PROCESS CONTROL TO ACHIEVE STANDARDS AND IMPROVE PRODUCTIVITY

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ABSTRACT

Printing is a sophisticated and precise process capable of delivering repeatable high quality results. It is perceived as straightforward as it is well established based on years of hard won experience. It is the complexity of the interactions of ink, substrate and process that have required the development of the craft of the printer. As presses run faster with more complex jobs that include security features and smart packaging, the pressure also mounts to cut costs, reduce downtime, reduce start up waste, reduce waste and emissions. Therefore, printing has to move from being a craft to being a manufacturing process. To achieve this, it is necessary to understand the underpinning science of the printing process to be able to adapt quickly and efficiently to challenges posed by new suppliers, consumables and technology.

Printing involves the accurate and reliable transfer of a complex fluid through a complicated process. Ink is a complex fluid as it can comprise of multiple fluids with different boiling points, with some materials in solution, some as an emulsion with the added complexity of solid pigment particles and additives to modify properties such as surface tension. The printing process itself involves deforming the image, compressing the ink, causing it to flow, ripping it apart and then levelling while it cures. It is impossible to obtain meaningful results by examining one aspect in isolation, it is essential to take a holistic look at the process. While WCPC has research programs applicable to all the major processes (flexo, gravure, screen, pad and digital) and all applications, this paper looks at some of the research that specifically relates to offset.

1. INTRODUCTION

Printing is a major world industry. It is one of the largest industries in Europe where there are over 123,000 printing firms, employing 820,000 people in the 25 EU countries. The range of graphic products includes packaging, publication, newsprint, fabrics, wall coatings, ceramics and product decoration. Printing is a sophisticated and precise process capable of delivering repeatable high quality results. It is perceived as straightforward as it is well established based on years of hard won
experience. It is the complexity of the interactions of ink, substrate and process that have required the development of the craft of the printer. This empirical development of the printing process has been assisted by the interpretation and compensation of images inherent in the human brain. However, as presses run faster with more complex jobs that include security features and smart packaging, the pressure is also growing to cut costs, reduce down time, reduce start up waste, running waste and emissions. Therefore, it is essential to move printing from a craft to a manufacturing process. This is further exacerbated by the desire to use printing as an advanced manufacturing process for polymer electronics, sensors, PV and bio devices, with the integration of these into traditional graphics products as a way for the printer to add value. It is necessary to understand the underpinning science of the printing process to be able to adapt quickly and efficiently to challenges posed by new suppliers, consumables and technology.

Thus, the printing industry is at a cross road. In order to compete, there is pressure to deliver higher quality with more efficiency and less waste, it needs transformative action to move it from a craft to a manufacturing process. This requires both the understanding of the underpinning science and, more importantly, the translation of the impact of that science into production. This is vital for the long term survival and success of the graphics and packaging industry and essential if traditional volume printing processes are to compete for a role in the manufacture of sensors, plastic electronics, biomedical devices etc.

Forward thinking companies have realised that understanding the process will produce long term, effective solutions. However, the fewer resources available internally are being focused on delivering instant results to solve customer problems. Often, the same problem will reappear in the future when an underlying cause changes and the whole exercise has to be repeated again.

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In other fields of engineering, the fundamental science and understanding have been built up over many years which have enabled the development of computation methods to enable designs to be evaluated before their physical creation. For example in aerospace the designs of new aircraft and their performance are fully evaluated before they leave the drawing board.
The vision of the WCPC is “to be able to predict the geometry and performance of a multi layer product printed by volume manufacturing processes”. While WCPC has research programs applicable to all the major processes (flexo, gravure, screen, pad and digital) and all applications, this paper looks at some of the research that specifically relates to offset. In particular, it will look at:

- Thermal build up within the press
- Ink film splitting and misting
- Expanding colour gamut

However, the need to understand the fundamental science transcends all processes.

**Thermal build up within an offset press**

Temperature stability has for sometime been identified as having a major influence on ink transfer in offset printing. Changes in density of 0.4 have been observed for a 10°C change in temperature. This is approximately equivalent to the density tolerance expected during a typical production run. Increasing temperature causes the viscosity of the ink to reduce and also changes other rheological properties such as surface tension, which in turn affect the ink transfer. The temperature will also influence the mechanical operation of the press, causing changes to the nip settings due to differential thermal expansion, as well as to the properties of blankets. Therefore the changing temperatures in the press will not only affect the colour consistency through a print run but could also compromise the ability to match the proof, due to the interrelationship between coverage and the effect of temperature.

A major source of heat within the press is the compression and relaxation of the rubber as it passes through nips in the press. The build up in an individual roll will be a function of the speed, the number of contacts and the amount of impression (deformation) at each contact. The temperature build up in the middle of the rubber layer is more significant than at the core. However, because of the low conductivity of the rubber, the heat generated tends to build up in the middle of the roll.

The temperature build in the press can be demonstrated by comparing the temperature with no temperature control of the press rolls and the ink duct with the press when supplied with water at a constant temperature. The temperature measurements were simultaneously taken through the inking train using thermal imaging. The thermographs during the start of printing are shown in figure 1. This was the first run of the day, so the press was at ambient temperature at the start of the test. The flow of the ink, which was preheated to 25°C, through the press is clearly visible from the images, taking under 1 minute to coat all the inking train. Significant differences are observed between the different components of the inking train. This
would suggest that the thermal image camera was effectively measuring the temperature of the components through a thin ink/fount layer.

**Figure 1.** Thermographs of the ink train showing flow of ink during start up without cooling
The high temperatures that occurred in the rubber covered components once printing had stopped and hot spot in non printing area of blanket can be seen in Figure 2, which is of the ink train immediately after it had stopped printing. Throughout the print run, the edge of the blanket where there was no flow of ink/fount to the substrate experienced a build up to a higher temperature of 32°C (compared to the 29°C of the adjacent part of the blanket where the image was being carried), reaching over 35°C when the press stopped.

![Image](image_url)

**Figure 2.** Press immediately after printing had stopped.

The temperatures derived from the thermal images obtained during printing without temperature control of press rolls or ink duct are shown in Figure 3. The temperature of all the components of the press rises steadily throughout the print run. The highest temperatures occur in the two rubber covered rolls and the blanket roll, with the roll K attaining the highest temperature. When the press stops at 11.33am, the cooling effect of the ink and fount solution stops. The thermal energy stored in the rubber covered rolls then produces a rapid rise of 3°C in approximately 1 minute.

When the press is running, all of these components maintain a constant temperature relative to the copper roll (Fig.4). This suggests the ink and fount solution plays a major role in maintaining equilibrium throughout the press. Towards the end of the print run the rubber covered rolls and the blanket experience a rapid rise in temperature. This suggests the heat generated by the printing process was initially absorbed by the thermal inertia of the press. Towards the end of the run, the temperatures rise is more in accord with the rate of heat generated. This is reflected in the frame temperature, which remains constant for the first part of the print run and then increases by 0.5°C during the second half of the trial. Once the press stops, then the rubber-covered rolls undertake major excursions to more elevated
temperatures as the thermal energy generated in the rubber coverings is no longer removed by the ink and fountain solution.

![Graph of temperature over time for different press components.](image1)

**Figure 3** Temperature (C) of press components

![Graph showing temperature difference over time for different press components.](image2)

**Figure 4** Temperature (C) of press components relative to Copper roll

At the start of the second trial, the press was already warm from the previous test (Figure 5). The press cools as it sits idle waiting for the next print run. For this trial, the water was supplied at 28°C to the press rolls and at 26°C to the ink duct. The effect of the flow of water is seen immediately the press starts. The copper roll stabilises at 29°C. There is a slight rise in temperature of the copper roll towards the end of the run, suggesting a slight imbalance between the heat generated by the press and the thermal capacity of the cooling system. The flow of ink when the press starts printing drops the surface temperature of all the rolls in 45s. Again when the press stops, the thermal energy stored in the rubber covered rolls causes their temperature to rise rapidly.
The thermal transfer affected by the ink and fount solution is evident from the relative temperature of the rubber rolls compared with the copper cylinder (Figure 6). Once the press is printing, the ink train maintains a constant temperature relative to the copper roll. Once the press stops, then the temperature of the ink train rises rapidly relative to the copper roll.

The flow of fount solution plays a major role in the thermal balance of the press, transferring heat between the rolls of the inking train. Thus when the press is running, the flow of ink and fount tends to equalise the temperatures between the different components in the inking train. In regions such as the non-printing areas of the blanket beyond the web edge, there is no cooling flow and the temperature increases throughout the print run. However, the different components of the inking train are still operating at subtly different temperatures, which would undoubtedly affect the ink transfer through the train, particularly the film splitting in the nip. This reduces the effectiveness of separate zone control. However, the residual thermal energy that builds up in rubber-covered rolls and the blanket that causes the
temperature rise during printing, produces rapid temperature excursions on shut down.

Stable printing conditions can be achieved from start up by balancing the thermal production with the cooling at appropriate points in the press. However, the press is a complex interaction of heat sources and sinks. In order to minimise transient conditions, there is a need to develop a thorough understanding of the press behaviour. The optimum cooling temperatures are a complex interrelationship between temperature, water flow rate, press speed ambient conditions, substrate and coverage.

**Ink Splitting and Misting**

Printing nips, where the surfaces of two rollers covered with a film of ink are forced into intimate contact, occur throughout the offset roller train. The same fundamental physics also occurs in separation of areas of solid in flexo and offset printing. As the rolls separate, the ink film splits between the two rolling surfaces in a region of negative pressure. The continuous film first splits into a series of ribs in the direction of rolling and then into a series of discrete filaments which extend and rupture. This can give rise to an uneven distribution of the ink on the roller, misting and non homogeneous coverage of the solid.

![Figure 7 Ink film splitting into ribs and filaments at the exit of two rolls](image)

Ribbing is primarily generated due to elongation mechanism at the nip exit, where ink is deformed in filaments and splits. The rotation rates do not allow ink to recover its elasticity or redistribute itself before the next time it is split. The film thickness, viscosity and speed were found to have the most effect on ribbing both the frequency and width of the ribs.

In offset presses the inking trains are more complex, with multiple nips on a single roll, have larger diameter rolls and include oscillating rolls to distribute the ink. While these will prevent the build up of ribbing, the interaction of variations in the
ink film thickness caused by the splitting process will feed through the press. Understanding the fundamental physics of the splitting process and its interaction with subsequent nips will contribute to the design of roller trains. It will also lead to a better understanding of the printing of solids in processes such as flexography.

Decreasing viscosity, which also alters the capillary number and increasing speed both of which increase misting. This affects misting droplets volume, spreading rates and droplet size range. There is a strong influence of ink film thickness which interacts with these parameters. The misting is related to the ink film thickness.

Misting increases with speed as the tensile forces generate instabilities leading to filaments failure and formation of satellite droplets. High viscoelasticity and adhesive dynamics allow the ink to extend in extremely thin filaments that break-up in multiple points across the length. The fine droplets are formed at the nip exit, which tend to follow the air flow.

However, in some cases there will be a significant volume of ink which remains attached to one of the rollers via a filament of ink. Aggregation occurs due to surface tension as a function of the ink film thickness or filaments width and extension rate. Those aggregate parts generate instabilities in the ink filaments with increased volume at the filaments neck. The filaments split unequally at the thinner area of the filament, sometimes giving rise to further satellite drops while a high volume ink droplet remains attached by the thicker filament to a roller. The roller surfaces accelerate away from each with rotation. If the drop is small, then the elastic forces will cause it to be drawn to the roller and the continuing changing direction of acceleration will cause it to fall back onto the surface. This mechanism is an integral part of rib formation. However, if the appended drop is large enough, the centripetal forces will overcome the elastic forces, the filament will extend and fail, leaving a larger volume droplet whose direction is dependent on it’s velocity at the time of separation and whose trajectory is affected by gravity with little aerodynamic effects until it impacts on the mist trap. This produces large drops with characteristic tear drop shapes. This is could also be referred to as splashing or spitting.

The misting effect has previously been calculated as a function of the misting characteristics. The misting occurrence was the number of droplets versus the average droplets size. Therefore, the misting effect was calculated as the ratio of occurrence to the characteristic viscosity of the ink dilution.

\[ \text{Misting effect} = \frac{(Nd/Sv)}{\eta^*} \]

where \( Nd \) is the number of droplets, \( Sv \) is the average droplets size, and \( \eta^* \) is the characteristic viscosity at 147/sec-1 shear rate.

The misting increases with increased ink film thickness and decreased viscosity. The number of misting droplets also increases with the viscosity decrease and surface tension. This indicates an effect of capillary number which decreases with Butyl-Diglycol concentration (Figure 8). This indicates that the misting becomes critical as
the Capillary number is reduced. The ink filaments tend to split unequally and aggregated ink parts are forced to extend and finally to flow away due to centrifugal forces.

![Graph showing the effect of Butyl-Diglycol concentration on Misting Effect and Capillary number.](image)

**Figure 8** Effect of dilution with Butyl-Diglycol on capillary number and misting effect

While there is a correlation between the capillary number and the misting effect, the breakup of the individual filaments is influenced by the structure of the ink. A suspended solution (i.e. one in which there are particles and two phase elements) will produce more droplets and at lower speeds than a pure solution (Fig. 9). The filament splits around the particle or by cavitation in the negative pressure caused by the separation. Understanding these phenomena is subject of current research programs.

![Image showing a comparison of a pure solution (left) with a suspension subject to extension.](image)

**Figure 9** Comparison of a pure solution (left) with a suspension subject to extension.

**Expanding Colour Gamut**

The limited colour gamut of CMYK is well documented 7,8 and as such there is scope for improving the rendition of colour by printing. In order to widen the colour
gamut numerous commercial products have been launched, e.g. Hexachrome9 and Opaltone10. Both these system provide more or less a standard CMYK with the addition of other colours (Green & orange for hexachrome, RGB for Opaltone) to produce the increased colour gamut. Darker colours are achieved by the addition of black to the colour. This not only reduces the lightness of the colour but also reduces the saturation of the colour, making deep strong colour impossible. An alternative approach is to utilise a base set of colours which naturally darken each other without loss of saturation11. This is based on established ink colours which have been used in paint formulation for artists. The ink colours selected are a green shade yellow, red shade yellow, green shade blue, violet shade blue, a blue shade red and a yellow shade red. As the printed colour relies on light absorption, then the mixing of any of these colours will lead to the common colour (e.g. the green in the blue and yellow) to become dominant. While this concept is effective in mixing paint, colour printing relies on the transparency of each ink film layer and therefore there was a need, as part of the development, to establish the gamut that could be obtained by overprinting halftones of these inks.

The main advantage of the 7 colour sets is the ability to achieve many pantones and special colours with a process colour set, i.e. eliminating the need to change colours between jobs. This can be illustrated by examining the colour gamut of the Wilcox 6 (a proprietary colour set) with colour gamut available using pantone11. As any colour space is three dimensional, the printed colour gamut of the ink colour system are best shown in the 2D plane of the paper by examining the orthogonal views of the L*a*b* colour system. In each case the measurements are compared to the colour gamut available in the pantone colours for coated paper. Examining the a*b* plane, Figure 10, shows that colour gamut matches of the Wilcox 6 (W6) most of the pantone colours, but with deficiencies in the green region.

![Figure 10](image-url)
This deficiency in the green can also be seen when one examines the view of the L*<i>a</i>* colour plane, Figure 11, where some of the pantone light green colours are beyond the W6 colour gamut. When the L*<i>b</i>* plane is examined, the wide colour gamut produced by colour set is easily seen. Some very dark blues are not covered by the colour gamut of the W6.

![Figure 11](image)

**Figure 11** A comparison between the Wilcox 6 ink system colour gamut and the pantone range of colours in the L*<i>a</i>* and L*<i>b</i>* plane.

The selection of colours for an alternative wider gamut colour set is still the subject of debate. The FFTA Quality Consortium has the evaluation of alternative sets as a current project. Even once one has selected the 7 colours for the alternative colour set, then there is still the need to have a consistent operator independent separation software12. Also, if one is using more than three colours to achieve a coloured image, then there is a need for better process control than with CMYK. This is another area where there is a need for further research to establish the optimum combination of colours for economic printing.
Closure

Advanced manufacture by printing requires the process to be moved from a craft to a science. This requires a holistic approach because of the interactions between the various operations and the finished process. In the example of thermal transients, the overall impact of heat dissipation can be observed, but heat release is a function of many variables including material properties, compressive load, speed and ink flow. To reduce waste there is a need to have heating and cooling to maintain the press at a constant temperature, thus eliminating a “noise” variable. The ink film splitting affects the quality of the finished product and is in itself a combination of fluid dynamics and materials properties under stress. With colour and expanded gamuts there is a need to quantify the benefits, the optimum combination and the economic advantage. While this paper has focused on a snapshot of some of the offset related research and development, the same issues need to be addressed by all processes.

REFERENCES


