INFLUENCE OF THE VISCOSITY OF GRAVURE PRINTING INKS ON THE QUALITY OF PRINTED PACKAGING

UTJECAJ VISKOZNOSTI BAKROTISKARSKIH BOJA NA KVALITETU OTISNUTE AMBALAŽE

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Abstract

Viscosity is the property of gases and liquids to resist the flow or relative motion of adjacent layers. Viscosity is a form of internal fluid friction that occurs when fluid molecules move their layers during flow under the influence of appropriate stress. Ink viscosity affect the ink transfer and is therefore a very important parameter for the overall quality of the print and is defined by the printing technique. If the viscosity of the ink is not properly adjusted, the quality of the print will deteriorate, i.e., when the fluidity of the ink changes, the thickness of the ink layer will also vary. The quality of the gravure printing process depends on many chemical and physical properties of the materials and components involved in the process itself. In this study, the influence of the viscosity of conventional and UV curable gravure inks was observed in comparison with visual quality control and undertone parameter. The printing substrates prepared for this research were made by mixing recycled wood pulp with wheat, barley, or triticale pulp in a ratio 7:3 which gave insight into their potential use as packaging intended for printing.

***Keywords**: gravure printing, ink viscosity, printing substrate, undertone*

Sažetak

Viskoznost je svojstvo plinova i tekućina da se opiru protoku ili relativnom gibanju susjednih slojeva. Viskoznost je oblik unutarnjeg trenja tekućine koji nastaje kada molekule tekućine pomiču svoje slojeve tijekom strujanja pod utjecajem odgovarajućeg naprezanja. Viskoznost boje definirana je tehnikom tiska jer utječe na njezin prijenos tijekom otiskivanja i stoga je vrlo važan parametar za ukupnu kvalitetu otiska. Ako viskoznost boje nije pravilno definirana, kvaliteta otiska će se pogoršati, tj. kada se fluidnost boje promijeni, debljina sloja boje će također varirati. Kvaliteta procesa dubokog tiska ovisi o mnogim kemijskim i fizikalnim svojstvima materijala i komponenti uključenih u sam proces tiska. U ovom istraživanju promatran je utjecaj viskoznosti konvencionalnih i UV sušećih bakrotiskarskih boja te je uspoređivan s vizualnom kontrolom kvalitete i parametrom podtona. Tiskarske podloge pripremljena za ovo istraživanje izrađene su miješanjem reciklirane drvne pulpe s pulpom pšenice, ječma ili pšenoraži u omjeru 7:3, što je dalo uvid u njihovu potencijalnu upotrebu kao ambalaže namijenjene tisku.

***Ključne riječi:** bakrotisak, podton, tiskarska podloga, viskoznost*

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1. INTRODUCTION

Printing inks consist mainly of colorants (pigments or dyes), vehicles (binder or resin), additives and carrier substances (solvents). Depending on the type of printing process, printing inks have very different flow properties, ranging from extremely low to high viscosity. Above all, the ink transfer and the way the ink dries on the printing substrate are determined by the components of the printing ink and its viscosity. [1]. Viscosity, as a property of the printing ink, and the engraved cell geometry have a considerable influence on the ink transfer and the subsequent quality of the gravure printed product [2]. The depth of the engraved cell and the number of cells per unit area determine the amount of ink available for transfer. Gravure printing inks are divided into two basic groups: conventional and modern printing inks. Conventional inks are dried by evaporation of the solvent (water or alcohol), whose main function is to dissolve the binder, disperse the pigments and transfer the ink to the printing surface. Conventional gravure inks are typically composed of 10% pigment, 15% binder (usually polyurethane resin), 70% solvent and 5% auxiliaries to improve the quality of the ink [3]. Modern printing inks have a different drying process, where the drying process begins with the action of UV radiation. In UV-curing inks, the conventional solvent has been replaced by low-viscosity monomers that act as thinners. Monomers are light chemical substances that determine the surface properties of the ink itself, while oligomers play the role of binders and ensure absorption of the ink on the printing substrate [4]. In addition to pigments, oligomers, monomers and additives, the basic components of these printing inks are photoinitiators that react to UV energy and thus initiate the drying process itself. The ink coverage that can be achieved after printing with conventional gravure ink is in the range of 0.8 μm to 2 μm, while even more than 5 μm to 8 μm is possible with UV-curing ink. [1].

One of the most important properties of gravure inks is thier fluidity. The fluidity coefficient (ϕ) is the property of a substance not to resist movement, i.e., its ability to flow easily, which is described in Equation 1.

$$\phi = \frac{1}{\eta} \qquad (1)$$

where ϕ [Pa·s]$^{-1}$ is fluidity coefficient, and η [Pa·s] is coefficient of dynamic viscosity.

The fluidity depends on the structure of the substance and the temperature. It increases significantly with rising temperature and is measured in reciprocal viscosity units. Dynamic viscosity is determined by the coefficient η, which is defined by the force (F/S) per unit area required to achieve a unit velocity difference between two parallel layers at a distance *x (dv/dx*), which is defined by Equation 2.:

$$\eta = \frac{\frac{F}{S}}{\frac{dv}{dx}} = \frac{\tau}{D} \qquad (2)$$

where $\tau = F/S$ [Pa] is shear stress, $D = dv/dx$ [s^{-1}] is velocity gradient.

In Newtonian fluids, the tangential tension or shear stress is linearly dependent on the decrease of the velocity gradient *D*. Newtonian fluids are low viscosity fluids such as water, mineral oils, and gravure inks. If the dynamic viscosity coefficient is independent of the shear stress gradient, the ink behaves like a Newtonian fluid. For Newtonian fluids, the kinematic viscosity (ν) is determined, which is the relationship between dynamic viscosity and density according to Equation 3 [5]:

$$\nu = \frac{\eta}{\rho} \qquad (3)$$

where ν [m^2s^{-1}] is kinematic viscosity, η [Pa·s] is coefficient dynamic viscosity and ρ [kg m^{-3}] is fluid density.

Gravure printing is characterized by excellent print quality and high printing speed for large print orders. Other advantages include a simple printing process, accurate ink reproduction and flexibility of the printing machine. Nowadays, gravure printing is one of the technologies that will continue to develop due to a series of technological innovations. The market for packaging printing represents the largest segment, and further growth is predicted.

When printing packaging with conventional solvent-based printing inks, the printing substrates on which the printing was done may contain a certain amount of residual solvents that can affect the properties of the product packaging, i.e., change odour, stain and taste of product. Therefore, it is important to ensure that the limits for solvents in the packaging material are not exceeded [6].

UV-curing inks are increasingly being used in graphic industry to reduce emissions of volatile organic compounds (VOC) due to several advantages over conventional inks, including increased scratch and wear resistance, excellent durability, improved gloss, excellent adhesion, greater environmental friendliness, and better resistance to chemical and solvents [7]. Due to the high printing speed, the use of UV-curing gravure printing inks is still very low, as the inks must have an extremely low viscosity, which can only be achieved by using volatile solvents [8].

Due to the unfavorable impact on the environment, the consumption of artificial materials in the graphic industry is gradually decreasing, while at the same time the consumption of natural resources from lignocellulosic materials is increasing. Wood remains the world's most widely used raw material for the production of paper and pulp, but its supply has been greatly reduced due to irrational long-term exploitation of this natural resource. The use of new sources of virgin cellulosic fibers is crucial for the paper and printing industry, since the reduction of forest cover has decreased the availability of wood raw materials. [9].

The properties of the substrate are one of the factors that undoubtedly influence the overall quality of the print. Therefore, this research was focused on the analysis of the use of wheat, barley and triticale straw fibers in the composition of paper for the production of more environmentally friendly packaging prints. The aim of this research is to compare whether there is a dependence of the viscosity of conventional and UV-curing gravure inks with the undertone parameter. A subjective analysis of gravure printing on paper substrates containing straw was additionally carried out.

1. MATERIALS AND METHODS

1.1. Production of laboratory paper substrates with straw pulp

Today, the production of paper and paper products is mainly focused on replacing virgin wood raw materials with alternative ones. Since Croatia is an agricultural country that produces large quantities of different types of cereals, straw as a by-product of agricultural cultivation appears as a possible raw material alternative [10]. The straw of wheat (*Triticum spp.*), barley (*Hordeum vulgare L.*), and triticale (*Triticale sp.*) was chosen for obtaining pulp which was mixed with pulp of recycled wood fibres for the purpose of this study to evaluate the quality of printed packaging from alternative raw materials. By soda pulping process cut and purified straw of each cereal was converted into semi-chemical pulp under same process conditions [11], which in a further step was added to the pulp of recycled fibers in a ratio of 3:7. According to the standard EN ISO 5269-2:2004 [12], four different types of laboratory paper substrates were formed by Rapid-Kothen sheet former (FRANK-PTI) in a grammage of 42.5 g/m^2. Laboratory paper made only from the pulp of recycled fibers, marked with N, was used as a reference sample to evaluate the possibility of using straw pulp in the production of packaging intended for printing. Laboratory paper made by mixing 70% of recycled wood pulp with 30% wheat was marked as 30NW, with 30% barley was marked as 30NB and with 30% triticale pulp was marked as 30NTR.

1.2. Printing of paper substrates with with straw pulp

The gravure printing process can reproduce high quality images, excellent color density and strong solid areas. It is mainly used as a long-term process for wet gluing of labels, paper, cardboard and flexible packaging. The Asia-Pacific region, dominated by gravure printing, is expected to witness significant market growth by 2025, owning to the growing lamination and food packaging industries. The demand for processed and preserved food is expected to increase in developing countries such as China and India, which will have a positive impact on the market in this region [13]. The basic component of the gravure unit is the image carrier, which consists of a steel cylinder with an outer copper shell on which the image is created from millions of tiny cells of varying depths formed either by chemical etching, laser etching or electromechanical engraving. To prolong its life, the cylinder is also chrome-plated [14].

Printing of the produced laboratory paper substrates was carried out with cyan, magenta, yellow and black Sunprop inks (conventional inks) and Solarflex UV (UV-curing inks) from the company Sun Chemical using the laboratory equipment KPP Gravure System with an impression cylinder of mechanical hardness (HS) 65 Shore and an engraved printing plate at an angle of 37° with a diamond needle at an angle of 130°, with a screen of 40 lines/cm. Prints printed with UV-curing ink were cured with a Technigraf Aktiprint L 10-1 dryer containing a UV-C tube with ultraviolet light from 100 nm to 380 nm with a source power of 120 W/cm and an intensity of 60%.

1.3. Analysis of the dynamic viscosity of gravure printing inks

The measurement of the viscosity of gravure printing inks was performed on a Fungilab - Viscolead One rotational viscometer, which is based on the measurement of the torque of the rotating spindle in the sample at a at a specific speed of 100 rpm. It is used exclusively for indoor measurements. Viscosity is determined by measuring the torque on the vertical axis rotating the spindle (ISO 1652) [15]. Silicone oil RT 50 (ISO 17025) was used to calibrate the instrument [16]. The temperature range of the gravure ink was maintained between 22.2 °C and 23.5 °C using a heat bath and a Kruess pt31 thermostat.

1.4. Qualitative parameter undertone

The qualitative parameter undertone is defined on the basis of the colorimetric difference between the colours of the reverse side of the printed laboratory papers and the colour of the same unprinted laboratory paper. The spectrophotometric values of the reverse side of the prints were determined with an eXact spectrophotometer, X-Rite (under the standard illumination D50, status E and viewing angle of 2°, M1), and the mean values were calculated from 20 measurements per sample.

The colour difference was determined by the ΔE_{00}^* colour difference (calculated by Equasion 4) which takes the CIE $L^*a^*b^*$ spectrophotometric values from two target colours, where L^* represents lightness (from black, $L^* = 0$, to white, $L^* = 100$), while a^* and b^* represent the hues in the CIE $L^*a^*b^*$ colour space (a negative a^* value represents green colour, a positive a^* value represents red colour, a negative b^* value represents blue colour and a positive b^* value represents yellow colour).

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (4)$$

Where $\Delta L'$ represents the difference in lightness between reverse side of the unprinted sample and the reverse side of the printed sample, $\Delta C'$ represents the chroma difference between reverse side of the unprinted sample and the reverse side of the printed sample and $\Delta H'$ represents the hue difference between reverse side of the unprinted sample and the reverse side of the printed sample, R_T represents the rotation function, while k_L, k_C, k_H represent the parametric factors for variation in experimental conditions and S_L, S_C, S_H represent the weighing functions.

1.5. Visual quality control of gravure prints

For any graphic product, in addition to objective quality analysis, a subjective quality analysis is also very important, based on which the final customer decides whether to buy a product or not. Therefore, in this study we included a subjective analysis of the quality of gravure prints, which was conducted with 30 educated observers from a mixed male and female population at standardised illumination D50.

The evaluation criterion was for the respondents to make a subjective decision about the overall quality of conventional and UV-curing gravure prints. The prints were graded on a scale of 1 to 3, and the meaning of the grades is shown in Table 1.

Tab. 1: Description of the meaning of grades in visual quality assessment

Grade	Meaning
3	satisfactory (best) quality
2	medium quality
1	lowest quality

2. RESULTS AND DISCUSSION

Figures 1 and 2 show comparisons of the dynamic viscosity of the ink with the print undertone parameter.

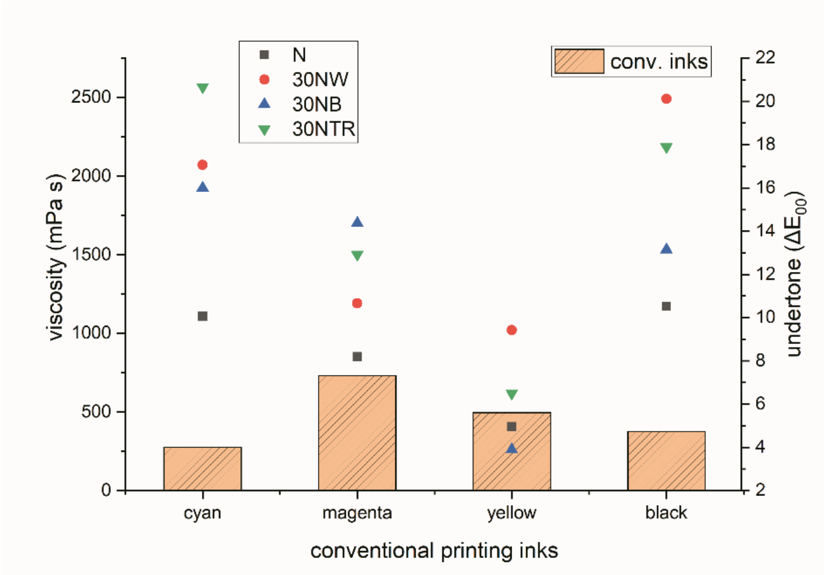

Fig. 1: Comparisons of the dynamic viscosity of conventional gravure inks with the undertone parameter

From Figure 1, it can be seen that conventional gravure inks have a viscosity in the range of 276.05 to 495.06 mPa·s. It is noticeable that the undertone parameter is higher for black prints (ΔE_{00} = 20.67) and for cyan prints (ΔE_{00} = 10.53), indicating greater penetration of inks with lower viscosity in the printing substrates, while inks with higher viscosity, magenta and yellow inks, produce prints with lower undertone values on all produced laboratory paper substrates.

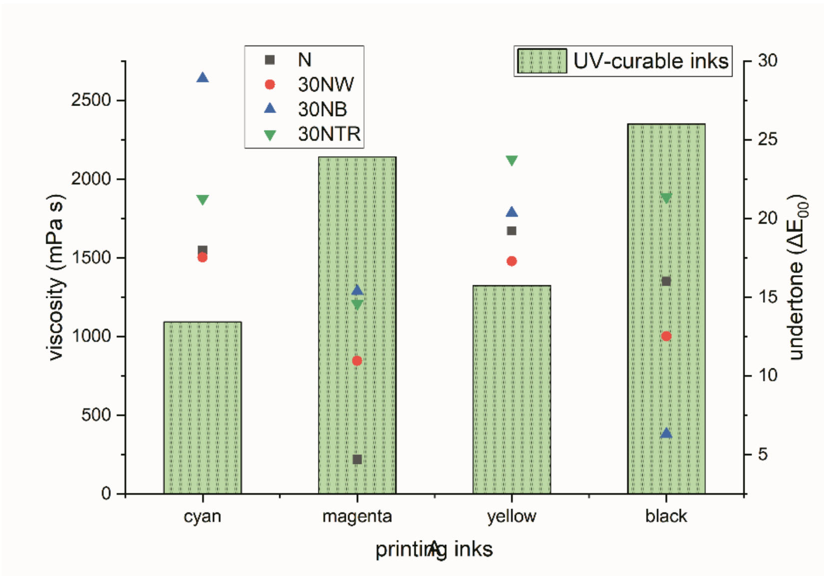

Fig. 2: Comparisons of the dynamic viscosity of UV-curing inks with the undertone parameter

Figure 2 shows much higher dynamic viscosity values for UV-curing inks. The values of ink viscosity range from 1093.33 to 2351.56 mPa·s, i.e. from 1.093 to 2.351 Pa·s. The same behavior is observed as with conventional printing inks. Namely, inks with higher viscosity (in the case of UV-curing gravure inks magenta and black) produce prints with lower values of the undertone parameter, while inks with lower viscosity (cyan and yellow) produce prints with higher values of the undertone parameter (up to a maximum of ΔE_{00} = 28.89).

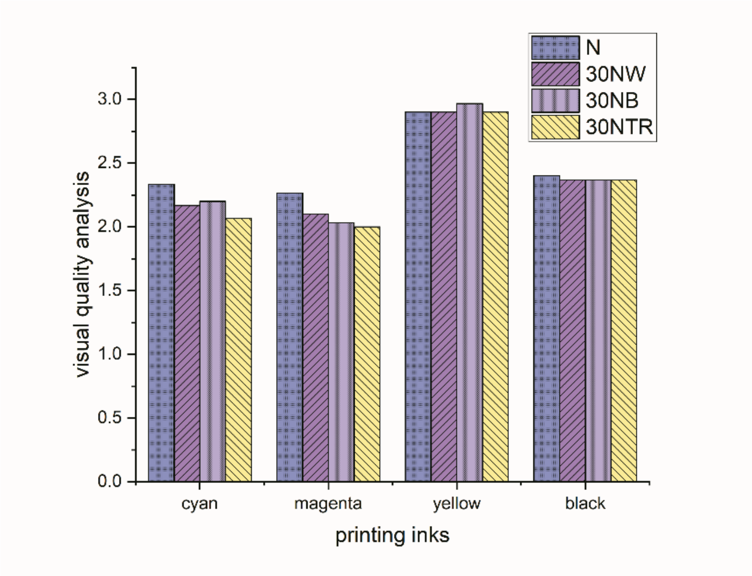

Fig. 3: Visual quality control of gravure prints with conventional inks

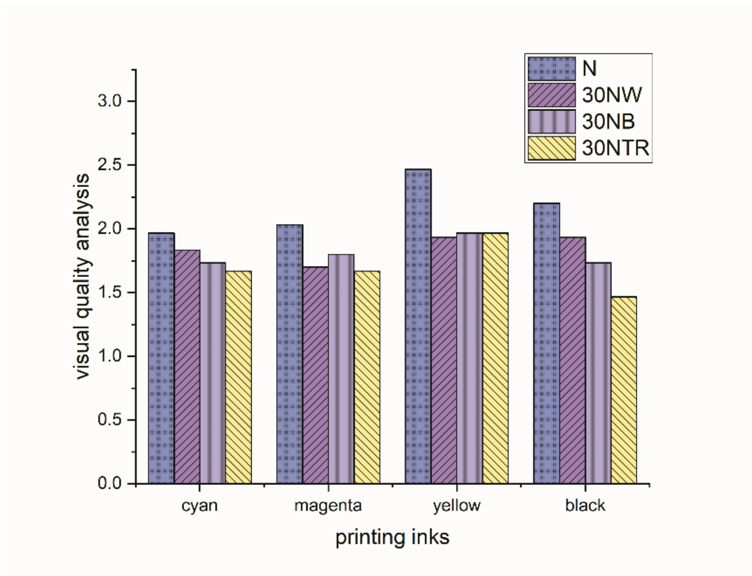

Fig. 4: Visual quality control of gravure prints with UV curable inks

The results of a visual analysis of the quality of prints made on laboratory papers with the addition of straw pulp have showed that the gravure prints obtained with conventional inks (Figures 3) are better compared to prints made with UV curable inks (Figure 4). Printing substrates that were printed with UV-curing ink achieved medium print quality, while prints made with conventional inks were mostly rated with scores describing satisfactory or best quality. With regard to the printing substrates between the analyzed gravure prints, the observers did not notice any major difference, only in the case of the UV-curing prints, where the printing substrates produced only from pulp of recycled fibres (N) were given a slightly higher score.

3. CONCLUSION

Based on the results of the influence of viscosity of gravure printing inks on the quality of printed packaging papers with 30% wheat pulp (30NW) or 30% barley pulp (30NB)or 30% triticale pulp (30NTR) and without non-wood straw pulp (N), the following conclusions can be made:

◦ The dynamic viscosity of gravure printing inks directly affects the qualitative parameter of undertone. It can be assumed that the printing ink penetrates deeper into the printing substrate, the lower its viscosity.

◦ UV-curing inks show higher values of dynamic viscosity compared to conventional gravure inks.

◦ During the visual quality analysis, it was observed that higher quality of the prints was achieved with conventional inks.

◦ No significant differences were found between the analyzed laboratory produced printing substrates. Therefore it can be concluded that the use of wheat, barley and triticale straw pulp for the production of printing substrates for packaging printing with the gravure process is possible.

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