The Effect of Polymer Chain Length on the Rate of Phase Migration

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Phase migration is a common and undesirable phenomena sometimes encountered when processing highly concentrated pastes. It occurs when the liquid phase flows preferentially to the solid matrix and can result in a number of failure modes, including damage to equipment[1].

While working on binder formulations for a phenolic resin paste, it was noticed that two superficially similar binder systems exhibited very different degrees of phase migration. It was thought that this may have been related to the relative polymer chain lengths of the binder material. This work was undertaken to determine the reason for the difference in phase migration behaviour.

Two authors have proposed models of phase migration, both based on modifications to the Benbow-Bridgewater extrusion model. Bayfield et al.[2] has found the growth rate of static zones in a sugar paste could be liked with the increase in extrusion pressure. The model proposed by Rough *et al.* [3] takes a Darcy's Law approach to calculate the relative flowrate of the liquid phase and thus the moisture profile in the extrusion barrel. If the relationship between the moisture content and Benbow-Bridgewater parameters of the system is known, it is possible to predict the increase in the extrusion pressure.

Four grades of Polyethylene Oxide (PEO) were tested (Molecular weights 200,000; 400,000; 1 million and 4 million). A relationship between the concentration of the PEO in water and the power law rheological model parameters, k and n, was derived through a series of shear rheometry experiments. Using this relationship, it was possible to formulate two PEO binder systems with the same shear rheological characteristics, but formed from two different grades of PEO.

A paste was formulated to encourage the occurrence of phase migration. It was found that phase migration was more prevalent close to the lowest solid/liquid ratio at which a paste could be formed and with a highly permeable phenolic resin solid matrix.

The results were found not to agree with all the assumptions made in the models proposed by Rough and Bayfield. Firstly, the density and moisture content of the paste remaining in the barrel was not found to vary significantly as predicted by Rough. Handling errors may be at the root of this finding as the paste was extremely dry when removed from the extrusion barrel and had a tendency to crumble. Also, the extrudate was not found to become measurably drier as extrusion continued, as assumed by both authors. Significant static zones were observed in the paste pug after extrusion, but their rate of growth has not been measured.
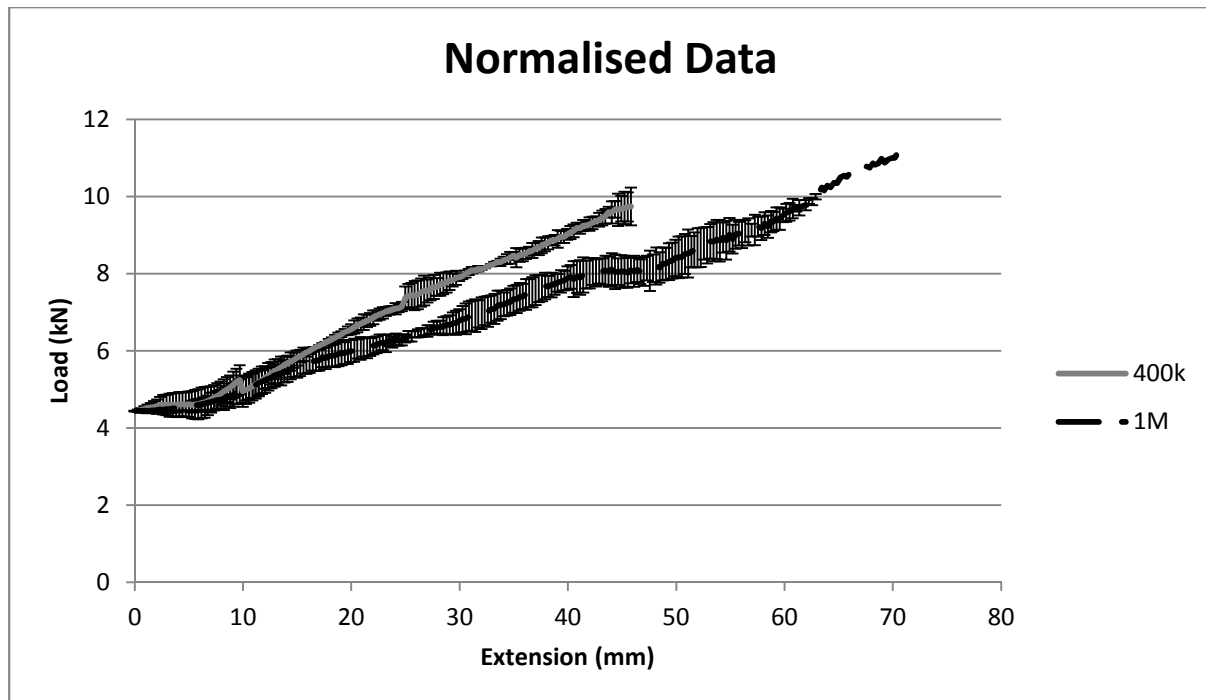
Figure 1 – Normalised extrusion profiles after the onset of extrusion (α = 0.05)

The rate of phase migration as measured by the gradient of the load/extension trace after the onset of extrusion was found to be significantly different between the two grades of PEO, despite having the same shear rheological properties. The increase in extrusion pressure in the lower molecular weight binder system was 0.12 MPa/mm and 0.09 MPa/mm for the higher molecular weight binder system.

Models available in the literature do not appear to fully account for the observed behaviour. Work is ongoing to establish what is causing the difference between the two systems. It may be due to a secondary permeability interaction of the water phase through a PEO network or due to differences in viscoelasticity of the binders.

1.   Benbow, J.J. and J. Bridgwater, *Paste Flow and Extrusion*. Oxford Series on Advance Manufacturing. 1993, New York: Oxford University Press Inc. 176.
2.   Bayfield, M., et al., *Liquid Phase Migration in the Extrusion of Icing Sugar Pastes.* Food and Bioproducts Processing, 1998. **76**(1): p. 39-46.
3.   Rough, S.L., D.I. Wilson, and J. Bridgwater, *A Model Describing Liquid Phase Migration Within an Extruding Microcrystalline Cellulose Paste.* Chemical Engineering Research and Design, 2002. **80**(7): p. 701-714.