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Intensification of humic acid extraction by pulse flow of vermicompost and sapropel slurries

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ABSTRACT

The extraction by pulse flow of slurry can be intensified in rotor–stator devices (RSDs). The humic acid (HA) yield after treatment with aqueous alkaline vermicompost slurry (VS) and sapropel slurry (SS) in the RSD is higher than that in the extraction apparatus with a helical ribbon impeller (HRI) at the same specific energy dissipation rate. The increase in the HA yield is caused by the destruction of particles and particle agglomerates of vermicompost and sapropel, deep penetration of the extractant in the pores of particles due to macro- and micropulsations in the fluid flow and cavitation.

1. Introduction

Humic acid (HA) is used in dyes, corrosion inhibitors, medicinal products, drilling fluids, plant growth stimulants (Tan, 2014). In industrial production HA is extracted from raw materials containing humic substances, using aqueous alkaline solution and vessels with anchor, gate or helical ribbon impellers. Helical ribbon impeller (HRI) can also be used in turbulent applications (Paul et al., 2004). HRI is effective for treatment of low-viscosity slurries, forming intensive radial and axis vortices in the vessel, and producing a mechanical action on the particles in the slurry by transverse blades and a helical surface of the blades. Particle size degradation, hydrodynamic flow pulsations, and cavitation increase the yield of water soluble HA due to an increase in the surface of contact between the phases, deep penetration of the solvent into the particle pores. These effects make it possible to obtain aqueous solutions of HA without using chemicals.

A promising direction is the development of devices with a multifactorial effect on slurry. The RSD operation principle is based on unsteady energy and substance flows (Paul et al., 2004; Bałdyga et al., 2007). RSDs have mechanical, hydrodynamic and acoustic effects on extraction processes in heterogeneous liquids (Promtov, 1997, 2009). To intensify the HA extraction process it is necessary to study RSD integrated effects on slurry.

In order to intensify solid-to-liquid extraction of a target component it is necessary to ensure that liquid penetrates into the pores of a solid body and is removed from the particle surface. In the RSD a heterogeneous liquid is subject to mechanical, hydrodynamic and acoustic effects through pulse, accelerating–decelerating nature of fluid flow motion in the device channels. Intensification of the extraction process in the RSD is determined by the energy expended on the slurry treatment.

The HRI is typically used when the viscosity of liquid is high. The viscosity of the VS and the SS was low. The HRI

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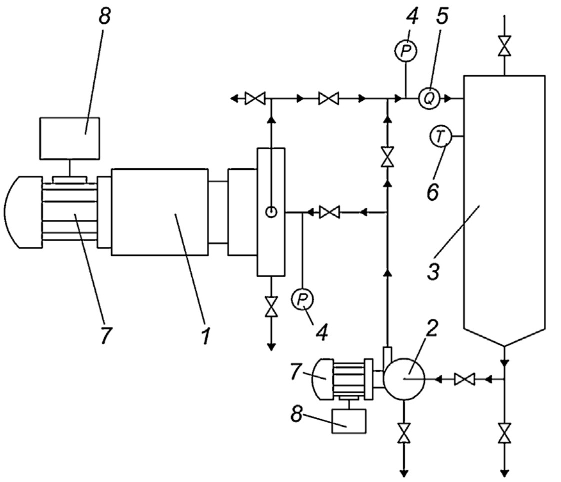

Fig. 1 – Schematic of the set-up for slurry treatment. 1 – RSD; 2 – pump; 3 – vessel; 4 – manometer; 5 – flowmeter; 6 – thermometer; 7 – electric motor; 8 – inverter.

was chosen because it had a strong mechanical effect on the suspension and agitated most of the fluid batch through the physical contact at a high rotational speed.

The aim of this work is to study the determinants of the HA yield from VS and SS for the RSD and in the HRI at the same level of energy consumption.

2. Experimental

The HA extraction from VS and SS was carried out in the prototype unit consisting of the industrial RSD (Fig. 1) and in the vessel with a HRI. The RSD has a cylindrical rotor and a cylindrical stator. The rotor and stator have rectangular slotted holes. The intensity of treatment in the RSD and in the HRI can be determined by the specific energy (dissipation energy). The specific energy in the RSD and in the HRI can be determined by the power spent by HRI or RSD and pump, W/kg. The power was measured by the inverter. The inverter displayed the total energy consumption, taking into account mechanical and electrical losses.

In the RSD we treated 90 kg of VS suspended in the solution with or without adding 1% alkali, and 90 kg of SS suspended in the solution with adding 1% alkali for 60 s at a temperature of $20\,^{\circ}C \pm 2\,^{\circ}C$. In the vessel with a HRI we treated 2 kg of VS in the solution with or without adding 1% alkali and 2 kg of SS in the solution with adding 1% alkali for 60 s at a temperature of $20\,^{\circ}C \pm 2\,^{\circ}C$. The ratio of components of the VS was 80% water or aqueous alkali solution and 20% dry vermicompost. The ratio of the components of the SS was 50% water or aqueous alkali solution and 50% sapropel gel.

The pressure was measured by testing manometers, and the temperature was measured by the SH-04016 digital single-channel temperature gauge with a relative error of measurement ±0.3%. The flow was measured by the VMG-50 flowmeter with a relative error of measurement ±2.0%. The frequency of rotor spinning and power of RSD was modified and measured by the VESPER EI-7011-100H inverter with a relative error of measurement ±0.01%. The inverter was connected via the RS485 communication protocol to the computer to control and record the motor shaft rotational speed and power consumption when operating the machine. The pump shaft speed was changed and measured with the TOSHIBA TOSVERT VF-S11 frequency inverter with a relative error of measurement ±0.01%. The centrifugal pump supplied the slurry through the RSD at a rate of $Q = 43 \pm 1\,m^3/h$. The pressure at the inlet of the RSD was $P_1 = 0.45 \pm 0.02$ MPa, and the pressure at the outlet of the RSD was $P_2 = 0.05 \pm 0.01$ MPa.

The RSD parameters were as follows: the rotor diameter $d_R = 0.25$ m; the width $a = 0.003$ m and the height $h_c = 0.04$ m the rectangular channels of the rotor and stator; the rotor height $h = 0.05$ m; the gap between the rotor and stator $\delta = 0.0001$ m; the number of channels in the rotor and the stator $z = 36$; the length of the channel of the stator $l_S = 0.035$ m; the length of the channel of the rotor $l_R = 0.015$ m.

The slurries were treated using the universal laboratory AID type MPW-309 with the HRI for the HA extraction from VS and SS. The frequency of spinning and power of the HRI was changed and measured by the TOSHIBA VFnC3S inverter with a relative error of measurement ±0.01%.

The HRI parameters were as follows: the HRI diameter $d_S = 0.08$ m; the blade height $h = 0.18$ m; the number of blades $f = 2$; the blade pitch (height of one turn around the helix) $p = 0.05$ m; the blade-wall clearance $e = 0.015$ m; the blade width $w = 0.01$ m; the vessel height $H = 0.3$ m, the vessel diameter $D = 0.11$ m. The density and viscosity of the VS were $\rho = 1150\,kg/m^3$; $\mu = 1.23 \cdot 10^{-3}$ Pa s. The density and viscosity of the SS were $\rho = 1050\,kg/m^3$; $\mu = 1.17 \cdot 10^{-3}$ Pa s.

The fractional composition of fine particles of vermicompost was measured with the Micro Sizer 201C laser particle analyzer.

The concentration of the humic acid in the aqueous solution of VS or SS was calculated in compliance with ISO 5375-85 "Solid fuel. Method for determination of humic acids yield".

3. Results and discussion

3.1. *Calculation of the specific energy of RSD and HRI*

The specific energy dissipated in the volume of the slurry is composed of the energy N_1 spent on the rotor spinning of the RSD, and energy N_2 expended by the external pump on pumping the slurry through the RSD. The specific energy dissipated in the volume of the slurry is expended on mechanical, hydrodynamic and acoustic effects.

The RSD specific energy dissipation rate ε_1, W/kg is:

$$\varepsilon_1 = (N_1 + N_2)/m_1, \tag{1}$$

where m_1 is the mass of treated slurry, kg; N_1 is the power required to spin the rotor, W; N_2 is the power expended by the pump on the slurry supply, W.

The power required to spin the rotor was determined by the formula (Promtov et al., 2015):

$$N_1 = Re^B \left(\frac{\delta}{R}\right)^{k_1} \left(\frac{az}{R}\right)^{k_2} \left(\frac{h}{R}\right)^{k_3} \omega^3 \rho R^4 h, \tag{2}$$

where $Re = \omega R^2 \rho/\mu$; ω is angular velocity of the rotor, s^{-1}; R is the radius of the rotor, m; $B = -0.21$; $k_1 = 0.2$; $k_2 = 0.7$; $k_3 = -1.3$ are empirical coefficients.

The power N_2 expended by the pump on the slurry supply is calculated as

$$N_2 = \Delta P \cdot Q, \tag{3}$$

where Q is the flow rate, m^3/s; ΔP is the pressure drop, Pa.