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RHEOLOGICAL PROPERTIES OF ABS LUSTRAN QE1455 IN DIFFERENT TEMPERATURES

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ABSTRACT

Paper ini menyajikan sifat-sifat rheology ABS Lustran QE1455. Sifat-sifat yang diteliti meliputi shear rate on viscosity, effect of shear stress on viscosity, and effect of temperature on viscosity. Pengukuran in-line atau in-process dirancang untuk mengukur dan mengontrol proses fluida. Data diambil dari penelitian yang dilakukan di Laboratoritum Polymer, the University of Bradford, England. Percobaan menggunakan Cincinnati ACT30 untuk mengukur in-line rheometry. Data yang diperoleh akan disajikan dalam paper ini. Shear stress sebagai fungsi dari shear rate disajikan dalam grafik dan terlihat bahwa grafik membentuk kurva yang berbentuk cekung ke bawah. Perilaku shear stress meningkat apabila shear rate meningkat. ditunjukkan dalam grafik itu. Viscosity sebagai fungsi dari shear rate diplotkan dalam beberapa temperatur yang berbeda. Penurunan viskosity terjadi saat peningkatan shear rate seperti ditunjukkan dalam grafik lain. Perilaku ini disebut aliran pseudoplastic. Pada shear rate sama, grafik menunjukkan implikasi semakin tinggi temperatur semakin rendah shear viscosity.

***Kata kunci**: Rheology, ABS Lustran, in process, pseudoplastic.*

INTRODUCTION

Engineers need to know the mechanical and rheological properties of materials. The instrumental measurement of the rheological properties of sample is performed for two reasons as a technique for scientists to study material structure, and as a quality control method for material makers. Consequently, an objective instrumental method of determining rheological properties of one material would be quite valuable.

Rheology deals with deformation and flow behaviour a body in response to an applied force. The body means solid, fluid, and gas. Fluid behaviour types themselves can be distinguished into two main types i.e. non-Newtonian and Newtonian (Griskey, 1995, Cogswell, 1997). The non-Newtonian fluids could be time independent or dependent. The viscosity of a Non-Newtonian time independent fluid is dependent not only on temperature but also on shear rate. Whereas the viscosity of the Non-Newtonian time dependent fluid is dependent on temperature, shear rate and time. On the other hand, the viscosity of a Newtonian fluid is dependent only on temperature but not on shear rate and time.

ABS is widely used in many applications throughout industry including very low temperature for agriculture and health purposes and the impossible part of a complicated machine. Therefore, the rheometry of ABS is quite relevant to be discussed as a topic of applied agriculture.

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RELEVANT THEORIES LITERATURE AND DATA BACKGROUND

Non-Newtonian fluids, time independent

The viscosity of a Non-Newtonian time independent fluid is dependent not only on temperature but also on shear rate. Depending on how viscosity changes with shear rate the flow behaviour is characterised as:

- shear thinning - the viscosity decreases with increased shear rate
- shear thickening - the viscosity increases with increased shear rate
- plastic - exhibits a so-called yield value, i.e. a certain shear stress must be applied before flow occurs.

Shear thinning fluids are also called pseudoplastic and shear thickening fluids are also called dilatant. Fruit juice concentrates, ketchup, slurries, GRS (Groove Roll Small) latex solutions, sewage sludge's, molasses, starch, soap, paper pulp, and most emulsions are examples of shear thinning fluids. Whereas examples of shear thickening fluids are wet sand and concentrated starch suspensions. Some goods of plastic fluids are quark, tomato paste, toothpaste, and some ketchups.

Non-Newtonian fluids, time dependent

The viscosity of the fluid is dependent on temperature, shear rate and time. Depending on how viscosity changes with time the flow behaviour is characterised as:

- thixotropic (time thinning, i.e. viscosity decreases with time)
- rheopectic (time thickening, i.e. viscosity increases with time)

Thixotropic fluids are quite common in chemical as well as in food industry. Rheopectic fluids are very rare. Bear in mind, some fluids show time thinning behaviour due to breakdown of structure. This phenomenon is sometimes known as rheomalaxis. Yoghurt is examples of thixotropic and gypsum paste is an example of rheopectic.

Temperature Control

Vibration can reduce viscosity of the polymers, polystyrene and polypropylene during processing so that allowing the possibility to operate at lower temperature (Ibar, 1988). Low temperature operation will reduce energy consumption yet temperature control is the key factor in anyway.

Good temperature control is important for obtaining accurate viscosity values. The viscosity of a Newtonian fluid decreases with temperature in an exponential fashion. Hence, to obtain viscosity values accurate to ±1%, temperature must typically be controlled to better than ±0.3°C. Since many materials can be completely characterized at or near room temperature, a temperature control system which covers the range -10 to 100°C is sufficient. A Peltier system is ideal for this region. In this case an induction heating system coupled with liquid N2 cooling is preferred. Gas use becomes more common to assist polymer process because materials used can be reduced. However, some materials such as molten polymer may require a broad temperature range (-100 to 400°C). Data in this paper were in 220, 240, 260, and 280° C.

The speed at which the measurement temperature is achieved is also important since it affects analysis time (productivity) and the ability to evaluate thermally unstable materials before degradation occurs. Active heating and cooling systems out perform passive systems such as ovens and circulation baths.

Viscosity and elasticity measurements

Rheological measurements are normally performed in kinematic instruments in order to get quantitative results useful for design and development of products and process equipment. For design of products, rheometric measurements are often performed to establish the elastic properties, such as gel strength and yield value, both important parameters affecting e.g. particle carrying ability and spreadability. For design of process equipment the properties during shearing of the product is of prime interest. Those properties are established in a normal viscosity measurement. The most important equipment in polymer process could be die in which the shape of product determined.

A rheometric measurement normally consists of a strain (deformation) or a stress analysis at a constant frequency combined with a frequency analysis. A viscometric measurement normally consists of a shear rate analysis. The shear rate sweep should preferably cover the range applied in the intended equipment.

Kinematic and dynamic viscosity

Kinematic viscosity is measured with kinematic instruments and their values are little or no use for design of equipment for non-Newtonian fluids.

Dynamic viscosity takes into account the effect of shear rate and time and is therefore the only type of viscosity relevant for non-Newtonian design purposes. Dynamic viscosity is measured with dynamic instruments, either rotating (shearing) or oscillating. An instrument only capable of measuring shearing viscosities is called a viscometer and the oscillating type is called a rheometer.

Viscoelasticity

All materials, from gases to solids, can be divided into the following three categories of rheological behaviour:

- Viscous materials: in a purely viscous material all energy added is dissipated into heat
- Elastic materials: in a purely elastic material all energy added is stored in the material
- Viscoelastic materials: a viscoelastic material exhibits viscous as well as elastic behaviour

Typical examples of viscoelastic materials are bread dough, polymer melts and artificial or natural gels.

ABS

ABS is a generic name for a versatile family of amorphous thermoplastics produced by combining three monomers, acrylonitrile, butadiene, and styrene. The ratio of these monomers, as well as the molecular structure, can be manipulated to optimize the characteristics of the resulting polymer. Acrylonitrile contributes chemical resistance and thermal stability. Butadiene contributes product toughness, impact resistance, and property retention at low temperatures. Styrene contributes rigidity, surface appearance, and processability. The resultant polymer's properties can vary over a large range to suit the manufacturer's needs. For this reason, ABS is widely used in countless applications throughout industry.

ABS is a polymer and has properties as the following.

Table 1. ABS Properties (Selfridge, A. R., 1985)

Plastic material	Velocity long. meter/min	Density g/cm^3	Acoustic Impedance (Z) (Mrayls)	Attenuation dB/cm
ABS, beige	2230	1.03	2.31	11.1
ABS, black	2250	1.05	2.36	10.9
ABS, grey	2170	1.07	2.32	11.3
Lustran, SAN	2510	1.06	2.68	5.1
Styrene Butadiene	1920	1.02	1.95	24.3

The letter Z is used for the impedance and is expressed in [kg/s m^2] = 1 Rayl. For water Z = 1.49 Mrayls. Application of ABS includes tactile sensor for agricultural purposes and equipment operating in very low temperature for agriculture and health purposes.

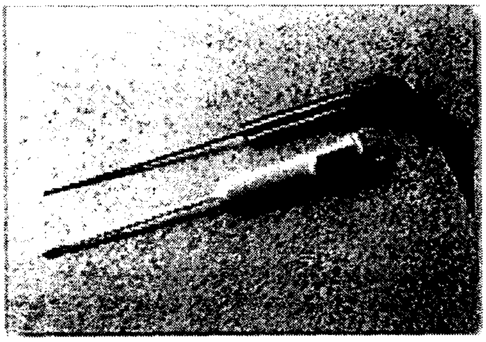

Figure 1. Cryoprobing spare part (Ref.*1)

Two Lustran® acrylonitrile-butadiene-styrene (ABS) materials from Bayer Corporation's Plastics Division froze out the competition for the cryoprobe and control unit portions of the new First Option1 Uterine Cryoblation Therapy1 from CryoGen, Inc. Gray Lustran ABS 248 resin is used for the probe's three-component handle while the snow white 348 grade is used for the disposable control unit that slips over the probe. Both applications require tight tolerances, which can reach as low as 0.0005 inches.

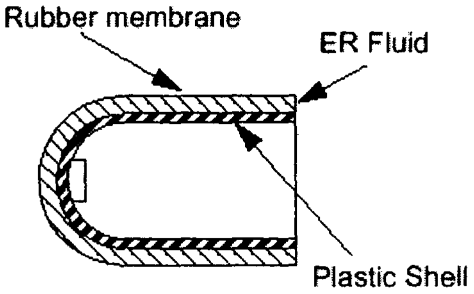

Figure 2. Extrinsic Tactile Sensor Design

The extrinsic sensor shell will be made of plastic, probably delrin or ABS (as are our current prototypes). The body of the sensor must be insulating to hold the individual capacitive electrodes (Voyles, R. M. Jr., Fedder, G. and Khosla, P. K., 1996).

RESEARCH METHODOLOGY

In the presented study effect of shear rate on viscosity, effect of shear stress on viscosity, and effect of temperature on viscosity were investigated. The materials used, ABS (Acrylonitrile-butadiene styrene) grade QE1455, were supplied by Bayer/Monsanto with trade name of Lustran. In-process measurements are designed to measure and control the process fluids. Data were taken from the research in Polymer Laboratory, the University of Bradford, England. Experiments using Cincinnati ACT30 were performed to measure In-line rheometry. A part of that data will be discussed in this paper.

The melt rheological measurement was carried out using a capillary rheometer attached to equipment/machine. The in-line investigation of the rheological properties of complex fluids is based on the superposition of a Pressure Difference measuring method (PD) with the Ultrasound Velocity Profile method (UVP). The method uses a high frequency ultrasonic beam that is emitted into the flow field to be investigated. The signal is scattered by tracer particles in the flow and the time delay and the frequency shift between emitted and received pulse is determined. This shift, know as the Doppler shift, is related to the speed and the direction of the moving scatterers. The shape of the obtained velocity profile together with the pressure drop is used to calculate the rheological properties, i.e. the flow curve of the sample. Conventional process rheometers are in general not suitable to accurately measure in-line rheological properties because of their "invasive" nature that may cause non-rheometric conditions. Also these methods may create severe bio-safety problems due to contamination. The in-line measurement would be simplified as seen Figure 3.

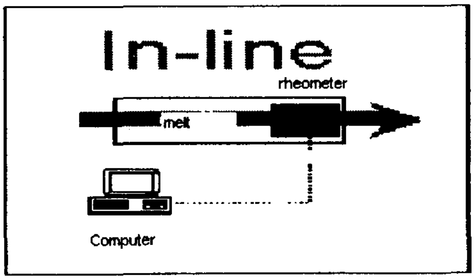

Figure 3. In-line measurement

During measurement controller output can be utilized to visually monitor or automatically control the process fluid viscosity. Also, the electrical signal may be brought to a recorder, external controller, or other computer control system. This paper will disclose the ABS behaviour with variable temperatures in rheology properties. In-line measurement will be showed and analyzed.

DATA AND CALCULATION

The theories behind fundamental measurements are covered by Collyer and Clegg (1988). A viscosity function dependent on shear rate, it can be defined in analogy to the Newtonian viscosity (Bird, Armstrong, and Hassager 1987).

Non-Newtonian fluid

Rheological equation of state (power law):

$$\tau = K(\dot{\gamma}_a)^n \tag{1}$$

$$\mu = K'\dot{\gamma}_a{}^{n-1} \tag{2}$$

$$n = \frac{\log \tau}{\log \dot{\gamma}_a} \tag{3}$$

Where
a : apparent
K: consistency index
n : power law (non-Newtonian) index
τ : shear stress (Pa)
γ : shear rate (1/s)
μ : shear viscosity (Pa.s)

Correction for non-Newtonian behaviour

Newtonian fluids develop a parabolic velocity profile. Whereas non-Newtonian fluids with pseudoplastic behaviour flow with flattened velocity profile. Therefore there are significant discrepancies between actual and calculated shear rate. This error can be eliminated by applying 'Weissenberg – Rabinowitsch' correction to the apparent shear rate, $\dot{\gamma}_a$, as indicated in the following

$$\dot{\gamma}_{true} = \left(\frac{3n+1}{4n}\right)\dot{\gamma}_{apparent} \qquad (4)$$

The greater the non-Newtonian behaviour (low n) causes the more significant the correction.

The true shear rate is calculated based on Equation 4. K is calculated based on Equation 1 K' is calculated based on Equation 2. Example of hand calculations is shown as the following.

$$\dot{\gamma}_{true} = \left(\frac{3*0.2+1}{4*0.2}\right)937.58 = 1875.16$$

$$251917 = K(1875.16)**0.2$$
$$K = 55801.97$$

$$268688 = K'*1875.16**(0.2-1)$$
$$K' = 111603.93$$

In-line rheometry data of experiments using Cincinnati ACT30 will be exposed in Table 2,3, 4 and 5. Whereas some graphs based on that data can be seen in Figures 3,4, and 5.

Table 2. ABS Lustran QE1455 Results for 180 degree die entry at 220C, n = 0.2

Average Shear Rate (1/s)	Shear Viscosity (Pa.s)	Shear Stress (Pa)	True Shear Rate (1/s)	K	K'
937,58	268,688	251.917	1.875,16	55.801,97	111.603,93
2.794,25	108,840	304.127	5.588,50	54.149,73	108.299,45
4.889,27	69,085	337.773	9.778,55	53.773,72	107.547,45
5.846,15	59,334	346.875	11.692,30	53.283,56	106.567,12
7.943,16	43,179	342.980	15.886,32	49.552,34	99.104,69
8.857,15	42,242	374.145	17.714,30	52.890,14	105.780,28
9.786,42	40,804	399.323	19.572,84	55.334,17	110.668,34
11.901,06	33,932	403.830	23.802,11	53.811,57	107.623,14
17.882,80	24,415	436.604	35.765,60	53.628,32	107.256,64
27.884,91	17,068	475.945	55.769,82	53.490,57	106.981,13
41.932,01	12,117	508.072	83.864,01	52.627,16	105.254,32
55.866,91	9,909	553.584	111.733,83	54.143,50	108.287,01
69.786,24	8,033	560.607	139.572,49	52.444,29	104.888,58

Table 3. ABS Lustran QE1455 Results for 180 degree die entry at 240C, n = 0.2

Average Shear Rate (1/s)	Shear Viscosity (Pa.s)	Shear Stress (Pa)	True Shear Rate (1/s)	K	K'
35,69	223,185	208.832	1.871,38	46.276,85	92.553,70
2.803,05	100,831	282.635	5.606,11	50.291,37	100.582,73
4.901,57	61,399	300.951	9.803,14	47.887,62	95.775,23
5.823,79	52,674	306.765	11.647,59	47.158,33	94.316,66
7.900,48	40,630	320.994	15.800,97	46.425,84	92.851,67
8.832,72	37,132	327.974	17.665,43	46.388,99	92.777,98
9.798,28	33,097	324.295	19.596,56	44.926,64	89.853,29
11.826,05	28,068	331.934	23.652,09	44.287,10	88.574,21
17.880,18	20,667	369.530	35.760,35	45.390,91	90.781,81
27.966,09	14,037	392.570	55.932,17	44.094,58	88.189,15
41.961,06	10,126	424.880	83.922,11	44.003,91	88.007,83

Table 4. ABS Lustran QE1455 Results for 180 degree die entry at 260C, n = 0.2

Average Shear Rate (1/s)	Shear Viscosity (Pa.s)	Shear Stress (Pa)	True Shear Rate (1/s)	K	K'
933,37	170,428	159.073	1.866,75	16.606,24	70.535,85
2.791,21	79,428	221.699	5.582,41	16.661,63	78.964,09
4.895,47	49,962	244.587	9.790,94	15.530,49	77.857,00
5.824,93	43,181	251.527	11.649,86	15.159,60	77.330,30
7.920,99	33,618	266.290	15.841,98	14.635,67	76.988,09
8.914,13	30,420	271.170	17.828,26	14.384,98	76.568,53
9.784,23	27,497	269.042	19.568,46	13.878,81	74.565,51
11.823,75	23,947	283.145	23.647,50	13.799,82	75.558,26
17.874,13	17,071	305.126	35.748,26	13.137,21	74.964,99
27.914,20	11,982	334.460	55.828,39	12.597,61	75.162,95
41.903,04	8,519	356.983	83.806,08	11.903,22	73.964,27
55.802,97	6,788	378.802	111.605,94	11.590,61	74.114,82
69.892,77	5,733	400.708	139.785,53	11.460,13	74.948,95

Table 5. ABS Lustran QE1455 Results for 180 degree die entry at 280C, n = 0.3

Average Shear Rate (1/s)	Shear Viscosity (Pa.s)	Shear Stress (Pa)	True Shear Rate (1/s)	K	K'
931,55	94,292	87.838	1.474,96	9.841,21	15.581,92
2.794,31	56,459	157.667	4.424,33	12.705,35	20.129,16
4.909,11	39,373	192.349	7.772,76	13.089,32	20.825,56
5.825,99	35,931	209.335	9.224,48	13.531,92	21.425,54
7.945,08	28,936	229.899	12.579,71	13.540,51	21.439,15
8.860,59	26,891	238.272	14.029,26	13.581,94	21.504,74
9.815,84	24,818	243.608	15.541,75	13.466,08	21.321,29
11.890,48	21,138	251.336	18.826,59	13.116,64	20.768,01
17.812,60	14,775	263.185	28.203,28	12.166,66	19.263,87
27.905,40	10,419	290.737	44.183,55	11.746,85	18.599,18
42.002,95	7,492	314.674	66.504,68	11.246,18	17.806,45
55.846,25	6,057	338.277	88.423,24	11.099,47	17.574,15
69.846,35	4,978	347.663	110.590,06	10.667,02	16.889,45

Figure 4 shows shear stress as a function of shear rate. The curves exhibit the same behavior, the shear stress increases as shear rate increases as well. The figures also exhibit concave downward curves.

Figure 5 shows shear viscosity as a function of shear rate. The curves show a decrease in viscosity with increased shear rate. This behaviour is called pseudoplastic flow. A plot of viscosity as a function of shear rate as determined at different temperatures. At the same shear rate, the figures would imply that the higher temperature the lower shear viscosity.

Figure 6 shows shear viscosity as a function of shear stress. The curves exhibit the same pattern, the shear viscosity decreases as shear stress increases.

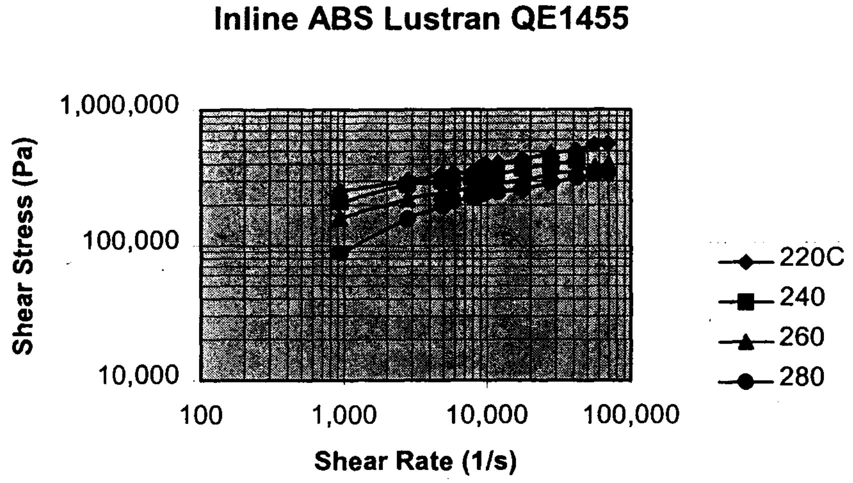

Figure 4. Shear rate vs. shear stress

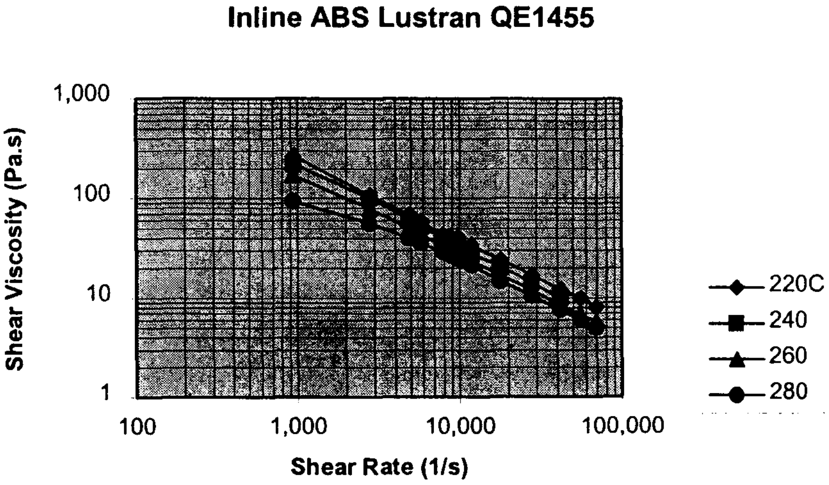

Figure 5. Shear rate vs. shear viscosity

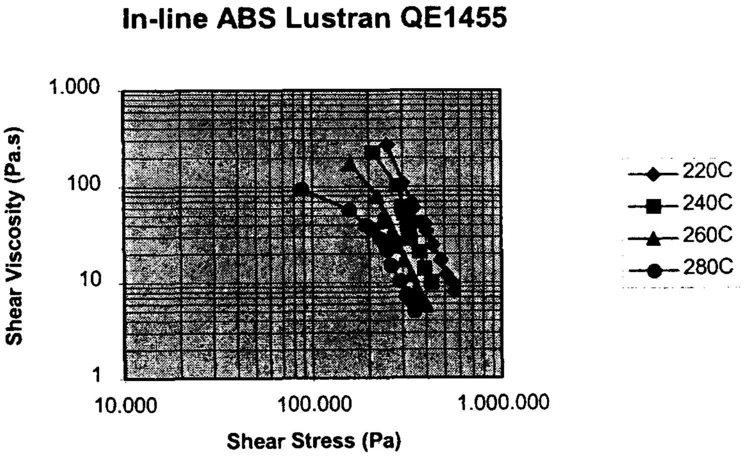

Figure 6. Shear stress vs. shear viscosity

CONCLUSION

The curves of shear stress as a function of shear rate exhibit concave downward curves and the shear stress increases as shear rate increases. The ABS' shear viscosity will decrease as shear rate increases. A decrease in viscosity with increased shear rate is called pseudoplastic flow. In general, changes in temperature can readily affect the viscosity of a fluid. For ABS, an increase in temperature will decrease the viscosity of the liquid. However, the curves exhibit the same behavior, indicating that there is no significant change in the function at different various temperatures. The tested materials ABS Lustran QE1455 did not experience excessive changing of function at for different temperatures.

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Ref.*1, for more information, contact: CryoGen, Inc., 11065 Sorrento Valley Court, San Diego, Calif. 92121. 888-634-0444.