Environment Protection Engineering

Vol. 28 2002 No. 2

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ANALYSIS OF CENTRIFUGAL SEDIMENTATION PROCESS OF POSTPRODUCTION SUSPENSION FROM TIMBER PROCESSING PLANT USING FLOCBEL TYPE FLOCCULANT

The results of the study dealing with the treatment of wastewater from a timber processing plant were presented. The investigations have been carried out for one flocculant, namely Flocbel FC 170H, applied to improve centrifugal sedimentation process. The experiments were performed with the use of condensed product of industrial effluents in a laboratory centrifuge. The relationship between the flocculant dose and sediment humidity as well as solid concentration in the drained off liquid have been determined. On the basis of earlier research the mathematical equations describing the relationship between the parameters of the sediment (humidity, solid concentration) and the independent variable parameters (time of centrifuging, rpm of the setting centrifuge, initial temperature of the sediment, dose of flocculant) have been derived. The flocculant Flocbel FC 170H used in the experiments only slightly improved the centrifugal process, but the process proved to be more efficient than in the case of flocculants applied in earlier study (Praestol 2900, Flocbel FC190).

1. INTRODUCTION

Agriculture and timber industry predominate in the Middle Pomerania. In this area, the biggest and most modern plants involved in timber processing are ALPEX at Karlino and POLSPAN-KRONOSPAN at Szczecinek. This paper is a continuation of earlier research on the treatment of effluents from a timber processing plant [1]–[4], [6], [7], [13], [14]. The general block diagram of such comprehensive wastewater treatment and thermal utilisation of solid waste technology is shown in figure 1 [9]–[12].

The results of research carried out for just one of a few selected and tested flocculants, namely Flocbel FC 170 H applied to facilitate centrifugal sedimentation process, are presented in this paper.

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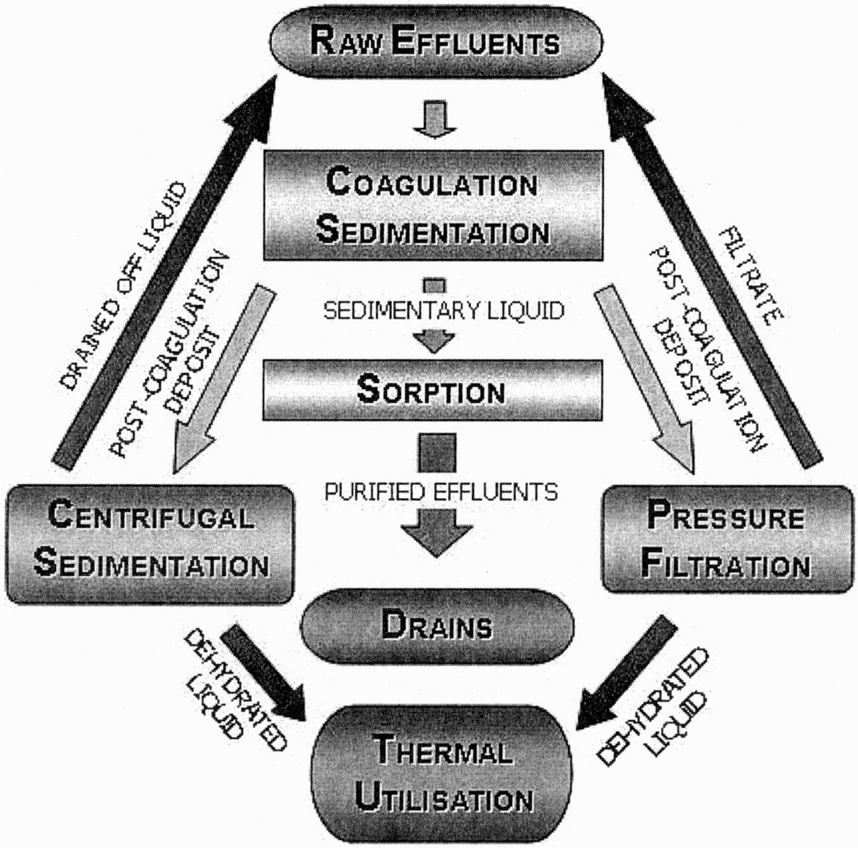

Fig. 1. Block diagram of effluent purification and post-production waste utilisation at POLSPAN-KRONOSPAN Szczecinek Plant [12]

2. CHARACTERISTIC FEATURES OF THE EFFLUENTS

Table 1 shows the general characteristics of postproduction effluents from POLSPAN-KRONOSPAN Szczecinek Chip Washing Station [12].

The suspension used in tests of centrifugal process was a condensed product of industrial effluents as characterised in table 1. Earlier it was subjected to the process of gravity sedimentation enhanced by adding calcium hydroxide. The coagulant dose established on the grounds of earlier optimisation work was 2.0 g/dm^3 of post-production effluents at an initial temperature being approx. 20 °C.

Table 1

Characteristic features of postproduction effluents from
POLSPAN-KRONOSPAN Szczecinek Chip Washing Station [12]

Indicator	UoM	Value	Std. value*	Std. value**
Reaction	pH	5.7	6.5–9.0	6.5–9.0
Chemical oxygen demand	Mg O_2/dm^3	12300	150	350
Biochemical oxygen demand	Mg O_2/dm^3	4800	30	200
Total suspension	mg/dm^3	23520	50	150
Dissolved matter	mg/dm^3	2830	2000	1200
Total solids	mg/dm^3	26350	2050	1350
Ether extract	mg/dm^3	426	30	40
Total organic carbon	mg/dm^3	14830	40	40

* Ordinance by the Minister of Environmental Protection, Natural Resources and Forestry dated November 05, 1991 regarding classification of water and conditions to be met by effluents discharged to waters and ground, Official Journal of Laws No. 116, Section 503.

** Contract made with the Water Supply and Sewerage Company for delivery of water and discharge of effluents to municipal sewerage system No. 19/95 dated June 09, 1995.

3. STATUS OF THE UP-TO-DATE RESEARCH ON THE APPLICATION OF AGENTS FACILITATING CENTRIFUGAL SEDIMENTATION PROCESS

In the centrifugal processes tested so far, the independent variable parameters were as follows [12]: time of centrifuging, rpm of the setting centrifuge, suspension initial temperature, doses of flocculants of the type of Praestol 2900 D [6] and Flocbel FC 190 [7]. The dependent variables, the so-called resultant variables, were: sediment humidity and concentration of solids in the drained off liquid.

The tests were carried out in a laboratory centrifuge, MPW-360 type, made in Poland [8]. Their results illustrated in figures 2 and 3 were approximated by an appropriate analytical-empirical mathematical function [5] using the central point approximation method. The general calculation problem to be solved in such analysis consists in matching up the curve being a *n*-degree polynomial with a point pattern. The functional relationships between the variables in question are initially determined through approximation by the least-squares method, which consists in such a selection of an equation being mostly a polynomial that the sum of squares of point distances from the approximation curve in the dispersion graph is the smallest possible. Following completion of a full series of tests certain abstract mathematical space of curve pencil is obtained [5]:

$$y = f(x_1, x_2, \ldots x_n), \tag{1}$$

where:

y – polynomial at the n-th degree of approximation,

$x_1, x_2, \ldots, x_n$ – input independent values (factors).

A specific feature of this method is that all curves always pass through one common central point. Obviously each particular curve has its beginning and end limited by the change intervals (from–to) in which particular independent variables $x_1, x_2, \ldots, x_n$ were set. Therefore, one can assume that those particular patterns create between themselves a certain space in which equations obtained due to such an approximation are often sufficiently accurate. It should also be stressed that in the central point approximation method, a simplifying assumption is adopted. According to this assumption the independent variable parameters $x_1, x_2, \ldots, x_n$ being tested do not interact mutually or their interactions are negligible compared with the effect of the change of a single factor x_i on the process result, therefore such interactions can be omitted without making a big error.

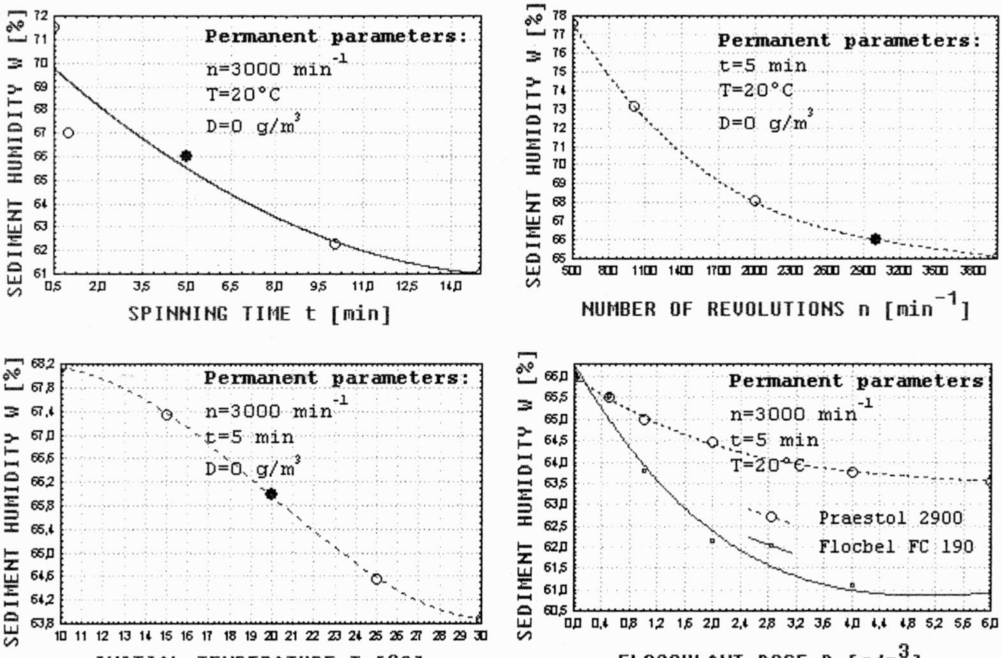

Fig. 2. Collective graphs of influence of the centrifuging time t [min], number of revolutions n [min^{-1}], initial temperature T [°C] and the flocculant Praestol 2900 and Flocbel FC 190 doses [g/m^3] on sediment humidity W [%] [12]

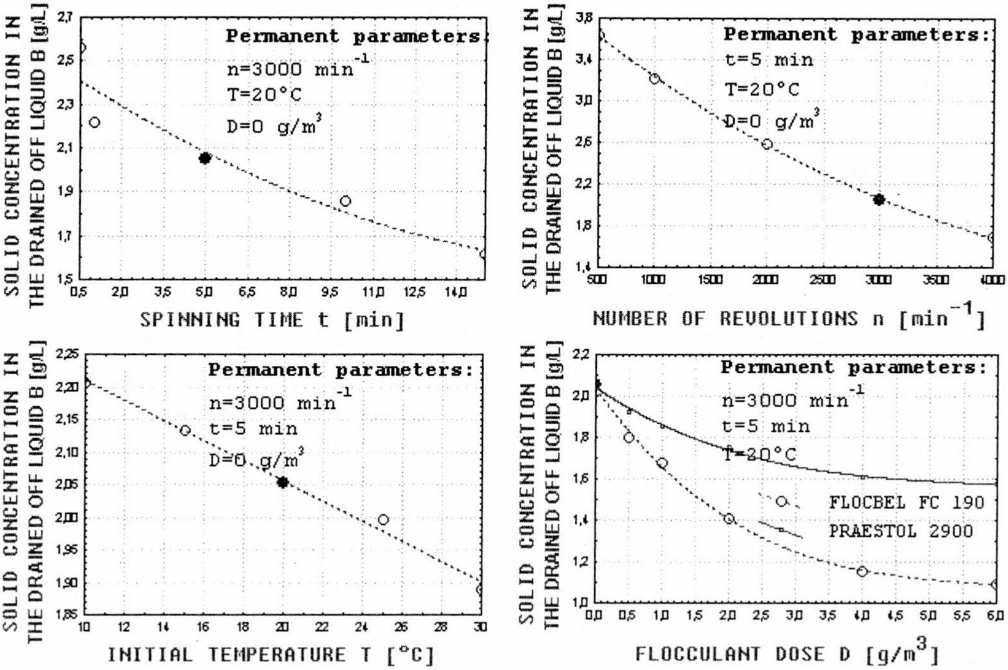

Fig. 3. Collective graphs of influence of the centrifuging time t [min], number of revolutions n [min^{-1}], initial temperature T [°C] and the flocculant Praestol 2900 and Flocbel FC 190 doses [g/m^3] on solid concentration in the drained off liquid β [cm^3/dm^3] [12]

After completing such a series of tests and arriving at the final analytic-empiric mathematical equations the above method was verified. To this end several random experiments were carried out with arbitrary pre-selected values of particular variables $x_1, x_2, \ldots, x_n$ falling within the initially tested change intervals that would be selected intentionally in such a way as not to be linked with the central point of approximation, but with the space around that point, i.e. the space in which it was assumed that the equations obtained can be applied [5]. At the third level of approximation with relation to the factors considered herein, the above general equation (1) takes the following form [12]:

$$W(t,n,T) = 0.0348t^2 - 1.134t - 3.37710^{-10}n^3 + 3.586\cdot 10^{-6}n^2 - 0.0014n$$
$$+ 8.874\cdot 10^{-4}T^3 - 0.052T^2 + 0.731T + 88.812 \tag{2}$$

and

$$\beta(t,n,T) = 0.002t^2 - 0.084t - 3.852\cdot 10^{-12}n^3 + 9.974\cdot 10^{-8}n^2$$
$$- 9.333\cdot 10^{-4}n - 0.015T + 4.740. \tag{3}$$

At the same time general equation (1) in its full functional notion, taking into account the constant factor values for independent variables, takes its final shape at the fourth level of approximation:

- Flocbel FC 190 [6]:

$$W(t,n,T,D) = 0.0348t^2 - 1.134t - 3.377\cdot 10^{-10}n^3 + 3.586\cdot 10^{-6}n^2 - 0.0014n$$
$$+ 8.874\cdot 10^{-4}T^3 - 0.052T^2 + 0.731T - 0.025D^3 + 0.466D^2 - 2.785D + 89.119 \tag{4}$$

and

$$\beta(t,n,T,D) = 0.002t^2 - 0.084t - 3.852\cdot 10^{-12}n^3 + 9.974\cdot 10^{-8}n^2$$
$$- 9.333\cdot 10^{-4}n - 0.015T - 0.004D^3 + 0.075D^2 - 0.449D + 4.399\,; \tag{5}$$

- Praestol 2900 [7]:

$$W(t,n,T,D) = 0.0348t^2 - 1.134t - 3.377\cdot 10^{-10}n^3 + 3.586\cdot 10^{-6}n^2 - 0.0014n$$
$$+ 8.874\cdot 10^{-4}T^3 - 0.052T^2 + 0.731T - 0.011D^3 + 0.182D^2 - 1.106D + 88.832 \tag{6}$$

and

$$\beta(t,n,T,D) = 0.002t^2 - 0.084t - 3.852\cdot 10^{-12}n^3 + 9.974\cdot 10^{-8}n^2$$
$$- 9.333\cdot 10^{-4}n - 0.015T - 0.002D^3 + 0.034D^2 - 0.212D + 4.716\,, \tag{7}$$

where:

W – sediment humidity [%],
β – solid concentration in the drained off liquid [g/dm^3],
t – spinning time [min],
n – number of revolutions [min^{-1}],
T – initial temperature of the process [°C],
D – flocculant dose [g/m^3].

Within the tested intervals of the changes in technical/technological parameters of independent variables, i.e. centrifuging time, number of revolutions and temperature, the most decisive qualitative effect both for reduction of humidity in sediment and for reduction of solid concentration in the drained off liquid was obtained with the increase in the number of revolutions within the interval of 500–4000 min^{-1}. The flocculants applied to enhance the centrifugal process, i.e. Flocbel FC 190 and Praestol 2900, raised the quality of the process although this improvement was not as substantial as for such technical parameter as the increase in the number of revolutions of the setting centrifuge.

4. EXPERIMENTAL

Influence of another flocculant, namely Flocbel FC 170H used for dehydration of paper industry suspensions and for dehydration of limed effluence, has been established in the framework of this publication. The flocculant is prepared as a 0.1% solution. Equations (2) and (3) are considered to be the starting point for the 4th level approximation analysis for this reagent.

The results of tests on the effect of the change in Flocbel FC 170H dose on water content in the sediment and concentration of solids in the drained off liquid after centrifuging are given in table 2 and in figure 4.

Table 2

Results of tests on the influence of Flocbel FC 170H D (g/m^3) dose on sediment humidity W (%) and solid concentration in the drained off liquid β (g/dm^3)

Flocculant dose (g/m^3)	Sediment humidity W (%)	Solids concentration in drained off liquid β (g/dm^3)
0.00	66.0	2.052
0.05	64.5	1.802
1.00	63.7	1.625
2.00	62.0	1.421
4.00	60.8	1.102
6.00	60.5	1.051

Continuous line in figure 4 proves that if flocculant dose increases from 0 up to 6 g/m^3 water content after centrifuging drops from approx. 66% to approx. 60.5%, whereas the curve in figure 5 proves that concentration of solids in the drained off liquid drops from approx. 2.05 g/dm^3 to approx. 1.05 g/dm^3. This indicates that the effect of the flocculant dose in the interval tested on reduction of sediment water and thickening of solids in the drained off liquid is not as significant as, for example, the change in the number of revolutions. Nevertheless this causes almost 5% reduction of humidity, and a decrease in thickening of the solids in the drained off liquid by approx. 1.0 g/dm^3. Figures 4 and 5 show the results obtained when Praestol 2900 and Flocbel FC 190 were applied [6], [7].

The approximated equations of the curves in figures 4 and 5 take the following forms at the 4th level of approximation:

$$W(D) = 65.945 - 2.873D + 0.535D^2 - 0.034D^3 \tag{8}$$

and

$$\beta(D) = 2.031 - 0.447D + 0.069D^2 - 0.004D^3 \, . \tag{9}$$

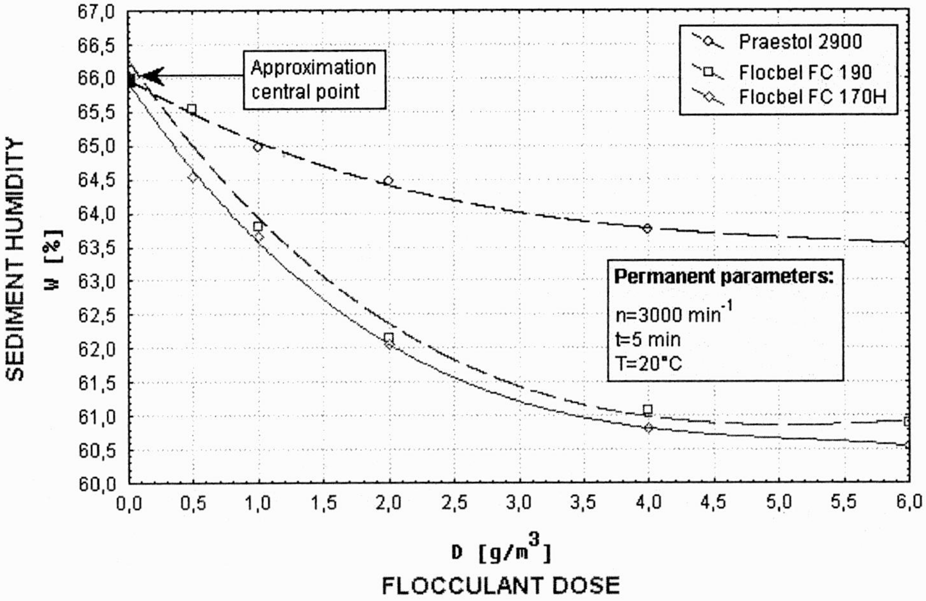

Fig. 4. Influence of flocculant dose D (g/m^3) on sediment humidity W (%)

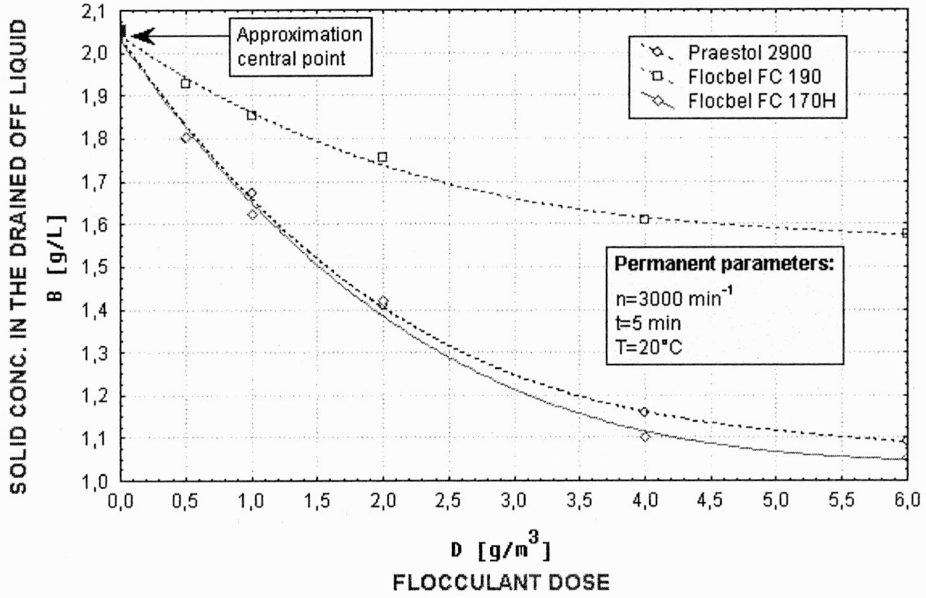

Fig. 5. Influence of flocculant dose D (g/m^3) on solid concentration β in the drained off liquid (g/dm^3)

Therefore, the general equations take the following forms at the 1st, 2nd, 3rd and 4th levels of approximation:

$$W(t,n,T,D) = W_t(t) + W_n(n) + W_T(T) + W_D(D) - C_t - C_{tn} - C_{tnT} \tag{10}$$

and

$$\beta(t,n,T,D) = \beta_t(t) + \beta_n(n) + \beta_T(T) + \beta_D(D) - C_t - C_{tn} - C_{tnT}\,. \tag{11}$$

The above equations take their final forms in full functional notion, taking into account the constant factors values for independent variables:

$$\begin{aligned} W(t,n,T,D) = {} & 0.0348t^2 - 1.134t - 3.377\cdot 10^{-10} n^3 + 3.586\cdot 10^{-6} n^2 \\ & - 0.0014n + 8.874\cdot 10^{-4} T^3 - 0.052T^2 + 0.731T - 0.034D^3 \\ & + 0.535D^2 - 2.873D + 88.791 \end{aligned} \tag{12}$$

and

$$\begin{aligned} \beta(t,n,T,D) = {} & 0.002t^2 - 0.084t - 3.852\cdot 10^{-12} n^3 + 9.974\cdot 10^{-8} n^2 \\ & - 9.333\cdot 10^{-4} n - 0.015T - 0.002D^3 + 0.034D^2 - 0.212D + 4.707\,, \end{aligned} \tag{13}$$

where:

W – sediment humidity (%),
β – solid concentration in the drained off liquid (g/dm^3),
t – centrifuging time (min),
n – number of revolutions (min^{-1}),
T – initial temperature of the process (°C),
D – flocculant dose (g/m^3).

To check the accuracy of the above equation a series of seven experiments involving independent variables taken at random but not being the values of the central point of approximation were carried out.

Then from equations (12) and (13) percentage of humidity content in the sediment and solid concentration in the drained off liquid were calculated and compared with the respective results of humidity content and solid concentration obtained in particular seven experiments. The results were set up in table 3 along with evaluating the accuracy of equations (12) and (13) for this space, in which they can be applied based on the tests discussed above. The equations accuracy for 95% significance level was tested by the *t*-Student test [5].

Table 3

Statistical analysis results

t	N	T	D	Fixing			
				Lab.	Equation	Lab.	Equation
				Humidity		Concentration	
(min)	(min^{-1})	(°C)	(g/m^3)	(%)		(g/dm^3)	
12	600	12	3.5	65.25	70.73	2.46	2.39
3	1200	17	1.2	74.21	72.44	2.87	2.79
4	1500	19	1.5	70.48	68.62	2.35	2.40
6	2500	22	2.4	63.87	61.29	1.52	1.44
7	3500	23	2.8	58.48	58.32	1.33	0.86
1	2500	27	3.0	64.25	64.15	1.65	1.62
3	3500	28	5.0	59.89	59.81	1.39	0.83
D_{av}				1.7194		0.1893	
Σd^2				43.3498		0.5476	
Variance S^2				3.2364		0.0424	
Standard deviation				1.7990		0.2059	
t-Student test				2.341		2.253	

For 6 degrees of freedom and the error risk the limit value taken from the t-Student tables is [5]:

$$t_{0.05} = 2.447.$$

As the calculated values of the t-Student function, being respectively: $t^0 = 2.341$ for sediment humidity and $t^0 = 2.253$ for solid concentration in the drained off liquid, do not exceed $t_{0.05} = 2.447$, we can arrive at conclusion that at 5% significance level no significant differences between the values obtained from equations (12) and (13) and the test results were found.

Therefore, under the above conditions, equations (12) and (13) can be possibly applied to forecasting dehydration quality, provided that a centrifuge is introduced in the technological system as shown in figure 1 and Flocbel FC 170H flocculant is used. Equations (12) and (13) can be applied in the change interval for time $t \in (0.5–15)$ min, for revolutions $n \in (500–4000)$ min^{-1}, initial temperature of suspension $T \in (10–30)$ °C and Flocbel FC 170H D dose $\in (0–6)$ g/m^3. Of course, these equations might be used for a wider change interval of the above independent variable parameters, but after some additional research. Because under industrial conditions the effluent temperature is constant and in continuously operating industrial centrifuge the time of a suspension holdup is usually also constant, figures 6 and 7 show a 3-D representation of equations (10) and (11), respectively, for a variable number of revolutions n [min^{-1}] and the flocculant dose $D = 0$ g/m^3 at always constant temperature $T = 20$ °C and spinning time $t = 5$ min.

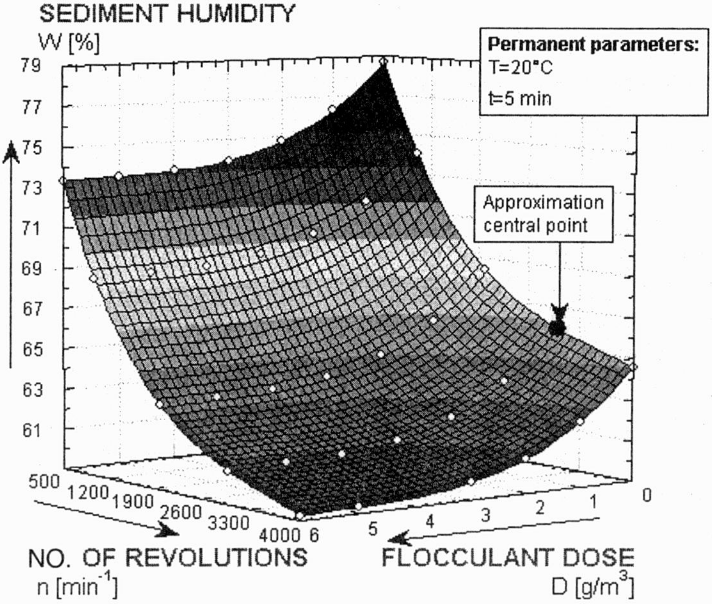

Fig. 6. 3-D graph showing the influence of a number of revolutions *n* (min^{-1}) and the dose of Flocbel FC 170H D (g/m^3) on sediment humidity *W* (%)

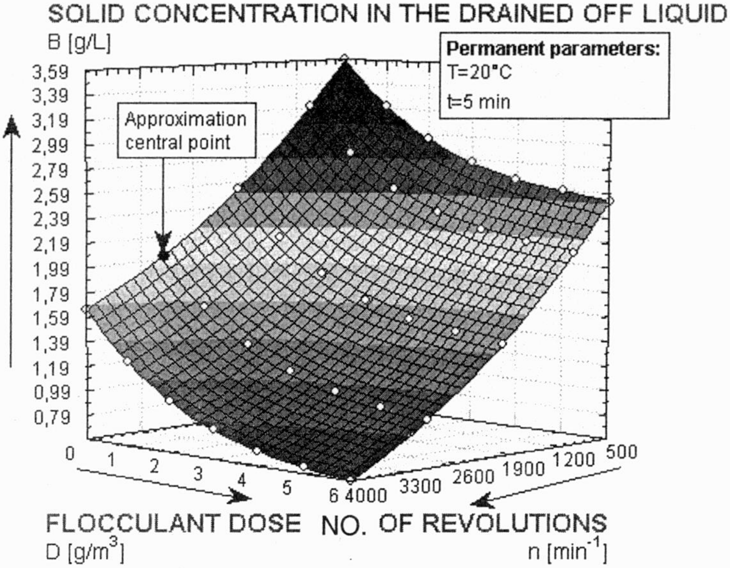

Fig. 7. 3-D graph showing the influence of a number of revolutions *n* (min^{-1}) and the dose of Flocbel FC 190 D (g/m^3) on solid concentration β in the drained off liquid (g/dm^3)

5. CONCLUSIONS

Based on the examinations carried out the following general conclusions can be drawn:

1. Flocbel FC 170H flocculant applied to the centrifugal process improved its quality although this improvement was not so significant as for the technical parameter, i.e. the increase in the number of centrifuge revolutions.

2. Flocbel FC 170H proved to be better flocculation improver than Praestol 2900 or Flocbel FC 190.

3. The centrifuging process tested within certain intervals of independent variables, i.e. time of centrifuging, number of revolutions, initial temperature of suspension supplied and Flocbel FC 170H dose, can be described by fairly simple analytical-empirical equations allowing determination of principal dependent variables of the process, i.e. sediment humidity and solids concentration in the drained off liquid.

4. Thermal annihilation and utilisation of the sediments recovered should be thoroughly tested.

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ANALIZA PROCESU SEDYMENTACJI ODŚRODKOWEJ ZAWIESINY POPRODUKCYJNEJ Z ZAKŁADU PRZETWÓRSTWA DREWNA PRZY ZASTOSOWANIU FLOKULANTA TYPU FLOCBEL

W artykule przedstawiono wyniki badań nad oczyszczaniem ścieków z zakładu przetwórstwa drewna. Eksperymenty przeprowadzono z wykorzystaniem jednego flokulanta Flocbel FC170, stosowanego do wspomagania procesu sedymentacji odśrodkowej. Procesowi odwirowania w warunkach laboratoryjnych poddawano zagęszczone ścieki przemysłowe. Ustalono zależność pomiędzy dawką flokulanta a wilgotnością osadu oraz zagęszczeniem fazy stałej w odcieku. Na podstawie wyników wcześniejszych badań przedstawiono matematyczne równania, opisujące zależność pomiędzy parametrami osadu (wilgotność) i odcieku (zagęszczenie fazy stałej) a niezależnymi zmiennymi parametrami (czas wirowania, liczba obrotów wirówki, temperatura początkowa zawiesiny, dawka flokulanta). Stosowany w badaniach flokulant Flocbel FC170H tylko nieznacznie poprawił skuteczność procesu sedymentacji odśrodkowej zawiesiny poprodukcyjnej, jednakże efektywność procesu była znacznie lepsza niż w przypadku wcześniej przebadanych flokulantów (Praestol 2900, Flocbel FC190).