THEORETICAL FOUNDATION OF BIODIESEL FLUSHING

ТЕОРЕТИЧЕСКИЕ ОСНОВЫ ПРОМЫВКИ БИОДИЗЕЛЯ

Polischuk A., Ass. Prof. PhD Drahniev S., Ass. Prof. PhD Polischuk V.

National University of Life and Environmental Sciences of Ukraine – Kiev, Ukraine
E-mail: polischuk.v.m@gmail.com, svdragnev@gmail.com

Abstract: *The settling dynamics of aqueous solution potassium citrate plates and water droplets in the bulk of biodiesel were considered. The settling time of their deposition was determined. Rational water droplet sizes for washing biodiesel were defined.*
KEYWORDS: BIODIESEL, DEPOSITION RATE, POTASSIUM CITRATE PLATE, WATER DROPLETS, REYNOLDS.

1. Introduction

The calcium salts (citrate) are formed during biodiesel neutralization with citric acid, which together with water are connected in a plate shape similar to the shape of a cylinder with a maximum diameter about 1,5-3 mm. These plates are broken down into smaller maximum diameter of approximately 50 μm under the mixing of biodiesel during the neutralization. The ratio of the height of the plate an aqueous solution of potassium citrate to its diameter is approximately 1/10. The density is 1237 kg/m^3.

Calcium salts should be removed from biodiesel to reduce its alkalinity after neutralization. This can be done by the settling.

2. Preconditions and means for resolving the problem

The particle in a vertical channel of liquid is sustained the gravity force: $P_g=m_ч g=V_ч \cdot \rho_ч \cdot g$ [1], the Archimedes force $P_A=V_ч \cdot \rho_p \cdot g$ [2],
where $M_ч$ – the mass of particle, kg; $V_ч$ – the particle volume, m^3; g – the acceleration of gravity, m/s^2; $\rho_ч$, ρ_p – respectively the density of the particle and fluid, kg/m^3.

If $P_a>P_A$, the particle starts to fall in the bulk liquid. The force acting on the particle at this point is:

$$P_a–P_A=V_ч \cdot \rho_ч \cdot g–V_ч \cdot \rho_p \cdot g=V_ч \cdot g \cdot (\rho_ч–\rho_p). \quad (1)$$

When the particle motion starts toward the bottom of the tank, beginning to act the resistance force, which opposing the difference of the forces $P_g–P_A$: $P_o = \zeta \cdot S_÷ \left[\left(\rho_p v_÷^2\right)/2\right]$ [1],

where ζ – coefficient of resistance; $S_ч$ – the projected area of a particle on the horizontal plane, m^2; v – the velocity of the particle, m/s.

The particle moves with acceleration at the initial settling. But with increasing speed, the resistance of the medium is increased and consequently the acceleration is decreased. Very soon it will come the equilibrium: the environment resistance force P_o compares with the power of moving particles $(P_a–P_A)$ and will come to a dynamic equilibrium: $P_o=P_a–P_A$. From this point, the particle will move uniformly with constant velocity. This velocity is called the settling rate v_{oc}.

The settling velocity can be found from the condition of equality of the forces driving the particle and the environment resistance force $P_g - P_A = P_o$ [2]:

$$V_ч \cdot g \cdot \left(\rho_ч - \rho_p\right) = \zeta \cdot S_ч \left[\left(\rho_p v_ч^2\right)/2\right]. \quad (2)$$

Hence the settling velocity of particles is:

$$v_{oc} = \sqrt{\frac{2 \cdot V_ч \cdot g \cdot \left(\rho_ч - \rho_p\right)}{\zeta \cdot S_ч \cdot \rho_p}} \quad (3)$$

Coefficient of resistance ζ depends on the mode of particle motion at the settling $\zeta=f(\text{Re})$, which is characterized by the Reynolds number [2]:

$$\text{Re} = \frac{\rho_p d_ч v_{oc}}{\mu_p}, \quad (4)$$

where Re – Reynolds number; $d_ч$ – the particle diameter, m; μ_p – the dynamic viscosity of the liquid, Pa·s.

There are different modes of particles settling, all of them depends on the certain value of the Reynolds number Re.

In laminar mode Re<2 the ratio of the environment resistance is defined as ζ=24/Re. With the development of turbulent flow the local turbulence begins to appear and the transition zone occurs (Re=2-500). The resistance coefficient of the medium is defined as $\zeta=10/\text{Re}^{0,5}$. Since some values of the Reynolds number, when fully developed turbulent flow is $500<\text{Re}<2 \cdot 10^5$, the frictional resistance can be neglected, since the main force becomes a drag. For the turbulent region the ratio of the environment resistance is ζ=0,44 [2]. When $\text{Re} \geq 2 \cdot 10^5$ the crisis resistance begins, and the value ζ is sharply drops (4-5 times) [3]. Given values ζ are fair, when the moving particle has the shape of a sphere.

For other bodies with regular geometric shape the experimental values ζ do not amenable to exact generalization of empirical formulas. With some approximation, we can calculate the value ζ for particles of irregular geometric shapes in the above formulas for spherical particles using the sphericity coefficient φ_c, the value for particles of cylindrical shape range $h=(1/2) \cdot d \ldots (1/30) \cdot d$ can be approximated by the expression $\varphi_c = \left(0,2233 \cdot \ln(a) + 0,9869\right)$ when $R^2=0,9993$, where a – the multiplier in the range from 1/2 to 1/30.

The coefficient of non-spherical particles for the laminar regime is $\varsigma = 28,47/\left[\text{Re}_e \cdot \lg\left(\varphi_c/0,065\right)\right]$, where Re_e – the equivalent Reynolds number, which is defined as $\text{Re}_e = \left(\rho_p d_e v_{oc}\right)/\mu_p$,

where d_e – the equivalent diameter of equal sphere, m. Equivalent diameter equal of the sphere is determined from the expression $d_e = \sqrt[3]{6 \cdot V/\pi}$. For turbulent regime the coefficient of non-spherical particles is defined as $\varsigma = 5,31 - 4,87 \cdot \varphi_c$ [3]. In the area of the transient regime for non-spherical particles is recommended to use a value ζ, listed in [3, c. 70]. They can be approximated by the expression $\varsigma = 19,848 \cdot \text{Re}_e^{-0,3858}$ when $R^2=0,899$.

However, formula (3) is difficult to use in practice, because it includes a coefficient that depends on the Reynolds number and mode of particle motion. At the same time, the mode of the particle motion and the Reynolds number, in turn, depend on the settling velocity.

Therefore, **the aim of our research** is development a mathematical model of the aqueous solution potassium citrate plates settling, which will allow to set and optimize the velocity and time of their settling.

3. Results and discussion

Due to the difficulty of applying the formula (3), the particles settling in the bulk liquid is useful to consider in the dynamics. According to [1], the equations of particles motion in the bulk liquid can be recorded as a system of differential equations:

$$\begin{cases} m_ч \dfrac{dv_ч}{dt} = P_O - \left(P_g - P_A\right) \\ \dfrac{dl_к}{dt} = v_ч \end{cases} \quad (5)$$

where $l_к$ – is the length of the channel (distance, which passes settling particles in bulk of biodiesel), m.

Substituting in the expression (5) the values of the forces of gravity, resistance and Archimedes, we get the system of differential equations describing the particles settling in the static liquid located in the bore of $D_к$:

$$\begin{cases} \dfrac{dv_{÷}}{\mathrm{dt}} = \dfrac{\zeta \cdot S_{÷} \cdot \rho_p v_{÷}^2 \cdot \left(1 - \left(\dfrac{d_{÷}}{D_{ê}}\right)^2\right)}{2 \cdot m_{÷}} - \dfrac{\mathrm{V}_{÷} \cdot g \cdot (\rho_{÷} - \rho_p)}{m_{÷}} \cdot \\ \dfrac{dl_{ê}}{\mathrm{dt}} = v_{÷} \end{cases} \quad (6)$$

By solving the system of equations (6), it is received dynamics of change in time of the settling velocity of particles, Reynolds number and the settling time.

Dynamics of change of the settling velocity of aqueous solution potassium citrate plates in time is shown in Fig. 1. As can be seen from the table 1, plate diameter ranging from 10 μm to 100 μm are settled in laminar mode, because Re<2.

Table 1

Indicators of aqueous solution potassium citrate plates settling in biodiesel

Parameter	The plate diameter, microns		
	10	50	100
Re	$2{,}39 \cdot 10^{-13}$	$7{,}47 \cdot 10^{-10}$	$2{,}39 \cdot 10^{-8}$
v_{oc}, m/s	$3{,}125 \cdot 10^{-7}$	$7{,}82 \cdot 10^{-6}$	$3{,}125 \cdot 10^{-5}$
t_{oc}*, days	37	1,48	0,37

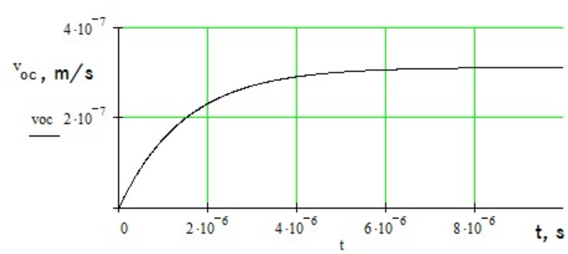
* – the settling time of aqueous solution potassium citrate plates in the biodiesel column with height 1 m

The settling velocity of aqueous solution potassium citrate plates is gradually growing, as can be seen from Fig. 1. After stopping the mixer the gravity force acts on the plate, gradually it begins to exceed the Archimedes force and effect resistance, the settling velocity increases according to the law, which is close to linear. However, starting from some point in time, due to increased resistance, the acceleration of the plate decreases and at a certain point, when the force of gravity is balanced by the Archimedean force and the resistance force, the settling velocity is stabilized.

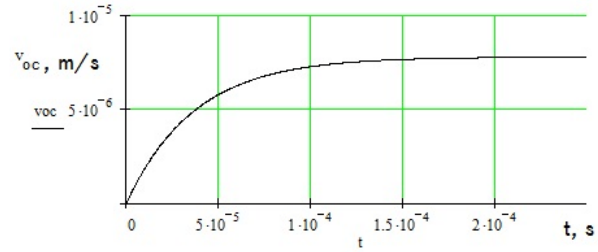
If the aqueous solution potassium citrate plates would be kept the size that they form by neutralizing biodiesel with aqueous solution of citric acid (0,5 to 1,5 mm), the settling time would take from 2 to 20 minutes in the thickness of biodiesel with height of 1 m.

However, during neutralization the formed plates are broken with a mechanical stirrer into smaller ones, their settling time increases substantially. If the settling time of plates with a diameter of 100 μm is about 10 hr, then plates with a diameter of 50 μm are settled within 1,5 days, and with a diameter of 10 μm is up to 40 days. The situation is complicated by the fact that there is a wide polydispersity of the aqueous solution potassium citrate plates in the biodiesel after neutralization, resulting in incomplete cleaning of potassium hydroxide.

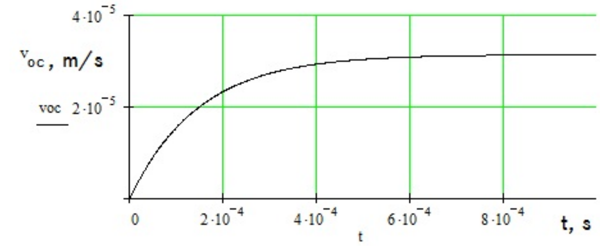
1)



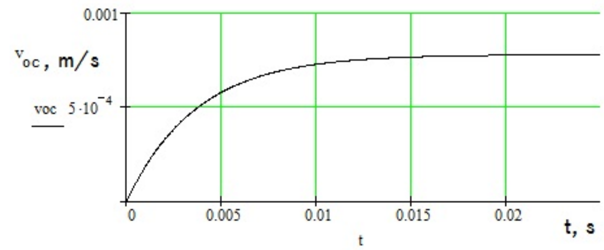
2)



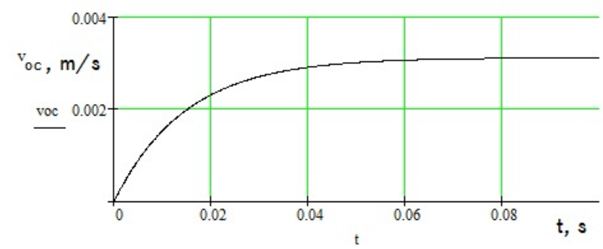
3)



4)



5)



6)

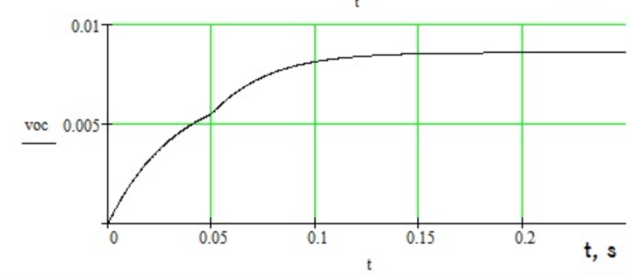


***Fig. 1**. The settling velocity of the aqueous solution potassium citrate plates (the ratio of height to diameter 1/10) in the biodiesel column, where the diameter of the plate: 1 – 10 μm; 2 – 50 μm; 3 – 100 mm; 4 – 500 μm; 5 – 1000 μm; 6 – 1500 μm*

One of the ways to increase the efficiency of biodiesel purification is flushing with water by spraying it over the surface of the biodiesel with the subsequent movement of water droplets toward the bottom of the tank. During the movement of liquid droplets are connected with the plates of pollutants and captured them.

Dynamics of change of the water drops settling velocity over time in the absence of the initial velocity are shown in Fig. 2. As can be seen from the table 2, droplets with a diameter of 2 mm are settled in laminar regime (Re<2), by increasing the diameter of the drops of more than 2000 μm their settling is carried out in a transient mode.

The action mechanism of the forces: gravity, Archimedes and resistance on the drop is similar to the action of these forces on the plate with a cylindrical shape.

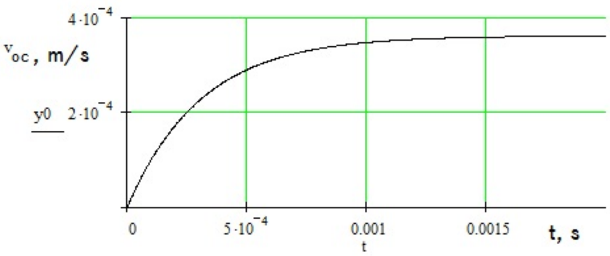
Table 2

Indicators of water droplets settling in biodiesel

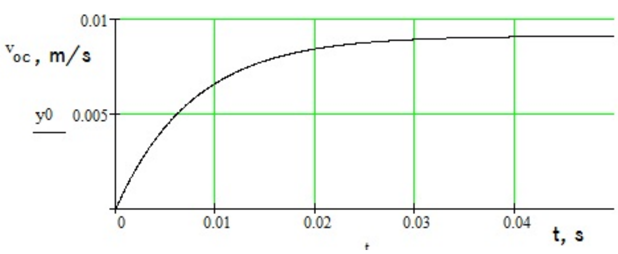
Parameter	The plate diameter, microns					
	100	500	1000	1500	2000	2500
Re	$3{,}2\cdot10^{-6}$	0,01	0,24	0,8	1,9	3,7
v_{oc}, m/s	$3{,}6\cdot10^{-4}$	$9{,}1\cdot10^{-3}$	0,031	0,047	0,062	0,078
t_{oc}*, s	2778	110	32	21	16	12,8
min.	46,3	1,8	0,54	0,35	0,27	0,21

* – the settling time of water droplets in the biodiesel column with height 1 m

1)



2)



3)

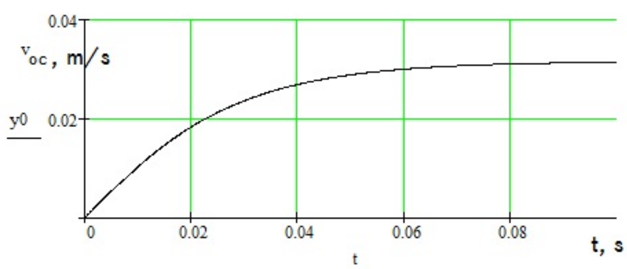
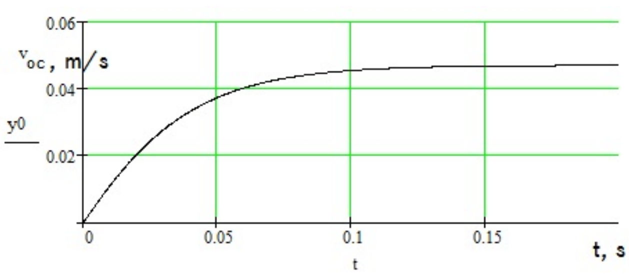
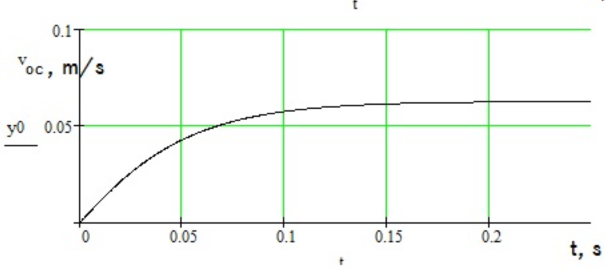


Fig. 2. *The settling velocity of water drops in the biodiesel column, where their diameter: 1 - 100 µm; 2 - 500 µm; 3 - 1000 µm.*

4)



5)



6)

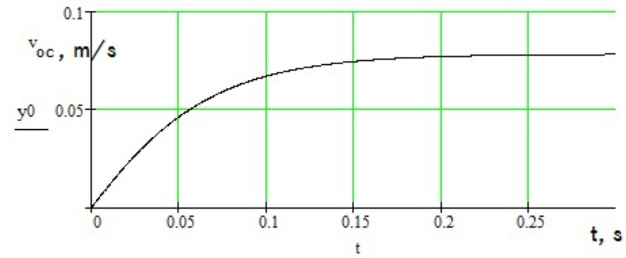


Fig. 2. (continued) The settling velocity of water drops in the biodiesel column, where their diameter: 4 - 1500 µm; 5 to 2000 µm; 6 - 2500 µm

4. Conclusions

1. The settling time of aqueous solution potassium citrate plates is from 0,5 to 40 days during the biodiesel cleaning from the catalyst. Therefore, to speed up this process, it is recommended to spray into the biodiesel column the water droplets that attach to themselves contaminant particles and transport them to the reactor bottom.
2. From the water droplets diameter 1 mm further increase of their dispersion do not significantly affect the settling velocity. It is therefore desirable to wash the biodiesel by water drops spraying in it with a diameter of 0,5 to 1 mm. The settling velocity of these drops does not exceed 2 minutes. Decreasing the dispersion drops their settling velocity increases significantly.

5. References

1. Зуев Ф.Г. Пневматическое транспортирование на зерноперерабатывающих предприятиях / Ф.Г. Зуев. – М:. Колос, 1976. – 344 с.

2 Шалугін В.С. Процеси та апарати промислових технологій: [Навч. посібник для студ. вищ. навч. закладів] / В.С. Шалугін, В.М. Шмандій. – К: Центр учбової літератури, 2008. – 392 с.

3. Гальперин Н.И. Основные процессы и аппараты химической технологии: [Учебн. пособие для студ. вузов] / Н.И. Гальперин – В двух книгах. – М: Химия, 1981. – 812 с.