沖縄の製糖工場における各中間産物の粘性挙動(農業工学科)

Viscositic Behavior of Products in Several Steps in Sugar Cane Mills in Okinawa

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Summary

The viscosity of suger cane juice were measured as a function of shear rate, temperature and process variables. Sample solutions of clear juice, syrup, molasses and massecuite were kindly supplied by five sugar manufacturing factories in Okinawa. The measurements of viscosity were carried out with a co-axial viscometer at various temperatures and shear rate. The flow properties of these solutions were also compared with that of Hawaiian factories. The results obtained were as follows:

When viscosity exceeded about 20 poise or more, rheological behavior of molassess exhibited non-Newtonian flow. Temperature dependence of viscosity for molasses was different from each other among five factories. Logarithm of viscosity (log η) versus logarithm of temperature (log t) curves of five kinds of molasses were proximated by the straight line, which indicated that temperature dependence of viscosity could be expressed by the Arrhenius type equation. In general, the slope ($-$d log η/d log t) of the molasses which was produced by the diffusion method had larger values than the molasses by roll mill method. These results indicated that the difference of process variables including extraction method of cane juice, concentration of clear juice and crystallization of sugar so on reflected the flow properties of the molasses.

Viscosity of clear juice were almost independent to shear rate and their absolute values were about 0.01 poise at 50 ℃. Syrup also showed Newtonian flow and viscosity was about 0.1 poise at 50 ℃.

Viscosity of the third massecuite was 10 times as large as the first massecuite, and their flow propeties exhibited non-Newtonian behavior more significantly with increasing crystallization times.

These results seems to reflect that the increase in high molecular

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weight substance or impurities in addition to the sugar crystal in the massecuite would enchance the molecular interaction of massecuite solution giving non-Newtonian flow.

Viscosity values of suger cane juice in this study were coincide very well with that of Hawaiian factories within a reasonable defference.

Introduction

It is very important to know the physical properties, especially the viscositic behavior, of products in each steps of sugar cane mill processing in designing of equipments and in maintenance of them. There are more than twenty sugar cane manufacturing factotries in Okinawa Prefecture[1]. However no data concerning viscosity measurements of those products in detail were reported, and only a few data measured by USDA Experiment Station in Hawaii[2] has been used, having some suspicion whether those natures could be applied to materials produced in Okinawa. Although the characteristics of these viscosity is of considerable importance, a limited amount of work has been carried out on them.

In this work, the flow properties of clear juice, syrup, molasses and massecuite from five sugar manufacturing factories were investigated. Comparison was also made with that of Hawaiian factories.

Materials and Methods

Sugar Cane Juice

Sugar cane juice at various steps of processing, namely, clear juice, syrup, molasses (final molasses) and massecuite were kindly supplied by five sugar manufacturing factories (A, B, C, D and E), in which roll mill method is employed in A, B and C factories whereas, diffusion method in D and E factories.

Chemical component and sugar contents of the molasses, clear juice, syrup and massecuite were determined by the above factories. The results are listed in Table 1.

Table 1 Analytical data of sugar cane juice from five (A,B,C,D and E) factories in Okinawa

sample(factory)	solid content	sucrose	reducing sugar	total sugar	ash	brix	pol	pH	purity
molasses (A)	76.17	31.26	11.50	44.40	14.47	80.52	28.20	5.65	–
molasses (B)	79.35	32.95	14.11	48.79	16.49	81.66	28.80	5.65	–
molasses (C)	77.75	26.73	13.34	41.48	14.05	81.66	25.80	5.60	–
molasses (D)	76.51	30.81	12.53	44.96	16.83	80.45	29.60	5.95	–
molasses (E)	–	–	–	–	–	86.18	38.65	–	–
clear juice (D)	–	–	–	–	–	14.12	12.45	–	88.17
syrup (D)	–	–	–	–	–	55.14	48.63	–	88.19
1st massecuite (D)	–	–	–	–	–	92.10	–	–	87.32

Viscosity Measurements

The viscosity at different shear rate (22.2～241.3 sec^{-1}) and temperatures (21～60°C) was measured by means of co-axial cylinder method with continuous varying rotation speed. Used apparatus was 3-D Rheometer (Iwamoto Seisakusho Co., Ltd., Kyoto). Inner cylinder was 20 mm in diameter, 60 mm in length and outer cylinder was 22 mm in diameter. Preparation and detrmination of sample solutions were performed in a similar method as described in the previous papers[3,4]. Viscosity was calculated according to the single bob method. The details of the viscometer and measuring techniques were presented by Ferry (1970)[5] and the other[6].

Results and Discussion

Molasses

Figure 1-a and b show the shear rate dependence of viscosity at various temperatures (21, 22, 30, 40, 50 and 60°C) for molasses obtained from A and E factories, respectively. As is seen in the figure, when viscosity exceeded about 20 poise or more, flow properties exhibited non-Newtonian behavior. A similar results were observed in other sample solutions. Viscosity of sample E was about 10 times as large as that of sample A. This may be partly explained by the difference of sugar contents that

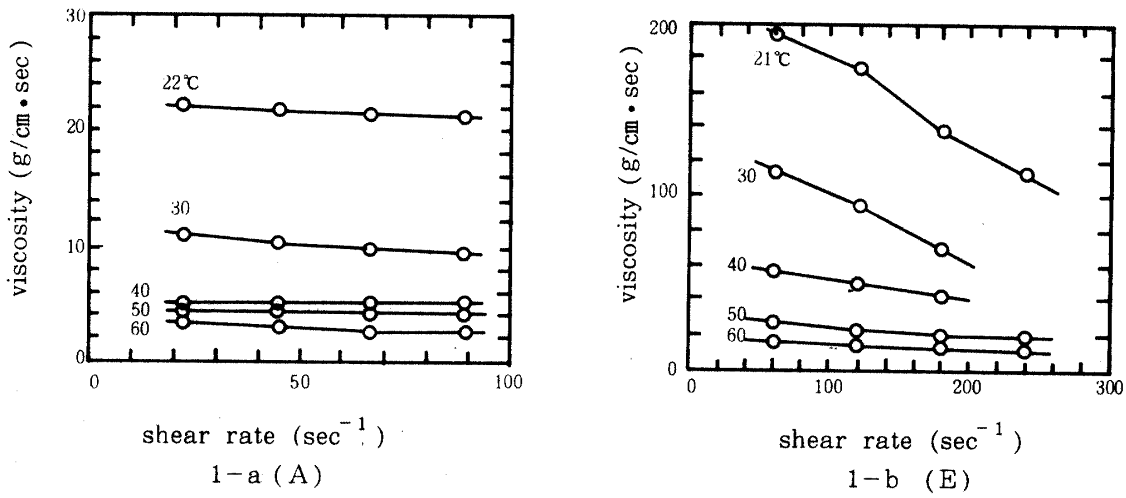
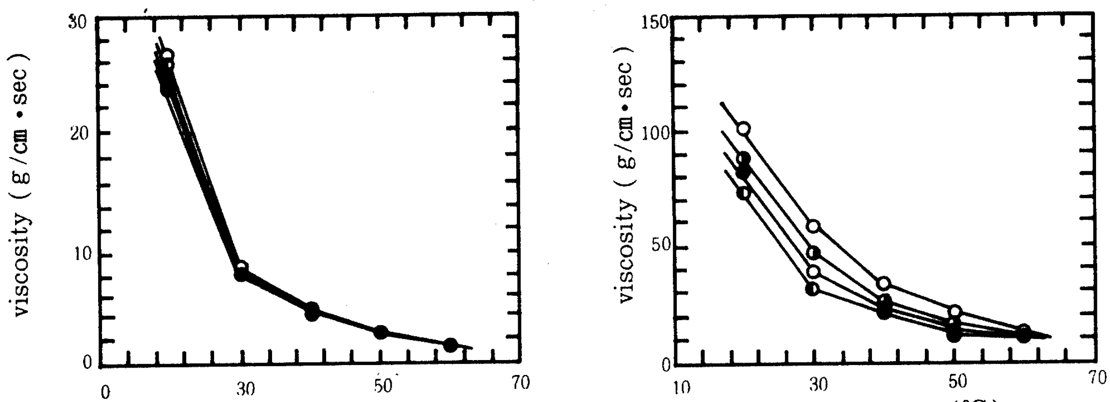


Fig. 1−a and b Shear rate dependence of viscosity for molasses from A and E factories at various at various temperatures.

the brix and pol value of the former is 86.18, 38.65, whereas that of the latter is 80.52, 28.2, respectively (Table 1). On the limited data available, it is not possible to be definitive as to which of these factors are important, but viscosity might depend to some extent more on pol value, because the increase of pol were larger than that of brix. A more probable explanation is that the method of sucrose extraction might influence the viscosity of the molasses as mentioned later. The viscosity versus shear rate curve for molasses had a tendency to increase its negative slope rapidly at lower temperature and higher viscosity level.



temperature (°C)
2-a (D)
shear rate (sec^{-1})
○ 22.2 ◑ 80.0
◑ 44.5 ◒ 88.9
● 66.7

temperature (°C)
2-b (E)
shear rate (sec^{-1})
○ 60.3 ● 181.0
◑ 120.6 ◑ 241.3

Fig. 2-a and b Temperature dependence of viscosity for molasses from D and E factories at various shear rate.

Figure 2-a and b show the temperature (t) dependence of viscosity (η) for molasses from D and E factories, respectively. Temperature dependence of viscosity was larger for molasses of E factories than D factories. This fact suggests that molasses obtained from different factories contain different components.

In order to ascertain the effect of temperature or shear rate on the five kinds of molasses, logarithm of viscosity versus logarithm of temperature at various shear rate were compared. Figures 3-a, b, c, d and e show the molasses of A, B, C, D and E factories. In these figures, log η-log t curves were proximated by the straight line, indicating that viscosity behavior of molasses could be expressed by the Arrhenius type equation. Similar behaviors and tendency of the line were found in five molasses, but in detail, higher dependence of viscosity on temperature were exhibited for samples of D and E factories as seen in Fig. 3-a and c, respectively, in which sugar cane juice is extracted by the diffusion method. On the other hand, lower value ue of temperature dependence was observed for A, B and C factories as indicated in Fig. 3-b, d and e, respectively in which cane juice was produced by the roll mill method. At shear rate of 60~66 sec^{-1}, the slopes of these straight lines, that is, $-(d \log \eta / d \log t)$ for A, B, C, D and E factories were 1.95, 1.96, 1.25, 2.31 and 2.27, and intersect at shear rate of 10 sec^{-1}, for them were 95, 380, 100, 180 and 950 (g/cm • sec), respectively. These results indicate that the difference of process variables

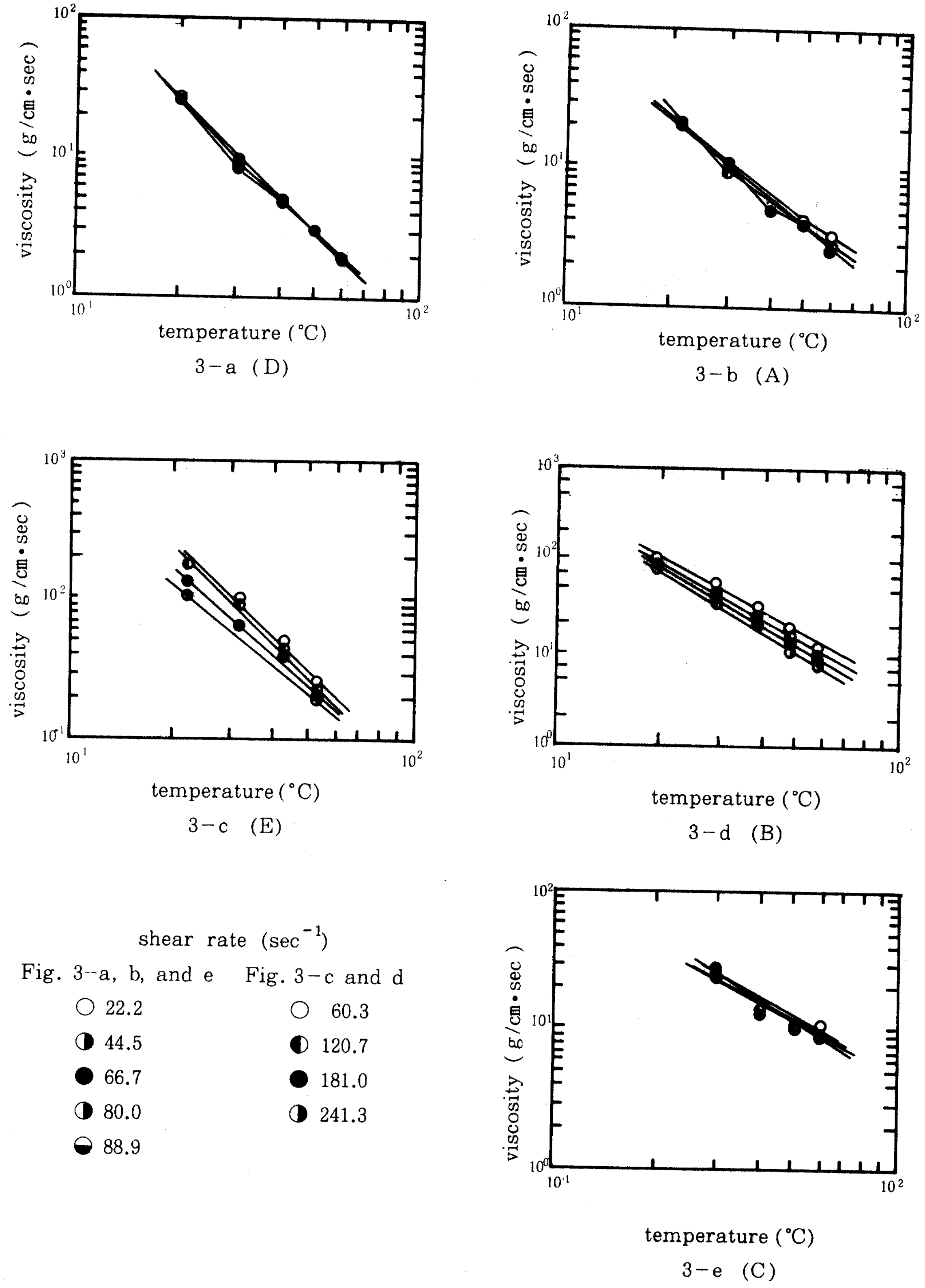


Fig. 3-a, b, c, d and e Log-temperature dependence of log-viscosity for molassec from A, B, C, D and E factories at various shear rate.

including method of cane juice extraction, concentration of clear juice, crystallization of sucrose and so on reflect the flow properties of molasses. This enables us to distinguish the molasses of five factories from the flow curves of them.

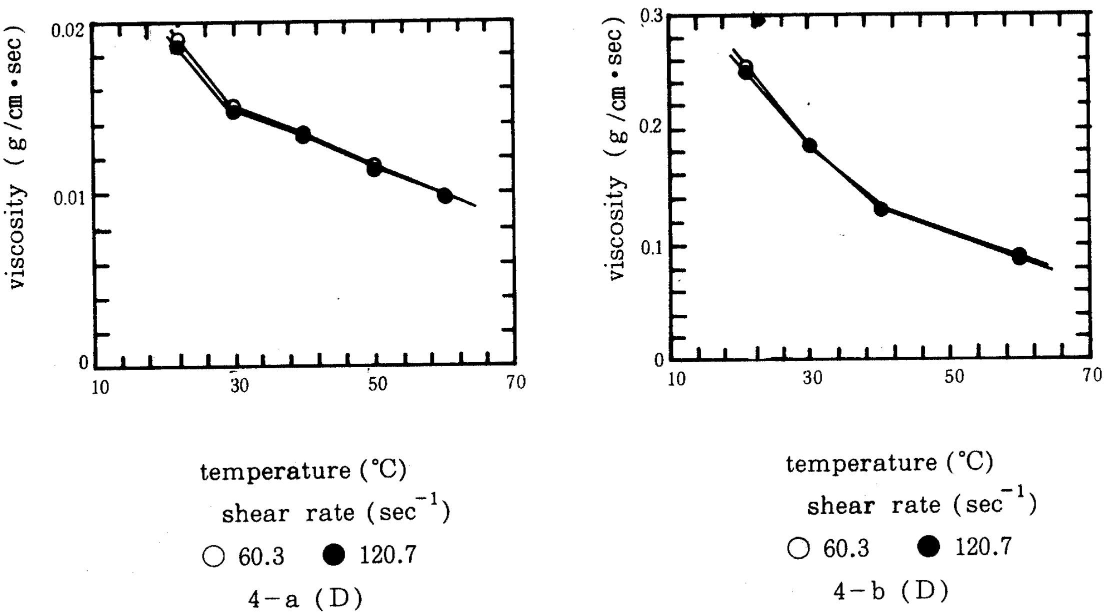


Fig. 4-a and b Temperature dependence of viscosity for clear juice and syrup from D factory at various shear rate.

Clear Juice and Syrup

Figures 4-a and b show the viscosity versus temperature curves of clear juice and syrup from D factories. In Fig. 4-a viscosity of clear juice were almost independent to shear rate. A similar behavior was observed also in the case of syrup. As shown in Table 1 and Fig. 4-a and b, when brix value increased 5 times as large, the viscosity increased 10 times.

Massecuite

Temperature dependence of viscosity for the first and the third massecuite are shown in Fig. 5-a and b, respectively. Viscosity of the third massecuite was about 10 times as large as the first massecuite and its flow properties exhibited non-Newtonian behavior significantly. Although these results could not be directly compared each other because of the difference of the factory, this may be partly responsible for the increase in high molecular weight substance or impurities such as insoluble fraction during the cryistallization process. Furthermore, it was considered that the crystal in the massecuite was disturbing the flow characteristics especially at low temperature.

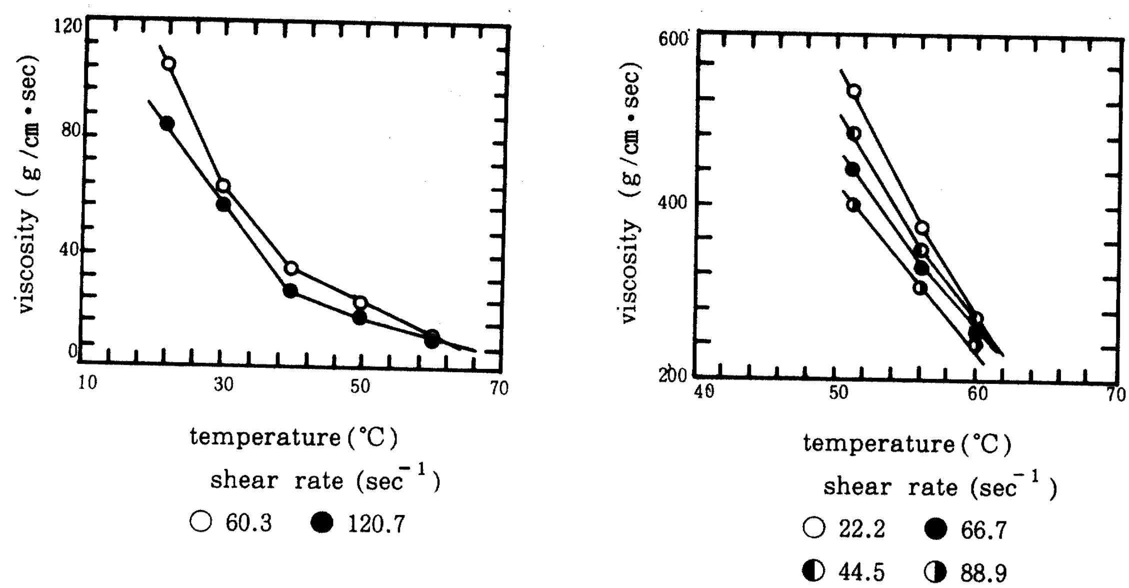


Fig. 5 – a and b Temperature dependece of viscosity for first and third massecuite from D factory at various shear rate.

In order to ascertain these results, viscosity data of molasses from Hawaiian factories introduced by Payne[2] were compared with our values of those obtained from factories in Okinawa. As was expected, the values of Fig. 1, 2, and 3 coincided very well with that of Hawaiian factories within a reasonable differences. Viscosity of pure sucrose solutions at various temperatures and concentrations[2] were also compared with our data to ensure the measurements of sugar cane juice, which suggested that no difference were found between viscositic behhavior or sugar cane juice produced in Hawaii and Okinawa.

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沖縄の製糖工場における各中間産物の粘性挙動

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要　　約

沖縄の製糖工場から得られた各工程中の産生物である清浄汁，濃縮汁，白下，糖蜜を用いて定常流粘性を測定し，それらの流動特性を解析した。またこれらの知見をもとにハワイ製糖工場における測定結果と比較を行った。

糖蜜は粘度が約20ポイズ以上になると顕著に非ニュートン流動を示すようになった。各ずり速度と温度は両対数グラフ上で直線近似ができ，アレニウス型の粘性挙動をとることが示された。これら直線の勾配及び切片は各製糖工場に特徴的であり，製造工程中の操作条件や装置の相異がこれら産生物の流動特性に大きな影響を及ぼしていることが明らかとなった。

清浄汁及び濃縮汁は50℃において粘度が各々 0.01 及び 0.1 ポイズであり，ともにニュートン流動を示した。

三番白下は一番と比較すると粘度が10倍程度高くなっているが，これは晶出操作に伴う高分子画分の増加や，あるいは蔗糖の結晶が粘性の増加に起因しているものと思われる。

本実験によって得られた糖蜜の粘性挙動はハワイ産糖蜜の結果とよく一致した。