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ANALYSIS OF HAZARDS FROM BIOTECHNOLOGY LABORATORY EQUIPMENT

Abstract: *Biotechnology laboratories are specialized facilities that utilize biocatalysts for research, development, and production in various fields, including medicine, agriculture, industry, and ecology. These laboratories typically share standard equipment, regardless of their specific focus. The aim of this paper is to analyze the hazards associated with the use of work equipment that is commonly used in a biotechnology laboratory. The subject of the analysis is the work equipment in the biotechnology laboratory, which includes simple bench-top devices, as well as larger standalone and integrated systems, which are used for sample analysis, diagnostics, bioprocessing, providing appropriate working conditions and processes (bioreactors, centrifuges, autoclaves, microscopes, incubators, digesters, heating plates, microwave ovens, water baths, freezers, laboratory glassware, spectrophotometers, electrophoresis and PCR equipment, etc.). In the paper, identified hazards are given for each unit of work equipment, which are grouped by category, and possible causes and consequences of each of the identified hazards are given and recognized. The hazard analysis of work equipment is an essential starting point for an appropriate risk assessment of work equipment in the working environment of biotechnology laboratories.*

Keywords: biotechnology laboratories, working environment, work equipment, hazards, risk assessment

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INTRODUCTION

Safety and health at work is important in all branches of industry, business, and trade, including all work processes and working environment in facilities for production and non-production activities and facilities for education, health and social care, culture, sports, tourism, traffic, etc. Safety and health at work contribute to increased productivity in the workplace, stimulate economic growth and employment, and improve the functioning of the labour market (Goetsch, 2019).

Risk assessment represents the identification of preventive and protective measures based on the evaluation of the risk arising from the hazard, taking into account the adequacy of the existing risk control and deciding whether the risk is acceptable. Risk assessment focuses on the organization of work, work processes, means of work, raw materials and materials used in technological and work processes, means and equipment for personal protection at work, as well as other elements that can cause the risk of injuries at work, damage to the health or illness of the employee (Aven, 2015).

Identified hazards can be classified into several categories based on the severity of their possible consequences (e.g. low, medium, and high), which allows comparing these threats and prioritizing the 'dangerous'. As a result of the risk assessment, corrective measures are defined that are needed to eliminate the risks arising from these hazards (Elmontsri, 2014).

Hazard identification is realized through several activities, such as immediate inspection of the workplace and work activities with work equipment that can cause injuries or damage the health of employees. Once it has been determined where hazards may exist, it is important to look at the processes and work cycles taking place to determine if the hazards actually exist. It is important to have direct contact with the operators of the work equipment, who can provide first-hand information on whether there are any dangers during their work.

An insight into the records of previous incidents on the work equipment provides information about what has recently caused a risk for an employee, that is, led to their injury or illness. Also, reviews of the records of employees' sick days and absences can reveal hidden risks or organizational factors that affect absence, i.e. specific information that provides even more guidance on where significant hazards occur.

Analysis of the work equipment manufacturer's instructions involves checking whether the operators follow the instructions. This provides all the relevant information for the given work equipment, and allows significant hazards to be identified more easily. Also, through the appropriate regulations on measures for safe work with work equipment, as well as annual reports on work safety, information is obtained about the dangers that occur with work equipment in certain sectors of the industry. Analysis of the records of the service and maintenance regime of the work equipment identifies potential hazards on the observed work equipment, considering that the present dangers on the given work equipment are managed through the service and maintenance regime (Kharzi et al., 2020).

After hazard identification, it is recommended to group hazards into specific categories (Henderson, 2017). Creating categories makes it easier to review risks, which can help make decisions to eliminate risks. The categorization can be made on the basis of the type of impact on human health (chemical, biological, psychological, physical), on the basis of the activities at a given workplace (e.g. activities related to the handling of chemicals, work on a bioreactor), etc. In many companies, there are four groups of hazards: hazards of human origin, technological hazards, medical hazards, and other hazards.

Technological risks are a large group of risks that include risk factors that affect (or arise from) work equipment in the workplace. Most often, these types of risk factors appear due to poor condition or poor maintenance of work equipment, but this category also includes risks arising from the inexperience of workers (Hughes and Ferrett, 2007).

Biotechnology laboratories are specialized facilities where biotechnological methods are applied, using biocatalysts (microorganisms, enzymes, plant and animal cells) for research, development and production of new products or solutions in various fields (medicine, agriculture, industry, ecology, etc.). In general, all biotechnology laboratories include certain work equipment that can be marked as common to almost all biotechnology laboratories, regardless of their purpose, i.e. the field of application (Gupta et al., 2017).

Biotechnology laboratories can be classified into several types based on their purpose and application, namely: industrial biotechnology laboratories, medical biotechnology laboratories, environmental biotechnology laboratories, and agricultural biotechnology laboratories.

The aim of this paper is to analyze or identify the hazards of work equipment that is commonly used in a biotechnology laboratory, regardless of its purpose or area of application.

MATERIALS AND METHODS

The subject of analysis is selected equipment for work in a biotechnology laboratory, which includes simple desktop devices, as well as larger independent and integrated systems, which are used for sample analysis, diagnostics, performing bioprocesses, and ensuring appropriate working and process conditions (bioreactors, centrifuges, autoclaves, microscopes, incubators, digesters, heating plates, microwave ovens, water baths, freezers, burners, laboratory glass, spectrophotometers, electrophoresis and PCR equipment, etc.).

The analysis identifies hazards for each unit of work equipment, as well as the possible consequences of each identified hazard.

Hazard analysis of work equipment is a necessary starting point for an appropriate risk assessment of work equipment in the work environment of a biotechnology laboratory.

The subject of the risk assessment is the work environment of a model for a general biotechnology laboratory in which common work equipment is used, that is, equipment used in most biotechnology laboratories with a similar design of the work space.

Hazard identification was carried out on the model of a general biotechnology laboratory taking into account all risk factors arising from work equipment.

Identification of hazards is the first stage in risk assessment, followed by the stages of identification of persons exposed to hazards, risk evaluation, assessment of existing risk control and recommendations for improvement, and revision and documentation of risk assessment.

The information about the dangers of work equipment is collected through: direct insight into the work equipment at the workplace, observation of the work of employees with the given equipment, review of records of earlier incidents with the work equipment, review of the instructions of the manufacturer of the work equipment, application of regulatory guidelines, as well as review of information on the maintenance regime of the equipment and observation of posted warning pictograms for using the work equipment.

Table 1 shows the analyzed work equipment used in the biotechnology laboratory.

Table 1. *Analyzed work equipment and its use in the biotechnology laboratory*

Equipment	Description / Use
Centrifuges	They are used to separate the components of mixtures based on their density. The samples placed in them rotate at high speed, creating a strong centrifugal force, as a result of which denser materials move to the bottom of the cuvette, while materials of lower density occupy the upper layers. In biotechnology, it is primarily used for the separation of biomass from the medium, but also for the purification of biological products.
Bioreactors	Complex and diverse devices that enable the cultivation of microorganism cells, plant and animal cells, in controlled conditions for the production of a wide range of biological products, from pharmaceutical products to biofuels. Bioreactors provide controlled conditions as well as sterile conditions during operation.

Cooking and mixing plates	They are used for heating and mixing different media. They are usually used to facilitate the dissolution of substances in a liquid medium, to melt substances and to thermoregulate mixtures.
Autoclaves	They are used for sterilization with steam at a pressure of 2.1 bar and a temperature of 121 °C. Hot steam destroys the structure of the cell wall and membrane of microorganisms, which is important for the sterilization of laboratory instruments and materials.
PCR equipment	It is used for amplification (duplication) of DNA sequences, whereby the DNA sequence being examined is made into a large number of copies, which enables further manipulation with them.
Electrophoresis equipment	It is used to separate and analyze macromolecules such as DNA, RNA, and proteins based on their size, charge, and other physical properties.
Microwave ovens	They are used for rapid heating of materials, most often for faster dissolution of soluble substances or for faster reaction of the medium.

RESULTS AND DISCUSSION

The dangers associated with the use of centrifuges in a biotechnology laboratory are manifested as mechanical and electrical hazards, as well as chemical and biological hazards. The main danger when working with a centrifuge is its movement/sliding on the work surface during operation, which can occur if the centrifuge is improperly loaded or unbalanced. During the operation of the centrifuge, the unbalanced mass in the centrifuge, due to the centrifugal force, leads to an imbalance, that is, an uneven distribution of forces that act on the centrifuge itself and lead to its movement on the work surface and possible fall from it.

When working with dangerous chemicals or pathogenic microorganisms, when the centrifuge is opened, evaporation of dangerous substances can occur, which poses a danger to the respiratory organs of people in the laboratory. A similar danger exists if the centrifuge lid is not adequately closed before centrifugation begins.

Electrical energy also poses a great danger in situations where the centrifuge is not regularly serviced and maintained, which can lead to equipment failure and the risk of electric shock for the user of the centrifuge. Table 2 lists the identified hazards of working with a centrifuge, as well as possible consequences.

Table 2. *Centrifuge hazards*

Hazard	Possible consequences
Centrifuge movement	The centrifuge may move or fall off the work surface due to imbalance.
Exposure to hazardous substances or pathogens	The centrifuge lid does not close during centrifugation. When lifting the centrifuge lid, dangerous substances and pathogens can be released.
Electric shock	During frequent use of the centrifuge, a malfunction may occur, which poses a risk of electric shock to the user.

Due to the complex structure and diversity of bioreactors, they pose a great danger in the biotechnology laboratory, through mechanical and electrical hazards, physical and chemical properties of chemicals, as well as chemical and biological hazards. When analyzing the operation of a bioreactor, the main focus is on the bioprocess that takes place in it, that is, on the biocatalysts in the nutrient medium in the bioreactor. One of the biggest dangers for such equipment is the microorganisms themselves, which in some cases can be pathogenic. The danger appears mostly only after the end of the bioprocess (when the ports on the bioreactor are opened), because the concentration of pathogens can increase several thousand times compared to the initial one, and through the vapours they can easily reach human organisms. Often, in addition to microbiological biomass, organic substances (by-products or final products) can also be formed, and they can cause a harmful effect.

During bioprocesses, carbon dioxide or other gaseous metabolites are often produced as by-products, which can accumulate in bioreactors. In non-hermetically sealed bioreactors, this can be extremely dangerous, as carbon dioxide can enter the laboratory atmosphere and lead to an asphyxiation hazard.

Metabolic gases as a product of bioprocesses also represent an additional risk of explosion. During intensive gas production, the pressure inside the bioreactor can increase, which can lead to the explosion of the bioreactor vessel itself. Table 3 shows the identified hazards of working with the bioreactor, as well as the possible consequences.

Table 3. *Bioreactor hazards*

Hazard	Possible consequences
Exposure to pathogens and hazardous substances	When opening the bioreactor, there is a risk of inhaling pathogens or dangerous substances.
Lack of oxygen	During the bioprocess, carbon dioxide is often produced as a by-product to which workers are exposed.
Explosion	Metabolic gases can increase the pressure in the bioreactor, which can lead to an explosion.
Fire	If pure oxygen is used for aeration, the risk of fire may increase due to the oxygen-enriched air.
Cuts	The edges of bioreactor components (dispersers, mixers, impellers) can be sharp and lead to cuts.
Electric shock	Irregular servicing and maintenance of the bioreactor can lead to failure, which can pose a risk of electric shock.

Some bioprocesses require the use of pure oxygen for aeration in the bioreactor, but this entails an increased risk of fire. During a leak in the oxygen supply system,

the air is enriched with oxygen, which helps the fire develop and spread more quickly.

When using the bioreactor, there may be cuts from the sharp ends of the air blowing system or the impeller of the mixer. As with most electrical machinery and/or equipment, an improperly maintained device poses an additional electrical hazard.

Cooking and mixing plates serve to heat liquids, so the greatest danger is the high temperatures that develop during work. High temperatures pose a risk of burns, in case of unprofessional handling of the equipment, leading to overheating of the liquid, which further increases the risk of burns. There is also a risk of electric shock when working with cooking and mixing plates. Table 4 lists the identified hazards associated with the use of the hob and stirrer, as well as the possible consequences.

Table 4. *Cooking and mixing plates hazards*

Hazard	Possible consequences
Burns	A hob with a stirrer usually works at a high temperature, which is why there is a risk of burns during use.
Electric shock	Probability of electric shock in case of device failure.

Steam sterilization is performed in autoclaves. During sterilization, autoclaves use steam at high temperature (121 °C) and high pressure (2.1 bar), which ensures the destruction of microorganisms and sterilization of materials. Therefore, most of the dangers arise from the high pressure and high temperature prevailing in the autoclave. After sterilization, the hot steam in the autoclave can condense and come into contact with the user's body when the autoclave is opened, causing burns. Such injuries can also occur when coming into contact with hot parts of the autoclave and sterilized material.

In the event of autoclave failure, there may be an increase in pressure in the chamber and its explosion. Glass containers are often used during laboratory work, which must be sterilized after the work is finished. If working with materials that can be sensitive to the presence of hot water vapor (e.g. glass), they can break or crack due to high temperature and pressure and can cause cuts to the user of the autoclave at the moment of its discharge. Autoclave users who sterilize biologically contaminated equipment and materials are at risk of infection if the waste is not properly stored or if the sterilization cycle is not properly completed.

During the condensation of water vapor, waste water is produced, which leaves the autoclave through the water outlet. If this water is not properly collected or drained, it can create a wet floor around the autoclave, which is a slip hazard. In the event of autoclave failure, there may be a risk of electric shock to the user of the autoclave. Table 5 lists identified hazards related to the use of autoclaves, as well as possible consequences.

Table 5. *Autoclave hazards*

Hazard	Possible consequences
Exposure to pathogens or genetically modified microorganisms	Users who autoclave biologically contaminated instruments are at risk of infection if the waste is not properly stored or if the sterilization cycle is not properly completed.
High pressure	If the autoclave is faulty, there is a possibility of an explosion. This can cause injury to people near the autoclave.
Sharp glass container, cuts	Glassware may crack or break during the sterilization process.
Burns	High temperature – hot condensate is possible when the user is emptying the autoclave. Certain parts of the equipment may be heated during the sterilization cycle.
Electric shock	If the autoclave malfunctions, users may receive an electric shock.
Slipping	Spills or leaks on the floor can cause a slip hazard.

The use of PCR equipment is considered relatively safe. It is rare but possible for the user of the PCR equipment to get burned during contact with the equipment or the samples inside it, as the temperature inside it usually ranges between 50 and 100°C. Often, repetitive pipetting can lead to muscle strain, which is why it is recommended that when working with many samples, pipetting should be done by several people, who take turns regularly. The dangers and possible consequences related to the use of PCR equipment are shown in Table 6.

Table 6. *PCR equipment hazards*

Hazard	Possible consequences
Burns	The user of the PCR equipment may suffer burns during contact with the equipment after the end of the cycle.
Muscle fatigue	Frequent pipetting can lead to muscle strain.

One of the biggest risks during electrophoresis is contact with dangerous chemicals. During analysis, fluorescent markers are used to monitor the progress of test substances through the porous gel in an electric field. Among the markers, one of the most common choices is ethidium bromide, which is a well-known carcinogen. Similar to ethidium bromide, the porous gel is often based on polyacrylamide, which is also a carcinogenic material.

Electrophoresis can also lead to burns, because when pouring liquid hot gel, the gel can burst or spill onto the hands or clothes of the person performing the electrophoresis. Electrophoresis is usually performed at a voltage of 100 V, which results in a current of 25 mA, so during electrophoresis, in addition to the above, there is also a risk of electric shock if the person using the equipment comes into contact with the electrophoretic buffer. Electric shock can also result from electrophoresis equipment failure. Table 7 lists

identified hazards and possible consequences when using electrophoresis equipment.

Table 7. *Electrophoresis equipment hazards*

Hazard	Possible consequences
Exposure to carcinogenic substances	During gel electrophoresis, ethidium bromide (marker) and polyacrylamide (porous gel) are often used, which can cause carcinogenic effects when inhaled.
High temperature	Pouring and mixing of the hot gel can cause splashes and burns.
Electric shock	Electrophoresis is usually performed at a voltage of 100 V resulting in a current of 25 mA.

Microwave ovens are used to rapidly heat solutions or materials, so the primary hazard associated with the use of microwave ovens is high temperature. Materials heated in a microwave oven can reach very high temperatures, so direct contact with them or the equipment can cause burns.

The basic element of every microwave oven is a magnetron, which enables the generation of microwaves. These microwaves are reflected from the wall inside the microwave oven and enter the molecules of the material being heated, where the rays are absorbed in the form of vibrational energy. As a result of the vibration, friction is created between the molecules, which leads to the release of heat. If these microwave rays leave the microwave oven, they can cause heating of the tissues of the human body and cause burns or cataracts of the eye. Table 8 shows information about the dangers and possible consequences of using a microwave oven.

Table 8. *Microwave oven hazards*

Hazard	Possible consequences
High temperature	Contact with heated materials or equipment can cause burns.
Electromagnetic radiation (microwaves)	The eye or skin can absorb microwave energy, causing cataracts or minor burns.
Electric shock	A malfunction may result in an electric shock.

CONCLUSION

Bioreactors and autoclaves are considered the most dangerous equipment for work in a biotechnology laboratory, which have a significant number of hazards with possible severe consequences for the safety and health of the operator (explosion, high temperature, chemical and biological hazards, electric shock, pathogens, etc.). Work with bioreactors and autoclaves is recommended only to persons with appropriate professional knowledge and work experience. The dangers of electrophoresis equipment are significant, as contact with carcinogenic materials is possible, as well as the high voltage required for electrophoresis. Both dangers are significant due to possible severe consequences, which requires that the electrophoresis process itself must be performed with special attention by the operator. The use of the other analyzed work equipment also includes possible hazards to human health, but these hazards manifest minor consequences for the operator's safety and most of them are easily eliminated through careful handling and compliance with prescribed work procedures.

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