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ANALYSIS AND QUALITY IMPROVEMENT OF THE UV PRINTING PROCESS ON GLASS PACKAGINGS

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Abstract: The paper presents the results of qualitative analysis and improvement of the printing process with UV inks on glass packaging with the use of selected quality management tools and methods. The research was carried out in a glass factory located in the Silesian Voivodeship in Poland. The qualitative analysis included the risk assessment related to the printing process with UV inks, print quality, and the type of nonconformities occurring during printing. Based on the conducted analyses, proposals for improving the printing process with UV inks were determined. As part of the analyses, such methods and quality tools as fault tree, FMEA analysis, Pareto-Lorenz diagram, and tree diagram were used. It was found that the most common nonconformity of printing with UV inks on glass packaging is smearing of the emulsion covering the glass vessel and that most of the nonconformities resulted from errors made by employees, which were caused by non-compliance with the instructions for individual activities by people employed in production positions and quality inspection employees. It was proposed to implement employee training at individual workplaces, in particular the implementation of instructions for performing specific activities, as well as the introduction of additional employee supervision and implementation of changes in the management of the printing process and quality inspection of the decorated products.

Keywords: quality management, quality tools, glass packaging, UV printing process, improvement

1. INTRODUCTION

Glass is an extremely functional material that is difficult to replace. In everyday life, a person uses many everyday products that are made of glass. Glass is decorative, modern, effective and practical. Contemporary designers unambiguously turn towards lightness, transparency and fanciful solutions, creating perfect combinations for all those who appreciate individualism and uniqueness. Seemingly cold and uncomfortable glass can be warmed by using various prints directly on the glass pane (Dobrzyński and Żołędziowski, 2011). It is possible thanks to the use of the latest digital printing technique with UV inks. It is an environmentally friendly technology that fixes paints with ultraviolet rays on the surface of the printed substrate. The technology of printing with UV inks on glass has many advantages. The most important ones include high productivity, which is obtained thanks to the fixing of paints under the influence of UV radiation, as well as the aesthetics of the product, which is obtained thanks to varnishing. Moreover, glass products decorated with the use of UV technology are ecological and safe for health, as the paints and varnishes used in the decoration process do not contain harmful substances. Thanks to this, UV printing technology can be successfully used in the decoration of glass bottles and packaging used in the food, cosmetics, and pharmaceutical industries (Khadzhynova and Jakucewicz, 2016).

Currently, Poland occupies an important place on the global market for the production of glass packaging. All this has been achieved thanks to the constant improvement of production processes, technologies and products. As a result, consumers receive the highest quality glass products that are safe for the environment (BOSBank, 2018). The main recipients of glass packaging are enterprises in the food, spirit, pharmaceutical, cosmetic and tableware industries (Jaworski, 2015). Many companies decide to put their products in glass packaging due to the lack of harmful effects on the product. Glass does not go in reactions; it does not change the properties of the product, e.g. taste. The quality of glass packaging is certainly influenced by the high quality of the raw materials from which it is produced (Ziemba, 2011).

Enterprises offering their products in glass packaging strive to present their products in the best possible way. For this reason, they choose decorated packaging. They are decorated with the use of several methods. The most important of them are screen-printing, matting, varnishing, hot stamping, laser, and decal (Chmielewska et al., 2014). Of these methods, the most commonly used is the screen printing method, also referred to as the screen printing method. Screen-printing is performed with the use of a printed form, which is a template placed on a woven mesh, and the printing is performed with water or plastisol paints. Screen-printing is divided into flat and oval-shaped printing. In the case of flat screen-printing, the decorated element is placed on the table, where the screen is attached with the pattern. The screen is stationary during the printing process. A squeegee slides over it. This is done in the same way as with ceramic decal. When screen-printing on oval and round objects, the screen is flat or individually shaped to a given product. The screen moves with the printed object and the doctor blade is stationary (Ziemba, 2011).

The implementation of the process of printing with UV inks on glass is associated with the possibility of nonconformities. To effectively eliminate nonconformities, it is necessary to analyse them and find their root causes (Kardas, 2017; Kardas, 2018). For this purpose, qualitative analyses based on statistical analysis should be carried out using appropriate methods and tools (Makarov, 2015). To reduce variation of process and number of defects by effective problem solving Six Sigma techniques can be used (Tran et al., 2020; Simanova and Gejdoš, 2021). To reduce waste by streamlining the process Lean concept can be used (Ulewicz et al., 2021). The work is a case study with the use of selected methods and basic quality tools to reduce the incidence of nonconformities and the same improving the printing process with UV inks on glass.

2. METHODOLODGY

The aim of the work is to analyse and evaluate the printing process on glass packaging on the example of a glass bottle decorated with direct screen-printing with UV inks. The specific objectives include identifying critical areas and opportunities to improve the glass printing process.

The subject of the research is a glass factory located in the Silesian Voivodeship in Poland. The examined glassworks is one of the largest and most modern producers of coated glass, processed glass, and float glass in the world. The plant produces glass for use in residential and public utility interiors, for transport as well as for commercial applications. The largest group of products is made of float glass. In addition, the assortment offer of the tested glassworks also includes glass for applications in architecture, transport, and glass for technical applications. The examined glassworks also offers glass decoration services with UV paints and thermoplastics. The technology of this printing is reserved both for flat glass with regular shapes, as well as for oval and for round glass. Depending on the shape of the glass on which the printing is applied, there are flat-screen printing and screen-printing on oval objects. For the aim of the study, the analysis covered the process of printing with UV inks on flat glass, i.e. flat screen-printing. It consists of placing a decorated glass on a screen. The sieve is fixed and during the decorating process, the squeegee moves over the glass surface.

The work focuses on the qualitative analysis of glass decoration with UV paints in the studied enterprise with the use of selected methods and quality management tools. The analysis covered the risk associated with the printing process with UV inks, print quality, and types of nonconformities occurring during printing. Based on the conducted analysis, proposals were made to improve the printing process with UV inks.

A fault tree as a tool of the Fault Tree Analysis – FTA method (Patil, 2013) was used to analyse the risks associated with UV printing. The analysis of the risk associated with the printing process with the use of the fault tree was started by the identification of the so-called peak event, which in the analysed case was the most frequently found nonconformity. The reasons for the occurrence of this event were identified in four stages:

- the first stage consisting of the identification of the so-called intermediate events, i.e. events leading to the peak event,
- the second stage, which consists in establishing a hierarchical structure of the causal tree by taking into account intermediate events and linking them to the existing choices,
- the third stage, which focuses on identifying the sources of the peak event, i.e. basic events,
- the fourth stage consists in identifying the lowest level faults, which are the basic and at the same time the key factor of the peak event (Patil, 2013).

A cause tree developed in this way will be a graphical representation of the combination of events that could lead to the peak event. The analysis of this tree will allow identifying the causes leading to the error in the process of printing with UV inks on glass.

Enterprises strive to ensure that the products they produce are of the highest quality and that the number of nonconformity products was as small as possible (Siwiec and Pacana, 2019). To achieve this, actions should be taken to indicate the causes of the production nonconformities risk (Stasiak-Betlejewska and Czajkowska, 2017). For this purpose, the FMEA analysis was used in relation to the company and the analysed glass printing process. Its conduct will allow not only to indicate production nonconformities on the tested product but also to determine their causes and effects (Dziuba et al., 20121). The results of this analysis make it possible to formulate

corrective actions, the implementation of which may reduce the number of nonconformity products, risk of the process (Krynke et al., 2021) and thus improve the quality of painting on glass. The FMEA analysis carried out for the aim of the study was carried out in three stages. The first was to list the types of nonconformities found. They were: *smearing of the coating emulsion, chipping of the coating emulsion, blur overprint, chipping overprint, recovering overprint on the left side, recovering overprint in the middle part, recovering overprint on the right side, slandering the vessel thread, slandering the vessel ring, slandering the edge of the vessel bottom, cracking the vessel*. Each of these nonconformities has been assigned a symbol and has also been quantified in a quality inspection conducted over the six weeks of plant operation. This inspection covered 846 glass products decorated with the use of UV technology. The second step was to identify the effects of these nonconformities, and the third was to identify their causes. On this basis, the general level of risk related to nonconformities (RPN) was determined. It was calculated as the product of the incidence of nonconformities (OCC), the significance of the detected nonconformities for customers (SEV), and the potential detection of errors during product quality inspection (DET). Each of the indicators used could take values from 1 to 10 (Mazur, 2018).
The structure of nonconformities found during the UV printing process was determined using the Pareto-Lorenz diagram (Bamford and Greatbanks, 2005). For this purpose, the individual types of nonconformities found during the production process (Bhale et al., 2017) over the six-week period were analysed. The identified nonconformities were divided according to the frequency of occurrence with the use of the ABC method (Borkowski et al., 2014). The nonconformities were divided into three groups, namely: A - critical nonconformities, B - important nonconformities, C - less important nonconformities. Group A includes nonconformities, the cumulative percentage share of which was less than or equal to 80%, group B - whose cumulative percentage share was less than or equal to 95%, and group C - whose cumulative percentage share was greater than 95%.
Proposals for improving the quality of the UV printing process are presented using a tree diagram, one of the new 7 quality tools (Mizuno, 1988; Andrássyová et al., 2013; Nayatani et al., 2006). Based on the analysis of the process of printing with UV inks, the most common nonconformities, as well as the quality inspection methods used, the information on the methods of obtaining high-quality products was organized. The importance areas for the proper implementation of the printing process with UV inks were identified. The formulation of these groups of problems formed the basis for the development of the tree diagram. This diagram made it possible to indicate the appropriate and the most effective means of achieving the adopted goal, i.e. improving the quality and customer satisfaction (Ingaldi, 2021; Klimecka-Tatar, 2021) of the printing process with UV inks. The use of quality tools and methods is not an end in itself, but only a means to achieve an end - quality improvement and end-customer satisfaction (Pacana and Czerwińska, 2020; Pavletic, 2008; Tarí and Sabater, 2004).

3. RESULTS AND DISCUSSION

For nonconformity, which was one of the most common nonconformities found in the process of printing with UV inks on glass, a risk analysis was performed using the fault tree. The critical nonconformity (the so-called the peak event) was the blurring of the emulsion covering the glass vessel. Out of 1,200 inspected products, this nonconformity occurred in 258 cases, which was almost one-sixth of all nonconformities.

In order to find the cause of the blurring of the emulsion coating the glass vessel, it was necessary to determine the so-called intermediate events. The conducted analyzes showed that an indirect event that led to the occurrence of this nonconformity was the excessive drying time of the paint with UV rays or improper coating of the glass vessel with the emulsion. Improper setting of the machine, which in turn was caused by human error, could cause too long drying time of the paint with UV rays. Inadequate coating of the glass vessel with the emulsion could result from too thin or too thick a layer of the emulsion applied to the glass vessel. Both in the first and in the second case, the reason for this may be human error, because the emulsion coating is a manual process, or a device error, because a specially designed device measures the thickness of the applied emulsion. The fault tree for the analysed event - blurring of the emulsion covering the glass vessel is shown in Figure 1.

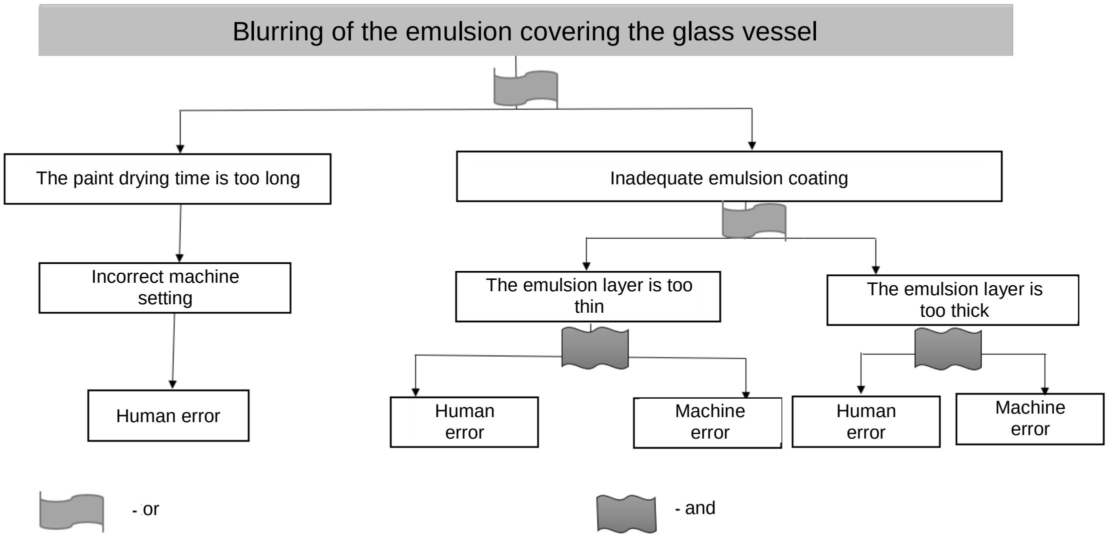

Fig. 1. Fault tree for the analysed event - blurring of the emulsion covering the glass vessel

The main cause of critical nonconformity - blurring of the emulsion covering the glass vessel was primarily human error. The plant's employees apply the emulsion by hand. Its layer must be of an appropriate thickness, which is measured using dedicated tools. The analysis of the identified nonconformities showed that the applied emulsion layer was too thin, and this problem was not detected as the measurement made with a dedicated device was incorrect.

The results of the FMEA analysis to determine the level of risk associated with all identified nonconformities during the analysis period are summarized in Table 1.

Table 1.
FMEA analysis for detected nonconformities of glass products decorated with UV technology

Symbol	Potential Failure Mode (the nonconformity name)	Potential Failure Effect	Potential Causes	Current State				
				Current Controls	OCC	DET	SEV	RPN
T1	Smearing of the coating emulsion	The product does not meet the aesthetic values	Employee error - too thin layer of the coating emulsion, incorrect measurement of the emulsion thickness	SCOOTCH test	9	8	8	576
T2	Chipping of the coating emulsion	The product does not meet the aesthetic values	Employee error, incorrect measurement of the emulsion thickness	Xcross test - paint adhesion test	8	8	8	512
T3	Blur overprint	The product does not meet the functional requirements or aesthetic values	Employee error, too thin a layer of paint	SCOOTCH test	8	7	8	448
T4	Chipping overprint	The product does not meet the functional requirements or aesthetic values	Drying time too long	Medium resistance test	7	8	7	448
T5	Recovering overprint on the left side	The product does not meet the aesthetic values	Employee's error - lack of uniformity of the coating with a layer of covering emulsion, incorrect measurement of the thickness of the emulsion	Medium resistance test. Abrasion test when the assortment is in contact with the assortment. Abrasion test in contact with the packaging	7	8	7	448
T6	Recovering overprint in the middle part	The product does not meet the aesthetic values	Employee's error - lack of uniformity of the coating with a layer of covering emulsion, incorrect measurement of the thickness of the emulsion	Medium resistance test. Abrasion test when the assortment is in contact with the assortment. Abrasion test in contact with the packaging	7	8	7	448

T7	Recovering overprint on the right side	The product does not meet the aesthetic values	Employee's error - lack of uniformity of the coating with a layer of covering emulsion, incorrect measurement of the thickness of the emulsion	Medium resistance test. Abrasion test when the assortment is in contact with the assortment. Abrasion test in contact with the packaging	7	8	7	448
T8	Slandering the vessel thread	The product is not suitable for use	Excessive pressure when washing	Visual inspection	9	9	9	729
T9	Slandering the vessel ring	The product is not suitable for use	Excessive pressure when washing	Visual inspection	9	9	9	729
T10	Slandering the edge of the vessel bottom	The product is not suitable for use	Excessive pressure when washing	Visual inspection	9	9	9	729
T11	Cracking the vessel	The product is not suitable for use	Excessive pressure during product quality inspection	Testing	9	9	9	729

The adopted minimum value of the risk priority number (RPN) was 100. The analysis showed that for each of the eleven identified nonconformities the indicator value was much higher. The highest value - 729 was obtained by four nonconformities, namely: slandering the vessel thread (T8), slandering the vessel ring (T9), slandering the edge of the vessel bottom (T10) and cracking the vessel (T11). A product with such nonconformities is not suitable for use. The first of the three nonconformities results from excessive pressure on the vessel during washing after the drying process with UV rays has been completed. On the other hand, the vessel cracks because of excessive pressure during the product quality inspection. These errors are caused by non-compliance with the instructions for performing specific activities by employees working in production positions, as well as by quality inspection employees. In order to reduce the number of these nonconformities, it is necessary to implement employee training at individual workplaces, in particular the implementation of instructions for performing specific activities, as well as the introduction of additional employee supervision.

In the case of one of the identified nonconformity, the value of the risk priority number (RPN) was 576. This nonconformity was smearing of the coating emulsion (T1). The product is covered with this emulsion by hand. It was diagnosed that the reason for the occurrence of this nonconformity was the application of too thin a layer of the emulsion and the failure to detect this error with a device designed to check the thickness of the applied emulsion layer. In order to reduce this type of nonconformity, it is necessary to implement more frequent and more precise checks on the thickness of the emulsion layer applied to the vessel.

The value of the risk priority number (RPN) in the case of nonconformity, which is the chipping of the coating emulsion (T2), was 521. A product with such nonconformity does not meet the aesthetic values, and thus the customer's requirements. It was diagnosed that the splashing of the covering emulsion occurs because of an employee's error in the stage of covering the vessel with the emulsion. The layer of this emulsion over the entire surface of the vessel should be even and have the same thickness. It was found that in places where a thicker layer of the emulsion was applied, it was chipping.

In the case of the remaining nonconformities, the value of the priority risk of non-compliance was 448. These nonconformities related to the blurring of the overprint (T3), which was caused by the application of too thin a layer of ink, printing chipping resulting from excessive drying time (T4), as well as the recovery of the overprint on the left side of the vessel (T5), the middle of the vessel (T6), and on the right side of the vessel (T7). It was found that the reason for these nonconformities was an employee's error - the lack of uniformity of the coating with a layer of the coating emulsion, as well as incorrect measurement of the thickness of the emulsion applied to the glass product.

Reducing the occurrence of the identified nonconformities requires the implementation of corrective actions. In particular, it is recommended to increase the supervision of employees involved in the implementation of individual production activities, in particular activities related to emulsion coating of the NBC polyester mesh and activities related to the application of paints. The implementation of the proposed repair activities may improve the quality of the decorated products manufactured by the examined glassworks. It can be assumed that increased supervision over employees performing individual production activities will contribute to the elimination or at least limitation of nonconformities arising during the process of decorating glassware.

The result of the analysis of the nonconformities structure using the Pareto-Lorenz diagram is shown in Fig. 2.

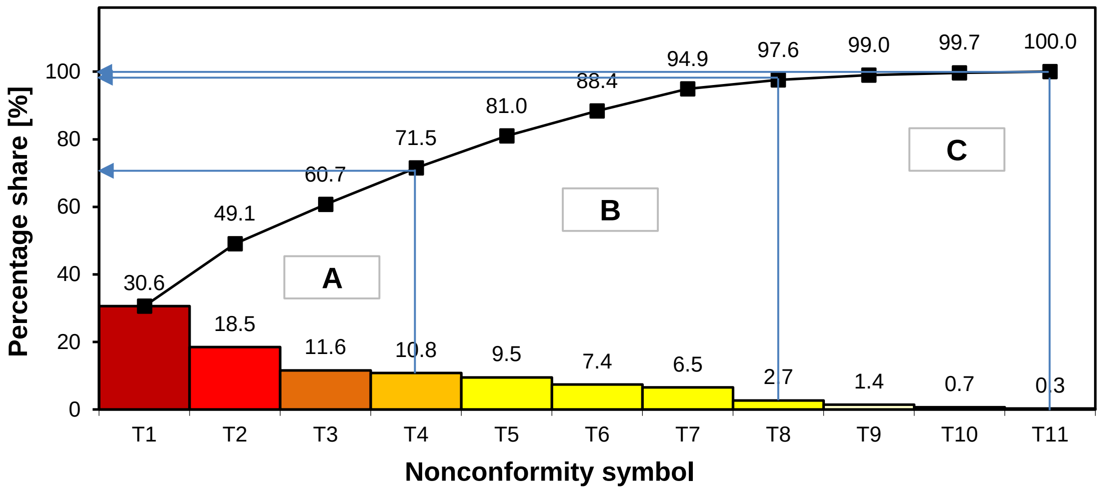

Fig. 2. Pareto-Lorenz diagram for detected nonconformities of glass products decorated with UV technology

The critical nonconformities (nonconformities from the "A" group) marked in the Pareto-Lorenz diagram in terms of their frequency of occurrence (cumulative percentage share ≤ 80%) are the smearing of the coating emulsion (T1), splashing of the coating emulsion (T2), blurring of the overprint (T3) as well as the chipping of the overprint (T4). These nonconformities accounted for 71.5% of the identified quality problems. The result of their occurrence is that the products do not meet the functional requirements or the aesthetic values required by the customer. Blurring and chipping of printing on glass products make the description printed in UV technology illegible, and therefore the customer is not able to learn about the basic features of the product from the packaging.

This is of particular importance for companies in the food, cosmetic and pharmaceutical industries, for which the examined glassworks produces glass packaging. In accordance with the provisions of the law in force in Poland and European Union countries, the manufacturer of glass packaging is obliged to include on each packaging information about the name of the product, the name of the manufacturer and the country of origin, the required and recommended precautions when using the product, the quantity of the product in the packaging, as well as the batch number and ingredients used in the production of the product. All kinds of chipping or blurring of the print on the glass packaging produced by the tested plant cause that the packaging does not meet the functional requirements. On the other hand, smears or splashes of the covering emulsion mean that these products do not meet the aesthetic requirements set by the customer. Important nonconformities (nonconformities from the "B" group) from the point of view of their frequency were recovery of the print on the left side (T5), recovery of the print in the middle part (T6), recovery of the print on the right side (T7), as well as slander of the thread vessels (T8). All these nonconformities mean that the products with which they were found do not meet the functional requirements. Less important nonconformities (discrepancies from the "C" group) from the point of view of frequency were slander of the vessel ring (T9), slander at the edge of the vessel bottom (T10), and vessel cracking (T11). In addition, these nonconformities mean that the products with which they were found do not meet the user requirements of the product. The result of using the tree diagram to improve the quality of the printing process with UV inks is shown in Fig. 3.

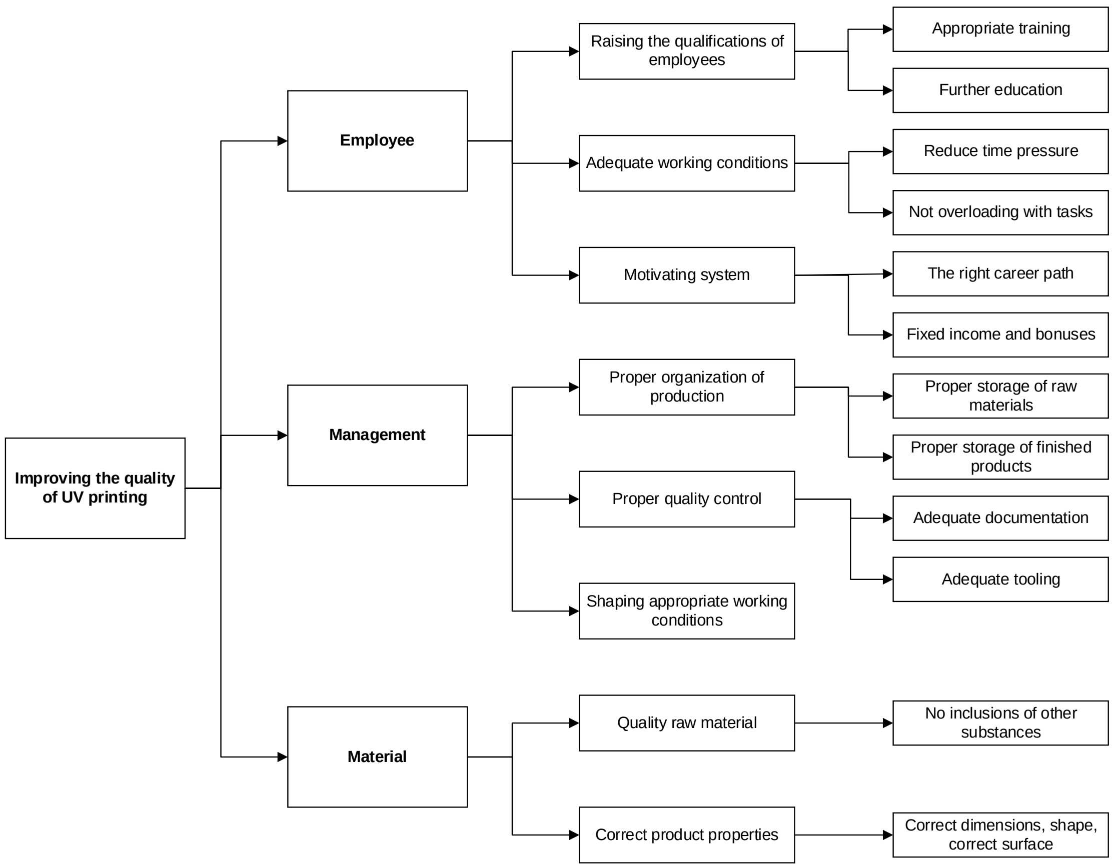

Fig. 3. Tree diagram for improving the quality of the printing process with UV inks

When analysing the diagram, it can be noticed that in order to improve the quality of the implemented process, it is necessary to implement changes in each of the three selected areas: employee, management, and material. In the first place, it is recommended to implement changes in the area of employees. The analyses of the reasons for the occurrence of nonconformities showed that the employees are responsible for most of them. Hence, it is necessary to improve the qualifications of employees through their appropriate training and continuous education, as well as to provide employees with appropriate working conditions by reducing time pressure and not overloading with excess tasks and information. It is equally important to implement an appropriate incentive system, and in particular to define clear criteria for career development and provide employees with a steady income and incentive bonuses (Potkány et al., 2021). It is also important to encourage the company's employees to strive for the perfect performance of their assigned tasks. However, this involves the need to develop and implement job instructions and to inspection employees, and in particular to check whether they perform their tasks flawlessly.

Another area requiring the implementation of changes is management. In this area, the company should introduce changes in the organization of the production process. It is recommended that they mainly cover issues related to the storage and warehousing of materials for production, mainly emulsions, and paints, as well as finished products. Changes in management should also cover the provision of appropriate working conditions for all persons employed in the production process, as well as for quality inspection employees. In terms of management, it is also recommended that the company implements changes in the field of quality inspection, and in particular that it should ensure proper documentation of all activities carried out in the field of quality inspection, as well as ensure the appropriate condition of the instrumentation used for this inspection.

The third area requiring the implementation of changes is the material used in the implementation of the printing process with UV inks. In order to ensure the high quality of this process, the glassworks should always use high-quality raw materials, and glass products decorated with UV technology had the correct dimensions, shape, and surface.

It is assumed that the implementation of changes in the three characterized areas may significantly contribute to the improvement of the quality of the printing process with UV inks. Certainly, these changes may reduce the number of nonconforming products.

4. CONCLUSION

The aim of the study was to analyse and evaluate the printing process on glass packaging on the example of a glass bottle decorated by direct screen printing with UV inks. The analyses carried out for the purposes of the study focused on determining the risk associated with the printing process with UV inks, print quality, and indicating the types of nonconformities appearing during printing. These analyses show that, despite the fact that in the glasswork understudy, the decorating process in UV technology is carried out in accordance with the requirements for this process and with all requirements regarding the type of paints used and drying time, there are irregularities that result in the production of non-compliant products. It was found that the most common nonconformities are: smearing of the coating emulsion, chipping of the coating emulsion, blur overprint, chipping overprint, recovering overprint on the left side, recovering overprint in the middle part, recovering overprint on the right side, slandering the vessel thread, slandering the vessel ring, slandering the edge of the vessel bottom, cracking the vessel. Most of these nonconformities are the result of mistakes made by employees. These errors are caused by non-compliance with the instructions for performing specific activities by people employed in production positions, as well as by quality inspection employees. In order to reduce the number of these nonconformities, it is necessary to implement employee training at individual workplaces, in particular the implementation of instructions for performing specific activities, as well as the introduction of additional employee supervision. It is also recommended to implement changes in the management of the printing process and quality inspection of the decorated products. It is important for the analysed production plant to implement changes in the documentation of all activities carried out in the field of quality inspection, as well as to ensure the appropriate condition of the tooling used for this inspection.

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