Biblid: 1450-5029 (2009) 13; 4; p.320-323
UDK: 547.458.82:664.1:582.661.15

Original Scientific Paper
Originalni naučni rad

VISCOSITY CHANGE OF SUGAR BEET MOLASSES WHILE ADDING STARCH
PROMENA VISKOZNOSTI MELASE ŠEĆERNE REPE DODAVANJEM SKROBA

Svetlana POPOVIĆ, MSc, Dr. Ljubinko LEVIĆ, Dr. Ratomir PAUNOVIĆ, Nevena MIŠLJENOVIĆ, BSc, Gordana KOPRIVICA, BSc
Faculty of Technology, 21000 Novi Sad, Bulevar cara Lazara 1
e-mail: megamum@uns.ac.rs

SUMMARY

Viscosity change of sugar beet molasses while adding different amount of starch, up to 2% and temperature diapason of 40-60 °C was studied. Results show that system has non – Newtonian fluid characteristics. Coefficient of consistency decreased to a great extent when temperature was increased. Influence of added starch wasn't significant as temperature change, but the increase of the coefficient of consistency was achieved. Arrhenius's exponential curve equation for viscosity and temperature and "Power law" rheological model, contigent shear stress upon shearing velocity, was used for the description of combined influence temperature and starch on viscosity change of sugar beet molasses. Recommended equation fits with experimental results in a satisfactory level, and can be used for the description of rheologycal changes in system.

***Key words**: sugar beet molasses, starch, apparent viscosity, rheology appears*

REZIME

Promena viskoznosti melase šećerne repe ispitana je pri dodavanju različitih količina skroba, do 2%, i pri temperaturnom dijapazonu 40-60 °C. Dobijeni rezultati ukazuju na nenjutnovsko ponašanje sistema. Koeficijent konzistencije značajno se smanjuje pri porastu temperature. Uticaj dodatog skroba nije izražen kao pri promeni temperature, mada je zapaženo povećanje koeficijenta konzistencije sa porastom sadržaja skroba. Kako bi se opisao kombinovani uticaj temperature i skroba na promenu prividne viskoznosti melase šećerne repe, odnosno njeno reološko ponašanje, korišćena je Arenius-ova jednačina sa eksponencijalnom zavisnošću viskoznosti i temperature i stepeni („Power law") reološki model zavisnosti napona smicanja od brzine smicanja (deformisanja). Predložene jednačine saglasne su sa eksperimentalnim rezultatima na zadovoljavajućem nivou i mogu da se iskoriste za opis reoloških promena navedenog sistema.

***Ključne reči**: melasa šećerne repe, skrob, prividna viskoznost, reološke pojave*

INTRODUCTION

Molasses, defined as the concentrated liquid extract of the sugar refining process, depends on processing technology, sugar beet quality and composition variation. Composition varies in the following range: dry substances 76 – 84% (sucrose 46 – 51 %), reducing substances 1.0 – 2.5%, raffinose 0.8 – 1.2%, inverted sugar 0.2 – 1.0%, volatile acids 1.2%, pigments 4 – 8% and ash 6 – 10% [1]. Molasses is used in production of ethanol [5] and baker's yeast [10], as an additive in animal feed industry and natural sweetener in bakery products [8, 12].

Flow behavior of fluids is important in engineering application related to their processing and handling. Knowledge of appropriate flow models is necessary for design of pumps and piping system and design of processes related to mixing, and heat and mass transfer. Previous studies of rheological behavior of molasses were carried out by *Broadfoot* and *Miller* [2], *Kaur* et al. [4], *Leong* and *Yeow* [6] and *Toğrul* and *Arslan* [13]. It was found that the rheological behavior of molasses depends on nature and amount of non-sucrose components present in it.

Starch is such constituent of molasses which if present, even in a small percentage, as a non-sucrose component increases viscosity of molasses. Also, as a drying agent, starch is used to dry molasses either in drum or spray driers. However, only *Kaur* et al. [4] reported data about effect of starch on the rheological behavior of molasses. *Kaur* et al. [4] studied the effect of different starch concentrations on rheology of sugar molasses as well as the effect of temperature. Primary, it's important in case if molasses was used in confectionery and bakery industry because in their products, the temperature and concentration of starch are increased [7, 11].

The aim of this work was, firstly, to investigate influence of temperature and different levels of starch content on rheological behavior of sugar beet molasses, and secondly, to propose mathematical model for prediction of combined effect of temperature and added starch on the apparent viscosity of molasses.

MATERIAL AND METHODS

Preparation of sample and analytical determination

Molasses was purchased from Sugar Factory in Bač (Serbia). The Brix was determined by Refractometer (Abbe, Carl Zeiss, Jena). Raw sugar beet molasses did not contain starch. Water-soluble starch was collected from Ipok Starch Factory (Serbia). Starch was added to 300 g of raw molasses in varying amounts of 2, 4 and 6 g. Each mixture of starch and molasses was stirred thoroughly for half an hour so that homogenous mixture was obtained. These mixtures of molasses and starch were then taken into water-jacketed stainless steel cylindrical 55 ml tank. Using rotational viscometer (Gebbrüder Haake, Germany) apparent viscosities were determined varying rpm at several temperatures.

Rheological properties

Rheological parameters (shear rate, shear stress and apparent viscosity) of raw molasses and starch mixtures were recorded at 40, 45, 50, 55 and 60 ^{o}C. In order to attain desired temperature, sample was kept in water-jacketed tank for a half an hour. As removable parts of used viscometer torque measuring head MK 500 and spindle MV II were used. Chosen rpm was such that the torque was maintained within 10-90%. Shear rate, shear stress and apparent viscosity data were obtained directly from the instrument.

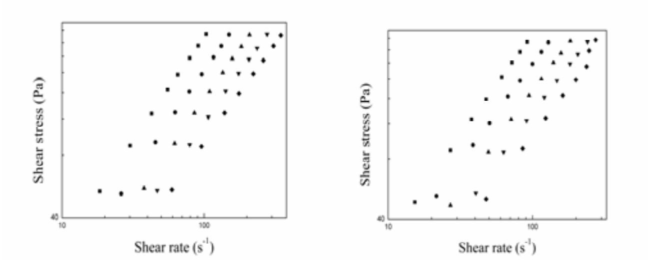
RESULTS AND DISCUSSION

Rheological model

In order to analyze the flow behavior of molasses, without and with added starch, curves of shear stress versus shear rate were plotted in log-log diagram. As shown by Figs. 1 and 2, the curves are consistent with the “Power law” model [3]:

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

where τ is shear stress (Pa), γ is shear rate (s^{-1}), k consistency coefficient (Pa s^n) and n the flow behavior index.



a) b)

Fig. 1. Plot of shear stress (Pa) vs shear rate (s^{-1}) for: a) raw molasses: (■) 313.15 K, (●) 318.15 K, (▲) 323.15 K, (▼) 328.15 K, (♦) 333.15 K and b) molasses with 0.6% of starch: (■) 313.15 K, (●) 318.15 K, (▲) 323.15 K, (▼) 328.15 K, (♦) 333.15 K.

Sl. 1. Zavisnost napona smicanja (Pa) od brzine smicanja (s^{-1}) za: a) čistu melasu: (■) 313,15 K, (●) 318,15 K, (▲) 323,15 K, (▼) 328,15 K, (♦) 333,15 K i b) melasu sa 0,6% skroba: (■) 313,15 K, (●) 318,15 K, (▲) 323,15 K, (▼) 328,15 K, (♦) 333,15 K

Consistency coefficients (k) and flow behavior indexes (n) were calculated by fitting shear stress and shear rate data by the model (1) and presented in Table 1.

Table 1. Rheological parameters and activation energy values of molasses

Tabela 1. Reološki parametri i vrednosti energije aktivacije melase

Concentration Koncentracija (%)	T (°C)	Consistency coefficient Koeficijent konzistencije (Pa s^n)	n	Arrhenius constant Arrhenius-ova konstanta (μ Pa s^n)	Energy of activation Energija aktivacije (kJ/mol)	σ	R^2
Raw molasses Sveža melasa	40	2.820	1.013			0.006	0.999
	45	1.973	1.007			0.008	0.999
	50	1.485	0.998	0.066	45.64	0.009	0.999
	55	1.263	0.997			0.009	0.999
	60	1.068	0.965			0.009	0.999
0.6 %	40	2.986	1.026			0.008	0.999
	45	2.519	0.988			0.007	0.999
	50	1.821	0.989	0.219	42.82	0.015	0.999
	55	1.540	0.968			0.019	0.999
	60	0.996	1.01			0.06	0.995
1.3 %	40	3.655	1.006			0.003	0.999
	45	2.537	1.004			0.009	0.999
	50	2.151	0.971	4.95	34.96	0.013	0.999
	55	1.813	0.967			0.018	0.999
	60	1.508	0.937			0.015	0.999
2 %	40	3.896	1.003			0.007	0.999
	45	2.974	0.985			0.015	0.999
	50	2.354	0.965	0.41	41.8	0.012	0.999
	55	1.988	0.934			0.016	0.999
	60	1.390	0.945			0.073	0.993

As it was expected, the consistency coefficient (k) is found to decrease significantly with increase of temperature. Regarding the effect of starch content on the viscous nature of the system, the consistent trend could not be observed because of some scattering of the calculated consistency coefficients. However, a general increase of consistency coefficients with increase of starch content is indicated. The flow behavior index (n) values do not differ significantly from unity, although some increase of pseudo plastic behavior with increase of temperature and increase of starch concentration is noticed.

Effect of temperature and starch concentration on viscosity

The Arrhenius equation:

$$\mu_a = \mu_o e^{\frac{E_a}{RT}} \tag{2}$$

was found to be suitable to describe the effect of temperature, where μ_a is apparent viscosity (Pa s^n), the concentration dependent parameter μ_o can be interpreted as the viscosity at the infinite temperature (Pa s^n), E_a is activation energy (J/mol), R is the molar gas constant (J/mol K) and T is temperature (K).

The values of activation energy and pre-exponential parameter μ_o, calculated by the least square method, are reported in Table 1. To describe the effect of starch concentration on the parameter μ_o, the following exponential relationship was tried [9]:

$$\mu_o = \delta\, exp(\varepsilon C) \tag{3}$$

where δ (Pa s^n) and ε ($\%^{-1}$) are parameters, and C is concentration of starch (% w/w).

By combining equations (2) and (3), the following single equation for predicting viscosity is obtained:

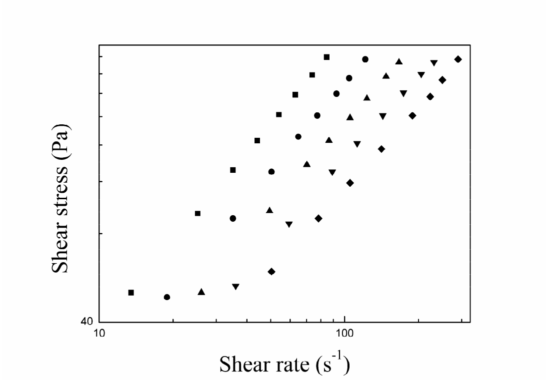
$$\mu_a = \delta\, exp(\varepsilon C) exp\left(\frac{E_a}{RT}\right) \tag{4}$$

As it is illustrated by Fig. 3, the effect of starch content on the viscosity was found to decrease with increase of temperature, that was consistent with the selected model (4).

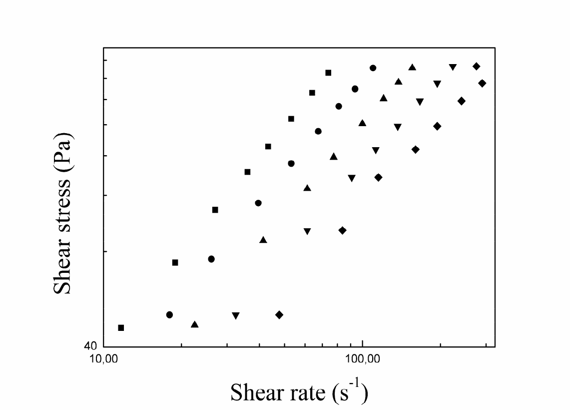
The values of parameters δ and ε were calculated by the nonlinear least square method using the statistical package *Statistica 7.0*. The resulting empirical equation that is valid in the studied interval of temperatures and starch concentrations is as follows:

$$\mu_a = 0.189 \cdot 10^{-8} exp\left(\frac{6626.55}{T} + 0.142C\right) \tag{5}$$

The parity plot of experimental data and predictions by Eq. (5), presented in Fig. 4, shows a fairly good agreement between experimental and predicted viscosities of molasses in the observed temperature and starch concentration ranges. In Fig. 5 a three-dimensional graph of the Eq. 5. is shown.



c)



d)

Fig. 2. Plot of shear stress (Pa) vs shear rate (s^{-1}) for: c) molasses with 1.3% of starch: (■) 313.15 K, (●) 318.15 K, (▲) 323.15 K, (▼) 328.15 K, (♦) 333.15 K and d) molasses with 2% of starch: (■) 313.15 K, (●) 318.15 K, (▲) 323.15 K, (▼) 328.15 K, (♦) 333.15 K

Sl. 2. Sematski prikaz zavisnosti napona smicanja (Pa) od brzine smicanja (s^{-1}) za: melasu sa 1,3% skroba: (■) 313.15 K, (●) 318.15 K, (▲) 323.15 K, (▼) 328.15 K, (♦) 333.15 K i d) melasu sa 2% skroba: (■) 313.15 K, (●) 318.15 K, (▲) 323.15 K, (▼) 328.15 K, (♦) 333.15 K

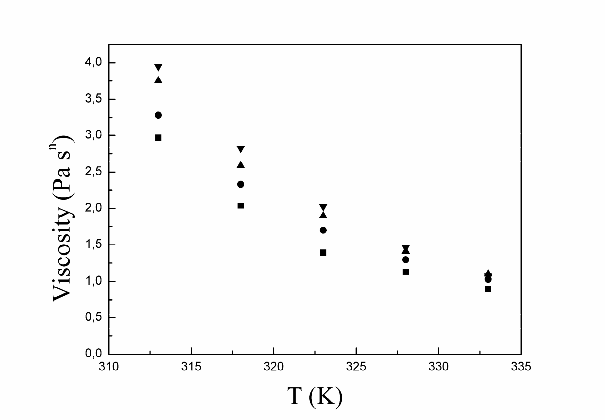


Fig. 3. Plot of apparent viscosity (Pa s^n) vs temperature (K): (■) raw molasses, (●) 0.6% of starch, (▲) 1.3% of starch, (▼) 2% of starch

Sl. 3. Šematski prikaz zavisnotsi prividne viskoznosti (Pa s^n) od temperature (K): (■) čista melasa, (●)sa dodatkom 0,6% skroba, (▲) sa dodatkom 1,3% skroba, (▼) sa dodatkom 2% skroba

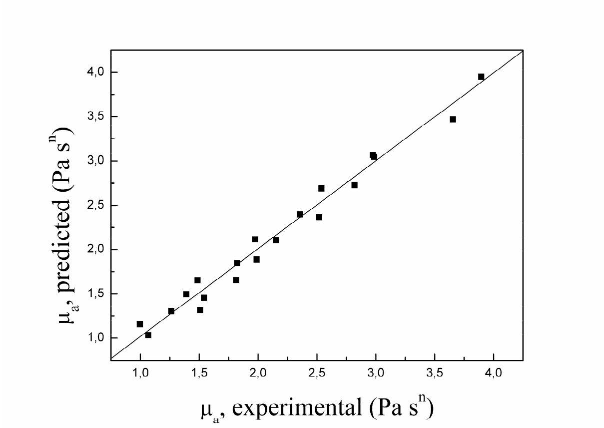


Fig. 4. Predicted versus experimental apparent viscosity of molasses

Sl. 4. Zavisnost predviđenog i ekperimentalno određenog prividnog viskoznost melase

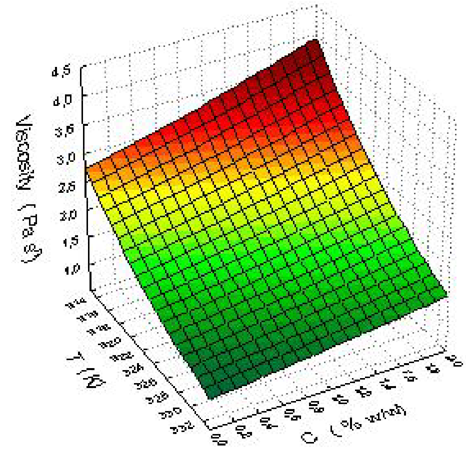


Fig. 5. Response of the apparent viscosity (Pas^n) on temperature and starch concentration variations, calculated using Eq. (5)

Sl. 5. Ponašanje prividnog viskoznost (Pas^n) zavisno od temperature i različitih koncentracija skroba, izračunato korišćenjem jednačine (5)

CONCLUSION

The studied sugar beet molasses with added starch exhibited some pseudoplastic behavior that was slightly promoted by increase of temperature and by starch addition. General increase of consistency coefficients with increase of starch content was indicated. An Arrhenius-type empirical equation, with the pre-exponential factor varying exponentially with starch content, was established for predicting combined effects of temperature and starch concentration on the apparent molasses viscosity. The proposed equation proved to fit the experimental data satisfactory and could be useful for design purposes.

*ACKNOWLEDGEMENTS**:** This research is part of the project supported by the Ministry of Science and Technological Development, Republic of Serbia, TR – 20112, 2008-2010.*

LITERATURE

[1] Bolobova, A. B., and V. I. Kondrashchenko*:* Use of yeast fermentation waste as a biomodifier of concrete (review), Applied Biochemistry and Microbiology, 36 (2000), 243-253.

[2] Broadfoot, R., and K. F Miller: Rheological studies of massecuites and molasses. International Sugar Journal, 92 (1990), 107-112.

[3] Heldman, D. R., and R. P. Singh: Food process engineering, AVI Publishing, West Port 1981.

[4] Kaur, S., Kaler, R. S. S., and A. Aamarpali: Effect of starch on the rheology of molasses. Journal of Food Engineering, 55 (2002), 319-322.

[5] Kurtanjek, Z.: Principal component ANN for modeling and control of baker's yeast production, Journal of Biotechnology, 65 (1998), 23-25.

[6] Leong, Y. K., and Y. L. Yeow: Processing the Couette viscometry data of molasses by Tikhonov regularization. International Sugar Journal, 104 (2002), 463-467.

[7] Lević, Lj., Filipčev Bojana, Šimurina Olivera, Kuljanin Tatjana: Promena reoloških osobina testa i parametara kvaliteta pšeničnog hleba sa dodatkom melase šećerne repe, PTEP- Journal on Processing and Energy in Agriculture, 9 (2005) 5, 129-131.

[8] Pribiš Vjera, Lević, Lj., Kuljanin Tatjana: Promena senzorskih osobina melase šećerne repe sa ciljem njene primene u pekarskoj industriji, PTEP- Journal on Processing and Energy in Agriculture, 9 (2005) 5, 127-129.

[9] Rao, M., Cooley, M. J., and A. A. Vitali: Flow properties of concentrated juices at low temperatures. Food Technology, 38 (1984), 113-119.

[10] Roukas, T.: Ethanol production from non-sterilized molasses by free and immobilized Sacchoromyces cerevisiae cells using feedbatch culture, Journal of Food Engineering, 27(1996), 87-96.

[11] Šimurina Olivera, Filipčev Bojana, Lević, Lj., Pribiš Vjera, Pajin Biljana: Melasa šećerne repe kao dodatak u proizvodnji čajnog peciva, PTEP- Journal on Processing and Energy in Agriculture, 10 (2006) 3-4, 93-96.

[12] Svrzić Gordana, Lević, Lj., Pribiš Vjera, Popović Milorad, Bošnjaković, L.,: Mogućnost korišćenja melase šećerne repe u proizvodnji fino usitnjenih barenih kobasica, PTEP- Journal on Processing and Energy in Agriculture, 10 (2006) 1-2, 36-38.

[13] Toğrul, H., and N. Arslan: Mathematical model for prediction of apparent viscosity of molasses. Journal of Food Engineering, 62 (2004), 281-289.

Received: 10.10.2009. Accepted: 28.11.2009.