ANALYSIS OF METHODS OF PRINTING IMAGES ON TEXTILE MATERIALS AND EVALUATION OF THEIR QUALITY

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Abstract: *The peculiarities of the methods of printing images on textile materials are analyzed; the research of the criteria for choosing the method of printing is performed. The list of criteria is supplemented and presented in a form convenient for use in the analysis and selection of the method of printing images on textile materials in each case. The method of calculating the cost of a batch of products for each of the methods of printing the image is given. The results obtained, according to this method, make it possible to make an economic assessment of each of the printing methods and decide on the appropriateness of their use. In the course of experimental research the degrees of resistance of the images put by various methods of printing to friction and in the process of washing were established. The application of the results of this study will allow a qualitative and effective assessment of methods of printing images on textile materials depending on the production conditions for each type of product.*

Keywords: *images, textile materials, printing methods, screen printing, digital printing, sublimation printing, thermal transfer printing, printing cost, performance.*

1 INTRODUCTION

Art decoration of clothes, as an element of aesthetics of everyday life, is of great importance for many categories of the population in the modern world. Nowadays, there are many of ways to decorate clothes, which differ in the use of various technologies and materials. One of the ways to decorate light industry products is to print on textile materials.

Today, the print on clothes is popular both among people who want to stand out from the crowd, and among business owners who want to draw attention to their brand. Fabric printing first appeared in the 1950s in Florida, USA, thanks to Tropix Togs [1-2]. The method was used for inscriptions on T-shirts: mostly the names of popular resorts were printed. A little later, the organization received the right to apply images of Disney characters to clothing. After that, the method rapidly began to gain popularity among other companies; there were factories for printing on fabric, the largest of which was Sherry Manufacturing Company [3-4].

In 1959, a new stage in the history of printing on clothing began - durable inks were invented for printing on sweatshirts, T-shirts and other textiles, thanks to which it was possible to significantly diversify the possibilities of the method and significantly improve product quality. Only in the 80s of the twentieth century, the print on the fabric began to acquire a new meaning - it became a kind of way to tell the world about one`s views and hobbies [2].

In addition to clothing decoration, printing on textile materials is used to create souvenirs, and advertising on textiles has become the most popular area of business for printing. Stylish baseball cap or T-shirt with a logo can quickly increase the popularity of the brand, compared to expensive advertising on TV or radio. The main thing is to choose the right method of application and model of the product, which is suitable in accordance with this method of decoration. Types of printing on fabric allow you to get an inexpensive, but at the same time highly effective advertising tool that can be implemented on any textile: from caps and T-shirts to blankets, pillows and umbrellas. Creating a corporate style of the company, family look, promotional forms, interior design, all these areas require such a service as printing on textiles [5-10].

Despite the long history of the development of printing on fabric, there are still some problems that manufacturers face when organizing the application of high-quality images to textiles. Namely: there are no recommendations on the choice of the method of applying the image, the parameters of the selected technological process (temperature, time and pressure of processing), depending on the chemical composition of the material [2, 11-12].

2 DISCUSSION IDEAS

To date, there are several ways to print images on textiles used by modern manufacturers. The choice of imaging technology depends on several factors: the number of products; image areas; the number of image colors; raw material composition of the fabric; fabric color. Each method has its advantages and disadvantages that must be considered before applying the image. You need to understand that there is no better technology, because each type of product requires its own method. For printing on flat surfaces (flags, banner ads, scarves, tablecloths, etc.), one method can be used, and for products of complex shapes, such as baseball caps, other methods will be preferred. And not every one of them is suitable for certain types of textiles [11-17].

The available information on the criteria for selecting methods of printing images on textile materials is quite diverse, so it is necessary to systematize and present it in a form convenient for use in the analysis and selection of printing methods in each case.

The end user of the products with the applied image is interested in their operational characteristics. Therefore, for the manufacturer to increase the competitiveness of their products through the production of quality goods, it is important to have information about the stability during their operation of the images applied to textiles by different methods. A review of information sources did not reveal relevant information on this issue, so the authors of this study are tasked with investigating the preservation of the quality of images during their operation printed by different printing methods.

In addition, when choosing a method of printing images on textiles, manufacturers are interested in the financial aspect, so the task is to estimate the cost of applying the image per unit of product depending on the method of printing.

3 METHODS

To choose the method of printing on textile materials, it is necessary to take into account all the factors that will affect the quality and performance of the product. Consider in more detail each of the ways to apply the image on textiles. Including:

- screen printing, which is also called silk screen printing;
- direct printing on fabric by DTG (Direct to Garment) technology, which is also called digital;
- sublimation printing;
- thermal transfer printing or flex printing;
- thermal transfer made by screen printing.

Screen printing (silkscreen printing): The essence of this method of printing is to push by a special tool (squeegee) ink through the open holes of the flexible mesh stencil on the printing surface. Printing can be done on paper, tin, glass, fabric, polyethylene, plastic, leather and other sheet or roll materials and products from them.

The main differences between the process of screen printing on textiles, natural and artificial leather from printing on paper and other dense materials are the features of light industry materials, namely, their resistance to high temperatures, hygroscopicity, adhesive properties of paint and surface material, significant linear deformation, temperature shrinkage, operational features of clothing and footwear. For screen printing on textiles, artificial and natural leathers use inks that differ in their chemical composition, adhesive properties and temperature regimes. The most commonly used paints include plastisol, aqueous, solvent and etching ones [18-19].

This printing technique allows you to get any detailed image, but each color requires the manufacture of a separate stencil on the frame. Screen printing is advantageous to use in circulations of more than 100 copies. This method allows you to get a rich image with special effects through the use of metallized, reflective and fluorescent paints, foil and more.

Direct printing on fabric by DTG technology (digital): Digital printing is simple and one of the most competitive technologies. It is suitable for printing on both synthetic and cotton fabrics. The CMYK digital model is used for printing (the image is reproduced from an electronic file), thanks to which the photos are bright and saturated. The biggest problem with digital printing on fabrics is the reproduction of rich blue tones. They turn out either blue or dark purple, but not blue. The product after digital printing can withstand many washing cycles without losing brightness and the image is not erased from the surface of the material. This method of printing is quite expensive due to the peculiarities of the ink used, and therefore suitable only for small runs and branded products [3, 6].

Sublimation printing: This method allows you to transfer the image with a special paper on the fabric under the influence of high temperature, so it requires the use of equipment for heat treatment. It should be noted that this method of printing is suitable only for light fabrics with a high content of synthetic fibers. During printing, special inks are used, which under the action of high temperature turn into a gaseous state, fill the fibers of the fabric and are evenly distributed on the surface. The quality of images and colors in this type of printing is high.

The manufacturers declare that the main feature of the method is that the images are resistant to fading and are not destroyed during washing and operation. However, this information has not been

confirmed by any experimental studies, or not covered in scientific journals. The method of sublimation printing is usually used to print small runs of T-shirts, caps and sportswear [6].

Thermal transfer printing (flex printing): This method is based on the transfer of the image from a special film to the fabric under the action of pressure and high temperature. The image is printed on a printer and cut out on a cutting plotter, excess film elements are removed, and then image is applied to the fabric and, by means of high temperature, transferred to it. The film consists of two layers: the first is a film that reacts to changes in temperature, and the second is a heat-resistant substrate that holds the film until it is transferred to the fabric. This method is considered to be one of the convenient options for applying images and has many advantages: applying both single and large batches of images; high resistance to washing, small amount time spent on preparation and application of the image. The main disadvantage is the inability to obtain small details of the image. In addition, this method of printing requires the use of additional equipment - a cutting plotter, which cuts only the heat-sensitive layer, and leaves the substrate uncut, which also requires additional removal of unnecessary elements of the print. If you use a printing plotter that runs on eco-solvent inks and has the function of a cutting plotter, you can get multi-color images. This method of application is often used for printing logos, quotes, souvenirs, gifts, etc. [4].

Thermal transfer made by screen printing: This method of applying images to textiles is similar to screen printing. The difference is that in direct screen printing the image is applied directly on the details of the cut or product, while in the transfer printing it is applied to the intermediate carrier - transfer. The image requires additional processing, namely mirror imaging. Accordingly, the printing plates for each color are prepared in a mirror image, and the application of colors is in reverse order. Similarly to direct screen printing, each color is dried, and after applying the last color, which acts as a base, special glue is applied. As a rule, the following glues are used: on a transparent plastisol base - for light types of fabrics; on a white plastisol base - for dark fabrics; or powder adhesives. Powder adhesives can be of different fractions: <70 μm, from 70 to 180 μm, from 180 to 300 μm and >300 μm. The desired fraction is obtained by grinding the granular material [19]. In terms of chemical composition, it can be polyurethane, co-polyester, etc. After applying the adhesive base it is dried in the temperature range from 105 to 120°C (depending on the manufacturer's recommendations). The transfer or intermediate carrier contains a special antistatic coating on the printing surface, which is used to eliminate the sticking of the powder in places where no image is provided, as well as a coating that allows you to easily remove the carrier after applying the image to the product without damaging the image. Transfer is carried out using a thermo-press or iron. Exposure time ranges from 10 to 20 seconds, and the temperature range from 145 to 170°C, depending on the type of carrier, type of paint and manufacturer's recommendations.

The first three methods are the application of paint (direct method, or sublimation), which penetrates directly between the weaves or into the fibers of the fabric. We refer them to the first conditional group. The second conditional group includes thermal transfer printing methods, the feature of which is that during heating the polymer adhesive or film melts and is fixed on the surface of the fabric under the action of pressure. Accordingly, these two conditional groups will have different adhesion between the fibers of the fabric and the image material.

Therefore, in our opinion, it is not correct to evaluate the above methods of printing images on textile materials by the same criteria. For these reasons, in this article the authors consider only the application of the image in the first three ways: direct digital printing, direct screen printing and sublimation.

Based on the information available in open sources and the empirical experience of the authors of the article, a systematization of the criteria for evaluating the methods of printing images on textiles is made [2-4, 11]. As a result of the analysis of information sources it is established that, first of all, the choice of the way of printing on textile materials depends on raw material structure and color of fabric.

For example, sublimation is possible only to light-colored synthetic fabrics, ideally white. While, direct printing on fabric by DTG technology is possible on both light and dark fabrics with a high content of natural fibers - cotton. Screen printing is possible on all types of fabric, regardless of chemical composition and color.

The solution of the problems of this research was performed on the example of applying to textile materials a drawing by the artist Patrice Murciano [7], which is executed in watercolor style. The dimensions of the image are 170x190 mm (Figure 1). In order to further divide it into colors and prepare individual printing plates for screen printing, the authors of the article translated the image into a color scheme CMYK.

Figure 1 shows markers for combining printing forms when applying an image to textiles by screen printing.

As a result of the analysis of the methods of printing images on textile materials, the criteria that are recommended to be used when choosing the method of printing in each case are highlighted.

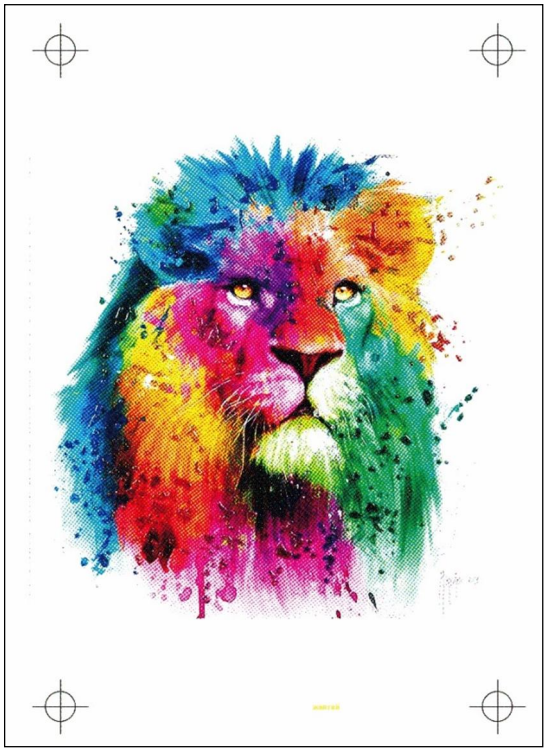


Figure 1 Pattern for application to textiles

Criteria for evaluating the methods of printing images on textiles are given in Table 1.

One of the factors influencing the choice of imaging technology is the color of the fabric. Applying images directly by direct digital printing on colored fabrics requires additional surface preparation. The print surface is first coated with a special base, called a primer, which acts as a barrier between the fabric and subsequent layers of ink. As a rule, the primer is fixed on a thermo-press. The barrier is applied to prevent the fabric dye from interacting with the white base of the print. After that, the image is applied to the surface, the first layer of which is a white base over the entire area of the print, and the next - a color image. Thus, a saturated image resistant to interaction with the fabric dye is obtained. Because for dark fabrics, the ink does not penetrate directly into the structure of the fibers and between them, the stability of the print depends on the adhesion between the primer and the fabric, as well as between the primer and the ink. Therefore, there is a need for additional research on the resistance to washing images applied to dark fabrics by direct digital printing.

Table 1 Types of printing on textile materials and their technological parameters

Evaluation criteria	Printing method		
	Direct printing on DTG technology (digital)	***Sublimation printing***	***Direct screen printing***
Fabric with a high content of synthetic fibers	-	+ (>70%) polyester	+
Fabric with a high content of cotton (> 60%)	+	-	+
Print on white fabric	+	+	+
Printing on colored fabrics with an additional substrate	+	-	+
Processing pressure [N/mm^2]	From 0.02 to 0.05	From 0.05 to 0.08	From 0.02 to 0.05
Processing temperature [°C]	170±5	195	From 40 to 180 depending on the type of paint
Print elasticity	+	+	+
Obtaining relief images or 3D prints	-	-	With the use of special additives
Ability to create additional effects (fluorescent, phosphor, reflector)	-	-	+
Basic equipment	Inkjet printer for printing on fabric	Inkjet printer, thermo-press	Workbench for screen printing
Additional equipment	The chamber for applying a primer, convection or tunnel dryer, thermo-press	-	Intermediate dryer, tunnel dryer, thermo-press
Additional tools	-	-	Printing forms, squeegee, cuvette
Materials used	Textile ink, primer	Sublimation paper - transfer, sublimation ink	Inks for screen printing, special additives for additional effects, means for the manufacture and preparation of printing plates
Loss of color on contact with the hotplate	+	-	-
Productivity at the printing on color / white fabrics, piece /hour	20/30	12	60/90 for manual printing device 360/500 for automated printing device

In direct screen printing, when applying the image to dark fabrics, a special barrier is also used as a base for the print, followed by the application of one or more layers of white ink. The base of the anti-migration primer - barrier and white paint, as a rule, has the same composition as the main paint, so it is not necessary to examine additional samples of images on dark fabrics for resistance to washing and abrasion.

One of the important factors influencing the choice of the method of applying the image to textile materials is the cost of making the print. To determine the total cost, it is necessary to take into account the cost of each stage of the technological sequence, as well as the cost of electricity and the cost of preparing the print. In order to determine the cost of one print (Figure 1) calculation was made for a batch of 100 units. Execution of a batch of 100 units made it possible to determine the cost of ink for different methods of printing. The above method of calculating the cost of a batch of products is simplified and corresponds to each of the methods of applying the image to textiles. However, each of the printing methods has its own technological operations that affect the final result of the cost calculation. The total cost of the batch of products:

$$C = C_D + C_E + C_p + C_I + C_W + C_{EI} \quad (1)$$

where: C_D - the cost of the designer`s work, [hryvnia (UAH)]; C_E - the cost of the manufacture of technological tools, UAH; C_p - the cost of paint [UAH]; C_I - the cost of the intermediate carrier [UAH]; C_W - the cost of the work of specialist in applying the image to the textile material [UAH]; C_{EI} - electricity cost [UAH].

Design preparation includes the cost of the designer's salary and takes into account the time spent on training and appropriate skills of the worker. The cost of electricity during the work of the designer is less than 1%, respectively, it can be neglected. Designer's work costs:

$$C_D = \frac{T_D \times N_D}{60} k_D, \quad (2)$$

where: T_D - designer's tariff rate [UAH/year]; N_D - rate of time for operation [min]; k_D - coefficient that takes into account additional costs and tax accruals on the salary.

For screen printing, the cost of technological tools per batch of 100 units (production of printing plates):

$$C_E = \frac{T_E \times N_E}{60} k_E + P_M + P_E, \quad (3)$$

where: T_E - the tariff rate of the worker for the manufacture of technological tools [UAH/hour]; N_E - time rate for the operation of manufacturing technological tools [min]; k_E - coefficient that takes into account additional costs and tax accruals on the salary; P_M - cost of materials [UAH]; P_E - the cost of energy consumption [UAH].

The cost of the work of specialist in applying the image to the textile material is:

$$C_W = C_1 + C_2 + C_3 = \\ = \frac{T_1 \times N_1}{60} k_1 + \frac{T_2 \times N_2}{60} k_2 + \frac{T_3 \times N_3}{60} k_3, \quad (4)$$

where: C_1 - the cost of the specialist`s work to apply the image to the intermediate carrier [UAH]; $C_2$ - the cost of the specialist`s work to apply the image on the product/work-piece [UAH]; C_3 - the cost of the employee to fix the image [UAH]; T_1, T_2, T_3 - tariff rate of the specialist for applying the image on the intermediate carrier, product/work-piece and its fixing, respectively [UAH/hour]; N_1, N_2, N_3 - the rate of time for the operation of applying the image to the intermediate carrier, product/work-piece and its fixation, respectively; k_1, k_2, k_3 - coefficients that take into account additional costs and tax accruals on the salary for the operations of applying the image to the intermediate carrier, product / work-piece and its fixation, respectively.

Electricity costs are:

$$C_{EI} = P_1 + P_2 + P_3 \quad (5)$$

where: P_1 - the cost of electricity for transfer operations from the intermediate carrier to the product [UAH]; P_2 - electricity cost for intermediate drying operations [UAH]; P_3 - electricity cost for finishing drying operations [UAH].

Data for calculating the costs of manufacturing images on textile materials by different printing methods were obtained as a result of the practical activities of the authors of the article in terms of production in enterprises FOP Zozulyuk and Dprint Studio, Khmelnitsky, Ukraine. The results of calculations according to the above method are presented in Table 2. When an operation is absent in the technological sequence the sign «–» is put into Table 2. The calculation is given for the national currency of Ukraine, at the time of calculation the exchange rate of UAH to the EURO was 33:1 at the rate of the National Bank of Ukraine. The calculation for European countries will differ in the absolute value, but in relative terms, i.e. in percentage terms will be fair. This will give a general idea of the economic feasibility of using a particular method of printing images. Based on the results of the cost calculation summarized in Table 2, it is possible to draw conclusions about the economic feasibility of each of the methods under consideration. For a batch of 100 units, the cost of printing for all three methods differs for both light and dark fabrics. For example, for light fabrics, the difference between sublimation and screen printing is 60%, while for printing on dark fabrics, the difference between direct printing using DTG technology and screen printing is 300%.

If we consider the manufacture of a single sample, then in contrast to mass production, the cost of the product increases significantly. This is due to the fact that the cost of technological tools is fully transferred to the cost of the product. In this case, the cost of printing on light fabrics for the first two methods is almost equal, and for screen printing is 240% higher.

Table 2 The cost of applying the image to textile materials

№	Cost item	Printing method		
		Direct printing by DTG technology (digital)	Sublimation printing	Direct screen printing
1	Image design preparation [UAH]	80	80	80
2	The cost of technological tools for white / colored fabrics [UAH]	-	-	120/180
3	The cost of ink C_p for printing on white / colored fabrics [UAH]	112/1344	200	20/30
4	The cost of the intermediate carrier, C_1 [UAH]	-	250	-
5	Worker's labor costs [UAH:]			
	- applying the image to the intermediate medium;	800		200/300
	- drawing the image on a product or preparation;	-	200	-
	- fixing the image	200	-	200*
6	Electricity costs C_{El} for white / colored fabrics [UAH]:			
	- transfer from the intermediate carrier to the product;	-	10	-
	- intermediate drying operation;	-/10	-	23/35
	- finishing drying operation	10	-	17
∑	The cost of printing on white / colored fabrics [UAH:]			
	- batches of 100 units of products;	1202/2444	740	460/642
	- product units	12.02/24.44	7.4	4.6/6.42
	The cost of making a single sample on white / colored fabrics [UAH]	91.22/103.64	86.51	204.6/235.99

* only in case of additional processing on a thermopress

Therefore, in the case of single production, screen printing is considered inexpedient in terms of economic effect, however, for serial production it is the cheapest way to apply the image, and given the results in Table 1, it is the most productive and versatile in terms of raw material composition and fabric color.

4 EXPERIMENTAL

The next, no less important, step in choosing a printing method is to assess the performance of the applied image. The main performance characteristics that affect the quality of the applied images to the textile material are resistance to friction and washing.

The first stage of experimental research to assess the preservation of image quality on textile materials during friction was performed according to GOST 9733.27-83, DSTU ISO 105-X12: 2009. It is known that friction is a physical phenomenon that occurs during the contact interaction of two bodies. Friction can be external or internal. External friction occurs when the surfaces of two materials come into contact and move relative to each other. Internal friction occurs in the material between its structural elements, when exposed to the external environment (mechanical impact, electromagnetic field, etc.).

Devices for determining the abrasion resistance of textile materials must mimic the actual abrasion process during the operation of garments. The material can be worn on its plane surface, or on the folds - imitation of rubbing on the edges of the lapel and sleeves, the bend of the collar, the bottom of the pants and so on. To determine the resistance of textile materials to abrasion using one of the existing devices: DIT-M, TI-1M, IS-3M, ITIS, which simulate friction. As an abrasive material, in these devices, a gray overcoat woolen cloth is used. To stop the device at the moment of destruction of the sample, metal contact grids are placed between the membranes and the samples. The number of friction cycles is recorded by the counter. Samples with a diameter of 80 mm should be prepared for testing and fixed in the holder with the front side facing outwards. For each fabric sample, three tests are performed under the appropriate test conditions, and the arithmetic mean of the three tests is taken as the end result characterizing the abrasion resistance.

Tests of samples for friction resistance were performed on the device DIT-M (Figure 2), according to standardized methods [12]. During the image stability study, samples were scanned every 50 cycles and the image quality loss during operation was assessed. Abrasion was performed until complete destruction of the material.

Images of samples scanned at different stages of the study are shown in Table 3.

Sample 1: The image to the textile is applied by sublimation. Knitted fabric is used with fibrous polyester composition of the studied sample.
After 50 cycles there are no peels, no color loss.
After 100 cycles: small peels are visible to the naked eye, no discoloration is observed, no mechanical damage to the fabric.
At 150 cycles, the number of peels increases; barely noticeable loss of color along the abrasion trajectory, due to the growth of peels and optical perception.
200 cycles: the number of peels increases; there is a barely noticeable loss of color along the abrasion trajectory; the structure of the fabric is broken. The study of this sample is stopped.

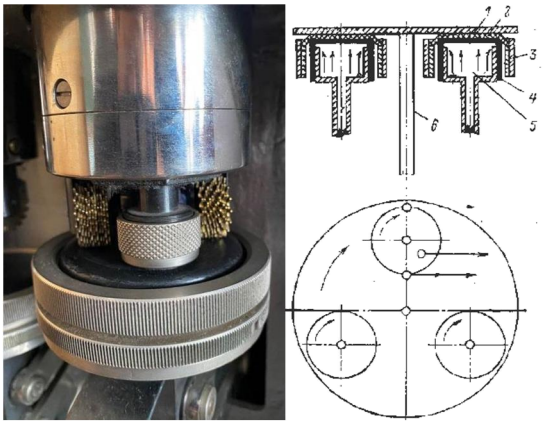


Figure 2 Photograph and diagram of the working bodies of the device for the external friction measurement: 1 - friction disk; 2 - sample material; 3 - clip; 4 - rubber membrane; 5 - working heads; 6 - axis

Sample 2: The image on the textile is printed by screen printing. Knitted fabric is used with fibrous composition of the studied sample includes: cotton, nitron.
After 50 cycles: no saws, no color loss.
After 100 cycles: no peels; no discoloration; no mechanical damage to the fabric.
At 150 cycles: no peels; barely noticeable loss of color along the abrasion trajectory, due to abrasion of paint particles.
After 200 cycles: no peels; color loss along the abrasion trajectory becomes more noticeable; the fabric structure is broken. The study of this sample is stopped.

Sample 3: The image to the textile is applied by direct printing using DTG technology. Digital printing is made on a white base. The fibrous composition of the studied sample of knitted fabric includes: polyester, cotton, elastane.
After 50 cycles of friction, there is a slight loss of color; but the structure of the fabric is destroyed. The study of this sample is stopped.

Sample 4: The image to the textile is applied by direct printing using DTG technology. Digital printing of primer and white ink, as the fabric is white. Fibrous composition of the knitted fabric for studied sample consists of cotton.
After 50 cycles there are no peels; no other changes in image characteristics.
As a result of performance of 100 cycles: there are no peels; insignificant change of color is observed; the structure of fabric is broken. The study of this sample is stopped.

The next step in the study of the performance characteristics of images on textiles was to determine the stability of the image during washing. According to the results of research, based on organoleptic evaluation, it is possible to draw conclusions about the gradual loss of color of each sample. The most resistant to washing were samples with sublimation and screen printing, but Digital printing is less stable.

Table 3 The results of the study of image stability during friction

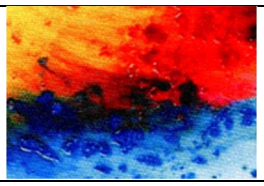
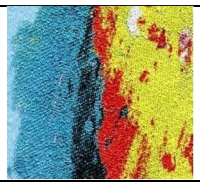
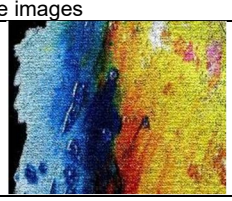
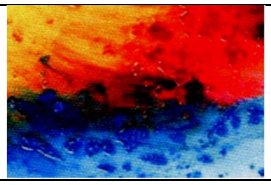
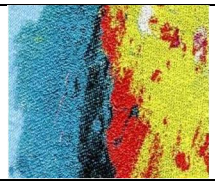
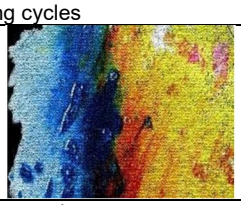
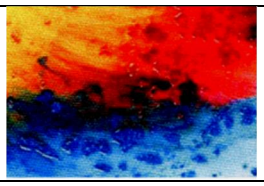
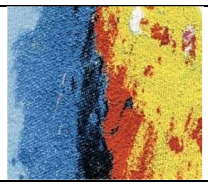
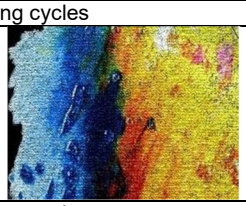
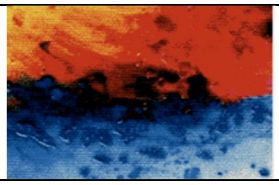
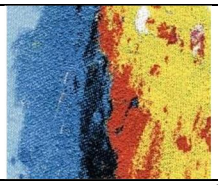
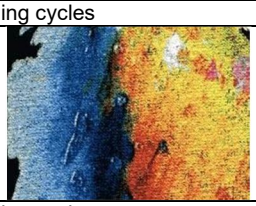
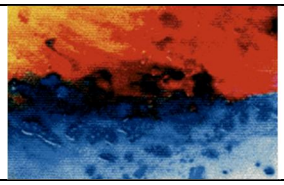
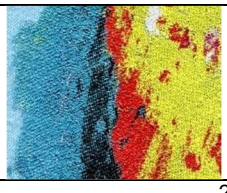
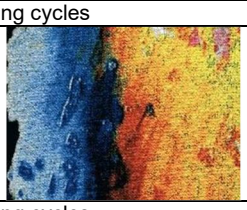
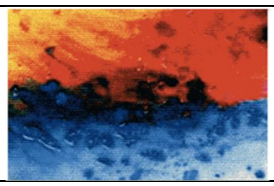
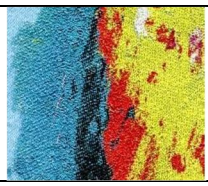
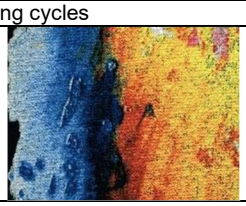
Sample №	Raw material composition and printing method	Photographs of the sample after friction				
		Reference images	50 cycles	100 cycles	150 cycles	200 cycles
1	Polyester Sublimation					
2	Cotton, nitron Screen printing					
3	Polyester, cotton, elastane Digital printing on a white base					
4	Cotton Digital printing without a base					

Washing is considered as a method of cleaning textiles, which consists in the hydro-mechanical treatment of things using soap or detergent. As a result of such cleaning, the aqueous detergent solution is able to separate the contaminants from the surface of the textile during hydro-mechanical treatment, transfer them to the solution, and keep it there. Laundry can be washed manually, using household washing machines, using ultrasound.

Washing was performed according to DSTU ISO 105-C06:2009 on a household washing machine using detergents, in accordance with the composition of the textile. The temperature mode is 40°C; washing time 30 minutes; spin 800 min^{-1}. Drying took place in a vertical position until completely dry, after which the ironing of the sample was performed at a temperature of 100-110°C. For each sample, 25 washing cycles were performed, which corresponds to the maximum period of operation of textile products [9]. Sample scans were performed every five wash cycles.

The results of studies of the loss of image quality on textiles during washing are presented in Table 4. Samples for washing and abrasion tests were cut from one print, but in different places; so the Figures in Table 4 show a different fragment of the image, not the same as in Table 4.

Table 4 The results of research on the loss of image quality on textiles during washing

Printing method			
Sublimation	***Screen printing***	***Digital printing on a white base***	***Digital printing without a base***
Reference images			
			
5 washing cycles			
			
10 washing cycles			
			
15 washing cycles			
			
20 washing cycles			
			
25 washing cycles			
			

As a result of organoleptic evaluation of images on textiles applied by different printing methods, a gradual loss of color of each sample was established. The most resistant to washing were the samples of images applied by sublimation and screen printing on a white base. The image obtained by digital printing turned out to be less stable. Analyzing the image of digital printing on black fabric (Table 4), it seems that the image after washing becomes more saturated and bright. This is an optical illusion caused by the removal of the primer and the white base of the print, as a result of which the fabric itself is visible and the overall picture becomes darker.

5 RESULTS

In addition to organoleptic evaluation of the degree of wear of the print as a result of testing on the abrasion machine, repeated washing and ironing, which is a subjective method of evaluation and based solely on human experience and visual perception, there is a need to develop an objective method of assessing wear. To this end, a PC program has been developed that compares the reference image (immediately after application) with the image that has been tested for abrasion and washing.

In order to verify the reliability of the software, a comparison of the two figures is made. The first figure with a resolution of 7x9 pixels contains 28 black pixels, and the second figure with a similar resolution contains 14 black pixels, i.e. 50% less than the first (Figure 3).

The comparison algorithm is as follows:

1. Translation of reference and worn images in grayscale
2. Conversion of images in bit format with the same parameters.
3. Uploading images to the comparison program.
4. Pixel-by-pixel comparison on the abscissa axis of the selected image fragment corresponding to the first pixel of the ordinate axis.
5. Going to the second pixel on the ordinate axis.
6. Pixel-by-pixel comparison on the abscissa axis of the selected image fragment corresponding to the second pixel of the ordinate axis.
7. Going to the n-pixel on the ordinate axis.
8. Pixel-by-pixel comparison along the abscissa axis of the selected image fragment corresponding to the n-pixel along the ordinate axis.
9. Carrying out calculations.
10. Derivation of the comparison result.

According to the results of the comparison of the two figures, the wear is 50%, which corresponds to the specified parameters and confirms the reliability of the software.

The software was also tested to determine the level of wear in the selected fragment for further comparison of the samples tested for abrasion resistance. For this purpose, the initial computer simulation of the process of image wear at 50% of the initial level of only the image fragment was performed.

The image in the CMYK color scheme with the subsequent conversion to a bit format is selected as the reference. According to the results of computer comparison of the reference and software "worn" image, the wear is 50% in the area of artificial wear, which corresponds to the specified parameters. The results of computer image modeling and artificial wear are shown in Table 5.

This software was then used to compare scanned reference images and images that were subject to wear and repeated washing.

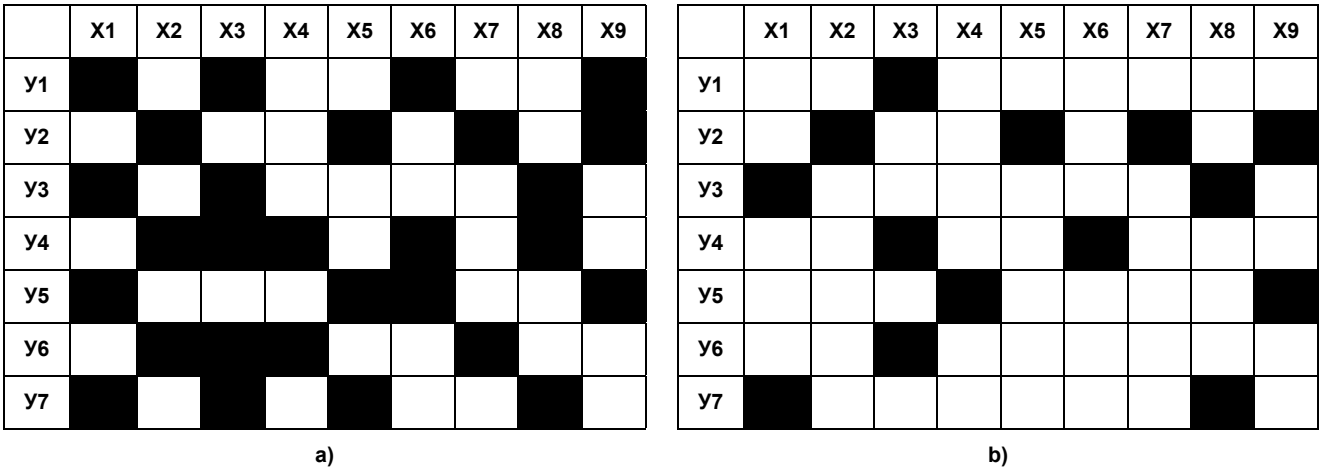
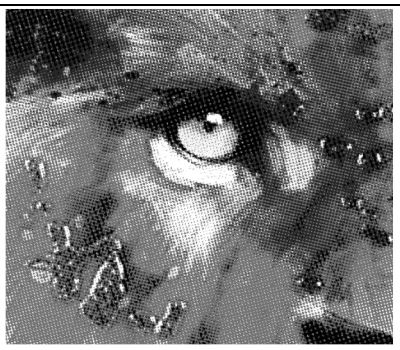
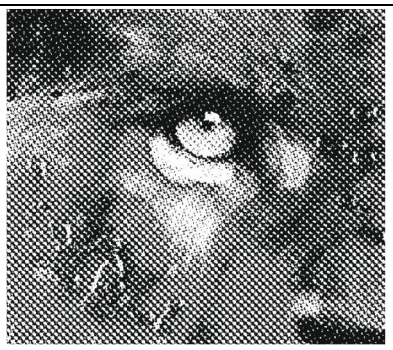
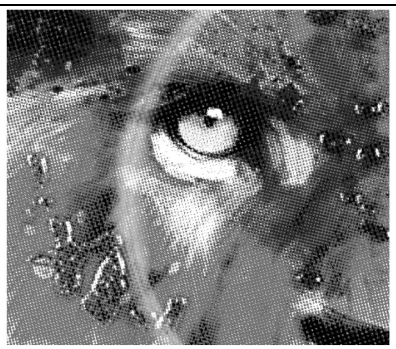
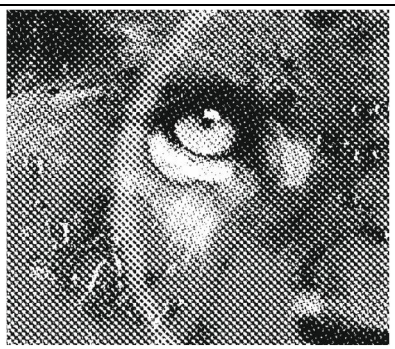


Figure 3 Pixel layout in the test image of the software: a) the total number of pixels - 63, the number of dark pixels - 28; b) the total number of pixels - 63, the number of dark pixels - 14

Table 5 Computer simulation of image wear

Images in CMYK color scheme	Grayscale image	Images in bit format
Reference images		
		
Artificially worn images		
		

For samples tested for abrasion, the program compares the intensity or degree of wear only by the friction trajectory. For samples tested for repeated washing, the comparison took place over the entire area of the test sample. The results of software evaluation of image quality for resistance to washing and abrasion are presented in Table 6.

As a result of using the proposed computer method for assessing image quality, it was found that the image quality during friction in sublimation printing samples is lost by 1.5% compared to the reference; screen printing loses 10% quality compared to the reference with the same number of cycles.

Table 6 The results of software evaluation of image quality for resistance to washing and abrasion

Research method	Loss of quality of the sample relative to the reference image [%]			
	Sublimation	***Screen printing***	***Digital printing on a white base***	***Digital printing without a base***
Study of image stability during friction	50 cycles			
	-	3.0	25.0	10.0
	100 cycles			
	1.5	10.0	-	17.0
	150 cycles			
	2.7	-	-	-
	200 cycles			
	5.0	-	-	-
Investigation of image quality loss during washing	5 cycles			
	-	-	1.1	0.8
	10 cycles			
	1.3	1.5	2.5	2.0
	15 cycles			
	4.0	4.0	8.5	6.5
	20 cycles			
	8.0	10.0	12.3	10.0
	25 cycles			
	10.0	14.0	18.0	15.0

Digital printing as a result of research is less stable than the previous two. The investigated samples of digital printing on a white basis lose 25% of image quality from the reference after 50 cycles. Baseless digital printing loses 17% after 100 cycles.

Studies of image quality dependence on wash cycles quantity have shown the following result. The most stable were samples made by screen and sublimation printing; less stable were samples made by digital printing on a white base and without a base.

6 CONCLUSIONS

In the process of analyzing the information available in open sources, it was found that the choice of technology for applying images to textile materials depends on the following factors: the number of products in the batch; image area; the number of image colors; raw material composition of the fabric; fabric color.

As a result of this study, the list of criteria is supplemented and presented in a form convenient for use in the analysis and selection of the method of printing images on textile materials in each case (Table 1).

One of the important factors influencing the choice of the method of applying the image to textile materials - the cost of making the print - was considered separately.

According to the simplified method of calculation, the cost of a 100 unit batch of products is determined for each of the image printing methods. The influence of the features of individual technological operations of each printing method on the final result of the calculation is taken into account.

The obtained results (Table 2) make it possible to perform an economic assessment of each of the methods and decide on the appropriateness of their use in each case.

The next result of this study is the evaluation of the performance of the image on textile materials, applied by different printing methods. In the course of experimental researches the degree of resistance of the images made by various ways of the printing to friction and in the course of washing was established.

The conclusions obtained as a result of organoleptic assessment of image quality loss in the process of testing on the abrasion machine (Table 3), repeated washing and ironing (Table 4) are confirmed by the results obtained using a specially developed computer method for image quality assessment (Table 6). It was found that the most resistant to abrasion and washing were samples of images applied by screen printing and sublimation.

Therefore, we can conclude that the application of the results of this study will allow a qualitative and effective assessment of methods of printing images on textile materials, depending on the manufacturing conditions for each type of product.

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