CHEMISTRY & CHEMICAL TECHNOLOGY

Vol. 6, No. 3, 2012 Chemical Technology

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RELEASE OF CAPSULATED MINERAL FERTILIZERS COMPONENTS. PROCESS SIMULATION

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Received: January 12, 2012 / Revised: February 13, 2012 / Accepted: May 12, 2012

Abstract. Theoretical investigations concerning the compounds release out of globular capsulated particles within a wide variable range of criteria diffusive complexes have been examined. The effect of capsulated particle size on the process kinetics has been determined. The simplified analytical dependencies have been obtained to calculate the parameters of particles coating for the main soluble nitrogen fertilizer in order to ensure the necessary active time.

Keywords: capsulated fertilizers, components release, simulation.

1. Introduction

The plating over the surface of dispersed materials particles (capsulation) allows to modify their physico-chemical properties. If mineral fertilizers are capsulated the compounds with prolonged action are obtained. It is especially urgent for easy-soluble fertilizers, losses of which may achieve 50 % due to the washout or ventilation [1]. The active time of capsulated fertilizers is essentially higher than that of traditional granulated fertilizers and may achieve 10–12 months [2]. Therefore, the determination of release time for the compounds of mentioned matters depending on shell material and shell thickness is of great importance. In our previous work [3] we obtained the equation connecting sizes of globular particle and dilution time. In the dimensionless form it is as following:

$$\left[\left(1+2\frac{Bi+1}{Sh}\right)\frac{k}{3a}-\frac{1}{3bk}\right]\cdot$$
$$\cdot\left[\frac{1}{2}\ln\frac{(k+j)^2(k^2-k+1)}{(k^2-kj+j^2)(k+1)^2}+\right. \quad (1)$$
$$\left.+\sqrt{3}arctg\frac{\sqrt{3}k(j-1)}{2(k^2+j)-k(j+1)}\right]=3Fo$$

where $\frac{r}{R}=j$; $m=\frac{3W}{4p R^3}$;

$a=\frac{C_s}{r_s}; a=a-\frac{1}{m}(1-a); b=\frac{1}{m}(1-a); \quad k=\sqrt[3]{\frac{a}{b}}$

Fo, Sh, Bi – criteria dependencies of Fourier, Sherwood and Bio, respectively [4]:

$$Fo=\frac{t D_2}{R^2}; \; Sh=\frac{b R}{D_2}; \; Bi=\frac{bd}{D_2}$$

r_s – solid phase density, kg/m^3; W – solvent volume, m^3; R – solid phase radius at the process initial time, m; r – radius of the solid phase which dissolves in any moment of the process, m; C_s – saturation concentration of the compound on the dilution boundary, kg/m^3; d – shell thickness, m; D_1 – diffusion coefficient inside the particle, m^2/s; D_2 – diffusion coefficient in the membrane pores, m^2/s; b – mass transfer from the external surface to the solvent medium, m/s; t – process time, s.

The intensity of compounds release from the capsulated particles during their dilution is determined by components diffusion in the solvent and through the shell, as well as by the mass transfer from the external surface of the capsule. Such parameters come part of the criteria complex (Bi + 1)/Sh of the process mathematical model [3]. The prognosis based on theoretical dependencies of active time and release kinetics is of great practical interest for the production of capsulated mineral fertilizers.

2. Theoretical Investigations and their Interpretation

In order to capsulate the dispersed materials with the aim of dilution rate regulation we may use various film-forming compositions [5]. By means of mathematical model (3) we may theoretically investigate the components diffusive release within a wide range of penetrating ability of the coatings. The easy soluble nitrogen granulated mineral fertilizers were the investigation objects: ammonium nitrate, calcium nitrate, carbamide and nitroamophose. These fertilizers are widely used in agriculture. The capsulation of the mentioned compounds will reduce the unproductive losses of feeding elements [6]. The dependencies $C_1/C_s = f(Fo)$ were calculated under different values of $(Bi+1)/Sh$ complex. The bounds of the complex were taken from 0.01 to 1000 with the step 10 on the basis of diffusion values and mass transfer coefficients [7, 8]. The results of calculations are represented in Fig. 1.

One can see from Fig. 1 that under $(Bi+1)/Sh < 0.01$ the theoretical lines are superimposed one upon another for all matters. In such a case release kinetics does not depend upon coating parameters but it is determined by the properties of the solid phase. Thus we may determine the value of $(Bi+1)/Sh$ complex under which the capsulated matter obtains the necessary properties.

The first aim of the mineral fertilizers capsulation is to reduce the solubility of easy soluble matters. The producers of capsulated mineral fertilizers declare different active times: 3–4, 5–6 and 12–14 months for Osmocot fertilizers and 4, 6 and 8 months for Plantcot [2].

For theoretical investigations we assume the equal size of the particle for all samples. The granulated mineral fertilizers refer to polydispersed mixtures. The particle sizes in them vary from 1 to 5 mm. During the components release the particle size is a determinative parameter affecting the process kinetics. The parameters of the shell which determines the release intensity are taken into account in the criteria dependence ***Bi***. The other criteria in the mathematical model characterize the properties of a solid phase. The dependence of ***Bi*** value ensuring the definite active time for capsulated fertilizers upon the particles size is calculated by means of the mathematical model. The results are represented in Fig. 2.

The analysis of presented results shows that the increase of particle size decreases the coating value and increases the part of components of mineral feed capsulated particle. Hence, it is more advisable to use fractions of the large size for the capsulation of mineral fertilizers by the material which is inert to plants. It is especially actual for the fertilizers with long active time.

The dependencies $Bi = f(R)$ represented in Fig. 2 are described by the following equation:

$$Bi = A \cdot R^{-B} \quad (2)$$

The values A and B are determined from the equations of the corresponding curves on the basis of computer's treatment. The obtained results are given in Table 1.

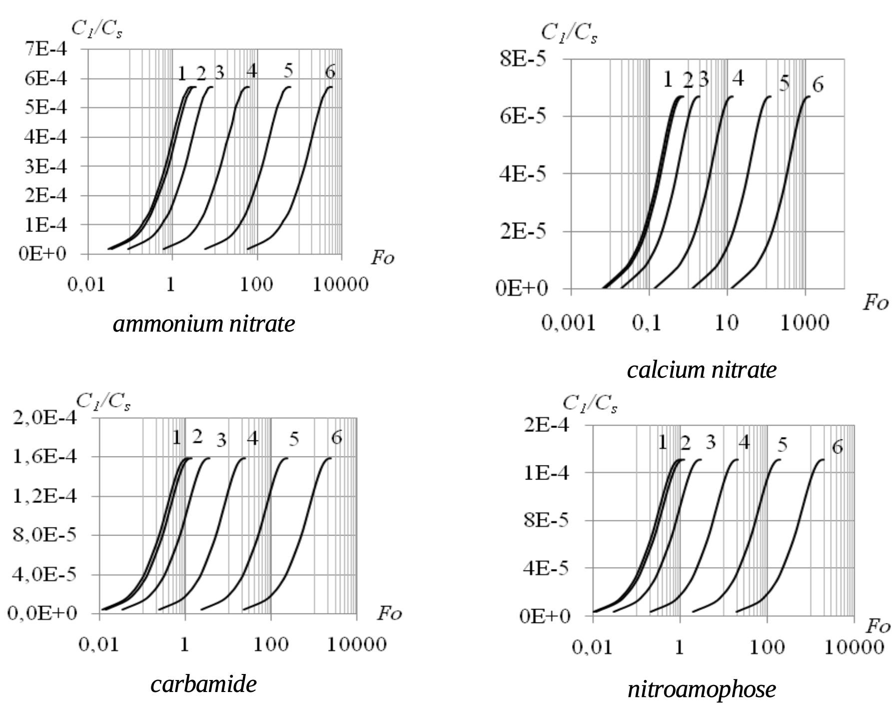

Fig. 1. Theoretical dependencies of release kinetics of mineral fertilizers components out of globular particle covered with insoluble shell at different values of $(Bi+1)/Sh$: 0.01 (1); 0.1 (2); 1 (3); 10 (4); 100 (5) and 1000 (6)

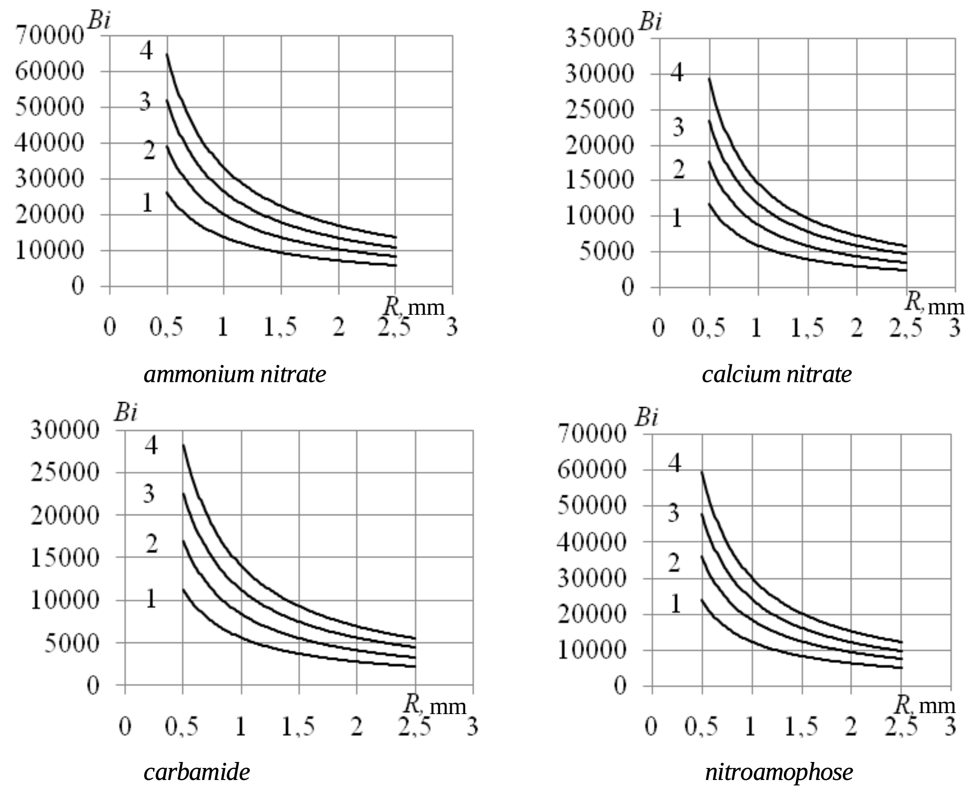

Fig. 2. Dependence of ***Bi*** criterion upon the particle size at which capsulated fertilizers are characterized by the corresponding active time: 4 (1), 6 (2), 8 (3) and 10 (4) months

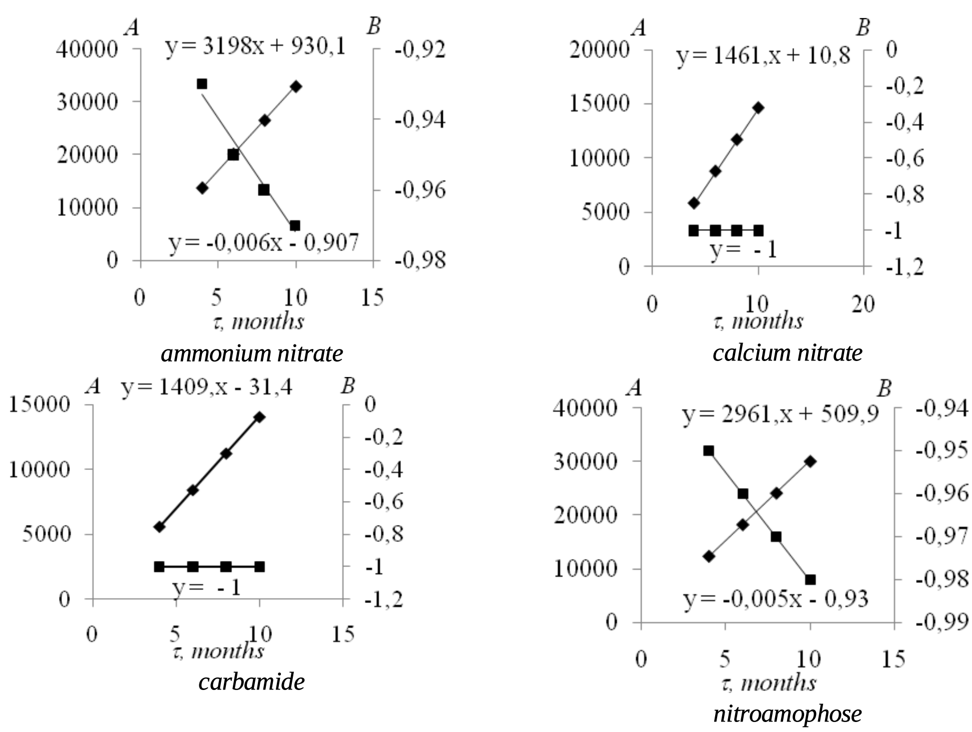

Fig. 3. Dependence of A and B constants on the active time for different fertilizers

On the basis of the data from Table 1 a graphical dependence of A and B constants upon the active time is plotted. The results are represented in Fig. 3.

Table 2 represents the dependencies of A and B constants upon the active time of capsulated fertilizers.

Substituting the obtained results (Table 2) into Eq. (2) we receive the analytical formulae to calculate Bi criterion depending upon the particle size and necessary active time of capsulated fertilizers (Table 3).

The difference between the results obtained by means of the mathematical model and equations from Table 3 does not exceed 0.1 %.

Using the dependency $B_i = f(t)$ (Table 3) the criterion B_i is calculated. According to this criterion the active time of mineral fertilizers is 4 months. Then the coating thickness d with penetration D_2 over the particles with radius R = 2 mm is determined. The polystyrene-hydrolysis lignine blend with the ratio of 8:2 is used as a film-forming medium. The calculation results and coating parameters are given in Table 4.

The theoretical data of the release kinetics are obtained using data of Table 4 and then they are compared with experimental results (Fig. 4).

Table 1

Dependence of *A* and *B* constants in the dependence *Bi = f(R)*

t, months	Matter							
	Ammonium nitrate		Calcium nitrate		Carbamide		Nitroamophose	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
4	13717	-0.93	5851	-1	5601	-1	12355	-0.95
6	20126	-0.95	8790	-1	8430	-1	18281	-0.96
8	26512	-0.96	11695	-1	11251	-1	24186	-0.97
10	32908	-0.97	14625	-1	14057	-1	30127	-0.98

Table 2

Dependencies of A and B constants upon the active time of capsulated fertilizers

Matter	Dependencies	
	$A = f(t)$	$B = f(t)$
Ammonium nitrate	$A = 3198t + 930.1$	$B = -0.006t - 0.907$
Calcium nitrate	$A = 1461t + 10.8$	$B = -1$
Nitroamophose	$A = 2961t + 509.9$	$B = -0.005t - 0.93$
Carbamide	$A = 1409t - 31.4$	$B = -1$

Table 3

Dependencies of *Bi* criterion upon the particle size and necessary active time

Matter	Dependencies $Bi = f(t)$
Ammonium nitrate	$Bi=(3198\tau+930.1)R^{-0,006\tau-0,907}$
Calcium nitrate	$Bi=(1461\tau+10.8)R^{-1}$
Nitroamophose	$Bi=(2986\tau+509.9)R^{-0,005\tau-0,93}$
Carbamide	$Bi=(1409\tau+31.4)R^{-1}$

Table 4

Coating parameters under which the mineral fertilizers have necessary active time

Matter	Bi	$D_2\cdot10^{12}$, m^2/s	$\beta\cdot10^5$, m/s	$\delta\cdot10^5$, m
Ammonium nitrate	7197.1	2.41	17.85	9.72
Calcium nitrate	2927.4	6.22	16.57	11.0
Nitroamophose	6394.7	0.798	5.58	9.15
Carbamide	2802.3	2.61	3.03	24.1

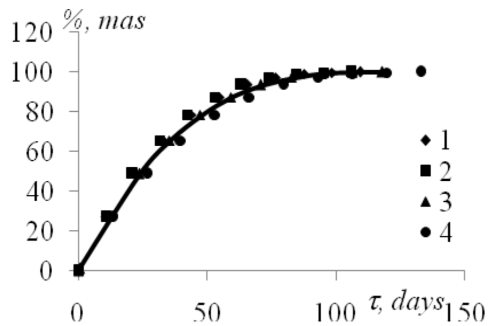

Fig. 4. Comparison of theoretical (line) and experimental (dots) values of the release kinetics of the capsulated fertilazers: carbamide (1); ammonium nitrate (2); calcium nitrate (3) and nitroamophose (4)

The analysis of obtained dependencies shows their satisfactory coincidence. The maximum difference between experimental andtheoretical results are (%): 8.8 – for carbamide; 11.9 – for ammonium nitrate; 1.6 – for calcium nitrate and 10.8 – for nitroamophose.

3. Conclusions

Equations given in Table 3 were obtained on the basis of developed mathematical model of the solid phase release during its dilution from the capsulated globular particles. They are applied for specific type of mineral fertilizers and are more suitable for practical engineering calculations.

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ВИВІЛЬНЕННЯ КОМПОНЕНТІВ КАПСУЛЬОВАНИХ МІНЕРАЛЬНИХ ДОБРИВ. МОДЕЛЮВАННЯ ПРОЦЕСУ

Анотація. *Приведено теоретичні дослідження процесу вивільнення речовин з капсульованих частинок кулястої форми в широких діапазонах зміни критеріальних дифузійних комплексів. Визначено вплив на кінетику процесу розміру капсульованої частинки. Отримані спрощені аналітичні залежності розрахунку параметрів покриття частинок основних легкорозчинних азотних добрив для забезпечення необхідної тривалості їх дії.*

Ключові слова: *капсульовані добрива, вивільнення компонентів, моделювання.*