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# Effects of the Coating Mixture on the Penetration of Liquids into Paper

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**Abstract**
*The pigment coating of paper is usually performed to enhance the physical properties of paper and its printability. The coating generally makes paper whiter, brighter and more opaque. The properties of the coated paper depend, among others, on the porous structure of the coating developed, which is determined by the pigments, binders and their reactions. The influence of the type and quantity of coating components and ink absorption into the coating layer was studied in this work. Printing ink penetration was measured using a Penetration Dynamic Analyser with a HVL module (High Viscous Liquid). The evenness of liquid penetration into paper was measured using a Penetration Dynamic Analyser with a PEA module (Print Evenness Analyser). Results obtained indicate that all three variables – coating pigment type, latex dose and ink type – may have an equally strong influence on liquid and ink penetration, and thus on print quality.*

**Key words:** *coating mixture, paper, liquid penetration, PDA.*

## Introduction

Paper in different forms has a wide range of uses, for example, newspapers, books, packaging materials, paper towels, construction materials and for decorative purposes. To meet the stringent quality demands and to achieve a smoother and more printable surface, paper is often coated. As discussed by Kogler et al. [1], coating improves the surface quality of paper, resulting in higher brightness, gloss and smoothness as well as better opacity and generally significantly improved printability. According to Lehtinen and Sood [2, 3], although about 80% of all coated paper properties depend on the properties of the base paper, coating is still required to fill the voids in the paper in order to create a uniform surface for the best print quality. The properties of the coated paper also depend on the porous structure of the coating developed, which is determined by the pigments, binders and their reactions. Pigments are the main coating components for improving the surface properties of coated paper. The pigment particles, forming a porous structure, which can also accommodate ink, must also simultaneously be incorporated in a binder to form a continuous porous film. The binder improves the retention of pigment particles at the surface of the coating film during the printing process. Basra et al. [4] claimed that the interaction between binders and pigment particles is important since it influences the properties of the coated papers.

As discussed by Ström, one of the most important properties of a coating is its pore structure, which determines the rate of ink setting [5, 6]. The studies of Xiang et al. [7] indicate that for a dry coating, the pore size typically ranges from 0.01 to 1.0 µm, with a porosity of 20 to 40%. The main contributing factors to ink consolidation and setting behaviour are the release of the fluid components from the ink composition, absorption of the fluid released into the porous structure as well as its diffusion into the polymer matrix of the coating layer, and the adhesion of the ink resins to the coating surface. Rousu et.al [8, 9] showed that the rate of ink setting is highly dependent on the properties of the fluid phase separating from the ink composition.

The desired coating layer properties can be obtained by modifying the coating composition: pigment blends and binder type. Another important factor in addition to the porosity of the coating is also the permeability, that is, pore connectivity. The porous structure is often described by the particle size distribution and aspect ratio of the pigment [10]. There are four popular minerals used in paper coating: kaolin clay, calcium carbonate (available ground or precipitated), titanium dioxide and talc. Both titanium dioxide and talc are used in small quantities for special applications where extreme whiteness and opacity, or pitch control are required. Kaolin clay improves paper appearance, which is characterised by gloss, smoothness, brightness and opacity, and is of greatest significance as it improves printability. Paper is also filled with kaolin to extend fibres [11, 12]. Precipitated calcium carbonate (PCC) is a particularly effective coating pigment because it can either increase paper quality for no extra cost, or maintain quality at reduced cost. PCC is also a supremely versatile pigment: its physical characteristics allow it to be customised to its end-use and, therefore, adapted to the requirements of different paper grades [13, 14].

Through coating processes, paper with good properties produced from a worse raw material can be obtained, for example, from wastepaper, which is therefore much cheaper than high-grade mass. Depending on the raw materials used, the surface properties of paper can be changed. With a coating blend affixed to the surface of paper, forming an additional barrier to overcome, the penetration of contaminants is lower. The influence of the coating structure on the ink setting rate has been widely investigated [15-18]. The porosity distribution and surface roughness are the main factors that affect the interaction between printing ink and coated paper. Ink receptivity and ink absorption are two important properties of coated papers to be printed. There are a number of factors affecting the ink receptivity and ink absorption of coated surfaces, but the most important factor is the binder level in the coatings. As mentioned by Gigac and Gruner [19, 20], liquid penetration is a phenomenon taking place in the short contact time of the paper, which is simultaneously filed, during which there are many different changes. Due to the actual time of the impact of ink on printed material, very useful are devices which record process liquid penetration in paper creations at the time of contact with the test sample. An example of such a device is the Penetration Dynamic Analyser PDA. A special characteristic of the Penetration Dynamics Analyser is the fact that it measures immediately after liquid contact after a dead

***Table 1.*** *Coating blends.*

| Components, pph | Blend 1 | Blend 2 | Blend 3 | Blend 4 |
|---|---|---|---|---|
| | SPS | | PCC | |
| Pigment | 50 | 50 | 50 | 50 |
| Latex | 5 | 20 | 5 | 20 |
| Lopon | 0.5 | 0.5 | 0.5 | 0.5 |

***Table 2.*** *Roughness and air permeance coated samples.*

| Coating weight, $g/m^2$ | Roughness, $cm^3/min$ | | | | Air permeance, $cm^3/min$ | | | |
|---|---|---|---|---|---|---|---|---|
| | Blend 1 | Blend 2 | Blend 3 | Blend 4 | Blend 1 | Blend 2 | Blend 3 | Blend 4 |
| 6 | 190 | 130 | 276 | 214 | 38 | 10 | 288 | 119 |
| 14 | 134 | 75 | 176 | 154 | 20 | 7 | 282 | 118 |
| 24 | 126 | 68 | 162 | 153 | 16 | 4 | 251 | 86 |
| 40 | 77 | 64 | 158 | 117 | 13 | 3 | 244 | 66 |

time of only 6 milliseconds. This means that it provides information about the surface area of the paper, which is generally the most interesting. This ensures a high degree of efficiency for investigations since the measurements supply significant process related information before the material is printed.

## Material and methods

The study was conducted on offset paper samples with a basic weight of 80 $g/m^2$ as base paper. The scope of the research included preparing four coating mixtures and applying them to the base paper. The coating blends were applied to the offset base paper using a wire-wound Meyer rod. The coating mixtures were prepared using the following as pigments: kaolin (SPS, English China Clays, $\rho$ = 2.59 $g/cm^3$) and precipitated calcium carbonate (PCC, $\rho$ = 2.71 $g/cm^3$). Sodium polyacrylate salt (Lopon 890, BK Giulini, $\rho$ = 1.3 $g/cm^3$) was used as a dispersing agent. Styrene-butadiene latex (DL-950, DOW Chemicals, $\rho$ = 1.0 $g/cm^3$) was used as a binder. In the dispersion the content of solids was 50% by weight. The pH of the coating suspensions was adjusted to 8.5 with a 0.5 molar sodium hydroxide solution to assure good dispersion. ***Table 1*** shows the raw material composition of the mixtures. After the coating blend transfer, water was removed by treatment with heat (IR radiation). The coated papers were not calendered.

Roughness and air permeance tests were performed using a Bendtsen Tester K-513 in accordance with ISO 5636-3:2013 Paper and board – Determination of air permeance (medium range) – Part 3: Bendtsen method. The results are reported as the average of five measurements (***Table 2***).

Base paper roughness – 430 $cm^3/min$, air permeance – 1385 $cm^3/min$.

The coated papers were printed using an IGT AC2 laboratory press. Printing speed – 0.2 m/s, nip pressure – 400 N and 0.5 $cm^3$ ink volume on the distributor rolls were used. The inks were three types of offset inks marked with numbers one, two and three (1 – based on vegetable oils, 2 – ink with reduced odour, 3 – low migration ink). The amount of ink transferred onto the paper was calculated using the following formula:

$$M_f = \frac{(m_1 - m_2)}{S} \times 10^4$$

where:
$M_f$ – amount of ink applied to the substrate, $g/m^2$
$m_1$ – mass form with ink before printing, g
$m_2$ – mass form with ink after printing, g
$S$ – print surface, $cm^2$

The printing ink penetration was measured using an EMTEC GmbH PDA Penetration Dynamic Analyser with an HVL module (High Viscous Liquid) at 1 MHz frequency, 35 mm sensor diameter, and 3.5 $cm^3$ volume of testing liquids. Ink was applied on the horizontal area of the foil protecting the measuring cell, which included an ultrasound transmitter. The paper sample was applied by means of double sided adhesive tape to the measuring head, which contained the ultrasound receiver. For measurement, the measuring head was lowered together with the paper sample unit in contacted with the ink. The paper sample was brought into contact with liquid in the measuring cell. From the moment of liquid contact, it was radiated in the Z-direction with high-frequency low-energy ultrasonic signals. These signals were received by a highly sensitive sensor before they were processed in the device and transmitted to a personal computer. The main advantage of this method compared to others is that the penetration dynamics can be tracked in real time with millisecond time resolution. The evenness of liquid penetration into the paper was measured using an EMTEC GmbH PDA Penetration Dynamic Analyser with a PEA module (Print Evenness Analyser). This module ultrasonically multisensory, comprising 32 horizontally arranged sensor elements measuring approximately 1 $mm^2$ each. The sensor data are simultaneously logged by the system's electronics. The 32 curves thus obtained represent the degree of uniformity of liquid absorption by the sample under test and allow to form conclusions as to the product quality. The sample was fixed with double–sided tape onto a sample holder and was brought into contact with liquid in the measuring cell. The test liquid was deionised water.

## Results and discussion

The influence of the type and quantity of coating components and liquid penetration into the coating layer was studied. ***Figures 1-4*** show the results of researches with the PDA-PEA analyser. The 3-D diagram shows the signal intensity (I) versus time (t) and the sensor element position (x). The diagram is intended to enable the visual assessment of measurements. The water used as test liquid characterises the surface hydrophobic/sizing as the water penetration is exclusively determined by this. It is seen that the coating pigment type and latex dose had an influence of the rapidity and evenness penetration. In the case of coated samples SPS, water has to go a longer way through the tortuous platy packing. As the particle size distribution becomes narrower, the water has a shorter penetration path and the tortuosity factor becomes less. The higher latex concentration in the coating layer causes a delay in water penetration. The influence of the type and quantity of coating components and ink absorption into the coating layer was also studied. The absorption of the minimum amount of ink receptivity was indicated for economic reasons. Another factor in favour of this is also consumer safety; less ink means less harmful substances that can penetrate the packed product. Analysing the relationship between the type and quantity of coating components and the amount of ink transferred onto the paper, it was found that the relatively largest amount of ink was

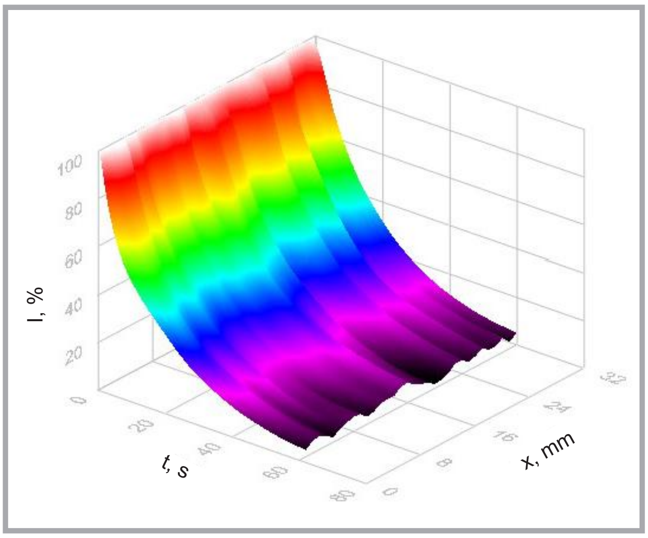


*Figure 1. PDA-PEA diagram: paper coated with blend 1 in contact with water.*

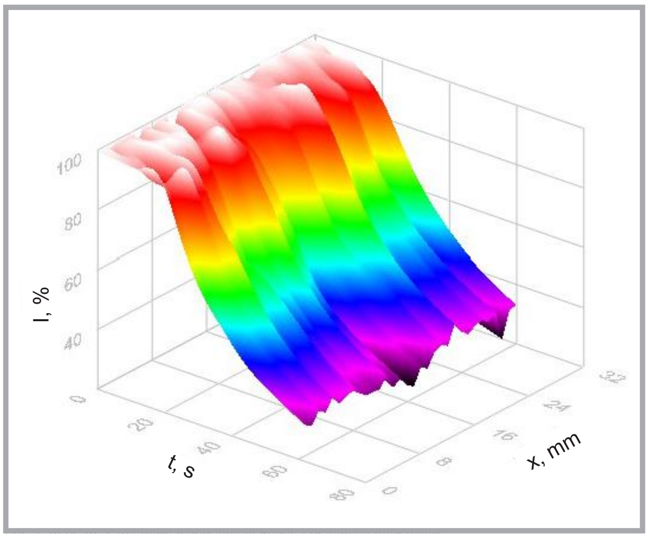


*Figure 2. PDA-PEA diagram: paper coated with blend 2 in contact with water.*

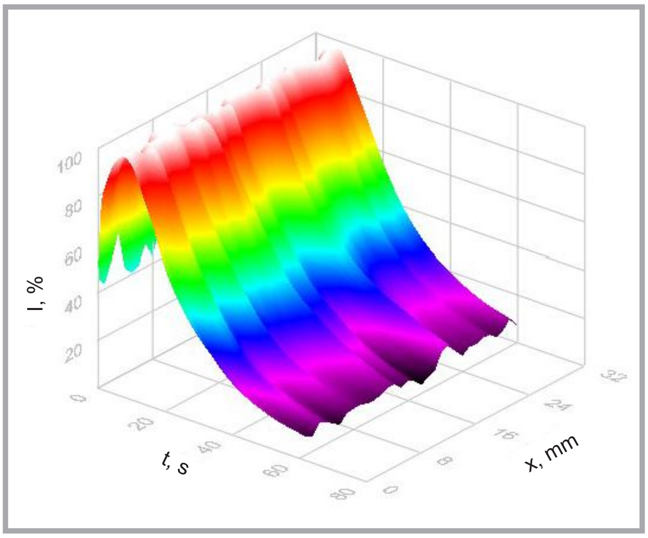


*Figure 3. PDA-PEA diagram: paper coated with blend 3 in contact with water.*

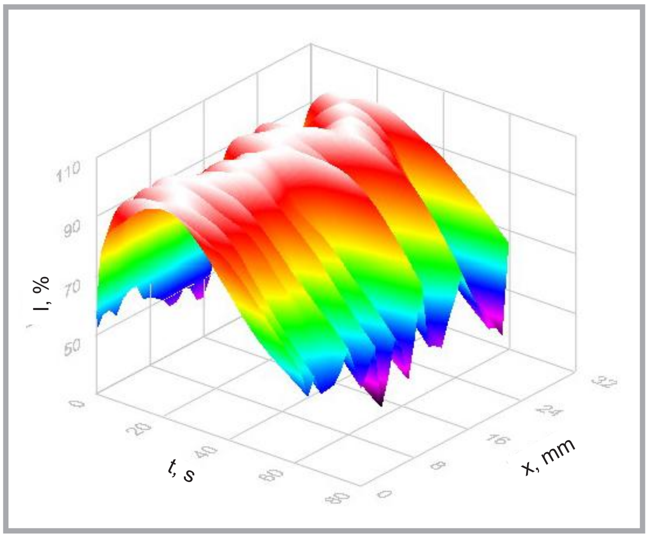


*Figure 4. PDA-PEA diagram: paper coated with blend 4 in contact with water.*

absorbed by samples which had a coating weight of 14 or 24 g/m$^2$ (***Table 3***). Some differences can be observed between samples containing kaolin with different doses of latex (blends 1 and 2). Ink receptivity decreased with an increasing latex level. A similar trend occurred in coated samples of coating blends with precipitated calcium carbonate (blends 3 and 4). Regardless of the composition of the coating blend, the most absorbed was ink based on vegetable oils.

Ink receptivity and ink absorption are two important properties of coated papers to be printed. The most important factors affecting the ink receptivity and ink absorption is the binder level in the coating. Ink absorption becomes slower when the content of the latex binder is increased, which is the result of decreased

*Table 3. Amount of ink transferred onto the paper samples.*

| | Coating weight, g/m$^2$ | Amount of ink no. 1, g/m$^2$ | Amount of ink no. 2, g/m$^2$ | Amount of ink no. 3, g/m$^2$ |
|---|---|---|---|---|
| Blend 1 | 6 | 0.015 | 0.010 | 0.008 |
| | 14 | 0.017 | 0.010 | 0.009 |
| | 24 | 0.019 | 0.014 | 0.009 |
| | 40 | 0.012 | 0.011 | 0.006 |
| Blend 2 | 6 | 0.008 | 0.008 | 0.007 |
| | 14 | 0.016 | 0.008 | 0.008 |
| | 24 | 0.016 | 0.008 | 0.004 |
| | 40 | 0.009 | 0.008 | 0.004 |
| Blend 3 | 6 | 0.016 | 0.013 | 0.012 |
| | 14 | 0.018 | 0.015 | 0.013 |
| | 24 | 0.021 | 0.016 | 0.015 |
| | 40 | 0.016 | 0.012 | 0.010 |
| Blend 4 | 6 | 0.012 | 0.006 | 0.006 |
| | 14 | 0.016 | 0.008 | 0.004 |
| | 24 | 0.019 | 0.008 | 0.002 |
| | 40 | 0.014 | 0.005 | 0.003 |

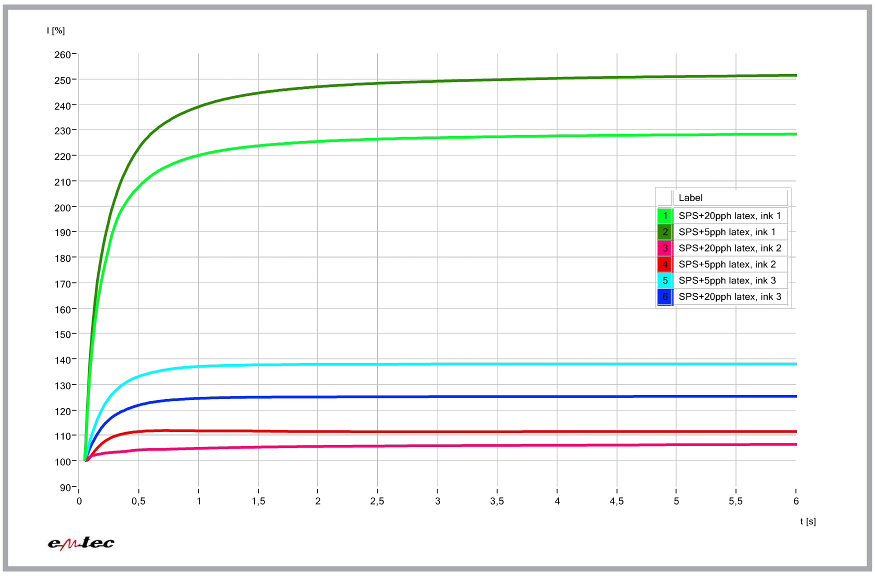


***Figure 5.*** *PDA-HVL diagram of SPS coated samples with different latex doses.*

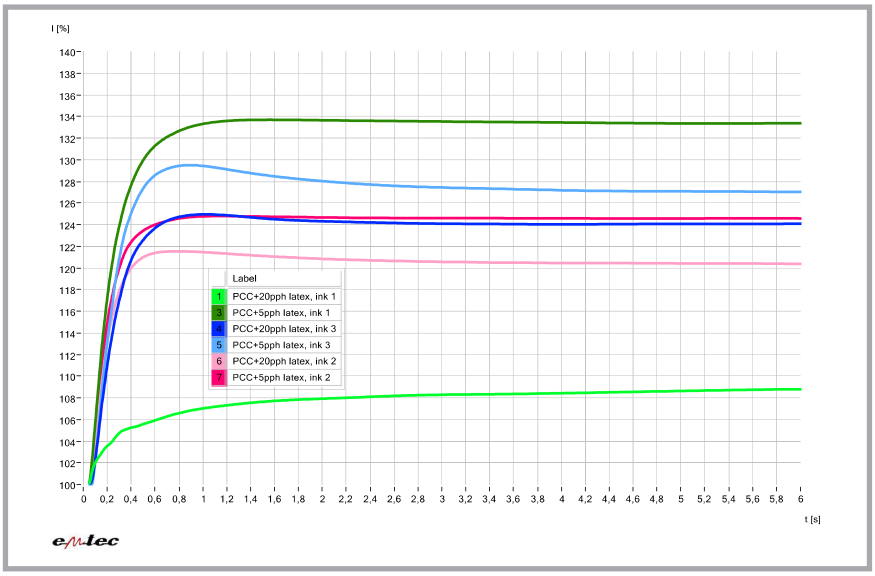


***Figure 6.*** *PDA-HVL diagram of PCC coated samples with different latex doses*

roughness (***Table 2***). The lower the binder level, the higher the receptivity and absorption of ink. The results indicate that the samples coated with the mixture containing PCC absorb somewhat more ink. The change in ink absorption in the case PCC coating layers might be a consequence of the higher roughness and air permeance which occurred. Generally, calcium carbonate is used when a white surface is given priority. Kaolin pigment penetrates less into the base paper and tends to give a better surface coverage as well as a smooth and glossy surface in comparison with PCC.

***Figure 5*** shows the intensity of the ultrasound signal received during ink contact with the surface of samples coated with SPS (coating weight 14 g/m$^2$). The curves for measurements carried out with inks number one, two and three show clear differences between the inks used. Comparing the ultrasound signals, the deep penetration of ink number one was observed in samples coated with SPS. In the case of other curves, a low intensity ultrasound signal indicates low depth penetration of inks number two and three. Generally,ink penetration into the structure of the samples becomes slower when the content of the latex binder increases. A larger amount of latex in the coating layer decreases the wettability of the surface, as demonstrated by Ström [21]. ***Figure 6*** shows a time record of ultrasound intensity changes received at the contact of inks with the surface of PCC coated samples (coating weight 14 g/m$^2$). In the case of coated samples with a 5 pph latex dose, the penetration of ink number one occurs deeply as compared with the sample containing a higher binder level. Similar trends are seen in curves obtained for inks number two and three. Comparing the results of the research, it is noted that penetration is dependent on the ink type. Differences in ink penetration may be a consequence of the distribution of the coating layer with different pigment and latex doses or/and components of printing inks. Overall, all three variables – coating pigment type, latex dose and ink type – may have an equally strong influence on ink penetration and, thus, the print quality.

## Conclusions

The type of pigment used and the amount of the latex as a binder dispensed have a great impact on the amount of ink which was adopted by the coated samples. This relationship is maintained for each type of coating mixture and type of ink. Ink receptivity decreased with the increasing of latex. Regardless of the composition of the coating blend, the most absorbed was ink based on vegetable oils. Ink absorption and penetration into the structure of samples becomes slower when the content of the latex binder increases. Comparing the results of the research, it is noted that penetration is dependent on the ink type. Differences in ink penetration may be a consequence of the distribution of a coating layer of different pigment and latex doses and/or components of printing inks. Results obtained indicate that all three variables – coating pigment type, latex dose and ink type – may have an equally strong influence on water and ink penetration, and thus on print quality.

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