Non-Newtonian effects of ink-jet printed droplets

P.C. Duineveld[*], J.F. Dijksman[*], H. Huang[**]

[*]Philps Research, Eindhoven, The Netherlands,
[**]York University, Toronto, Canada

Summary *The influence of non-Newtonian effects on the droplet formation in an ink-jet printer has been investigated both experimentally and theoretically. For the experiments, Newtonian liquids and solutions of flexible and stiff polymers were used. The non-Newtonian effects were modelled by only using the elongational viscosity and not the stress history effect. It is shown that this in itself is not sufficient; the stress history effects can not be neglected.*

The viscosity of an ink is an important parameter for the droplet formation in an ink-jet head. Standard in the ink-jet printing world is to measure the shear viscosity of the liquid. Most common inks in graphical applications are Newtonian liquids and therefore the shear viscosity is a suitable characterization technique.

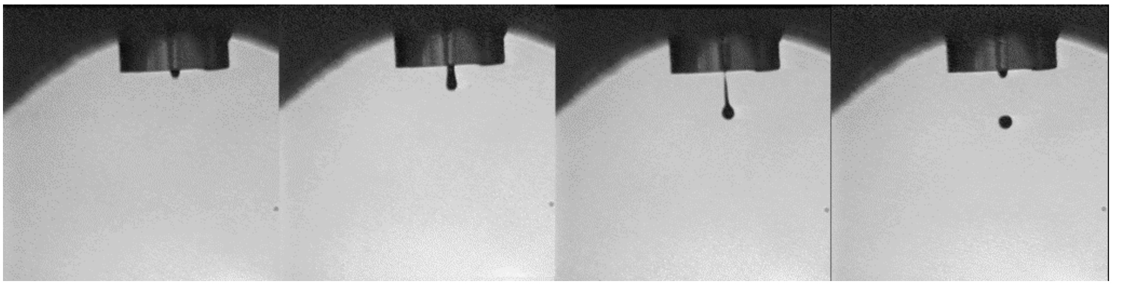
Recently, several applications are appearing where small concentrations of high molecular weight, functional, polymers in a suitable solvent are deposited by means of an ink-jet printer. Examples are light-emitting polymers for display applications, polymers for transistors and biological applications. The drop formation of these solutions is considerably different from a pure Newtonian liquid. There is more energy needed to eject the droplet from the nozzle and droplets are formed with a filament connecting the nozzle and the main droplet. When this filament is too long it can break up in satellite droplets and also the directional accuracy of the main droplet can decrease, which is problematic in applications. An example of the different stages of droplet formation of a Newtonian liquid and a non-Newtonian liquid are shown in figure 1.

When these solutions are measured in a shear rheometer the viscosity is constant as a function of the shear rate, and in the proper regime for ink-jet printing, i.e. 3 to 20 cP. The droplet formation, however, shows the strong filament formation, which is due to non-Newtonian effects. There are two effects that may contribute to this non-Newtonian behaviour: stress history effects and an increase of the elongational viscosity. There are no suitable rheometers that can measure in the regime of ink-jet printing, which has a very large elongational rate of order 10^5 s^{-1}. Therefore we have studied if it is possible to use the droplet formation in an ink-jet printer as a simple method to obtain information on the non-Newtonian effects of the solution.

The functional polymers often are quite polydisperse, therefore experiments were performed with Newtonian liquids and model polymer solutions, with both very flexible polymers (PEO, polyethylene oxide) and stiff polymers (Xanthan Gum). The molecular weight of the PEO was 10^5 and 3.10^5 gr/mol. The length and the radius of the filament was measured during the droplet formation for initial droplet velocities varying between 5 and 20 m/s.

We have set-up a very simple model for the non-Newtonian effects. Only the elongational viscosity was taken into account and stress history effects were neglected. With this simple approach we have investigated whether the increase in elongational viscosity is sufficient for the long filament formation. The elongational viscosity of the flexible PEO was modelled with a FENE-P model, while for the rigid polymers the rigid rod theory of Batchelor was used. The contribution of the elongational viscosity is incorporated in a model, together with surface tension effects, that describes the filament formation and droplet motion.

From our calculations and experiments we can conclude that the elongational viscosity is not sufficient to describe the long filament formation. Especially in the later stages of thinning of the filament it can be shown that the contribution of the elongational viscosity is negligible compared to the surface tension. Yet the filament does not break-up which we attribute to the neglected stress history effects.



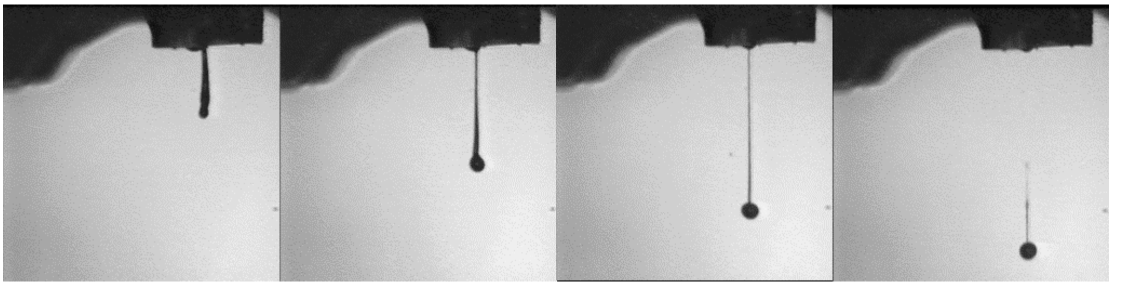


Figure 1: Stroboscopic images of droplets, produced by ink-jet printing. The upper picture series shows a Newtonian fluid. The lower picture series shows the effect of an addition of a small amount of a high molecular weight polymer. Note the formation of a filament connecting drop and nozzle. The diameter in the lower right image is 70 μm. Typical time scale for the events is less than 100 μs.