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THE ANALYSIS OF NO-COST SOLUTIONS FOR TOXIC WASTE REDUCTION AT THE COMMERCIAL CHEMISTRY PLANT

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Purpose: The aim of the research was to implement innovative technologies and management practices that would allow the chemical company to reduce the amount and harmfulness of toxic waste generated.
Design/methodology/approach: The research took a quantitative approach, based on a detailed analysis of production processes and waste management. Techniques were used to monitor waste at each stage of the production cycle, allowing a precise assessment of the effectiveness of the solutions implemented. A production process analysis and waste balancing method were used. The study included detailed measurements of the consumption of toxic substances and the identification of opportunities to return them to the production cycle, with both economic and environmental benefits.
Findings: The implementation of new technologies and the optimization of resource management enabled the company to significantly reduce emissions of hazardous substances and reduce costs associated with waste management and potential environmental penalties.
Practical implications: The results of the project indicate that other companies in the chemical industry can use similar solutions to achieve a reduction in toxic waste and increase the efficiency of production processes, while reducing operating costs.
Social implications: The project to reduce the production of hazardous substances emitted into the environment described in the article has produced the desired environmental results. The environmental impact of the company has been reduced thanks to the solutions applied.
Originality/value: An important aspect of the article was to describe the innovations introduced in an operational innovative line with a closed production cycle.
Keywords: toxic waste, production line, pipe cleaner, no-cost innovation.
Category of the paper: Technical paper.

1. Introduction

In light of escalating environmental and public health challenges, the reduction of toxic waste in industrial processes has emerged as a critical concern not only for environmental protection but also for economic efficiency (Alloway, Ayers, 1999). These substances, which may possess poisonous, corrosive, flammable, explosive, or other hazardous properties, pose significant risks. Toxic waste can take various forms, including chemical, biological, radioactive, and other hazardous materials (Kuczyńska, 2000; Wardasz, 2003). By comprehensively understanding these two key dimensions, we can evaluate the benefits for the environment, public health, and the operational efficiency of industrial enterprises (Bilitewski, Härdtle, Marek, 2006; Rosik-Dulewska, 2008).

With the growing imposition of regulatory requirements and environmental standards, industries are increasingly compelled to minimize the generation of hazardous waste (Dyrektywa Rady EWG, 1991; Dz.U. RP, 2023). Poor management of such waste can result in severe threats to ecosystems, contamination of groundwater and surface water, air pollution, and ultimately, adverse health effects on both human and animal populations. Therefore, there is an urgent need to implement advanced technologies and waste management strategies that not only comply with but also surpass existing regulations. Such measures will optimize the reduction of environmental harm (Pyssa, 2014; Nemerow, 2007).

Investment in cutting-edge technologies and innovative waste management practices is pivotal for the sustainable development of industry. It also serves as the foundation for fostering a more responsible and environmentally conscious society. By adopting modern methods of recycling, raw material recovery, and emission control, the industrial sector can significantly mitigate its environmental footprint. Additionally, this approach enhances public awareness regarding the issue of environmental pollution and promotes sustainable production and consumption practices. Educating the public about the consequences of toxic pollution and encouraging changes in consumer behavior are essential for achieving long-term environmental sustainability (Rostek, Wiśniewski, 2021; Feld, 2018; Wodecki, 2013).

2. No-cost solutions applied within the company

By their very nature, no-cost solutions represent the most commonly adopted initial actions within the industry. These typically involve aspects related to organizational practices, standards, and training. Matters of industrial automation, particularly those related to software optimization, operations, or sequencing, are also considered within the organizational framework—provided that such changes do not necessitate alterations to the mechanical infrastructure of the production line (Nawrot, 2016).

An American company specializing in household chemicals initiated a zero-waste project at one of its manufacturing facilities. The primary objective of this project was to reduce the costs associated with toxic waste, which had risen significantly between 2021 and 2023. The project focused on a production line dedicated to mass-producing bottles of pipe cleaner for the consumer market, consuming 4 million liters of toxic substances per month. This line is a fully integrated production unit, managing the entire process from raw material intake to the finished product, including all necessary steps of manufacturing, processing, assembly, testing, and packaging (Nogała, 2024).

The products manufactured are 0.5-liters and 1-liter bottles of pipe unblocking agent. This agent contains hazardous substances, specifically 15% sodium hypochlorite ($NaCl$) and 8% sodium hydroxide ($NaOH$) (Figure 1). The residual mixture is a carefully formulated concentrate, the specification of which is proprietary. The bottles are made from high-density polyethylene (HDPE) and are sealed with safety caps equipped with a special mechanism designed to prevent children from easily opening the packaging.

Figure 1. 0.5 l and 1 l bottles of pipe unblocking agent.

Source: Nogała, 2024.

The production line was comprised of eight segments, each employing different technological processes. Its capacity was measured by a filling rate of 150 liters per minute.

The line included a SKID system – an assembly of dosing units, mixers, pumps, and tanks. This system enables the precise combination of eight different raw materials, which are dosed into buffer tanks according to a specific formulation (proprietary know-how), producing the semi-finished concentrate of the final product. Each of these raw materials is classified as a hazardous substance, with the most toxic being caustic soda ($NaOH$) at a concentration of 50% (Figure 2).

Figure 2. SKID infrastructure.

Source: Nogała, 2024.

Surge Tank – the final tank where the completed formulation is created. This tank, with a capacity of 2 m³, receives the previously prepared concentrate, ultra-pure CIP water with a conductivity level not exceeding 7 µS/cm, and sodium hypochlorite (NaOCl) with an active chlorine concentration of 14-16% (Figure 3).

Figure 3. Surge-Tank.

Source: Nogała, 2024.

Pouring Machine with Capper – a machine that dispenses the prepared formula into the final packaging, consisting of 0.5-liters and 1-liter bottles made of high-density polyethylene (HDPE) with high chemical resistance (Figure 4). This machine maintained a pouring accuracy of ±2 ml, verified each time a bottle was filled. The capper was equipped with a system that evaluated the cap tightening force by monitoring the current loads on the servo drive, allowing the cap tightening torque to be precisely adjusted within a tolerance range of 1.2-1.4 Nm.

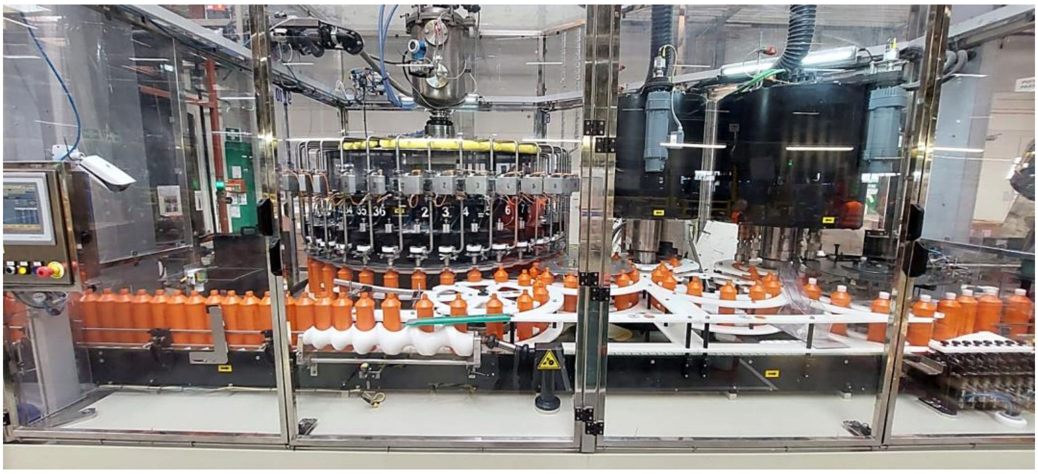

Figure 4. Pouring and capping machine.

Source: Nogała, 2024.

Plasma Machine – a device responsible for reducing the electrostatic charge that accumulates on bottles during transport, particularly due to friction against plastic components such as guide rails or transport wheels (Figure 5).

Figure 5. Plasma machine.

Source: Nogała, 2024.

Labelling Machine – a device responsible for applying wax labels to the bottles using water-based adhesive (Figure 6).

Figure 6. Bottle labelling machine.

Source: Nogała, 2024.

Carton Folding Machine – a machine responsible for unfolding pre-prepared cartons supplied by the manufacturer and shaping them to accommodate the finished products (Figure 7).

Figure 7. Carton folding machine.

Source: Nogała, 2024.

Manual Packaging Zone – a network of conveyors featuring eight open stations where the finished bottles are removed and manually packed into cartons (Figure 8).

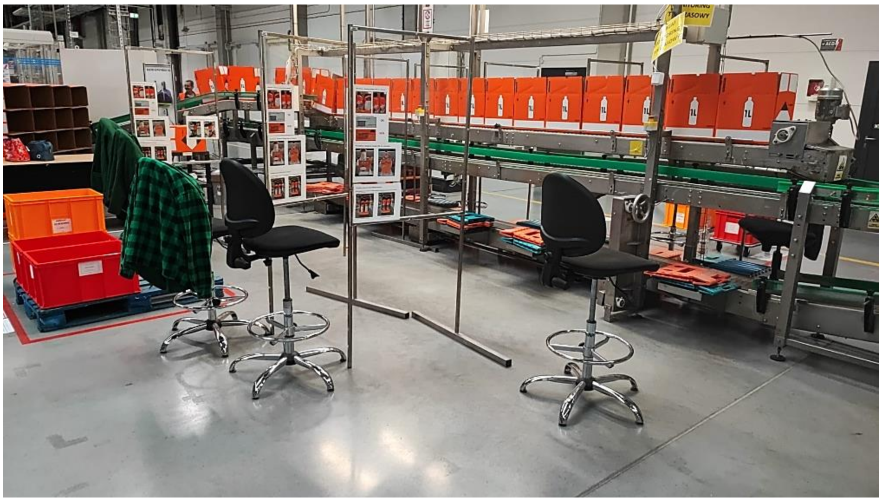

Figure 8. Manual bottle packing zone.

Source: Nogała, 2024.

Palletizing Machine – equipped with a carton closing and sealing module, a weighing system that verifies the quantity of packed products per the specified recipe, a robotic arm for palletizing the cartons, and a stretch wrapping system for securing the pallets (Figure 9).

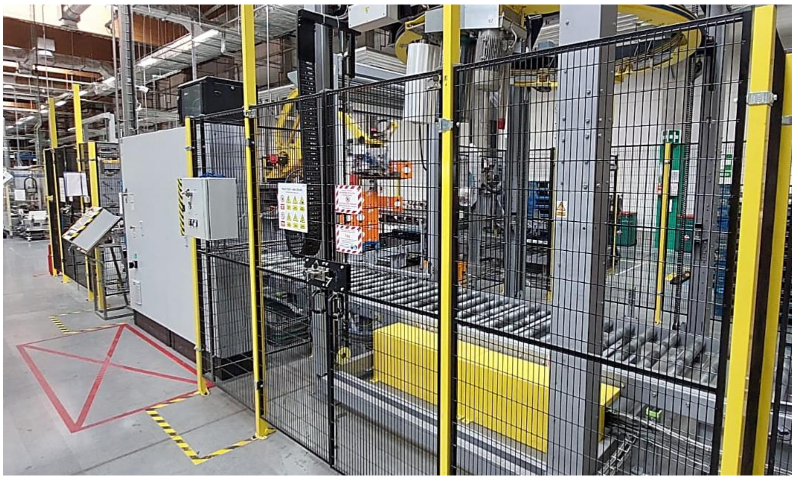

Figure 9. Palletizing machine with stretch film wrapping system.

Source: Nogała, 2024.

The complexity of this production line, with its numerous processes – each generating waste in the form of bottles containing hazardous substances – presents a significant design challenge for implementing a zero-waste policy.

3. Identification of Types and Quantities of Toxic Waste Generated by the Selected Production Line

In the production line depicted, there is a risk of generating waste at each stage of the process. Waste can be categorized into controlled and uncontrolled types. Controlled waste refers to waste produced as a result of quality testing, including liquid waste or waste contained in packaging. Uncontrolled waste, on the other hand, arises from the inadequate performance of machinery and equipment, leading to the production of non-compliant products of various kinds.

3.1. Controlled waste

At the start of the line in the 'SKID' module, controlled waste includes samples of concentrates sent to the laboratory for quality testing, amounting to 0.5 kg per sample. Before sampling, any remaining concentrate is discharged into a 15 kg bucket to drain the system. This discharge is stored as waste in external Intermediate Bulk Containers (IBCs). With a maximum line capacity, sampling occurs 7 times per day, resulting in 108.5 kg of waste.

Quality sampling of raw materials before processing also contributes to additional waste. There are 8 raw materials used in production, each tested at different frequencies and volumes:

- **Raw Materials 1, 2, 3, 4, and 5**: These additives are each tested once per day at 0.5 kg per sample. After testing, the samples are disposed of, resulting in a total of 2.5 kg of waste daily.
- **Raw Materials 6 and 7**: These additives are tested once per day and once per delivery. Each sample is 0.5 kg, and with two deliveries per day, this results in 4 kg of waste.
- **Raw Material 8**: This additive is sampled three times per day at 0.5 kg per sample, resulting in 1.5 kg of waste.

In total, controlled waste from the sampling process amounts to 116.5 kg per day.

The Surge Tank module, where the final product is created, generates 93 kg of waste. This includes sampling for testing six times per day at 0.5 kg per sample and a 15 kg drainage discharge.

The Bottle Filler with Capper module produces the largest amount of controlled waste due to quality checks. Daily, the twist-off torque of eight bottles is measured. Because this test affects the thread design and prevents reuse, each test results in waste. With sampling every 15 minutes in batch production, this module generates between 384 kg and 768 kg of waste per day, depending on the bottle format (0.5 l and 1 l).

In the plasma machine process, surface tension tests on bottles, using markers with special liquid density, result in 3 kg to 6 kg of waste per day, depending on the bottle format.

The labelling machine performs validation tests for label position and use-by date printing, requiring nine bottles per day. This results in 4.5 kg to 9 kg of waste, depending on bottle size.

The carton assembly, packing area, and palletizing area do not generate process-controlled waste through quality control measures.

A summary of the waste generated by the production line over a 24-hour period is presented in Table 1.

Table 1.
Summary of Controlled Waste [kg] Generated by the Production Line During 24 Hours of Operation

Bottle format	Process module								
	SKID	Surge-Tank	Pouring/ cooling machine	Plasma machine	Labelling machine	Case folding machine Packing zone Palletizing machine			Total
	Controlled waste, kg								
Bottle 0.5 l	116,5	93	384	3	4,5	0	0	0	601
Bottle 1 l			768	6	9	0	0	0	992,5

Source: own elaboration based on Nogała, 2024.

3.2. Uncontrolled waste

Uncontrolled waste results from process or human errors. To identify such waste, it is essential to monitor the process and conduct analyses to validate the data and draw appropriate conclusions.

Assessing the scale of uncontrolled waste involves documenting all activities and operations performed on the equipment. A comprehensive analysis of the entire machine infrastructure—including component performance and operational activities carried out by personnel—was conducted across all modules.

The SKID system comprises tanks, metering sections, pumps, and valves. Due to the presence of strong acids (part of the additives) and strong bases such as 50% NaOH, the system requires a closed infrastructure. This includes tanks and piping made from type 316 steel. Most pumps are pneumatically powered diaphragm pumps, chosen for their ability to handle the viscosity of raw materials. To prevent component degradation, electric pumps are equipped with polypropylene impellers. Pneumatic valves feature stems made from acid-resistant steel. This infrastructure supports the preparation of the concentrate for the final product and its transfer to the Surge Tank.

The concentrate is produced up to seven times daily, with a volume of 2500 liters per batch. The production process takes approximately two hours, while consumption of the concentrate takes around 3.5 hours. During production, raw materials are delivered to the tank in the correct sequence and quantity.

An identified process error occurred with the closing valve during the addition of the fourth raw material when the concentrate volume was 1500 kg. The valve jammed during closure, resulting in an overdose of the fourth raw material. This caused the concentrate to deviate from quality specifications. Consequently, the affected concentrate was disposed of by pumping it to external IBC tanks.

Another process error observed was excessive aeration of the concentrates, negatively affecting key parameters such as viscosity and density. An analysis of the raw material delivery process revealed that the eighth raw material, which was pumped into a 50-liters intermediate tank, was dosed from the top through a spigot. The high fill level caused the agent to hit the surface of the liquid, leading to aeration. Given that this component constitutes 20% of the concentrate, it adversely impacted the final product specifications.

The Surge Tank module, where the final product is prepared, also experienced issues with aeration. Quality control results showed deviations in viscosity and density specifications. Analysis revealed that the spigot delivering the final mixture to the tank was positioned at the top. The filling control automation allowed the formula to be dispensed at low levels, causing the agent to create air bubbles upon hitting the liquid surface. With a product density of 1123 kg/m^3 and a high consumption rate, outgassing of the formula in the tank was problematic.

The Pouring/Bottle Cap machine underwent two separate analyses for the pouring and capping modules. In the pouring module, common issues included overfilling bottles beyond the set tolerance, leading to waste and production downtime for machine cleaning. Another problem was the formation of drips on the outer walls of the bottles due to splashing from the filling nozzles, which was a critical defect affecting user safety. In the capping module, issues included caps being screwed on at an angle, damaging bottle threads and causing loss of tightness. Additionally, excessive torque during capping could break the child-proof safety mechanism, rendering the bottle unusable.

The plasma machine did not generate uncontrolled waste. Its simple design, comprising a conveyor and plasma heads applying a charge to the bottle surfaces, proved effective without creating additional waste.

The labelling machine, responsible for applying front and back labels and printing expiration dates, also contributed to waste. Strict tolerances for label positioning and adhesion resulted in significant waste from poorly applied or missing labels. The printing of expiry dates, using an industrial inkjet printer, was a critical stage monitored by a vision system. Inefficiencies in the print head service led to deteriorating print quality, with bottles featuring illegible prints set aside as waste.

The carton erecting machine, packing zone, and palletizing zone were mostly free from defects causing toxic waste. Analysis confirmed that manual packing was the only area with potential for physical damage to bottles due to human error. While this did not require major intervention, awareness and training were recommended for the crew. Quality defects identified in the packaging area were typically linked to errors from previous stages, such as improperly labelled bottles or bottles with defective caps.

4. Solving the problems of toxic waste generation

In the SKID line area, addressing the current issues related to toxic waste generation led to the proposal of updating the concentrate production program. The analysis focused on the delivery of the second raw material, which is 1.8 kg with a tolerance of ±10%. The system involved using a bulk flow meter upstream of the concentrate tank and incorporating a 'timer' for the bucket rotor pumps. This timer set a predetermined running time for the pumps in the program.

The flow meter collected data correlating with the pump settings based on the preset start-up and shut-down times. If the flow meter reading approached the preset quantity too closely and the pump shutdown was delayed, it resulted in an overdose of the raw material. Consequently, this would lead to a concentrate with a concentration of the second raw material that fell outside the specified tolerance, resulting in waste. By analyzing the durations of pump start-up, valve opening, and raw material delivery, the delivery efficiency was improved, achieving a dose deviation of ±2%, which is within the specification tolerance. Following confirmation of the optimized program's efficiency, a new Management of Change (MOC) procedure was prepared to implement the revised program after testing.

Another no-cost improvement involved testing methods to remove labels from bottles deemed waste due to poor label positioning outside quality tolerances (Figure 10). Water tanks, with temperatures not exceeding 30°C, were used for this purpose. Twenty bottles were placed upright in the tanks, with the water level not surpassing the height of the bottle necks. After conditioning the bottles in the water for 20 minutes, a cotton cleaner was used to dry the bottles and remove the labels. The warm water caused the glue to lose its viscosity, allowing the labels to peel off more easily.

Figure 10. Example of a badly labelled bottle.

Source: Nogała, 2024.

Another initiative aimed at waste reduction involved removing incorrectly printed production dates from 1-liter bottles (Figure 11). To achieve this, a specialized chemical designed for printer head cleaning was used. This dust-free cleaner, when applied, enabled the removal of the erroneous use-by date from the bottle's surface. Subsequently, the date could be re-printed correctly.

The implementation of this cleaning process, along with the label removal process, necessitated the development of detailed procedures and instructions. Additionally, staff training was provided to ensure proper execution of these measures.

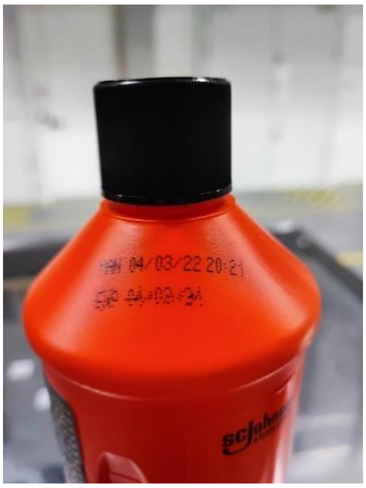

Figure 11. Example of a photograph with a bad expiry date printed on it.

Source: Nogała, 2024.

Three main cost-free measures were implemented in two production processes:

1. **Optimizing the Supply of Raw Material No. 2 in the Concentrate Stage**

   The first measure focused on optimizing the concentrate blending process through program enhancements for the delivery of raw material number 2. This material, required in an amount of 1.8 kg, is added in the second step of concentrate formation, following the dosing of CIP water. Prior to introducing the second raw material, a 50 kg water flush was performed to clear the system.

   The process involved:

   - **Initial Pump Operation:** A signal was sent to the pump for raw material no. 2 to operate for 1.2 seconds, raising the pressure before the pneumatic valve.
   - **Valve Operation:** The valve was then signaled to open. During its opening, the pump received a second signal to operate for 2.4 seconds.
   - **Blending Mode:** The pump entered a blanking mode for 0.8 seconds, synchronized with a signal to the closing valve to move it to a closed position.

   Volumetric flow analysis ensured that the set quantity of raw material was delivered. If the total run time of the pump and valve deviated from the program, causing flow to fall outside the ±10% tolerance, the program entered a problem/failure mode and halted further mixture creation.

   Key to this process was the efficiency of the valve, which was confirmed to fully move within 0.95 seconds. Consequently, the signal controlling the pump's run time was adjusted from 2.4 seconds to 2.25 seconds, and the quench time was extended to 0.95 seconds, aligning with the valve's closing time. This adjustment significantly reduced pressure fluctuations at the end of raw material delivery and improved precision to within a constant tolerance of ±2%. The improvement minimized the risk of mixtures falling outside quality specification tolerances, thereby reducing hazardous substance waste to approximately 500-1000 kg per month.

2. **Implementing a Procedure for Removing Labels from Bottles**

The implementation of the label washing procedure in the labelling production process required establishing a clear set of operational standards (Figure 12). This involved preparing specialized water tanks equipped with compartments for the bottles, a thermometer for monitoring water temperature, and a stopwatch to time the conditioning of the bottles. Dedicated areas were set up for bottles to be washed and for those to be relabelled. Additionally, a specific cleaner was selected to assist in drying the bottles after washing. A tracking form was created to document the types of unsaleable bottles based on labelling quality. This form, combined with a defect chart, allowed for trend visualization, guiding appropriate actions to improve labelling quality. Finally, these procedures and standards were documented in a comprehensive set of procedures and work instructions to ensure consistency and effectiveness in the process.

Figure 12. Bottle label washing zone and production date imprint.

Source: Nogała, 2024.

3. **Implementing a Procedure for Removing Production Dates from Bottles**

The activation of the procedure for washing off the production date on the packaging was a critical action due to legal requirements. Products requiring an update to their overprint for quality reasons were first identified by an automated vision system, which separated them from the serial production line. The operator then transferred these products to a designated table, where the need for reprinting was confirmed, and the bottles were directed to the washing process to remove the old code. At this stage, a double-check procedure was implemented: a third party verified that the bottles could not return to the serial production line and documented the need for repair. The bottles were then moved to a designated area, where they were prepared for reprinting with a detailed description specifying the period, model, and date required. This process was confirmed with a signature to ensure accuracy and compliance.

Investing in optimizing production processes and reducing toxic waste emissions not only benefits the environment but also enhances a company's operational efficiency and competitiveness. By leveraging modern technology, adopting sustainable production practices, and collaborating with business partners, companies can achieve both economic and environmental objectives.

A prerequisite for initiating the project to reintroduce non-conforming finished products into production was to establish a procedure ensuring that the formula could be returned to production within 24 hours of manufacture. Consequently, a workshop was organized to prepare the material management areas from an organizational standpoint. A specific area was designated across the production line for storing bottles that were non-repairable. Each bottle had to be registered on a form and labeled with the date and time of manufacture. To minimize the time between production and reintroduction, it was mandated that each shift close the area with a status of zero bottles by the end of its shift. Additionally, a position was created to oversee and record the quantities of returned products once they overflowed. A location next to the Surge-Tank was chosen for the formula turnaround station, and another site was designated for hazardous waste storage. All planned activities were documented in a procedure and incorporated into job instructions for employee training.

The volume of hazardous waste generated was substantial, and its associated costs significantly impacted product expenses. Implementing corrective measures to reduce waste generation provided both economic and environmental benefits. To fully assess the effectiveness of the proposed solutions, a comparison was made between the period before the zero-waste project and the results after implementing the measures. Over a six-month observation period, the effectiveness of the zero-waste measures was confirmed. The measures resulted in a significant economic and environmental success, saving over PLN 350,000 and reducing waste emissions by 71 tonnes.

The recurring quantity of waste was evaluated six months after the project's implementation, which was carried out in two phases. During peak operation, the line produced approximately 3,456,000 1-liter bottles and 864,000 0.5-liters bottles per month, resulting in the generation of 4,366,224 kg of hazardous substances. Over this period, the line produced non-conforming products amounting to 64 tonnes of waste. Although the waste-to-product ratio was approximately 1.5%, the monthly cost associated with this waste was PLN 325,000. Prior to the project's implementation, the toxic waste stockpile was 11.8 tonnes, comprising waste from poor bottle labeling and off-specification concentrate (Table 2).

Table 2.
Volume of waste generated per month for the no-cost stage

Type of waste generated	Monthly waste, kg	Monthly cost, PLN
NOK bottles (label quality) 0.5 l	2 400	12 000
NOK bottles (label quality) 1 l	8 400	42 000
Off-spec concentrate	1 000	5 000
Total	11 800	59 000

Source: own study.

With the introduction of the label-washing procedure and improvements in the raw material supply program, which effectively enhanced product specifications, the risk of producing out-of-specification waste was completely eliminated. Bottles with washed labels were successfully reintroduced into the production process. As a result, the effectiveness of the measures was confirmed to be 100%. After six months of operation following the project's initiation, no waste from these categories was recorded.

Operating at full capacity, the line generated up to 62 tonnes of waste per month. The disposal costs alone, not including other factors such as production time and raw material consumption, amounted to PLN 310,000. To address this, no-cost measures were implemented, and their effectiveness was confirmed six months later. These measures successfully reduced hazardous waste production from 12 tonnes to zero, resulting in monthly savings of approximately PLN 60,000. This achievement was notable, especially since it required no financial investment but only changes in work organization and minor program adjustments.

Protecting the environment by reducing hazardous substance emissions is crucial for human health, biodiversity, water and soil quality, and climate stability. Such actions are essential for ensuring societal sustainability and maintaining ecological balance. Reducing emissions of harmful substances benefits ecosystems, protects flora and fauna, and improves human living conditions by lowering the risk of pollution-related diseases.

5. Summary

The project aimed at reintroducing the formula into the production process yielded significant environmental and economic benefits. By optimizing technological processes and adopting more efficient resource management methods, the company achieved notable reductions in hazardous substance emissions. These measures not only decreased the company's environmental impact but also led to substantial cost savings related to waste management and pollution penalties.

In summary, the initiative to minimize hazardous substance emissions achieved its environmental goals while delivering tangible economic advantages. The project enhanced the company's market competitiveness, earned recognition from customers and business partners, and contributed to both local and global environmental protection. This demonstrates that investing in ecological and sustainable practices is both an ethical and financially sound strategy.

References

1. Alloway, B.J., Ayres, D.C. (1999). *Chemiczne podstawy zanieczyszczenia środowiska.* Warszawa, Wydawnictwo Naukowe PWN.
2. Bilitewski, B., Härdtle, G., Marek, K. (2006). *Podręcznik gospodarki odpadami. Teoria i praktyka.* Warszawa. Wydawnictwo Seidel - Przywecki.
3. Dyrektywa Rady 91/689/EWG z 12 grudnia 1991 r., w sprawie odpadów niebezpiecznych, Dz.U. UE L z dnia 31 grudnia 1991 r. (1991). Place: https://www.prawo.pl/akty/dz-u-ue-l-1991-377-20,67428017.html
4. Dz.U. RP (2023). Poz. 1587. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 7 lipca 2023 r. w sprawie ogłoszenia jednolitego tekstu ustawy o odpadach.
5. Feld, M. (2018). *Podstawy projektowania procesów technologicznych typowych części maszyn.* Warszawa. Wydawnictwo PWN, WNT.
6. Kuczyńska, I. (18-22.09.2000). *Odpady niebezpieczne i przygotowanie ich do wykorzystania lub unieszkodliwiania.* Materiały Szkoły Gospodarki Odpadami. Sympozja i Konferencje nr 44, s. 145-156, Rytro.
7. Nawrat, R. (2016). *Doskonalenie procesów. Podejście praktyczne.* Katowice, Elamed.
8. Nemerow, N.L. (2007). Industrial waste treatment. Contemporary practice and vision for the future. Elsevier INC.
9. Nogała, Ł. (2024). *Projekt instalacji stacji zawracania produktu (substancji niebezpiecznych) do bieżącej produkcji*. Praca magisterska. Akademia im. Jakuba z Paradyża. Wydział Techniczny. Gorzów Wielkopolski.
10. Pyssa, J. (2014). Odzysk i unieszkodliwianie odpadów niebezpiecznych: uwarunkowania techniczne, ekonomiczne oraz ekologiczne. *Nowoczesna Gospodarka Odpadami. Nr 1, s. 38–43.*
11. Rosik-Dulewska, Cz. (2008). *Podstawy gospodarki odpadami*. Warszawa: PWN.
12. Rostek, K., Wiśniewski, M. (2021). *Modelowanie i analiza procesów w organizacji.* Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.

13. Wandrasz, J.W., Biegańska, J. (2003). *Odpady niebezpieczne podstawy teoretyczne*. Gliwice: Wydawnictwo Politechniki Śląskiej.
14. Wodecki, J. (2013). *Podstawy projektowania procesów technologicznych, części maszyn montażu*. Gliwice: Wydawnictwo Politechniki Śląskiej.