Limitation of Manufacturing Defects of the Selected Product in the Glass Mill

doi:10.2478/mape-2021-0041
Date of submission to the Editor: 05/2021
Date of acceptance by the Editor: 06/2021

MAPE 2021, volume 4, issue 1, pp. 453-464

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INTRODUCTION

Glass companies have a very difficult task because ensuring the quality of glass requires many specific activities. The aim of the plants is to ensure the appropriate, correct performance of products and, at the same time, to convince buyers that the manufactured products are not defective and that all customer expectations are met. There are many different types of defects in the production of glass. There may be visual defects, e.g. scratches or critical defects that directly endanger the life and health of the consumer, e.g. sharp rim, glass inside the product, bursting blisters, point at the bottom and others. All defects that occur during production create post-production waste, which has a significant impact on production costs. Hence, an extremely important role in the glass production process is played by quality control, which is of interest to many researchers (Bajdur et al. 2015; Borkowski et al. 2014; Raszewska and Ligarski 2017). Quality control can be active or passive, total or partial. Passive quality control is used in relation to finished products and consists in eliminating poorly made products, while active quality control covers the entire process and identifies sources of errors during its duration. Complete control is more reliable, but also more expensive, as all products are checked. However, it is not always feasible due to the complexity or nature of the product. For this reason, partial quality control is more often used, where individual pieces of a production batch selected at random are checked, or statistical control, where, based on statistical data and the calculus of probability, the number of products from a given batch to be checked is determined. The problem of ensuring high quality of manufactured products is one of the greatest challenges in managing a company today.

Actions aimed at identification and exclusion of defective products based on controls after the end of the production process should give way to preventive actions already during the production of the product. While 100% control of

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individual elements seems simple, with complex teams it becomes cumbersome and does not bring measurable benefits on the scale of the enterprise. A huge number of potential causes that may affect the formation of defects in the product makes it necessary to identify and take preventive actions against the most important ones, because removing all defects would turn out to be impossible due to the excessive time-consuming and required actions on a large scale, which could not bring the expected benefits (Lenik 2011).

This article presents the results of tests carried out as part of a project aimed at developing a method of reducing manufacturing defects of a selected product in a glass factory. Significant reasons for taking action in this area were too late detection of defects, an increased amount of post-production waste, i.e. bumps, and thus increased production costs, as well as a complaint from a customer who received defective goods. For the steel mill, these were high costs, as well as a loss of trust and the company's good image.

METHODOLOGY

The subject of the research was a bottle production line for a well-known brewing brand located in a glassworks. The bottles were manufactured using the blow blow method. The observation lasted 4 months. For the identification and analysis of the most important causes of defects occurring during production, qualitative methods were used, i.e. defect catalog, histogram, Pareto-Lorenz method, Ishikawa Diagram and FMEA (Failure Mode and Effects Analysis). As a result of the conducted research, the so-called post-production waste was calculated. cullet and costs related to the resulting defects. Moreover, on the basis of the obtained results, a new quality control work schedule was created and introduced, the production after the introduced changes was analyzed and a technical and economic comparison was made.

RESULTS

Description of the production process and the glass production control process

The production of the selected bottle is carried out in accordance with the specification containing the requirements of PN-EN ISO 9001:2008 and PN-EN ISO 22000:2005 as well as customer requirements. The bottles are manufactured using the blow blow method. This technology is used for the production of thick-walled narrow-hole packaging. This method uses blow molding for the entire product forming operation, both on the blank and mold sides. A bubble is blown out and formed into the shape of the finished product. Then the bubble is transported by means of a trigger to the proper form, where the finished product is blown out. The blow-blow method is used to produce packages with a maximum diameter of 95 mm and a height of 32 mm to 325 mm and a head diameter of 48 mm. The specificity of creating the bottle in question causes that the production is exposed to more frequent defects, such as:

- too much concavity/convexity,
- holes in technological overshoot,
- air bubbles,
- scratches on the entire surface of the bottle.

In order to reduce the production waste of this assortment, increased control of the wall thickness is carried out in the place of technological darkening, the measurement of the width and relief as well as the measurement of thermal shock. Due to large external damage (scratches), hot finishing is kept at the upper tolerance limit.

The glassworks works in a 4-team system, which means 3 shifts during one day, 7 days a week. It should be noted that with each change of machines, which is made when the assortment changes, there is always a smaller amount of bottle production. The time needed to change the assortment is approx. 3 hours. During this time, production continues, but the bottles do not meet the specifications and go directly to the sewer, where they are transported for smelting. The resulting waste was not taken into account in the conducted research.

As a result of a 10-day production analysis of the tested assortment, a production report was created containing the following data:

- total number of bottles produced,
- number of pallets produced during one shift,
- number of correctly made bottles, approved for shipment to the customer,
- number of defective bottles, including:
- number of defective bottles with the so-called critical defect,
- the number of defective bottles that are subject to further selection in order to separate the good parts from the defective ones.

A critical defect is a defect that is completely unacceptable due to the risk to health. The procedure in the event of a critical defect is predetermined in accordance with a specially developed instruction. A product with this type of defect is directly remelted as glass cullet. It is very important that no bottle with such a defect reaches the customer.

The production process of the bottles in the selected glassworks is carried out continuously. It is characterized by no breaks in production, raw materials are supplied on a regular basis and it is done simultaneously with the receipt of finished products. The continuous process is permanently connected with the production equipment, and the production itself is automated. It runs in a 24/7 work cycle. Due to the technological system, work in the described glassworks takes place in a 4-team system. This means that the employees are divided into 4 brigades, and the schedule is set in such a way that 3 shifts are working and one is resting. During continuous production, employees change their jobs. The production of glass is carried out by producing, in a more or less complex process, basic glass products from hot melted glass mass, the so-called metallurgical method. Chemical, physical and physicochemical transformations taking place at very high temperatures are very important at each stage of production (Osiecka, 2010). Glass is characterized by its amorphous, disordered spatial structure resembling a liquid, while its stiffness and brittleness make it similar to solids. The formation of glass is possible by supercooling the molten raw materials without crystallizing them. Figure 1 shows a diagram illustrating the manufacturing process of a glass bottle.

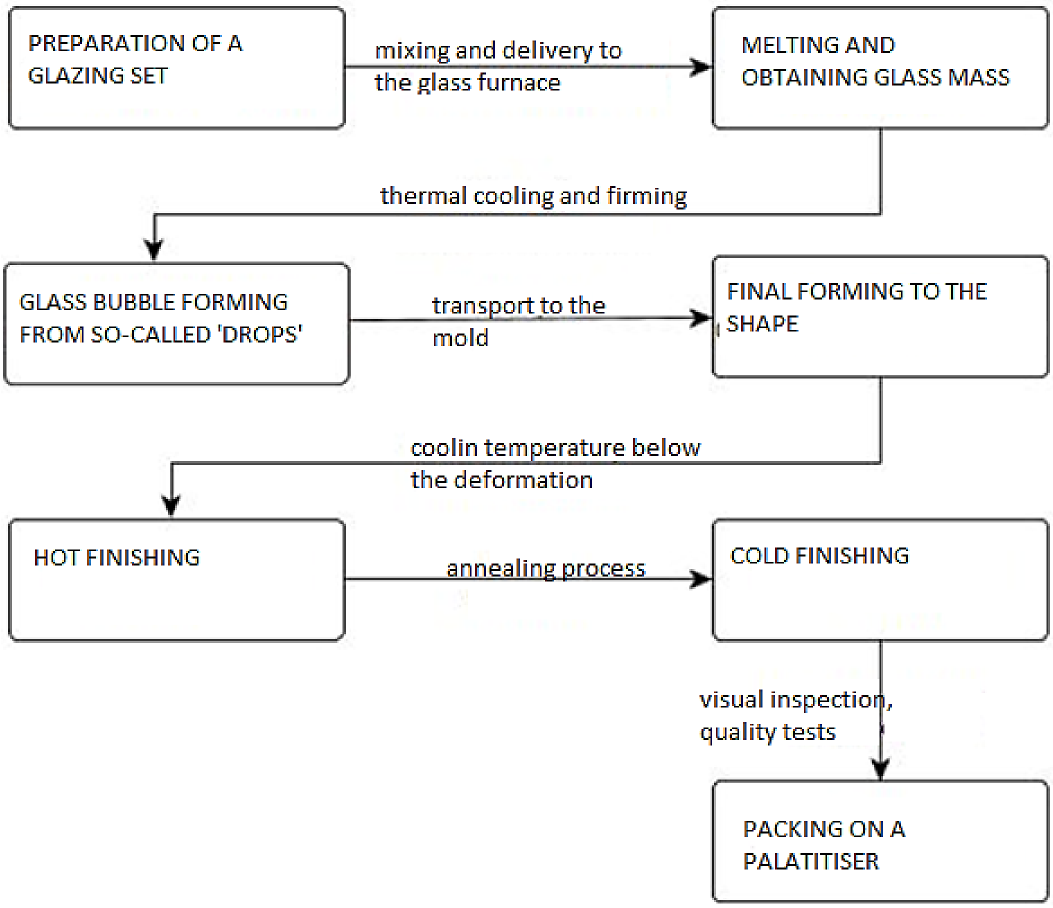

Fig. 1 Diagram of the glass bottle production process
Source: Own study

Obtaining glass mass is the result of the melting process and physicochemical phenomena. The obtained liquid glass mass is transported through special channels, the so-called power supplies and directed to the forming machines. At the same time, it is cooled down to the forming temperature and thermally firmed. Such prepared mass creates a portion of glass – a "drop", which goes to one of the sections of the forming machine. A two-tier forming process is created with the in-line automatic glazing machines. First, the so-called the bubble, which is immediately transferred to the mold. The mold is then finalized and cooled to below the deformation temperature. In the further stages of production, the following occurs:

• hot refining – a process involving the application of appropriate oxides on the coating of glass containers in order to improve properties;

• relaxing, ie slowly cooling down in order to relax thermal stresses;
• cold finishing – modifying the surface properties;
• inspection – in order to eliminate defective products;
• transport to so-called palletizers, where the products are packed and transported to the warehouse.

All glass packages that do not meet the quality requirements are returned for remelting.

Analysis of defects

During the analysis of production, it was found that 5.14% of the manufactured products are bottles not compliant with the specifications of the so-called NOK's.
5 types of defects have been identified:

1. glass inside the product (critical defect),
2. breaking blisters (critical defect),
3. crack in the body,
4. cracking under the head / collar,
5. Breakout in the seam.

Due to the impossibility of limiting all disadvantages, it was decided to try to reduce the most important ones. Using the Pareto-Lorenz method, the most important disadvantages were identified, taking the frequency of occurrence as the criterion. The Pareto-Lorenz method is otherwise called the ABC method or the 20/80 law. The Pareto analysis assumes the division of factors into 3 groups (Szczęśniak et al., 2012):

Group A – the most important factors belong to it. It covers about 20% of the total number of elements that generate 80% of the value of a given phenomenon. In this group, actions should be taken first, as they bring the greatest benefits.

Group B – includes about 30% of factors that influence about 15% of the value of a given phenomenon. Medium significance group. You can take actions in this group, but the results obtained will be much weaker than actions in group A.

Group C – includes about 50% of factors, the least influencing group, only 5% of a given phenomenon. Actions taken in this group have no economic justification.

Summarizing briefly, it can be stated that a small number of people or causes is responsible for most of the phenomena (Mroczko, 2011; Miller, 2011).

The results of the analysis of the glass bottle production process are presented in Table 1 and Figure 2.

On the basis of Table 1 and Figure 2. Pareto-Lorenz regarding the number of defects occurring during the bottle production process, it can be concluded that the defect W1 (glass inside the product) and W2 (bursting bubbles) constitute 86.89% of all defects identified during the process analysis production. The remaining three drawbacks – W3, W4 and W5 account for 13.11%.

Unfortunately, the most numerous are the disadvantages that pose a threat to human health and life.

Table 1 Percentage of product nonconformities/defects

Designation of non-compliance/defects	Name of the nonconformity/defects	Percentage of defects [%]	Cumulative share [%]
W1	Glass inside the product (critical defect)	55.74	55.74
W2	Bursting blisters (critical defect)	31.15	86.89
W3	Crack in the body	9.84	96.72
W4	Crack under the head / collar	1.64	98.36
W5	Breakout in the seam	1.64	100.00

Source: Own research on Mroczko, 2011

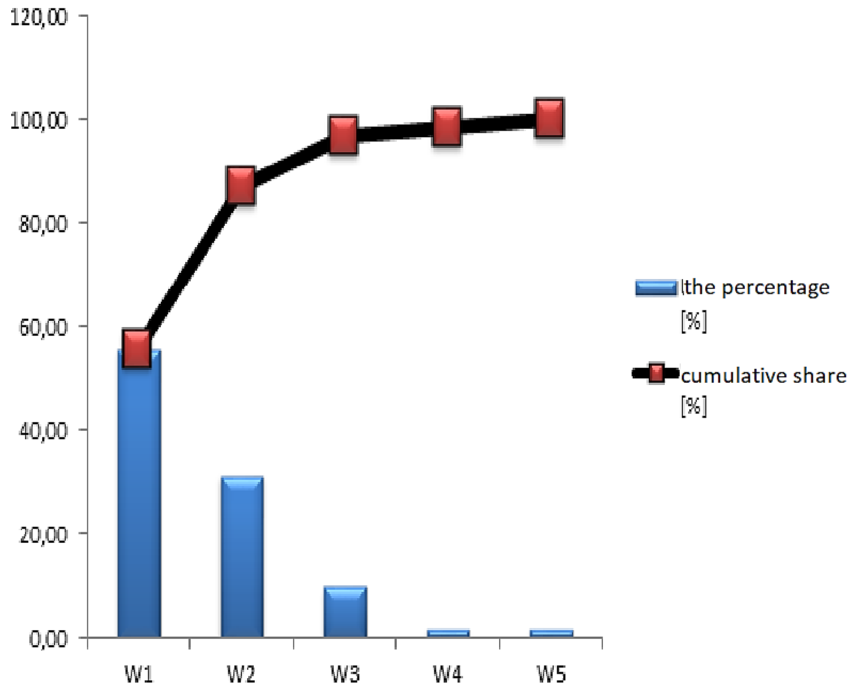

Fig. 2 Pareto-Lorenza chart

Own research on Mroczko, 2011

Taking into account the safety criterion and the frequency of occurrence of defects, a cause-and-effect analysis was carried out with regard to the defect W1 and the defect W2. For this purpose, the Ishikawa diagram was used. The defects were considered in the 5M categories: materials, methods, man, machine and management (Wawak, 2002). The results of the work are presented in Figure 3 and Figure 4.

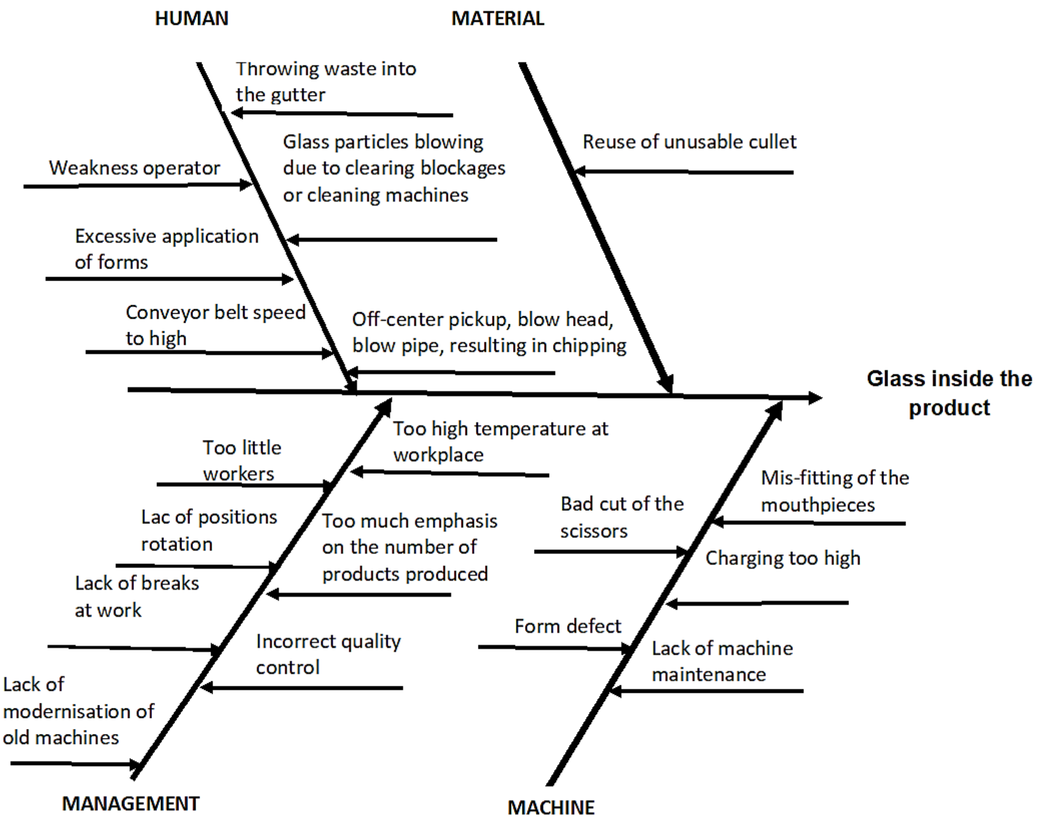

Fig. 3 Ishikawa Diagram – glass inside the product (W1)

Source: Own research on Frąś and Siwkowski, 2011

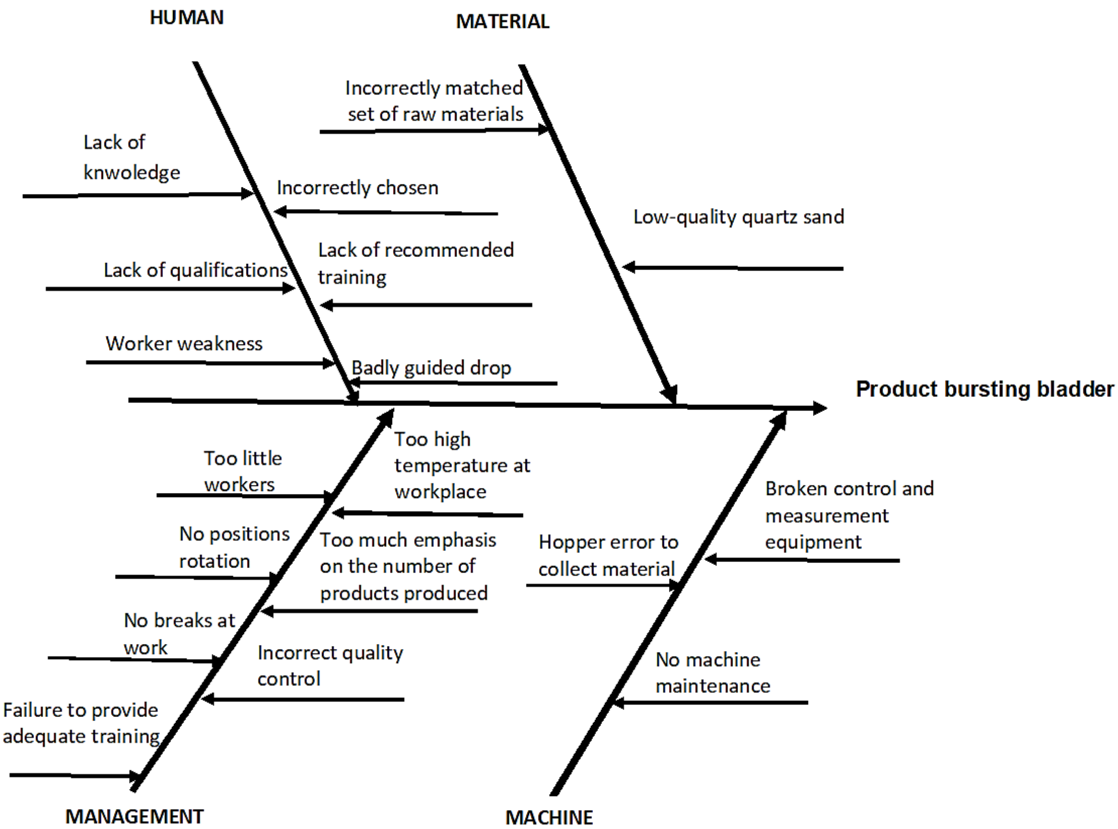

Fig. 4 Ishikawa Diagram – product bursting bladder (W2)

Source: Own research on Frąś and Siwkowski, 2011

When creating the Ishikawa diagrams, it was found that most of the causes of W1 and W2 defects are on the side of humans and improper management in the production area. What was of great importance here was the lack of adequate training for employees on the defects and methods of preventing these defects.

The significance of individual defects was also determined using the FMEA – Failure Mode and Effects Analysis method (Table 2). Additionally, this concept made it possible to indicate preventive solutions and estimate the risk of product non-compliance with technical requirements. The assessment of the risk of non-compliance consisted in the analysis of defects in terms of the following criteria (Molenda et al., 2016):

- probability of error/defect (R),
- significance of the error for the customer (C),
- probability of error detection by the supplier, manufacturer (W).

The significance of the defect was determined using the RPN (Risc Priority Number) risk level criteria, which is the product of the R, Z, and W parameters. The higher the product, the more significant the defect.

Table 2 Fragment of the sheet containing the results of the FMEA analysis for the defects W1 and W2

Prouct	Potential defect	Potential results of defect	Z	Potential cause of the defect	R	Currect product control	W	RPN
Glass bottle	Glass inside the product (W1)	Customer complaint. Swallowing glass by the customer.	10	Glass particle blowing when clearing blockages or cleaning the machine. Off-center pickup, blow head, or blow tube.	7	Flex Inspekt Bucher Emhar Glass control device. Visual control.	2	140
Glass bottle	Blisters bursting (W2)	Customer complaint. Bottle breakage when pouring.	8	Incorrectly selected glass mass. Badly guided drop. Hopper error.	6	Flex Inspekt Bucher Emhar Glass control device. Visual control.	6	288

Source: Own research

FMEA analysis showed that the most significant disadvantage is the defect of W2, i.e. bursting bubbles. Despite the fact that the defect W1 occurs most often and is of the greatest importance to the customer, the highest RPN index (288) was obtained by the defect W2 due to the high probability of the defective bottle getting to the customer.

Knowing the disadvantages that should be emphasized, the first thing to consider was how to limit their occurrence in the future. During the meeting with the top management, technologists and machine operators, the following corrective and preventive actions were proposed:
• defect W1:
o training employees in the field of segregation of waste;
o markings on the gutters "glass only" cullets;
o increasing the number of visual inspections;
• W2 defect:
o introducing cyclical wall thickness measurements;
o retraining hot end employees in operating the vending machine;
o cyclical review of photos from the control device.

Analysis of the functioning of the quality control department

During the 10-day observation of bottle production, quality control was carried out at 3 stages of production. 1st stage of inspection – at the "hot end", i.e. at the point where the bottle is formed. The bottles were collected immediately after leaving the mold, cooled down on a special stand and then checked by the operators of the machines with the use of appropriate gauges. Kontola consisted in checking the diameter of the head and the throughput (a full set every 2 hours). Also every 2 hours. visual inspection was carried out. At this stage, the detection of the defect generates the lowest costs and it is eliminated the fastest. The next stage of the control – stage 2 – was the "cold end". The bottles at this point are already relaxed and the quality control is carried out by an employee of the production line. It checks the following parameters:

- head diameter (a full set every 2 hours),
- cruising capacity (full set every 2 hours),
- pressure (a full set once a shift),
- impact strength (the set of the top of the bottle and the set of the bottom of the bottle are changed once)
- shock (a full set once a change),
- visual inspection of the screen every 2 hours. for 5 min.

The employee carries out the above-mentioned tests according to a previously agreed work schedule.
The last control – stage 3 – is carried out by the Quality Control (QC) employee. It is the "last line of defense" against defective bottles reaching the customer. The controls are performed according to the approved schedule.

DISCUSION

The conducted analysis showed that the biggest problem is too late detection of defects. Unfortunately, the characteristics of the steel plant and the speed of bottle production leave workers with very little margin for error. It was therefore concluded that the changes must include quality control workers and direct production workers (line operator and vending machine operator). Before starting the analysis, an interview was conducted with the manager and the quality director, who expressed concern that employees would have problems with fulfilling additional tasks. During the observation of employees, it was noticed that the problem does not only concern the lack of control, but above all the lack of a schedule for their conduct. A situation was observed in which the line operator performed a pressure measurement, and shortly after, an employee of the quality control department took samples in order to perform the same tests. Each of the aforementioned employees, in accordance with the guidelines, should perform quality control once in their shift, i.e. once every 8 hours. It should be mentioned that the lack of systematicity and too long intervals between inspections resulted in late detection of defects. As a result of the observed situation, as a streamlining action, it was proposed to create a work plan for line operators (OL) and quality control employees (QC). The focus was on increasing visual controls and organizing working time so that machine workers had more time to maintain molds and control purges. It was realistically assumed that faster defect detection will not completely eliminate defects, but will reduce production waste, and thus lower production costs. Thanks to the introduced changes, production should be smoother, the number of manufactured products should be greater, and the likelihood of complaints should be lower due to more thorough product inspections.

In addition, a complaint from a customer led to the decision to double the number of bottle wall thickness checks. It was found that only such a solution would be able to prevent the occurrence of the defect of W2.

CONCLUSION

The creation and introduction of a new schedule introduced law and order in the documentation. Employees gained more time for visual inspections, which resulted in increased defect detection. The new quality control plan, in line with the adopted assumptions, increased the smoothness of production and thus the number of bottles produced. Due to the introduced changes, the post-production waste has significantly decreased. During the production during the 10-day observation carried out before the changes, it was 5.14%, while after the changes made, it decreased to 3.73%. The changes introduced in the inspection also resulted in the reduction of the number of critical defects. By spreading the control tests over time, the number of visual controls was increased. Thanks to this treatment, employees were able to observe the occurrence of defects faster. The introduction of the proposed improvements resulted in the liquefaction of production. After the introduction of the new organization of quality control work, production increased by 0.9%, and the cost of post-production waste decreased by 11.5%.

ACKNOWLEDGEMENTS

This paper was financed from the resources of the Silesian University of Technology, project no. 13/010/BK_21/0057.

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Abstract: In the era of global market and internationalization of enterprises, an extremely important element influencing the competitiveness of companies is ensuring high quality of manufactured products, taking into account the requirements and expectations of buyers. At the moment when defects appear in the manufactured product, the production plant ceases to meet the expectations of customers. Not only is this related to the costs of production or complaints, but above all to the loss of credibility and good customer opinion. It is extremely important to identify and analyze the causes of this phenomenon as soon as possible, without allowing it to repeat itself. The problem of manufacturing defects becomes even more important when it poses a threat to the health or life of the customer. This also applies to products manufactured for the purposes of food protection. This article presents the results of the research that enabled the development of a method to reduce the production defects of a selected product in a glass factory. In order to achieve the goal, an analysis of the production process of the selected glass packaging was carried out, which allowed to identify defects and determine the causes and effects of their formation. Based on the presented research results, improvement measures have been proposed, consisting in developing a new organization of work in the area of quality control.

Keywords: quality control, qualitative methods, defectiveness, glass products