# Modelling the Flow in a Flexographic Ink Chamber

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Abstract:
The performance of the anilox roll controls the ink transfer in flexographic printing. One of the critical regions is the filling of the cells in the ink chamber. This is undoubtedly influenced by the ink flow in and the pressure distribution within the ink chamber. A parametric study was carried out on the effect of ink rheology, press speed and chamber geometry on the flow in a flexographic press ink chamber. The modelling was carried out using a proprietary finite volume Computational Fluid Dynamic (CFD) software, FLUENT. A power law approximation was used to simulate the non Newtonian nature of the ink. The predominant force driving the flow within the chamber was found to be the flow induced by the anilox roll. The cross flow produced by the ink supply was found to have a negligible effect. The primary parameters dictating the flow pattern were found to be the interaction between the ink viscosity and the press speed. All the pressure required for ink transfer is generated at the doctor blade. The doctor blade angle strongly dictated the static pressure generated at the tip of the doctor blade while the Pseudoplastic nature of the ink resulted in an appreciable loss in doctor blade static pressure. A reduction in chamber size increases the ink pressure at the doctor blade tip

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## 1. Introduction

The transfer of ink in flexography is controlled by the filling and release of ink from the cells in the anilox roll. The filling of the cells in the ink chamber is influenced by the local pressure distribution along the anilox surface in the chamber. This in turn is a function of the ink supply, the flow induced by the roller and the geometry of the chamber.

There is a potential benefit if the volume of the inking chamber were to be reduced as this would require less "live" ink to be present during printing, allow reduced cleaning time between colours / jobs as area to be cleaned is reduced and reduce the quantity of ink wasted during colour changes. Changes in chamber design may also allow press speeds to be increased.

One of the most effective methods of investigating the influence of the chamber geometry and press parameters on the flow patterns and ink transfer is to use numerical modelling techniques. A reliable numerical model enables a wide range of chamber geometries and process conditions to be investigated without the time consuming process of building physical models and running experimental trials. Numerical modelling does not replace the latter but enables a rapid rationalisation of the proposed designs. This paper reports the first stage in developing a full simulation of the chamber. It reports a parametric study of geometries / inks and press speeds on the flow within the chamber using finite volume modelling techniques. After first describing the background to the model, the results are presented and their implications discussed.

## 2. Numerical model details

The numerical models were created in Fluent 5, a proprietary computational fluid dynamic (CFD) software package. The package solves the steady state continuity of mass and momentum (Navier – Stokes) equations :

$$\frac{\partial U_i}{\partial x_i} = 0 \quad \text{and} \quad \frac{\partial}{\partial x_j}(\rho U_j U_i) = -\frac{\partial p}{\partial x_i} + \mu \frac{\partial U_i^{\,2}}{\partial_2 x_i} \qquad \textit{Eqn (1)}$$

Of all the methods available to solve the governing equations the finite volume technique is the most efficient, reliable and flexible, ref. [1]. The governing equations are cast on a grid where pressures and velocities are calculated at grid points distributed within the domain. Each of these grid points lies at the centre of a cell and their number and distribution is critical to the success of the model, ref. [2].

As the equations cannot be solved directly, the solution is obtained itterritvely using a SIMPLE (Semi Implicit Method for Pressure Linked Equations) procedure where an initial guessed pressure and velocity are used to calculate a pressure and velocity correction to ensure that each iteration results in a reduction in the momentum and mass imbalance. Each model generally requires at least 2000 iterations in order to obtain a converged solution.

Where applicable, the non Newtonian nature of the inks was modelled using a power law approximation where:

$$\eta_{\min} < \eta = k\gamma^{n-1} < \eta_{\max} \qquad \textit{Eqn (2)}$$

where $\eta$ is the viscosity, $k$ is a constant, $\gamma$ is shear strain rate, $n$ is the viscosity index and the subscripts *min* and *max* denote the infinite and near zero viscosity respectively.

## 3. Model descriptions

A preliminary study was undertaken to the assess the relative importance of the supply of the ink through the system, and that induced by the rotation of the anilox roll. This required the use of a 3 dimensional model for a single chamber geometry, a range of ink supply rates and rotational speed with the corresponding increase in complexity of the numerical grid and model run time. The principal flow feature is a recirculation zone induced by the anilox roll in a plane orthogonal to the axis of the anilox roll. The effect of the supply cross flow (as shown by the 3D model) is negligible over the whole range of normal ink supply recirculation rates and anilox roll roller speeds with near identical velocity magnitudes being predicted, *Figure 1*. Thus, the remainder of the models were developed for a 2 dimensional case in the plane orthogonal to the axis of the chamber. This allowed for the use of a more refined grid to improve the accuracy and resolution of the model without excessively increasing run time.

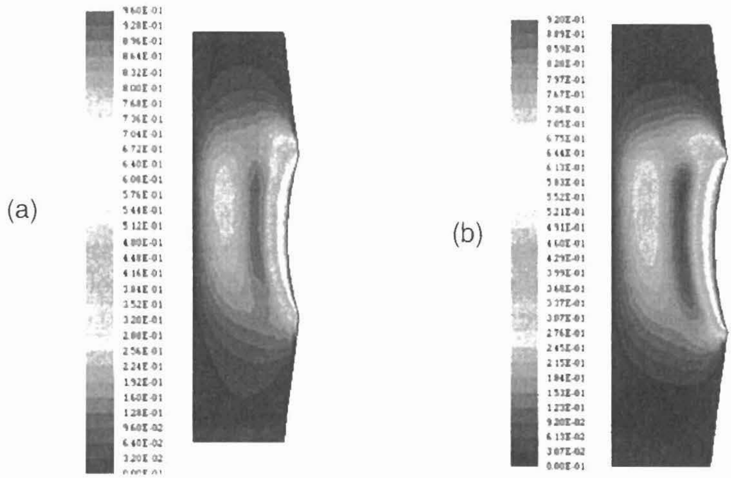

*Figure 1*: A comparison of the predicted velocity magnitudes in the (a) three dimensional and (b) two dimensional models for a print speed of 1 m / s and an ink supply rate of 0.6 litres / min.

The chamber design parameters were based around a refined chamber design developed from the results of the preliminary study and are summarised in *Table 1* & *Figure 2*. The doctor blade angle is a parameter which can usually be set on press via changes in the anilox / doctor blade engagement. The inclusion of the rear radius of the chamber allowed the volume of the chamber to be investigated without altering the anilox / doctor blade geometry. The gap width models represents a scenario where a contoured intrusion has been formed from the rear wall of chamber, a feature which has been introduced into recent chamber designs.

*Table 1*: Geometrical variations tested in the inking chamber geometry (standard value indicated by bold type)

| Geometrical parameter | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Rear radius of chamber mm (R1) | 25 | **35** | 45 | - |
| Doctor blade angle °(A1) | 15 | **20** | 25 | - |
| Gap (W) % width of standard chamber width | 10 | 50 | 80 | **100** |

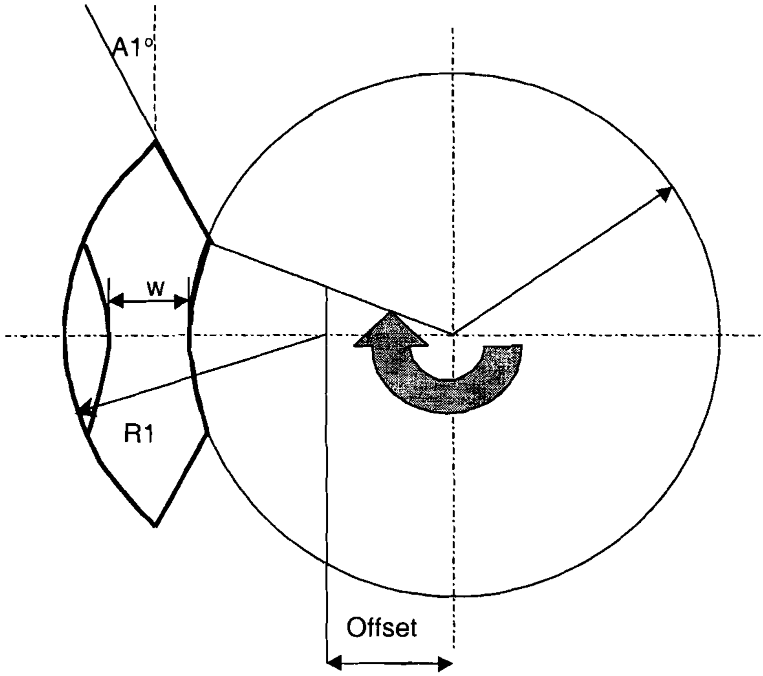


*Figure 2*: The generic chamber geometry examined in the model.

Each model consisted of a two dimensional cross section through the chamber and consisted of 50 x 100 grid of cells, the base models grid is shown in *Figure 3*. The air entering the chamber from the engraving on the anilox roll was ignored in analysis.

*Figure 3*: The finite volume grid for the basic geometry used in the study (50 x 100 cells).

Three ink types were chosen for the study, a water based UV cured ink (WBUV), a water based air dried ink (WBA) and a conventional UV cured ink (CUV). Rheological measurements of the inks using cone and plate rheometry showed that the water based inks could be approximated to a Newtonian fluid but that the conventional UV ink exhibited pseudo plastic behaviour, *Figure 4*.

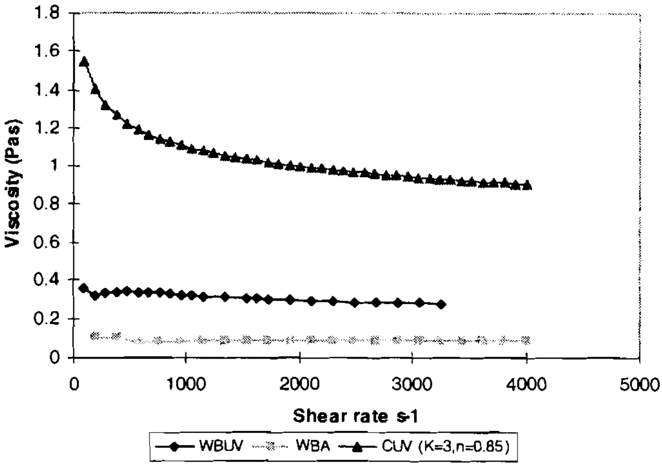


*Figure 4*: Experimentally measured flow curves for the three inks used in the investigation.

In order for the flow to become turbulent then the Reynolds number needs to be greater than 5 x $10^5$, if the system is approximated to flow between parallel plates, ref. [3]. If the maximum rotational speed of the anilox roll is assumed to be 1000 rpm, equivalent to a print speed of 3.84 m/s, then it can be shown that the flow is laminar as the Reynolds number does not exceed 11500, even for least viscous fluid and largest chamber. The viscosities of the inks were WBUV = 0.306 PaS, WBA = 0.0083 PaS. The constants used for the power law behaviour of the CUV ink are shown in *Eqn 3*.

$$1.6 < \eta = 2\gamma^{0.8477-1} > 0.9 \qquad \textit{Eqn (3)}$$

## 4. Results

### 4.1 General flow trends

The flow in the standard model is characterised by recirculation zones approximately mid - way between the anilox roll surface and the rear wall of the chamber, *Figure 5*. The contours of stream function show that the ink on the right hand side of the chamber is accelerated by the rotation of the anilox. The lowest viscosity ink (WBA) produces a single recirculation zone with ink being drawn up the anilox surface by the anilox rotation before returning to the bottom of the chamber along the rear wall. At low speed, the increased viscosity of the UV cured inks results in another recirculation zone being produced at the bottom of the chamber. At higher speed the size of the lower recirculation zone with the UV cured inks is reduced appreciably. The vertical position of the centre of the main recirculation zone is dependent on both the speed and ink type. With the higher viscosity inks, the position of the recirculation zone centre gradually moves down the chamber as the speed is increased.

### 4.2 Anilox surface pressure distributions

The role of the inking chamber and doctor blade is to fill the cells of the anilox roll with the ink which is to be transferred to the Flexo plate. This is achieved via the generation of static pressure on the anilox roll surface which forces the air out of the cells and forces the air in. The pressure can therefore be used as a quality criteria in examining the effectiveness of a chamber.

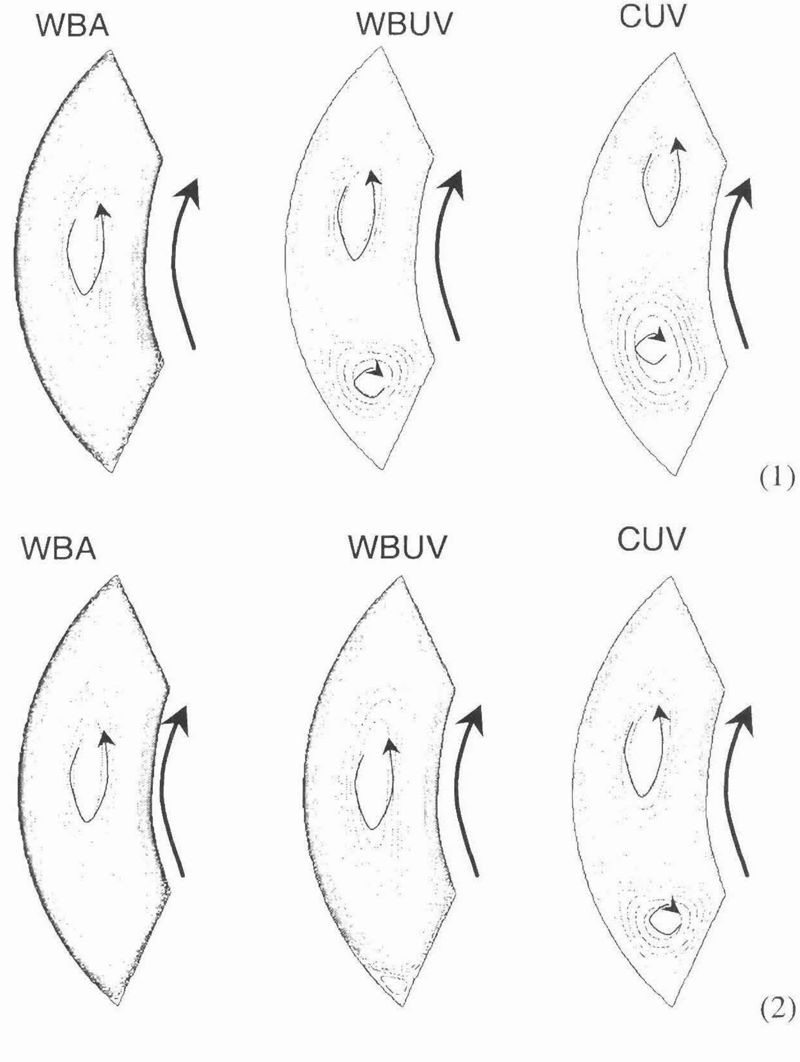


*Figure 5*: Contours of stream function for the basic chamber at a substrate speed of 1 $ms^{-1}$ (1) and 3.8 $ms^{-1}$ (2).

In all cases where the rear of the chamber remains curved (i.e. there are no intrusions in the chamber), the static pressure distribution along the anilox surface shows a negligible increase along the ink / anilox interface and increases sharply towards the doctor blade, *Figure 6*. The static pressure generated at the doctor blade / anilox junction was thus used as criteria for assessing the performance of the each of the design and operational parameters.

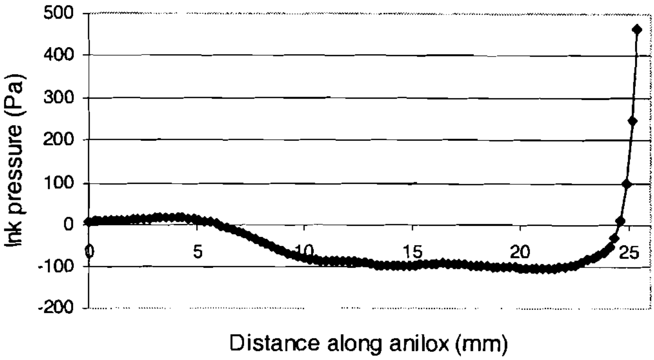


*Figure 6*: An example of the static pressure distribution long the anilox surface for the basic geometry at 3.82 m/s with the CUV ink.

For brevity, the presentation of the results will focus on the water based UV ink (being the mid range viscosity) and standard chamber geometry, except where explicitly stated. An increase in the print speed causes a linear increase in the static pressure generated at the doctor blade / anilox junction, *Figure 7*.

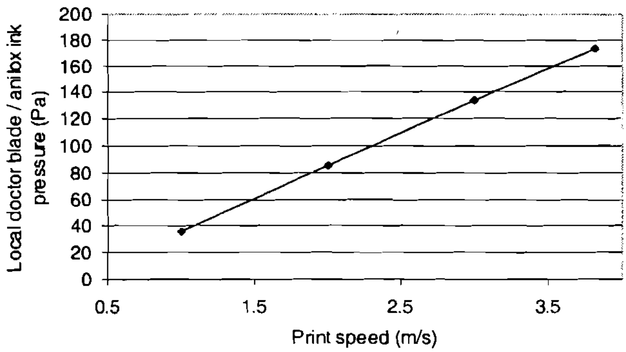


*Figure 7*: The linear effect of print speed on the ink pressure.

The dominant factor which determines the maximum pressure at the doctor blade / anilox junction is the ink type, *Figure 8*. The increase in viscosity of the UV ink results in the highest pressure at the doctor blade /anilox junction.

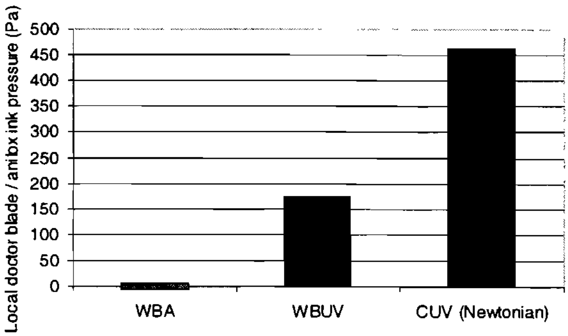


*Figure 8*: The influence of ink type on the doctor blade / anilox junction ink pressure at 3.8 m/s.

When the non Newtonian nature of the CUV ink is described using the power law the pressure is reduced as the ink becomes more pseudoplastic, *Figure 9*.

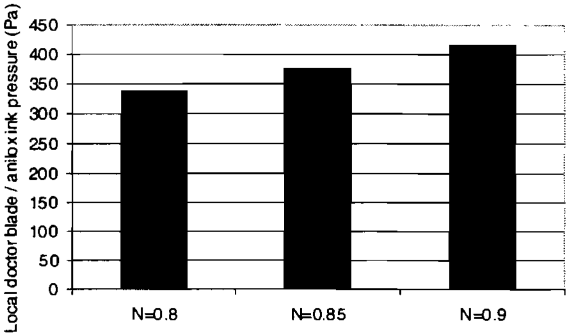


*Figure 9*: The effect of the non Newtonian nature of the CUV ink on the maximum pressure generated at the doctor blade / anilox at 3.8 m/s.

The geometry of the chamber has an appreciable effect on the pressure generated in the chamber. As the doctor blade is moved further from the vertical the pressure generated at the doctor blade tip increases, *Figure 10*.

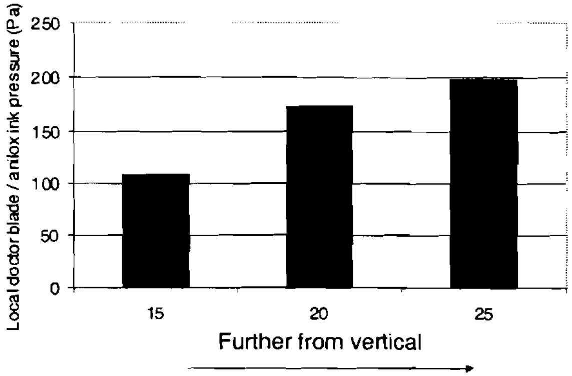


*Figure 10*: A increase in the angle between the doctor blade and the vertical increases the pressure generated.

When the volume of the ink chamber is increased the pressure that is generated under the doctor blade reduces, *Figure 11*.

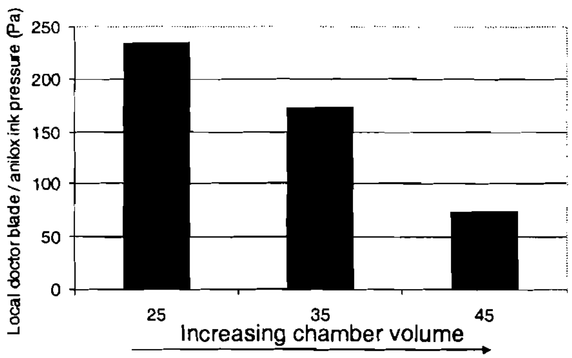


*Figure 11*: An increase in the chamber volume results in a significant drop in the pressure generated.

When the centre width of the chamber is reduced, the pressure profile along the anilox surface changes with a small increase in the pressure mid way along the anilox, *Figure 12*. Although this geometrical change results in a 90% increase in pressure, the doctor blade continues to be the location where there is a sudden and substantial increase in pressure.

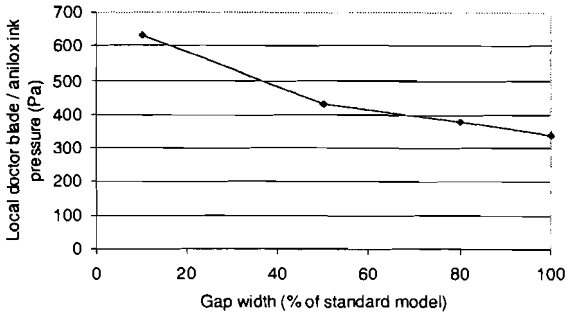


*Figure 12*: The effect of the reduction in the mid point chamber width for the CUV ink.

## 5. Discussion.

The pressure distribution along the surface of the anilox would suggest that the large majority of the ink transfer into the anilox occurs in the high pressure field ahead of the doctor blade. The doctor blade thus fulfils two roles as it provides both the doctoring action and also generates the pressure necessary for ink transfer to the anilox.

An increase in press speed increases the pressure generated at the doctor blade. Given that increased pressure would generate increased ink flow this may at first contradict experimental trials which have shown that the quantity of ink transferred to the print decreases with print speed, ref. [4]. However, he ink transfer process is dynamic and the time available for ink transfer is reduced as the press speed is increased, thus the net effect of theses two factors could be to reduce the amount of ink transferred into the cells.

When examining the reduction in peak pressure when operating with a pseudo plastic fluid it should be remembered that the pressure required to transfer the same quantity of ink at a lower viscosity into the anilox roll is also reduced. Experimental press trials have shown that the increased viscosity of the UV cured ink generally has a detrimental performance when the press operates at its highest speed. For improved performance at speed, it may be beneficial for the UV ink to possess more pseudoplastic behaviour such that its viscosity is reduced at high shear strain rates.

The importance of the angle between the doctor blade and anilox junction illustrates the need for control of the chamber / anilox engagement pressure on press. Where flexible doctor blades are used a small change in the contact pressure may change the contact angle appreciably.

The reduction in chamber dimensions would appear to improve the chamber anilox filling performance while yielding the benefits of a reduction in the chamber size. This has been partly corroborated by the reduction in chamber size and shape from the chamber used in the preliminary trial to the one used in the parametric study. Further potential reductions in chamber size should be validated with a combination of numerical modelling and experimental trials.

The increase in pressure as a result of the reduction in chamber volume appears to be significant. However, this may be in part a result of the reduction in chamber volume as the high pressure region for ink transfer continues to be the doctor blade / anilox junction. To gain a substantial increase in the mid height pressure the chamber width may need to be reduced to 5% of the current chamber width.

The ink transfer mechanism is reliant on two process, the removal of the air from the anilox cells and the flow of the ink into the cells. The surface of the anilox roll has been shown to be lower than atmospheric and may benefit the release of the air which is present in the anilox roll.

The results from this investigation can also be used to assess the performance of closed inking chambers in the rotogravure process and coating process, where generally the ink viscosity is much reduced.

One limitation of the models developed thus far is that it assumes that the ink fills the chamber which neglects the air which is sometimes present in the top of the chamber. The addition of this air would result in a model which contained two fluids and possessed a free surface at the interface of the ink and air. Such a model would require many other factors such as the air pressure and fluid service tension to be included in the model and would also result in an appreciable increase in the computational load.

There is a need to develop a detailed model of the ink transfer into individual cells. This would take into account surface tension, pressure gradient effects and the centrifugal force on the air in the anilox roll. This will provide information in the time necessary for ink transfer to occur. This would allow potential limits in terms of residence time at the increased pressure to obtained. This could infer maximum roller speeds which can be used without loss of performance.

## 6. Conclusions and recommendations.

A parametric study has been carried out on the effect of design and ink parameters on flow and pressure distribution in a flexographic inking chamber.

- The pressure along the majority of the surface of the anilox roll is near atmospheric but increases rapidly as one approaches the doctor blade.
- Ink viscosity has the dominant effect on the ink pressure at the doctor blade and the flow pattern.
- The non Newtonian nature of the ink is sufficient to reduce the static pressure generated at the doctor blade tip by around 20%.
- The doctor blade ink pressure is linearly related to press speed.
- A reduction in ink chamber volume increases ink pressure at the doctor blade.
- The impact of a raised area in the middle of the chamber is minimal until the it constitutes 90% of the total chamber width.
- Computational fluid dynamics has given a valid insight into the operation of the flexographic inking chambers.

Future steps in the study should address the following :

- The free surface which is created when the ink does not completely fill the chamber and there is a free surface near the top of the doctor blade.
- The inclusion of the air which enters the chamber from the anilox roll.
- The model should be expanded to examine the pressure and flow characteristics when the fluid viscosity is much lower which is applicable to rotogravure and many coating applications.

- Detailed modelling of the flow of ink into the individual cells on the anilox roll.
- Modelling of gravure and coating applications.

## Acknowledgements

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