

Jet Flows of Amorphous Borate Esters for Ink Jet Printing

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Abstract

Solid ink jets are used in printers. Invariably, solid ink jets are crystalline materials, which under go dramatic change in modulus in moving from solid to liquid state. During jetting, flow instability can occur depending on jet velocity, viscosity, surface tension and elasticity of the fluid. Satellite formation can occur when Weber number is high. The flow can range from dripping to jetting depending on the flow rate. A high Weissenberg number can lead to die swell or melt fracture in a jet flow.

In contrast to crystalline solid ink jet material, we are proposing the use an amorphous material, a borate polyester which exhibits an exponential decrease in viscosity on heating and is miscible with small molecular, semi-crystalline diluents enabling fine tuning of viscosity and temperature that a specific composition transitions from solid to liquid state. Specific rheological characteristics can be engineered by the nature of alcohols or glycols that are reacted with boric acid and by making mixtures of the various borate esters,

Introduction

In both drop-on-demand and continuous ink jet printers; drop size is critical in determining print quality because of its influence on size of a dot. Dot diameter, intensity of a dot and roundness of a dot is also affected by impact time reaching an asymptote.¹ In the absence of external forces, the process of break up of beads on string is dependant on relative importance of viscous and elastic contribution to the stress and the capillary pressure within the fluid thread. The level of fluid visco-elasticity can be used to control drop size. Newtonian fluids can be characterized by the Reynolds number being, $Re = \rho V l / \eta_0$ and the capillary number being $Ca = \eta_0 V / \sigma$. On the other hand, Reynolds number and Weissenberg number, $Wi = \lambda V / l$ with elasticity number $El \equiv Wi / Re = \eta_0 \lambda / \rho l^2$ characterize non-Newtonian fluids. High speed jet breakup can be given in terms of Weber number, $We = Re Ca = \rho V^2 l / \sigma$, Re is Reynolds number, Ca is capillary number, ρ is density of fluid, V is flow velocity and l is length scale. There is a Weber number based on droplet diameter $We_D = \rho V^2 D / \sigma \geq 8$. Analogously, inertio-capillary break-up of an inviscid jet is given by intrinsic Deborah number

$$De_0 \equiv El / Oh = \lambda \sigma^{1/2} / (\rho l^3)^{1/2},$$

where Oh Ohnesorge number is given by

$$Oh^2 \equiv Ca / Re = \eta_0^2 / (\rho \sigma l), \lambda$$

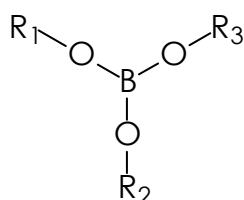
is time scale of elastic relaxation to Raleigh time scale is

$$t_R = (\rho l^3 / \sigma)^{1/2}.$$

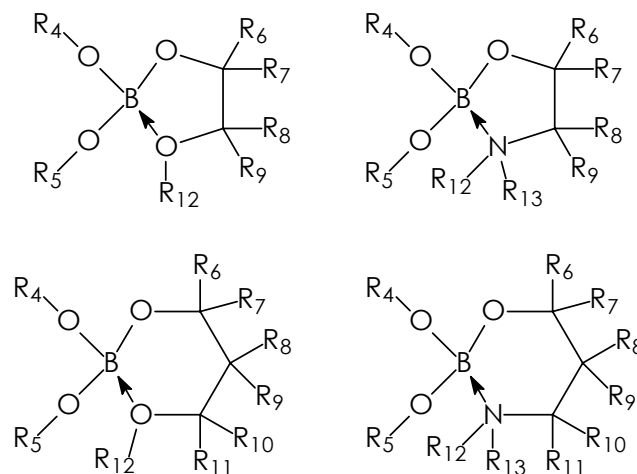
Drop dynamics of Newtonian jets has been compared with visco-elastic jets and it is found that a visco-elastic jet breaks up slowly compared to a Newtonian jet and that elastic force makes a liquid flow from a small drop to a large drop.³ The use of phase change inks in acoustic ink printing processes is also known. Several polymers have been used as materials for ink jets. They vary from being Newtonian to shear thinning to being visco-elastic under temperature and shear. We have studied a class Borate esters for use in ink jet printers.⁴

Materials

Borate esters that can be synthesized for phase change inks include those of the general formula

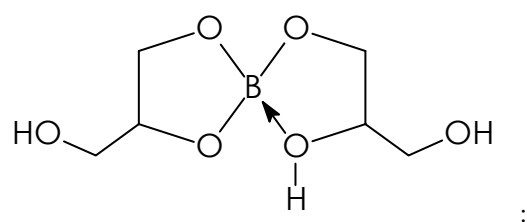
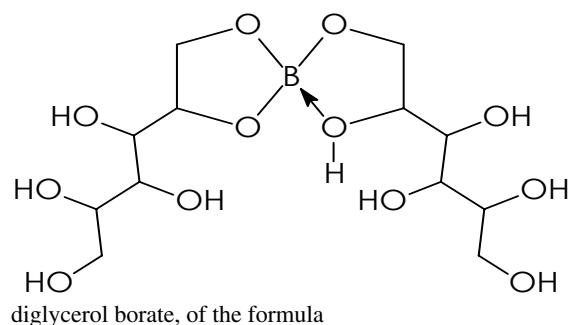


where in R_1 , R_2 , and R_3 each, independently of the others, is an alkyl group, typically with from about 2 to about 30 carbon atoms. Additionally, groups, carbonyl groups, mixtures thereof, and the like, wherein two or more substituents can be joined together to form a ring, and wherein R_1 , R_2 , and/or R_3 can be joined together to form an aliphatic or aromatic ring, and those of the general formulae



wherein R_4 and R_5 each, independently of the other, is an alkyl group (including linear, branched, saturated, unsaturated, cyclic,

and substituted alkyl groups, and wherein hetero atoms, such as oxygen, nitrogen, sulfur, silicon, phosphorus, and the like can be present in the alkyl group), typically with from 1 to about 30 carbon atoms.



Polyester	k	n-1	Temperature
Glycerol Sorbitol Borate Polyester	961.7	0.877	75C
Glycerol Sorbitol Borate Polyester	258.92	0.845	95C
Diglycerol Borate Polyester	9.35	0.997	75C
Diglycerol Borate Polyester	2.98	0.991	95C

Compared to polyglycerol Sorbitol borate, polydiglycerol borate has lower viscosity and power law exponent moves to unity indicating that polyglycerol sorbitol borate is a more structured macromolecule.

Doshi has recently applied power law fluids and Carreau fluids and has shown that midpoint radius for power law fluids

$$\eta = k|\dot{\gamma}|^{n-1} \text{ is given by } \frac{R_{mid}}{R_0} = \phi(n) \frac{\sigma}{k} (t_c - t)^n,$$

where n is power law index, k is consistency index and $\phi(n)$ is a numerical constant.⁵

Experimental and Results

The polyglycerol Sorbitol borate we have synthesized was characterized by DSC at 10C/Min Heating Rate and was found to have an onset Tg of -37.4C.

ARES, a TA instrument using linear viscoelastic sinusoidal deformation, investigated viscosity and viscoelasticity of Poly Glycerol Sorbitol Borate. Below is given elastic modulus, G', viscous modulus, G'' and complex viscosity η^* of the material at 75C and higher temperatures. The results were compared to poly diglycerol borate at the same temperatures and shearing frequencies. Viscosity as function of shearing frequency was subjected to power law dependence and power law exponents were obtained,

$$\eta = k|\dot{\gamma}|^{n-1},$$

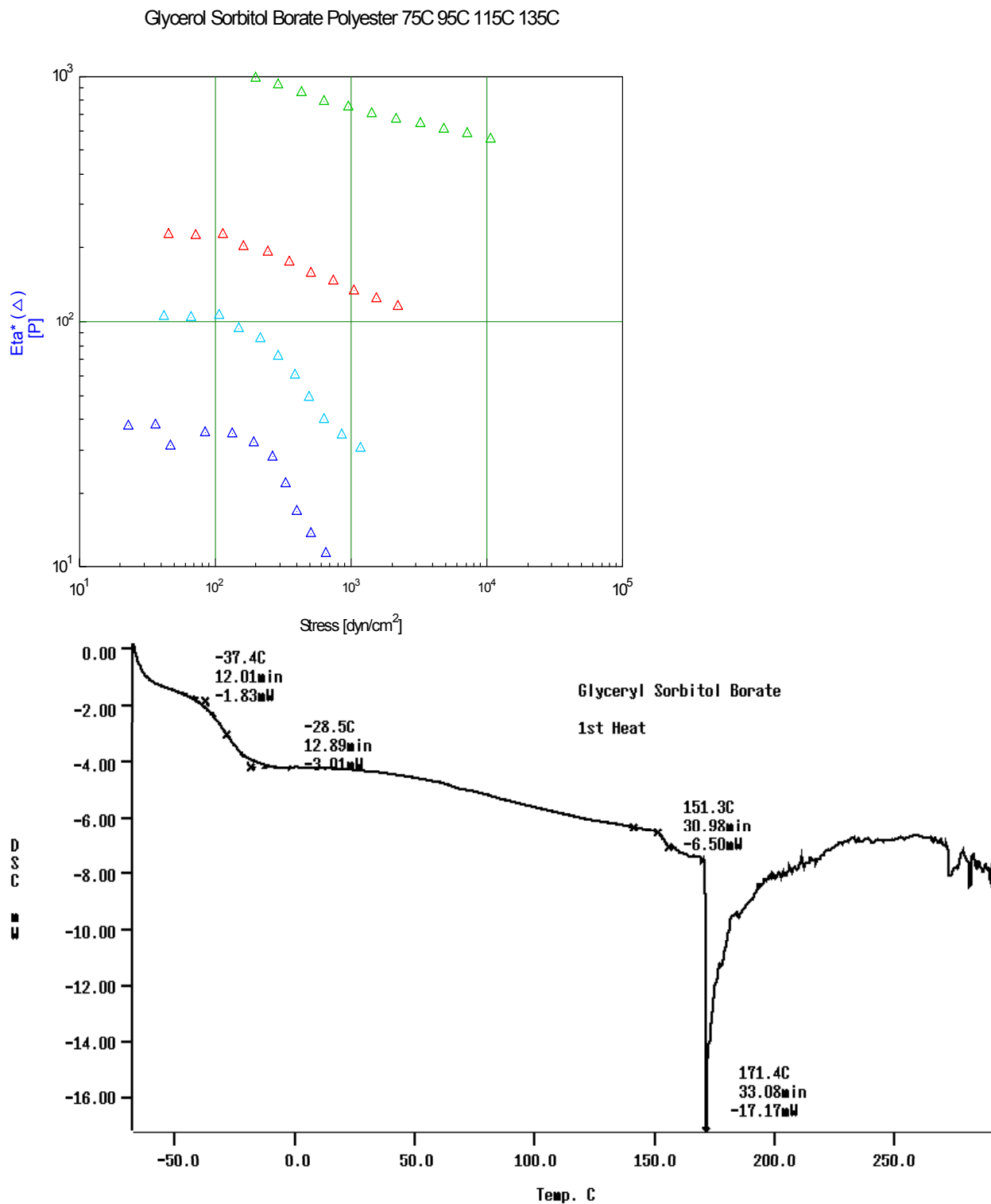
where η is viscosity, k is a measure of the consistency of the fluid, $\dot{\gamma}$ is shear rate and n is a measure of the degree of non-Newtonian behavior.

Next we apply Rouse model to the behavior our fluids. Rouse model considers polymer as made up of bead and springs in series. Rouse model was applied to data from the two polymers. The viscous or loss modulus decreases with increase in temperature but viscous modulus higher for polyglycerol Sorbitol borate than polydiglycerol borate decreases more rapidly with increase in temperature. The polyglycerol Sorbitol borate is probably a stiffer molecule than polydiglycerol borate.

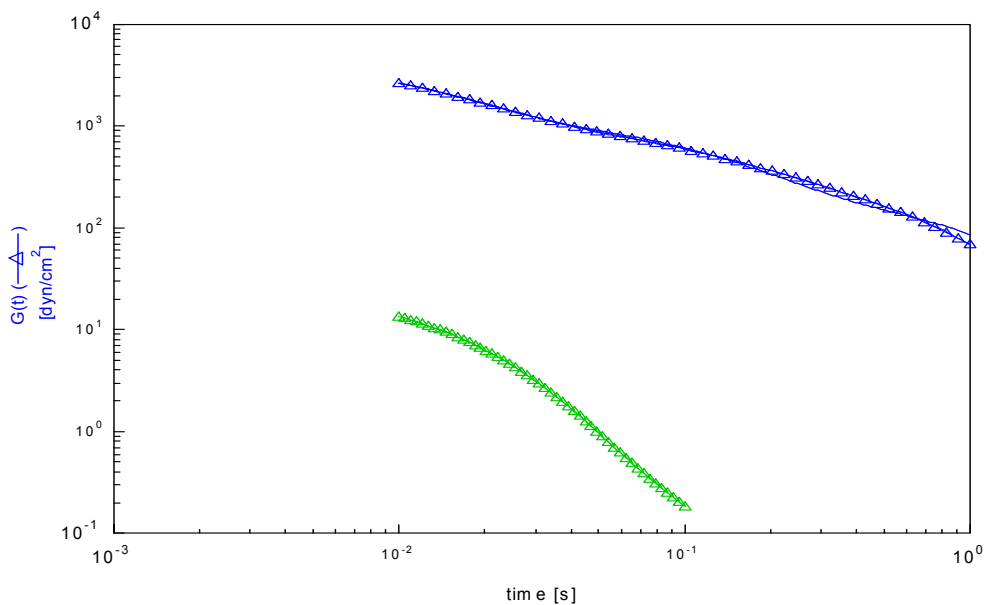
From viscous and elastic modulus as function of frequency, relaxation modulus as function of time was obtained using transformation function. The relaxation modulus as function of time was fitted into exponential decay and parametrs and coefficients were found for both polyglycerol Sorbitol borate and polydiglycerol borate.

Shown below is a graph of viscosity as function of shear stress of Glycerol Sorbitol Borate Polyester. It illustrates drop in viscosity at a particular shear stress. There is likelihood that hydrogen bonding is occurring giving rise to yield stress.

Capillary pressure in proportion to the magnitude of yield stress affects the flow of liquid in a jet through the existence of critical radius at the neck or midpoint.



Relaxation Modulus G(t) of Glycerol Sorbitol and Diglycerol borate esters at 75 C



G(t) kernel fit

$$\sum C_i \exp(-x/a_i)$$

Parametrs and coefficients

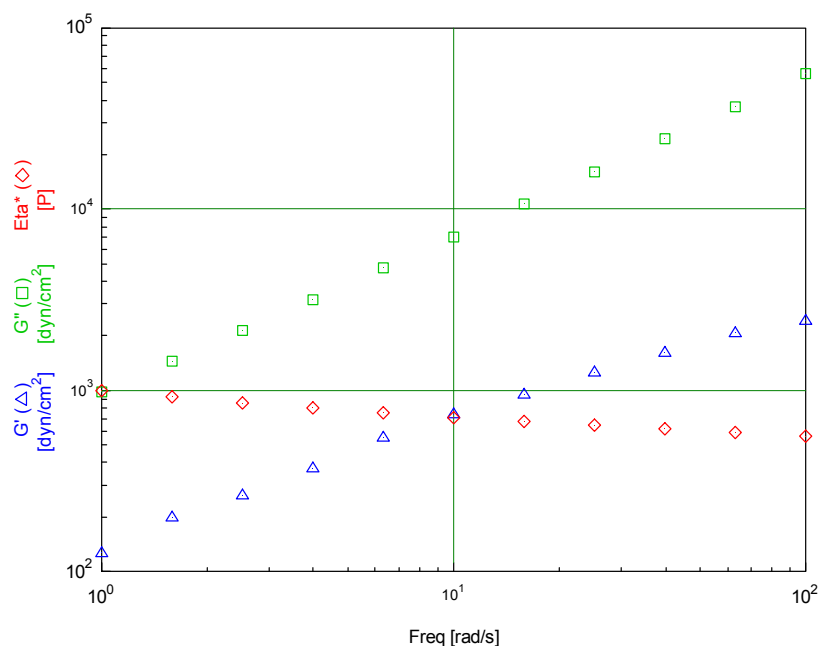
Glycerol Sorbitol Borate Ester

Index	Parameter	Coefficient
1	0.01	3936.61
2	0.1	1076.93
3	1	234.05

Diglycerol Borate Esters

Index	Parameter	Coefficient
1	0.01048	30.4041
2	0.03237	3.134
3	0.1	0.0701

GLYCERYL SORBITOL BORATE AT 75C



Conclusions

A new class of polyesters that is borate polyesters have been synthesized which differ in structure with significant application in fundamental studies and in jet flows for inkjet application.

Borate polyesters were evaluated for fluid flow and their flow behavior was applied to viscometric and visco-elastic models demonstrating that structure of the borate esters affect shear thinning and dependence of visco-elastic modulus on shear, temperature and relaxation time. Jet flows with application to inkjet can be studied with respect to their flow stability by using borate esters with different viscosity and elasticity affecting neck radius and drop size.

References

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5. P. Doshi and O. A. Basaran, Self-similar pinch-off of power law fluids, Physics of Fluids, Vol. 16, 2004, pp. 585-593.

Author Biography

Sam Ahuja joined Xerox Corporation in 1970 after completing Ph. D in Polymer Chemistry and M.S in Physical Chemistry. He has contributed papers at European conference on electrophotography, international conference on theoretical and applied mechanics and theoretical and applied rheology. His subjects of study include contact electrification in polymers, rolling contact of polymer layers, collision and rate of deformation of polymeric particles as well as viscous and visco-elastic deformation of homopolymers, copolymers, cross-linked polymers and composites. He has contributed towards several patents on the use of polymers and nano structures in electrophotography.