Original scientific paper http://doi.org/10.24867/JGED-2023-3-037

Analysis of factors and construction of prognostic quality models of flexographic printing process of packaging with solvent based inks

ABSTRACT

The presented article shows the results of the analysis of the factors influence on the flexographic printing process with solvent based inks. The main factors influencing the printing process quality are identified, a semantic network of influence and dependencies of these factors is constructed. The priority of factors, taking into account their influences and dependencies, is established by the ranking method. Using the Pareto rule and the construction of the corresponding diagram, four main factors are identified, the influence of which provides 70 % of the studied process quality. It is established that the most priority factors are the parameters of the printing plate, the rheological parameters of the ink, the lineature of the anilox roller and the surface properties of the material to be printed, with the following calculated values: 150, 120, 105 and 90 units, respectively. The selected factors are used to analyse their impact on the flexographic printing process by means of fuzzy logic. Accordingly, a universal set, corresponding terms and a fuzzy knowledge base with the condition "If-Then" are established for these factors in the form of linguistic variables. The formed knowledge base is tested with the help of the Fuzzy Logic Toolbox package of the Matlab technological computing environment and the corresponding prognostic models of the influence of the selected factors on the printing process quality are constructed.

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First received: 20.3.2022.
Revised: 7.11.2022.
Accepted: 1.12.2022.

KEY WORDS
Flexography, semantic network, priority factors, ranking method, Fuzzy logic, term, linguistic variable, quality

Introduction

Despite ecological challenges, the global solvent-based printing inks market is expected to grow from $ 11.63 billion in 2021 to $ 13.49 billion in 2025 at a compound annual growth rate (CAGR) of 4 %. The growth is mainly due to the companies rearranging their operations and recovering from the COVID-19 impact, which had earlier led to restrictive containment measures involving social distancing and the closure of commercial activities that resulted in operational challenges (The Business Research Company, 2021). Flexographic printing method of flexible packaging with solvent based inks for food and industrial products maintains a leading position in this segment compared to other printing methods (Siegwerk, 2017). Its development is accompanied by constant improvement of materials and technologies. The use of new types of polymers in combination with the latest technologies of exposure and processing has completely changed the plate making processes. Ukrainian flexographic printing companies are not far behind world leaders and are actively implementing the latest developments. These processes require constant and thorough testing, analysis and research. Accordingly, the analysis of the factors influence on the flexographic printing process of flexible packaging with solvent based inks and the creation of a prognostic model of their influence is extremely relevant.

Literature Review

In the work (Gurgal et al., 2013), the factors analysis of narrow-web flexographic printing of a labels by UV inks was carried out. If one talks about flexographic printing technology with solvent based inks, this printing method differs from the narrow-web one in a more complex preparation of consumables for printing. This primarily applies to the preparation of printing inks (Harper Anilox & Coating Division, 2020), control of its viscosity, control of the surface energy of printed materials (Kukura, Kukura & Repeta, 2010). The influence of the surface properties of polymer films on the optical parameters of imprints and the adhesion of flexographic inks was studied by Repeta (2013). It is established that the optimal optical and adhesive values of the imprints can be obtained at the surface energy above 38 mN/m.

Another element of the ink supply systems in flexographic printing method is a doctor blade, which is designed to remove the excess ink from the surface of the anilox roller and thus adjust the amount of ink supplied to the photopolymer printing plate and consequently printed material. Manufacturers of doctor blades produce blades of different configurations and of different materials (Repeta, 2018). There is no opinion about the use of a certain universal doctor blade. According to practical recommendations, different types of doctor blades are used for different inks in one printing press, for example, with white inks and inks with metallized pigments it is necessary to install thick doctor blades, and with increasing the image lineature it is recommended to select a blade with a thinner working edge (Daetwyler, 2021).

Double-sided adhesive mounting tapes are used to install the flexographic plate on the sleeve or plate cylinder and hold it firmly during the printing process. According to the results of the study (Eggleston, 2007; 3M, 2022), it is found that with increasing the tape stiffness increases the solid area saturation, and squeezing begins in 2% of the halftone value. In the case of the plate mounting that contains solid and halftone areas at the same time, a universal tape with intermediate stiffness is selected.

Photopolymer properties (thickness, roughness and surface properties) and reproductive characteristics of the printing plate are very important in terms of quality of the finished imprint, determining the lineature of the raster image, the accuracy of all its elements reproduction, the uniform printing of solid areas and the plate wear resistance (Hamblyn, 2015; Valdec, Miljković & Čerepinko, 2018). That is why the improvement of manufacturing technology of printing plates and the use of new types of polymers have revolutionized flexography, allowing one to raise the quality of the reproduced image to a new level (Vest, 2017). This breakthrough would be impossible to achieve without improving the technology of manufacturing anilox rollers, the parameters of which are a determining factor in the formation of the ink layer on the printing plate elements (Harper, 2005; Savickas, Stonkus & Jurkonis, 2020) and a key element in the ink transfer system in flexography (Bould et al., 2011).

The regulating element of this system is the pressure between the anilox and the printing plate and between the printing plate and the printing cylinder, which ensure the optimal ink application on the imprint (Bohan et al., 2003). As for the solvent based printing ink itself, its main technological parameter, which requires constant monitoring during the printing process, is its viscosity (Gencoglu, 2012; Kukura & Kukura, 2008). And since the fixation of alcohol-soluble inks occurs as a result of the solvent evaporation, a significant influence on this process has the drying temperature of the imprints (Olsson et al., 2007).

All these parameters, influencing each other, as a result determine the final quality of the imprint, which is characterized by the optical density parameters as well as squeezing of printing elements in addition to the accuracy of the original reproduction (Żołek-Tryznowska et al., 2020).

Thus, the flexographic printing process of packages with solvent based inks can be considered as a set of elements that are in certain relationships and connections with each other, interact with each other and create a certain integrity – the system.

The aim of the article is to establish the importance of factors, determine the optimal parameters and construct prognostic models of the impact of selected priority factors on the quality of the flexographic printing process using fuzzy logic tools.

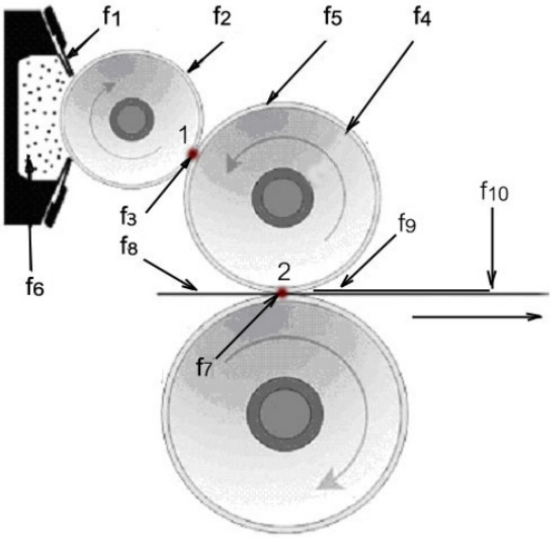
Methods, Results and Discussions

Analysis of Factors by Ranking Method

Accordingly, the following factors are established that determine the quality of the flexographic printing process with solvent based inks:

f_1 – is a type of knives of Doctor Blade system (DB)
f_2 – is a type of an anilox roller (AN)
f_3 – is pressure between an anilox roller and a plate (PR1)
f_4 – is a type of an adhesive mounting tape (TE)
f_5 – are parameters of a photopolymer printing plate (PP)
f_6– are rheological parameters of the ink (VI)
f_7 – is pressure in the printing NIP (PR2)
f_8 – are surface properties of the printed material (SP)
f_9 – is thickness of the ink layer (IL)
f_{10}– is a drying mode of imprints (ID).

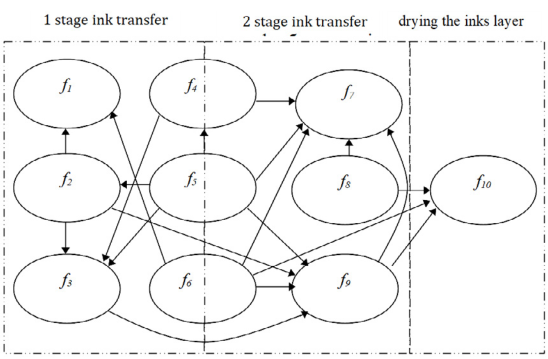
Figure 1 shows the scheme of operation of the flexo–graphic printing press and the influence of selected factors on the printing process.



» **Figure 1:** *Scheme of the operation of the flexographic printing press: f_1-f_{10} are factors that determine the printing process quality; 1 and 2 are areas where the ink transfer happens*

One of the tools for constructing the output information field in the analysis of processes is the semantic network.

The set of factors that determine the flexographic process quality is a set $F=(f_1, f_2, f_3 ... f_n)$. The set of factors F and possible relationships between them are presented in the form of semantic network (oriented graph). The vertices of the graph (Figure 2) indicate the presence of the set elements, and the arcs connect these vertices according to the established connections. The use of such a semantic model allows one to clearly describe the basic procedures of the process, identifyty the factors of influence, the relationship between them, and to ensure the appropriate level of their formalization for further study by the appropriate mathematical apparatus.



» **Figure 2:** *Stages of the ink layer formation and the oriented graph of the quality factors of the flexographic printing process with solvent based inks*

Factors, as elements of a semantic network (Figure 2) are placed taking into account the stages of the ink layer formation on imprints as it can be seen from Figure 1. Thus, the factors f_4 – a type of an adhesive tape, f_5 – the parameters of the photopolymer printing plate, f_6 – the rheological parameters of the ink are involved in two stages of the ink layer formation, which clearly makes it one of the most important. To establish the importance of all factors in the flexographic printing process of flexible packaging with solvent based inks, the ranking method is used (Senkivskyy et al., 2020; Tymchenko et al., 2022).

To begin with, the number of calculated influences and dependencies for each of the factors is schematically shown in Table 2. Based on the semantic network (Figure 2) partial graphical models are constructed for each of the factors showing the hierarchy of influences or dependencies between factors. These partial models (Figure 3) will also be the input base for numerical values to quantify and determine their importance.

Table 1

Number of influences and dependencies of factors

The Ways	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
influences	0	3	1	2	5	4	0	2	2	0
dependencies	2	1	3	1	0	0	5	0	4	3

Total weight and rank of factors taking into account direct and indirect influences and dependencies is calculation as follows: For our semantic network, the following conditions are set (Senkivskyy, Pikh & Melnykov, 2013):

1. Let k_{ij} - is a number of influences (i = 1 – direct and i = 2 – indirect) or dependencies (i = 3 – direct, i = 4 – indirect) for j–th factor (j = 1,...,n); w_i– is the weight of i–th type.
2. A factor that has no relationships is assigned a value of zero.
3. The conditional values for the weight coefficients of direct and indirect influences in conventional units are the following: w_1 = 10, w_2 = 5, w_3 =-10, w_4 =-5;
4. The total weight values are denoted by S_{ij}:

$$S_{ij} = k_{ij} w_i \;\; (i = 1,2,3,4; \;\; j = 1,...,n) \tag{1}$$

where n – is the number of the factor;

5. For the semantic networks (Figure 1) in view of (1), the formula for calculating the total weight values for each factor is received:

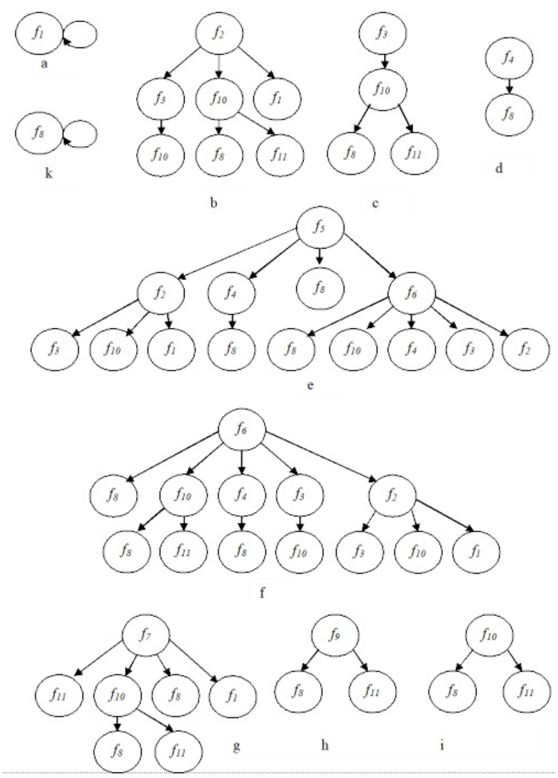
$$S_{ij} = \sum_{i=1}^{4} \sum_{j=1}^{10} k_{ij} w_i \tag{2}$$

6. The weight values are S_{3j} < 0 and S_{4j} < 0, because according to the given initial conditions w_3 < 0 and w_4 < 0;

7. To reduce the total weight values of the factor with the lowest priority to zero and the rest to a positive value, the formula (2) is transformed into the form:

$$S_{Fj} = \sum_{i=1}^{4}\sum_{j=1}^{10} k_{ij} w_i + P \tag{3}$$

where P = max|S_{3j}| + max|S_{4j}|



» **Figure 3:** *Graphic models of the influence of factors of the flexographic printing process (a – k)*

The coefficient k_{1j} are determined direct influences. Dependencies are determined by obtaining the coefficients are determined by obtaining the coefficients k_{3j}. The combined consideration of indirect influences or dependencies of the factor (i. e. the influence or dependency due to other factors) determines the coefficients k_{2j} and k_{4j}.

The results of the calculations form a table with the subsequent establishment of the ranks of the factors (Table 2).

When determining the total weight and ranking factors, both direct and indirect influences and dependencies for each of them are taken into account (Senkivskyy, Pikh & Melnykov, 2013).

Analysing the semantic network, four coefficients can be calculated for each factor that will characterize all the options for the relationship between them.

Table 2

Calculated data of coefficients and factor ranking

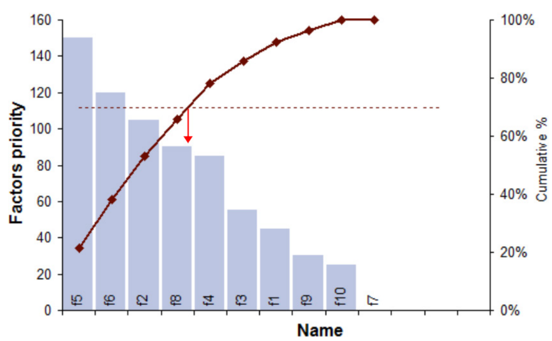
Factor number j	k_{1j}	k_{2j}	k_{3j}	k_{4j}	S_{1j}	S_{2j}	S_{3j}	S_{4j}	S_{Fj}	Factor rank r_j
f_1	0	0	2	1	0	0	-20	-5	45	7
f_2	3	3	1	0	30	15	-10	0	105	3
f_3	1	2	3	1	10	10	-30	-5	55	6
f_4	2	1	1	0	20	5	-10	0	85	5
f_5	5	6	0	0	50	30	0	0	150	1
f_6	4	2	0	0	40	10	0	0	120	2
f_7	0	0	5	4	0	0	-50	-20	0	10
f_8	2	0	0	0	20	0	0	0	90	4
f_9	2	0	4	4	20	0	-40	-20	30	8
f_{10}	0	0	3	3	0	0	-30	-15	25	9

As it can be seen from Table 2, the value *P* (formula 3) will be obtained from the sum of numerical values max|S_{3j}| = 50; and max|S_{4j}| = 20 will be 70 units. As a result, one obtains the resulting quantitative weight of factors, which is the basis for establishing the appropriate rank for each of them, which is equivalent to the priority of their impact on the flexographic printing process of packaging with solvent based inks.

Construction of a prognostic model of the factors influence using the fuzzy logic tools

Using the Pareto empirical rule, the most important factors are selected that determine 70% of the quality of the flexographic printing process. As it can be seen from Figure 4, these will be the following factors:

f_5 – parameters of a photopolymer printing plate (PP);
f_6 – rheological parameters of the ink (VI);
f_2 – a type of an anilox roller (AN);
f_8 – surface properties of the printed material (SP).



» **Figure 4:** *Diagram of Pareto factor selection*

Having obtained four selected factors, their impact on the quality of the flexographic printing technological process of packaging is analysed. Taking into account that the information obtained in the survey on the factors influence on the process is characterized by fuzziness, the basis of fuzzy logic is used to analyse it.

Fuzzy logic is seen as an attempt to formalize two human capabilities: 1. The ability to communicate, consider and make rational decisions in an environment of inaccuracy, uncertainty, incomplete information, conflicting information, partial truth and partial possibilities; 2. The ability to perform various physical actions and mental tasks without any measurements and any calculations (Zadeh, 2008). The concept of a linguistic variable was introduced in the work of Latfi Zadeh (1970), who laid the foundations of fuzzy logic. Each lingvistic variable stands for a hypothetical proposition, it may assume either of the two truth values; the variable is not committed to either truth value unless a particular proposition is substituted for it (Klir & Yuan, 1995). The main stage of fuzzy logic is the fuzzyfication operation, i. e. the transformation of the original numerical data into a distribution that corresponds to the terms of the linguistic variable. In this case, each numerical value is described by one or more terms, and its degree of correspondence to the term is given as the degree of belonging to a fuzzy set (Zadeh, 1970).

The quality of the flexography printing process *Q* depends on the priority factors presented as linguistic variables such as Parameters of photopolymer printing plate (*PP*), Type of anilox roller (*AN*), Rheological ink parameters (*VI*) and Surface properties of the printed material (*SP*):

$$Q = f\,(PP, AN, VI, SP) \tag{4}$$

These linguistic variables, which ensure the quality of the printing process and assessment terms, are presented in Table 3.

Table 3
Linguistic variables of factors influence on the flexography printing quality

№	Variable	Universal set	Assessment terms
1	Parameters of photopolymer printing plate (lineature)	46-54 l/cm	Low
			Medium
			High
2	Type of anilox roller (lineature)	250-420 l/cm	Low
			Medium
			High
3	Rheological ink parameters (viscosity)	16-20 sec (Cup 4 mm)	Low
			Medium
			High
4	Surface properties of the printed material (surface energy)	34-40 mN/m	Low
			Medium
			High

As a result, the expert knowledge base which corresponds to the printing process for the highest level can be presented as follows:

if (PP = Low) or (PP = Medium) or (PP = High)
and (AN = Low) or (AN = Medium) or (AN = High)
and (VI = Low) or (VI = Medium) or (VI = Big)
and (SP = Low) or (SP = Medium) or (SP = High)
then (Q = Low) or (Q = Medium) or (Q = High)

Based on technical recommendations on the factors influence on the flexographic printing quality, the membership functions are constructed. Accordingly, the value of the variable "Parameters of photopolymer printing plate (lineature)" is determined on the universal set: $u_1 = 46$ l/cm; $u_2 = 48$ l/cm; $u_3 = 50$ l/cm; $u_4 = 52$ l/cm; $u_5 = 54$ l/cm. To linguistically assess this parameter, a set of fuzzy terms is used: *T (x) = <Low, Medium, High>*. In accordance with these terms, the membership functions of the linguistic variable "Parameters of photopolymer printing plate (lineature)" are obtained. The value of the variable in the form of fuzzy sets is as follows:

$$\text{Lineature of Printing Plate is Low} = \left(\frac{1}{46};\frac{0,90}{48};\frac{0,67}{50};\frac{0,33}{52};\frac{0,11}{54}\right),\ \text{l/cm;}$$
$$\text{Lineature of Printing Plate is Medium} = \left(\frac{0,11}{46};\frac{0,67}{48};\frac{1}{50};\frac{0,67}{52};\frac{11}{54}\right),\ \text{l/cm;}$$
$$\text{Lineature of Printing Plate is High} = \left(\frac{0,11}{46};\frac{0,33}{48};\frac{0,67}{50};\frac{0,90}{52};\frac{1}{54}\right),\ \text{l/cm.}$$

For the linguistic variable "Type of anilox roller (lineature)", the parameter is defined on the universal set: $u_1 = 250$ l/cm; $u_2 = 300$ l/cm; $u_3 = 340$ l/cm; $u_4 = 370$ l/cm; $u_5 = 420$ l/cm. To assess the variable, a set of fuzzy terms is used: *T(y) = <Low, Medium, High>*. Therefore, in relation to this parameter according to these terms, the value of this variable in the form of fuzzy sets is received as follows:

$$\text{Lineature of anilox roller is Low} = \left(\frac{1}{250};\frac{0,78}{300};\frac{0,55}{340};\frac{0,33}{370};\frac{0,11}{420}\right),\ \text{l/cm;}$$
$$\text{Lineature of anilox roller is Medium} = \left(\frac{0,11}{250};\frac{0,55}{300};\frac{1}{340};\frac{0,55}{370};\frac{11}{420}\right),\ \text{l/cm;}$$
$$\text{Lineature of anilox roller is High} = \left(\frac{0,11}{250};\frac{0,33}{300};\frac{0,55}{340};\frac{0,78}{370};\frac{1}{420}\right),\ \text{l/cm.}$$

For the linguistic variable "Rheological ink parameters (Viscosity)", the parameter is defined on the universal set: $u_1 = 16$ s; $u_2 = 17$ s; $u_3 = 18$ s; $u_4 = 19$ s; $u_5 = 20$ s. To assess the variable, a set of fuzzy terms is used: *T(z) = <Low, Medium, High >*. Therefore, in relation to this parameter according to these terms, the value of this variable in the form of fuzzy sets is received as follows:

$$\text{Viscosity is Low} = \left(\frac{1}{16};\frac{0,88}{17};\frac{0,55}{18};\frac{0,33}{19};\frac{0,11}{21}\right),\ \text{s;}$$
$$\text{Viscosity is Medium} = \left(\frac{0,11}{16};\frac{0,55}{17};\frac{1}{18};\frac{0,55}{19};\frac{0,11}{21}\right),\ \text{s;}$$
$$\text{Viscosity is } \textit{High} = \left(\frac{0,11}{16};\frac{0,33}{17};\frac{0,55}{18};\frac{0,88}{19};\frac{1}{21}\right),\ \text{s.}$$

The linguistic variable "Surface properties of the printed material (surface energy)", as another factor in the printing process quality, is defined on the universal set:

u_1 = 34 mN/m; u_2 = 36 mN/m; u_3 = 38 mN/m;
u_4 = 40 mN/m; u_5 = 42 mN/m.

For linguistic assessment of the parameter, a set of fuzzy terms is used: *T (r) = <Low, Medium, High>*.

Different values of the variable "Surface properties of the printed material (surface energy)" are presented in the form of fuzzy sets:

$$\text{Surface energy is Low} = \left(\frac{1}{34};\frac{0,88}{36};\frac{0,55}{38};\frac{0,33}{40};\frac{0,11}{42}\right),\ \text{mN/m;}$$
$$\text{Surface energy is Medium} = \left(\frac{0,11}{34};\frac{0,55}{36};\frac{1}{38};\frac{0,55}{40};\frac{0,11}{42}\right),\ \text{mN/m;}$$
$$\text{Surface energy is High} = \left(\frac{0,11}{34};\frac{0,33}{36};\frac{0,55}{38};\frac{0,88}{40};\frac{1}{42}\right),\ \text{mN/m.}$$

A fuzzy knowledge base is formed on the selected quality parameters of the flexographic printing process with solvent based inks:

1. For the flexographic printing quality term «Low»:
- If «PP» is «Low», «AN» is «Medium», «VI» is «Medium», «SP» is «High»
or
- If «PP» is «Medium», «AN» is «Low», «VI» is «Big», «SP» is «Low» then Q is «Low»

2. For the flexographic printing quality term «Medium»:
- If «PP» is «Medium», «AN» is «Medium», «VI» is «Medium», «SP» is «Medium»
or
- If «PP» is «Medium», «AN» is «High», «VI» is «Big», «SP» is «High» then Q is «Medium»

3. For the flexographic printing quality term «High»:
- If «PP» is «High», «AN» is «High», «VI» is «Low», «SP» is «High»
or
- If «PP» is «High», «AN» is «High», «VI» is «Medium», «SP» is «High» then Q is «High».

According to the knowledge base, fuzzy logical equations are formed to prognostic variant of the quality of printing process of packaging:

$$\begin{aligned}\mu^{low}(Q) &= \mu^{low}(PP)\wedge\mu^{med}(AN)\wedge\mu^{med}(VI)\wedge\mu^{high}(SP)\vee\mu^{med}(PP)\wedge\mu^{low}(AN)\wedge\mu^{big}(VI)\wedge\mu^{low}(SP);\\ \mu^{med}(Q) &= \mu^{med}(PP)\wedge\mu^{med}(AN)\wedge\mu^{med}(VI)\wedge\mu^{med}(SP)\vee\mu^{med}(PP)\wedge\mu^{high}(AN)\wedge\mu^{big}(VI)\wedge\mu^{med}(SP);\\ \mu^{high}(Q) &= \mu^{high}(PP)\wedge\mu^{high}(AN)\wedge\mu^{low}(VI)\wedge\mu^{high}(SP)\vee\mu^{high}(PP)\wedge\mu^{high}(AN)\wedge\mu^{med}(VI)\wedge\mu^{high}(SP).\end{aligned} \quad (5)$$

When substituting the degrees of belonging to the system of fuzzy logical equations, one of the options for calculating the quality of the flexography printing process of packaging is obtained:

$$\begin{aligned}\mu^{low} &= 0,33\wedge 0,78\wedge 0,55\wedge 0,88\vee 0,67\wedge 0,22\wedge 0,88\wedge 0,33 = 0,33\\ \mu^{med} &= 0,67\wedge 0,78\wedge 0,55\wedge 0,55\vee 0,67\wedge 0,89\wedge 0,88\wedge 0,55 = 0,55\\ \mu^{high} &= 0,9\wedge 0,89\wedge 0,55\wedge 0,88\vee 0,9\wedge 0,89\wedge 0,89\wedge 0,9 = 0,89\end{aligned}$$

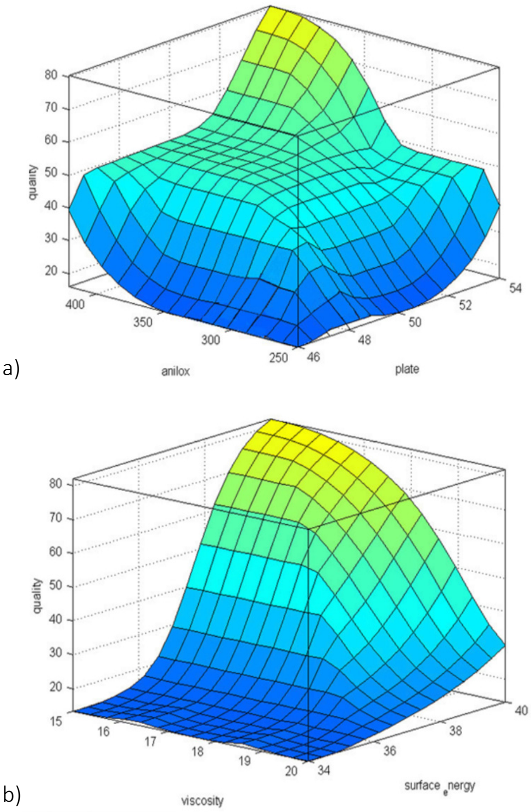
After performing the defuzzyfication operation "centre of gravity" principle using the factors values, the numerical value of the quality parameter of the flexography printing process is obtained (Rotshteyn, 1999):

$$Q = f(PP, AN, VI, SP) = \frac{\sum_{i=1}^{m} u_i \cdot \mu(u_i)}{\sum_{i=1}^{m} \mu(u_i)} \quad (6)$$

Therefore, having performed the defuzzyfication operation, a quantitative parameter of the process quality is obtained:

$$Q = \frac{1\cdot 0,33 + 50\cdot 0,55 + 100\cdot 0,89}{0,33 + 0,55 + 0,89} = 66,0\%$$

To test the formed knowledge base and construct a prognostic model of the influence of priority factors, a package for developing fuzzy control systems – Fuzzy Logic Toolbox system of the Matlab technological calculation environment and Mamdani principle is used (Mamdani & Assilian, 1975). Figure 5 presents the constructed membership functions for three linguistic variables.



» **Figure 5:** *Prognostic models of the influence of selected factors on the flexographic printing process of packaging: a - the influence of the parameters of the anilox roller and the printing plate; b - the influence of the viscosity of the printing ink and the surface energy of the substrate.*

The simulation results (Figure 5) show the adequacy of the developed knowledge base and the possibility of its use for forecasting assessment of the quality of flexography printing process when selecting the priority factors weight.

Conclusions

The quality factors of flexographic printing process of flexible packaging with solvent based inks were determined. By constructing semantic networks of the influence and dependencies of factors and the ranking method, the factors priority has been established by giving them the appropriate weight. Using the Pareto rule and the construction of the corresponding diagram, four main factors are identified, the influence of which provides 70 % of the studied process quality. It is established that the most priority factors are the parameters of the printing plate, the rheological parameters of the ink, the lineature of the anilox roller and the surface properties of the material to be printed, with the following calculated values: 150, 120, 105 and 90 units, respectively.

As a result of the simulation of the influence of priority flexographic printing factors using fuzzy logic, a base of knowledge and fuzzy logical equations are formed to calculate the membership functions of linguistic variables with the corresponding given terms. Their logical analysis and the defuzzyfication operation had allowed obtaining a quantitative assessment of the quality of the flexographic printing process. In addition, the Fuzzy Logic Toolbox system of the Matlab technological computing environment has constructed prognostic models of the influence of parameters of the printing plate, anilox roller, printing ink viscosity and surface energy, which will a priori predict the quality of flexographic printing process with solvent based inks.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

3M (2022) *3M Adhesives & Tapes Solutions.* Available from: https://www.3m.co.uk/3M/en_GB/bonding-and-assembly-uk/applications/flexographic-plate-mounting-tapes [Accessed 12th January 2022].

Bohan, M., Townsend, P., Hamblyn, S., Claypole, T. & Gethin, D. (2003) *Evaluation of Pressures in Flexographic Printing.* Foundation of Flexographic Technical Association, Inc. Available from: https://www.researchgate.net/profile/Tim-Claypole-2/publication/265409485_Evaluation_of _Pressures_in_Flexographic_Printing/links/54ccbb2a0cf298d6565ac1fa/Evaluation-of-Pressures-in-Flexographic-Printing.pdf [Accessed 12th January 2022].

Bould, D., Hamblyn, S., Gethin, D. & Claypole, T. (2011) Effect of impression pressure and anilox specification on solid and halftone density. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture.* 225, 699-709. Available from: doi: 10.1177/2041297510394072

Daetwyler (2021) *Ink transfer technology. dot gain and ink film thickness.* Available from: https://daetwyler.co.uk/wp-content/uploads/2021/12/ink_transfer_technology.pdf [Accessed 20th January 2022]

Eggleston, J. (2007) *Plate mounting tapes and print quality... Staying on top at high speed.* Available from: https://www.researchgate.net/publication/296854547_Plate_mounting_tapes_and_pri%20nt_quality_Staying_on_top_at_high_speed [Accessed 20th January 2022].

Gencoglu, E. (2012) Influence of ink viscosity on dot gain and print density in flexography. *Asian Journal of Chemistry.* 24 (5), 1999-2002.

Gurgal, N., Repeta, V., Senkivsky, V. & Shybanov, V. (2013) Definition of Quality Criteria of the Technological process of Narrow Web UV-Printing. *Journal of Graphic Engineering and Design.* 4 (2), 7-11.

Hamblyn, A. (2015) *Effect of plate characteristics on ink transfer in flexographic printing.* PhD thesis. Swansea University.

Harper Anilox & Coating Division (2020) *Specifying the Right Anilox Roll.* Available from: https://www.harperimage.com/AniloxRolls/Anilox-Guides/Specifying-the-Right-Anilox- [Accessed 14th January 2022].

Harper, C. (2005) Anilox line screens – stabilizers of the ink film. *Flexo & Gravure Asia*. 3-2005, 14-15.

Klir, J. G. & Yuan, B. (1995) *Fuzzy Sets and Fuzzy Logic: Theory and Applications.* Upper Saddle River, New Jersey, Prentice Hall, p. 574.

Kukura, V. & Kukura, Yu. (2008) Research of some parameters of the printing process of flexographic printing in production conditions. *Scientific notes of UAP.* 1 (13), 106-109.

Kukura, Y., Kukura, V. & Repeta, V. (2010) Investigation of surface properties of polypropylene films in production conditions. *Printing and Publishing.* 1, 107-111.

Mamdani, E. H. & Assilian, S. (1975) An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies.* 7 (1), 1-13. Available from: doi: 10.1016/S0020-7373(75)80002-2

Olsson, R., Yang, L., van Stam, J. & Lestelius, M. (2007) Effects of elevated temperature on flexographic printing. In: *Advances in Printing and Media Technology, Proceedings of the 34th International Research Conference of iarigai, 9-12 September 2007, Grenoble, France.* Zagreb, Acta Graphica Publishers. pp. 85-91.

Repeta, V. (2013) Influence of Surface Energy of Polymer Films on Spreading and Adhesion of UV-Flexo Inks. *Acta Graphica.* 24 (3-4), 79-84.

Repeta, V. (2018) Innovations in flexographic and gravure printing (squeegee knives for ink systems). *Packaging magazine.* 1, 35-37.

Rotshteyn, A. (1999) *Intelligent identification technologies: fuzzy sets, neural networks, genetic algorithms.* Vinnytsia, UNIVERSUM-Vinnytsya, p. 320.

Savickas, A., Stonkus, R. & Jurkonis, E. (2020) Investigation of anilox roller cell clogging. *Journal of Graphic Engineering and Design*. 11 (2), 63-67. Available from: doi: 10.24867/JGED-2020-2-061

Senkivskyy, V., Pikh, I. & Melnykov, O. (2013) The method of ranking factors influencing the quality and manufacturing processes. *Printing and Publishing.* 61-62 (1-2), 33-41.

Senkivskyy, V., Pikh, I., Senkivska, N., Hileta, I., Lytovchenko, O. & Petyak, Y. (2020) Forecasting assessment of printing process quality. In: *International Scientific Conference "Intellectual Systems of Decision Making and Problem of Computational Intelligence", ISDMCI 2020, 25-29 May 2020, Zalizniy Port, Ukraine.* New York, Springer. pp. 467-479. Available from: doi: 10.1007/978-3-030-54215-3_30

Siegwerk (2017) *Flexible packaging. Two ink systems, different strengths.* Siegburg, Siegwerk Druckfarben AG&Co. KGaA.

The Business Research Company (2021) *Solvent-Based Printing Inks Global Market Report 2021: COVID-19 Impact And Recovery To 2030.* The Business Research Company. Report number: TBR669B

Tymchenko, O., Khamula, O., Vasiuta, S., Sosnovska, O. & Mlynko, O. (2022) A Comparison of Methods for Identifying the Priority Hierarchy of Influencing Factors. In: *3rd International Workshop on Intelligent Information Technologies and Systems of Information Security, IntelITSIS'2022, 23-25 March 2022, Khmelnytskyi, Ukraine.* CEUR Workshop Proceeding. pp. 228–237.

Valdec, D., Miljković, P. & Čerepinko, D. (2018) The Impact of Top Dot Shapes of the Printing Plate on Dot Formation in Flexography. *Technical Gazette*. 25 (2), 596-602. Available from: doi: 10.17559/TV-20161003121341

Vest, R. (2017) *Flat-Top Dots for All: The Evolution of Flexo's Game-Changing Technology.* Available from: https://graphics.macdermid.com/application/files/9215/5136/8937/TAGA17_Vest_3-9-17.pdf [Accessed 12th January 2022].

Zadeh, L. (1970) Decision-Making in Fuzzy Environment. *Management Science*. 17 (4), 141-160. Available from: doi: 10.1287/mnsc.17.4.B141

Zadeh, L. (2008) Is there a need for fuzzy logic?. *Information Sciences.* 178 (13), 2751-2779. Available from: doi: 10.1016/j.ins.2008.02.012

Żołek-Tryznowska, Z., Rombel, M., Petriaszwili, G., Dedijer, S. & Kašiković, N. (2020) Influence of Some Flexographic Printing Process Conditions on the Optical Density and Tonal Value Increase of Overprinted Plastic Films. *Coatings*. 10 (9), 1-12. Available from: doi: 10.3390/coatings10090816