VISCOSEN CHANGE OF SUGAR BEET MOLASSES WHILE ADDING STARCH

PROMENA VISKOZNOSTI MELASE ŠECERNE REPE DODAVANjem SKROBA

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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, contingent 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 rheological changes in system.

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

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

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 Toerul 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. Watersoluble 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 (Gebrüder 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 °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]:

\[ \tau = k(\dot{\gamma})^n \]  

(1)

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

Fig. 1. Plot of shear stress (Pa) vs shear rate (s\(^{-1}\)) for: a) raw molasses: (■) 313.15 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.

Table 1. Rheological parameters and activation energy values of molasses

<table>
<thead>
<tr>
<th>Concentration (w/w)</th>
<th>Consistency coefficient ((k))</th>
<th>Flow behavior index ((n))</th>
<th>Arrhenius constant (a)</th>
<th>Energy of activation ((E_a))</th>
<th>(\sigma)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw molasses</td>
<td>40 2.820 1.013</td>
<td>0.066</td>
<td>45.64</td>
<td>0.006</td>
<td>0.999</td>
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<tr>
<td></td>
<td>50 1.973 1.007</td>
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<tr>
<td></td>
<td>60 1.068 0.965</td>
<td></td>
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</tr>
<tr>
<td>Sveža melasa</td>
<td>40 1.485 0.998</td>
<td></td>
<td></td>
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<td></td>
<td>50 1.263 0.997</td>
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<td></td>
<td>60 1.068 0.965</td>
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<tr>
<td>0.6 %</td>
<td>40 2.986 1.026</td>
<td>0.219</td>
<td>42.82</td>
<td>0.008</td>
<td>0.999</td>
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<td></td>
<td>45 2.519 0.988</td>
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<td></td>
<td>50 1.821 0.989</td>
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<td></td>
<td>60 1.540 0.968</td>
<td></td>
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<tr>
<td>1.3 %</td>
<td>40 3.655 1.006</td>
<td>4.95</td>
<td>34.96</td>
<td>0.003</td>
<td>0.999</td>
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<td>45 2.537 1.004</td>
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<td>50 2.151 0.971</td>
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<td></td>
<td>55 1.813 0.967</td>
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<td></td>
<td>60 1.508 0.937</td>
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<tr>
<td>2 %</td>
<td>40 3.896 1.003</td>
<td>0.41</td>
<td>41.8</td>
<td>0.012</td>
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<td></td>
<td>50 2.354 0.965</td>
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<tr>
<td></td>
<td>55 1.988 0.934</td>
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<tr>
<td></td>
<td>60 1.390 0.945</td>
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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:

\[ \mu_a = \mu_0 e^{\frac{E_a}{RT}} \]  

(2)

was found to be suitable to describe the effect of temperature, where \( \mu_a \) is apparent viscosity (Pa s\(^n\)), the concentration dependent parameter \( \mu_0 \) 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 \( \mu_0 \) calculated by the least square method, are reported in Table 1. To describe the effect of starch concentration on the parameter \( \mu_a \), the following exponential relationship was tried [9]:

\[ \mu_a = \delta \exp(\varepsilon C) \]  

(3)

where \( \delta \) (Pa s\(^n\)) and \( \varepsilon \) (\%\(^{w/w}\)) 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:

\[ \mu_a = \delta \exp(\varepsilon C)\exp\left(\frac{E_a}{RT}\right) \]  

(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 \( \delta \) and \( \varepsilon \) 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:

\[ \mu_a = 0.189 \times e^{-7 \exp\left(\frac{6626.55}{T} + 0.142C\right)} \]  

(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.
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 satisfactorily 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


Received: 10.10.2009. Accepted: 28.11.2009.