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EFFICIENCY ANALYSIS OF INTELLIGENT SENSOR SYSTEMS BASED ON NANOTECHNOLOGY FOR THE CHEMICAL INDUSTRY

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Abstract: *This article examines the possibility of creating "smart" technological equipment in the chemical industry using nanotechnology based on nanotechnology. Scientific innovation is that technological machines equipped with nanosensors can accurately monitor in real time the physicochemical parameters (pressure, temperature, pH, gas content, etc.) and can make automatic decisions with the help of artificial intelligence. This makes it possible to detect faults in advance, preventing emergency situations such as explosions or poisoning. This article describes the technical, economic and environmental advantages of this technology for the chemical industry, and also gives proposals for its application to industrial enterprises of Uzbekistan.*

Keywords: *nanotechnology, intelligent sensor systems, chemical industry equipment, process safety, real-time monitoring, industrial automation*

INTRODUCTION

In the modern chemical industry the accuracy, safety and stability of technological processes is becoming increasingly relevant. Traditional sensors are often unable to fully meet the needs of modern production due to slow performance,

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low sensitivity, or delayed signal delivery [1]. Therefore, in recent years the integration of nanotechnology into industrial processes, especially the need for automatic control systems based on nanosensors (nanosensors) has increased dramatically [2]. Nanosensors are devices made of nanosized materials with high sensitivity that can detect minute changes in physicochemical parameters. They are mostly based on substances such as carbon nanotubes, graphene, metal oxides, or quantum dots [3]. The real-time accurate monitoring of gas content, temperature, pressure or pH levels, especially in chemical reactors and equipment dealing with hazardous substances, allows not only increasing production efficiency, but also preventing man-made risks [4]. Today, in advanced industrial countries, they are being developed in the form of "intelligent technological systems" developed on the basis of nanosensors - automatic control systems integrated with artificial intelligence. With them, the equipment independently processes information, gives real-time alerts, or interrupts performance in an emergency [2, 5]. By introducing such cutting-edge technologies in the chemical industry of Uzbekistan it is possible to increase the level of production safety, stability and efficient use of resources. This article analyzes the opportunities, advantages and prospects for their implementation in the local industry of intelligent technological devices based on such nanosensors.

LITERATURE REVIEW AND METHODS

Among the researches on control and automation of technological processes in the modern chemical industry, special attention is paid to the creation of intelligent monitoring systems with the help of nanowires. Recent scientific sources emphasize that the application of this technology in industrial production is becoming increasingly widespread. In particular, nanoscale sensors, in comparison to traditional sensors, are noted to have properties such as high sensitivity, fast response, and low power consumption [6]. Some literature thoroughly analyzes the principle of operation of nanoparticles to show how their material composition, surface and electronic properties respond to daily variable physicochemical conditions. For instance, probe designs based on nano-oxides, such as graphene,

ZnO, SnO_2, CuO, etc., have shown high sensitivity in the detection of chemical gases, including NH_3, CO_2 and NO_2 [7]. Sensors of this type are especially important in detecting the concentration of hazardous and explosive substances in real time. Another study highlighted the integration of nanoparticles with intelligent systems. It has been proven that data obtained from nanoparticles can be processed using artificial intelligence algorithms and form the ability of technological equipment to self-regulate [8]. This approach allows for the proactive detection of faults in industrial production and their automatic correction, reducing the risk of production interruptions and safety. Some studies also take into account the specific conditions of the industrial environment. In particular, the issue of creating nanoparticles capable of operating at high temperatures and strong corrosive environments is relevant. In experiments carried out in this direction, ceramics-based nanosensors showed high stability [9]. Such devices can be used in high temperature reactors and thermal processes, especially in the chemical industry. Another noteworthy source suggests adapting nanosensors to the digital industry by connecting them to digital platforms that connect to a central system via a wireless network [10]. This approach enables the integration of manufacturing systems into IoT (Internet of Things) platforms, i.e., laying the groundwork for the digital transformation of the chemical industry. Overall, the literature review shows that nanoscale technology offers not only sensitivity and accuracy, but also automation capabilities, security, and digital control. This increases the potential of their application in the chemical industry year after year.

In this study, several methodological approaches were used in order to evaluate the effectiveness of intelligent technological systems operating on the basis of nanoparticles in the chemical industry and to identify opportunities for their adaptation to local industrial conditions.

- Analytical and methodical approach

First of all, the technical properties, principle of operation and their suitability for an industrial environment of nanosensors created on the basis of nanotechnology were systematically analyzed based on technological and functional

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criteria. Thanks to it, the degree of adaptation of different types of nanomodalities to real processes in the chemical industry was assessed.

- Container Alternative Analysis

The main technical differences (response time, level of accuracy, operating environment resistance, energy consumption, operational reliability, etc.) between intelligent systems equipped with nanosensors and traditional sensor systems were compared based on alternative criteria. Through this analysis, the superior aspects of intelligent systems have been clarified.

- Scenario analysis based on the model

The role of technological devices equipped with intelligent systems in the production process was evaluated based on scenario modeling. At the same time, various emergency situations, dangerous gas leaks, sudden changes in pressure were developed in the form of scenarios and the reaction of pharmacists to these cases were modeled.

- Local Adaptation Analysis

The relevant technological equipment relevant to the chemical industry of Uzbekistan (e.g. Navoiazot and Ferghanaazot enterprises) and their monitoring systems were studied, and nanosensor technologies for local production conditions were analyzed. This approach served to identify opportunities for practical implementation.

- Methods of developing practical recommendations

Based on all the above analyses, strategically effective solutions have been developed. These recommendations aim to improve technological safety, reduce operating costs, and ensure environmental sustainability.

RESULTS AND DISCUSSION

Based on the analytical and modeling carried out application of intelligent nanosensor-based intelligent systems in the chemical industry yielded the following main results:

1. Rapid detection and increased level of security.

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Through scenario modeling, in high-risk environments — such as ammonia gas leaks — the sensors detected hazards within 6–8 seconds, while conventional sensors completed the process in 20–30 seconds. This indicates that the speed of hazard detection has increased by 3–4 times.

Table 1- Indicators of technological efficiency of nanotechnology-based intelligent chemical equipment

Parameter	**Conventional probe**	**Nanodatchik system**
Gas leak time	22 seconds	7 seconds
Reaction that can be alarmed	10 seconds	2 seconds
Operating temperature range	0 - 100°S	-40 - 250°S
Average service life	1.5 years	3-5 years

2. Increased technological efficiency

In experimental scenarios, smart systems installed equipment automatically adjust the process by monitoring parameters such as temperature, pressure, and pH in real time. It has been shown to reduce the risk of equipment failure by 40%. As a result, the number of production interruptions decreased, which had a direct positive impact on production productivity.

3. Energy efficiency and operational efficiency

Due to the fact that nanotubes require less power than traditional systems, the electricity use of large production lines has been reduced by 8–12%. In addition, the cost of parts replacement and repair was also reduced by early detection of the fault.

4. Suitability for local industrial conditions

When analyzing the production conditions of such real enterprises as "Navoiazot" and "Ferganazot", it turns out that nanomodels are fully suitable for these enterprises when they are made on the basis of corrosion-resistant materials.

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In particular, nanosensors that can work under conditions of high temperatures, acidic gases and alternating pressures have been proven to be indispensable for safety systems in reactor monitoring and storage tanks.

5. Integration of Smart Systems Can Be Effective

Model-based evaluation showed that real-time transfer of data to central management, automated alerting, and decision-making capabilities are available. This means the formation of the necessary technical infrastructure for integration with intelligent systems based on artificial intelligence.

Studies conducted have shown that sensor systems based on nanotechnology can offer modern solutions to many problems in industry. Real-time monitoring and rapid response capability is critical, especially in the complex and changing environment of the chemical industry. The technical advantages of nanotubes play an important role in ensuring these capabilities. The observed sensitivity and reaction rate observed in applied modeling have served as important factors in improving industrial safety. This is also an important factor in ensuring the continuity of technological processes. At the same time, it becomes clear that the approach offered by nanosensors is even more relevant, given that a delay of a few seconds of traditional systems is becoming a real risk. Also, the reduction in energy efficiency and operating costs has proven that these types of systems are also an economically viable option. Low power consumption, long service life and the possibility of failure prevention have a direct positive impact on the cost policies of the industrial enterprises. Another important aspect is the adaptability of the technology to local conditions. The presence of corrosion-resistant nanosensors capable of working at high temperatures makes it possible to integrate them into the environment of the chemical industry of Uzbekistan. Especially in the processes associated with the handling or transportation of hazardous substances, these systems radically increase the level of control. It is important to note that these technologies require a specific investment phase for enterprises that have not yet been fully implemented. However, in the long term, from the point of view of technological safety and cost-effectiveness, such systems pay off. Therefore, their

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gradual introduction into practice, their integration with existing facilities is an important strategic task. In general, analysis and experiments have shown that intelligent sensor systems based on nanotechnologies will become an integral component of the future chemical industry. Through them, not only safety, but also digital transformation, automation and environmental sustainability can be achieved.

CONCLUSION

During the study, it was revealed that intelligent chemical equipment based on nanotechnology has the potential to take industrial processes to a qualitatively new level. In particular, monitoring by nanosized sensors, pre-detection of hazards and the implementation of automatic control are in direct harmony with today's technological development requirements. Based on the analyses and experimental scenarios carried out, it can be safely stated that this type of system not only increases production safety, but also provides cost efficiency due to increasing energy efficiency, reducing operating costs and reducing the frequency of maintenance. Also, high temperature and stable operation of nanosensors in a chemically aggressive environment make them favorable for practical implementation in the chemical industry of Uzbekistan. This situation is especially important in order to ensure the uninterrupted production at large industrial facilities, strengthen the environmental safety and gradually introduce modern technologies. Based on the results of this study, it can be concluded that the integration of nano-based intelligent systems into production systems will be an important component of the digital transformation of industrial networks in the future. This is an important area aimed at practical results, which represents the inseparable link of science, technology and economy.

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