Assessment and prognostic models of the efficiency of anilox rollers cleaning process*

Vyacheslav Repeta[1,*,†], Tetiana Kukura[1,*,†], Yurii Kukura [1,*,†], Ihor Myklushka[1,*,†], Bohdan Durniak[1,*,†]

[1] *Institute of Printing Art and Media Technologies of Lviv Polytechnic National University, S. Bandera Street, 12, Lviv, 79013, Ukraine*

Abstract

An important element of the correct implementation of the flexographic printing process is the preliminary cleaning of anilox rollers of the inking unit. The assessment of the efficiency of anilox rollers cleaning process is carried out both visually and with the help of special control systems. In the paper, for the complex analysis of the anilox roller surface, the developed application "AniTest" is proposed, which performs additional processing of digital images obtained on AniCAM microscope. With the given lineature of the anilox roller, the calculation and determination of the cleaning degree of the anilox roller cells is carried out with visualization of the result by the terms "high", "medium" and "low". The results of the analysis by the application of the cleaning degree of anilox cells are the basis of the limits of the output linguistic variables values for anilox rollers with different lineatures when prognostic models are created. These models are formed using fuzzy logic tools. Using data on the influence of the duration of cleaning process and the degree of ink structuring, a knowledge base with the condition "If – Then" is formed, a logical diagram and fuzzy logic equations are formed. The establishment of universal variables and assessment terms makes it possible to form a quantitative indicator of the efficiency of the cleaning process. The formed fuzzy knowledge base is verified by modelling using the Fuzzy Logic Toolbox system of the Matlab technological computing environment according to the Mamdani algorithm with defuzzification according to "Centre of gravity" principle. The proposed technique for assessing the efficiency of the anilox cleaning process makes it possible to construct two-factor models for its forecasting.

Keywords

Flexographic printing, anilox roller, cleaning process, fuzzy logic, linguistic variable, universal set, prognostic model

1. Introduction

The flexographic printing market, which plays a key role in the technological processes of creating flexible packaging, continues to develop rapidly. According to this year's forecast of the authoritative company Smithers Pira «The Future of Flexographic Printing to 2027», the global demand for flexographic printing will already reach $172.2 billion this year [1].

As it is known, the surface of an anilox roller consists of evenly distributed cells of the same shape and depth that form a raster structure on its surface. The raster structure and the shape of the raster cell are two interrelated parameters that determine the ink capacity of the anilox roller, as well as its behaviour in the printing process, primarily the ink transfer. The size of the cells and the density of their location on the anilox roller surface determine its lineature [2-4]. The ink capacity of the anilox roller depends on the lineature, the raster structure of the cells and their shape. Knowing the ink capacity of the roller, it is possible to calculate the ink amount and the layer thickness on the printing plate and on the imprint, which makes the ink capacity the main indicator when selecting anilox

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* Corresponding author.
† These authors contributed equally.
Viacheslav.B.Repeta@lpnu.ua (V. Repeta); tanyakukura@gmail.com (T. Kukura); Yurii.A.Kukura@lpnu.ua (Yu. Kukura); Ihor.z.myklushka@lpnu.ua (I. Myklushka), Bohdan.V.Durniak@lpnu.ua (B. Durniak)
0000-0003-3412-1639 (A. Ometov); 0000-0002-5385-5761 (T. P. Sales); 0000-0002-9421-8566 (M. Jeusfeld)

rollers for specific types of work [5, 6]. Contamination of anilox cells during the operation can lead to a violation of the colour reproduction correctness, problems with ink transfer and, in the final case, to the printing of defective products [7]. A variety of methods are used for the anilox roller cleaning, the goal of each of them is to maximally remove the remaining ink from these cells. Accordingly, there arises a question of assessing and forecasting the efficiency of the cleaning process of the anilox roller cells of different lineatures. Such measures will make it possible to reduce the energy consumption of production, its impact on the environment, which corresponds to the concepts of the sustainable development strategy.

2 Literature review

Various methods are used to clean anilox rollers that according to the cleaning principle can be divided into: manual or mechanical cleaning using special solutions, sandblasting cleaning, ultrasonic cleaning; laser cleaning [8, 9]. It was established that, despite the high efficiency, the process of cleaning aniloxes with ultrasound will lead to further increase of microcracks and destruction of the ceramic coating [10]. The improvement of each of the cleaning methods is accompanied by thorough scientific research, for example, the use of ultrasound technology, the use of a laser and the study of its settings in the anilox cleaning processes [11-13]. There are also recommendations for comprehensive cleaning and rinsing of aniloxes. Neglecting rinsing can lead to longer cleaning cycles, unnecessary downtime, and additional maintenance costs [14]. One of the questions that arises when choosing the principle of washing aniloxes is the type of inks that are used in production and with which there were difficulties in washing.

It is important what the component scale of the printing ink is, namely solvent-based, water-based or UV. For example, washing aniloxes with the remains of water-based inks with ordinary water can only complicate the process by lowering the pH of the inks medium [15].

The effect of the anilox lineature on the cleaning process was also established. Thus, the study found when washing heavily contaminated anilox rollers with a high lineature, at least 2 rinses are necessary, for anilox rollers with an average ineature, 1-2 rinses are needed, and for low lineature anilox rollers, using Flexo Hard cleaning agent allows one to qualitatively clean the roller surface in one wash [16].

It is clear that after the cleaning process, it is necessary to control the quality of the anilox roller cells. The analysis of the anilox roller surface and the contamination degree is determined using AniCAM 3D microscope and Anilox QC Application software of the British company Troika Systems [17]. The result of the cooperation between the companies Cheshire Anilox Technology and MicroDynamics was the development of systems for monitoring the state of the anilox roller cells 3DQC Veritas, 3DQC Classic and with MicroScan3 software [18]. To perform similar tasks, the company Print Tech Solutions offers developments CellScope and CellStore [19]. Using these tools to regularly inspect and monitor the condition of anilox rollers, will enable to identify possible root causes of flexography printing quality issues.

Today, there is a range of works related to the presentation and printing reproduction of information, in which the basics of fuzzy logic are used and the corresponding results are achieved. In particular, the work [20] proposed a method based on: system analysis of a long technological process; factors affecting the implementation quality of technological procedures; alternative options for the implementation of the technological stages of preparation and release of book editions; an automated system of prognostic assessment of the technological process quality based on fuzzy logic. In the work [21], the author used the fuzzy logic tool and proposed an integral indicator of the quality of flexographic printing imprints.

Taking into account the availability of quantitative and qualitative indicators, paper [22] analyzed the course of socio-economic processes in Ukraine by means of fuzzy logic and developed recommendations for improving their management policy. On the basis of calculations using the fuzzy logic theory in [23], an indicator of the prognostic quality level of the data visualization process in infographics was established. The procedure for evaluating the degree of cell cleaning requires certain skills and professionalism of the operator, accordingly, the development of a system that could perform the evaluation and was understandable at the a priori level is an urgent task.

3 Method of assessing the degree of anilox cell contamination

To quantitatively assess the degree of the cell contamination we have AniTest application is developed, which performs additional processing of digital images obtained on AniCAM 3D microscope. The application analyses the image colour pixels and when determining pixels in the red range, replaces them with white pixels, after which it also converts the blue and green colours of the image into black pixels and calculates the number of white pixels, setting their percentage in the image, which characterizes the area cells of the anilox roller. After setting the given condition – the lineature of the anilox roller, the calculation and determination of the cleaning degree of the anilox roller cells is carried out with the visualization of the result by the terms "sufficient", "medium" and "low".

The interface of AniTest application is shown in Figure 1, and the result of the image processing of the anilox surface is shown in Figure 2.

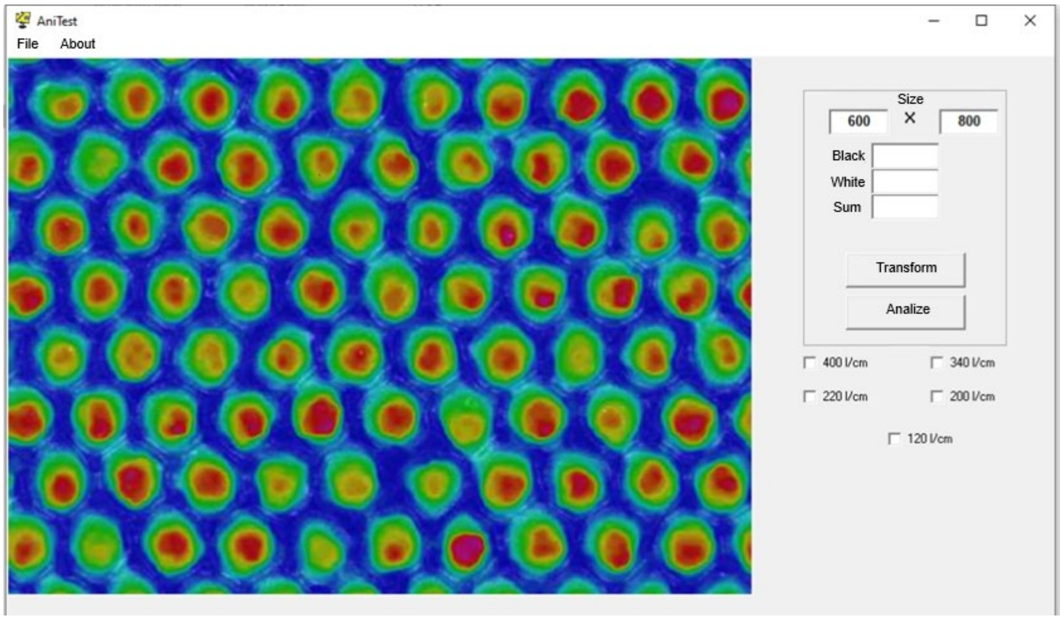


Figure 1: Interface of AniTest application.

When loading an image, pixels are counted along the image width and length, when "Transform" command is activated, red pixels are found and replaced with white pixels and blue pixels are replaced with black ones. Unidentified shades remain unchanged. The study of the transformation shows that if the image is made immediately black and white, then the unidentified colours become white and represent "noise" when they are counted. Sequential counting of the number of black and white pixels occurs after the presentation of the digital image in the form of an array.

The following line of anilox shafts was used to study the effectiveness of washing: 120 l/cm, 200 l/cm, 220 l/cm, 340 l/cm, 400 l/cm. When According to the results of the analysis of the anilox surface images with different cleaning degrees, the following parameters of the area distributed over the cell surface are determined as the ratio of white pixels to the total number of pixels in %:

– For the anilox with the linerature 400 l/cm:

≥ 19 % of cleaning the cells is “sufficient”

<19 and >13 % of cleaning the cells is “medium”

≤ 13 % of cleaning the cells is “low”

– For the anilox with the linerature 340 l/cm:

≥ 22,5 % of cleaning the cells is “sufficient”
<22,5 and >15 % of cleaning the cells is “medium”
≤ 15 % of cleaning the cells is “low”
– For the anilox with the linerature 220 l/cm:
≥ 24 % of cleaning the cells is “sufficient”
<24 and >16 % of cleaning the cells is “medium”
≤ 16 % of cleaning the cells is “low”
– For the anilox with the linerature 200 l/cm:
≥ 26 % of cleaning the cells is “sufficient”
<26 and >17 % of cleaning the cells is “medium”
≤ 17 % of cleaning the cells is “low”
– For the anilox with the linerature 120 l/cm:
≥ 19 % of cleaning the cells is “sufficient”
<19 and >12,5 % of cleaning the cells is “medium”
≤ 12,5 % of cleaning the cells is “low”.

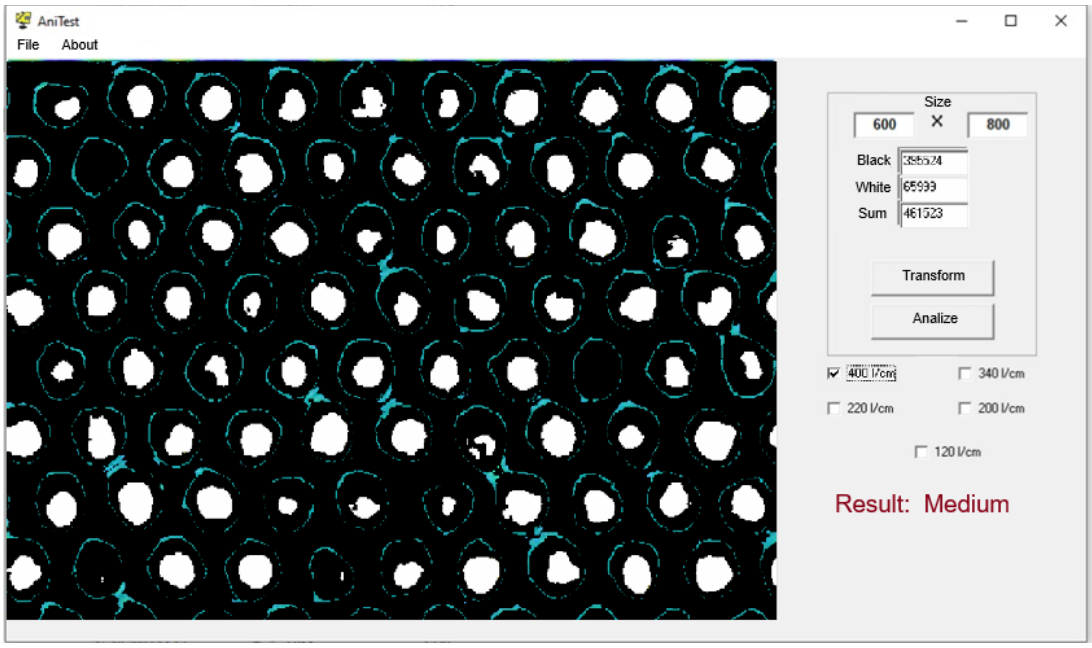


Figure 2: The result of the digital image processing by AniTest application.

The results of the application's analysis of the cleaning degree of the anilox cells will be the basis of the limit values of the output linguistic variables for anilox rollers with different lineatures and, accordingly, with the difference in the cell volume.

4 Forecasting the efficiency of the anilox cleaning process by means of fuzzy logic

Fuzzy logic is one of the options for analysing the influence of factors on the technological process, which is used to interpret ambiguous statements into the language of understandable mathematical formulas with quantitative assessment. The founder of the fuzzy logic principle is Lotfi Zadeh, and the principles themselves were implemented in his work. Lotfi Zade laid the foundations of the fuzzy logic trend and introduced the concept of some universal set for a certain problem area. The advantages of fuzzy logic systems are the ability to operate on fuzzy input data.

The efficiency of the cleaning process Qe depends on the duration of anilox cleaning and the degree of the printing ink structuring:

$$Qex = f(T, Av), \quad (1)$$

where T is a linguistic variable that characterizes the duration of the anilox cleaning process;

Av is a linguistic variable that characterizes the degree of the printing ink structuring (viscosity anomaly);

x is an index which indicates the anilox lineature.

Table 1 presents the assessing terms for linguistic variables that characterize the efficiency of the anilox cleaning process, and Table 2 shows the linguistic variables of the output parameters when cleaning anilox rollers with different lineatures, according to the diagram presented in Figure 3.

Table 1

Linguistic variables and input parameter terms for forecasting the anilox cleaning efficiency

Name of the valuable	Universal set	Assessment terms
Time of the anilox cleaning	5-20 min	low average long
Degree of the ink structuring (viscosity anomaly)	1,02-1,4 c.u.	low average high

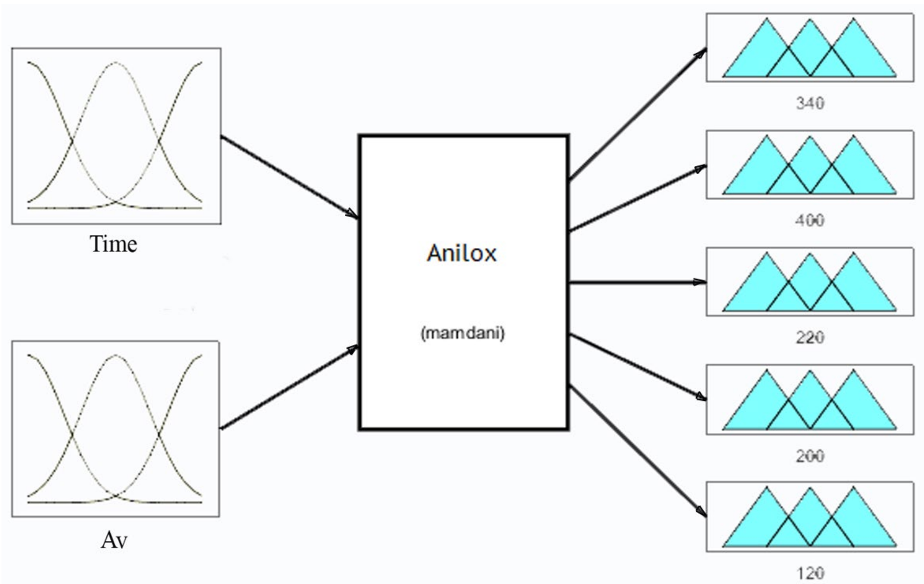


Figure 3: The diagram of the influence of the cleaning process duration and viscosity anomaly on the anilox cleaning efficiency with different lineatures.

The linguistic variable "Time of the anilox cleaning" on the universal set U (x1) = [5-20] min is identified with the membership functions shown in Figure 4, a.

In accordance with universal set U (x2) = [1,02-1,4] c.u., the membership functions of the linguistic variable "viscosity anomaly" are obtained (Figure 4, b).

Let one form a fuzzy knowledge base for determining the efficiency of the anilox cleaning process with different lineatures using a set of fuzzy rules "if ... then":

– if (T is “Long”) and (Av is “Low”) then (Qe400 is “Sufficient”; Qe340 is “Sufficient”; Qe220 is “Sufficient”; Qe200 is “Sufficient”; Qe120 is “Sufficient”).

or

– if (T is “Average”) and (Av is “Average”) then (Qe400 is “low”; Qe340 is “low”; Qe220 is “Medium”; Qe200 is “Medium”; Qe120 is “Medium”).

or

– if (T is “Low”) and (Av is “High”) then (Qe400 is “low”; Qe340 is “low”; Qe220 is “low”; Qe200 is “low”; Qe120 is “low”).

or

– if (T is “Average”) and (Av is “Low”) then (Qe400 is “Medium”; Qe340 is “Medium”; Qe220 is “Sufficient”; Qe200 is “Sufficient”; Qe120 is “Sufficient”).

or

– if (T is “Long”) and (Av is “Average”) then (Qe400 is “Medium”; Qe340 is “Medium”; Qe220 is “Medium”; Qe200 is “Sufficient”; Qe120 is “Sufficient”).

or

– if (T is “Average”) and (Av is “High”) then (Qe400 is “low”; Qe340 is “low”; Qe220 is “low”; Qe200 is “Medium”; Qe120 is “Medium”).

or

– if (T is “Long”) and (Av is “High”) then (Qe400 is “low”; Qe340 is “Medium”; Qe220 is “Medium”; Qe200 is “Medium”; Qe120 is “Medium”).

or

– if (T is “Low”) and (Av is “Low”) then (Qe400 is “Medium”; Qe340 is “Sufficient”; Qe220 is “Sufficient”; Qe200 is “Sufficient”; Qe120 is “Sufficient”).

When constructing the membership function for "Duration of cleaning" variable, its value is determined on the universal set: u1= 5 min; u2= 8 min; u3= 12 min; u4= 16 min; u5= 20 min. For the linguistic assessment of this indicator, a set of fuzzy terms is used: T(x)=<low, average, long>.

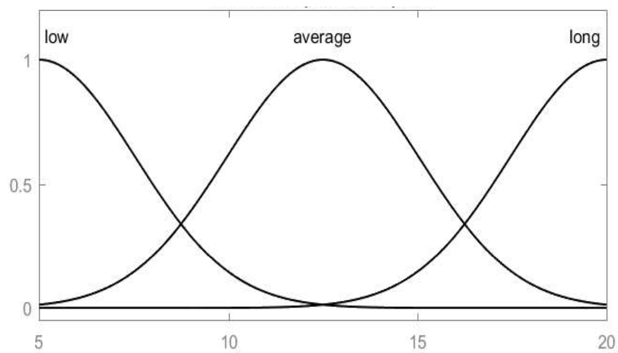
The value for the variable "Degree of ink structuring (viscosity anomaly)" for the construction of membership functions is determined on the universal set: u1= 1.02 c.u.; u2= 1.1 c.u.; u3= 1.2 c.u.; u4= 1.3 c.u.; u5= 1.4 c.u. For the linguistic assessment of this indicator, a set of fuzzy terms is used: T(y)=<low, average, high >.

Table 2

Linguistic variables of the output parameters in forecasting the anilox cleaning efficiency with different lineatures

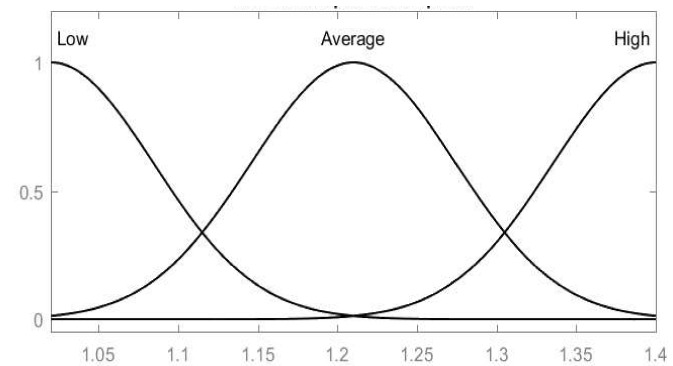
Name of the valuable	Universal set	Assessment terms
Area of the anilox cells with the lineature 400 l/cm	13-19 %	low medium high
Area of the anilox cells with the lineature 340 l/cm	15-22,5 %	low medium high
Area of the anilox cells with the lineature 220 l/cm	16-24 %	low medium high
Area of the anilox cells with the lineature 200 l/cm	17-26 %	low мedium high
Area of the anilox cells with the lineature 120 l/cm	12,5-19 %	low мedium high

The membership function for "Duration of cleaning" and "Degree of ink structuring (viscosity anomaly)" variables is is shown in Figure 3. For our membership functions, can apply the division into three members of each input variable with a symmetric Gaussian membership function.



input variable «T»

a



input variable «Av»

b

Figure 4: Membership functions of the influence of the Duration of cleaning (a) and Degree of ink structuring (b).

For example, one of the options of fuzzy logic equations is formed to establish the anilox cleaning efficiency with the lineature 400 l/cm:

$$\mu^{s} = \mu^{long}(x) \wedge \mu^{low}(y) \vee \mu^{av}(x) \wedge \mu^{low}(y), \quad (2)$$

$$\mu^{m} = \mu^{low}(x) \wedge \mu^{h}(y) \vee \mu^{av}(x) \wedge \mu^{h}(y), \quad (3)$$

$$\mu^{l} = \mu^{low}(x) \wedge \mu^{low}(y) \vee \mu^{av}(x) \wedge \mu^{h}(y). \quad (4)$$

The notations ^ and ˅ are the operations for determining the minimum and maximum in logic equations. Using the membership functions and substituting the membership degrees into the system of fuzzy logic equations, one can forecast the going through the anilox cleaning process.

To simulate the influence of technological factors on the efficiency of the anilox cleaning process, the capabilities of the fuzzy control system development system is used – Fuzzy Logic Toolbox of the MATLAB computing environment using the Mamdani fuzzy logic inference algorithm [24] with defuzzification according to "Centre of gravity" principle [25].

Choice of the defuzzification according to "Centre of gravity" explained by its popularity in the analysis of diverse processes, which was highlighted in the work.

In Figure 4 prognostic models of the influence of time and viscosity anomaly on the efficiency of the anilox cleaning process with different lineatures are presented.

The simulation results (Figure 5) show the adequacy of the developed knowledge base and the possibility of its use for forecasting assessment of the process efficiency when selecting the duration of the anilox cleaning process and the degree of the ink structuring.

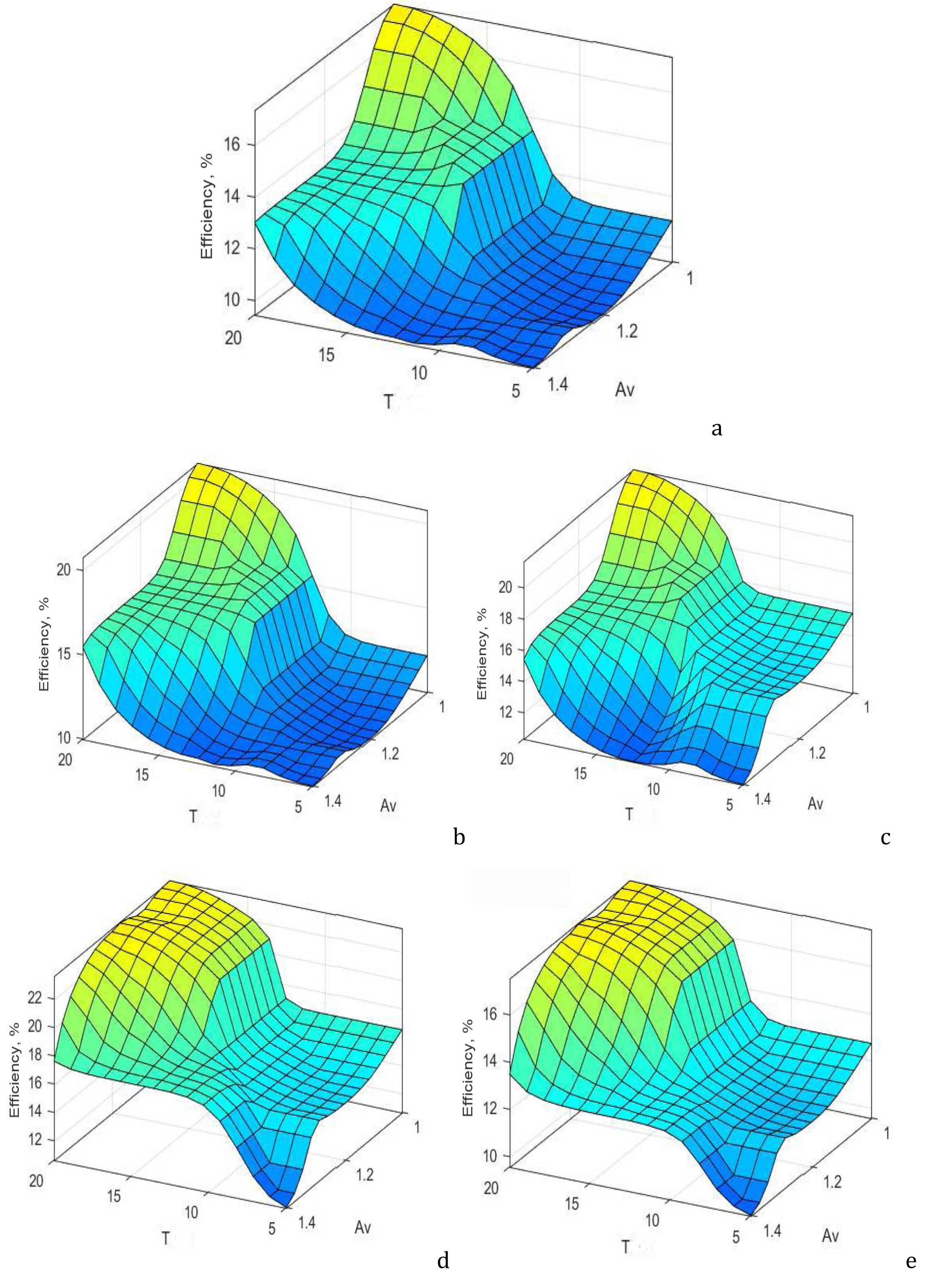


Figure 5: Prognostic models of the influence of duration of the anilox cleaning and viscosity anomaly on the efficiency of the anilox cleaning process: a – lineature 400 l/cm; b – lineature 340 l/cm; c – lineature 220 l/cm; d – lineature 200 l/cm; e – lineature 120 l/cm.

Table 3.
Results of calculating the efficiency of the anilox cleaning process

Lineature, l/cm	Time of the anilox cleaning, min	Degree of the ink structuring, c.u.	Efficiency, %
120	18	1,3	14,2
120	10	1,4	12,3
200	18	1,3	19,1
200	10	1,4	16,4
220	18	1,3	15,7
220	10	1,3	10,7
340	18	1,4	14,3
340	10	1,3	10,2

For example, in accordance with the received models of efficiency of the anilox cleaning process was calculated. The simulation results are summarized in Table 3 and show how the duration of the process and the degree of the ink structuring affect the effectiveness of the process of cleaning aniloxes with different lineature. Constructed prognostic models for achieving process efficiency demonstrate the difference in approaches to cleaning anilox shafts when transitioning from high-line to low-line anilox roll.

5. Conclusions

Therefore, the presented paper describes the dependency of the anilox cleaning process on two factors: the duration of the process and the degree of the printing ink structuring. The use of the computer application "AniTest" makes it possible to assess the degree of anilox cells cleaning, and shows the difference in the openness of anilox cells with different lineatures, which are visualized in the form of fuzzy terms "sufficient", "average" and "poor". The obtained data of the corresponding limit for the output parameter Qex are used when creating prognostic models. Accordingly, to clarify the assessment process results, it is advisable to use the methods of the fuzzy logic theory, which provides an opportunity to operate with fuzzy input data. Using the data on the influence of the duration of cleaning process and the degree of ink structuring, a knowledge base with the condition "If – Then", a logic diagram and fuzzy logic equations are formed, which result in a quantitative indicator of the efficiency of the cleaning process. The formed fuzzy knowledge base is verified during modelling using the Fuzzy Logic Toolbox system of the Matlab technological computing environment according to the Mamdani algorithm with defuzzification according to "Centre of gravity" principle. The further use of the developed prognostic models will make it possible to perform the reverse task, namely to forecast a reduction in the duration of anilox cleaning process depending on their lineature and the ability of the printing ink to structure, which in turn will allow to establish the optimal process duration, reduce the energy costs of flexographic production, which lies in the concept of the sustainable development strategy.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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