Inkjet Deposition of Complex Mixtures to Textiles

Wallace W. Carr, leader; David Bucknall (Georgia Tech), Jeffrey F. Morris (City College of NY)

We are developing a fundamental understanding of the process of deposition of complex mixtures

Inkjet printing is already established as a useful technology to the textile industry. Not only is it important in textile printing, but also has potential for creating high-value textiles such as e-textiles. Broad utilization of this flexible method faces a number of barriers, springing from the requirement that "inks" in a growing number of textile applications contain solid particles which may serve as colorant or binder, but may also be ceramic or metallic particles in other applications. We will expand the scientific knowledge base critical for textile inkjet technology and will provide a foundation for rational design and advancement of the inkjet technology in textiles. Economic benefits are expected to include creation of new and high-value markets, as well as optimization of the design process for specialty treatments in textiles.

Based on prior studies (NTC projects C99-G08 and C02-GT07), we have identified and begun the process of surmounting technical hurdles in the technology, which come in two forms. The first is in the dynamics of drop formation and drop impaction of solids-laden inks. The second is the role of the surface morphology and surface chemistry encountered in textile materials. Currently, we are utilizing this foundation to guide characterization of these processes at the very small-scale and high speed typical of application. We will also develop a model incorporating the material properties for deposition of complex mixtures by the inkjet method. The approach to characterize and model the phenomena associated with inkjet deposition to textiles involves a detailed experimental study based on image analysis to determine the drop formation behavior from complex particle-laden liquids, and to analyze the drop impact and spreading.

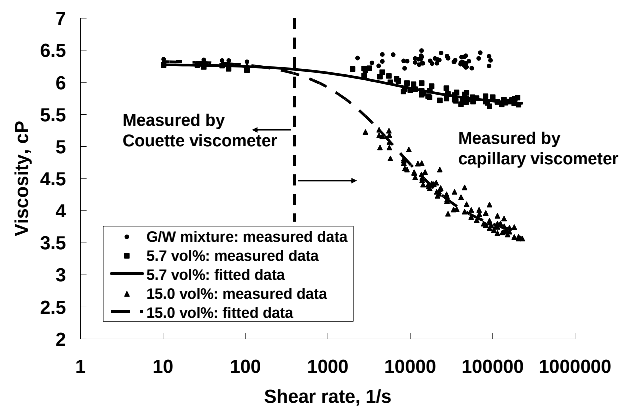
Dynamics of Inkjet Drop Formation

Drop-on-demand (DOD) inkjet printing is considered to be an efficient approach for depositing picoliter (10^{-12} liter) drops on various targets. It is compatible with various liquids and is a non-contact ink delivery method. Drop formation and impaction on the substrate are important because they significantly affect the final state of the material on the substrate. Our experimental setup (C02-GT07) using high-speed photography has successively been used to visualize the micro-motions involved in inkjet deposition.

We have studied the DOD drop formation process for pure liquids and are currently extending our study to particle-laden liquids. The formulation of high performance / high value-added treatments in the form of inks for textiles may affect deposition and ink-substrate interaction. Characterization of the effects of the solids-laden inks on drop formation and substrate interaction is crucial to utilization. Since inkjet inks are subjected to very high shear rates in DOD inkjet printing, the characterization of high material loading inkjet inks using apparent shear viscosity measured at low shear rates, which is done in both academy and industry, may not be appropriate.

Since no experimental data on shear viscosity at high shear rates (up to 10^5 s^{-1}) typically found in DOD inkjet printheads was found in the literature, one of the goals of this research is to investigate the shear rate dependency of shear viscosity of pigmented inkjet inks. A capillary rheometer has been designed, constructed and used to measure shear viscosity for shear rate ranging from 103 to 2×10^5 s^{-1}.

The viscosity of samples measured using the capillary viscometer is shown in the figure below. The results reveal that surface-modified-carbon-black pigmented water-based inkjet ink samples exhibit Newtonian behavior at low shear rates, a pseudo-plastic one in the middle shear rate range, and a second Newtonian plateau at very high shear rates. Although the three samples have almost the same shear viscosity (~ 6.4 cP) at low shear rates, at shear rate of 2×10^5 s^{-1}, the shear viscosities of the two particle-laden inks drop to about 5.7 and 3.5 cP. The shear-thinning behavior observed for the particle-laden inks is attributed to the structure breakdown of agglomerates in the inkjet ink samples due to strong hydrodynamic motion.



Shear viscosity of inkjet ink as a function of shear rate at 22°C (fitting curves are obtained with a generalized Cross equation).

Drop Impaction

In our previous NTC research project we studied pure-liquid, millimeter drops impacting smooth surfaces as well as a rough, textile-like surface. It provided the required background for ongoing research of the effect of particles on the impaction process for micron drops.

In the present work, we examined the characteristics of the micron-scale drop impaction process based on a series of comprehensive experiments and demonstrate the ability to resolve the dynamics of these small drops, as well as determine the scalability of the impaction process from millimeter to micron drops. Future work will address more complex mixtures.

Future Research

One of the final year's goals in DOD drop formation is to investigate the role of solids fraction in drop formation at the application scale and to determine the critical value of particle concentration where drop formation is adversely affected.

Research focusing on the impaction process for particle-laden-liquid drops in the micron-size range and process parameters that are typically found in inkjet printing is needed. Experimental studies of model-fluid impact (dynamic) and wetting (equilibrium) on model surfaces (well-defined topology, chemistry and porosity) are being conducted. The model fluids will include high viscosity fluids (nonvolatile, i.e., non-aqueous/non-solvent based) since these are very important in a number of growing digital printing applications. The impact studies will determine the effects of particles on the impacting process and establish whether or not experimental results for particle-laden-liquid drops of millimeter-size scale down to drops in the micron size.

The effects of fabric parameters (surface chemistry, weaving pattern, roughness, and yarn size) and the ink properties (viscosity and surface tension) on image quality have been evaluated in the last NTC project (C02-GT07). Further work is being conducted to better understand the results. The current research will include image analysis of drop impaction on yarns and fibers to determine how fluid interactions with fibers/yarns translate to ultimate image quality.

Other Contributors: **Graduate Students**: *Hyunyoung Ok, Hongming Dong, Xi Wang, Xuejia Yan* (Georgia Tech).

Industry Interactions: 11 [The Sawgrass Co, FUJIFILM Dimatix Corp.]

Other Non-NTC Academic Interactions: 5 [U. of Marseille].

Project Web Address:

http://www.tfe.gatech.edu/faculty/carr/ntcproject.htm

http://www.ntcresearch.org/projectapp/?project=C05-GT07

For Further Information:

1. Dong, H., W.W. Carr, and J.F. Morris, *Visualization of drop-on-demand inkjet: drop formation and deposition*, Review of Scientific Instruments 77 (8): 085101 (2006).
2. Dong, H., W. W. Carr, and J. F. Morris (2006), *An experimental study of drop-on- demand drop formation*, Physics of Fluids 18 (7), 072102 (2006).
3. W.W. Carr, H. Park, H. Ok, R. Furbank, H. Dong, and J. F. Morris, *Drop formation and impaction*, in Digital printing of textiles. H. Ujiie, Ed; Cambridge, UK, Woodhead Publishing Limited and CRC Press, 53-68 (2006).
4. Furbank, R. J. & Morris, J. F., *Pendant drop thread dynamics and pinch-off in particle-laden liquids*, Int. J. Multiphase Flow, 33 (4), 448-468 (2007).
5. Park, H., Carr, W.W., Ok, H., and Park, S., *Image Quality of Inkjet Printing on Polyester Fabrics*, Textile Research Journal, in press.
6. Park, H., W.W. Carr, H. Ok, and S. Park, *Image quality of ink-jet printing on polyester woven fabrics*, NIP 21 Proceedings, Baltimore (September 2005).
7. **Copyright**: in Hyunyoung Ok, Ph.D. thesis, Georgia Tech, *Particle-laden drop impingement on a solid surface* (2005).
8. **Copyright**: in Hongming Dong, Ph.D. thesis, Georgia Tech, Drop-on-demand Inkjet Drop Formation and Deposition (2006).

Wallace Carr, a Professor in Polymer, Textile and Fiber Engineering at Georgia Tech since 1980, earned a BME at Univ. of Virginia in 1966 and a Ph.D. in mechanical engineering from Georgia Tech in 1973. Before joining the faculty, "Chuck" was a senior research engineer at Monsanto. His research interests include digital printing of textiles (ink jet and electrophotography); thermal sciences in industrial fiber and textile processes; and polymer processing.
C92-G05, C92-S06, C95-G01, C95-G02, C96-G02, C97-G11, F98-G15, C98-G30, C99-GT08, C02-GT07, C05-GT07
chuck.carr@ptfe.gatech.edu
(404)-894-2538
http://www.ptfe.gatech.edu/faculty/carr/carr.html;

David Bucknall, a Professor in Polymer, Textile and Fiber Engineering at Georgia Tech, joined the faculty in 2004, after 6 years as Lecturer at Univ. of Oxford (UK). David earned a B.Sc. Hons in Chemistry from Nottingham Univ. (UK) in 1988 and a Ph.D. and DIC from Imperial College (UK) in 1991. After a post-doc at MPI for Polymer Research in Mainz (Germany) he spent 7 years as senior research scientist at the Rutherford Appleton national laboratory (UK). His research interests include polymer surface and interfaces, ink-jet technology, neutron scattering, microfluidics and polymers for medical applications.
C05-GT07
david.bucknall@ptfe.gatech.edu
(404)-894 2535
http://www.tfe.gatech.edu/directory/faculty/index.php?id=db297;

Jeffrey F. Morris, an Associate Professor of Chemical Engineering and a member of the Benjamin Levich Institute for Physico-Chemical Hydrodynamics at City College (NYC), joined the faculty in 2004 from a position in Engineering Research at Halliburton Energy Services. Jeff was an Assistant Professor at Georgia Tech from 1996-2002. He earned a B.Ch.E. in 1989 from Georgia Tech and a Ph.D. in ChemE. at Caltech and spent a year with Shell Research in Amsterdam. Since 1999-he has also been a Visiting Professor at the Universite de Provence in Marseille (France). His research interests include suspensions, colloids, and gels, with a focus on particulate effects upon rheology and bulk flow behavior.
C98-G30, C99-GT08, C02-GT07, C05-GT07
morris@ccny.cuny.edu
(212)-650-6844
http://csauth.ccny.cuny.edu/prospective/engineering/departments/chemical/faculty/Jeffrey-Morris.cfm;