions separated from the mixture composition at step m is determined by dependencies

$$V_{\text{ot}_1}^{(i,m)} = V^{(i)}C_1^{(i,m)}P_{\text{ot}1}^{(i,m)}; \quad (12)$$

$$V_{\text{ot}_2}^{(i,m)} = V^{(i)}C_2^{(i,m)}P_{\text{ot}_2}^{(i,m)}. \quad (13)$$

There is a decrease in the volume of sublayers as a result of separating fine and product fractions

$$V^{(i)} = V^{(i)} - \left(V_{\text{ot}_1}^{(i,m)} + V_{\text{ot}_2}^{(i,m)}\right). \quad (14)$$

Concentrations of these fractions can be defined using dependences

$$C_1^{(i,m)} = \left(VK_1^{(i,m)} - V_{\text{ot}_1}^{(i,m)}\right)/\left(V^{(i,m)} - V_{\text{ot}_1}^{(i,m)}\right); \quad (15)$$

$$C_2^{(i,m)} = \left(VK_2^{(i,m)} - V_{\text{ot}_2}^{(i,m)}\right)/\left(V^{(i,m)} - V_{\text{ot}_2}^{(i,m)}\right), \quad (16)$$

where $VK_1^{(i,m)}$, $VK_2^{(i,m)}$ are volumes of fine and product fractions in sublayer i at time moment $T=(m-1)\Delta T$; $m=1,2,...,k$.

In the case of describing the screening process from the fine material to the large one a similar mechanism of separating fine and product fractions from the mixture can be used. A distinctive feature is that in the division of the classifier into two zones fine fracture is separated in the first zone, and product fraction – in the second zone. As a consequence, first the probability of the particles separation is calculated by formula (11), the amount of fine fraction by formula (12), its concentration - by expression (15). Then, in the second section to determine similar characteristics of product fractions dependences (10), (13) and (16) are used.

Thus, from the present mathematical description of the process both the mechanism of segregation of the components and the mechanism of separating the mixture into individual fractions can be seen. The above model concepts can be successfully used to describe the process in drum vibrating screens [13]. The vibration in these devices is a factor intensifying the process of separating the mixture into fractions, which, in turn, leads to an increase in coefficients ER_1 and ER_2 which determine the intensity of separating the particles of fine and product fractions from the mixture.

Conclusion

It should be noted that screening process efficiency essentially depends on the concentration of particles of fine and product fractions in the mixture [12]. According to the results of numerical experiments based on the model description recommendations on the selection method of screening can be made: from the fine material to the large one or from the large material to the fine one.

This study argues that classification includes simultaneous implementation of two oppositely directed processes: mixing and separation of the mixture particles into individual fractions due to sifting through the drum perforation. As a result of mixing there occurs segregation of particles of fine and product fractions. These particles move to the center of circulation, and the outer sublayers of the circulation circuit are depleted of these components.

The process of separation of the particles takes place mainly in the area of the outer sublayers contact with the drum shell. The depletion of these sublayers of particles of fine and product fractions reduces the overall performance of the classifier. In the continuous mode, the intensity of the separation process decreases when the material moves from the loading edge of the drum to its unloading edge. At the same time the concentration of fine and product fractions in the circulation center increases.

Practical value of the proposed mathematical description is the following:

– Firstly, in designing new equipment based on the results of the numerical experiments made using the proposed model representations, rational process mode and geometric parameters of the process can be calculated. This can be justified by the results of the analysis of the efficiency of mixture separation into individual fractions along the length of the classifier. The efficiency of the operating equipment can be also increased based on the results of model calculations, for example, as a result of purposeful correction of the extent of mixture filling and changes in mode parameters.

– Secondly, the radial blades, that periodically destroy segregation core and move fine particles from the circulation center to the screening surface, can be fitted inside the drum [13]. As a consequence of the destruction of the segregation core, the intensity of screening increases. The results of numerical experiments can help to determine the cross-section of the classifier, in which the separation efficiency of fine particles and product fractions from the mixture decreases due to the increased negative effect of segregation. It is in this section of the classifier calculated in advance where the radial blade must be installed.

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Composite Materials for Sorbents, Solar Energy Converters, Supercapacitors and Chemical Sources of Current, Modified with Polyaniline

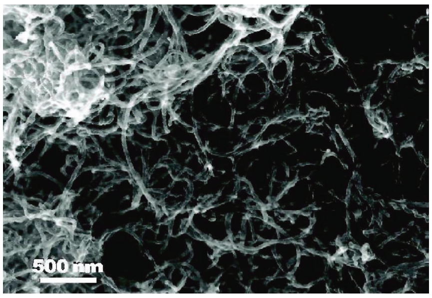
Designated purpose, application area

Nanocomposites based on nanocarbon dispersed carriers and electrically conductive polymers are perspective materials to be applied in different spheres. Since polyaniline adsorbs bacteria and viruses, effective adsorbents for water decontamination, biological fluids and medical bandaging material can be created.

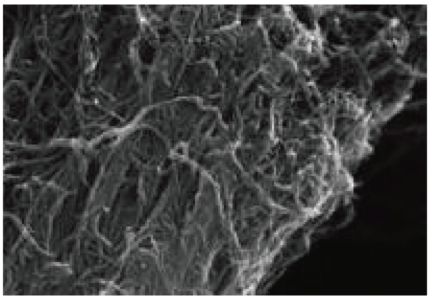
Materials and coatings, absorbing electromagnetic radiation can be produced by combination of polyaniline with other organic and inorganic components. Anti-corrosion properties of polyaniline are noted.

Polyaniline additives of polymer materials give such materials fire resistance. Nanostructured polyaniline materials are used as electrode materials in chemical power sources, photocatalysts, solar energy converters.

Thus, nanostructured materials containing polyaniline, organic and mineral components can have a wide range of application, and, considering the low cost of starting materials, they are economically beneficial. At the same time it is possible to produce multi-functional materials, such as sorbent effective to remove ions of heavy metals, radionuclides, harmful organic compounds, viruses, bacteria from water.



Composite PANI/“Taunit-M”



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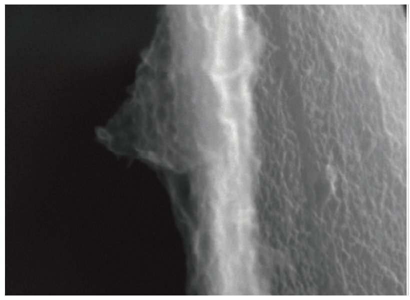

Composite PANI/Graphene

Originality, uniqueness

Developed composites have improved electrochemical stability under repeated recharging for supercapacitors and chemical current sources. **Specifications.** The specific electric capacity up to 500 F/g, keeping for at least 100 charge-discharge cycles. Specific surface area – 200 m^2/g. Stable high electrical conductivity.

Patent documentation

– Patent RF № 2501602 “Complex Granular Nanosorbent”.

– Application RF № 2014145155 “Method of Powder Sorbent Obtaining”.

– Patent RF № 2446188 “Method of Workpieces Preparation for Thermoplastic Polymer Composite Nanomaterials for Processing by Pressure in the Solid Phase”.

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