Research of the effect of solvents on the rheological characteristics of drop-on-demand inkjet liquid toner

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Abstract. In this work the relationship of the rheological characteristics of liquid toner with external factors (shear strain rate, temperature) depending on the solvent used is investigated, experiments with a number of solvents (sulfolane, 3-methoxypropionitrile or acetonitrile) are carried out.

1. Introduction
Inkjet printing is an oil-free application of toner with micrometer precision and material savings. Drop-on-Demand technology is often used in laboratory experiments. This technology is currently being developed in the production of printed devices such as solar panels and printed circuit boards. For the development of printing devices, high resolution printing and the possibility of printing on a wide range of materials are being investigated. To achieve these goals, it is necessary to ensure the stability of dropping. An important role in the printing process is played by the behavior of the toner on the substrate, which depends on the rheological properties of the liquid toner [1].

Under the influence of electrical impulses, the plate piezoelectric transducer (lamella), which is attached to reservoir, bends and exerts pressure on the meniscus with the ink reservoir. The reservoir, which is contracting under the pressure of the lamella, acts on the principle of a pump and pushes microscopic portions of ink from the nozzle, which are sprayed onto the printed material. After the ink drop escapes, the lamella receives the opposite tension and bends in the opposite direction, dragging the reservoir meniscus along with it. At the same time the volume of the reservoir increases and this makes a new portion of ink to drawn into it [2].

Liquid toner is a multicomponent substance that consists of a mixture of particles. Due to the mutual forces in the toner and the reflective force of the material when stationary, the system is unmixed. After the application of deformation and shear, the toner may first exhibit induced elasticity, since the mixing resistance reaches a maximum, which causes dilatation. Dilatancy caused by high shear rates leads to rapid evaporation during ejection, and hence to undesirable clogging of nozzles [3]. Using liquid toner with various solvents (sulfolane (SFN), 3-methoxypropionitrile (MPN) and acetonitrile (ACN)) under various printing temperature conditions, the change in rheological parameters during the operation of printing device should be compared. The rheological characteristics of toner, which vary with external factors such as temperature and shear rate, affect print results.

2. Research and results
To achieve ideal printing results, a high-performance jetting ink should meet certain options in terms of its physical properties. The boiling points of the solvent, which are the key parameter for the volatility of the ink at the nozzle orifice, are 285°C, 164°C and 82°C for SFN, MPN and ACN electrolytes, respectively. Surface tension values were measured with an optical tensiometer in pendant drop mode at room temperature and the inks were more characterized at higher temperatures as indicated in the results section. To characterize the interaction of the substrate and ink, contact
angle measurements were carried out in sessile drop mode at room temperature in 65% relative humidity using an optical tensiometer [4].

A Fujifilm printer (DMP-2831) was selected as a printer for testing. In order to ensure the same conditions in the experiments, which were carried out for all paints, a jet frequency of 1 kHz was used [5]. The substrate type was identical throughout all experiments. The droplet feeding temperature took different values - 23°C, 40°C, and 60°C.

Jetting trajectories and velocity of the ejected drops were determined by embedded stroboscopic drop watcher camera. Deviation of the drop trajectory and a drop travelling velocity different than optimal value (7-9 m/sec for this printer geometry) are highly detrimental for the printing results and might give rise to shorter cartridge life cycle by clogging the nozzles due to possible agglomeration on the orifice [6].

Dynamic measurements of toner viscosity (Figure 1 (a)) indicate a decrease in viscosity at shear rates of up to 150 s⁻¹ and an increase in viscosity at shear rates above 150 s⁻¹. Complex viscosity (Figure 1 (b)) is a characteristic of the structural deformation of the toner. Viscoelastic measurements also indicate a change in viscosity decrease η* at low angular frequencies. With an increase in the value of ω, the complex viscosity increases. Compared to liquid toners based on ACN and MPN, sulfolane based (SFN) toner showed the greatest resistance to shear rate changes.

![Figure 1](image.png)

**Figure 1.** Changing the viscosity of toners: a) η, b) η*.

The dependence of the viscosity of the toner on the change in the rate of shear deformation in different time intervals is shown in Figure 2 (a). With an increase in the shear strain rate in the 60-90 sec region, the viscosity of all toners drops sharply. With the reverse decrease in the deformation rate (90-150 sec), the viscosity of the toners began to exceed the initial values at 0.1-60 sec. This behavior is typical for dilatants. Figure 2 (b) shows the dilatant behavior of the toner with a linear increase in the shear rate (50-400 sec). Figure 2 shows that the SFN solvent has much lower viscosity fluctuations compared with other solvents at a constant shear rate.
Figure 2. Graphs of changes in viscosity of samples: a) a gradual increase in shear strain rate with an increase in shear rate by 60-90 sec, b) a linearly increasing shear strain rate in the range of 50-400 sec.

Figure 3 shows images of substrates obtained with an atomic force microscope at a temperature of 23°C. The image in Figure 3 (d), corresponding to the sulfolane based liquid toner, has the smoothest and most uniform texture compared with other toners (Figure 3 (b, c)).

Figure 3. Atomic force microscope images: a) unprinted surface, b-d) printing surface (acetonitrile, 3-methoxypropionitrile and sulfolane).

As shown in Figure 4, as the temperature rises, the dilatancy of all three toners decreases at high shear rates. At low shear rates, the dilatancy is higher than at high shear rates, but decreases markedly with increasing temperature, because the heating of the toner reduces particle vibration.
Figure 4. Dynamic viscosity ($\eta$) and shear strain rate ($\gamma$) at various temperatures.

Figure 5 shows the contact angle of droplets on a printed substrate (paper) and the surface tension of suspended droplets. Sulfolane (SFN) maintained the contact angle throughout the experiment (150 sec), acetonitrile (20 sec), 3-methoxypropionitrile (80 sec) (Figure 5 (a)). This slow drying procedure for sulfolane toner droplets is due to the high degree of particle redistribution over time. The surface tension is determined when the temperature rises from 25 to 60 °C (Figure 5 (b)). The higher the temperature of the medium, the lower the surface tension. The sulfolane-based (SFN) liquid toner had the smallest change in surface tension.

Figure 5. Characteristics of toners: a) the contact angle of the toners as a function of time, b) surface tension of toners with temperature change.
3. Conclusion
This article investigated the effect of the solvent used on the rheology of a liquid drop-on-demand inkjet toner. Sulfolane liquid toner performed better than its main competitors acetonitrile (ACN) and methoxypropionitrile (MPN) in all tests. This means that the usage of sulfolane as a solvent for the liquid inkjet toner provides the best print quality due to optimal rheological characteristics depending on changes in various external factors such as shear strain rate and temperature.

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