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GREEN CHEMISTRY IN THE LAB: PROMOTING SUSTAINABLE PRACTICES FOR A HEALTHIER ENVIRONMENT

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ABSTRACT

Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. It aims to protect human health, while enhancing the efficiency and competitiveness of the chemical industry. Green chemistry laboratory practices are also important to protect the environment from the harmful effects of chemical waste, pollution, and resource depletion. Green chemistry principles can be applied to various stages of research and development, from the selection of starting materials and solvents, to the optimization of reaction conditions and catalysts, to the minimization of waste and energy consumption. This paper reviews the current status, challenges and opportunities of implementing green chemistry practices in laboratory settings, both in academia and industry. It provides examples of how chemists can adopt greener alternatives for common laboratory operations, such as synthesis, purification, analysis and storage. It also discusses the benefits and barriers of adopting green chemistry practices, such as cost savings, safety improvements, regulatory compliance, innovation potential, education and outreach, as well as technical limitations, lack of awareness, resistance to change and insufficient incentives. The paper highlights the need for further research and innovation in green chemistry to address the emerging challenges and opportunities in the chemical sciences.

Keywords: *Green Chemistry, Chemicals, Environment.*

Introduction

Chemicals are essential for economic growth and human well-being, but if handled improperly, they can pose serious health concerns to people. They even impact the environment and the ecosystems that support human life. Such chemicals can affect human health in various ways, depending on the type, amount and duration of exposure. According to Chang and Lamm (2003), the impact of hazardous chemicals in laboratory on health and environment is a serious issue that requires attention and action. Some of the hazardous chemicals found in laboratory and their effects have been given in Table1. To reduce the impacts of hazardous chemicals on human health and the environment, it is important to adopt a precautionary approach that minimizes the use, production and release of such substances. It is also essential to implement effective regulations and policies that ensure the safe management of chemicals throughout their lifecycle.

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Table 1: Hazardous Substances in Laboratories

Type of Chemicals	Effect	Examples of Chemicals
Dangerous chemicals	Harmful to the human body and environment	Acetonitrile, chloroform, formaldehyde, sodiumazide, sodium hydroxide, etc.
Oxidizers	React violentlyand cause fires or explosions	Nitrates, perchlorates, permanganates, chromates, peroxides, etc.
Flammable liquids	Ignite easily and burn rapidly	Methanol, ethanol, acetone, xylene, toluene, etc.
Water-reactive	Release flammable or toxic gases on exposure to moisture or water	Alkali metals, metal powders, carbides, boranes, etc.
Pyrophoric	Spontaneously ignite in air or oxygen	Metal alkyls and aryls, nonmetal alkyls, phosphorus (white), etc.
Poisons	Cause acute or chronic toxicity to the human body or the environment	Acrylamide, cyanides, sulfides, mercury compounds, etc.

Impact of Hazardous Chemicals

Chemicals released into the environment can have far-reaching health consequences through pollution of air, water, and soil. This can affect ecosystems and the health of both humans and wildlife. Many chemicals are toxic to humans and can cause acute or chronic health problems. The severity of the toxicity depends on factors like the chemical's toxicity level, the route of exposure (e.g., inhalation, ingestion, dermal contact), and the dose. Exposure to specific chemicals, such as heavy metals (e.g., lead, mercury), can damage organs like the liver, kidneys, and heart. Significant impact areas of hazardous chemicals have been outlined as under:

Hazardous chemicals can seep into the soil and water sources from a variety of sources, including mining operations, agricultural runoff, industrial waste, landfills, and spills. Water quality and quantity for irrigation and human consumption may suffer as a result. Crop output and soil fertility may also be impacted.

Hazardous chemicals can cause ozone depleting or greenhouse gas emissions, which can contribute to air pollution and climate change. As a result, the climate may warm up and weather patterns may change. Additionally, it can impact the quality of the air and raise the risk of cardiovascular and respiratory disorders**.**

Hazardous chemicals might make wildlife poisonous, mutate, sick, or even die. They may also have an impact on the ecological balance and food chain resulting into loss of biodiversity.

Exposure to air pollution from dangerous chemicals can harm the heart and lungs of living beings by inflaming them and by causing irritation and inflammation.

Allergic reactions or sensitization in some people may be triggered by some hazardous chemicals.

Some hazardous chemicals which have the potential to cause cancer in both people and animals, can damage the DNA or interfere with the normal functioning of cells.

Review of the Literature

The American Chemical Society (ACS) designed and endorsed a framework of 12 Principles developed by Dr. Paul Anastas and Dr. John Warner (1998) to guide chemists in thinking about how to reduce the risk that chemical interactions pose to human health and the environment. For a holistic safety culture to exist, Orgill et al. (2019) stated that a system thinking approach to incorporate green chemistry and safety into laboratory culture must be embraced at all educational stages. This is essential because if academic institutions establish a safety culture, then that will be carried over into subsequent career paths. As we look to the future, Zimmerman et al. (2020) states that we must ensure that chemistry not only does no harm but is also carried out in a life-friendly manner. Kümmerer (2017) said that the expansion of the 12 green chemistry principles to wider dimensions with the label sustainable chemistry education in university and other curricula is a more recent phenomenon. The objective of the green lab program, according to Wissinger (2018), is to inform stakeholders about the lab's environmental effects and to help them select safe, sustainable practices that they may include into their

work. According to Noce (2018), chemists will be involved at the molecular level of the solutions to our global problems; as a result, they must have the education, expertise, and culture to support these goals in the safest manner possible. Methods for integrating green chemistry into laboratory practices should be researched to assist stakeholders in creating a learning environment that is free from health hazards and strong on safety.

Objective of Green Chemistry Practices in Laboratory

Laboratories, as places of scientific discovery, often have a moral responsibility to minimize their environmental impact and contribute positively to society. Sustainable practices help safeguard a lab's operations and research capabilities for future generations. Green practices in laboratories are essential for several reasons, as they promote sustainability, reduce environmental impact, and enhance safety and efficiency. Here are some compelling reasons for implementing green practices in a lab setting:

- **Environmental Conservation**

Reduction of hazardous waste, Energy conservation and Water conservation can help conserve this precious resource which can be successfully achieved by following green practices.

- **Regulatory Compliance**

Compliance with environmental laws and regulations is mandatory. Green practices help labs meet these requirements and avoid penalties.

- **Cost Savings**

Reduced resource consumption will lead to cost savings over time, benefiting the lab's budget. This will also cause less waste generation meaning lower disposal and treatment costs.

- **Health and Safety**

Proper handling and disposal of hazardous chemicals and materials reduce the risk of accidents and health issues for lab personnel.

- **Public Image and Funding**

Labs that prioritize sustainability and environmental responsibility often enjoy a better reputation, which can be crucial for attracting funding, partnerships, and talented researchers. Even, many funding agencies and organizations prioritize environmentally responsible projects and practices.

- **Innovation**

Implementing green practices encourages labs to explore and develop environmentally friendly technologies and solutions.

Green Chemistry Principles

The 12 principles of green chemistry were developed by Paul Anastas and John Warner in 1998 as a framework to guide the design and implementation of environmentally friendly chemical processes and products. These principles promote sustainability, safety, and the reduction of environmental impact in the field of chemistry. Here are the 12 principles of green chemistry:

- Prevention: It is better to prevent waste and pollution at the source than to treat or clean up after it is formed. This principle encourages designing processes that minimize the generation of hazardous substances.
- Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product, minimizing the production of byproducts and waste.
- Less Hazardous Chemical Syntheses: Whenever possible, use and design chemical products and processes that are inherently safer, with reduced toxicity and fewer hazardous materials.
- Designing Safer Chemicals: Aim to develop chemicals that have reduced toxicity, are less harmful to human health and the environment, and are biodegradable.
- Safer Solvents and Auxiliaries: Use solvents and auxiliary substances that are non-toxic, non-flammable, and have minimal environmental impact. Consider water as a green solvent.
- Design for Energy Efficiency: Optimize chemical processes to require less energy, reduce energy consumption, and decrease greenhouse gas emissions.

- Use of Renewable Feedstocks: Whenever possible, use raw materials and feedstocks that are renewable, biodegradable, and sustainably sourced.
- Reduce Derivatives: Minimize the use of blocking or protective groups, which can lead to waste generation, by designing more selective reactions.
- Catalysis: Use catalytic processes to increase the efficiency of chemical reactions, reduce the amount of reagents needed, and minimize waste production.
- Design for Degradation: Develop chemicals and materials that can break down into non-harmful substances after their useful life, reducing their environmental impact.
- Real-time Analysis for Pollution Prevention: Employ real-time monitoring and analytical techniques to ensure the safe and efficient operation of chemical processes and minimize waste.
- 12.Inherently Safer Chemistry for Accident Prevention: Design chemical processes and products that are inherently safer, reducing the risk of accidents, releases, and explosions.

These 12 principles provide a framework for chemists, researchers, and industries to develop more sustainable and environmentally friendly practices in chemistry. By following these principles, the field of chemistry can contribute to a greener and more sustainable future, with reduced environmental impact and improved safety.

Green Laboratory Practices

Chemicals are being used in enormous amounts, creating a ton of toxic and dangerous chemical waste in the process. Every day, more than 70,000 chemicals are used worldwide, and these chemicals have an effect on our life. When used and disposed of properly, they improve quality of life; nevertheless, when misused and dumped, they significantly affect health of living beings and environment. Most laboratory and non-laboratory operations generate modest amounts of trash, many of which are highly toxic, and the environmental damage caused by that chemical waste is of growing concern. Even micro-scale operations, which are intended to be more environmentally friendly by reducing the amount of chemicals used, have an inherent risk of exposure because of the nature of the chemicals being employed, according to Singh et al. (1999). Education- and research-related organizations contribute to this waste generation. Green chemistry lab practices, also known as sustainable chemistry or environmentally friendly chemistry, aim to minimize the environmental and health impacts associated with chemical processes and experiments. Green chemistry offers stakeholders a secure, healthy and environmentally friendly studying environment. The green chemistry tenets include the use of less hazardous chemicals, energy saving, waste reduction, and more sustainable and secure products. Students at the universities can implement a variety of green laboratory practices to foster a pro-active attitude towards environmental conservation and protection. These practices are essential for promoting sustainability, reducing hazardous waste, and ensuring the safety of laboratory personnel. According to Schulte et al. (2013), eliminating hazards or substituting them with less hazardous or nonhazardous alternatives is the most efficient way to lower risk. According to Aubrecht et al. (2019), adding greener experiments to the chemistry lab makes the subject of chemistry safer for students because they are exposed to less harmful compounds.

Initiatives for Green Processes in Laboratories

From an environmental and health point of view, green practices at labs at all levels are also necessary as a means of dealing with risk reduction and pollution management. Such methods seek to increase stakeholders' understanding, attitudes, abilities, and commitment to preserving and enhancing the environment. Cannon et al. (2017) explains that all chemicals present a risk at a particular concentration, hence chemical exposure must always be taken into account, even in the best green chemistry facilities. Some initiatives that can be taken are as follows:

Replace hazardous chemical with a less dangerous or nonhazardous option that is not just cost-effective and widely accessible in large amounts everywhere.

Time-consuming experimental techniques should not be used in experiments, such as lengthy reaction periods or high-temperature reactions.

The use of many dangerous compounds can be avoided by using modern, sophisticated instruments like spectrophotometers in labs for qualitative and quantitative research. These instruments allow for the avoidance of old procedures.

- Semi-micro or micro-scale analysis needs to be done in every lab.
- Spot testing should be utilized wherever possible.
- The preparation of derivatives on a large scale should be avoided
- Better management and monitoring of laboratory-used chemical reagents.
- Recycling of solvents should be in practice.
- Purity of compounds should be checked using TLC.
- To eliminate hazards of chemicals, all stakeholders will have to focus on green laboratory practices. Some key green chemistry lab practices and actions to be taken are given in Table 2.

Table 2: Green Chemistry Lab Practices and Action to be taken

Green Practice	Action to be Taken
Use of Safer Chemicals	Choose less toxic and hazardous chemicals whenever possible. Replace hazardous substances with safer alternatives.
Chemical Inventory Management	Maintain an up-to-date inventory of chemicals to prevent unnecessary purchases and waste. Properly label and store chemicals to prevent spills and accidents.
Minimize Chemical Use	Use chemicals in the smallest quantities necessary to achieve the desired results. Design experiments and processes to minimize chemical consumption.
Solvent Selection	Choose green solvents (e.g., water, ethanol) over hazardous or volatile organic solvents. Employ solvent recycling and recovery.
Energy Efficiency	Use energy-efficient equipment in laboratory. Turn off equipment when not in use, and optimize experimental setups to reduce energy consumption.
Waste Reduction:	Implement techniques such as microscale chemistry to reduce waste generation. Recycle and reuse chemicals and materials when possible.
Catalysis	Employ catalytic processes to reduce the need for reagents and minimize waste.
Green Synthesis	Use environmentally friendly synthesis
Green Equipment	Invest in energy-efficient equipment
Education and Training	Provide training for environmentally friendly techniques and technologies to stakeholders
Safety Practices	Prioritize safety by following established safety protocols

Result and Discussion

In order to help stakeholders select safe, sustainable green practices that they may use in their work, we need create ways to inform them about the environmental effects of the lab. Educating lab personnel about green practices is not only essential for reducing the environmental impact of laboratories but also for ensuring safety, financial efficiency, compliance, and long-term sustainability. It empowers lab members to be environmentally responsible, innovative, and informed contributors to scientific research and laboratory operations. Educating students about green practices fosters a sense of responsibility and stewardship towards the environment, encouraging them to minimize their lab's environmental footprint. Such lab practices promote sustainable resource management. Educated lab personnel are more likely to implement strategies to reduce resource consumption, minimize waste, and choose environmentally friendly alternatives. Moreover, proper training in green lab practices ensures that lab personnel are aware of the potential hazards associated with their work. It teaches them how to handle chemicals, equipment, and materials safely, reducing the risk of accidents and health problems.

Conclusion

Green chemistry, a method of dealing with risk reduction and pollution prevention by addressing the inherent risks of the chemicals, is required from both an environmental and a health standpoint. The paper concludes with some recommendations for promoting and facilitating the adoption of green

chemistry practices in laboratories, such as developing green chemistry curricula and training programs, establishing green chemistry networks and awards, creating green chemistry guidelines and tools, and engaging with stakeholders and policymakers. Implementing these practices not only benefits the environment and lab personnel but also contributes to the overall sustainability of scientific research and innovation. Education on green practices should be an ongoing process. By continuously educating lab personnel and encouraging them to share their insights and experiences, labs can foster a culture of continual improvement, where sustainable practices evolve and become integrated into everyday operations.

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