CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
 ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021128

Rheological Characterization of Recovery Yeast (*Saccharomyces cerevisiae*) Cream from Brewing Process

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This study presents models to describe the rheological behavior of recovery *Saccharomyces cerevisiae* yeast cream after eight fermentations from a brewing process. It was verified that the suspension rheological behavior is influenced by temperature. For temperatures up to 45 °C, the suspension behaves as Newtonian fluid. For temperatures between 45 °C and 55 °C, occurs modification in the yeast consistency, and it depends on the plastic viscosity. For $55^oC \leq T \leq 75^oC$, the waste yeast suspension behaves as Bingham plastic. This biomass suspension was centrifuged, and the precipitate follows Ostwald-Waele model, and it is strongly influenced by temperature.

1. Introduction

The wasted biomass of *Saccharomyces cerevisiae* obtained from beer production is, in general, considered as commercial commodity utilized as nutritional complement due to its high protein content (Baccarin and Pezzato, 2001; Alvim et al, 2002; Santucci et al., 2003; Guilherme et al., 2007; Junqueira et al., 2008). This biomass has also been studied as a quite promising bioadsorbent, especially to adsorb heavy metals (Wilhelmi et al., 1996; Özer and Özer, 2003; Han et al., 2004; Çabuk et al., 2007; Chen and Wang, 2007). Independently on the use of biomass, it is necessary to know its rheological behaviour for further processing as filtration and centrifugation.
Fluid rheological behaviour has been described by relation between the shear stress (τ) and its respective deformation $(\dot{\gamma})$, resulting in:

$$\tau = \tau_0 + k(\dot{\gamma})^n \tag{1}$$

where τ_0 is the initial shear stress; *k* is the consistency coefficient; *n*, flow behavior index. Fluids that do not need an initial shear stress (τ_0) to flow are described by the power law or Ostwald-Waele model according with:

$$\tau = k(\dot{\gamma})^n \tag{2}$$

When n = 1, the rheological behaviour is known as Newtonian fluid. In case of $n \neq 1$, the fluid is classified as pseudo plastic or dilatant according to *n* value. When n < 1, they are known as pseudo plastic fluids, and when n > 1, they are called dilatant fluids.

Please cite this article as: Cremasco M. A. and Melo K. P., (2010), Rheological characterization of recovery yeast (saccharomyces cerevisiae) cream from brewing process, Chemical Engineering Transactions, 21, 763-768 DOI: 10.3303/CET1021128

Fluids that need an initial shear stress to flow are known as Bingham plastic, and present linear relationship between shear stress and strain rate, after initial shear stress (τ_0) or

$$\tau = \tau_0 + \mu_p(\dot{\gamma}), \text{ to } \tau > \tau_0 \quad (3)$$

where μ_p is the plastic dynamic viscosity.

The aim of this paper is to present the rheological characterization of waste yeast suspension from a brewing process and of the sediment from yeast suspension centrifugation.

2. Experimental

The biomass suspension utilized was resulted from beer manufacturing. This suspension was obtained from beer storage after eight fermentations. The yeast biomass suspension (YS) can be identified as unbound-dispersed group, in which the particles are freely suspended in a dispersed liquid phase. YS was centrifuged using a HAAKE Z20 Ti, and the precipitate (YP) can be characterized as bound-dispersed suspension, in which the particles are connected in a dispersed liquid phase. The rheological behaviour yeast tests were performed by a HAAKE rotational and dynamic rheometer, Rheostress RS1 type. The geometry (Couette flow) consists of concentric cylinders of 20 mm in diameter, HAAKE Z20 Ti - DIN 53019/ISSO 3219. The cylinder internal and external radius are 10 and 11 mm, respectively; the cylinder internal length is 30 mm. The temperature was controlled by external baths (HAAKE DC30) with 0.1 ºC of precision. Deformation rate was made from 10 s^{-1} to 500 s^{-1} for YS, and 0.1 s^{-1} to 15 s^{-1} for YP.

3. Results and Discussion

The rheological study of YS was performed by ten rheometer operation temperatures: 25 ºC, 35 ºC, 40 ºC, 45 ºC, 50 ºC, 55 ºC, 60 ºC, 65 ºC, 70 ºC and 75 ºC, obtaining one hundred points for each experiment. The results for shear stress (τ) as result of strain rate ($\dot{\gamma}$) are shown in Figure 1. It is verified, for reasonable range of deformation rate, there is a linear dependence of shear stress with deformation rate for $25^oC \le T \le 50^oC$ when compared with range $55^oC \le T \le 75^oC$. For the first range, the straight lines tendency to converge to graph axis (0.0) in *y* = *ax* form. Table 1 shows the angular coefficient values associated with each temperature.

It is verified that the rheological curve for YS ranging between 25 °C and 50 °C is described by Eq. 2 with n = 1, as:

$$\tau = \mu\dot{\gamma} \quad (4)$$

where μ is dynamic viscosity. Eq. 4 represents, for $25^oC \le T \le 50^oC$, the YS suspension has a *Newtonian fluid* behaviour, where the inclination coefficient, *a*, is the dynamic viscosity, which is temperature dependent.

Table 1 YS rheological behavior (between 25 °C and 50 °C).

Temperature (^oC)	*Inclination coefficient, a*	*Determination coefficient, r^2*
25	1.401×10^{-2}	0.999
35	1.020×10^{-2}	0.999
40	0.921×10^{-2}	0.999
45	0.655×10^{-2}	0.995
50	0.439×10^{-2}	0.990

This dependence can be correlated, with $r^2 = 0.987$, as

$$\mu = 2{,}364\times10^{-2} - 3{,}788\times10^{-4}\,T \qquad (5)$$

with μ in Pa.s; and T in ^oC.

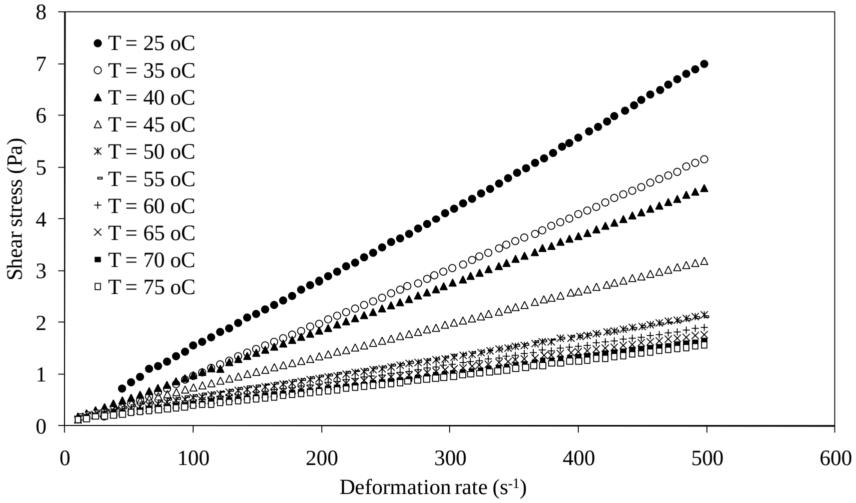

Figure 1: Rheological curves for waste yeast suspension, YS.

Table 2 Rheological waste yeast suspension behaviour (between 55 °C and 75 °C).

Temperature (^oC)	*Inclination coefficient, a*	*Interception coefficient, b*	*Determination coefficient, r^2*
55	0.386×10^{-2}	0.194	0.999
60	0.356×10^{-2}	0.121	0.999
65	0.329×10^{-2}	0.114	0.999
70	0.307×10^{-2}	0.104	0.999
75	0.291×10^{-2}	0.091	0.999

The rheological model, for YS and $55^{o}C \leq T \leq 75^{o}C$ is describes by Eq. 3, and the waste yeast suspension behaves as Bingham plastic. The coefficients, *a* and *b*, are presented in Table 2, and recognized as the plastic dynamic viscosity (μ_p) and initial shear stress (τ_0), respectively. This table shows the dependence of μ_p and τ_0 with temperature. For plastic dynamic viscosity this dependence can be write, with r^2 = 0.986, as

$$\mu_p = 6{,}445 \times 10^{-3} - 4{,}780 \times 10^{-5} T \quad (6)$$

with μp in Pa.s; T in °C.
The result obtained for the initial shear stress (τ0), with r2 = 0.990, is

$$\tau_0 = 14{,}19 - 0{,}627 \times 10^{-2} T + 9{,}304 \times 10^{-3} T^2 - 4{,}600 \times 10^{-5} T^3 \quad (7)$$

with τ_0 in Pa; T, in ^{o}C.
Figure 2 establishes the dependence of the plastic dynamic viscosity with temperature, or how temperature influences the fluid consistency. There is a substantial change in the plastic viscosity when temperature ranges between 45 °C and 55 °C, showing the change from Newtonian to non-Newtonian (Bingham plastic) rheological fluid, influencing, in this intermediate zone, the initial shear stress values (τ_0).

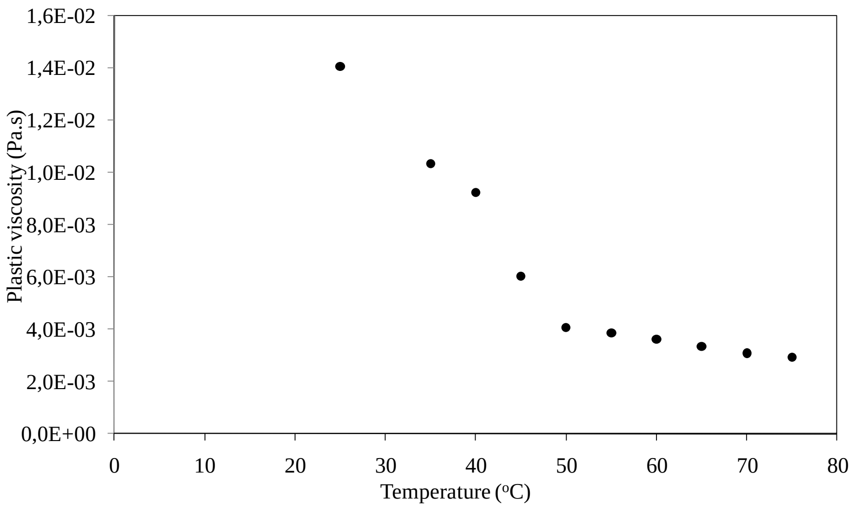

Figure 2: Plastic dynamic viscosity dependence on temperature for YS.

The increase in temperature causes an increasing in the molecular agitation intensity, which causes the breaking of molecular binding, and a change in the present physical situation, from an unbound-dispersed suspension to a soft pastelike bound-dispersed type. Note that for temperature above 50 ^{o}C this effect is minimized when compared with situations of temperatures below 45 ^{o}C. In other words, for temperatures below 45 °C, its effect is more important, which is a characteristic of unbound-dispersed materials (suspended particles are more dispersed). Temperatures over 50 °C there is an increase of particle concentration in the suspension, characterizing the bound-dispersed type.

In order to evaluate the rheological behaviour of precipitate cream from centrifugation (YP) of biomass suspension (YS), four tests were performed for the operation temperatures of 25 ºC, 35 ºC, 40 ºC and 45 ºC, obtaining one hundred points for each assay. The results for values of shear stress (τ) as result of strain rate ($\dot{\gamma}$) are shown in Figure 3. From this figure, it was observed the tendency to describe the curves as $y = ax^b$. The coefficients *a* and *b* are in Table 3.

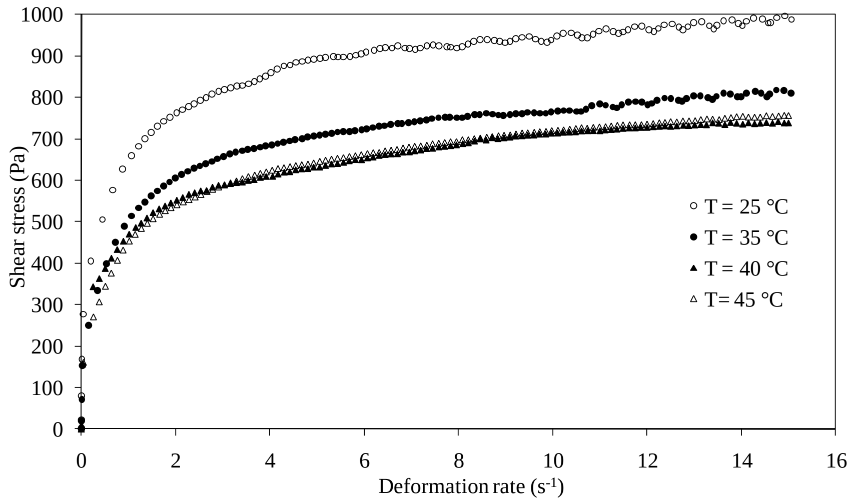

Figure 3: Rheological curves for waste yeast precipitate, YP.

Table 3 Rheological waste yeast precipitate.

Temperature (°C)	*a* coefficient	*b* coefficient	Determination coefficient, r^2
25	702.12	0.132	0.961
35	548.23	0.149	0.977
40	491.27	0.158	0.993
45	482.46	0.174	0.990

The rheological model for YP can be described by Eq. 2, in which the flow behaviour index, *n*, is identifies with *b* coefficient, and it is lower that unity, denoting pseudo plastic behaviour. This index presents temperature dependence, with r^2 = 0.997, as

$$n = 0.123 + 5.584\times10^{-4}T + 3.655\times10^{-5}T^2 \tag{8}$$

with T in °C. The consistency index, *k*, identified with *a* coefficient, is temperature dependent, and can be correlated, with r^2 = 0.997, as

$$k = 1531.496 - 45.339T + 0,488T^2 \tag{9}$$

with k in Pa.s; and T in °C.

4. Conclusions

In this paper, was verified that the evaluated residual yeast suspension behavior is strongly influenced by temperature. For temperature up to 45 °C, the suspension behaves as Newtonian fluid. For temperature range between 45 °C and 55 °C, an important rheological change was verified, which depends on the plastic viscosity, indicating the change in the rheological behaviour of the fluid from Newtonian fluid to non-Newtonian fluid, as well as in the suspension from unbound-dispersed to bound-disperse. For $55^o C \leq T \leq 75^o C$ the waste yeast suspension behaves as Bingham plastic. After centrifugation of yeast suspension, the precipitate follows the power-law model in $25^o C \leq T \leq 45^o C$. The information in the previous paragraph, besides considering the rheological characterization intended in this study, is also important to define the operational conditions of the equipment used for recovery yeast concentration for subsequent drying, storage and commercialization.

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