An Investigation into Ink Transfer in Rotogravure Printing

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Abstract

This paper describes an investigation into the ink transfer characteristics in rotogravure printing. Analysis of sequential copies was used to optimise the number of samples used in experiments. No cyclical frequencies were detected in the printed colour. Extensive monitoring of the printing press was carried out to evaluate the natural fluctuations on the press parameters and printed product. An orthogonal array experimental programme was performed to determine the effect of process parameters on the ink transfer characteristics from the cylinder to the substrate. The results highlight the significant non-linear variation in colour with respect to changes in ink viscosity and the change in colour with the doctor blade angle.

Introduction

Rotogravure printing is a complex manufacturing process and the understanding of the influence of different process parameters is limited. The purpose of this work was to identify key parameters and to quantify their effects numerically. This will allow appropriate control limits to be placed on these parameters to ensure a stable and repeatable printing environment. The parameters are currently set using experience by the press crew. Hence, when a new job is to be printed both time and material are wasted in obtaining the correct colour. The work aimed to identify those parameters having a large effect in the product quality.

The number of parameters affecting the process is large, Figure 1. These are divided into five sections of ink, process, pre-press, cylinder and substrate. The parameters in the process category are those that are generally altered by the print crew to achieve good copy and as such the parameters for investigation were chosen from this category. At present all values are selected using experience by the press crews, as are the tolerance and limits of controls on each. It is impractical to assess all the parameters experimentally. The analysis of sequential copy variation was carried out to ensure the optimal collection rate for samples and that the results presented are significant. Monitoring was used to evaluate parameters that altered in the press during normal operation and parameters were then selected for experimental investigation.

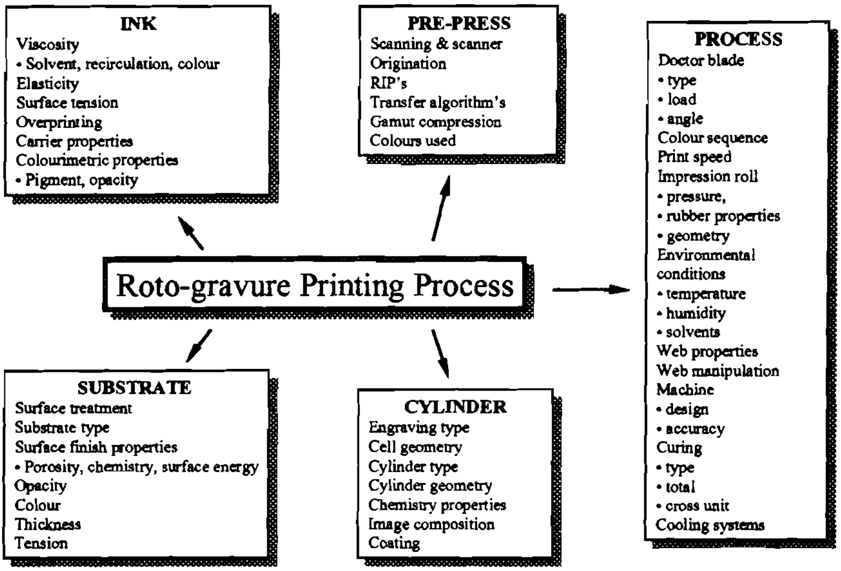

Figure 1 Parameters effecting image quality in rotogravure printing

This paper concentrates on the evaluations of the natural process variability in printing colour on flexible packaging. The monitoring identifies several parameters as the possible cause of colour fluctuation and these are evaluated experimentally using orthogonal array techniques. Summaries of the findings are presented.

Press instrumentation

A ten-unit rotogravure production press was used for the experimental trials and it was instrumented to provide data on the important press parameters. These included the measurement of strategic temperatures along the length of the press, with further temperature data being collected during the systematic orthogonal array experiments. The ink temperatures in the inking trays were measured using two sheathed K-type thermocouples per unit, mounted each side of the inking tray (operator and gear). This provided information on the temperature both along the press and across the width of the web. To obtain further temperature data during the systematic experiments three thermocouples were mounted onto each of the doctor blades used during the trial. The temperatures of the burners and hood dryers were measured using existing press instrumentation, for each unit. All this data was recorded on computer using a data acquisition system.

The ink viscosity was monitored using a video facility with the data being extracted at set time intervals later. The main control panel was monitored and in addition to the ink viscosity readout, it gave indications of changes that were carried out by the press operators.

Colour variation in sequential copies

Traditionally single sheets are collected from a print run and these are used for process assessment and control. However, colour fluctuations occur in all printing processes and these can lead to inaccuracies in the assessment of the process. To obtain the optimum collection rate for experimental evaluation of a rotogravure printing press, sequential copies were collected while the press was running in a stable operating condition. These tests were carried out prior to the monitoring or systematic experimental programme.

Measurement using spectrophotometry was carried out in the image area on 1024 sequential copies for several different print runs. The colour was shown to vary between cylinder revolutions and a representative presentation of the colour change over 130 copies is shown, Figure 2. The results are shown for ease of use as densities. Fourier analysis was applied to these measurements and this analysis showed there were no underlying cyclic trends. Moving average techniques were then applied to the data and this indicated an optimal collection rate of 30 consecutive samples (one per cylinder revolution) for any analysis into the effects of process parameters on product quality.

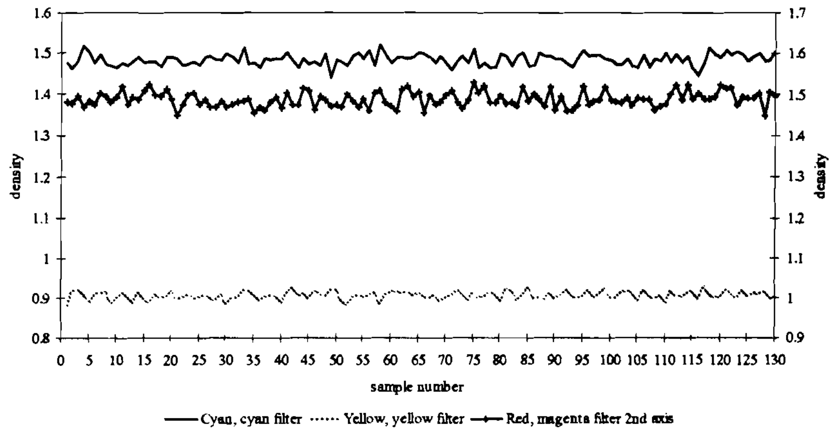

Figure 2 Colour fluctuation for 130 sequential copies

Monitoring of press performance

The press conditions were monitored during several print runs and samples were collected at regular intervals, at the end of each reel. The monitoring exercise was performed to document the natural fluctuations in press parameters and where possible to relate these changes to those that may be occurring in the colour of the printed product. The press speed, ink temperatures in the inking trays, burner temperatures, hood temperatures and press tensions were collected using data acquisition systems. Whenever possible the existing press instrumentation was used. The results presented represent nine hours of production on a single print job.

The variation in the ink temperature in the inking trays, for two units, on both the operator and gear side is shown in Figure 3. Also shown are the press speed and the sample collection points. There are small fluctuations in the ink temperature across the width of the machine and through the duration of production. This is in marked contrast to the temperature changes observed in web offset [1], where large temperature changes, up to 20°C were detected through the run and 8°C across the width of the press. The ink temperatures are not significantly affected by changes in press speed either from start up or by incremental changes in production rate. The temperature range over which samples were collected is approximately 3°C. The results show a good thermal stability in the ink supply system.

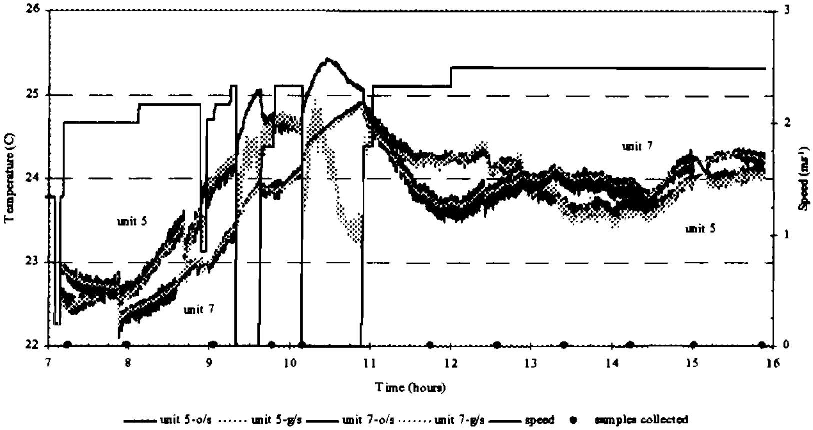

Figure 3 Ink temperature variations for units five and seven

The ten units have their own inter-station drying system, supplied from four burners. All these temperatures were monitored and showed very good control throughout production and between stops, a representative illustration for one of the burners and dryer unit being shown in Figure 4. Again, the thermal control of the hoods and burners was very stable and not effected by the operating conditions. Due to high level of control and consistency exhibited throughout all the monitoring, the ink, burner and drying temperatures were removed as factors from the subsequent systematic orthogonal array experimental programme.

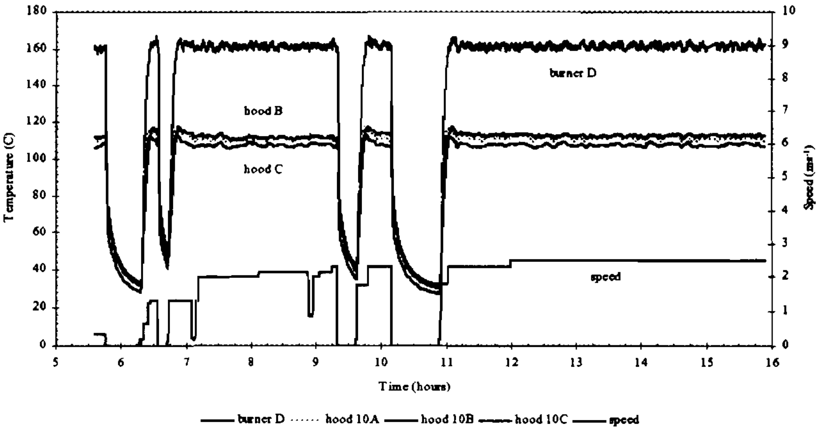

Figure 4 Burner and hood temperatures

The ink viscosity varied significantly both within single print units and between the units, Figure 5, through the full duration of the print run. By examining the ink viscosity fluctuations over the short term it is apparent there are slow drifts occurring in the ink viscosity, with the majority of the abrupt changes being the result of alteration made by the press crew.

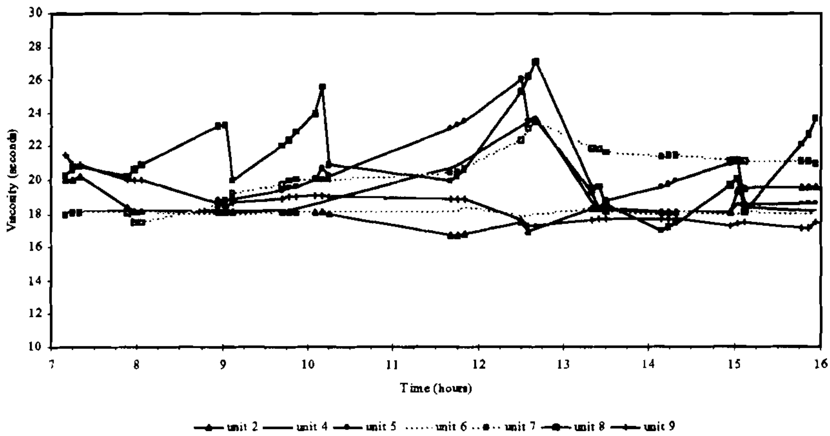

Figure 5 Ink viscosity variations through the run

The monitoring showed there was good control over the majority of the press parameters (notably thermal) with the most significant variations occurring in the ink viscosity. Samples were collected at the end of each reel, as indicted earlier, Figure 3. These were measured using spectrophotometry to assess the colour variation through the run. The sample intervals were evaluated earlier at thirty cylinder revolutions. The colour differences were calculated using the CIE ΔE^*_{94} colour difference equation with the weighting functions all set to unity. The colour differences for unit seven (blue) and unit two (yellow) are shown in Figure 6, with the calculation carried out relative to the last sample set that was collected. These show a large colour difference through the run for the blue measurement areas. The reel relating to the second set of samples collected was rejected as out of specification immediately it had been printed. Good stability was found for the yellow with a small ΔE^*_{94} between successive measurement patches. For all patches there is difference in colour between nominally the same patches across the web, though at the time it was not possible to measure the relative cell geometry of the appropriate cells.

A correlation between the ink viscosity and the colour change provided reasonable agreement, with R^2 values of approximately 0.85. This indicates the changes in colour could be caused by the changes in ink viscosity. Therefore, the ink viscosity was incorporated as one of the main factors in the systematic experimentation using orthogonal arrays. Also included were the main parameters altered by the press crew in controlling the colour, thereby identifying the relative sensitivity of the parameters investigated.

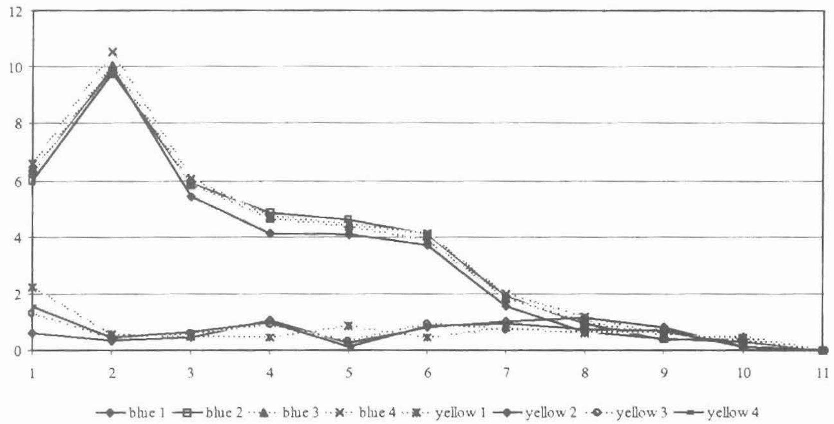

Figure 6 Colour variation through the duration of the print run

Analysis of factors affecting the ink transfer

A systematic experimental programme was used to evaluate the effect of four parameters on the solid ink transfer. These were split into two trials, one investigating the ink viscosity and impression roll pressure, with the other one investigating the blade angle and blade load. The full factorial numbers of experiments were used, though the analysis was carried out utilising a L_9 orthogonal array, which allowed the evaluation of any possible interactions between the parameters. The parameters were grouped together as those where it was most likely that interactions may occur. For further details on orthogonal arrays refer to [1], [2]. Three levels were selected for each of the parameters, allowing the investigation of the linearity of response. It was not possible to carry out a single trial, as this would have required a much larger experiment of 64 test runs. A production job was used to provide the image for the experimental trials. Experiments were carried out on two units simultaneously printing different sections of the image (different inks) and using a straight supported and a "Y"-shaped doctor blade configuration.

Experiment 1						
	Ink viscosity (Pa.s)			Impression pressure		
Level	1	2	3	1	2	3
Setting	0.032	0.038	0.044	1.0 b	1.3 b	1.6 b
Experiment 2						
	Blade load			Blade angle		
Level	1	2	3	1	2	3
Setting	1.0 b	1.4 b	1.8 b	steep	mid	shallow

Table 1 Parameter levels for orthogonal array experiments

The temperatures of the ink were consistent during the trials, with the largest differences occurring in the second experiment, Figure 7, with a small reduction in the temperature detected as the viscosity was lowered. Again, there was no cross web variation. The temperature measured on the doctor blade was approximately $1^{0}C$ higher than that of the ink in the tray. This is due to the rubbing action of the blade though the temperature of the ink in the tray provides a good indication of the temperature before application to the substrate.

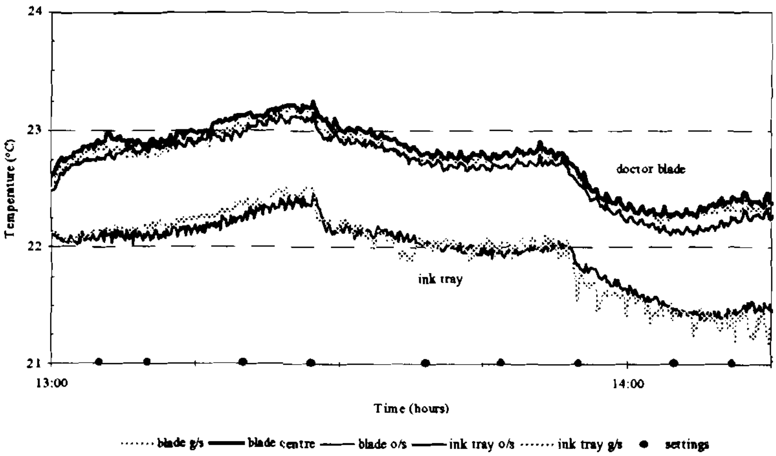

Figure 7 Ink temperature during systematic experiments

The printed copy for analysis consisted of a repeat image four times across the web and five times around its circumference. Measurements were carried out for thirty consecutive cylinder revolutions, with the results averaged for each of the test runs within the orthogonal array trial. From this, CIE $L^*a^*b^*$ values were calculated for each of the three levels (one, two and three) and then the CIE ΔE^*_{94} colour difference for each patch could be calculated.

The ink viscosity has a significant influence on the colour of the printed product, Figure 8. The results from both tests provided similar results, with those for the blue ink shown. The colour change is significant between all levels, with the total ΔE^*_{94} between levels one and three being greater than six. For the gravure cylinders, the colour change is similar across the width of the web and around its circumference, with low co-efficients of variation between patches. The results highlight the critical control that is required on the ink viscosity, which had earlier been shown to be poor, Figure 5. The results are significantly non-linear with a much larger colour change at the low viscosity values, level 1 to 2, Table 1. This shows the ink colour being increasingly sensitive to changes in the viscosity as it is reduced. This indicates the process tolerances need to be adjusted according to the ink viscosity, with smaller tolerances at low ink viscosity.

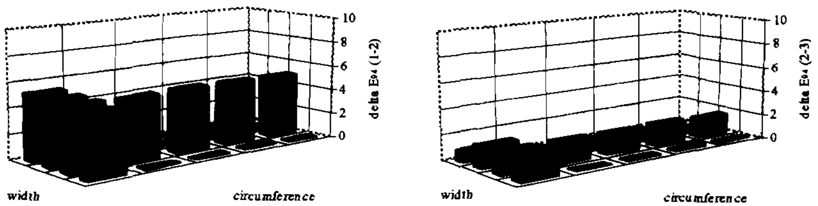

Figure 8 The effect of ink viscosity of the printed product, $\Delta E^*_{94(1\text{-}2)}$ and $\Delta E^*_{94(2\text{-}3)}$

The effects of the remaining process parameters on the printed colour are summarised in Figure 9. These show the averaged ΔE^*_{94} colour difference for all patches between each level and the cumulative effect between levels one and three. The blade angle is the most significant of the remaining parameters, though the colour change is almost an order of magnitude smaller than the effect caused by the ink viscosity. Again, the result is slightly non-linear with the largest change detected between levels two and three relating to the shallower angles. The doctor blade setting angle is therefore critical for both the solids in addition to the halftone areas. As the blade angle is increased, so the image becomes lighter with a reduction in chroma, indicating a thinner ink layer is being printed.

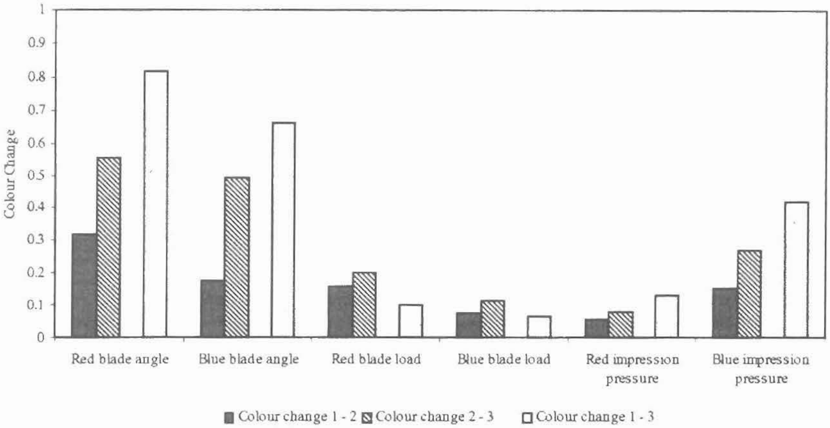

Figure 9 Average colour change between each level for impression pressure, blade angle and blade load

There is no effect on the solid colour by altering the loading on the doctor blade itself. The colour changes are not much larger than the repeatability of the measurements, with the doctor blade load changes having no visual effect on the colour. The increased load will not affect the flow from the cell but will increase wear in the long term, with the associated change in colour that would then occur from the change in cell geometry caused by the wear.

The impression pressure has only a very small effect on the solid density, and only for the blue image area. These results are in contrast to those presented by other authors. However these earlier reported results were carried out on a simulator [3] using coated paper and on a printability tester using coated board [4]. In both of these cases the substrate is absorbent and these changes in pressure would lead to an increase flow into the board and hence a change in colour.

No interactions were detected between the ink viscosity and impression pressure or the blade load and angle. The average ΔE^*_{94} colour difference was less than 0.1, within the accuracy band of the measurement instrument. This makes it possible to optimise the system variables independently.

Conclusions

An extensive experimental programme has been completed evaluating the effect of various process parameters on the solid printed areas on a non-absorbent film in a production environment. Assessment of sequential copy colour fluctuations indicated the use of thirty consecutive cylinder revolutions for colour assessment. The monitoring showed good thermal control with significant fluctuations in the ink viscosity through general production. This was included into a systematic experimental programme into the effects of control parameters used by the press crew whose findings can best be summarised as:

- Ink viscosity has a significant effect on the printed image and the sensitivity to changing value was more apparent at the lower ink viscosity levels, with a strong non-linearity in the response.
- The impression pressure had no effect on the solid density, at variance with earlier findings, though this work has been carried out on an impermeable film.
- The blade angle altered the colour with a reduction in ink film thickness as the blade angle is increased towards the perpendicular with respect to the cylinder surface.
- No effect on the solid colour was observed with changing blade load.
- No interactions were found between the parameters investigated.

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