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Research on Shallow Heat Source of Chemical Reagents by Infrared Imaging Technology

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ABSTRACT

As essential materials for biochemical experiments, chemical reagents are vital to the safety of faculty and students lives and property, making their warehouse supervision a critical task. This study investigates real-time temperature monitoring in chemical reagent storage facilities using infrared imaging technology specifically designed for such environments. The method enables continuous tracking of temperature and humidity levels, identifies subtle chemical changes, predicts trends, and issues timely warnings to minimize risks. By integrating manual management with digital monitoring systems, the research establishes risk assessment models for surface heat sources and implements comprehensive inspections. This dual-layered thermal monitoring system creates a robust safeguard mechanism, ensuring safer working conditions for educators and students in daily laboratory operations.

KEYWORDS: *chemical reagent; safety management; infrared imaging; heat source monitoring.*

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Chemical reagents serve as a vital material foundation for experimental courses in biology, chemistry, and related disciplines at higher education institutions, as well as for scientific research. Ensuring timely supply of various chemical reagents through on-demand procurement, along with strict temperature and humidity control during storage, are fundamental requirements for meeting teaching and research needs However, the storage of these reagents carries significant risks that cannot be overlooked. Given their inherently reactive properties, reagents are prone to degradation during storage, which not only leads to inventory depletion but also poses unique hazards due to their explosive, corrosive, and self-igniting characteristics.

Each management step requires extreme caution, as even minor deviations from storage standards could trigger these hidden "time bombs," potentially causing catastrophic economic losses.

Therefore, in order to ensure the safety of storing chemicals in hazardous chemical warehouses, it is very important to create a suitable storage environment for hazardous chemicals [1] Ensuring the safety of reagent storage is not only a protection of assets, but also a defense of life dignity and a manifestation of responsibility for the natural environment. Any negligence may trigger a chain reaction and bring irreversible consequences.

1. Current situation of chemical reagent safety management

1.1. Characteristics of chemical reagent pollution

Temperature and humidity monitoring in chemical storage facilities is crucial for ensuring the safety of hazardous material warehouses. In recent years, explosions have occurred multiple times in these warehouses, particularly when storing large quantities of explosive, corrosive, or self-igniting chemicals such as potassium nitrate, sodium nitrate, benzene, formaldehyde, and ethanol. A single leak could cause severe pollution and environmental damage to humans and surrounding areas. If fires or explosions occur, the consequences would be unpredictable.

1.2. Current situation of chemical reagent safety management

According to comprehensive statistics from Chinas State Administration of Work Safety, the scale of hazardous chemical production and storage enterprises in the country is staggering——. These facilities spread across the nation contain over 13,000 major hazard sources (referred to as "major hazard sources"). This not only represents an astonishingly large number but also highlights their widespread distribution. Like hidden warning signs lurking everywhere, they constantly remind us of the immense safety risks concealed behind these operations.

These major hazards loom like the Sword of Damocles hanging over our heads, constantly testing our safety management capabilities. Not only are they numerous, but each harbors formidable potential energy. Once out of control, the consequences could be catastrophic. From flammable and explosive chemicals to highly toxic substances, every category poses an instant threat that could trigger disasters, severely endangering peoples lives and property.

In recent years, the State Administration of Work Safety has formulated the Interim Provisions on the Supervision and Administration of Major Hazard Sources of Hazardous Chemicals (Decree No.40 of the State Administration of Work Safety, amended by Decree No.79[2]), 《 A series of regulations and standards such as the "Identification of Major Hazard Sources for Hazardous Chemicals" (GB 18218-2018) have been established. The government ensures their implementation through legislation, strengthening safety management of major hazard sources by clarifying daily management priorities and regulatory standards. It has also set up a monitoring system center for major hazard sources, emphasizing accountability and risk mechanisms while highlighting detailed and explicit daily management practices. Through legislative safeguards, the government reinforces safety management of major hazard sources, clarifies key aspects of daily supervision, establishes monitoring systems, and underscores the importance of accountability and risk control in routine management.

1.3. Safety risks in chemical reagent storage

For example, at around 23:30 on August 12,2015, a fire and explosion occurred in the dangerous goods warehouse of Ruihai Company in Tianjin Port, Binhai New Area,

Tianjin[3]The investigation report on the Tianjin explosion incident has been released.

The task force confirmed that in container areas south of the delivery zone at Ruihai Companys hazardous materials warehouse, nitrocellulose within containers became partially dry due to moisture loss. Under high-temperature conditions and other factors, this accelerated decomposition and heat release, leading to spontaneous combustion.

The accumulated heat caused prolonged large-scale burning of nitrocellulose and other hazardous chemicals in adjacent containers, ultimately triggering explosions involving ammonium nitrate and other dangerous substances stored in the delivery zone[4]It is not only a particularly serious production safety liability accident in recent years, but also a bloody lesson, reminding us that production safety can never be relaxed, and any negligence in any link may bring disastrous consequences that cannot be recovered.

Therefore, it is very necessary to establish the temperature and humidity monitoring system of chemical reagent library to minimize the occurrence of safety risks as far as possible, improve the hierarchical supervision mode, enhance the management level of relevant responsible persons for chemical reagent library, give full play to the sensitivity of accident warning and alarm, and avoid the recurrence of similar accidents.

2. Chemical reagent inventory detection

2.1. Current situation of chemical reagent inventory detection

In recent years, the rapid development of chemical industries in major developed countries has raised heightened demands for the safety and monitoring of chemical reagent storage. Traditional monitoring methods, often plagued by inefficiency, poor accuracy, and slow response times, have become inadequate for modern chemical storage management needs. Consequently, the storage approaches and safety monitoring systems for contemporary chemical reagents are undergoing a transformation from conventional practices to scientifically-based solutions.

The monitoring methods of chemical reagent warehouses in China in the new stage indeed reflect the current trend of intelligent and efficient development of chemical reagent storage management. Specifically, the installation of visual monitoring to observe key areas of the warehouse has become an important means for many chemical reagent warehouses to improve their safety management level.

However, this method incurs high operational costs and lacks direct visibility into chemical reactions triggered by temperature fluctuations within the reagent storage system. It fails to enable early detection, timely control, and prompt intervention to mitigate severe consequences from accidents. Modern chemical reagent warehouses are progressively overcoming the limitations of traditional monitoring technologies. By adopting advanced detection systems and enhancing integrated management approaches, these facilities now achieve comprehensive, real-time, and intelligent monitoring and management. This advancement will significantly improve warehouse safety, operational efficiency, and economic benefits, thereby providing robust support for the sustainable development of the chemical industry.

2.2. Scientific principle of temperature monitoring of chemical reagent inventory

2.2.1. Concept of infrared radiation

Infrared radiation refers to the continuous motion of atoms and molecules in a substance. When the temperature rises, the substance gains energy, and the internal motion of molecules and atoms intensifies. The energy released in the process of the transition from high energy levels to low energy levels of molecules and atoms[5]All objects above absolute zero emit infrared radiation, with wavelengths varying depending on the frequency of motion of molecules and atoms in the object[6]The wavelength and temperature determine the radiation infrared wavelength 0.76 μ m~1000 μm, divided into near infrared and far infrared, the former wavelength is less than 5.6 μm, the latter is greater than 5.6 μm. Infrared technology is formally used to measure temperature based on this principle.

2.2.2. Plancks blackbody radiation law

Decades after infrared radiation was discovered, Max Planck introduced the quantum concept in 1900. This groundbreaking breakthrough not only resolved critical challenges in physics at the time but also laid the foundation for quantum mechanics. He established Plancks Law, which defines the spectral distribution of blackbody radiation and reveals the relationship between radiated intensity, wavelength, and temperature across multiple wavelengths including ultraviolet, visible, and infrared [7] The mathematical expression is:

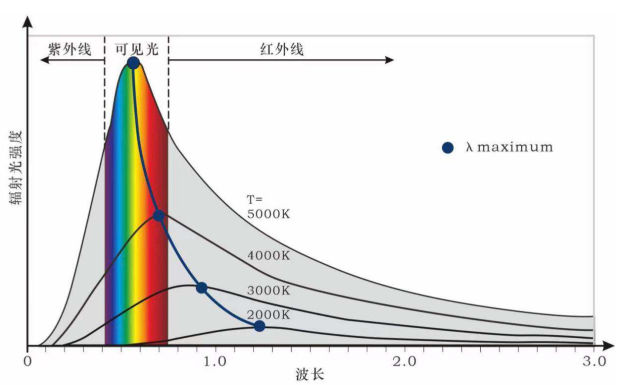

Figure 1. Emission spectrum of black body radiation

As shown in Figure 1, at a fixed wavelength, an object emits more light or heat (i.e., spectral radiation flux) as its temperature increases. Moreover, this emitted energy reaches a maximum value with varying wavelengths, and the corresponding wavelength is designated as L. Additionally, in an ideal black body, 75% of its radiation occurs in wavelengths longer than wavelength U.

3. Effect of temperature on volatilization of chemical reagents

This experiment is based on the existing national standards, and further explore the influence of temperature on the determination results of formaldehyde in indoor air by analyzing and comparing the traceable national standard samples in different temperature environments.

3.1. Experimental principle

Formaldehyde in air reacts with phenol reagent to produce azine, and azine is oxidized by iron ion in acidic solution to form blue-green compound. The color depth was used for colorimetric quantification.

3.2. Experimental instruments and reagents

3.2.1. Experimental equipment

10mL bubble absorption tube; air sampler with flow range of 0.2-2L/min; 25mL stoppered colorimetric tube; spectrophotometer; 10mm colorimetric dish.

3.2.2. Experimental reagents

Absorbent solution, absorbent solution, 1% ammonium ferric sulfate solution, iodine solution, 1mol/L sodium hydroxide solution, 0.5mol/L sulfuric acid solution, 0.5% starch solution, formaldehyde standard solution

3.2.3. Experimental instruments and equipment

Glassware conforming to national Grade A standard was used during the analysis. Stoppered colorimetric tube: 10mL; spectrophotometer: absorbance was measured at 630nm.

3.2.4. Determination steps

1. Sampling and sample preservation: Use a large bubble absorption tube containing 5mL absorbent solution to collect 10L of gas at a flow rate of 0.5L/min. Record the temperature and atmospheric pressure during sampling.

2. Standard curve drawing: Take 0, 0.10mL, 0.20mL, 0.40mL, 0.60mL, 0.80mL, 1.00mL, 1.50mL, 2.00mL formaldehyde standard solution into 25mL stoppered colorimetric tube, then add 5.00mL, 4.90mL, 4.80mL, 4.60mL, 4.20mL, 4.00mL, 3.50mL, 3.00mL absorbent solution in sequence, so that the corresponding formaldehyde content in each tube is 0.0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0 μ g respectively. Add 0.4mL1%

ammonium ferric sulfate solution into each tube and shake well.

Let the solution sit for 15 minutes. Using a 1cm cuvette with water as the reference at 630nm wavelength, measure the absorbance of each tubes solution. Plot the formaldehyde content on the x-axis and absorbance on the y-axis to create a curve. Calculate the regression slope, then use the reciprocal of this slope as the calculation factor Bg (μg/absorbance) for sample determination.

3. Sample Analysis: After sampling, transfer the entire sample solution into a colorimetric tube. Rinse the absorption tube with a small amount of absorbent solution and combine the solutions to achieve a total volume of 5 mL. Measure the absorbance (A) according to the standard curve preparation procedure. For each batch of samples, simultaneously prepare a reagent blank using 5 mL of non-sampled absorbent solution and measure its absorbance (A0).

3.2.5. Comparative analysis and results

The same formaldehyde standard sample was compared and analyzed in different temperature environments.

The standard formaldehyde samples were analyzed in 15℃ laboratory environment, and the determination results are shown in Figure 1.

管号	0	1	2	3	4	5	6	7	8
甲醛标准溶液	0.00	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
吸收溶液体积	5.00	4.90	4.80	4.60	4.40	4.20	4.00	3.50	3.00
甲醛含量	0.00	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
吸光度1	0.001	0.027	0.048	0.093	0.136	0.181	0.221	0.333	0.442
吸光度2	0.002	0.026	0.050	0.092	0.138	0.180	0.223	0.330	0.442
吸光度3	0.002	0.024	0.049	0.092	0.137	0.181	0.223	0.332	0.441
平均吸光度	0.002	0.026	0.049	0.092	0.137	0.181	0.222	0.332	0.442

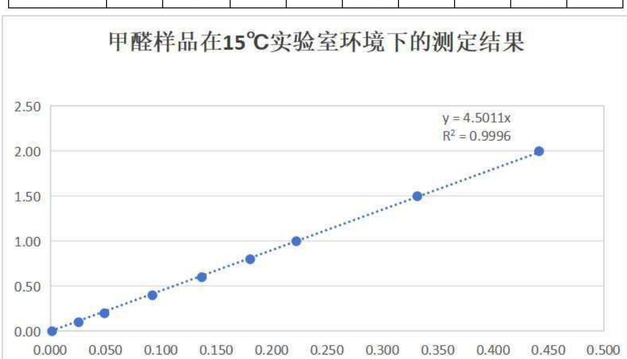

Figure 115℃ Determination results of marker A in laboratory Environment

The standard formaldehyde samples were analyzed in the 25℃ laboratory environment, and the measurement results are shown in Figure 2.

管　号	0	1	2	3	4	5	6	7	8
甲醛标准溶液	0.00	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
吸收溶液体积	5.00	4.90	4.80	4.60	4.40	4.20	4.00	3.50	3.00
甲醛含量	0.00	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
吸光度1	0.009	0.040	0.076	0.137	0.202	0.268	0.333	0.496	0.656
吸光度2	0.008	0.040	0.076	0.137	0.202	0.268	0.332	0.496	0.656
吸光度3	0.007	0.041	0.075	0.137	0.201	0.268	0.334	0.496	0.657
平均吸光度	0.008	0.040	0.076	0.137	0.202	0.268	0.333	0.496	0.656

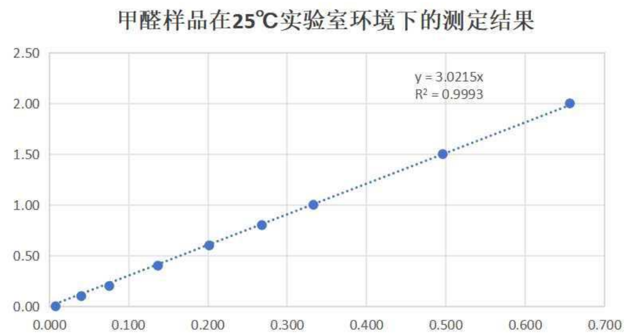

Figure 2. Determination results of methanol standard in laboratory environment 25℃

The standard formaldehyde samples were analyzed in the 35℃ laboratory environment, and the measurement results are shown in Figure 3.

管　号	0	1	2	3	4	5	6	7	8
甲醛标准溶液	0.00	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
吸收溶液体积	5.00	4.90	4.80	4.60	4.40	4.20	4.00	3.50	3.00
甲醛含量	0.00	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
吸光度1	0.009	0.063	0.119	0.212	0.300	0.410	0.496	0.746	0.995
吸光度2	0.010	0.060	0.117	0.210	0.298	0.413	0.492	0.748	0.993
吸光度3	0.008	0.062	0.118	0.219	0.301	0.411	0.494	0.747	0.994
平均吸光度	0.009	0.062	0.118	0.214	0.300	0.411	0.494	0.747	0.994

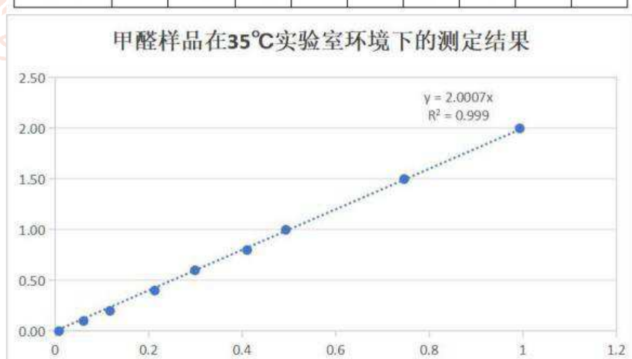

Figure 3. Determination results of methanol standard in laboratory environment 35℃

3.3. Result analysis

The standard formaldehyde samples were analyzed at 15 ℃ ,2 5 ℃ and 35 ℃ temperature respectively, and the results are shown in Figure 4.

甲醛含量	0.000	0.100	0.200	0.400	0.600	0.800	1.000	1.500	2.000
15度	0.002	0.026	0.049	0.092	0.137	0.181	0.222	0.332	0.442
25度	0.008	0.040	0.076	0.137	0.202	0.268	0.333	0.496	0.656
35度	0.009	0.062	0.118	0.214	0.300	0.411	0.494	0.747	0.994

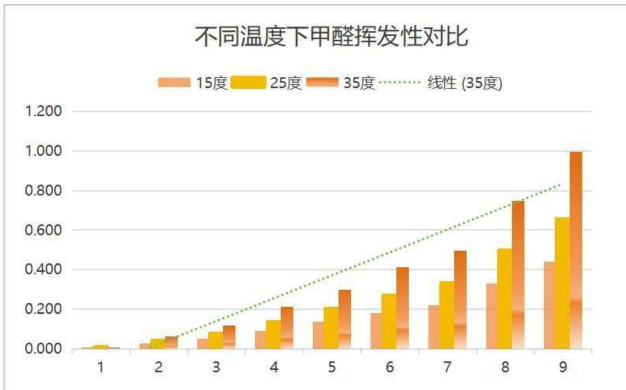

Figure 4 Analysis of measurement results of different temperature A markers

3.4. Result analysis

3.4.1. Result calculation: First, the volume conversion under standard conditions is carried out. The sampling volume is 10L. The volume under standard conditions is calculated by substituting the sampling volume, temperature and atmospheric pressure into the formula.

$$V_0 = V_t \frac{T_O}{273+t} \cdot \frac{P}{P_0}$$

Where:

Vo- Sampling volume under standard conditions, L;

Vt- Sampling volume, the product of sampling flow and sampling time, L;

t- Air temperature during sampling, ℃

To- Absolute temperature under standard conditions, 273K;

P- Atmospheric pressure during sampling, kPa;

Po- Atmospheric pressure under standard conditions, 101.3kPa.

3.4.2. Calculation Step 2: The standard volume, the absorbance of the sample solution and the absorbance of the blank reagent solution are calculated, and the calculated factor is put into the concentration calculation formula to calculate the formaldehyde concentration.

$$c = \frac{(A - A_0)Bg}{V_0}$$

Where:

C- The concentration of formaldehyde in air, mg/m3;

A- Absorbance of the sample solution;

A0- Absorbance of blank solution;

Bg- Calculated factor, μg/absorbance;

V0- Convert to the sampling volume under standard conditions, L

3.4.3. Result evaluation: The measured results were evaluated according to the indoor air quality standard (GB/T18883).

Air temperature at time of sampling	**15℃**	**25℃**	**35℃**
Formaldehyde concentration mg/m3	0.159	0.242	0.380

3.5. **Conclusion:** Experimental data confirm that temperature significantly influences both formaldehyde release rates and indoor air concentrations. When room temperatures decrease, the release rate of formaldehyde slows down as molecular activity decreases, making it less likely to volatilize from emission sources. Conversely, rising temperatures accelerate the release process. Research indicates that for every 10 ° ℃ increase in temperature, the formaldehyde release rate may rise by approximately 1.5 times.

4. Optimize the safety management of hazardous chemicals and strengthen the safety of production environment

The implementation of intelligent temperature monitoring systems enables administrators to track chemical reagents in storage facilities, enabling real-time sharing and dissemination of temperature data. This not only reduces manual inspection time but also enhances regulatory accuracy. Through the automated early-warning mechanism of central control systems, it demonstrates seamless integration between human expertise and digital technology. When fire hazards emerge, a system that triggers alerts first proves more effective than conventional fire alarm systems. By detecting risks at their earliest stage, such systems can potentially prevent fire accidents from occurring altogether.

4.1. Infrared thermal imaging temperature measurement technology

The primary advantage of infrared thermal imaging temperature measurement lies in its non-contact nature, yet this method carries the drawback of significant data discrepancies. To ensure accurate non-contact temperature readings, its crucial to master the "degree" of non-contact measurement. To prevent material degradation during the process and its substantial impact on results, we must properly select temperature measurement equipment, standardize operational procedures, control environmental factors, perform regular maintenance, and pay attention to relevant precautions throughout the measurement process. These measures collectively help guarantee both the accuracy and stability of temperature measurement outcomes.

In practical measurements, we compared various intrusion and semi-intrusion methods for temperature measurement. During the process, it was discovered that thermal imagers can capture and display infrared radiation emitted by object surfaces, accurately reflecting the temperature distribution of objects. This approach not only avoids direct contact with the measured object, reducing the possibility of interference and damage, but also enables rapid and large-scale temperature monitoring, significantly improving the efficiency and accuracy of temperature measurement.

4.2. Characteristics of infrared thermal imaging temperature measurement technology

Infrared thermal imaging technology, as a non-contact temperature measurement method, demonstrates exceptional long-range capabilities under atmospheric conditions. Its performance remains relatively unaffected by weather variations, ensuring stable and accurate measurements. This technology not only provides diverse data visualization methods—such as classic grayscale images—but also employs color enhancement techniques to present temperature distribution through unprecedented pseudo-color representations, making thermal variations immediately apparent.

The implementation of infrared thermal imaging technology has become a game-changer in chemical storage management. Its operational convenience lies in enabling temperature monitoring without direct contact with chemicals, significantly reducing safety risks. The systems safety features allow real-time detection and early warning of potential temperature anomalies, effectively preventing fire hazards and leakage incidents. The user-friendly aspect is highlighted through visualized data processing, enabling managers to easily identify abnormal temperature zones via image analysis and take timely corrective actions.

5. Summary and Outlook

As more enterprises transition into high-tech and biotechnology research, safety concerns in hazardous chemical warehouses have become increasingly prominent. To ensure warehouse security, it is crucial to enhance technical capabilities and implement digital supervision based on existing domestic and international safety measures for storing dangerous chemicals. Current challenges—including low temperature measurement accuracy, excessive resource consumption, difficulty in pinpointing hotspots, and poor data timeliness—continue to trigger frequent accidents. This necessitates professionals to improve their expertise through multi-level training programs, strengthen safety awareness, and master emergency response protocols. Concurrently, government agencies should establish effective policies while enterprises conduct regular inspections at designated locations to minimize safety risks through meticulous oversight.

The intelligent temperature monitoring system integrates infrared thermal modules with wireless transmission technology. The infrared module first detects the heat signature of hazardous materials to obtain baseline temperature readings, while continuously tracking thermal variations through color depth changes in infrared radiation, enabling rapid response to temperature fluctuations. Wireless modules then transmit data for automated report generation and content processing. When temperatures exceed preset thresholds, the system triggers alerts to identify potential risks. This intelligent approach reduces labor costs while providing comprehensive, accurate data, effectively minimizing human errors and delayed information updates. By leveraging these smart solutions, the system enhances regulatory oversight efficiency, effectively mitigates chemical storage risks, and ensures safer protection for both personnel and property.

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