Chapter 1

The Theory of Random Transformation of Dispersed Matter

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Additional information is available at the end of the chapter

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1. Introduction

The development of civilization, with regard to its consequences, requires appropriate research tools. This is the reason of significant progress in different fields in mathematical modelling of processes involving mass transfer. For their description there are often used widely known models which can be written in a general form of nonlinear differential equations. Woltera [1], who conducted the research of oscillation level of selected fish species in the Adriatic, described the interaction system in the population of predator-victim type. It is compatible with the obtained by Lotka [2] description of the reaction with the expected oscillations in the concentrations of chemical compounds. The process of destruction of organisms during disinfection is included in the model of Chick [3] developed by Watson [4]. The kinetics of the course of simple enzymatic reactions was described by Michaelis and Menten [5]. Mathematical description of the process of microorganisms disintegration in high-pressure homogenizer was developed on the basis of experimental data by Hetherington et al. [6]. After over twenty years since revealing the effect of the position of enzymes in a cell on their release rate [7], Melendres et al. [8] proposed a nonlinear description of the process as a consequence of the following events: cell disruption and release of intracellular compounds. The results of pioneering protease inhibitor therapy in HIV infection were the basis for the development by Ho et al. [9] of a simple model of treatment and solving the mystery associated with the quasi-stationary phase of infection. These models are still used to describe the processes or are often the basis for future studies of more complex mathematical problems.

The essence of all the above processes is random transformation of material objects dispersed in a limited space. Their relationships may help to increase the pace of knowledge development. A uniform theory of the presented issues was developed by Solecki [10]. The common general concept based on the knowledge and understanding of important factors shaping the specified sphere of events will facilitate particularistic analysis as well as transfer of knowledge and experience. The aim of the presented study was to develop a unified theory of the presented issues, allowing for phenomenal and mathematical modeling of various processes based on mass transfer.

2. Paradigm

This section presents a coherent conceptual system of uniform theory which includes various processes of random transformation of dispersed matter in a limited space.

2.1. Space and material objects

Let there be a set N consisting of n elements that are material objects. We assume that n is a natural number.

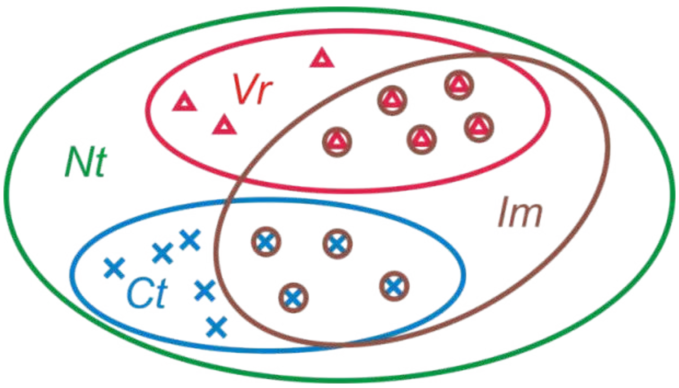

Figure 1. The set of identified properties of a material object belonging to set *N*.

Identified properties of material objects belonging to set N are the elements of set Nt (*notum*) (Fig. 1). The property of an object is the feature which characterizes it. Objects can have χ same properties (ct_1, …, ct_χ) belonging to set Ct (*constans*) which is a subset of set Nt. Objects from set N can differ with ξ properties (vr_1, …, vr_ξ). They belong to set Vr (*variabilis*) which is a subset of identified features of object Nt. We assume that the ψ- th property $vr_{\psi i}$ of any i-th object belonging to set N is included within the range described by the relationship

$$vr_{\psi\,\min} \le vr_{\psi i} \le vr_{\psi\,\max}. \tag{1}$$

Changing the feature of an object belonging to set Vr involves a change of the parameter $vr_{\psi i}$ described by the relationship (1). An object from set N may lose some features from set Vr or Ct. Any element belonging to set N must have all the φ features belonging to set Im (*inamissibilem*). They are the basic features of any object from set N and satisfy the relationship

$$0<\varphi\leq\chi+\xi. \tag{2}$$

Set *Im* is a subset of set *Nt*. We assume that after the loss of at least one basic feature of set *Im* the object is no longer what it was, that is it no longer belongs to set *N*.

Objects from set *N* have limited duration after which they lose at least one basic feature from set *Im* and they do not belong to set *N* anymore.

It is assumed that the fact of existing of objects in set *N* results in a possibility of generating new elements which are objects of set *N*.

Let there be a limited medium of volume *V* described by the relationship according to the equation

$$V=f_1(t). \tag{3}$$

In his medium there is set *N* consisting of *n* dispersed material objects described by the relationship

$$n=f_2(t). \tag{4}$$

We assume that the volume of material object *V* is incomparably greater than volume V_{ni} of any *i*-th object of set *N*, according to the formula

$$V_{ni}<<V. \tag{5}$$

At the initial moment $t_0 = 0$ the number of objects from set *N* dispersed in space *V* amounts n_0, where n_0 is large natural number. We assume that after time Δt the number of objects belonging to set *N* may be changed. Changes may be caused by:

- addition of new objects from the outside to volume *V* – introduction,
- exclusion of some objects from volume *V* to the outside – removal,
- generating new objects resulting from the fact of existing of material objects from set *N* in volume *V* – multiplication,
- natural exclusion of objects from set *N*, resulting from its duration appropriate for the elements of this set, caused by the loss of at least one feature from set *Im* – exclusion.

Change in number of objects belonging to set *N*, resulting from introduction, removal, multiplication and exclusion, described by functions respectively f_{31} (t), f_{32} (n, t), f_{33} (n, t) and f_{34} (n, t), at the moment *t* is described by the relationship consistent with the formula

$$\Delta n_A = f_{31}(t) - f_{32}(n,t) + f_{33}(n,t) - f_{34}(n,t). \tag{6}$$

2.2. Converting of objects

The conditions of the existence of objects in the environment are determined by the interaction of physical, chemical, biological and psychical factors. We assume that for each material object from set N there exists such set of environmental conditions in which there is a loss of ς object properties (ς>0) belonging to set Nt. If at least one of ς lost features belongs to set Im we are dealing with the transformation of an element from set N. In this case the object from set N after the loss of at least one feature from set Im does not belong to set N. A set of environment conditions which may influence the transformation of an object from set N is called transformation conditions. Their intensity, at which the object is transformed, is called transformation intensity and is denoted as Γ_t. Locally occurring environmental conditions of transformation intensity were designated γ_t. The features of an object from subset Ct have no effect on the variation of transformation intensity of material objects. We assume, however, that the combination of ξ features of set Vr affects the value of the smallest transformation intensity γ_{ti} of the i-th object from set N, according to the formula

$$\gamma_{ti} = f_4\left(vr_1, \ldots, vr_\xi\right). \tag{7}$$

If none of ς lost properties by the i-th element belongs to set Im we are dealing with the formation of object from set N. After the loss of features not belonging to set Im an object from set N still belongs to set N. A set of environment conditions which may influence the formation of an object from set N is called formation conditions. Their intensity, at which the object is formed, is called formation intensity and is denoted as T_t. Locally occurring environmental conditions of formation intensity were denoted by τ_t. The features of an object from subset Ct have no effect on the variation of formation intensity of material objects. However, the combination of ξ features of set Vr affects the value of the smallest transformation intensity τ_{ti} of the i-th object from set N, according to the formula

$$\tau_{ti} = f_5\left(vr_1, \ldots, vr_\xi\right). \tag{8}$$

Later in this paper the theory of transforming objects is described. The formation of material objects is an important issue because of the possibility of changing their susceptibility to transformation. The theory of random formation of matter is analogous to the described theory.

2.3. Types of volume

The main parts of space V are volumes $V_{\alpha i}$. Environmental conditions occurring in them are safe for the individual objects from set N. Thus volume $V_{\alpha i}$ is safe for the i-th object from the

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set N. We assume that this volume there is intensive mixing. Its purpose is to homogenise the concentration of objects present in the volume $V_{\alpha i}$.

Volume $V_{\alpha i}$ consists of two parts:

a. $V_{\alpha ci}$ is a part of volume $V_{\alpha i}$, whose subsets are never transformed to other types of volumes,

b. $V_{\alpha ti}$ is a part of volume $V_{\alpha i}$, in which subsets can be transformed to other types of volumes ($V_{\gamma ji}$ and $V_{\beta ji}$).

Between the components of volume $V_{\alpha i}$ for the i-th object there are relationships which are described by the following formula

$$V_{\alpha i} = V_{\alpha ti} \cup V_{\alpha ci} \tag{9}$$

and

$$V_{\alpha ti} \cap V_{\alpha ci} = \varnothing. \tag{10}$$

In the space $V_{\alpha ti}$ there are generated transformation volumes $V_{\gamma ji}$. Possible cases of generating transformation volumes are shown in Figure 2. Volume $V_{\gamma ji}$ is the j-th transformation volume of the i-th material object from set N. We assume that transformation volumes generated for the i-th element are uniformly dispersed in space $V_{\alpha ti}$. Space $V_{\alpha ti}$ is incomparably greater than any j-th volume $V_{\gamma ji}$, which is described by the formula

$$V_{\gamma ji} \ll V_{\alpha ti}. \tag{11}$$

Volume $V_{\gamma ji}$ is limited from the outside with surface $F_{\gamma\alpha ji}$ and from the inside with surface $F_{\gamma\beta ji}$ (Fig. 2). Both surfaces belong to volume $V_{\gamma ji}$ according to the formula

$$F_{\gamma\alpha ji} \in V_{\gamma ji}, \tag{12}$$

and

$$F_{\gamma\beta ji} \in V_{\gamma ji}. \tag{13}$$

Component factors of transformation conditions of the i-th material object can affect it locally or even pointwise. Component factors of transformation conditions of the i-th material object can affect it locally or even pointwise. However, the effects of their action affect the whole object. We assume that the smallest transformation volume of the i-th object is equal to its volume at the moment of transformation and amounts $(V_{\gamma ji})_{min}$ (Fig. 3). Occurring in his volume

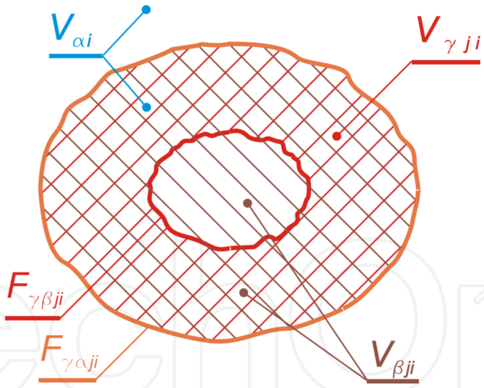

Figure 2. Schematic of formed transformation volume $V_{\gamma ji}$ mach larger then $(V_{\gamma ji})_{min}$: general case.

set of transformation conditions of intensity at least γ_{ti} ensures transformation of the *i*-th object from set *N*. Volume $(V_{\gamma ji})_{min}$ is a value characterizing the *i*-th material object from set *N*.

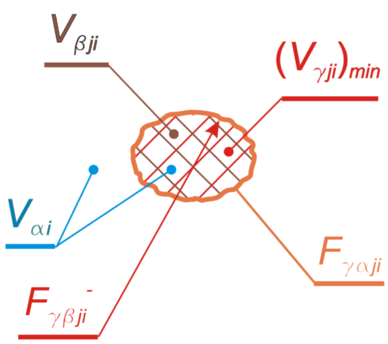

Figure 3. Schematic of formed transformation volume $V_{\gamma ji}= (V_{\gamma ji})_{min}$: special case.

The range of variation of generated in space *V* transformation volume $V_{\gamma ji}$ by the size of the volume is described by the following formula

$$\left(V_{\gamma ji}\right)_{\min} \le V_{\gamma ji} \le \left(V_{\gamma ji}\right)_{\max}, \tag{14}$$

and by the intensity of transformation conditions by a formula

$$V_{\gamma ji(\gamma_t=\gamma_{t\min})} \le V_{\gamma ji(\gamma_t)} \le V_{\gamma ji(\gamma_t=\gamma_{t\max})}. \tag{15}$$

By γ_{tmin} and γ_{tmax} denoted accordingly minimum and maximum intensity of transformation conditions which can be generated in space $V_{\gamma ji}$.

Transformation volume $V_{\gamma ji}$ is generated at time t ($t > t_0$) of process transformation duration. It can exist in any time interval $\Delta t > 0$. In this time interval $V_{\gamma ji}$ can increase; if it is greater than

$(V_{\gamma ji})_{min}$ it can decrease or stay unchanged. It can also be displaced randomly to any available place of volume $V_{\alpha ti}$. In general form $V_{\gamma ji}$ is described by the relationship in the following formula

$$V_{\gamma ji} = \iint_{D_1} \left[f_{61ji}(x,y,\gamma,t) - f_{62ji}(x,y,\gamma,t) \right] dxdy - \iint_{D_2} \left[f_{71ji}(x,y,\gamma,t) - f_{72ji}(x,y,\gamma,t) \right] dxdy \tag{16}$$

of course at the assumptions described by the relationships

$$f_{61ji}(x,y,\gamma,t) \geq 0 \tag{17}$$

and

$$f_{71ji}(x,y,\gamma,t) \geq 0. \tag{18}$$

Flat areas D_1 and D_2 describe relationships defined by formulas respectively

$$y = f_{63ji}(x,\gamma,t) \tag{19}$$

and

$$y = f_{73ji}(x,\gamma,t), \tag{20}$$

the range of changes in x value is described by the relationships defined in the formulas respectively

$$x_{6ji\min} \leq x \leq x_{6ji\max} \tag{21}$$

and

$$x_{7ji\min} \leq x \leq x_{7ji\max}. \tag{22}$$

Inside volume $V_{\gamma ji}$ volume $V_{\beta ji}$ is generated. It is not available for non-transformed i-th object from set N.

Axiom 1.

If linear dimensions of volume $V_{\gamma ji}$ are smaller than doubled linear dimensions of the *i*-th object belonging to set *N*, then the area of $F_{\gamma\beta ji}$ reached by the *i*-th object from the inside does not belong to volume $V_{\alpha i}$ according to

$$F_{\gamma\beta ji}{}^{-} \notin V_{\alpha i}. \tag{23}$$

Since for limit case $(V_{\gamma ji})_{min}$ there is

$$V_{\beta ji} \equiv \left(V_{\gamma ji}\right)_{\min}, \tag{24}$$

that is

$$F_{\gamma\beta ji} \equiv F_{\gamma\alpha ji} \tag{25}$$

then

$$F_{\gamma\alpha ji}{}^{-} \notin V_{\alpha i}. \tag{26}$$

and

$$F_{\gamma\alpha ji}{}^{-} \in V_{\beta ji}. \tag{27}$$

Axiom 2.

If the linear dimensions of the volume $V_{\gamma ji}$ are greater than doubled linear dimensions of the *i*-th object belonging to *N* then area $F_{\gamma\beta ji}$ does not belong to $V_{\alpha i}$ volume according to the formula

$$F_{\gamma\beta ji} \notin V_{\alpha i}. \tag{28}$$

For the case for which occurs a relationship described by a formula (28), volumes closed by area $F_{\gamma\beta ji}$ do not belong to space $V_{\alpha i}$.

Volume $V_{\beta ji}$ is closed by external surface $F_{\gamma\alpha ji}$.

Axiom 3.

If the linear dimensions of the volume $V_{\gamma ji}$ are smaller than doubled linear dimensions of the i-th object belonging to N then area $F_{\gamma\beta ji}$ reached by the i-th object from the inside belongs to $V_{\beta ji}$ volume according to the formula

$$F_{\gamma\beta ji}^{\;-} \in V_{\beta ji}. \tag{29}$$

Axiom 4.

If the linear dimensions of the volume $V_{\gamma ji}$ are greater than doubled linear dimensions of the i-th object belonging to N then area $F_{\gamma\beta ji}$ does not belong to $V_{\beta ji}$ according to the formula

$$F_{\gamma\beta ji} \in V_{\beta ji}. \tag{30}$$

For the case for which occurs relationship described by the formula

$$V_{\gamma ji} > \left(V_{\gamma ji}\right)_{\min}, \tag{31}$$

volumes closed by area $F_{\gamma\alpha ji}$ do not belong to $V_{\beta ji}$ volume according to formula

$$F_{\gamma\alpha ji} \notin V_{\beta ji}. \tag{32}$$

If the linear dimensions of the volume $V_{\gamma ji}$ are equal to the doubled linear dimensions of the i-th object belonging to N then area $F_{\gamma\beta ji}$ may be replaced by a segment (for example for cylindrical surfaces) or even a point (for example for spherical surfaces). They will belong to volume $V_{\beta ji}$ and they will not belong to volume $V_{\alpha i}$.

Volume component of the space V, apart from the above mentioned kinds of volumes, is $V_{\delta i}$. This volume meets the following conditions:

1. is safe for the i-th object from set N,

2. there is not mixing in it,

3. there is a possibility of object migration from volume $V_{\alpha i}$ to $V_{\delta i}$ and vice versa,

4. subsets of this volume are not transformed to other volumes.

We assume that there is a relationship

$$V_{\delta i} < V_{\alpha i}. \tag{33}$$

Volumes $V_{\delta i}$ may be dispersed in space V as volumes $V_{\gamma ji}$.

2.4. Transformation process

We assume that the above described events: introduction, removal, multiplication, and exclusion are not the events of the investigated process of random transformation of dispersed material objects.

In a given material medium V occurs process of random transformation of objects belonging to set N. It runs as follows:

At any moment t ($t > 0$) for the i-th object in space $V_{\alpha ti}$ there are generated randomly p transformation volumes $V_{\gamma ji}$, where p is a natural number. The i-th object belonging to set N is in the space safe volume $V_{\alpha i}$ described by a relationship

$$V_{\alpha i} = \bigcap_{j=1}^{p} V_{\alpha ji}. \tag{34}$$

We assume that random transformation of objects is independent events.

It is assumed that during transformation process the number of produced volumes $V_{\gamma ji}$ is large and may change over time, according to the formula

$$p = f_8(t). \tag{35}$$

Due to relative displacement the i-th material object is introduced for time t_{ti} to appropriate volume for its transformation $V_{\gamma ji}$. This is done by the surface $F_{\gamma\alpha ji}$ which limits volume $V_{\gamma ji}$ (Fig. 2 and 3). The considered element of set N remains unconverted if at least its one point is beyond volume $V_{\gamma ji}$. Transformation of the i-th object occurs simultaneously with its complete introduction to transformation volume $V_{\gamma ji}$. According to the conditions given in Section 2.2 transformation occurs when at least one of the ς features belonging to set Ba is lost. Only transformed in volume $V_{\gamma ji}$ i-th object may be dislocated to volume $V_{\beta ji}$.

Theorem about transformation of dispersed matter:

For each material object n_i from set N there exist such local conditions of transformation γ_{ti} belonging to set Γ_t, that if there is time t_{ti}, in which object n_i is included in volume $V_{\gamma ji}$ of transformation properties γ_{ti} then starting from time t_{ti} object n_i does not belong to set N.

This theorem recorded by means of quantifiers has the following form:

$$\left(\forall n_i \in N\right)\left(\exists \gamma_{ti} \in \Gamma_t\right)\left(\left(\exists t_t\right) n_i \subset V_{\gamma ji} \Rightarrow \left(\forall t \geq t_t\right) n_i \notin N\right), \tag{36}$$

and its falsification is included in the record

$$\left(\forall n_i \in N\right)\left(\exists \gamma_{ti} \in \Gamma_t\right)\left(\left(\exists t_t\right) n_i \subset V_{\gamma ji} \Rightarrow \left(\forall t \geq t_t\right) n_i \in N\right). \tag{37}$$

Proof of the theorem

The properties of an object from set N belonging to set Ba (Fig.1) are marked by ba. The relationship is introduced

$$Z_1(n;ba) \tag{38}$$

which expresses the statement that object n has the property ba. We can record the following observations:

object n_i has all the properties ba from set Ba

$$(\forall ba \in Ba)\left(Z_1\left(n_i;ba\right)\right), \tag{39}$$

and there is a property ba, which object n_i does not have

$$(\exists ba \in Ba)\left(\neg Z_1\left(ba;n_i\right)\right). \tag{40}$$

Let N be the set of all elements fulfilling condition $W(n)$ described by a logical statement (39)

$$\{n_i \in N : ((\forall\ ba \in Ba)(Z_1(n_i;ba)))\}. \tag{41}$$

The relationship is introduced

$$Z_2(V_\gamma;\gamma_t) \tag{42}$$

expressing the statement that volume V_γ has the property γ_t of object transformation n. We can write the following observation:

object $V_{\gamma ji}$ has got a property γ_{ti} of object transformation n_i

$$(\exists \gamma_{ti} \in \Gamma_t)\left(Z_2\left(V_{\gamma ji};\gamma_{ti}\right)\right). \tag{43}$$

Let P be the set of all elements fulfilling the condition $W_2(V_{\gamma ji})$ described by a logical statement (39)

$$\{V_{\gamma ji} \in P : ((\forall\ ba \in Ba)(Z_1(n_i;ba)))\}. \tag{44}$$

Let t_{ti} denotes time in which object n_i was introduced to volume $V_{\gamma ji}$. From the moment t_{ti} is true the statement about object n_i

$$\left(\forall t \geq t_{ti}\right)\left(\exists ba \in Ba\right)\left(\neg Z_1\left(ba; n_i\right)\right). \tag{45}$$

It is contrary to the assumption (31) so that from the moment t_{ti} the object n_i cannot be the element of set N according to

$$n_i \notin N \blacksquare. \tag{46}$$

Theorem about creating families of transformation volumes

If at any point 2 belonging to space $V_{\alpha ti}$ environmental conditions of the transformation would function γ_{t2} and in set N there would be r objects of the transformation conditions γ_{ti} fulfilling the relations

$$\gamma_{t2} \geq \gamma_{ti} \tag{47}$$

Then in point 2 there will be generated family consisting of r transformation volumes for r objects from set N.

Conclusions:

1. If set N consists of n elements and conditions of transformation γ_{ti} of any element from set N satisfy the relation

$$\gamma_{tmin} \leq \gamma_{ti} \leq \gamma_{tmax} \tag{48}$$

then the family can include from 1 to n transformation volumes.

2. If in any point 2 belonging to space $V_{\alpha ti}$ would function conditions of transformation γ_{t2} fulfilling the relationship

$$\gamma_{t2} < \gamma_{tmax} \tag{49}$$

and in set N there would exist s objects of transformation conditions greater then γ_{t2} then in space V there are s objects from set N which are not subjected to transformation in point 2.

Volume $V_{\gamma ji}$ is a transformation volume of the i-th material object which belongs to j-th family.

3. General phenomenological model

Figure 4 shows the general set of possibilities for generating volumes associated with the transformation of objects from set N distributed in space $V(t)$. Each vertical segment with the opposite ends located on segments AB and CD denotes space $V(t)$. On each subsequent vertical section there are marked up divisions of volume V in result of generated one transformation volume. The whole rectangle ABCD includes a set of all possible divisions of space V according to one defined system.

For any i-th object from set N rectangle ABCD is divided into five parts with four segments. The first part, contained between segments LM (marked with blue dashed line) and IJ (marked with red dashed line) is a set of possible volumes $V_{\alpha ji}$. From the bottom a single volume $V_{\alpha i}$ is limited by surface $F_{\gamma\beta ji}$. Depending on the size of generated volume $V_{\gamma ji}$ this surface according to formula (23) conditionally does not belong or according to formula (28) at all does not belong to volume $V_{\alpha i}$. Space $V_{\alpha i}$ is safe for both the i-th object and other objects from set N of the smallest transformation volume not greater than that which is appropriate for the i-th object. In volume $V_{\alpha ji}$ takes place intensive mixing. Its purpose is to homogenize the dispersion of objects present in it.

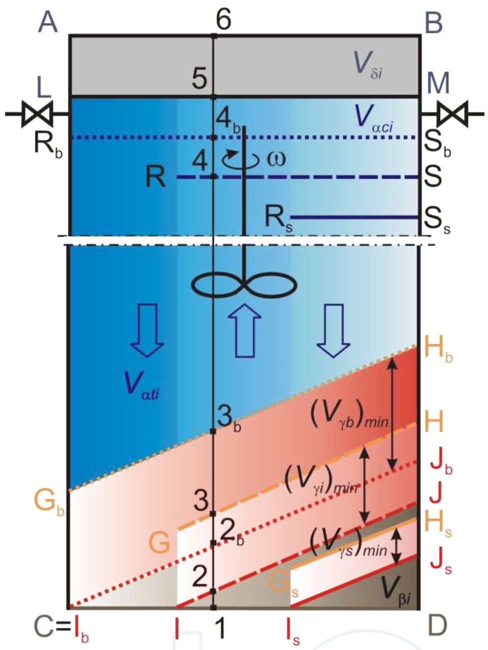

Figure 4. General set of space divisions $V(t)$ resulting from generating volume $V_{\gamma ji}$ for one hypothetical generating system.

In Figure 4 the area included between segments GH (marked with orange dashed line) and IJ (marked with red dashed line) is a set transformation volumes that can be generated. Single volume $V_{\gamma ji}$ is limited by surfaces: $F_{\gamma\alpha ji}$ from the top and $F_{\gamma\beta ji}$ from the bottom. Both these surfaces belong to volume $V_{\gamma ji}$, which is the result of assumptions accepted in formulas (12) and (13). In volume $V_{\gamma ji}$ occurs a transformation if the i-th object and other objects from set N of minimal transformation volume in accordance with that which is appropriate for the i-th object i.e. $(V_{\gamma i})_{min}$. During the process at time t there are p transformations volumes of the i-th object according to relationship (34) are they are uniformly dispersed in space $V_{\alpha ti}$. The size of the volume $V_{\gamma ji}$ in Figure 4 is defined by two parameters: $(V_{\gamma ji})_{min}$ and red colour intensity. The parameter – red colour intensity is a visualization of functional dependence.

Another area in Figure 4, contained between segments GH (marked with orange dashed line) and CD (marked with brown solid line) is a set of volumes $V_{\beta ji}$. Such single volume is limited by surface $F_{\gamma\alpha ji}$. Depending on the size of generated volume $V_{\gamma ji}$ this surface according to (27) conditionally belongs to $V_{\beta ji}$ or according to formula (32) does not belong to $V_{\beta ji}$. During the process at time t volume $V_{\beta ji}$ is no more than p. They are linked to appropriate volumes $V_{\gamma ji}$ and dispersed in space $V_{\alpha ti}$. In volume $V_{\beta ji}$ the existence of unconverted objects from set N is impossible, for which minimal transformation volume is not smaller than minimal transformation volume appropriate for the i-th object. The size of the volume $V_{\beta ji}$ in Figure 4 is defined by two parameters: vertical segment with ends located on segments GH and CD and brown colour intensity. The consequence of increasing volume $V_{\gamma ji}$ is increased volume $V_{\beta ji}$ and decreased volume $V_{\alpha ti}$. The size of volume $V_{\alpha ti}$ in Figure 4 is defined by two parameters: vertical segment with ends located on segments RS and IJ and blue colour intensity.

Between segment AB and segment LM there is volume $V_{\delta i}$.

Division of vertical segment 16 reflects the division of space V which appears after generation of the j-th volume for the i-th object n_i:

- segment $\langle 1, 3)$corresponds to volume $V_{\beta ji}$,
- segment $\langle 2, 3\rangle$ corresponds to volume $V_{\gamma ji}$,
- segment $(2, 4\rangle$ corresponds to volume $V_{\alpha tji}$,
- segment $(4, 5\rangle$ corresponds to volume $V_{\alpha cji}$,
- segment $(5, 6\rangle$ corresponds to volume $V_{\delta i}$.

In Figure 4, as for the i-th object, it is possible to determine components of space volume V for the objects of the highest and smallest transformation volume marked $(V_{\gamma b})_{min}$ and $(V_{\gamma s})_{min}$ respectively.

Between segments AC and BD it is possible to lead infinite number of vertical lines. Their division into sections, presented above, describes the field of possibilities of generation, in space V, the transformation volume $V_{\gamma ji}$ and connected with them volumes $V_{\beta ji}$. For segment AC transformation volumes are generated according to Figure 3. The divisions are on the right side of Figure 4 together with the segment BD is the general case shown in Figure 2.

At any moment of the transformation process in volume V a finite number transformation volume is generated.

Phenomenological model of random transformation of dispersed matter is constructed as follows:

1. The possibilities of generating transformation volumes in space V are shown on the system map appropriate for the given transformation process which is analogous to that presented in Figure 4. In space V transformation volumes according to many system maps can be generated simultaneously.

2. Phenomenological model consists of p layers formed by p transformation volumes generated at a given moment in volume V according to system maps.
3. The model is constructed in such a way that the sum of sets of all volumes is equal to V. The sum of all volumes safe for the i-th objects located above the generated in a given moment its transformation volume is equal to $V_{\alpha i}$, according to the equation (33).
4. Material objects belonging to set N, in space $V(t)$, were reduced to a point. One of their features is volume V_{ni}. On system maps (Fig. 4) and in the phenomenological model the size of volume is defined by vertical segments, so the i-th object will be a vertical segment of the length corresponding to volume $(V_{\gamma ji})_{min}$. This object can be displaced in space $V_{\alpha i}$ and $V_{\delta i}$ till the transformation moment in volume $V_{\gamma ji}$.

4. General mathematical model

In general, the concentration of elements of set N in volume $V(t)$ is determined by the number of not transformed objects n per volume V according to the formula

$$S(t) = \frac{n(t)}{V(t)}. \tag{50}$$

At the initial moment $t_0 = 0$ it will amount

$$S_0 = \frac{n_0}{V_0}. \tag{51}$$

We assume that for the process duration moment $t_0 = 0$ in space V volumes $V_{\gamma ji}$, $V_{\beta ji}$, $V_{\alpha i}$ and $V_{\delta i}$ are generated. Not transformed i-th object can occur only in the appropriate volumes $V_{\alpha i}$ and $V_{\delta i}$. From formulas (1) and (7) results the relationship between the volumes for the individual objects from set N (Fig. 4) given in the formula

$$V_{\alpha b} \subset \ldots \subset V_{\alpha i} \subset \ldots \subset V_{\alpha s}. \tag{52}$$

For relationship (52) equivalence

$$\left(V_{\gamma s}\right)_{\min} = \left(V_{\gamma b}\right)_{\min} \Leftrightarrow V_{\alpha s} = V_{\alpha b} \tag{53}$$

or

$$\left(V_{\gamma s}\right)_{\min} \langle \left(V_{\gamma b}\right)_{\min} \Leftrightarrow V_{\alpha b} \langle V_{\alpha s} \tag{54}$$

can be true. In the case included in formula (53) in the whole volume V_α defined by formula

$$V_\alpha = \bigcup_{i=1}^{n} \bigcap_{j=1}^{p} V_{\alpha ji} \tag{55}$$

occurs uniform dispersion of the elements of homogeneous set N. However, from the given in formula (54) alternative equivalence result the uneven dispersion of inhomogeneous objects from set N in volume V_α. Each object n_i characterized by feature vr_i which distinguishes it from other objects from set N results in introduction of the additional area $F_{\gamma\beta i}$ (Fig. 2 and 3). Each additional area $F_{\gamma\beta i}$ introduced in space V divides volume set V_α (Fig. 4). The resulting parts can differ with the concentration of the objects contained in them. The process of ideal mixing ensures homogeneity of the dispersion only within a volume limited by neighboring areas e.g. $F_{\gamma\beta(i-1)}$ and $F_{\gamma\beta i}$, $F_{\gamma\beta i}$ and $F_{\gamma\beta(i+1)}$. In the case covered by formula (54) due to the relationships given in formulas (5) and (11) as well as uniform dispersion of volume V_γ in space $V_{\alpha t}$ we can use average concentration of dispersed material objects. Thus, after starting the process, to the generated volumes $V_{\gamma ji}$ there will be introduced randomly appropriate objects n_i of set N dispersed in volume V_α. Elements from set N being in volumes $V_{\delta i}$ do not participate directly in the transformation process. In moment $t_0 = 0$ of process duration the number of unconverted objects $n(t)$ in volume V_α is defined by the equation

$$n_{\alpha 0} = n_0 - n_{\delta 0} \tag{56}$$

Average concentration of untransformed objects in volumes occupied by them volume V_α is described by formula

$$\left(\overline{S_\alpha}\right)_{t_0=0} = \frac{n_{0\alpha}}{V_\alpha} \tag{57}$$

where $n_{\delta 0}$ denotes initial number of elements from set N in volumes $V_{\delta i}$. Number of objects which were transformed n_{d0} for time t_0 is defined by the formula

$$n_{d0} = 0 \tag{58}$$

The degree of objects transformation $X(t)$ determined by the quotient of the number of transformed objects n_d to the initial number of unconverted objects n_0 for t = 0 equals 0, according to the formula

$$X = \frac{n_{d0}}{n_0} = 0. \tag{59}$$

At any moment of process duration t the number of transformed objects amounts $n_d(t)$. Converted objects may be located in any place of volume V. The number of unconverted objects, being exclusively in volume V_α, is defined by the difference of the initial number of objects $n_{\alpha 0}$ and converted objects n_d after time t of process duration corrected by a number of objects transferred between volumes $V_{\alpha i}$ and $V_{\delta i}$ and the number of objects described by the formula (6), which is described by equality

$$n_\alpha = n_{0\alpha} - n_d + n_{\delta\alpha} - n_{\alpha\delta} + \Delta n_A, \tag{60}$$

where:$n_{\delta\alpha}$ – means number elements of set N transferred from volume $V_{\delta i}$ to $V_{\alpha i}$,

$n_{\alpha\delta}$ – means number of elements of set N transferred from volume $V_{\alpha i}$ do $V_{\delta i}$.

After time t of process duration, to transformation volumes $V_{\gamma ji}$ there are introduced untransformed objects of average concentration $\left(\overline{S_\alpha}\right)_t$ defined by the number of unconverted n_α, per volume V_α. This is shown in formula

$$\left(\overline{S_\alpha}\right)_t = \frac{n_\alpha}{V_\alpha}. \tag{61}$$

Of course general concentration of unconverted objects in volume V will be defined by the relationship

$$S = \frac{n}{V}, \tag{62}$$

where

$$n = n_\alpha + n_\delta. \tag{63}$$

It will be shown, for example, after stopping the process. The degree of transformation of objects after time t of the transformation process is described by the formula

$$X = \frac{n_d}{n_0 + \Delta n_A}. \tag{64}$$

The increase of transformed objects dn_d in all transformation volumes $V_{\gamma ji}$ after the lapse of any small time interval dt is defined by the formula

$$dn_d = \left(\overline{S_\alpha}\right)_t dV. \tag{65}$$

The external area limiting the generated for the i-th object the j-th volume $V_{\gamma ji}$, consists of active and inactive part. Through the active part there can be introduced or removed the i-th element of set N while the inactive part is not available for such transfer. The active part of the surface is divided into surface $F_{\gamma\alpha\rightarrow}$, through which the i-th object can be introduced to $V_{\gamma ji}$ and surface $F_{\gamma\alpha\leftarrow}$, through which the transformed or not transformed i-th object can be introduced from $V_{\gamma ji}$ according to the formula

$$F_{\gamma\alpha ji} = F_{\gamma\alpha ji\rightarrow} + F_{\gamma\alpha ji\leftarrow}. \tag{66}$$

The sum of surfaces limiting the transformation volumes $V_{\gamma ji}$ generated in space V for the i-th object is described by the formula

$$F_{\gamma\alpha i} = \sum_{j=1}^{p} F_{\gamma\alpha ji}. \tag{67}$$

The sum of surfaces limiting the volumes $V_{\gamma ji}$ generated in space V for all objects form set N is described by the formula

$$F_{\gamma\alpha} = \sum_{i=1}^{n}\sum_{j=1}^{p} F_{\gamma\alpha ji}. \tag{68}$$

Volume dV displaced from space $V_{\alpha ji}$ to volume $V_{\gamma ji}$ in time increase dt depends on the size of limit area $F_{\gamma\alpha\rightarrow}$, through which dV is displaced from volume $V_{\alpha ji}$ to volume $V_{\gamma ji}$ and on the average speed of its displacement u, according to the formula

$$dV = uF_{\gamma\alpha\rightarrow}dt. \tag{69}$$

After substituting equations (61) and (69) to equation (65) we get the equation

$$dn_d = k\left(n_\alpha\right)dt \tag{70}$$

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describing the increase of objects transformed in generated volumes $V_{\gamma ji}$. Process rate constant k is described by the relationship

$$k = \frac{F_{\gamma\alpha\rightarrow}}{V_\alpha} u. \tag{71}$$

According to formulas (16), (19) and (20) parameters $F_{\gamma\alpha\rightarrow}$ and V_α depend on time t. Dislocation rate u can also be a function of process duration

$$u = f_9(t). \tag{72}$$

On the basis of formula (70) the loss of unconverted objects in set N can be expressed by the equation

$$dn = -k\left(n_\alpha\right)dt. \tag{73}$$

After substituting (60) to the relationship (73) we get

$$dn = -k\left(n_{0\alpha} - n_d + n_{\delta\alpha} - n_{\alpha\delta} + \Delta n_A\right)dt. \tag{74}$$

The total balance of the loss of objects dn_d in time interval dt will be equal on the right side of the formula (74) with the opposite sign

$$dn_d = k\left(n_0 - n_d + n_{\delta\alpha} + n_{\alpha\delta} + \Delta n_A\right)dt. \tag{75}$$

In case

$$\Delta n_A = 0 \tag{76}$$

the relationship (76) will be simplified to

$$dn_d = k\left(n_0 - n_d\right)dt. \tag{77}$$

After separation of variables in equation (77) and integration of both sides we get the relationship

$$\ln\left(\frac{n_0}{n_0 - n_d}\right) = kt, \tag{78}$$

often used to describe the kinetics of the course of transformation of various material objects. In case of homogeneity of set *N* (*Vr* is an empty subset) relationship (78) is a final description of the transformation process. Let's consider the case when the object of set *N* differ with only one feature vr_1, which has a considerable effect on the course of the process. In order to analyse it, the whole range of changes should be divided into *m* such intervals in which changes in features have no significant effect on the course of the process. Then the course of transforming objects from any interval ζ - th such that

$$\zeta \in \langle 1, m \rangle, \tag{79}$$

describes the relationship

$$\frac{n_{0\zeta}}{n_0} dn_{d\zeta} = \frac{n_{0\zeta}}{n_0} k_\zeta \left(n_{0\zeta} - n_{d\zeta}\right) dt \tag{80}$$

taking into account the existence of a whole set *N*.

Description of the transformation of the entire set of objects including the division of set *N* into intervals is described by the relationship

$$\sum_{\zeta=1}^{m} \frac{n_{0\zeta}}{n_0} dn_{d\zeta} = \sum_{\zeta=1}^{m} \frac{n_{0\zeta}}{n_0} k_\zeta \left(n_{0\zeta} - n_{d\zeta}\right) dt. \tag{81}$$

After the separation of variables (80) and integration of both sides we get

$$\sum_{\zeta=1}^{m} \frac{n_{0\zeta}}{n_0} \ln \frac{n_{0\zeta}}{n_{0\zeta} - n_{d\zeta}} = \sum_{\zeta=1}^{m} \frac{n_{0\zeta}}{n_0} k_\zeta t. \tag{82}$$

Relationship between speed constants in equations (77) and (80) is defined by a formula

$$\Phi \sum_{\zeta=1}^{m} \frac{n_{0\zeta}}{n_0} k_\zeta = k. \tag{83}$$

Coefficient Φ describes the relationship

$$\Phi = \ln\frac{n_0}{n_0 - n_d}\left(\sum_{\zeta=1}^{m}\frac{n_{0\zeta}}{n_0}\ln\frac{n_{0\zeta}}{n_{0\zeta} - n_{d\zeta}}\right)^{-1}. \tag{84}$$

5. Examples of application

The technological process based on the theory of random transformation of dispersed matter is the disintegration of microbial cells. At present many compounds coming from the inside of the microorganism cells have commercial application. They are used among others in the food, pharmaceutical, cosmetic, chemical industry as well as medicine and agriculture. In order to isolate the desired compounds it is usually necessary to destroy the cell walls and cytoplasmic membranes. The process of disintegration of microorganisms is carried out by different methods: physical, chemical and biological.

The technical means used to implement the process on an industrial scale are bead mills and high pressure homogenizers. On a laboratory scale there are often used vibrating mixers, ultrasonic homogenizers and enzymatic methods. All the listed methods of the process involve the random effects of the factor which destroys the cell walls of microorganisms dispersed in the liquid. The difference between them depends mainly on the method of generating the transformation volume of dispersed matter.

During the disintegration of microorganisms the suspension occupies volume V. It is constant in time. The process is carried out usually for the optimal initial concentration of biomass. The initial number of microorganisms is determined n_0. We consider the case of batch operation (constant charge). During the process microorganism cells are not added from the outside (we assume the sterility of conditions of disintegration) nor are they removed outside. The process duration compared to the lifetime of microorganisms and the time needed to form new cells is very short. So it can be assumed that the change in the number of objects described by the formula (6) satisfies the relationship (76).

In the case of disintegration of microorganisms in of bead mills the transformation consists in the disruption of microbial cell walls. Destruction volumes $V_{\gamma ji}$ are generated by circulating filling beads. To carry out the process in the bead mill, high degree of filling the working chamber with beads and high rotational speed of the agitator are applied. It can be assumed that at any time during the process for fixed working conditions number p (Eq. (35)) is constant in time and its value is high. Thus the relations given in the formulas

$$\sum_{j=1}^{p} V_{\gamma ji} = const, \tag{85}$$

$$\sum_{j=1}^{p} V_{\beta ji} = const \tag{86}$$

are fulfilled.

General diagram of cell disruption between the spherical surfaces is shown in Figure 5. It concerns the range of the distribution of suspension volume V to $V_{\alpha ji}$, $V_{\gamma ji}$ and $V_{\beta ji}$ shown on the right in Figure 4 in the area adjacent to the segment BD. Volumes $V_{\alpha c}$ occur close to the inside surface of the mill chamber in the case when filler elements have a diameter substantially greater than the dimensions of the cells of microorganisms. In a bead mill volumes $V_{\alpha c}$ occur at all surfaces of the working chamber and agitator. They are distant by a distance similar to the size of the largest cells and the thickness of their layer is slightly smaller than the radius of the smallest filling beads. In these volumes cells are never disrupted.

For a properly constructed mill chamber volumes V_{δ} (may be slots at the interface between two structural elements) are negligibly small and insignificant in terms of technology, especially when conducting sterilization of equipment between the processes. In the analyzed case it was assumed that disintegrated microorganisms have an ellipsoidal shape. After the limit deformation of the *i*-th cell, its walls are disrupted. (Fig. 5). The generated transformation volume $V_{\gamma ji}$ is limited by surfaces: active $F_{\gamma\alpha ji}$ (orange dashed line), $F_{\gamma\beta ji}$ (red dashed line) and two inactive spherical of filling elements. Limiting surfaces $F_{\gamma\alpha ji}$ and $F_{\gamma\beta ji}$ belong to volume $V_{\gamma ji}$. Its axis of symmetry is axis OO. To the presented in Figure 5 volume $V_{\alpha i}$, in which *i*-th living cell can be present, does not belong the volume limited by two spherical surfaces and surface $F_{\gamma\beta ji}$. Straight line OO is a symmetry axis of this volume. Surfaces limiting volume $V_{\alpha ji}$ do not belong to it. The volume unavailable for the living *i*-th cell $V_{\beta ji}$ is limited by two spherical surfaces and surface $F_{\gamma\alpha ji}$. Limiting surfaces do not belong to $V_{\beta ji}$. The axis of symmetry of volume $V_{\beta ji}$ is also straight line OO. In the special case the line dividing volume V in an AC position (Fig. 4), there is generated volume $(V_{\gamma ji})_{min}$ shown in Figure 6. It is limited by two spherical surfaces and active surface $F_{\gamma\alpha ji}$ (orange dashed line). Volume symmetry axis $(V_{\gamma ji})_{min}$ passes through points O and O. Surface $F_{\gamma\alpha ji}$ does not belong to generated volume $V_{\beta ji.}$ If all points of the *i*-th object are not introduced to $(V_{\gamma ji})_{min}$ it will not be transformed.

For monogenic set N (Vr is an empty subset) cell disintegration process, taking into account the above assumptions, is described by differential equation (77). The case when the objects of set N differ with only one feature vr_1 that has a significant impact on the course of cell disruption is included in equation (80) and (81). The process of release of intracellular compounds, using the theory of transformation of dispersed matter, has been widely described by Heim at all [12], Heim and Solecki [13] as well as Solecki [10 and 14]. These works included more complex cases of the course of the process, causes of nonlinearity of kinetics were given, and the effect of concentration of microorganism suspension was explained as well as disappearance of the largest size fraction during the process for very low concentrations of the suspension.

There are many devices implementing the process of disintegration of microorganisms due to critical stresses in the cell walls caused by stress in the liquid. Best known are: high pressure homogenizers [6, 15-18], French press [19], Ribie press [20], Chaikoff press [21]. The technical method of process realization in the above mentioned equipment is similar and consists in disruption of microorganisms during pumping suspension through a valve under high pressure. High performance in continuous operation and fairly wide range of diversity of disintegrated microorganisms made that high pressure homogenizers are widely used on a

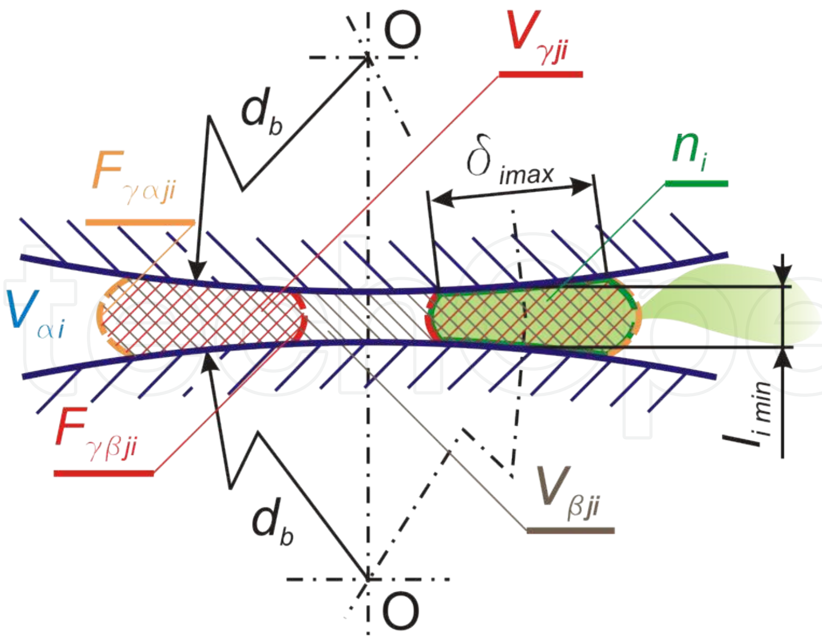

Figure 5. Model of cell disruption during non-axial hitting with spherical elements – general case [10].

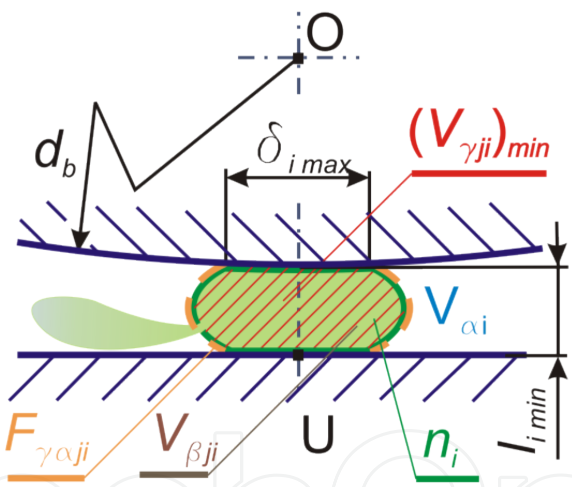

Figure 6. Model of cell disruption during axial hitting with spherical element and plane – special case [14].

technical scale. The general model of disintegration of mechanisms, developed by Hetherington et al. [6], and then modified by Sauer et al. [15] is included in a formula

$$\ln\left(\frac{R_m}{R_m - R}\right) = k N^{b_2} P^{b_1}, \tag{87}$$

where: R concentration of released proteins [mg/g],

R_m - maximum concentration of released proteins; [mg/g],

k - process rate constant; [1/s],

N - number of suspension passage cycles through homogenizer; [-],

P - suspension pumping pressure, [MPa].

b_1 - exponent depending on the type of microorganisms and their growth conditions; [-],

b_2 - exponent including the effect of suspension concentration on the course of the process; [-].

Pumping pressure of the suspension of microorganisms is within the range from 50 to 120 MPa. Transformation volumes $V_{\gamma ji}$ are generated, according to the results of research conducted by Keshavarz Moore at al. [16] and Engler [17] on the cell disruption mechanism, in homogenization zone within the valve unit and with the impingement in the exit zone. The results of research conducted by Lander at al. [18] showed that disruption of cells is mainly due to shearing of the liquid in the valve unit and as a result of cavitation occurring in the impingement section, where the stream of suspension hits the impact ring and follows an implosion of bubbles caused by the increased pressure.

High-frequency ultrasounds (in the supersonic wavelength range 15 - 25 kHz) are used for disruption of dispersed in a liquid microbial cells and releasing contained in them intracellular compounds [22-25]. The mechanism of microorganisms disintegration is associated with the occurrence of cavitation induced by ultrasound and hypothetically runs as follows:

1. Passing sound wave causes the thickening and thinning of the liquid.

2. During the thinning of the liquid occurs nucleation and growth of gas and vapor bubbles.

3. During the thickening of the liquid bubble implosion occurs at a rate not less than the speed of sound (hence the loud roar accompanying cavitation).

4. Bubbles which are not adhering to the cells of microorganisms are sinking evenly in all directions. Bubbles adhering to cells are sinking from the free side so that the surface of the liquid with a powerful force strikes the cell wall breaking it and releasing intracellular compounds. The striking force may be so powerful that the released compounds are often destroyed and free radicals are formed.

Daulah [22], using the theory of local isotropic turbulence Kolmogorov [26 and 27], presented a description of the process of ultrasonic disintegration of cells of baker's yeast as a model

$$1 - S_p = \exp(k \cdot t), \tag{88}$$

where: S_p – concentration of released proteins, [g/kg]

t – duration of the process; [min],

k – process rate constant; [1/min].

Dependence of constant k on energy dissipation P_d is described by the relationship

$$k = \zeta \cdot \left(P_d - P_c\right)^{0,9} \tag{89}$$

where: ζ - constant; [kg/J],

P_c - threshold energy dissipation ensuring occurrence of cavitation; [J/kgs].

Confirming the above results experimentally for brewing yeast showed no effect of suspension concentration on constant k and its proportionality to the energy dissipation level [25].

The process of disinfection consists in an impact of physical or chemical agents in a limited gas, liquid or solid medium on biological contaminants. They may be it viruses, bacteria and their spores, protozoa and their cysts and eggs of parasites. The purpose of disinfection is to destroy the above mentioned objects and to prevent in a required, limited period of time their re-growth. The disinfectants selected according to pathogens cause: an irreversible destruction of cells, disruption of metabolic processes, disruption of biosynthesis and growth. An example of such process is chemical disinfection of water [28]. Its kinetics is often described by Chick's model [3] in form of equation (77). The dependence of the rate constant

$$k = AC^s t \tag{90}$$

taking into account the disinfecting power coefficient A and the concentration of disinfectant C was given by Watson [4]. Exponent s is dependent on the type of disinfectant and medium's pH.

The developed theory can be used to model the impact of population of predator-prey or competition type. If we assume that:

- change objects from the set of N (f_{31} from Eq. (6)) in equation (75) is described under the law of Malthus by the formula

$$f_{31} = a_1 N \tag{91}$$

- rate constant from equation (75) will be marked as k_γ and is written in the form

$$k_\gamma = a_2 P, \tag{92}$$

directly dependent on the generated families of transformation volume (see formula (71)),

- unconverted objects N cause an increase in the families of transformation volume of families in the form of $a_3 NP$,

in the absence of objects N (N is an empty set), there is an exponential decrease in the number of families of transformation volume – $a_4 P$, the received equations in the form

$$dN = N\left(a_1 - a_2 P\right)dt \tag{93}$$

and

$$dP = P\left(a_3 N - a_4\right)dt \tag{94}$$

are a model for predator-prey for the Lotka-Volterra system [1 and 2]. The coefficients a_1, a_2, a_3 and a_4 are constants with positive values.

On the basis of the presented theory it is possible to build other more realistic models of predator-prey system taking into account e.g. natural selection, nutrient profile, the effect of age on the activity of predators and many other factors. It is also possible to model chemical reactions, and assuming the generation in space V of different types of transformation volume, including reversible transformation, enzymatic reactions can be modeled [5].

The theory can be used to study and model the action of immune system [10]. It can also be employed in constructing artificial immunology and controlling the support of various therapies. Simple applications cover responses of the immune system to viral, bacterial, fungal and parasitic infections. The immune response depends on the type, properties, portal of entry and severity of infection and the state of organism. Application of the theory is illustrated by viral infection. Virus replication in the host cells in space V is represented by the function in Eq. (6). The aim of an immune response is to inhibit virus replication in the cell and its spread to other cells. Next goals include the elimination of transformed objects from the organism and development of long-lasting immunity. Initially, transformation volumes $V_{\gamma ji}$ are formed as a result of action of the complement system, interferon (IFN) and natural killer cells (NK) within non-specific anti-viral response. At the next stage, neutralizing antibodies, mainly of class IgG (immunoglobulin G), prevent infection of other cells. Their fragment Fab (fragment antygen binding) binds to antigens of the virus, while fragment Fc (fragment crystallizable) to relevant receptors on NK cells, macrophages and others. This enables phagocytosis and cellular cytotoxicity dependent on antibodies, but probably also immediate destruction with the use of the complement system. In the case of infections through mucous membranes of the intestinal tract and respiratory system the same role is played by IgA (immunoglobulin A) antibodies. In development of humoral immune response the active role is played by $CD4^+$ lymphocytes. In this case antigen proteolysis occurs in endosome. Cytotoxic $CD8^+$ lymphocytes play the crucial role in the response to viral infections. They function inside the cells. They recognize a viral antigen on cells transformed by the infection in association with MHC (major histocompatibility complex) class I molecules. In the infected cells, cytotoxic lymphocytes can induce a synthesis of nucleases destroying genetic material of the virus and enhance IFN synthesis. Responses of the immune system occurring at subsequent stages of antigen destruction according to different mechanisms can be described by the relation analogous to Eq. (81).

Many pathogens developed such properties which allow them to avoid non-specific and specific immune response. High variability of a pathogen caused by differences in the gene sequence region leads to a delay of specific immune response. This is so in the case of influenza, hepatitis C and HIV (human immunodeficiency virus) viruses. Ho et al. [9] studied the effects of HIV treatment with inhibitors. A linear model based on experimental data in the form concordant with Eq. (77) well described the healing process at the first stage of the therapy. At the final stage, however, control over the virus population was lost due to multiplication of drug-resistant strains. A result of genetic modifications is the formation of virus mutations in transformation conditions γ_{lb} resulting from their properties which belong to set Pr. In volumes $V_{\gamma ji(\gamma<\gamma_{lb})}$ formed by the drug, the concentration of transformation conditions γ is smaller than that required for the transformation of so mutated viruses. Similar effects are observed in presently used, much more efficient highly active antiretroviral therapy (HAART). It includes the interactions of protease inhibitors combined with reverse transcriptase inhibitors. A mathematical model of the combined therapy was developed by Perelson et al. [29]. The same relations can be generated from Eq. (81). Objects from set N according to their properties may be vulnerable to any of the means used in combination therapy (usually five) or to none. In the case of AIDS (acquired immunodeficiency syndrome), HAART does not result in patient's recovery despite a decrease of virus concentration below the detectability threshold. One of the reasons can be hiding of the virus in the milieu of limited immune response, such as brain and testes. They are unreachable for therapy just like memory lymphocytes and dendritic cells which are also a target of HIV attack. In the phenomenological model (Fig. 3), regions inaccessible for transformations are volumes V_{δ} (brain, testes) and $V_{\alpha c}$ (dendritic cells, memory lymphocytes). Objects can remain in them until producing mutation which is resistant to the applied drug combination, capable of regaining the whole space V.

Now, to model an artificial immune system, the shape space concept proposed by Perelson and Ostera [30] is often used. Antigen and antibody were determined as a point in the L-dimensional space of complementary traits. The notion of threshold ε determines the level of imperfectness of fitting of the antigen-antibody activation.

The idea of the transformation process preceded by a process of forming objects from a set N (Section 2.2) can be used to model the epidemic taking into account such factors as vaccinations or immunization. The solution achieve for the simple SIR model (division of the individuals: susceptible, infecting and convalescents with acquired resistance) is consistent with a simple epidemic model developed by Kermack and McKendrick [31].

6. Summary

The presented theory relates to the physical, chemical and biological processes of random transformation of dispersed matter. It has the interdisciplinary significance allowing the phenomenological and mathematical modeling of mass transfer processes in many areas.

These include among others: industrial technology, ecology and environment protection, medicine, veterinary medicine, immunology, oncology, epidemiology, hygiene and agriculture. Specific descriptions of the processes create the possibility of linking phenomena, mechanisms and factors determining the process. Obtaining a correct modeling effect must be preceded by knowledge and deep understanding of the nature of the problem. However, full success depends on the proper, conducted on the basis of areas considered process, final interpretation of the results. The presented general concept of transformation of matter can be used both to study and describe the processes as well as for their management and control. It systematizes a range of knowledge concerning the transformation of dispersed matter whose nature has not previously been combined into unity. Together with the given methodology of building phenomenological and mathematical models it makes a platform on which it seems possible to achieve significant scientific development among others through analogies, critical comparisons and transfer of knowledge.

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