DYNAMICS OF PRINTED DROPS

This one-day conference was organised by the Printing and Graphics Science (PGS) Group of the Institute of Physics. It was held at the Institute's headquarters in London on the 4th July 2008.

It was a well-attended meeting with 44 delegates and 10 papers covering a wide variety of disciplines and applications with a mix of invited and submitted papers. One of the strengths of these meetings is the chance to debate these technologies with delegates outside your own area. The lunch and refreshment breaks were therefore busy and well used!

Although a lot of these papers covered ink jet systems the applicability of the presentations is much wider.

1 SESSION 1

This session was chaired by Dr Andrew Clarke of Kodak European Research and Honorary Treasurer of the PGS Group. It comprised mainly papers on mathematical models.

The first paper from Professor Yulii Shikhmurzaev of the University of Birmingham reviewed the main approaches to the modelling of dynamic wetting of surfaces, illustrating the approximations inherent in each. The presentation then took the interface formation model to describe the effect of surface chemistry on wetting dynamics. For this purpose the example of chemical patterning of a surface to produce wetting and non-wetting areas was used. The models illustrated the guiding of printed drops into wetting areas. Molecular dynamics show how these wetting and non-wetting areas affect liquids when there is a full surface coverage, producing concentration over wetting areas and rarefaction over the non-wetting areas as is required in the interface formation model. The presentation then examined the issue of drops on porous surfaces and showed how the models break down in these circumstances as porosity presents a problem on a microscopic scale. As a result, these models would be directly applicable for print onto solid substrates, but require extension for coated ink jet media or paper substrates.

A second paper from Dr Kensuke Yokoi of the Institute of Manufacturing at the University of Cambridge moved on to illustrate models for drops incident on wetting and non-wetting surfaces. In this case the measured dynamic contact angle as a function of triple line speed was a required boundary condition for the model. Again these results showed good agreement between theory and experimental data. Also demonstrated was how the agreement between theory and experiment degraded as the measured dynamic contact angle function was successively approximated.

A third paper given by Professor Victor Starov of Loughborough University expanded on some of these themes from a molecular viewpoint and concentrating on the disjoining pressure and absorbed vapour ahead of the dynamic wetting line. It also introduced a concept that was repeated through subsequent papers; that evaporation from a printed drop is strongest at the 3 phase contact line (air, printed liquid drop, substrate) on the circumference of the printed drop. The work presented models for drops on a *saturated* porous media and dry porous substrates where the absorbent layer is thin with respect to the printed drop. As such these models are once again not applicable without further assumptions to coated inkjet media or paper substrates.

2 SESSION 2

This was chaired by Dr Dilwyn Jones, an independent consultant and Chair of the PGS Group. This session showed the success of some of the models in explaining experimental observations.

Dr Patrick Smith, an ex-colleague of mine now at the University of Freiburg in Germany, started his presentation with the very valid point that what matters to the customer is the form of the dried drop on the substrate and charted the progress of polymer containing solvent or mixed solvent droplets from in-flight to dry on the substrate. The effect of in-flight solvent evaporation and the potential of droplet "skinning" as a result of this evaporation were covered. The correlation with theoretical models was shown with errors ranging from 2-20%. The presentation moved on to show how uniform particle size silicas deposit out of drying droplets, clustering at the edge of the drop in a "coffee ring" effect. Novel in this study is the observation that particulates deposit not at the wetting line, but at a position commensurate with the geometric constraint of liquid contact angle and size of the particle. This study is an interesting contribution to work on reducing coffee ring effects, which will be an enabling technology for printed electronics on many substrates. Mixed solvent systems may be one answer to this.

Professor Malcolm Mackley of the University of Cambridge gave a presentation on the effect of viscoelasticity on drop formation, and illustrated this with data from two novel pieces of equipment. The first was a piezo axial vibrator rheometer that can make dynamic viscoelastic measurements over a 1-10kHz frequency range. They are currently looking at further instrumentation to move this out to 100kHz, a frequency space that is critical in inkjet printing where deformation rates of $10^6 s^{-1}$ are typically encountered. The second piece of equipment is a high speed filament stretching device known as a Trimaster. Using this, a high speed camera can be used to observe the effect of viscoelasticity on the filament stretch and break process. As filament stretch and droplet formation are linked this can provide useful insights into fluid design.

Professor David Quéré of ESPCI in France gave an intriguing presentation on drop impact onto materials with a regular micro-texture. He explained, with typical clarity, the fundamental physics that describes the wicking of liquid within the surface and how to relate the observations to the geometry of the micro-texture. Of course, although the description was in terms of a regular structure the concepts translate naturally to random micro-structures such as lithographic plates. These textured materials together with surface treatments can give rise to complex behaviours ranging from absorption to repulsion resulting in droplet bounce.

Professor Stephen Wilson of the University of Strathclyde presented the results of work on droplet evaporation resulting from collaboration between experimental and theoretical groups at the Universities of Strathclyde and Edinburgh. The multiphysics numerical modelling that reproduced the data very well demonstrated the strong influence that thermal conductivity of the substrate has on the evaporation of printed droplets.

3 SESSION 3

This session was chaired by Dr Alan Hodgson of Alan Hodgson Consulting Ltd and Honorary Secretary of the PGS Group. This session illustrated the diversity of applications that can benefit from printed drop modelling.

The first presentation in this session was from Dr Jonathan Stringer of the University of Manchester, and showed that droplet-substrate interactions are key to an understanding of print performance. He illustrated that droplets laid down in close proximity can influence each other. As a result droplets that you would not expect to touch can meet before drying. This effect is believed to result from the diffusion of solvent vapour through the air between them and the results seem to fit this model. The presentation went on to describe the morphology of a printed line and its dependence on drop overlap, contact line pinning and capillary flow. The instability driven by capillary flow was mapped to a stability criterion based on a model that he also presented.

The next 2 presentations showed some of the breadth of applications that can benefit from this work. The first from Professor Glen McHale of Nottingham Trent University examined the effect of droplet wetting in the printing of micro arrays for DNA analysis. Although the micro deposition methods differ somewhat from conventional printing, this community faces the same issues of variable wetting and coffee ring effects that compromise the application. The presentation then went on to describe an interesting alternative to detection of the dots by fluorescent markers – the use of magnetic resonance imaging (MRI). The benchtop MRI system used had a spatial resolution of 10 microns and a further example of tracking liquid imbibition into a porous fabric was shown.

Finally, a presentation from Professor Steven Abbott of MacDermid Autotype examined the problems of adapting these models to screen printing. This application has added complexity due to the viscosity of the screen printing systems resulting in droplets with an initial non-spherical geometry.

4 CLOSING REMARKS

At the end of the meeting a straw poll of the delegates showed that this event had perceived value and that a repeat would be appreciated, probably in around a year’s time.

Alan Hodgson

With additional material from Dilwyn Jones and Andrew Clarke