IMAGE-IN: Improved Ink-Jet Printing by Control of Ink-Media Interactions

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Abstract

Digital ink-jet printing has huge potential as an alternative printing technology for many packaging and decorative applications. By its very nature, ink-jet printing provides high added value since it meets the needs for short run production demands of today's industrial and commercial markets. Use of UV cured inks is a rapidly developing technology in ink jet printing processes, and is making significant progress into areas until recently dominated by aqueous based ink formulations. However, despite this rapid adoption of UV cure inks in industrial processes, there is a lack of fundamental understanding in their behaviour at the media interface. Because of their historic and widespread adoption, aqueous based inks are much better understood in terms of process parameters. However, there is still significant scope for research to produce insights into the ink-media interaction behaviour that can lead to improvements in aspects of ink and media coatings.

By studying the whole digital ink-jet printing process the IMAGE-IN project is using a synergistic approach to develop both a complete understanding of the generic science, which underpins the printing processes, together with extending the capability to satisfy the commercial, economic and environmental requirements of industrial ink-jet printing. To achieve these objectives the IMAGE-IN consortium consists of 7 partners (5 industrial companies and 2 universities) who collectively posses core expertise in all the key components of the printing process (inks, materials, benchmarking and characterization, modelling). The project is funded through the Framework 5 'Promoting Competitive and Sustainable Growth' program.

Introduction

Digital printing techniques in the industrial context have huge potential for exploitation of a number of market especially targeting short run production demands. Among the printing methods that are being developed to exploit this market and arguably one of the most versatile is industrial ink-jet printing. However, in order to exploit the huge potential capability that is offered by the technique, the short comings of industrial ink-jet printing must be overcome. Among of the most challenging problems hindering its wide spread adoption is associated with the effective print quality. This is itself related in a complex way to the ink formulation, media and its treatment and the physico-chemical interactions between them. For wide spread use, ink-jet printing must be able to adapt easily to a wide variety of media. This typically requires reformulation of the key parameters of the system, which ultimately is both time consuming and wasteful in terms of material and chemical wastage.

Through a synergistic approach to developing a complete understanding of the generic scientific principles that underpins the printing processes, the IMAGE-IN[2] project ultimately will be able to enhance the commercial capability of ink-jet printing whilst satisfying both the necessary economic and environmental requirements. This will enable generic ink and media treatments to be quantified and parameter sets to be derived. For selected print media substrates trial industrial print tests will be conducted. To achieve this step-change in ink-jet capability the IMAGE-IN consortium consists of 7 partners (5 industrial companies and 2 universities) who collectively posses core expertise in all the key components of the printing process (inks, materials, benchmarking and characterization and modelling). The consortium consists of:

- *SunJet* – ink manufacturer and developer
- *AGFA-Gevaert N.V.* - media manufacturer and developer
- *Dotrix N.V.* - manufacture and development of printing technology
- *Ardeje SARL* - SME specialising in high-speed visualisation technology
- *Teich AG* - industrial printer
- *Laboratory of Geophysical and Industrial Flow, Universite Joseph Fourier*
- *Departments of Materials and Physics, University of Oxford*.

The overall aim of this project is to add intelligence into the ink jet printing process. To achieve this, two totally synergistic objectives are being pursued by the consortium:

- Development of ink jet printing processes capable of satisfying the commercial, economic and environmental requirements described above.
- A complete understanding of the generic science that underpins the key aspects of the ink jet process.

The project is funded through the Framework 5 'Promoting Competitive and Sustainable Growth' program (contract number G1RD-CT-2002-00663).

Results and Discussion

The project is essentially divided into four streams of work consisting of ink formulation and jetting behaviour, media treatment, ink-media interactions and consequently print quality, and finally print trials in the industrial setting. High quality commercial ink jet printing presents unique technical challenges to jet ink formulation. Commercial applications require high fastness properties and therefore we are initially developing pigmented systems based on high solids ink chemistry. These UV curing ink formulations are based on 100% solids utilising free radical chemistry. The primary phase of the research is also targeted toward piezo drop on demand print-heads with both wetting and de-wetting face plate surfaces. Although ink-head interactions cannot be ignored they are not the focus of this project as we are trying to make the understanding of inks generic and therefore independent of head manufacturer. As well as experimenting with full developmental formulations of ink, this work also utilises model ink formulations where individual components of the complex ink mixtures can be tested independently. In this way ink formulation parameters that are being systematically investigated include those associated with additives, photoinitiators and pigments. Dynamic effects both short time scale dynamics - time scales of droplet impact and spreading - as well as long time scale dynamic effects -such as prolonged shelf life - may also be important and are being studied in some detail. With potential applications in food and medical packaging, the odour and toxicity of the ink formulations are an important secondary property which also needs to be taken into consideration.

Coupled with developments in chemical formulations the jetting and impact behaviour of the inks is also being studied both from a theoretical and an experimental point of view. The latter is being tackled with development of ultra-high speed video capturing techniques (ie sub-microsecond), which allow us to visualise the ink behaviour after leaving the nozzle and the dynamic behaviour as the droplet impacts on the various media surfaces. Numerical modelling of these dynamic processes using the 'variation principle' are being applied. This model assumes that geometrical deformation of the initially spherical droplet as it hits the media can be described by simple differential equation. This approximation leads to simplifications in solving the Navier-Stokes equation which describe the behaviour of these fluids. In practice, the variation principle requires energy minimisation of the system to be undertaken. In doing this, kinetic and potential energy terms are taken into account. Explicitly included in this are frictional forces, as well as flow fields which account for the shear stress.

Some of the key industrial substrates we are initially targeting are polyesters, polyolefins, and metals. The general approach to improving both print quality and adhesion of the ink to the media is to modify the surface chemistry either with a suitable surface layer coating, i.e. lacquering, or by pre-treatment, i.e. plasma, corona, flame treatment. Surface coatings can be either absorbing or non-absorbing and a great variety of formulations have been tried by numerous groups in the industrial context. Although surface property modification by either coating or pre-treatment techniques has been widely employed, the exact nature of the ink-media interaction is not fully understood. To be able to exploit the technological and economic advantages of ink-jet printing we are developing a generic understanding of the ink-media interaction. This requires a careful and detailed systematic investigation of well defined systems, where key parameters can be tested independently, including surface energy, equilibrium contact angle and surface roughness. In addition to the analysis of the static equilibrium ie final print state of the ink on the media we are also exploiting our high speed visualization capability to look at the dynamics of droplet impact and spreading on media surfaces. The behaviour is being modeled using both lattice Boltzmann as well fluid dynamics numerical simulation.

Standard image quality analysis is undertaken using the standard ISO 13660 protocol, in addition we have also implemented development within the project of image quality star and parameterisation charts. This allows us for the first time to quantify in a very rigorous way the print quality by a number of critical factors. On a more fundamental level the behaviour of individual dots, printed lines and text, and solid colour fills are also being investigated with powerful analytical techniques available to us. Of great importance is to understand on a fundamental level the basis for print defects such as mottle, absorption and Marangoni effects, adhesion failure, etc. The aim of this strand of work is to develop a generic understanding of the interplay between ink formulation parameters, substrate surface and image quality and to build this into a complete printing system. In order to understand the complex set of interactions that combine to define print quality we are undertaking detailed theoretical and experimental studies on model systems with the aim of understanding the physico-chemical properties of the inks and how these are affected by surface modification or treatment of the media.

This can be illustrated by reference to the following example. When pre-treated the surface energy of the film plays an important role on how dot size and therefore print quality varies. Surprisingly, high surface energy substrates such as silica and fluoro-treated PET give much smaller printed dot size than lower surface energy equivalents, thereby suggesting chemical interactions are predominant over dynamic wetting characteristics. Figure 1 shows an example of how a printed dot size varies with substrate surface energy for a surfactant containing 100% UV ink formulation (UGE5529) and a model fluoro-surfactant free formulation (U3285). In the absence of surfactant, static surface tension of the ink increases from 28.0 dyn/cm to 35dyn/cm and when printed onto the above substrates, gives comparatively large droplet spread, even on fluoro-treated

PET. Similar analysis of droplet behaviour on other modified substrates shows that control over dot size is possible by a combination of ink chemistry and media surface modifications. The exact relationship between the parameters that dictate the ink and media behaviour in these industrial formulations is being investigated by looking at the fundamental aspects of the ink-media interaction. These studies are using a combination of experimental methods on model systems and computational modeling by the Universities of Joseph Fourier and Oxford.

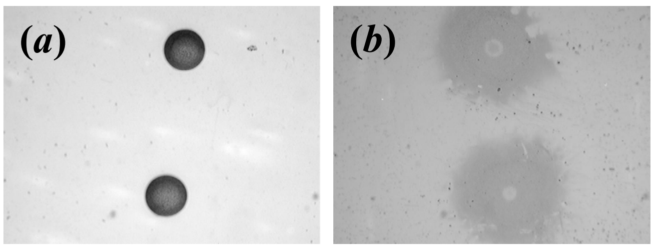

Figure 1. Optical micrographs (x100) of ink-jetted droplets on fluoro treated PET (Agfa). (a) surfactant containing jet ink (UGE 5529) with average drop diameter of 161 μm, (b) model jet ink (U3285) without surfactant with average drop diameter of 424 μm.

Conclusion

Through a strong collaborative program funded by the EU under the Framework 5 Growth Programme (G1RD-CT-2002-00663) the IMAGE-IN consortium are pursuing a fundamental understanding of the ink-media interactions to provide a full parametric basis for improving inkjet printing. We have established both theoretical modeling and experimental programs to look the behaviour of both at model and technologically relevant ink formulations and media treatments. An initial development phase has lead to improved ink formulation and media treatments which go beyond the quality of current state-of-the-art systems. These new materials developments have been tested in a number of laboratory based print test rigs to evaluate their performance. In order to facilitate the quantitative evaluation of the print quality of all ink-jet prints, we have also established star and parameter charts.

References

1. representing the members of the IMAGE-IN consortium: H Allen (SunJet), P Bracke (Dotrix), DG Bucknall (UOXF), N. Caiger (SunJet), J Claes (Agfa), G Desie (Agfa), R DeKeyzer (Agfa), J Duprez (Dotrix), A Grant (SunJet), B Lopez (Ardeje), P Mertens (Agfa), B Muys (Agfa), D Quintens (Agfa), A Soucemarianadin (UJF), T Ullrich (Teich), W Veit (Teich), SJ Wilkins (UOXF), D. Wilson(SunJet), JM Yeomans (UOXF).
2. see www.imagein.org for further details.

Biography

David Bucknall gained his PhD in polymer physics in 1991. Since this time he has specialised in studies of surfaces and interfaces, in both government research and academic institutes. He is currently a lecturer at Oxford University studying aspects of polymers and biomaterials. He is also co-ordinator of the multinational European funded IMAGE-IN research project to study and develop a better understanding of ink-media interactions for improved industrial ink-jet printing.