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Analysis of Disinfection Technologies that can Increase the Efficiency of Indoor Logistics Processes, which has been Reduced due to the COVID Pandemic

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Abstract. As a result of the Coronavirus, both supply chain and internal logistics processes at factories have changed a lot. In many areas, the effectiveness of the logistics processes has declined because of the restrictions implemented against the virus. The study lists some adverse effects where logistics processes had to be modified due to the changing and protection measures against or negative effects of the virus. The authors also argue that these restrictions decreased the efficiency of logistics processes and workers' productivity. One option to increase the logistics sector's efficiency is to use air purification technologies, like the ones studied in this paper: UV-C, Bioxygen® or plasma-ion decontamination technologies. These disinfection processes can create a safe indoor environment. The authors analyse the examined technologies with SWOT analysis. The analysis results demonstrate which disinfection application is the most beneficial to help in improving indoor air quality for logistics processes.

Keywords: logistics, efficiency, coronavirus, disinfection, UV-C technology, Bioxygen® technology, plasma-ion technology, SWOT Analysis

Introduction

The social and economic environment has changed because of the coronavirus pandemic. The protection measures introduced at national, regional, and institutional levels have an impact on the internal logistics processes of the supply chain and companies. Airborne transmission of pathogens is a critical pathway for spreading diseases transmitted this way, as these microorganisms cause many harmful infections. [8] Air purification technologies show great potential in preventing and reducing the spread of airborne diseases. The recent development of technologies is summarized based on the advantages, disadvantages and health-damaging effects of the inactivation mechanisms. The scope of application and energy consumption of the various technologies are compared, and the characteristics and future research perspectives of the air purifiers on the market are presented. [8] As the first step of the research, the solutions currently available on the market were examined in terms of competitors. After that, the typical alternative and experimental methods were listed, and then the new methods were mapped. Afterwards, a comparative analysis of the most popular technological solutions was carried out.

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1. The Effects of Coronavirus on Logistics Processes

From the outbreak of coronavirus in 2019 until July 2021, one of the study's authors worked in logistics. So he has first-hand knowledge of the restrictive measures that affected specific logistics processes. In all cases, the cycle times used in the pre-virus period increased, resulting in an apparent cost increase. The quality of logistics services has also decreased in many areas. The following are examples of changes in the company's internal logistics processes:

- Due to employee illnesses, the number of shifts has decreased, and fewer people had to do the same amount of work.
- Disinfection of the surface of production equipment during production processes decreased productivity.
- Quarantining and disinfecting incoming goods for ten working days resulted in slower access to raw materials.
- Wearing a mask and fogging glasses further reduce the productivity of logistics workers.
- Complete isolation of shifts changed the work order.
- Non-contact packaging of finished products, storage, and loading onto trucks was implemented.
- All these previously listed restrictions resulted in productivity decline and increased cycle time simultaneously.

In the next chapter, we present the three selected air-cleaning technologies, which could increase productivity in an indirect way.

2. Decontamination Technologies to Fight against Coronavirus

This chapter aims to describe the effectiveness of UV-C, plasma-ion and Bioxygen® technologies in dealing with viruses and bacteria, to explain the areas in which these technologies can be used, and finally to describe the possibilities of using these technologies in logistics.

2.1. UV-C Technology

As soon as airborne viruses are formed, they can be destroyed directly. When used at close range, bactericidal ultraviolet light at 254 nm can harm the skin and eyes [1] [2].
On the other hand, UV-C light (207–222 nm) destroys pathogens without harming human tissue [1] [2]. Previous research has shown that 222 nanometres of UV-C light can inactivate airborne influenza viruses. In addition, they examined whether far UV-C light radiation could effectively kill alpha HCV-229E and beta HCoV-OC43 human coronaviruses. The results show that low UV-C doses of 1.7 and 1.2 mJ/cm^2 kill 99.9% of airborne coronavirus types 229E and OC43 [1] [2].
Since all human-dangerous coronaviruses are similar in size and structure, the researchers hypothesize that far UV-C light may show similar neutralizing effectiveness against other human-harmful

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coronaviruses, including SARS-CoV-2. In addition to the current accepted official radiation limit value of 3 $mJ/cm^2/hour$, continuous far UV-C radiation destroys 95% of viruses in 11 minutes, 99% in 16 minutes, and 99.9% in 25 minutes [1] [2].

Thus, by complying with the current ones and staying within the frequency limits, the regulation of low-speed, distant UV-C light radiation can effectively, safely and at the same time significantly reduce the concentration of airborne coronavirus in public spaces.

Advantages of UV-C technology [3]:

- It is effective against most nosocomial pathogens.
- The duration of disinfection is short (approximately 15 minutes), but in the case of Clostridium difficile, more prolonged exposure is necessary (approximately 50 minutes).
- There is no need to close the room and the heating, ventilation, and air conditioning system.
- As a result of disinfection, no toxic by-products remain in the environment.
- Costs include only tangible assets, and there are no consumables.
- As a result, it diffuses throughout the entire room.

Disadvantages of UV-C Technology [3]:

- During the disinfection process, nobody is permitted to stay in the room.
- Suitable only for final disinfection.
- There is a high investment cost.
- Its effectiveness is influenced by the parameters of usage (e.g.: wavelength, UV-C dose, exposure time).
- The equipment and tools must be moved away from the walls.

Overall, it is a widely used technology with reasonable performance rates.

2.2. Bioxygen® Technology

Bioxygen® technology was chosen by the company for whom the research has been carried out. An ionization process caused by atomic collisions is the basis for Bioxygen® technology. A space fed by an oscillating electric field collides with fast-moving particles. The collisions cause atoms to lose one or more electrons, transforming them into positive ions. In contrast, atoms that gain one or more electrons are transformed into negative ions [4].

Researchers have developed a unique electric capacitor that creates controlled ionization of oxygen, water vapour and nitrogen molecules in the air. This ionization process initiates reactions on volatile organic compounds, reducing contamination in the air and surfaces. This ionization process damages the cell membranes of microorganisms and, at the same time, inhibits their vital functions [4].

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Until now, filters have controlled indoor air quality (mechanically). Thanks to Bioxygen® technology, air disinfection is now possible independently of mechanical filters or, if necessary, in combination. Using Bioxygen® technology in any environment reduces chemical, organic and microbial contamination in the air and surfaces. Bioxygen® technology differs from technologies that use air filtration and/or purification in the classical sense. The essence of Bioxygen® technology is that active ions can break the bonds of chemical compounds, transforming them into simpler and easier-to-handle essential elements. As for volatile organic compounds, the Bioxygen® technology "cuts" the main compounds into simpler molecules, which can then be oxidized. In addition, it is possible to oxidize the bonds during the process [4].

As with UV-C technology, Bioxygen® technology sterilizes the air as well. Bioxygen® is a natural technology that improves indoor air quality. This process eliminates bacteria, airborne dust, odours, and other chemical contaminants. Besides removing airborne microbes, Bioxygen® technology reduces volatile organic compounds in the air and on surfaces. It can be used in all areas necessary to prevent and reduce chemical and biological contamination (healthcare, food industry, residential and commercial buildings).

There are several advantages of using the Bioxygen® system [4]:

- There is less maintenance required.
- The heat exchanger coils and nozzles are less likely to be attacked by algae.
- Far fewer chemicals are required to eliminate algae and microbes, which cause pipeline damage.
- The water tower's heat exchanger efficiency does not decrease with time.

For bacteria and known viruses, as well as bacteria occurring in the food industry, the results show an effectiveness of over 99%, with no adverse effect on food quality [5] [6].

However, Bioxygen® technology's effectiveness against Coronavirus is no longer as convincing as UV-C technology. In the case of two different tests, only the 60-minute air purification resulted in a 95% result. Even 30- and 45-minute air purification gave successful results in one test, but in the other, 30- and 45-minute air purification failed [5] [6].

2.3. Plasma-ion Technology

Ions can also be found in nature, both positive and negative. Plasma-ion technology also uses positively and negatively charged ions found in nature. The technology was developed in the early 2000s and has continued to develop since then [7].

Machines produce hydrogen and oxygen molecules with positively and negatively charged ions using plasma-ion technology. In voltage, positive hydrogen ions are produced in the water, while positive oxygen ions are generated in the air [7].

Water molecules in the air surround these electrically charged particles. Due to their powerful oxidation effect, these water molecules extract hydrogen from viruses and other microbes found in the air and on various surfaces, thus destroying them. Structure destruction also results in the death of these organisms. As a result of the chemical reaction, neutral-charged water molecules are formed [7].

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As part of the industrial application of plasma-ion technology, the equipment for generating plasma-ions is connected to the equipment for exchanging air (air conditioning, air circulation, etc.). The equipment itself is situated in a separate room [7].

Various air cleaning procedures, including deodorization, pollution reduction, and sterilization are performed during air cleaning.

This is, without a doubt, one of the most effective technologies for preventing coronavirus infections. The plasma-ion technology can clean the air in 10-15 minutes with 99.99% efficiency, whereas UV-C technology can do it in 25 minutes. Compared to plasma-ion and UV-C technologies, Bioxygen® technology cannot even come close to disinfecting within 45 minutes with only 95% efficiency [7].

The comparative analysis of the previously introduced technologies shows that the plasma-ion technology has the highest sterilisation performance against coronavirus.

In the next chapter, we present the SWOT analysis analysing which disinfection technology should be used to reduce the harmful effects of coronavirus on production.

3. SWOT Analysis of the Compared Technologies

SWOT analysis was chosen as the analytical tool to compare the different air purification technologies. SWOT is an English acronym that highlights the essence of the analysis [9]:

- S (Strengths): to identify the strengths of the object of analysis. It is important to emphasise those aspects that make it unique.
- W (Weaknesses): identifying weaknesses and how to correct them.
- O (Opportunities): identifying opportunities.
- T (Threats): identifying threats and possible ways of avoiding them.

The analysis aims to derive a complex, comprehensive, complete picture of a market, industry, product, etc., in a straightforward, transparent way. As a first step, we have defined the criteria after reviewing the relevant literature to carry out the analysis separately. The SWOT aspects were [9]:

- Investment/acquisition cost level
- Investment and investment costs (based on energy consumption, Watt)
- Maintenance demand
- Possibility to combine the examined technology with other technologies
- Does the examined technology have adverse health effects?
- How large area can be disinfected with the examined technology?
- How can a wide range of particle sizes (bioaerosol concentration) be used?
- How efficient is the technology against Covid-19?
- Is the technology hazardous to human beings?

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- How sustainable is the technology (e.g., replacing a particular element considered hazardous waste; Is there a need for a particular treatment method?)
- What are the possibilities of applying the technology examined in other fields? (e.g. surface disinfection)
- What is the speed of the disinfection of the examined technology

Once the criteria had been defined, an analysis of each technology was carried out. In terms of the SWOT analysis parts (strength, weakness, opportunity, threat), the three selected technologies, UV-C, Bioxygen® and plasma-ion were categorised by each other.

3.1. SWOT analysis of UV-C Technology

The UV-C disinfection technology provides a chemical-free solution for the targeted destruction of airborne microorganisms. The characteristics mapped during the literature search are shown in Table 1 for the SWOT analysis of UV-C technology.

Strengths	**Weaknesses**
Effective against bacteria, viruses, fungi Surface treatment is possible Fast decontamination (max. 25 minutes) Effective against COVID 19 (99,99% after 25 minutes)	High energy consumption – 210-283 W – 283W for 75m^2 and 25 minutes High maintenance costs The room size is moderate where the technology is applicable – max. 75 m^2 UV-C fluorescent tubes have to be replaced after 7000 hours of usage The settings have to be proper such as air stream speed, wavelength, doze, exposition time
Opportunities	**Threats**
It can be combined with other technologies (e.g.: filters)	It harms health, and it can damage the skin and the eyes UV-C fluorescent tube is a hazardous waste

Table 1. SWOT analysis of UV-C technology (own research)

From the table and the literature review presented earlier, it is clear, that UV-C technology played a significant role in the control of the Covid-19 outbreak in the winter of 2019. This is due to its relatively fast, high efficiency in filtering out aerosol elements, bacteria, and viruses in the air and its ability to disinfect air and surfaces. However, it also has several drawbacks, such as relatively high running costs and maintenance requirements, as fluorescent tubes need to be replaced frequently. There is also a significant risk, as UV-C tubes are classified as hazardous waste, and their improper management can cause serious environmental problems. It is not only the device itself that is environmentally harmful but also the inappropriate use of the technology itself, UV radiation, which has serious adverse health

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effects on the human body, particularly on the eyes and skin. It is also important to mention the potential of the technology, as in many cases, we have seen solutions where air purification equipment with UV-C technology has been used for other functions, and there is still room for improvement in this area.

3.2. SWOT Analysis of Bioxygen® technology

The SWOT analysis of the Bioxygen® technology is shown in Table 2.

Strengths	**Weaknesses**
Low running costs Maintenance requirements are low, very minimal No adverse health effects Can disinfect 400-500 m^2, long range	Combination not known Efficiency by the size of airborne particles (aerosol, virus, bacteria, etc.) Effectiveness against Covid-19, 95% cleaning efficiency after 45 minutes Operation of mobile-type machines in terms of sustainability (e.g. batteries, batteries to be replaced) Not applicable in other areas (e.g. surface disinfection) Slowest disinfection speed up to 45 minutes The technology is not researched, not scientifically significant today
Opportunities	**Threats**
-	-

Table 2. SWOT Analysis of Bioxygen® Technology (own research)

The analysis of the Bioxygen® technology showed that it currently has the most weaknesses of any air purification technology on the market. It is at a disadvantage compared to both UV-C and plasma-ion solutions. Recent research has shown that it cannot be combined with any other solution and is less effective against Covid-19 of the three keys, this technology is the slowest to clean the air. It has almost completely disappeared from scientific research, and no further development is known. The analysis confirmed this, as it has neither potential nor significant risk. However, thanks to its advantages, as shown in the table, it is still on the market today as a relatively cheap, low-maintenance solution, capable of disinfecting large areas/premises, albeit relatively slowly.

3.3. SWOT Analysis of Plasma-ion Technology

Plasma ion technology is a relatively recent addition to air purification technology, but it is also an up-and-coming option, as shown in Table 3.

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Strengths	**Weaknesses**
Low running costs Low maintenance requirements Capable of cleaning up to 800-1200 m^2 - Can disinfect a much larger area than any other technology Efficiency by the size of airborne particles (aerosol, virus, bacteria, etc.) Effective against Covid-19, 99,99% after 15 minutes of decontamination Fast (fastest of the three solutions) No adverse health effects	Not for use in other areas (e.g. surface disinfection)
Opportunities	**Threats**
Can be combined with other technologies and solutions (e.g. filters)	-

Table 3. SWOT Analysis of Plasma-ion Technology (own research)

Plasma ion technology has several advantages over the other two air purification solutions presented earlier, in that it can clean the giant possible cubic metre of air of any technology known today, it is speedy, it is effective in controlling Covid-19, and it is also effective in destroying aerosol particles or bacteria, even with smaller particle sizes. It is relatively inexpensive and requires little maintenance. Its only weakness is that it has no known application in any other fields at the moment, and it is not considered to be a threat according to the criteria we have defined.

3.4. Summary of SWOT analysis

From the SWOT analysis of the three technologies, it emerged that of the air purification solutions currently in use, the Bioxygen® method is a narrow field of application, little researched and not of significant scientific importance. In the long term, plasma-ion technology could be an alternative and a substitute for UV-C technology, as it has many more strengths and advantages, including lower running costs, lower maintenance requirements and the ability to clean a much larger area in a unit of time. Overall, while Bioxygen® technology has excelled primarily in past solutions, UV-C technology has excelled in recent and current applications, and plasma-ion technology is absolutely the potential air purification technology of the future for the industry.

Conclusions

Air purifiers use different technologies to separate or remove one or more pollutants and particles from the air. Currently, various commercial air purifiers are available on the market with different

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mechanisms, including filtration, UV sterilization, catalytic degradation, and other purification technologies. The filter (e.g. activated carbon fibre) has a relatively large surface area for proper operation. During the photocatalytic reaction, free electrons and electron holes are generated on the catalyst's surface under the influence of UV. In this research, three technologies were examined and presented, UV-C, Bioxygen® and plasma-ion solutions. After their detailed description and presentation of their advantages and disadvantages, a SWOT analysis of the three technologies was carried out, looking for the answer to which of the best-known technologies is the most effective method according to today's conditions. During the analysis, we categorized the individual solutions in comparison to each other according to the specified criteria. After carrying out the analysis, the result was that the Bioxygen® method could be used in a narrow area, an area that is little researched nowadays and is not scientifically significant. On the other hand, plasma-ion technology can be an alternative solution in the long term and can replace the most popular and widespread UV-C technology today, which has much more strengths and advantages. However it should be noted that air cleaning devices can improve indoor air quality generally but cannot prevent transmission associated with close contact interactions, the primary route of transmission. Building owners or operators seeking to use air cleaning devices to supplement existing ventilation should carefully consider the potential benefits weighed against potential risks. [11]

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