Study on the Rheological Constants and Average Molecular Weight for Molasses

STUDY ON THE RHEOLOGICAL CONSTANTS AND AVERAGE MOLECULAR WEIGHT FOR MOLASSES

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ABSTRACT

Molasses is one of the important products of the sugar industry in OKinawa. The rheological constants and average molecular weights have been obtained at 25°C for the molasses of several sugar plants of Okinawa, Taiwan, and the Phillippines as follows:

Table 1

Molasses	Viscosity (poise)	Molecular Weight (averase)	Constant "n"
(1) HKB*	5.21 x 10^3	16,300	1.61
(2) DTO	6.15 x 10^3	18,000	1.62
(3) CBU	11.3 x 10^3	49,900	1.83
(4) IMN	8.41 x 10^3	23,200	2.51
(5) RTO	18.5 x 10^3	43,600	1.59
(6) FPN	22.3 x 10^3	49,200	1.93
(7) TWN	28.1 x 10^3	59,200	2.91

(*) The abbreviations are useb as follows:

HKB : Molasses from Hokubu Seitoh,
DTO : Molasses from Daitoh Seitoh,
CBU : Molasses from Chubu Seitoh,
IMN : Molasses from Daiichi Seitoh of Itoman,
RTo : Molasses from Ryukyu Seitoh,
FPN : Molasses from the Philippines,
TWN : Molasses from Taiwan.

1. INTRODUCTION

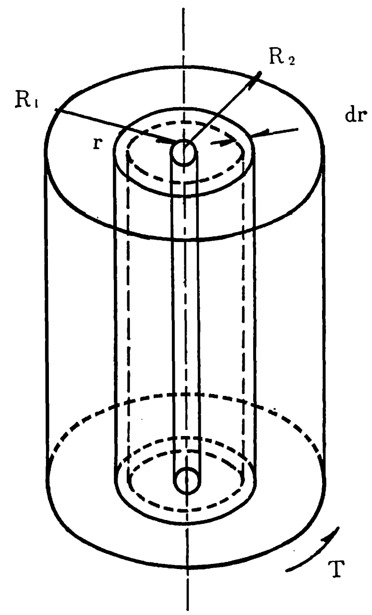
From the viewpoint of mechanical behavior, molasses is not like an ordinary Newtonian-liquid[1] and rheological constanrs had not previously been determind.

This investigation has tried to determine the rheological constants and to determine the molecular weight of several specimen of molasses taken from a number of sugar sources, by means of a BL-type viscometer.

There are two cylinders, one is a stationary inner cylinder of radius R_1; the other is a movable, outer cylinder of radius R_2. Both are sufficiently long so that end effect may be neglected.

Sample of viscosity "e" fills the annular interspace. A torque "T" is applied to the outer cylinder.

Scale 1 ; 1



Fif. 1 Flow in cylinber, rotational viscometer.

In the steady state of flow, the torque T is supported at the surfaces of the cylinders by a force tangential to the surface and perpendicular to the axis of the cylinder.

On a surface of radius r and of unit length, the total tangential force is [T/Lr], and the force per unit area is $[T/L \cdot 2\pi r^2]$.

Thus the sample at a distance r from the center is subject to a shear stress of $[T/L \cdot 2\pi t^2]$, which tends to turn each cylinder surface relative to the next. The gradient of angular velocity, dw/dr, will be given by the following equation[ii] :

$$dw/dr = (1/re)S = (1/e)(T/L2\pi r^3) \tag{1}$$

The actual angular velocity of any layer r may be shown to be-

$$w(r) = \int_{R_1}^{r} \frac{dw}{dr}\, dr = \int_{R_1}^{r} (T/eL2\pi r^3)\, dr \tag{2}$$

Hence,

$$w\ (r) = \frac{T}{2eL}\ (1/2R_1^2 - 1/2r^2) \tag{3}$$

The angular velocity of the outermost layer, R_2, will be givenas—

$$w\ (R_2) = \frac{T}{4eL}\ (1/R_1^2 - 1/R_K) \qquad (4)$$

Thus, because there is a linear relation between the torque T and the resulting angular velocityw of the outer cylinder-

$$w = (1/e)\ K \cdot T \qquad (5)$$

where K is a calibration constant for the instrument and is determined by the instrument.

$$K = 1/4L\ (1/R_1^2 - 1/R_2^2) \qquad (6)$$

And, for the velocity distribution of the fluid which isa non-Newtonian liquid, the relationship between rate of shear and the slope of velocity is expressed as- iii),iv)

$$\text{Rate of shear} = -\ (du/dr) = (g_c\, t_w)^{n/e}{}_p \qquad (7)$$

where u is velocity at radius r'; therefore—(du/dr) is velocity slope at radius r', g_c is conversion factor and e_p is viscosity of pseudoplastic fluids with the following dimensions-

$$[e_p] = [Kg^{-n},\ M^{-n},\ Sec^{1-2n}] \qquad (8)$$

Average velocity of pipe $\bar{u}$ is obtained from the following equation;v)

$$\bar{u} = \frac{R}{(n+3)e_p}(g_c\, t_w)^n \qquad (9)$$

then,

$$8\bar{u}/g_c\, D_p = \frac{8R'}{g_c\, D_p\,(n+3)e_p}(g_c\, t_w)_n$$

$$= \frac{4g_c^{\,n-1}}{e_p\ (n+3)}\ (t_w)_n \qquad (10)$$

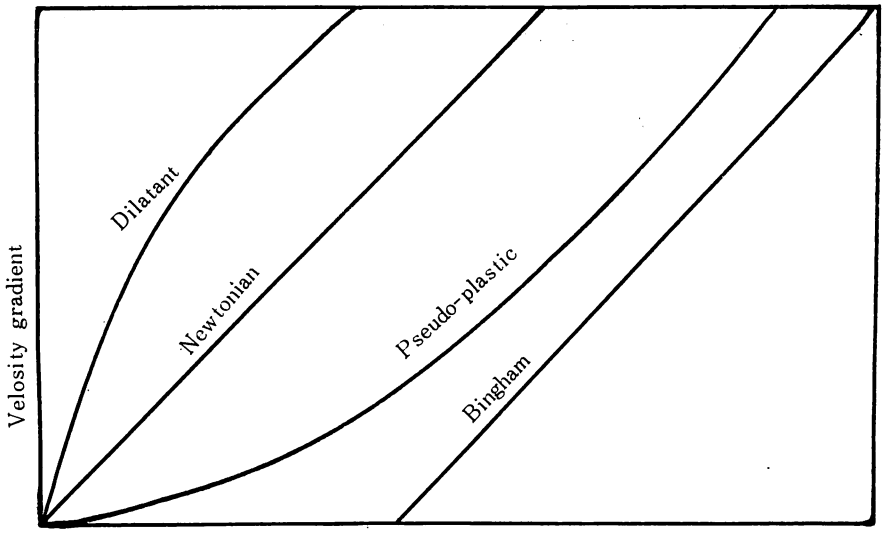


Fig. 2 Types of fluib dehavior.

where, t_w : Shearing stress at pipe wall,

D_p : Diameter of pipe,

R' : Radius of pipe,

n : Constant.

Several types of fluid behavior are shown in Fig.3;[vi]

2. EXPERIMENTS AND DATA:

The following apparatus was set up for this experiments; special attention was paid to keep the temperature constant. From the epuation (10), e_p was calculated from the following epuation:

$$e_p = (g_c D_p/8\bar{u})\ (4g_c^{n-1}/n+3)\ (t_w)_n \tag{11}$$

Both n and e_p were obtained.

Scale 1 : 1

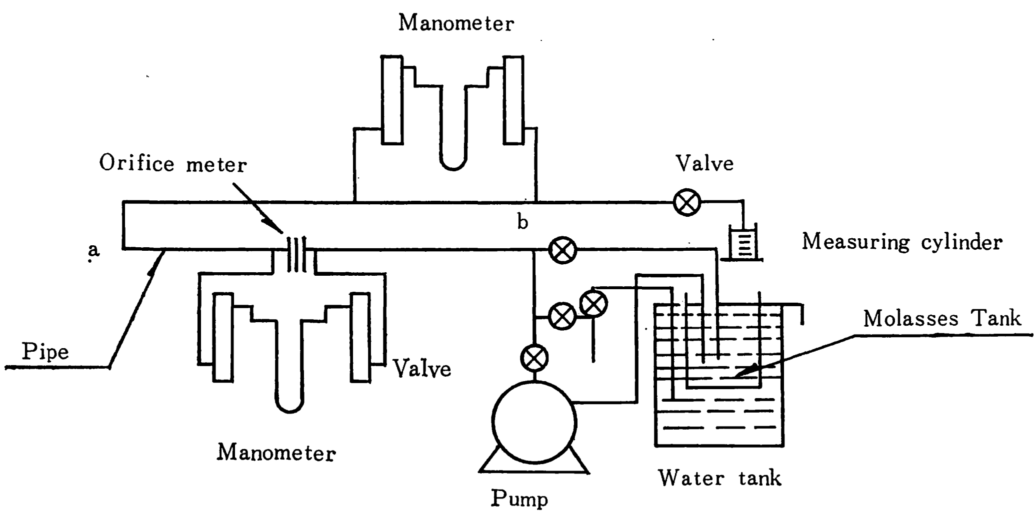


Fig. 3 Apparatus for experiment.

The shearing stress at the pipe wall, t_w, was obtained by calculation of the equation (12)-

$$t_w = 4p/(2j'xR') \tag{12}$$

where;

P : pressure drop through the orifice meter

j : distance on pipe from a to b in Eig. 3

R' : radius of pipe

t_w : shearing stress at the pipe wall.

The ratio of orifice area to the sectional area of pipe is 0.524 in this experiment.

[A] Relationship between temperature and viscosity fo molasses. From 20°C to 40°C, viscosity of molasses from several factories was determined as shown in the following table:

Table 2

Tempera-ture (°C)	HKB* x10³	DTO x10³	CBU x10³	IMN x10³	RTO x10³	FPN x10³	TWN x10³ (Poise)
20	6.92	8.73	17.8	15.1	33.5	39.4	51.7
21	6.48	8.40	16.2	13.2	29.0	35.3	45.8
22	6.08	7.52	14.7	11.8	25.2	31.1	38.5
23	5.72	6.98	13.1	10.5	23.2	27.5	35.7
24	5.38	6.60	12.2	9.35	20.8	25.2	31.2
25	5.21	6.15	11.3	8.41	18.5	22.3	28.1
26	4.93	5.88	10.4	7.73	17.2	20.1	24.8
27	4.60	5.42	9.55	6.82	15.3	18.5	22.6
28	4.42	5.19	8.90	6.20	14.1	16.5	20.3
29	4.19	4.98	8.18	5.83	12.9	15.5	18.5
30	4.00	4.65	7.65	5.21	11.8	14.2	16.8
31	3.87	4.50	7.41	5.04	11.3	13.7	16.2
32	3.64	4.25	6.78	4.40	10.2	11.9	13.9
33	3.52	4.13	6.57	4.27	9.87	11.1	12.5
34	3.38	3.82	5.91	3.85	8.53	10.0	11.8
35	3.28	3.72	5.74	3.74	8.27	9.72	10.4
36	3.13	3.45	5.33	3.21	7.40	8.65	8.92
37	3.04	3.35	5.17	3.13	7.20	8.42	8.70
38	2.90	3.25	4.70	2.85	6.51	8.22	8.75
39	2.82	2.68	4.58	2.78	6.35	7.00	8.23
40	2.75	3.00	4.12	2.52	5.83	6.45	7.31

(*) In tadle 2, addreviations are used as follows:

HKB : Molasses from Hokubu Seitoh
DTO : Molasses from Daitoh Seitoh
CBU : Molasses from Chuhbu Seitoh
IMN : Molasses from Daiichi Seitoh of Itoman
RTO : Molasses from Ryukyu Seitoh
FPN : Molasses from the Phillippines
TWN : Molasses from Taiwan.

The relationship between temperature and viscosity is shownin Fig. 4.

To obtain the equation for each curve, table 2 was plotted on log-log paper:

The following equations were obtained:

(1) HKB : $e=3.46 \times 10^5 \times \theta^{-1.31}$ (13)

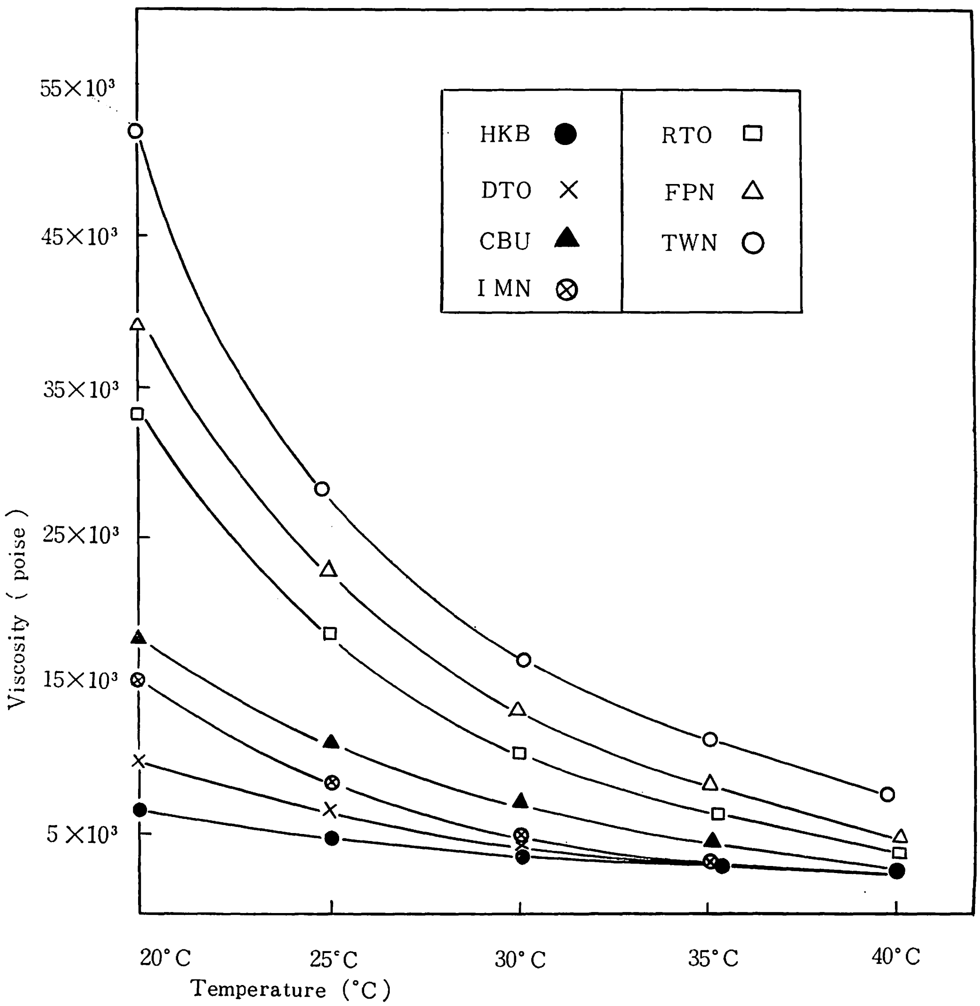


Fig. 4 The relationship detween viscosity anb temperature.

(2)	DTO	: $e=7.28 \times 10^{5} \times \theta^{-1.49}$	(14)
(3)	CBU	: $e=4.45 \times 10^{5} \times \theta^{-2.51}$	(15)
(4)	IMN	: $e=1.19 \times 10^{5} \times \theta^{-2.92}$	(16)
(5)	RTO	: $e=6.31 \times 10^{7} \times \theta^{-2.52}$	(17)
(5)	FPN	: $e=8.59 \times 10^{7} \times \theta^{-2.58}$	(18)
(7)	TWN	: $e=2.35 \times 10^{8} \times \theta^{-2.82}$	(19)

where,

e : Viscosity

θ : Temperature.

[B] Average molecular weight of molasses and viscosity relationship were

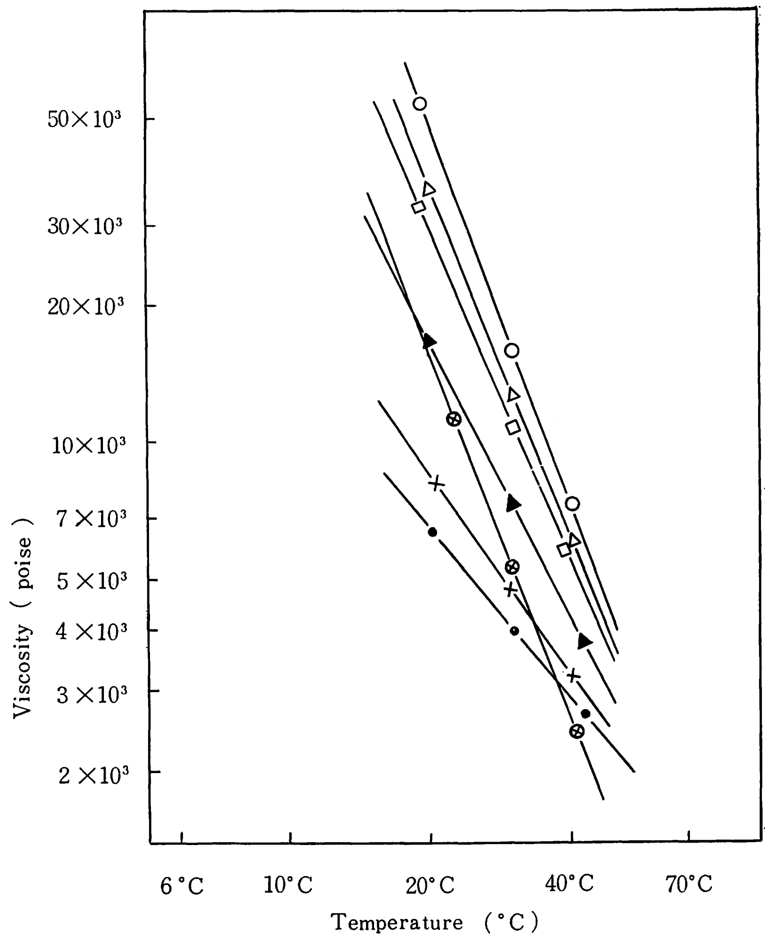


Fig. 5 The relationship detween viscosity anb temperature on log-log paper.

obtained by mesuring osmotic pressure of molasses,as in the following table; vii), viii), ix)

Table 3

Molasses	Viscosity (poise)	Average Molecular Weight
(1) HKB	5.21×10^3	16,300
(2) DTO	6.15×10^3	18,000
(3) CBU	11.3×10^3	49,900
(4) IMN	8.41×10^3	23,200
(5) RTO	18.5×10^3	43,600
(6) FPN	22.3×10^3	49,200
(7) TWN	28.1×10^3	59,200

These resolts depend on the viseosity at temperature 25°C, and the relationship is expressed in the following equation:

$$e = 0.66 \times M_{av}^{1.31} \qquad (20)$$

where,

e : Viscosity

M_{av} : Average molecular weight.

[C] Determination of constant "n".

From the equation (11), the constant "n" may be determined. The relationship between $(8\bar{u}/g_c D_p)$ and t_w was obtained asfollows:

(1) **HKB**

$8u/g_c D_p$	1.02	1.58	1.83	2.89	2.20	6.35	10.1	17.1	22.3	37.9
t_w	0.115	0.157	0.172	0.235	0.255	0.391	0.533	0.772	0.934	1.33

(2) **DTO**

$8u/g_c D_p$	1.68	2.49	3.45	5.80	8.25	10.5	14.2	20.0	26.5	41.7
t_w	0.320	0.341	0.446	0.599	0.721	0.833	0.955	11.2	13.3	16.8

(3) **CBU**

$8u/g_c D_p$	1.68	2.49	3.45	5.80	8.25	10.5	14.2	20.0	26.5	41.7
t_w	0.320	0.341	0.446	0.599	0.712	0.833	0.955	11.2	13.3	16.8

(4) **IMN**

$8\bar{u}/g_c D_p$	1.23	1.85	2.85	4.23	5.26	7.33
t_w	0.340	0.354	0.485	0.573	0.641	0.750

$8\bar{u}/g_c D_p$	12.2	17.1	24.3	33.0
t_w	0.900	1.05	1.23	1.46

(5) **RTO**

$8\bar{u}/g_c D_p$	1.36	1.50	2.00	2.59	4.21	5.85
t_w	0.472	0.481	0.553	0.615	0.743	0.860

$8\bar{u}/g_c D_d$	8.53	23.9	31.2	40.2
t_w	1.01	1.59	1.79	1.95

(6) **FPN**

$8\bar{u}/g_c D_p$	1.37	2.38	3.35	4.81	7.23	10.1
t_w	0.601	0.644	0.734	0.835	1.01	1.15

$8\bar{u}/g_c D_p$	18.5	28.7	43.3	58.2
t_w	1.47	1.72	2.11	2.38

(7) **TWN**

$8\bar{u}/g_c D_p$	1.37	2.05	5.25	9.26	13.7	18.3
t_w	0.601	0.703	1.05	1.27	1.49	1.63

$8\bar{u}/g_c D_p$	24.0	33.4	42.1	49.8
t_w	1.79	2.04	2.23	2.88

The results are shown in Fig. 6, a shear diagram for molasses at 25°C.

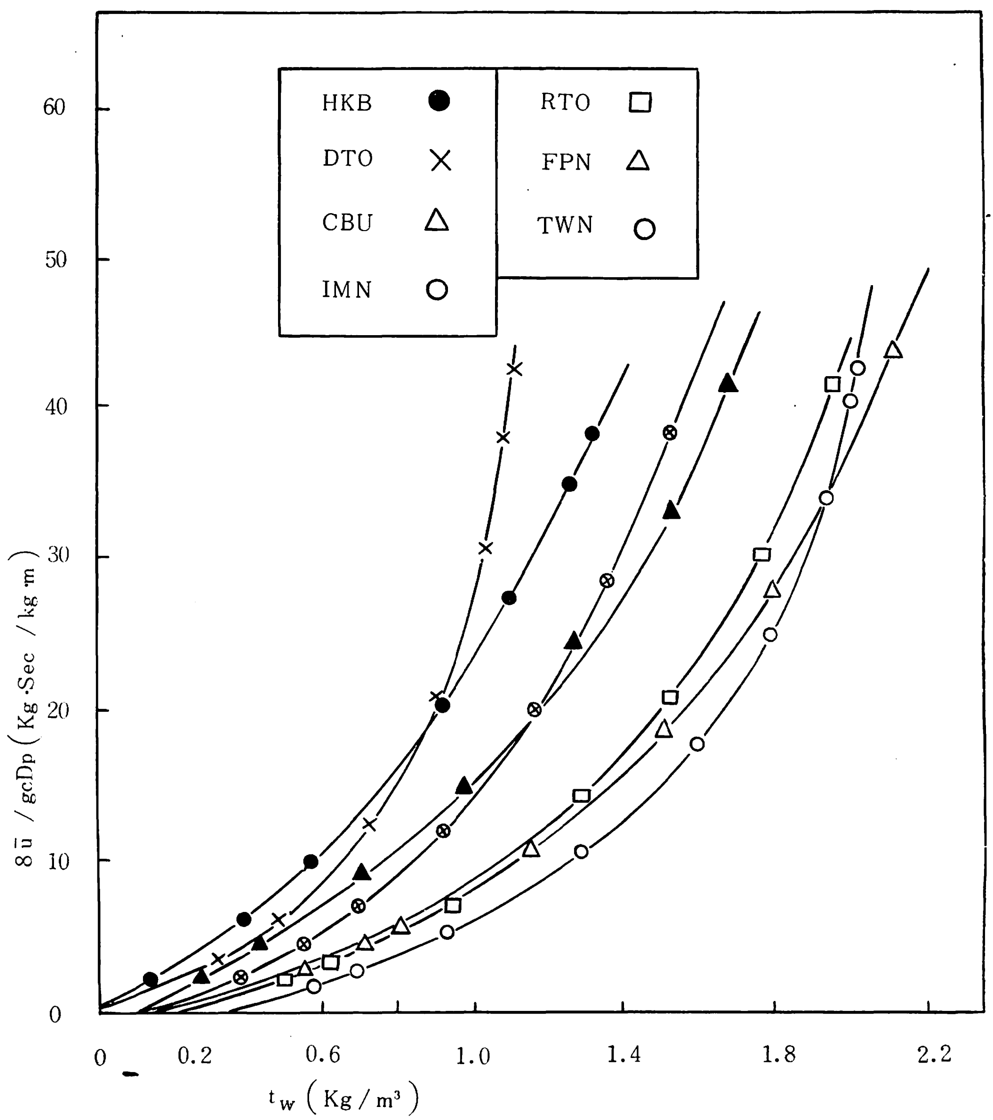


Fig. 6 Shear biagram for molasses at 25°C.

To obtain constant "n", these results can be plotted on log-log paper as follows:

The constant "n" is as follows:

(1) HKB : n=1.61
(2) DTO : n=1.62
(3) CBU : n=1.83
(4) IMN : n=2.51
(5) RTO : n=1.59
(6) FPN : n=1.93

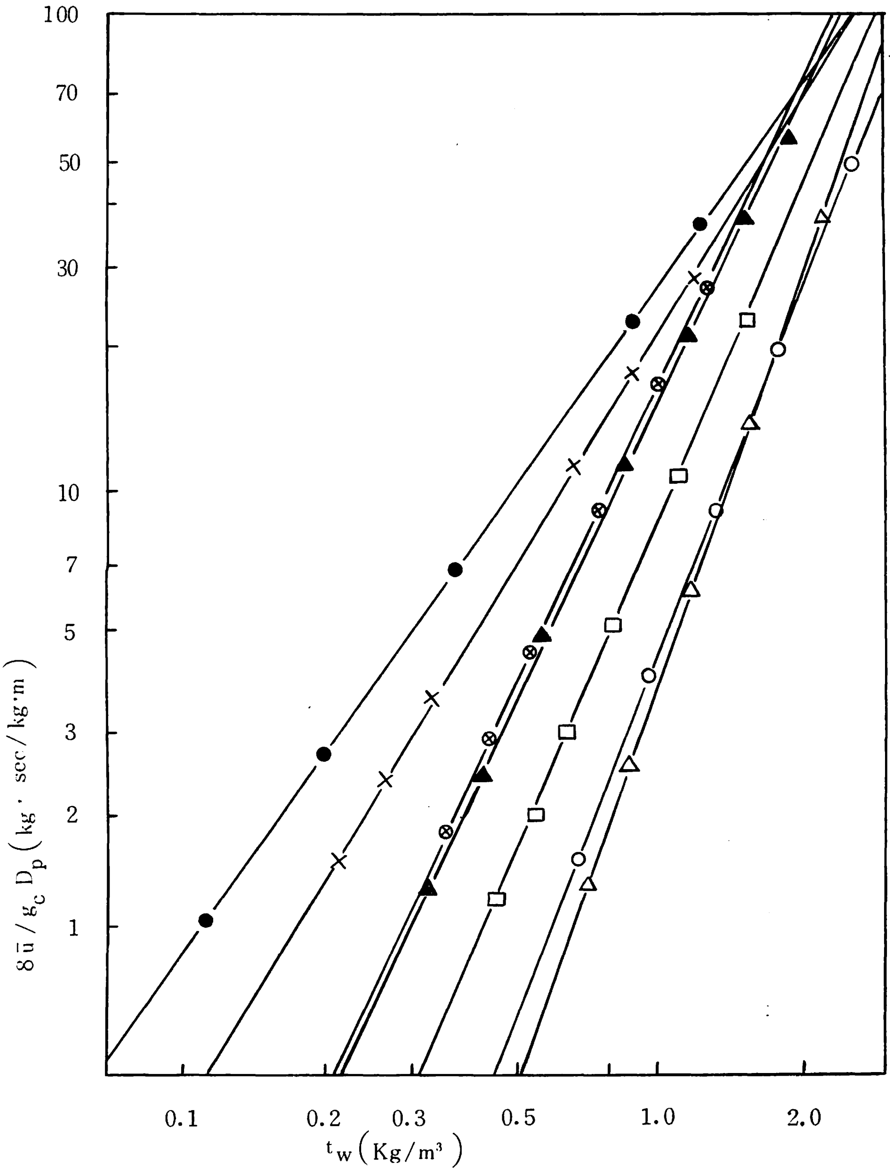


Fig. 7 Logarithmic plot of $8\bar{u}/g_c D_p$ vs. t_w

(7) TWN : $n=2.91$

Then the equations for each line are:

(1) HKB : $8\bar{u}/g_c D_p = 25.5 \times t_w^{1.61}$ (21)

(2) DTO : $8\bar{u}/g_c D_p = 21.6 \times t_w^{1.62}$ (22)

(3) CBU : $8\bar{u}/g_c D_p = 15.6 \times t_w^{1.83}$ (23)

(4) IMN : $8\bar{u}/g_c D_p = 15.5 \times t_w^{2.51}$ (24)

(5) RTO : $8\bar{u}/g_c D_p = 8.18 \times t_w^{1.59}$ (25)

(6) FPN : $8\bar{u}/g_c D_p = 7.21 \times t_w^{1.93}$ (26)

(7) TWN : $8\bar{u}/g_c D_p = 5.20 \times t_w^{2.91}$ (27)

3. CONCLUSION

In this experiment, especially as shown in Fig. 6, for the fluid molasses, a pseudo-plastic material, viscosity and rheological constants were obtained.

[A] Relationship between temperature and viscosity:

(1) HKB : $e = 3.46 \times 10^5 \times \theta^{-1.31}$ (13)
(2) DTO : $e = 7.28 \times 10^5 \times \theta^{-1.49}$ (14)
(3) CBU : $e = 4.45 \times 10^7 \times \theta^{-2.51}$ (15)
(4) IMN : $e = 1.19 \times 10^8 \times \theta^{-2.92}$ (16)
(5) RTO : $e = 6.31 \times 10^7 \times \theta^{-2.52}$ (17)
(6) FPN : $e = 8.59 \times 10^7 \times \theta^{-2.58}$ (18)
(7) TWN : $e = 2.35 \times 10^8 \times \theta^{-2.82}$ (19)

[B] Relationship between viscosity and average molecular weight at 25°C was obtained and is expressed in the following equation:

$$e = 0.77 \times M_{av}^{1.31} \quad (20)$$

[C] Constant "n".

(1) HKB : n=1.61
(2) DTO : n=1.62
(3) CBU : n=1.83
(4) IMN : n=2.51
(5) RTO : n=1.59
(6) FPN : n=1.93
(7) TWN : n=2.91

4. REFERANCES

i) Yoshio HIGA : The Bulletin of Arts & Science Division (Math. & Natural Science) No. 8, 87 (1965)

ii) Turner ALFREY : Mechanical Behavior of High Polymer Materials. p32 (1948)

iii) John RERRY's: Chemical Fngineer's Hand Book, pp. 5—36 (1964)

iv) Taketora HASEGAWA : Kagaku kogaku. 20 50 (1956)

v) Taketora HASEGAWA : Kagaku kogaku. 20 52 (1956)

vi) Turner ALEFREY : Mechanical Behavior of High Polymer Materials. p.34 (1958)

vii) G.M. BURNETT : Mechanism of polymer Reaction. p.273 (1953)

viii) Paul J. FIory : Principles of Polymer Chemistry. p.273 (1953)

iv) Yuichi IKEDA : Kobunsi Kagaku. 6 635 (1957)