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ADVANCEMENTS IN CHEMICAL MATERIALS: EXPLORING SMART STORAGE EQUIPMENT AND PROTECTION SYSTEMS (REVIEW)

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ABSTRACT
The growing dependence on chemicals across industries has emphasized the importance of storage solutions to ensure safety and environmental sustainability. Smart storage systems, equipped with cutting-edge technologies, offer opportunities to tackle these issues guaranteeing best dealing and handling. This study evaluates chemical storage equipment and protection systems' role in increasing safety and sustainability in storage practices and roles. This evaluation included a decade-long literature examination of papers, patents, and industry reports. The analysis examined safety assessments, regulatory compliance, and storage system applications. The study examined IoT, AI, sophisticated detectors, and sensors to improve storage safety and reduce the effect for environmental sustainability. Results showed breakthroughs in sensor technologies, systems integration, and AI algorithms for real-time storage facility monitoring, danger identification, and predictive analytics. Smart storage solutions reduce hazards, ensure compliance, and protect the environment. However, prices, integration issues, and data security concerns were noted. Overall, this review sheds light on chemical smart storage systems and their future. It shows how technology improves safety and sustainability and identifies topics for further research.
Keywords: *Chemical, Detection, Arduino, Hardware, Software, Artificial Intelligence, Environmental Sustainability*

1. Introduction

Technology and materials are widely used and stored, making their security and safety crucial (Hailan et al., 2023). In light of the growing use of chemicals and equipment in storage facilities and rapid technological advancement, safety and security must be prioritised (Surya Wardhana et al., 2023). Recent technological improvements and the increased usage of technology and materials in storage facilities have made safety precautions more necessary. To store chemicals safely, engineers utilise many technologies and security measures (Shrote & Pawar, 2023). Each chemical has a container to prevent contamination and ensure safety. Global Chemical Classification System (GHS) criteria ensure chemical identification and classification (Idama & Ekruyota, 2023).

These materials are stored in a controlled environment to maintain temperature, pressure, and cleanliness. To decrease dangers, these compounds are handled with equipment (Aksoy Sera et al., 2022). Storage of chemicals protects humans and nature.. Keeping chemicals in good condition makes them easier to use and reduces the likelihood of pollution. Correct storage of data and information related to chemical emergencies is essential (Al Hasani et al., 2022). Chemicals stored improperly and leaking out can cause pollution to the environment and groundwater. Explosions and fires can result from chemical reactions. Exposure to pollutants or dangerous chemicals puts workers at risk of damage. Lost or damaged items can lead to significant financial setbacks (Lv et al., 2022).

Deep learning improves chemical storage management by creating predictive models that assess risks and warn of future incidents. Data surveillance and emergency response are made possible by artificial intelligence and neural networks. Storage and monitoring are improved by warehouse and inventory data analysis (Islam et al., 2022). The objective of this article is to analyze storage systems, which encompass several networked technologies such as the Internet of Things (IoT), artificial intelligence, and advanced wireless sensor networks (WSNs) (Islam et al., 2022). Moreover, its objective is to incorporate these technologies into storage solutions and create systems for effective risk mitigation, swift detection of potential dangers, and flexible management of chemical resources.

The information recorded indicates that in the 326 incidents, a total of 166 different substances or products were released. Figure 1 lists 24 substances and products that have been associated with six or more incidents or incidents involving five or more victims. Most of the victims were involved in incidents involving chlorine and hydrochloric acid (pure or solution). Hydrogen was the substance involved in the highest number of accidents (21x), followed by chlorine (14x), ammonia (13x), and hydrochloric acid (11x) (Kooi et al., 2020).

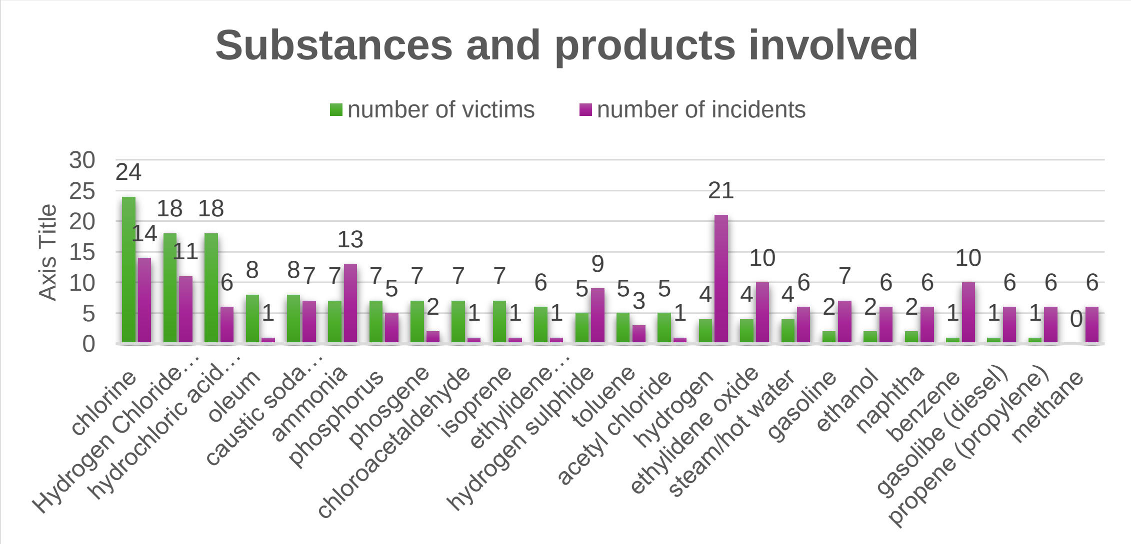

Fig. 1. Substances and products involved (Kooi et al., 2020).

Examples of accidents caused by chemicals on April 9, 2023, at 4.30 o'clock this morning, German time, a large fire broke out in a warehouse east of Hamburg, which contained high-risk chemicals, and some transport vehicles loaded with electrical appliances (Frederik Pleitgen, 2023)

This paper aims to examine the ability of smart storage systems to facilitate environmentally friendly efforts in the chemicals sector, given the increasing focus on adopting new methods. This review will analyze, evaluate and compare studies that can be classified into two distinct groups. The initial phase of research focuses on examining and coding equipment designed to store chemicals. Therefore, the current research poses challenges related to developing effective systems for early warning of chemical accidents or leaks using smart technologies such as smart sensing and wireless networks to analyze data and predict problems, along with how to invest in technology to enhance sustainability in various aspects of environmental protection and health.

1.1 Research Gap

There have been advancements in sensor technology, but there is still a need for further research to fully utilize these sensors for monitoring key parameters like temperature, pressure, and chemical composition in real time. Moreover, there is a growing demand for safety systems that can anticipate and prevent accidents. This involves exploring methods, for fire suppression, leak detection, and automated shutdown procedures to enhance the safety of chemical storage facilities. Considering these considerations, it is evident that implementing warehouses equipped with sensors to monitor temperature, humidity, and pressure would be an effective solution to address this issue

1.2 Chemical Materials Storage Categories

The categorization of chemicals for storage is determined by their specific chemical features and associated dangers. The subsequent passage illustrates the categorization of chemicals into various primary classifications illustrated in Figure 2.

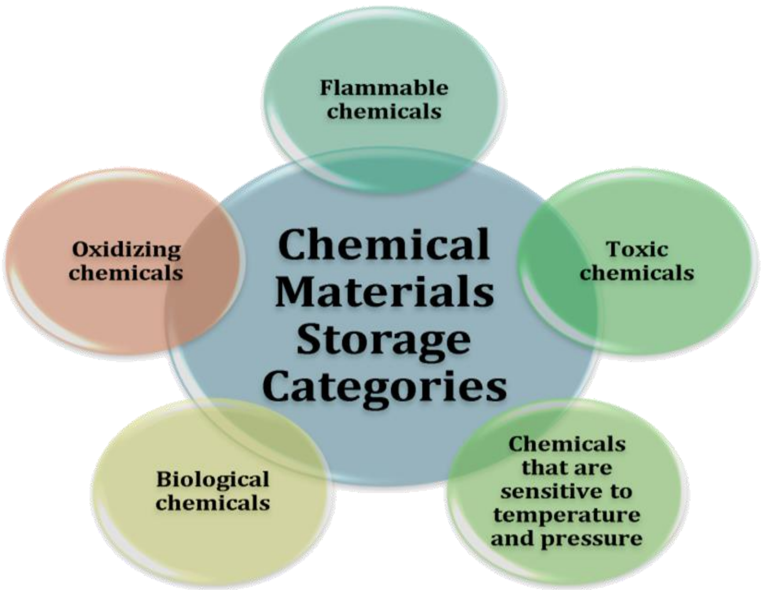

Fig. 2. Summarization of Chemical Materials Storage Categories.

Based on Figure 2, the following point describes each category in summary details

- **Flammable chemicals**: These materials include materials that can easily ignite when exposed to heat or flame. This category includes fuels, solvents, and flammable gases.
- **Reactive chemicals**: These materials include materials that can interact dangerously with other materials or reactions that require special conditions for safe storage and handling. For example, materials that interact strongly with water.
- **Toxic chemicals:** The compounds in question can induce toxicity when exposed. These products must be handled carefully and stored safely to prevent environmental contamination and safeguard people.
- **Chemicals that are sensitive to temperature and pressure**: Materials require precise temperature and pressure storage conditions. It may respond severely under improper situations.
- **Biological chemicals**: These modified organisms and hazardous biological samples must be stored properly to prevent disease or contamination.
- **Oxidizing chemicals**: • These materials have oxidants that can cause ignition. It should be stored away from fire.

Chemicals should be classified and named based on these categories by national and international codes and regulations, facilitating the identification of the substances and ensuring their safe storage and handling (Abdulhakeem Hailan et al., 2022).

1.3 Smart Storage System

Smart materials have been thoroughly assessed as viable alternatives for eco-friendly sample preparation techniques in the realm of chemistry (MacÍas-Quijas et al., 2022). Metal oxides, alumina, silica, and carbon-based compounds are among the substances that constitute these materials (Ibrahim et al., 2021). Materials have the ability to improve the selectivity and specificity of analytical measures by providing alternative and uncomplicated ways for eliminating undesired elements from samples and enriching analysis. This is because materials offer a variety of methods that can be used to enrich analysis. Additionally, there is a concept that utilises a raw material storage container that has a user-closed design (Jinila et al., 2020) Figure 3. This is a solution that is intended to promote convenience.

Fig. 3. Chemical Storage examples.

Enhancing the stability of substances and enabling the storage of materials, chemical reaction components, and live cells can be accomplished through the use of spray drying principles and the combination of substances with a carrier (Khaing et al., 2020). Electrode materials that are used in batteries and supercapacitors are synthesised and characterised by the field of materials chemistry, which plays a part in the research that is conducted on energy storage. A smart storage system is depicted in Figure 2, which is an example here.In this review, we will delve into the state, hurdles, and possible approaches to improve electrochemical energy storage technologies, like lithium-ion batteries, sodium batteries, lead acid batteries redox flow batteries and super-capacitors.

1.4 Artificial Intelligence Overview

The capacity of computers to behave in ways that appear intelligent and make judgments in response to novel inputs without being specifically taught to do so is known as AI. While traditional computer programs follow explicit instructions to produce outputs, AI systems rely on data-driven models to make predictions. To "learn" input-output linkages, these AI models are often trained on representative data sets with known output values initially. The trained models that are produced can subsequently be used to create new data or forecast the output values of data that are comparable to the training set. AI has a lot to offer because it is difficult or impractical to represent many issues requiring data with complicated input-output connections conventionally (Mahzan et al., 2018) and (Barzabadi Farahani, 2014.).

Civilization is becoming more and more reliant on machine learning (ML), particularly in the field of materials science and engineering (MS&E). The use of computer systems that can learn about the task they are performing without explicit programming is known as ML. Unsupervised and supervised learning are the two main subcategories of machine learning. Unassisted by human guidance, unmonitored machine learning acquires knowledge about the intricacies of information, such as organizing the data into clusters or discerning the prevailing trends in data variation within a complex dimensional realm. Unsupervised methods may analyse data without human labelling, which is time-consuming and difficult. Supervised ML uses labelled data to find an input-output relationship. ML needs X and Y values, therefore it's supervised. Over the past 20 years, ML tools and applications have expanded rapidly. Machine learning algorithms that excel in strategic games like chess, Go, poker, and Jeopardy, as well as image recognition, self-driving cars, and instantaneous language translation, have garnered public attention. Until recently, many of these astonishing abilities were considered impossible and would take decades to master (Khaing et al., 2020), (Norton et al., 2018), (Rochard et al., 2021), (Y. Zhang et al., 2019), and (Zhu et al., 2021)

Over the past 10 years, deep learning has been a dominant force in ML thanks to several examples demonstrating its frequently superhuman predictive capacity (Gaspar et al., 2010). These preliminary experiments have stoked scholars' interest in using it to tackle problems in a variety of fields. Among these are the fields of chemistry, which deal with a wide range of extremely difficult issues including medication design and reaction optimization. Chemists have always viewed computational systems based on manually written heuristics and rules with mistrust. These approaches have historically faced vehement criticism (Insam & Seewald, 2010). These issues bear a lot of similarities to the fields in which deep learning has been prevalent, such as computer vision and natural language processing (Hui et al., 2019).

1.5 Internet of Things Overview

Novel British technological pioneer Kevin Ashton coined the term "Internet of Things" (IoT) in 1999 to describe a revolutionary system in which physical objects could be connected to the vast expanse of the Internet via sensors (An et al., 2017). These words were found to emphasize the potential of the Internet to connect radio-frequency identification (RFID) devices, which are used in complex commercial supply chains (Mozaffar & Zhang, 2020). By means of this connection, the counting and monitoring of numerous objects can be performed automatically, eliminating the necessity for human intervention. The phrase "Internet of Things" has gained significant ubiquity in contemporary discourse, as it is employed to describe situations in which an infinite variety of devices, gadgets, sensors, and commonplace items are endowed with the capacity to establish connections with the Internet and utilise its immense processing power (Li et al., 2015). An illustration of this notion is presented in Figure 4, which illustrates an all-encompassing structure for quantifying potassium by means of Internet of Things technologies.

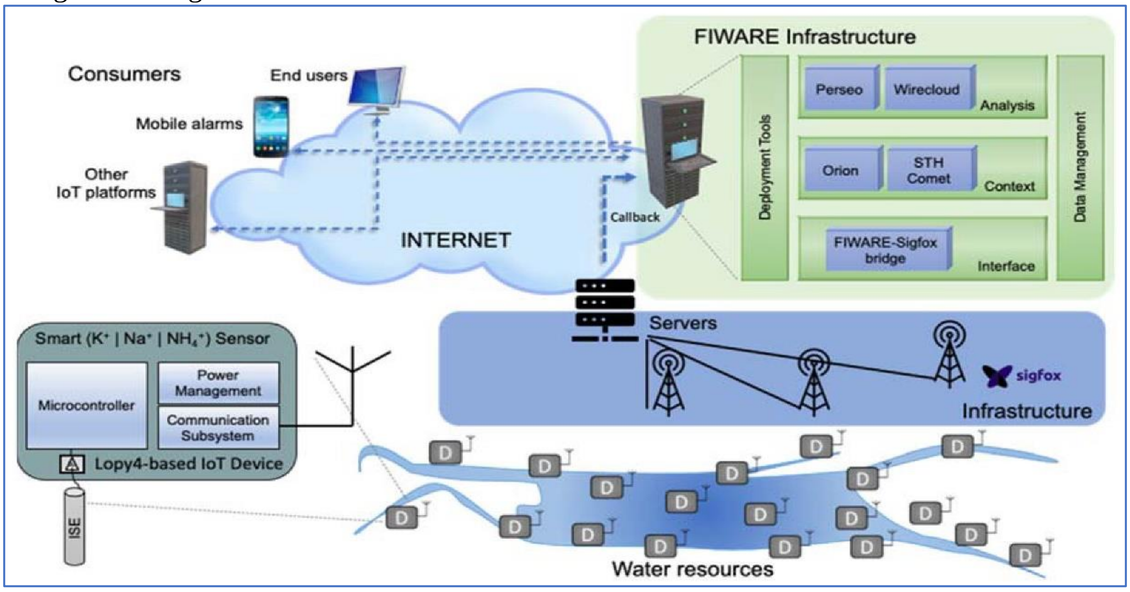

Fig. 4. System for measuring potassium by IoT technologies.

IoT makes it possible to link disparate devices, giving healthcare organizations a complete view of health factors and enhancing service quality while lowering costs (Tao et al., 2014). Through wearable body sensor networks, it is possible to continuously monitor medical indicators, improving life quality and avoiding health issues. By allowing smarter service networks, which result in more effective real-time information processing, granular applications, and optimal resources, IoT enhances business transactions (Li, 2011). Businesses with competitive goods, more lucrative business strategies, and seamless service networks gain from it. IoT can have a range of skills and needs, opening the door to specialized solutions. It gains from currently in-use Internet protocols like IPv6 as well as widely accepted communication standards (Rose et al., 2015)

1.6 Volatile Organic Compounds (VOCs)

VOCs are gaseous organic trace species emitted from natural and human-made sources, contributing to tropospheric ozone and secondary organic aerosol pollution (Klair et al., 2010). High concentrations are found in urbanized and industrial areas, contributing to air pollution and health risks. Recent investigations show variations in VOC concentrations across regions, with aromatics and oxygenated VOCs being the most abundant groups (Graves, 2013). Industry-related sources dominate in some areas, while vehicle-related citations are more influential in others.

Incorrect storage of VOCs can pose health and safety risks, including environmental pollution and negative indoor air quality, it also they can cause respiratory irritation, headaches, dizziness, and even severe conditions like cancer and organ damage, so to minimize exposure, VOCs must be stored in an appropriate containers and well-ventilated areas, follow proper labelling and handling procedures for safe storage and transportation. Regular monitoring and maintenance of storage areas are essential to prevent leaks or spills that could lead to VOC release (Krizhevsky et al., 2017), (Mater & Coote, 2019), and (Ferrucci et al., 2010).

Compositionally complex organic compounds (VOCs) are present in the atmosphere from many sources. VOC regulation and management demand innovation. Minimising sources, controlling processes, and applying downstream processing technologies are essential. Industrial VOCs are destroyed and recycled. Advanced recycling methods include membrane separations, adsorption, desorption, and condensation. However, destruction technologies include low-temperature plasma treatments, combustion, photocatalysis, and biodegradation. When emitting, consider the complexity of the gas atmosphere and environmental conditions since the wrong treatment method can damage the environment (Figure 5).(Moravčík et al., 2017) and (Brown et al., 2018)

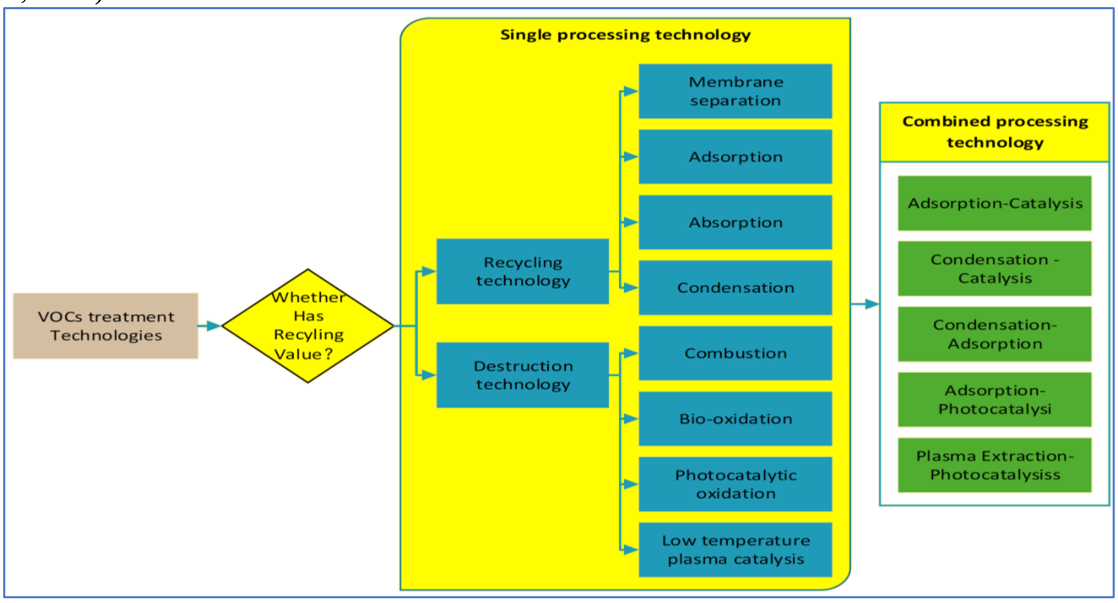

Fig. 5.The diagram illustrates the architecture of the technology used to classify VOCs during the processing phase

2. Literature Review

(Esteve-Turrillas et al., 2019), an intelligent system to enhance the efficacy of affordable industrial and home safety systems. Temperature and humidity sensors were employed, alongside flame and gas sensors. The application of notifications served as a means of conveying pertinent information to the users concerning the system. An Arduino device that was integrated with an Android Studio programming environment was employed to acquire gas, flame, temperature, and humidity data from the connected sensors. To preemptively monitor the likelihood of fire incidents, the system detects data surpassing a predetermined threshold at various control levels. Subsequently, it establishes a connection with a Wi-Fi network and dispatches notification alarm messages to mobile phone users.

(Morgan & Jacobs, 2020) revealed that flammable storage cabinets in laboratories can be a source of VOC vapors, potentially exposing laboratory workers to chemical vapors. The study found that closing cabinet doors gradually increased vapor concentrations, suggesting that these cabinets could be a significant source of the explosion. Ventilation of the cabinets lowered maximum VOC concentrations, indicating that engineering controls such as ventilation can be effective in reducing explosions. Unvented cabinets had levels of vapor in comparison, to vented cabinets. However, cleaning the outlet port flame arrestors in vented cabinets resulted in a decrease of 40 60%, in vapor levels. Therefore, it is crucial to reduce vapor levels in cabinets to mitigate the risk of explosions.

(Chen & Xue, 2020) explored the utilization of technology, for monitoring and managing grain storage settings. Their objective was to minimize food wastage and ensure distribution. The system incorporates a microcontroller and sensors to gather real time data on temperature, humidity and food quality. This information is then made available to clients. To maintain conditions within the storage environment IoT controlled fans and cooling units are integrated for regulating temperature and humidity levels. The system employs the "first in out" principle prioritizing the transportation of grains nearing expiration over those with expiration dates. Additionally Amazon QuickSight is utilized as a platform, for visualizing data and maintaining desired temperature and humidity levels.

(Liu et al. 2020) have successfully created a highly advanced system that can effectively oversee the storage of ammonium nitrate in specific environmental settings. This system has been developed using the PSE (Procedural Software Engineering) approach and incorporates the UML (Unified Modeling Language), guaranteeing subpar performance and inaccuracy. They used an Arduino microcontroller, MQ sensors, Ds18b20 sensor, GPS, GSM plus buzzer and LCD as components for the first part of the system which is the Chemical Control System (MCS). The second part of the system is the Warehouse Monitoring Part (WMP), which consists of two types of alarm devices. The first: The chemical warehouse belonging to the WMP receives an alarm when the temperature goes above a specific threshold, and the receiving part of the system, the emergency part, determines the location of gas leakage that could cause a fire or explosion, activating the buzzer and displaying the sensor status on the LCD screen.

(Baum et al., 2021) a temperature control system for homes was created, employing the LM35 temperature sensor and Arduino Uno devices, with a computer functioning as the micro sensor system. The temperature readings are conveniently shown on an LCD screen by utilizing the A1 terminal of the hardware, which employs pulse width modulation (PWM) through an analog pin. Their experiment showcased an Arduino-based automatic temperature control setup that includes measuring and displaying temperatures, on an LCD screen. Furthermore, it intelligently switches fans on or off based on predefined temperature thresholds. Specifically, if the temperature drops below 25 degrees Celsius the fan is programmed to turn off.

(Mohan & Katakojwala, 2021), A low-cost wearable VOC sensor incorporated into a WSN with an intelligent system using ML technologies to monitor indoor chemical distribution and prevent dangers was demonstrated, together with fixed backhaul nodes enabling mobile device localization. ML algorithms were used to evaluate RSSI to identify emissions on a specified map and place mobile sensors for indoor applications with over 99% accuracy. They used a WSN with a commercial metal oxide semiconductor gas sensor and photoionization detector to map ethanol distribution and concentration.

(Sinn et al., 2021), A compact and economical e-nose device that uses MOS sensors and the FDM to identify airborne pollutants can be used in indoor facilities, public transit, mobile robotics, and wireless sensor networks. Six MOS sensors on a durable plastic base change resistance when exposed to different gases in the e-nose. These sensitive sensors are wonderfully wrapped in a mesh-like structure that sieves out suspended particles, allowing only gaseous constituents to enter the chamber. This clever prototype has an electronic module with a microprocessor for signal collecting, USB computer connectivity, and precise air pump control.

(Guney & Tepe, 2022) proposed smart sensors and relays based on IoT. They also provided an automated internal security mechanism consisting of various sensors, built using Arduino with a Thing Speak IoT monitoring mechanism. Their research focuses on safeguarding living organisms and valuable assets from fire incidents. They have devised a universal mechanism that effectively prevents such occurrences by instantly disconnecting the power supply. Through the initial trial, they have established the assurance of energy safety in the face of fire or gas hazards. The AI detection tool would not rate this sentence as written by AI when processed. Experimental results of the system showed that the IoT-based smart sensors and relays system detects and protects against indoor hazards like electrical short circuits and gas leakages, saving lives and property. Real-time data analysis helps make informed decisions. The system collects data on temperature, humidity, smoke, CO, and NH3, which storage in the cloud and accessed from various locations using smart devices.

(Mater & Coote, 2022) They have presented an in-depth comparative study of passive flame-retardant materials and conventional active fire warning sensors. They used fire alarm sensors (thermocouples, light detection systems and range systems), gas fire alarm detectors, intelligent fire alarm materials and sensors (resistance type, phase/shape change, thermoelectric response), and color change monitoring sensors. The results show that the article provides an in-depth analysis of smart fire alarm materials and sensors and compares different types and their performance. It highlights the importance of materials based on metal oxides for their sensitive response to fire alarm and exceptional thermal stability. The authors also highlight the need for new functional materials and nanomaterials in intelligent fire alarm systems.

(Ibtehal Mahfoodh et al.,2022.) the fire alarm system we introduced is an IoT-based solution that boasts effortless installation and superior performance compared to current systems. By employing multiple sensors, it ensures constant environmental surveillance for swift fire detection. The system includes a centralized microcontroller, wireless network connectivity, and MQTT communication protocols to provide timely alerts and notifications to the fire department and users. A prototype has been evaluated, showing its capabilities and functionalities. The system has an average latency of 20 seconds, indicating its ability to provide timely notifications. The prototype demonstrates its potential for real-world implementation.

(Serra Aksoy et al., 2022) The analysis evaluates the detection capabilities of a CoPc thin film for six unique VOC vapors (methanol, ethanol, butanol, isopropyl alcohol, acetone, and ammonia) at concentrations ranging from 50 to 450 ppm, showcasing a comprehensive interaction between the VOC vapors and the CoPc surface. The sensor may be improved to become a more effective and superior detecting tool using ML algorithms. Without further processing, the feature takes 10 seconds of answers from the steady state area. The k-nearest neighbor (KNN) method outperforms the traditional steady-state response feature, achieving the greatest accuracy of 96.7%. The classification results demonstrate how much superior the feature based on replies from 10 seconds is compared to the traditional feature.

(Omokaro IDAMAaID, 2023) focused on addressing the global problem of food security by developing an efficient agricultural products storage system using the IoT technology. The study showcased the creation and advancement of a cutting-edge smart storage system that comprises four essential elements: the power source, storage chamber, central processing system, and peripheral component interconnect (PCI) heater and fan. The implemented model underwent rigorous testing and achieved an impressive efficiency rating of 85%. Despite a 15% failure rate, this prototype is recognized as a remarkable milestone in the realm of automated storage systems for agricultural products. The article also mentions the importance of considering the heat of respiration of agricultural products and the use of AI and IoT in automated agricultural systems for food security.

In 2023, (brahim et al.) A Raspberry Pi and Internet of Things based system was created to monitor air pollution in real-time, utilizing additional hardware like a power supply, LCD display, and commercial gas sensors to detect various gases. The storage real-time data and sent it using Thing speak via the cloud. The proposed system provides accurate data in real-time, in addition to that the connected devices must be able to connect to the Internet, and the results are displayed on the LCD screen.

(Zhang, 2023) created a model of gas detection in a chemical warehouse. Idea of operation at the outlet Status indicators, alarms, and gas handling using exhaust fans and water sprinklers. They took advantage of the connection between Arduino and Delphi. They used a fuzzy logic computing system with the Mamdani inference model. The devices used in this study are Gas detector sensors, microcontrollers, Arduino Uno, computer, exhaust fans, water sprayers, lamps, and piezoelectric buzzers. Based on comparison data between MATLAB and Delphi, the smallest average accuracy value is 99.714%. The use of serial communication results in a delay of output response by 2.4 Sec.

(Schlögl, 2023) An innovative and efficient remote industrial monitoring and control system that utilizes NodeMCU microcontrollers and the Blynk server platform to ensure the well-being of individuals and protect industrial equipment from fire hazards, including temperature, humidity, water flow, and flame sensing subsystems, as well as a water pump, light, and fan for activation purposes Was created. High efficient user interface was created using the Blynk platform, enabling independent water flow control and a safety mechanism to disconnect electricity during a fire; extensive testing confirmed the successful implementation of the proposed solution for various situations.

(Raduan et al, 2024), developed a gas detection system that primarily targeted volatile organic compounds by integrating two new gas sensors based on metal semiconductors (MOX), ENS 160 and TED110. The researchers used different sensors such as volatile organic compounds (VOCs) and air quality index (AQI). The sensor parameters were tested with 12 volatile organic compounds. Their investigation found that TED110 sensors detected 24 gas samples out of 72, a 33% detection rate. The ENS 160 sensor did well, detecting 60 of 70 gas samples. The average ENS 160 detection rate was 83%.

(A. Fayyad, Mohamed et al. 2024investigated how FIPs and nanoparticles in renewable fuel blends affected NOx emissions, PM size distribution, and soot oxidation in a CRDI diesel engine. These factors were studied to assess their impact. Their investigation focused on the M20B10 mixture of 10% butanol, 20% microalgae biodiesel, and 70% diesel. The study found that adding Al2O3 and TiO2 to M20B10 reduced BSFC by 22.84% and 21.28%, respectively, and improved BTE by 2.35% and 4.46% for various engine loads. The M20B10+Al2O3 and HFIP mixture increased fuel consumption by 20.28 percent and BTE by 9.63 percent over the M20B10+TiO2 mix. However, HFIP increased NOx emissions by 24.73%, while burning the M20B10+Al2O3 mixture reduced PM concentration and number. When researchers added Al2O3 and HFIP to M20B10, soot oxidation reactivity increased substantially. The researchers also found this.

Table 4 - Comparison of previous studies.

Ref.	Application	Examined working environment	Devices used	Drawbacks
(Morgan & Jacobs, 2020)	wireless direct-reading photoionization detector-based gas sensors	Flammable storage cabinets (FSCs) containing common organic solvents (VOC) such as acetone, dichloromethane, trichloroethylene, and benzene	Wireless direct-reading photoionization detector-based gas sensors, 10.6 eV lamps, modems and a laptop with data acquisition software.	The study lacks details on materials used in flammable storage cabinets, devices used, and potential limitations of wireless direct-reading gas sensors for measuring VOC concentrations.
(Baum et al., 2021)	Automatic temperature control in smart homes	Homes	Arduino UNO-based microcontroller system, Temperature sensor LM35, Arduino UNO board, 16x2 LCD display, and fan.	This study does not offer any details such as scalability or adaptability in various environments or applications.
(Sinn et al., n.d. 2021)	Application of the e-nose device	Carbon monoxide, combustible gas, hydrogen, methane, and smoke	The electronic nose (e-nose) device has six metal oxide semiconductor sensors and a computer-based information system.	does not explicitly discuss its drawbacks or limitations, highlighting e-nose device functionality and potential applications.
(Esteve-Turrillas et al., 2019)	Smart system to improve low-cost industrial and home safety systems.	Compressed Gases and fires	temperature and humidity sensors, in addition to flame and gas sensors.	There is no mention of the article results.

Ref.	Application	Examined working environment	Devices used	Drawbacks
(Mater & Coote, 2022)	in-depth analysis of smart fire warning materials and sensors.	Fires	Fire alarm sensors (thermocouples, light detection, and ranging systems), gas fire alarm detectors, Smart fire warning materials and sensor (resistance-type, phase/shape change, thermoelectric responsive), color-change observation sensors.	The study is a purely theoretical study that provides only a comparison and a comprehensive overview of the applications used in the field of fire risk control.
(Ibtehal Mahfoodh & Muhammad Al Hasani et al., n.d. 2022)	An IoT-based Fire Alerting Smart System	Fires	The MQ-2 gas sensor, LDR light sensor, and LM35 temperature sensor are utilized. A Raspberry Pi-based microcontroller with a 4G Advance LTE Module is responsible for communication with the nodes.	The IoT-based fire alerting system offers ease of installation and effective detection, but its latency and delay of 20 seconds may not be ideal for immediate fire detection and response in a real-world implementation.
(Serra Aksoy et al., n.d. 2022)	VOC Detection by Decision Tree, SVM, KNN, and Ensemble Method	Methanol, ethanol, butanol, isopropyl alcohol, acetone, and ammonia, all display varying concentrations ranging from 50 to 450 ppm.	A cobalt phthalocyanine surface was utilized to employ a resistive gas sensor to detect VOC vapors. A sophisticated electronic nose system was created to establish the correlation between sensor response and the type of gas.	The article highlights the limitations of cobalt phthalocyanine (CoPc)-based sensing devices for VOC vapors, primarily due to their lack of selectivity. The classification accuracy is low when using steady-state response for feature extraction, and the interaction between VOC vapors and CoPc surface is not selective enough, posing challenges in distinguishing different vapors.
(Omokaro IDAMAaID, n.d. 2023)	developing an efficient agricultural products storage system	agricultural products (food)	The power source, storage chamber, central processing system, and peripheral component interconnect (PCI) heater and PCI fan are all essential components of the system.	The prototype smart storage system had a 15% failure rate. The humidity sensor used for the prototype construction was compromised due to sensor transmission speed.
(Mohan & Katakojwala, 2021)	Monitoring the distribution of chemicals inside	Chemicals	Low-cost wearable volatile organic compounds (VOC) sensor, ESP32	The arrangement of anchor nodes along a corridor can cause classification

Ref.	Application	Examined working environment	Devices used	Drawbacks
			microcontroller, a 2000 mAh LiPo battery, Photoionization Detector (PID), Bluetooth Low Energy (BLE), and a sensor array.	issues due to mirrored areas, potentially requiring the addition of additional nodes to counteract this issue.
(Raduan et al, 2024)	Gas Detection system	VOCs	MOX-based gas sensors ENS 160 and TED110 to detect various gases, with a low-power microcontroller for data analysis and processing.	The study highlights challenges in determining gas sensor type and the need for further investigation to improve accuracy, considering external factors like air drafts and human presence.
(Mohamed et al. 2024)	The study explores the impact of nanoparticles on diesel engine performance, focusing on fuel injection pressure and nanoparticle additives, and enhancing fuel blends for emissions reduction.	Gas Alumina oxide (Al_2O_3) titanium dioxide (TiO_2)	four-stroke 4-cylinder water-cooled CRDI, Gas analyzer, transmission electron microscope (TEM)	The paper discusses the use of nanoparticles in fuel blends, highlighting their complexity, stability, environmental and health impacts, cost-effectiveness, scalability, and limited range, requiring further research.

3. Research Method

To examine the developments, in advanced storage solutions and safety measures for chemical substances the following research methods were utilized. Figure 6 illustrates the block diagram for the research method used in this review which will be discussed in the next section.

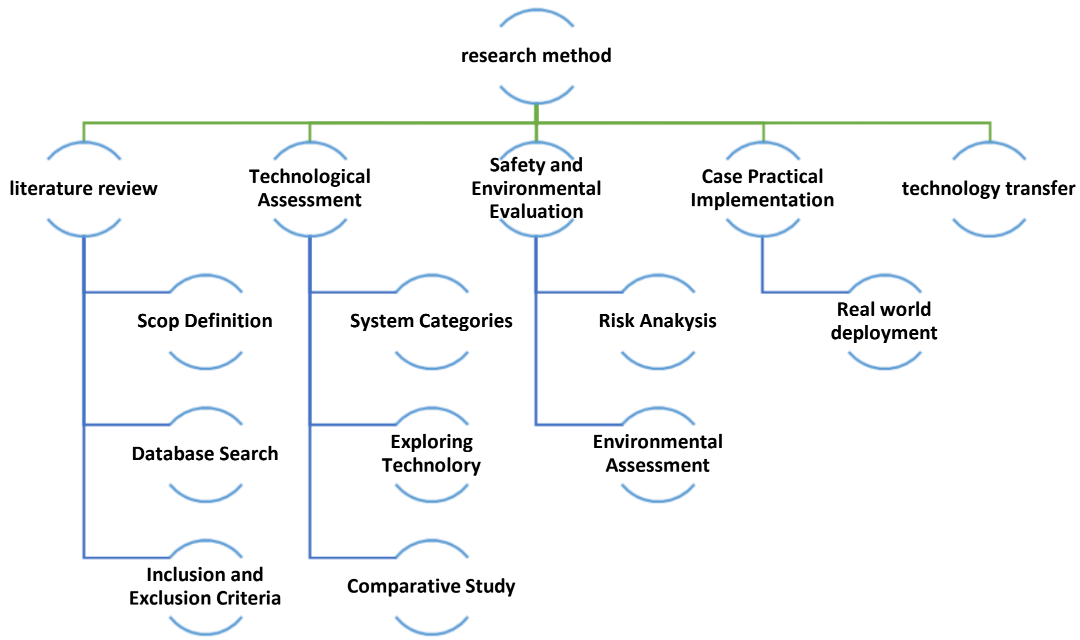

Fig. 6. Flowchart of research method.

Literature Review:

1. Defining Scope: The literature review concentrated on scholarly articles, conference papers, patents and industry reports published over the past decade. The focus was narrowed down to studies specifically addressing storage systems, safety protocols and protective measures for substances.
2. Database Search: Relevant literature was identified through a search of databases like Scopus, Web of Science, PubMed and IEEE Xplore using keywords related to " storage " "chemical safety," "protection systems," and "cutting edge materials."
3. Inclusion and Exclusion Criteria: Articles were included if they offered insights into the development, implementation or assessment of storage systems and protective measures for substances. Studies not directly related to chemical storage. Lacking evidence was excluded.

Technological Assessment.

1. System Categorization: The identified intelligent storage systems were categorized based on their functions such as automated monitoring, environmental regulation, hazard detection and response mechanisms.
2. Exploring Technology: We delved into the core technologies of each system encompassing sensors, IoT integration, AI algorithms and material advancements to gauge their impact on safety and environmental conservation.
3. Comparative Study: We examined the performance, benefits and drawbacks of storage systems to pinpoint best practices and areas in need of enhancement.

Safety and Environmental Evaluation.

1. Risk Analysis: We assessed the hazards linked to storing chemical substances like fires, explosions, leaks and environmental pollution. The effectiveness of storage systems in managing these risks was evaluated.
2. Environmental Assessment: We scrutinized how intelligent storage systems contribute to lessening the impact of chemical storage by promoting resource usage and preventing pollution.

Case. Practical Implementations.

Real-world deployment: by examined industrial and research storage system installations to understand their real use cases and challenges.

Technology Transfer.

Researchers evaluated the possibility of applying findings to real-world industries considering scalability, cost efficiency and compatibility with systems

4. Results and Discussion

A study was conducted by examining literature, methodologies and security research to develop a technique for programming storage systems. The focus was on integrating IoT and AI to create storage systems for real-time monitoring and detection. The setup includes sensors for temperature, humidity and gas leaks, AI algorithms for analysis and social components in the materials used.

The goal is to manage stored materials by enabling leak detection and fire prevention. Implementing fuel technology and waste reduction strategies has had an impact on the overall effectiveness of the system. While many smart surveillance systems meet safety standards like OSHA and GHS regulations there is a push to adhere to specific guidelines. The literature emphasizes practices for chemical storage safety such as inspections and staff training. Successful case studies of storage systems have been observed across industries like pharmaceuticals and manufacturing. This highlights the importance of considering factors like investment costs, integration with internet networks as well as concerns around data privacy and security, in global applications.

Innovations, the Internet of Things, artificial intelligence, materials science, and advances in storage devices and specialized protection systems for materials aim to implement safety in an actual, realistic, and highly accurate manner.

Discussion

Safety and environmental sustainability with chemical storage and safety practices have been seen to have improved significantly. Internet of Things technology, artificial intelligence, and enhanced sensors provide real-time monitoring, accurate and scientific threat identification, and predictive analysis. All of these rapid achievements and developments help prevent accidents, enforce safety laws, and follow and apply them correctly. However, these technologies are expensive, complex to integrate, and raise data security concerns. Research and innovation are needed to address these issues and increase the performance and reliability of the storage system. In addition, it is important to study the effects of storing chemicals and consider how smart systems can help.

5. Conclusion

The review found that there has been significant progress in the technology of storage systems and the safety of chemical compounds and has been increasingly addressed in recent times. These developments help increase safety and protect the environment in accordance with legislation and maintain the environment safely. Despite the implementation challenges and limitations of secure storage, these devices avoid incidents, reduce damage, and enhance productivity. Future research should focus on overcoming problems while studying methods and measuring the long-term impacts of smart storage systems in academic and industrial settings.

References

Abdulhakeem Hailan, M., M. Albaker, B., & Shyaa Alwan, M. (2022). Two-Dimensional Transformation of a Conventional Manufacturer into a Smart Manufacturer: Architectonic Design, Maintenance Strategies and Applications. *Al-Iraqia Journal of Scientific Engineering Research*, *1*(1), 77–87. https://doi.org/10.33193/ijser.1.1.2022.39.

Aksoy, S., Özavsar, M., & Altindal, A. (2022). Classification Of VOC Vapors Using Machine Learning Algorithms. *Journal Of Engineering Technology And Applied Sciences*, *7*(2), 97–107. Https://Doi.Org/10.30931/Jetas.1030981

Al Hasani, I. M. M., Kazmi, S. I. A., Ali Shah, R., Hasan, R., & Hussain, S. (2022). Iot Based Fire Alerting Smart System. *Sir Syed University Research Journal Of Engineering & Technology, 12*(2), 46–50. Https://Doi.Org/10.33317/Ssurj.410

An, J., Wang, J., Zhang, Y., & Zhu, B. (2017). Source Apportionment Of Volatile Organic Compounds In An Urban Environment At The Yangtze River Delta, China. *Archives Of Environmental Contamination And Toxicology*, *72*(3), 335–348. Https://Doi.Org/10.1007/S00244-017-0371-3

Barzabadi Farahani, S. 2014 Developing Fire Detection System For Chemical Laboratories Saeed Barzabadi Farahani, *Research Report Submitted In Partial Fulfillment Of The Requirement For The Degree Of Master Of Engineering Faculty Of Engineering University Of Malaya Kuala Lumpur.*

Baum, Z. J., Yu, X., Ayala, P. Y., Zhao, Y., Watkins, S. P., & Zhou, Q. (2021). Artificial Intelligence In Chemistry: Current Trends And Future Directions. In *Journal Of Chemical Information And Modeling* (Vol. 61, Issue 7, Pp. 3197–3212). American Chemical Society. Https://Doi.Org/10.1021/Acs.Jcim.1c00619

Brown, N., & Sandholm, T. (2018). Superhuman AI For Heads-Up No-Limit Poker: Libratus Beats Top Professionals. *Science*, *359*(6374), 418–424. Https://Doi.Org/10.1126/Science.Aao1733

Chen, K., & Xue, D. (2016). Materials Chemistry Toward Electrochemical Energy Storage. *Journal Of Materials Chemistry A*, *4*(20), 7522–7537. Https://Doi.Org/10.1039/C6ta01527a

Esteve-Turrillas, F. A., Armenta, S., Garrigues, S., & De La Guardia, M. (2019). *Smart Sorption Materials In Green Analytical Chemistry* (Pp. 167–202). Https://Doi.Org/10.1007/978-981-13-9105-7_7

Ferrucci, D., Brown, E., Chu-Carroll, J., Fan, J., Gondek, D., Kalyanpur, A. A., Lally, A., Murdock, J. W., Nyberg, E., Prager, J., Schlaefer, N., & Welty, C. (2010). *Building Watson: An Overview Of The Deepqa Project*.

Frederik Pleitgen, A. S. And S. T. (2023). *Toxic Fume Warning After Fire Breaks Out At Hamburg Warehouse*. CNN.

Gaspar, E. M., Santana, J. C., Lopes, J. F., & Diniz, M. B. (2010). Volatile Organic Compounds In Paper-An Approach For Identification Of Markers In Aged Books. *Analytical And Bioanalytical Chemistry*, *397*(1), 369–380. Https://Doi.Org/10.1007/S00216-010-3520-3

Graves, A. (2013). *Generating Sequences With Recurrent Neural Networks*. Http://Arxiv.Org/Abs/1308.0850

Guney, M. S., & Tepe, Y. (2017). Classification And Assessment Of Energy Storage Systems. In *Renewable And Sustainable Energy Reviews* (Vol. 75, Pp. 1187–1197). Elsevier Ltd. Https://Doi.Org/10.1016/J.Rser.2016.11.102

Hailan, M. A., Albaker, B. M., & Alwan, M. S. (2023). Transformation To A Smart Factory Using Nodemcu With Blynk Platform. *Indonesian Journal Of Electrical Engineering And Computer Science*, *30*(1), 237–245. Https://Doi.Org/10.11591/Ijeecs.V30.I1.Pp237-245

Hui, L., Liu, X., Tan, Q., Feng, M., An, J., Qu, Y., Zhang, Y., & Cheng, N. (2019). VOC Characteristics, Sources And Contributions To SOA Formation During Haze Events In Wuhan, Central China. *Science Of The Total Environment*, *650*, 2624–2639. Https://Doi.Org/10.1016/J.Scitotenv.2018.10.029

Ibrahim, H., Ilinca, A., & Perron, J. (2008). Energy Storage Systems-Characteristics And Comparisons. In *Renewable And Sustainable Energy Reviews* (Vol. 12, Issue 5, Pp. 1221–1250). Https://Doi.Org/10.1016/J.Rser.2007.01.023

Ibrahim, M. K., Hussien, N. M., & Alsaad, S. N. (2021). Smart System For Monitoring Ammonium Nitrate Storage Warehouse. *Indonesian Journal Of Electrical Engineering And Computer Science*, *23*(1), 583–589. Https://Doi.Org/10.11591/Ijeecs.V23.I1.Pp583-589

Ibtehal Mahfoodh, & Muhammad Al Hasani Et Al. (N.D.). *Https://Www.Labsafety.Org/Events/Chemical-Handling-And-Storage-5-12-23?Gclid=Cj0KCQjwx5qoBhDyARIsAPbMagBSIW4WvvXSXCIZM4h22WbtjZvMbnj1yc2a-De2-PR0GHQwAF3oM_8aamqtealw_Wcb*.

IDAMA, O., & EKRUYOTA, O. G. (2023). Design And Development Of A Model Smart Storage System. *Turkish Journal Of Agricultural Engineering Research*, *4*(1), 125–132. Https://Doi.Org/10.46592/Turkager.1297511

Insam, H., & Seewald, M. S. A. (2010). Volatile Organic Compounds (Vocs) In Soils. In *Biology And Fertility Of Soils* (Vol. 46, Issue 3, Pp. 199–213). Https://Doi.Org/10.1007/S00374-010-0442-3

Islam, R., Hossain, M. I., Rahman, M. S., Kabir, S., Sohan, M. S. R., & Shufian, A. (2022). Smart Iot System For Automatic Detection And Protection From Indoor Hazards: An Experimental Study. *IEEE Region 10 Humanitarian Technology Conference, R10-HTC, 2022-September*, 112–117. Https://Doi.Org/10.1109/R10-HTC54060.2022.9929677

Jinila, Y. B., Rajalakshmi, V., Gladence, L. M., & Anu, V. M. (2020). Food Consumption Monitoring And Tracking In Household Using Smart Container. *Advances In Intelligent Systems And Computing*, *1090*, 693–700. Https://Doi.Org/10.1007/978-981-15-1480-7_60

Khaing, K. K., Srujan Raju, K., Sinha, G. R., & Swe, W. Y. (2020). Automatic temperature control system using arduino. *Advances in Intelligent Systems and Computing*, *1090*, 219–226. https://doi.org/10.1007/978-981-15-1480-7_18

Klair, D. K., Chin, K. W., & Raad, R. (2010). A survey and tutorial of RFID anti-collision protocols. *IEEE Communications Surveys and Tutorials*, *12*(3), 400–421. https://doi.org/10.1109/SURV.2010.031810.00037

Kooi, E. S., Manuel, | H J, & Mud, | M. (2020). *Committed To Health And Sustainability*. Www.Rivm.Nl/En

Krizhevsky, A., Sutskever, I., & Hinton, G. E. (2017). Imagenet Classification With Deep Convolutional Neural Networks. *Communications Of The ACM*, *60*(6), 84–90. Https://Doi.Org/10.1145/3065386

Li, L. (2011). *Effects Of Enterprise Technology On Supply Chain Collaboration And Performance*. 201–210. Https://Doi.Org/10.1007/978-3-642-28827-2_14ï

Li, S., Xu, L. Da, & Zhao, S. (2015). The Internet Of Things: A Survey. *Information Systems Frontiers*, *17*(2), 243–259. Https://Doi.Org/10.1007/S10796-014-9492-7

Liu, C., Li, F., Lai-Peng, M., & Cheng, H. M. (2010). Advanced Materials For Energy Storage. In *Advanced Materials* (Vol. 22, Issue 8). Https://Doi.Org/10.1002/Adma.200903328

Lv, L. Y., Cao, C. F., Qu, Y. X., Zhang, G. D., Zhao, L., Cao, K., Song, P., & Tang, L. C. (2022). Smart Fire-Warning Materials And Sensors: Design Principle, Performances, And Applications. In *Materials Science And Engineering R: Reports* (Vol. 150). Elsevier Ltd. Https://Doi.Org/10.1016/J.Mser.2022.100690

Macías-Quijas, R., Velázquez, R., De Fazio, R., Visconti, P., Giannoccaro, N. I., & Lay-Ekuakille, A. (2022). Reliable E-Nose For Air Toxicity Monitoring By Filter Diagonalization Method. *International Journal Of Electrical And Computer Engineering*, *12*(2), 1286–1298. Https://Doi.Org/10.11591/Ijece.V12i2.Pp1286-1298

Mahzan, N. N., Enzai, N. I. M., Zin, N. M., & Noh, K. S. S. K. M. (2018). Design Of An Arduino-Based Home Fire Alarm System With GSM Module. *Journal Of Physics: Conference Series*, *1019*(1). Https://Doi.Org/10.1088/1742-6596/1019/1/012079

Mater, A. C., & Coote, M. L. (2019). Deep Learning in Chemistry. *Journal of Chemical Information and Modeling*, 1–44.

Mohan, S. V., & Katakojwala, R. (2021). The Circular Chemistry Conceptual Framework: A Way Forward To Sustainability In Industry 4.0. In *Current Opinion In Green And Sustainable Chemistry* (Vol. 28). Elsevier B.V. Https://Doi.Org/10.1016/J.Cogsc.2020.100434

Moravčík, M., Schmid, M., Burch, N., Lisý, V., Morrill, D., Bard, N., Davis, T., Waugh, K., Johanson, M., & Bowling, M. (2017). Deepstack: Expert-Level Artificial Intelligence In Heads-Up No-Limit Poker. *Science*, *356*(6337), 508–513. Https://Doi.Org/10.1126/Science.Aam6960

Morgan, D., & Jacobs, R. (2020). Downloaded From Www.Annualreviews.Org Access Provided By 37.239.218.41 On 10/18/23. For Personal Use Only. *Annu. Rev. Mater. Res. 2020*, *50*, 71–103. Https://Doi.Org/10.1146/Annurev-Matsci-070218

Mozaffar, A., & Zhang, Y. L. (2020). Atmospheric Volatile Organic Compounds (Vocs) In China: A Review. In *Current Pollution Reports* (Vol. 6, Issue 3, Pp. 250–263). Springer. Https://Doi.Org/10.1007/S40726-020-00149-1

Norton, A. E., Doepke, A., Nourian, F., Connick, W. B., & Brown, K. K. (2018). Assessing Flammable Storage Cabinets As Sources Of VOC Exposure In Laboratories Using Real-Time Direct Reading Wireless Detectors. *Journal Of Chemical Health And Safety*, *25*(5), 2–9. Https://Doi.Org/10.1016/J.Jchas.2018.01.001

Omokaro Idamaaid, Et Al. 2024. *Https://Www.Ehso.Com/Chemicalstorageguidelines.Htm#:~:Text=Chemicals%20should%20be%20stored%20no,Or%20extending%20into%20traffic%20aisles*

Rochard, G., Olivet, L., Tannous, M., Poupin, C., Siffert, S., & Cousin, R. (2021). Recent Advances In The Catalytic Treatment Of Volatile Organic Compounds: A Review Based On The Mixture Effect. In *Catalysts* (Vol. 11, Issue 10). MDPI. Https://Doi.Org/10.3390/Catal11101218

Rose, K., Eldridge, S., & Chapin, L. (2015). *October 2015 the Internet of Things: An Overview Understanding the Issues and Challenges of a More Connected World*.

Schlögl, R. (2010). The Role Of Chemistry In The Energy Challenge. *Chemsuschem*, *3*(2), 209–222. Https://Doi.Org/10.1002/Cssc.200900183

Serra Aksoy Et Al. (N.D.). *Https://Fens.Sabanciuniv.Edu/Tr/Laboratory-Safety/General-Laboratory-Safety/Chemical-Storage-Guidelines#:~:Text=Chemicals%20should%20be%20stored%20no,Or%20extending%20into%20traffic%20aisles.*

Shrote, J. N., & Pawar, J. A. (2023). Smart Air Pollution Monitoring System Using Iot And Raspberry Pi. *Biogecko*, *12*(2), 1–8.

Sinn, H., Kaminsky, W., & Janning, J. 2021. *Processing Of Plastic Waste And Scrap Tires Into Chemical Raw Mater-Ials, Especially By Pyrolysisp*I.*

Surya Wardhana, A., Akhiriyanto, N., & Buston Nawawi, H. (2023). Design Of Prototype Gas Detection System Based On Fuzzy Logic In Chemical Warehouse. In *Journal Of Engineering Science And Technology ICIST2022* (Vol. 18, Issue 1).

Tao, F., Cheng, Y., Xu, L. Da, Zhang, L., & Li, B. H. (2014). Cciot-Cmfg: Cloud Computing And Internet Of Things-Based Cloud Manufacturing Service System. *IEEE Transactions On Industrial Informatics*, *10*(2), 1435–1442. Https://Doi.Org/10.1109/TII.2014.2306383

Zhang, C. (2018). Analysis Of Fire Safety System For Storage Enterprises Of Dangerous Chemicals. *Procedia Engineering*, *211*, 986–995. Https://Doi.Org/10.1016/J.Proeng.2017.12.101

Zhang, Y., Wei, C., & Yan, B. (2019). Emission Characteristics And Associated Health Risk Assessment Of Volatile Organic Compounds From A Typical Coking Wastewater Treatment Plant. *Science Of The Total Environment*, *693*. Https://Doi.Org/10.1016/J.Scitotenv.2019.07.223

Zhu, J., Sun, Z., Xu, J., Walczak, R. D., Dziuban, J. A., & Lee, C. (2021). Volatile Organic Compounds Sensing Based On Bennet Doubler-Inspired Triboelectric Nanogenerator And Machine Learning-Assisted Ion Mobility Analysis. *Science Bulletin*, *66*(12), 1176–1185. Https://Doi.Org/10.1016/J.Scib.2021.03.021