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RESEARCH ARTICLE

Rheology analysis of sago processing wastewater with a variable starch content

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ABSTRACT

Rheology properties are considered to be essential for designing a bioreactor to understand the flow behavior of materials inside the reactor. In this regard, rheological measurements of sago processing wastewater with different starch concentrations ranged 10, 20, 30, 40, 50, 60, 70, and 80 g L^{-1} were evaluated. The sago wastewater with a starch concentration of 10 and 20 g L^{-1} indicated a non-Newtonian behavior, showing yield stress and shear thinning. Based on the results, it is concluded that sago wastewater with starch concentrations up to 20 g L^{-1} could be well suited for airlift bioreactors used for the microbial lipid production process.

Keywords: *Sago wastewater, Starch, Rheology, Shear stress, Viscosity.*

INTRODUCTION

Rheology is a science, which has had its main development in the transport field, in particular with the studies on bitumen and conglomerate used to pave roads, motorways and civil areas. Every fluid was studied by a rheological point of view, especially when it is necessary to understand its behavior in certain mechanical conditions (Novarino *et al.,* 2010). Rheological properties are crucial in wastewater processing plants since they severely impact the flow behavior and many aspects that interfere with process performance and energy consumption.

Sago processing wastewater (SWW) is one of the prominent southern industrial wastewater streams. During the extraction of the starch from tapioca tuber, 20,000 to 30,000 L of water per ton of sago was required, which eventually produced an equal quantity of wastewater was high in chemical oxygen demand up to 25 g.L^{-1} with biodegradable starch content varies between 4 to 7 g.L^{-1}(Sen and Suttar, 2012). While the sago wastewater is starchy, it serves an excellent source of microbial lipid production by the oleaginous microorganisms.

The rheological property of SWW can be defined as a suspension of organic and inorganic particles into a fluid; the presence of the suspended particles involves the fact that some interactions happen among solid-solid and solid-water particles whose characteristics depend on many factors such as particle dimensions, pH and temperature.

The main rheological parameter that is important to investigate is the viscosity; this parameter provides information about flow characteristics when it is subjected to deformations inflow conditions. Some aspects that influence the rheological behavior are the viscosity of the dispersion medium, the particle concentration, the particle size and shape, the particle-particle and particle-dispersion medium interactions. The solids concentration is the main parameter influencing the SWW viscosity; in particular an increase of solids concentration determines an increase of SWW non-Newtonian behavior instead of the Newtonian one that is typical of water and solutions with low solids concentration (Sanin,2002). The present study has been conducted to evaluate the rheological behavior of SWW prepared at various starch concentrations, which may be useful to design an airlift bioreactor for the microbial lipid production process.

MATERIAL AND METHODS

The rheological properties of SWW were studied by using the Modular Compact Rheometer MCR 52 (Anton Parr). Controlled shear-stress measurements were done using parallel-plate geometry of 25 mm diameter, with a gap of 2 mm, at a constant temperature of 30ºC. The applied shear stress ranged from 0.1 to 200 Pa. The properties such as viscosity–shear rate and shear stress–shear rate relationship of the sago wastewater with various starch concentrations for the growth of microorganisms were measured at different shear rates from 1 to 100 s^{-1}. The experiments were carried out at 30°C at different starch concentrations of

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sago wastewater viz., 10, 20, 30, 40, 50, 60, 70, and 80 g L^{-1}.

Bingham, Power-law, Casson, Ostwald, and Herschel-Bulkley rheological models were used to describe the viscous flow behaviors of wastewater samples. Before the measurements were carried out, a sample with the desired concentration was prepared and homogenized. The rheological measurements were carried out in triplicate for each sample of SWW with the addition of different starch concentrations. The rheological data were obtained from the Rheoplus 32V3.61 software and used for further analyses.

RESULTS AND DISCUSSION

The apparent viscosity and yield stress of the SWW with starch concentrations (10, 20, 30, 40, 50, 60, 70 and 80 g L^{-1}) were measured by modular compact rheometer at 30 °C. From the experimental data, two plots were drawn for shear stress (Pa) versus shear rate (s^{-1}) and viscosity (Pa.s) versus shear rate (s^{-1}). Various rheological models were used to analyze the experimental data of SWW. Herschel-Bulkley model was found to be the best fit for the shear stress versus the shear rate of tested sago wastewater samples, and it showed a good representation of the experimental data as compared to the other four models. Herschel - Bulkley model was found to be the best fit for the sago wastewater samples containing starch content ranging from 10 to 80 g L^{-1}.

Table 1. Different rheological models to analyze the experimental data of SWW

Herschel-Bulkley model	:	$= _y+K^n$
Bingham model	:	$= _y+K$
Casson model	:	$^{0.5}= (_y)0^{.5}+n (^n)^{0.5}$
Ostwald model	:	$= K^n$
Newton model	:	$= ^n$

The Yield stress provides the necessary initial energy to induce the flow of sago wastewater samples at high solid concentration. The starch particles were found to be highly disordered and misaligned, thereby increasing the residual stress.

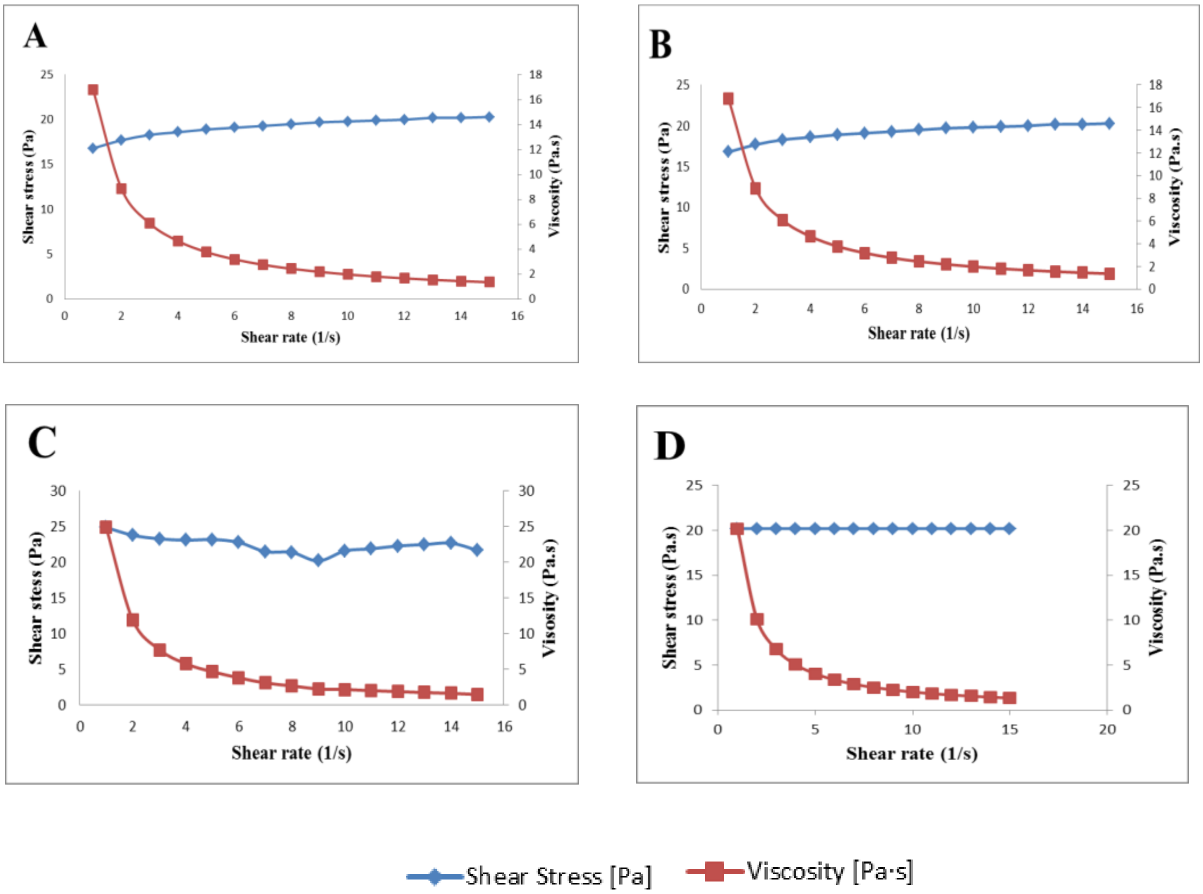

Figure 1. Rheology behavior of SWW. A. Raw sago wastewater (SWW), B. SWW with the addition of 10 g.L^{-1} C. SWW with the addition of 20 g.L^{-1} D. SWW with the addition of 30 g.L^{-1}

The breakdown of a three-dimensional structure along with the increase of shear rate caused the release of interstitial water, thereby reducing the apparent viscosity, resulting in shear-thinning behavior (Sato, 1995; Seka and Verstraete, 2003).

For any non-Newtonian fluid, the relationship between shear stress and shear rate is not constant. The viscosity of this kind of fluids depends on the applied shear force and time. Shear-thinning behavior was observed for raw SWW. It clearly showed that a decrease in viscosity of SWW was observed with respect concerning an increase in shear rate (Fig. 1). The main cause of this kind of flow behavior may be due to the breakdown of structural units of tested materials and the hydrodynamic forces generated by shear action (Rao, 2007).

The Herschel - Bulkley model has been used to model shear-thinning behavior in a diverse range of materials including blood, printing ink, food products, mineral, polymer suspensions and composites (Nguyen and Boger, 1992), also biomass slurries (Pimenova and Hanley, 2004; Kiruthika *et al.,* 2017). This shear-thinning behavior was also observed in different kind of suspensions such as fruit pulps like litchi juice (Sharma *et al.,* 2014), mango (Bhattacharya, 1999), slurries of limestone (He *et al.,* 2006), nickel (Bobicki *et al.,* 2014) and biomass of corn stover (Viamajala *et al.,* 2009). However, the SWW at different starch concentrations from 10, 20, 30, 40, 50, 60, 70 and 80 g L^{-1} followed the non-Newtonian shear thickening behavior. After the starch concentration of 20 g L^{-1}, there is no change observed in the viscosity and shear stress concerning the shear rate, which be due to the presence of starch content in the SWW. Shear thickening fluid, which tends to deform less or increase in viscosity as shear stress increases. So the starch concentration up to 20 g L^{-1} is chosen for optimization study.

CONCLUSION

The rheological study concluded that the Herschel-Bulkley model was the best fit for sago processing wastewater with starch concentrations of 10 and 20 g L^{-1} and they exhibited pseudo-plastic or shear-thinning behavior.Results also showed that starch concentrations of up to 20 g L^{-1} of sago processing wastewater could be used to design a bioreactor for microbial lipid production more particulalry airlift bioreactor.

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