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Study of quality indicators of gravure imprints obtained with fluorescent ink

ABSTRACT

The peculiarities of the decoration of gravure imprints on cardboard using fluorescent inks are considered. The influence of the number of fluorescent impurities added to gravure printing ink on the optical indicators of printed image quality, particularly optical density, and gloss, is investigated. Increasing the number of fluorescent impurities added to the ink from 10 to 30% helps to increase the gloss on imprints from 2 to 15 units. Conducted thermogravimetric studies show the resistance of fluorescent imprints to the influence of temperatures during drying in the printing process. The topography of the surface of the substrates and its influence on the quality of imprints is studied. Conducted electron microscopic studies of imprints obtained with inks with different amounts of fluorescent impurities show their uniform distribution on the surface of the substrate. Studies of the fluorescence spectra of the ink and the imprints formed by it confirm the phenomenon of an increase in the intensity of the glow of printed images. The studies confirm the well-known influence of substrate roughness on the smoothness of gravure imprints. It is established that the absence of significant macro irregularities on the surface of Koppargloss FBB cardboard is due to the presence of two coating layers. Analysis of the surface profiles of FBB cardboard shows that its roughness parameter (R_a = 0.424 µm) is three times smaller compared to Incada Silk C GC1 cardboard (the roughness parameter R_a = 1.28 µm), with a single-layer coating. Such a pattern is also preserved on the imprints, which is reflected in their quality accordingly. Studies show that for imprints on GC1 cardboard, the average ΔE value is 2.23, for imprints on FBB cardboard, the average ΔE value is 3.71, which is due to the presence of double coating. The factors that can influence the process of fluorescence of printed images are outlined. The technological characteristics of inks for gravure printing on packaging are described.

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Introduction

Analysis of marketing research shows increased consumer attention to packaging decoration. Therefore, the choice of the technological process of finishing packaging products is a responsible stage of production, which is influenced by several factors, in particular, the purpose of the packaging, the type of its design, the physical and mechanical characteristics of the materials, and their barrier properties. Gravure printing is widely used for packaging printing, which is in continuous development and provides high-quality imprints of various formats.

Gravure printing stands out from all the classic printing techniques primarily by the quality of the final product, excellent visual effect, high contrast, and the most accurate reproduction of single-colour and multi-colour originals in terms of the range and number of tones that can be reproduced. Particularly popular in gravure printing is the use of sheet-fed machines, which provide:

- Better surface quality of imprints;
- Lack of duplication when printing;
- Good ink coverage of the printed base;
- Easy printing with special inks, for example, gold, silver, metallic and glossy, flavoured, fluorescent, etc.;
- The possibility of covering with a thick layer of varnish;
- The possibility of printing on various surfaces: plastic, foil, paper, and cardboard with a grammage of 50 - 500 g/m^2.

The greatest attention in printing technologies of product protection is paid to the use of materials with special properties. This is, in particular, the use of inks visible or invisible in daylight, with fluorescent impurities, inks that manifest themselves under the influence of heat, cold, etc. Inks with fluorescent impurities are popular. The image printed with such ink begins to give off the energy accumulated during daylight (or artificial lighting). As is known, for the occurrence of fluorescence, it is necessary to transfer the particles of the investigated substance from the normal to the excited state and ensure its preservation during the time required for the electronic transition when the luminescence centres return to the excited state. The brightness and duration of the glow are subjective and depend on the properties of the human eye. Researchers identify several factors that can influence this process:

- Type of fluorescent impurities;
- Environmental temperature;
- The presence of impurities in the composition;
- Individual vision capabilities;
- The degree of darkness and the presence of "distracting" light sources;
- Brightness and duration of previous "charging" with light.

The ideal conditions for fluorescence are charging with bright light for 1-2 hours, immediately after that – additional afterglow without additional light sources. The afterglow is uneven: the first 15-20 minutes are the brightest, then within 40-60 minutes there is a gradual fading (60-70% of the initial, after 40-60 minutes – 30-40% of the initial), and after an hour-and-a-half – 20-25% The duration of the glow visible to the human eye can reach 12 hours (Elastoform, 2023).

The mechanism of ink transfer, the method of its drying or fixation on the printed material is determined by the structure of the substrate and the constituent components of the ink for gravure printing. As is known, liquid ink is used in gravure printing, which can fill the cells of forms well at high printing speed. The range of inks for gravure printing is very large: for example, there are inks with the help of which a layer of more than 2 µm is applied, as well as inks with special metallic pigments, etc. The chemical formulation of inks in connection with the direct transfer to the printed surface allows fundamentally great possibilities for composition variation. Toluene inks for gravure printing (with solvent regeneration) will have a limited release in the future due to the impact on the environment, in particular the possibility of its contamination with an excess of toluene. They can be replaced by water-based inks, they dry more slowly, but interact well with the paper base, but are more expensive.

The pigment content of gravure printing inks is lower than that of letterpress, offset, or flexographic printing inks because the thickness of the ink layer in gravure printing is greater. This thick layer of ink in the shadows of the image helps to provide that special gloss that characterizes "gravure printing quality".

Water-based gravure inks are widely used in packaging production, almost all gift packages are printed with these inks. Water does not require investments and does not create problems for the environment. Inks for gravure printing contain volatile (low-boiling) solvents, which easily evaporate when imprints are dried. They should not contain coarse particles that have an abrasive effect. Ink solvents are especially important in gravure printing. They provide low viscosity, and with their help, it is possible to change the concentration of pigments or the optical density of ink.

The most important solvents for gravure printing on packaging: are ethyl alcohol, ethyl acetate (acetic ether), and water (also together with organic solvents such as alcohols). To fulfil special, and differentiated requirements for packaging (for example, unacceptable reactions with the packaged product or absorption of smell), printing inks containing various organic solvents are used. However, their use is much less than that of inorganic solvents.

As is known, the ink system of the gravure printing machine consists of a thermostatic container with ink, an ink pan, an ink roller, and a scraper knife system - a doctor's blade. The ink roller is made of steel with a stretched coating of material, the lower part of which rotates in the ink pan, and the upper part of which is in contact with the printing form. The amount of pressure in the printing area (up to ~ 500 N/m^2) depends on:

- The type of used coating of the impression roller;
- Properties of the substrate for printing;
- The type of image being printed.

The thicker and more flexible the impression roller liner, the lower the pressure required. As the thickness of the substrate decreases, the required printing pressure increases. After each printing section, drying devices are installed, which cause consolidation of the printing ink with the substrate. The power and length of the installed drying chamber are determined by the required printing speed and the type of used inks. The type and parameters of the installed drying devices affect the possible printing speed and the quality of imprints. The next stage of the technological process is the final drying of the imprint in the final drying tunnel, which is equipped with a system of compressed air nozzles. Heated air (gas/electric) is supplied to the nozzles and blown onto the printed surface from one or both sides to evaporate the solvent. Very strong turbulence is created between the rows of nozzles, which significantly speeds up the entire process of ink fixing on the substrate. It also allows the use of a lower drying temperature, which has a positive effect on the stability of the paper dimensions. Effective dryers allow to reduce the time of fixing the ink on the substrate. Temperature distribution during the drying of imprints is very important. The high temperature of the drying chamber also accelerates the drying process itself, but there is a limit beyond which the substrate curls, causing problems with printability and the printing process (Bohan, Claypole & Gethin, 2000). That is why thermogravimetric studies of gravure imprints were conducted.

The process of ink transfer to a gravure imprint depends on the viscosity of the ink, which varies between 50- 250 mPa•s (Pilc, 2007).

A special device is installed on some machines after the first air drying device, where the surface of the imprint is exposed to microwave radiation. Such microwave pre-drying makes it possible to generate thermal energy directly in the printing section, thanks to which the temperature rises in it and thus the solvent and water evaporate.

During the drying of water-based gravure printing inks with an admixture of solvent, in addition to the solvent, water also evaporates, which creates additional problems with the combination (matching) of the colors of the imprint on the paper base. As the water content decreases, the width of the paper sheet may also change, that is, it may shrink after successive passage through the printing sections. To prevent paper shrinkage, additional devices are used in the machine to moisten the sheet with dry steam, or the technological parameters of printing are changed.

Analysis of literature and problem statement

There are well-known works (Gravure Association of America & Gravire Education Foundation, 1991; Wessendorf, 2012; Szentgyörgyvölgyi, 2016), in which authors investigate the technological features of gravure printing, the influence of electrochemical and laser technology for the production of form cylinders on the quality of imprints, the choice of inks depending on the structure of the form surface and its engraved elements.

In the dissertation work (Wu, 2008) studies of the influence of the surface structure of substrates on the quality of gravure imprints are given, the influence of the chemical composition of the coating on the optical, physical, and mechanical properties of papers is analysed and experimentally determined, models of the interaction of ink with substrates are developed. Based on studies of densitometric indicators of optical density, color reproduction, and mottling, the author offers solutions to problems that may arise during printing and deteriorate the quality of imprints, and which are associated with different compositions of latex paper coatings.

The work (Goyat, Singh & Sharma, 2018) describes the features of the gravure printing technique, focuses attention on the technology of manufacturing gravure printing forms, the process of filling the printing elements on the form with ink, and the role of the blade in removing excess ink. The authors emphasize the process of direct transfer of ink to the substrate during its passage between the form and the printing cylinder.

The work (Ceyhan, 2016) describes research on the features of gravure printing on flexible electronics. The problem of obtaining a high-quality imprint when reproducing images smaller than 50 µm, which cannot be recognized by the human eye, is indicated. In printed electronics, micron-sized defects degrade the printed characteristics, i.e., the reproduction accuracy deteriorates. The influence of surface energy and the chemical composition of the surface of the substrate on the mechanism of imprint formation is investigated, and the role of the contact of the blade with the form in ensuring the quality of the imprint is emphasized. The work carried out by several researchers focuses on the multifaceted problems of ensuring the quality of gravure imprints. However, taking into account the intensive use of gravure printing for packaging decoration, research aimed at an in-depth study of the influence of the surface topography of substrates on the quality of printed images, the possibility of using fluorescent inks to protect products from counterfeiting to meet the requirements of manufacturers and consumers of packaging are relevant.

The purpose and objects of the research

The object of the study was gravure imprints, images fragments of which were printed with ink with fluorescent impurities. A red fluorescent pigment with a particle size of 0.1- 0.5 microns of the Flamingo IX-ASJ type was used, which was added to the gravure ink in an amount from 10 to 30%. Inks with a solvent based on ethyl methyl ketone were used. The brightness of the fluorescent pigment is manifested due to the absorption and reflection of ultraviolet light with an imitation of pink colour. According to the manufacturer's recommendation, the fluorescent pigment must be stored away from light, as the colour saturation may weaken with constant exposure to direct sunlight. Therefore, the task of the study was to determine its effect on the optical and colorimetric indicators of imprints on cardboard. According to its technical characteristics, the pigment is stable in a wide pH range, withstands temperature changes, and is stable in various environments. The purpose of the research was also to check the heat resistance of imprints obtained with fluorescent ink since in gravure printing imprints are subjected to drying after each printing section and at the end of printing pass through a tunnel dryer.

As a substrate, FBB coated cardboard, Koppargloss brand with a weight of 200 g/m^2, was used (which consists of two layers of bleached cellulose and an intermediate layer of mechanical pulp. The double coating provides high levels of whiteness and gloss. The reverse side is uncoated. And also, GC1 cardboard of the Incada Silk brand with a weight of 220 g/m^2 (Holmen, 2023) was used, which is made of 100% primary fibres, the outer upper matte layer of bleached cellulose, and the lower one of chemical cellulose and the inner layer of mechanical cellulose, without wood mass, with high smoothness. Technical characteristics of these cardboard brands are presented in Table 1.

Materials and methods

Imprints obtained in laboratory conditions on the IGT F1 proof printing machine and dried in a thermal unit after successive application of CMYK colours and in a developed microwave dryer at the final stage were used for research (Figure 1). This made it possible to reproduce the real process of creating an imprint in a printing press with the help of simulation modeling.

The printing process on the proof printing machine was ensured by the following parameters: linear printing speed: 0.2÷1.5 m/s (12÷90 m/min); clamping force: 10÷500 N (0.25÷12.5 kN/m); printing width: 40 mm; printing length: 200 mm; diameter of the form cylinder: 167 mm; diameter of raster cylinder: 66-67 mm; mounting tape with a thickness of 5.2 mm; raster ruler of raster cylinder – 90 lines/cm and ink transfer – 18 ml/m^2; blade characteristics – blade width: 52 mm, blade angle: 60°, blade pressure: 67 N, blade type: MDC60.

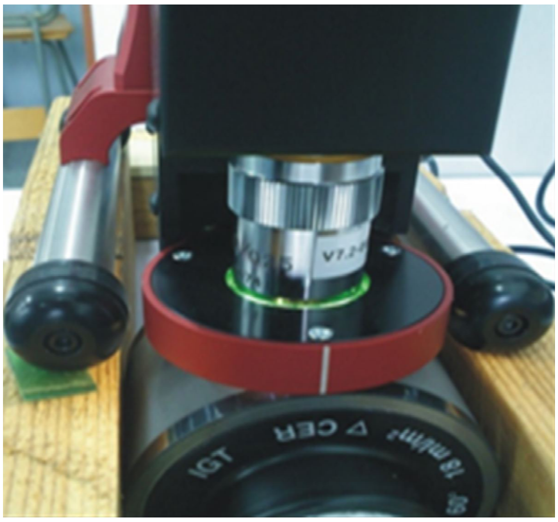
» **Figure 1:** *The proof printing machine of the IGT F1 model*

The topography of the surface of the cardboards and imprints was studied on the AniCam device of the company TROIKA Systems Limited (Figure 2), equipped with a 24-bit colour camera with a resolution of 640×480 pixels and a field of view from 1.25×0.92 mm. A three-dimensional image of the surface structure was obtained from the analysis of digital photographs of the surface of the substrate and imprint (measurement accuracy is ±1%).

Table 1

Technical characteristics of cardboard

Parameters	Units of measurement	Standard	Indicator	
			Cardboard FBB Koppargloss	Cardboard GC1 Incada Silk
Optical brightness	%	ISO 2470	82	91,5
Glossiness, 75˚	%	TAPPI 480 ISO 8254-1	> 40	50 ± 1
Roughness	µm	ISO 8791-4	< 1,3	0,9 1.2
Moisture absorption Cobb 60	g/m^2	ISO 535	55	30
Density	g/m^2	ISO 536:1996	200 ± 2,5%	220 ± 2,5%
Thickness	µm	ISO 534	340 ± 4%	325
Rigidity	mN/m	ISO 2493 TABER(15˚)	MD-8,2; CD-4,1	MD-18,5; CD-7,7



» **Figure 2:** *General view of the AniCam device for measuring the structure and profile of the surface of cardboard and imprints*

The densitometric indicators of imprints were studied on the GRETAG SPM 50 spectrodensitometer, which works in reflected light, determines the optical density of the background and printed areas, the squeezing (relative area) of the raster elements, trapping, grey balance, uniformity and contrast of printing. Standardized viewing angles of 20 and 100 are used for colorimetric measurements of images observed from different distances. To determine the value of colour distinguishing (ΔE), the colour coordinates in the CIE L*a*b system were measured. The gloss of the imprint was determined as a surface property expressed by the coefficient of direct light reflection measured on the print plane using a Zehntner ZGM 1020 gloss meter. Gloss measurements were performed at the same angle of 75° to avoid differences in reflectance from different measurement angles. Roughness was determined by the Bensen method.

The spectra of the fluorescent ink were measured on the FS5 spectrofluorometer (Edinburgh Instruments, 2023). All spectra were measured with the same slit configuration:

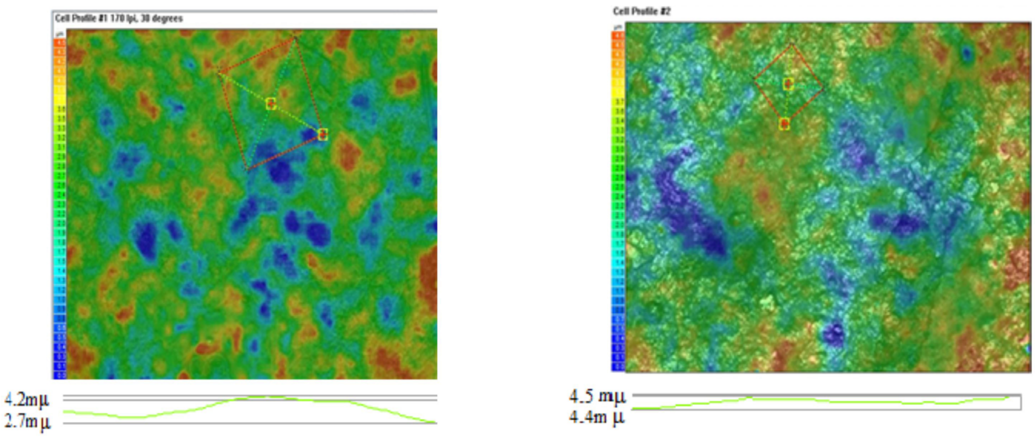
- For fluorescence excitation spectra – ExBW = 1 nm and EmBW = 3 nm
- For fluorescence spectra – ExBW = 3 nm and EmBW = 1 nm.

Using a Delta Optical Smart 2 MPix digital microscope, fluorescent images on imprints were recorded. This microscope provides a clear and richly coloured image. Magnification adjustment range from 10× to 250×. The maximum resolution is 2 MP (1600x1200).

To identify the effect of drying temperature on the quality of imprints, thermogravimetric studies were carried out on a Q-1500D derivatograph of the "Paulik-Paulik-Erdey" system, with computer registration of the analytical signal of mass loss and thermal effects. The samples were analysed in dynamic mode with a heating rate of 5˚/min in air. The weight of the samples was 200 mg, and the reference substance was aluminium oxide Al_2O_3 (Menczel & Prime, 2008).

Results

It is known that smoothness (roughness) characterizes the microstructure of the substrate surface and uniformity, which determines their secondary structure, that is, volumetric macro homogeneity, and affects the efficiency of interaction with ink (El-Sherbiny, 2003). The limits of the values of micro-uniformities for different types of cardboard are determined by the numerical values of the irregularities Ra, Rz, the area of micro peaks, and micro valleys. The morphology of the surface of the investigated cardboard is presented in Figure 3.



a *b*

» **Figure 3:** *Topography of the cardboard surface: a – FBB Koppargloss, b – GC1 Incada Silk C*

A uniform distribution of structure elements is observed in the investigated Koppargloss cardboard. The absence of large macro irregularities is due to the presence of two coating layers on the surface of the cardboard. Analysis of cardboard surface profiles and microphotographs of the structure shows that the presence of double coating reduces the roughness parameter three times. The smooth surface of coated cardboard contributes to the formation of a strong bond between the ink and cellulose fibres, ensuring its uniform distribution on the imprint and the high quality of the printed image. Microphotographs of imprints on Incada Silk C cardboard clearly show indentations, micro valleys that remain unsmoothed even after the ink layer is applied. As a result of studies of the morphology of the surfaces of imprints on two-layer coated cardboard FBB and GC1, the numerical values of the irregularities Ra, Rz were obtained, which are presented in Table 2.

Table 2

Results of studies of the morphology of cardboard surfaces

Cardboard brand	Weight, g/m^2	Coating	R_a, µm	R_z, µm	Peak area, µm^2	Valley's area, µm^2
Koppargloss FBB	200	two-layer	0,424	4,5	854	871
Incada Silk C GC1	220	one-layer	1,28	5,34	1084	1998

When applying an ink layer* on GC1 cardboard, the parameter R_a (arithmetic average deviation of the profile) decreases by 0.08 µm and is 1.2 µm, while the average roughness depth R_z increases from 8.34 to 8.79 µm. The peak area of the surface increases from 1084 to 1410 µm^2, and the valleys area decreases from 1998 to 1685 µm^2. The printed surface has become more uniform (there are no macro irregularities), but at the same time the R_z and peak area parameters have changed, which is explained by the fact that the ink is applied not a completely uneven layer, it has a raster structure, where each raster point has its microrelief, which affects the magnitude of peaks and valleys (Table 3). A similar pattern is observed for cardboard FBB with a two-layer coating: the roughness parameter R_a decreases and amounts to 0.419 µm, while the area of peaks increases to 892 µm^2, and the area of valleys decreases to 802 µm^2. Therefore, the conducted studies confirm that such a parameter as coating has a significant effect on the micro geometry of the surface.

The analysis of tabular data shows that GC1 cardboard is characterized by a large degree of surface irregularities from -4.27 to +4.76 µm, which indicates an uneven distribution of surface structure elements. This is also confirmed by the roughness parameter R_a = 1.28 µm. The studied FBB cardboard has an average degree of surface irregularities from-2.71 to +4.23 microns, which indicates a more uniform distribution of the structure elements of bleached and chemical-thermomechanical cellulose fibres, the absence of large macro-irregularities. However, there are partially thin deep gaps in the surface of the cardboard. Two coating layers are applied to the surface of the cardboard, and the roughness parameter R_a = 0.424 µm, which indicates a highly developed micro- and sub-microstructure of the surface.

The presence of a coating layer changes the roughness parameters and the area of peaks and valleys on the cardboard. It is known from scientific sources that the roughness of the substrate affects the smoothness of imprints of contact printing methods. Our research has confirmed that gravure imprints obtained with ink with introduced fluorescent impurities (30%) are characterized by a similar trend. The mechanism of influence of changing the number of fluorescent impurities in the ink on the smoothness of gravure imprints is insufficiently studied and requires further in-depth research. It was established that fluorescent impurities applied to the printed substrate affect the change in gloss value. Analysis of the diagrams (Figure 4) shows that the gloss of imprints varies depending on the colour of the image.

Table 3

Results of studies of the morphology of printed surfaces

Cardboard brand	Weight, g/m^2	Coating	R_a, µm	R_z, µm	Peak area, µm^2	Valley's area, µm^2
Koppargloss FBB	200	two-layer	0,419	5,72	892	802
Incada Silk C GC1	220	one-layer	1,2	8,79	1410	1685

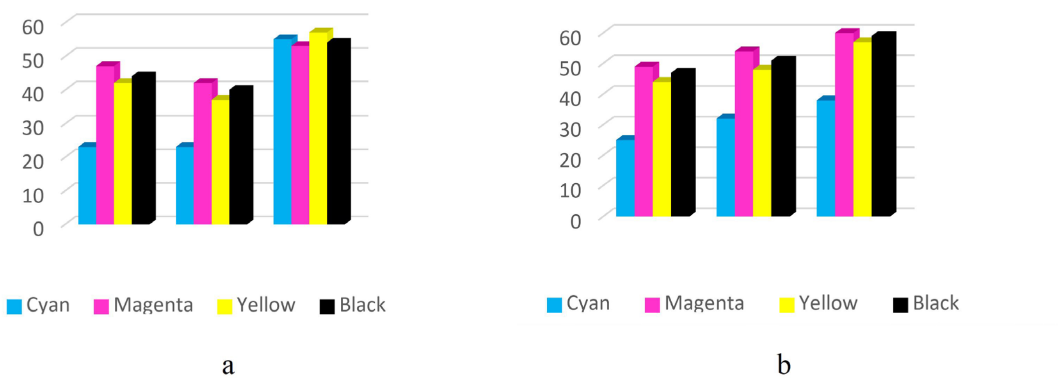
** content of fluorescent impurities 30%*

Thus, the gloss of the imprint of blue ink on GC1 cardboard remains unchanged (23.6 relative units) at 10 and 20% fluorescent impurities and increases more than twice (55.1 relative units) when adding fluorescent impurities to 30%. In the case of the magenta colour, when fluorescent impurities are increased to 20%, the gloss of the imprint decreases slightly (from 47 to 42 relative units) and when fluorescent impurities are 30%, it increases to 53 relative units. The results of studies of the gloss of imprints on FBB cardboard in printed areas with fluorescent impurities (from 10 to 30%) showed that fluorescent ink increases it from 2 to 15 units.

impurities), and Figure 7 shows the spectra of the obtained imprints.

In the course of the research, a CIE chromatic diagram was obtained with the determined emission of fluorescent impurities on the imprint. Under the influence of excitation, the emission of fluorescent impurities was obtained, which caused the material into which it was introduced to glow with color.

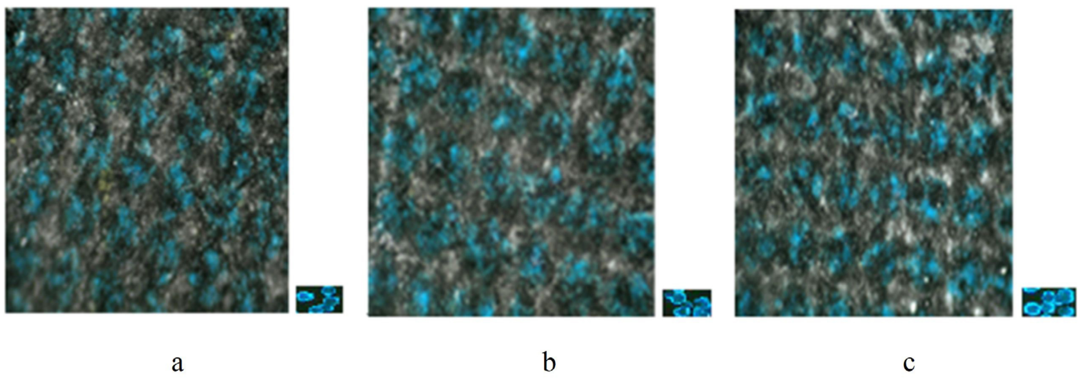
The glow effect was noticeable for CMY colors on imprints (Figure 8.).



» **Figure 4:** *Diagrams of the gloss of imprints formed by fluorescent ink on cardboard: a – GC1 Incada Silk C, b – FBB Koppargloss*

Conducted electron microscopic studies of imprints with different content of pigment (fluorescent impurities) proved that the impurities are evenly distributed on the surface of the image structure (Figure 5), therefore, they do not reduce the quality.

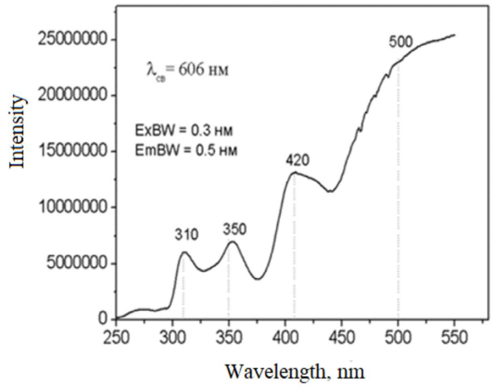
Studies of the optical density of imprints for each CMYK colour showed that yellow is characterized by the lowest values. The black imprint has the highest optical density. Moreover, the value of the optical density increases according to the increase in fluorescent impurities

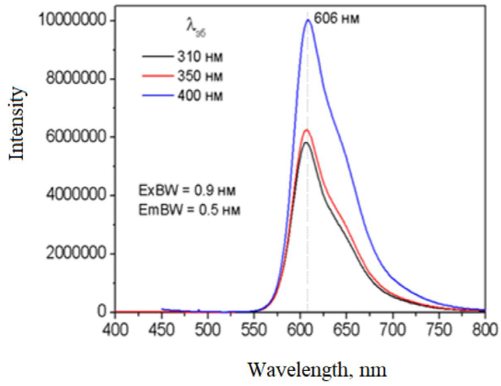


» **Figure 5:** *The surface structure of imprints formed by ink with different percentages of fluorescent impurities (magnification ×150): a – 10 %; b – 20 %; c – 30 %*

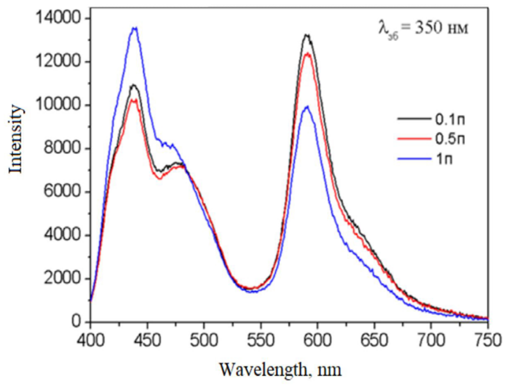
Analysis of the imprints showed that 30% of fluorescent impurities provide the maximum glow. Figure 6 shows the excitation and fluorescence spectra of ink (30%

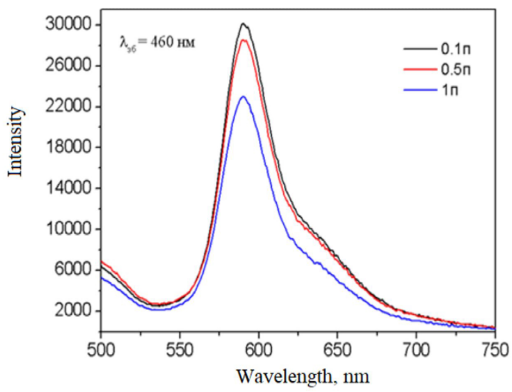
content (Table 4). For each CMYK colour, the optical density values obtained on imprints are different.



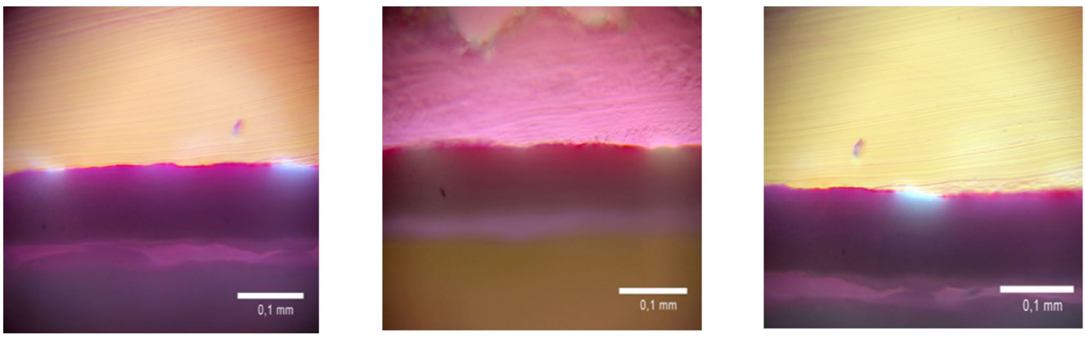


» **Figure 6:** *Excitation and fluorescence spectra of ink*
(where ExBW and EmBW are the sizes of the slits on the lamp and the detector, respectively)





» **Figure 7:** *Glow spectra of imprints formed by fluorescent ink*



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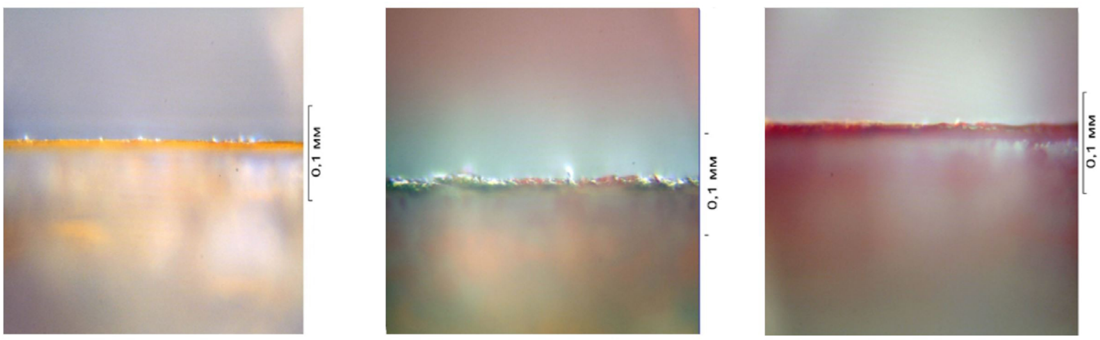


b

» **Figure 8:** *Microphotographs of imprints obtained with fluorescent ink*
(the content of impurities is 30%) on cardboard: a – FBB Koppargloss, b – GC1 Incada Silk C

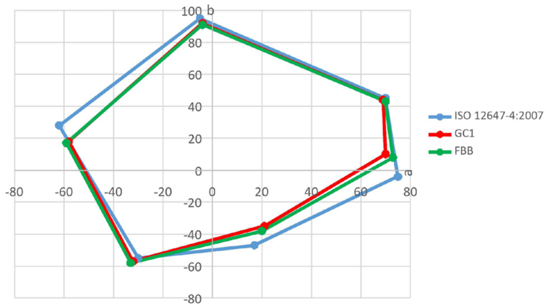
Table 4

The value of the optical density of imprints with different content of fluorescent impurities

Content of fluorescent impurities, %	Imprints on FBB cardboard				Imprints on GC1 cardboard			
	C	M	Y	K	C	M	Y	K
10	1,53	1,51	1,22	1,69	1,76	1,68	1,43	1,81
20	1,64	1,58	1,35	1,77	1,80	1,71	1,56	1,83
30	1,71	1,69	1,43	1,89	1,86	1,78	1,61	1,89

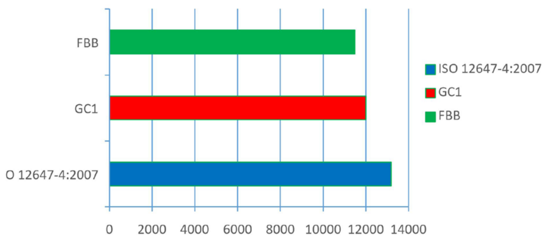
The addition of fluorescent nanoparticles to ink causes visible changes in colour perception. The differences in the colour characteristics of imprints show (Figure 9) that the imprint with 30% of fluorescent impurities has the largest colour coverage and the smallest – with 10% of fluorescent impurities. The constructed diagram shows the deviation from the standard of the determined colour coordinates on the imprint. Statistical processing of research results showed, that the largest measured colour difference was recorded for cyan and magenta ink, which is related to the more intensive interaction of fluorescent nanoparticles with these inks. This effect requires further research. The smallest measured colour difference was observed for black ink. An increase in fluorescent nanoparticles leads to an increase in the area of colour coverage on the imprint (International Organization for Standardization, 2007).

Studies have shown that for imprints on FBB cardboard, the average ΔE values were 3.71 (4.14 for light tones, 3.49 for medium, and 3.27 for dark areas of the image). For the imprint on GC1 cardboard, the highest ΔE value was 2.23 on average (1.41 for light tones, 2.69 for medium, and 2.59 for dark areas of the image), which indicates better printing stability.



» **Figure 9:** *A diagram of the color coverage of imprints*

Figure 10 shows the diagram of the surface area of the circle of color coverage.



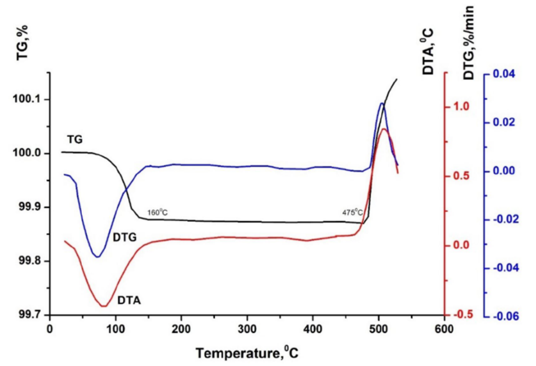
» **Figure 10:** *Area of the surface (hexagon) of the circle of color coverage*

Thus, one of the main reasons for the brightness of fluorescent inks is that these inks return a large percentage of the energy received by them to the surrounding space. The brightness of inks is determined both by the radiation of the absorbed part of the incident light and by the reflection of its unabsorbed part. Therefore, the more complete the reflection by the coating of the unabsorbed part of the incident light and the more complete the radiation of the of its absorbed part, the greater the brightness of the coating. Therefore, fluorescent inks have better reflectivity when applied to a smooth white surface with high reflectivity.

The thermal stability of the fluorescent ink sample was determined based on the data of the complex thermal analysis. The results of the thermal analysis of the ink sample are presented in the form of a thermogram (Figure 11). The thermogravimetric curve (TG) corresponds to the loss of mass of the sample when it is heated, the differential thermogravimetric curve (DTG) shows the rate of mass loss of the sample, the curve of differential thermal analysis (DTA) illustrates the thermal effects of the processes that occur in the sample when it is heated.

According to thermal analysis, a sample of fluorescent ink is thermally stable in the temperature range of 20-475˚C. A slight loss of mass (0.125%) in the temperature range of 20- 160˚C corresponds to the release of volatile impurities present in the sample.

This process is accompanied by a shallow endothermic effect on the DTA curve, with a maximum at a temperature of 70°C. At temperatures higher than 475°C, thermo-oxidative processes begin to occur in the fluorescent ink sample, which is accompanied by a clear exothermic effect on the DTA curve and an increase in the mass of the sample.



» **Figure 11:** *Thermogram of a sample of fluorescent ink*

Conclusions

Based on the conducted theoretical and practical studies, it can be stated that:

The use of fluorescent inks provides the desired decorative glow effect of printed images, which is observed when the light of a certain wavelength hits the imprint;

The amount of fluorescent particles in the ink is important for the fluorescence effect. It is noted that the glow of fluorescent impurities creates a better effect on the light areas of the imprint than on the dark areas of the image, which is apparently due to greater absorption of light in dark areas and less reflection;

Since the formation of imprints in the gravure printing machine occurs when the printed surface passes through the drying sections with high temperatures, a thermogravimetric analysis was conducted, which showed that the high temperatures of the drying devices do not hurt the quality of images formed by fluorescent inks and do not affect the effect of fluorescence;

The addition of fluorescent nanoparticles does not hurt the quality of the imprint by indicators of average values of optical density, ΔE, and color reproduction, and does not create problems in the printing process;

Studies have confirmed the existence of a connection between the parameters of the surface topography of the substrates and gravure imprints formed on them.

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