MODELS FOR PREDICTING THE FILTRATION PROPERTIES AND ECOLOGICAL SUSTAINABILITY OF NONWOVEN FABRICS

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https://doi.org/10.5281/zenodo.22301250

Abstract. This article analyzes the physicochemical properties of filtering materials, their importance in ecological systems, and modern methods for predicting ecological sustainability. The role of filtration technologies in reducing environmental problems caused by industrialization and urbanization is highlighted. In addition, the possibilities of forecasting environmental conditions using statistical, mathematical, and artificial intelligence-based models are discussed. The importance of GIS technologies and remote monitoring systems in improving the efficiency of environmental monitoring systems is also substantiated.

Keywords: filtration, ecological sustainability, environmental monitoring, forecasting model, artificial intelligence, nanofiltration, atmospheric pollution, water purification.

Introduction. One of the most pressing challenges facing humanity in the 21st century is ensuring environmental safety. The expansion of industrial production, the increase in the number of vehicles, the development of energy sectors, and the intensive use of natural resources are disrupting ecological balance. Toxic gases released into the atmosphere, water pollution, and soil degradation are causing global environmental problems. Under such conditions, protecting ecological systems and ensuring the rational use of natural resources have become important tasks. Filtering technologies are considered one of the main tools for reducing environmental problems. They are widely used to reduce industrial waste, purify air and water, and prevent the spread of harmful substances. To ensure ecological sustainability, it is necessary not only to monitor the current situation but also to predict future environmental changes. Therefore, the demand for environmental monitoring and forecasting models is increasing. Modern information technologies, mathematical modeling, and artificial intelligence methods make it possible to predict the development of ecological systems with high accuracy. Filtration is the process of separating harmful or excess particles from gases, liquids, or other media. Filtration is carried out through mechanical, chemical, or biological methods. The main objectives of filtration are:

- purification of the environment;
- reduction of harmful substances;
- enhancement of environmental safety;
- protection of human health.

Filtration systems are used in industrial enterprises, drinking water treatment, wastewater purification, and atmospheric protection. The efficiency of filtering materials depends on a number of properties.

For a filter to operate over a long period, it must be resistant to mechanical pressure. Especially in industrial enterprises, filters operating under high temperature and pressure conditions are manufactured from durable materials. The porous structure of a filter determines its efficiency in retaining particles. The smaller the pores, the higher the filtration level.

Some filtering materials retain harmful substances on their surface. Activated carbon is one of the materials with high adsorption properties. A filter should not deteriorate under the influence of aggressive chemical substances. Therefore, polymers and ceramic materials are widely used in modern filters.

Mechanical filtration is one of the simplest and most widespread methods. It retains particles using a physical barrier.

Applications: dust collection, preliminary water purification, ventilation systems. Advantages: simple structure, low cost, high efficiency. Disadvantages: cannot capture very fine particles, becomes contaminated quickly. In chemical filtration, harmful substances are neutralized through chemical reactions. Main filtering materials: activated carbon, zeolite, ion-exchange resins. Chemical filtration is important in: industrial gas purification, drinking water treatment, reduction of toxic substances. Biological filtration is carried out using microorganisms. In this process, bacteria decompose and neutralize organic substances. Advantages of biological filters: environmental safety, low energy consumption, natural method. Applications: wastewater treatment, recycling of organic waste. Nanofiltration is considered one of the most promising areas of modern environmental technologies. Capabilities of nanofilters: capturing viruses and bacteria, separating heavy metals, reducing microplastics. Filters based on nanomaterials: have high efficiency, provide long service life, are energy efficient.

Ecological sustainability means maintaining ecological balance in the use of natural resources. The concept of sustainable development implies meeting human needs while also protecting the interests of future generations. Main criteria of ecological sustainability: air quality, condition of water resources, biodiversity, waste management, energy efficiency. Environmental monitoring is the process of continuously observing and assessing the state of the environment. Main objectives of monitoring: identifying sources of pollution, assessing environmental risks, forecasting, developing environmental policy. Monitoring objects: atmospheric air, water bodies, soil, flora and fauna.

Analysis of the Obtained Results. Nonwoven fabrics are considered one of the most effective materials in modern filtration technologies. Their filtration efficiency depends on the arrangement of fibers, fiber diameter, porosity level, and electrostatic properties. Compared to ordinary woven fabrics, nonwoven materials have a random fiber structure, which increases their ability to retain harmful particles.

Nonwoven filter materials are widely used in: atmospheric air purification, industrial dust collection, medical protective equipment, water filtration systems, automotive filter production. The efficiency of the filtration process depends on several key properties. Porosity is one of the main filtering characteristics of nonwoven fabrics. The volume of voids inside the material and their distribution determine the filter’s ability to pass air or liquid. When the porosity level is high: air permeability increases, pressure resistance decreases, filtration efficiency improves. However, excessively large pores may reduce the efficiency of capturing fine particles. Therefore, selecting the optimal porosity is important in the production of filter materials. Porosity is determined by the following formula:

P=VpVt×100%

where: **P**–porosity (%); **Vp**–volume of voids; **Vt** – total volume of the material.

In nonwoven fabrics, porosity usually ranges from 70% to 95%. This ensures their high filtration efficiency. Air permeability represents the amount of air passing through the filter within a certain period of time. This property is very important for: respirators, medical masks, ventilation systems. If the air permeability of a filter is low: breathing becomes difficult, energy consumption increases, system efficiency decreases. Air permeability depends on the following factors: fiber diameter, fabric thickness, number of pores, density of fiber arrangement. Although fine-fiber meltblown materials have high filtration properties, they also have greater air resistance. Therefore, multilayer combined nonwoven materials are widely used. The main function of a filtering material is to retain harmful particles. The particle retention efficiency depends on: particle size, air velocity, fiber diameter, electrostatic charge. Filter efficiency is calculated using the following formula:

$\eta = C_1 - C_2 C_1 \times 100\%$

where: **η** – filter efficiency; $\mathbf{C_1}$ – concentration of incoming particles; $\mathbf{C_2}$ – concentration of outgoing particles.

High-quality nonwoven filters are capable of retaining: PM2.5 particles, bacteria, viruses, aerosols. For example, N95 respirators can capture 95% of particles as small as 0.3 microns. Electrostatic filtration is one of the important properties of modern nonwoven materials. In this process, fibers are electrically charged and attract fine particles.

Advantages of this method:

- high filtration efficiency;
- low pressure resistance;
- energy efficiency.

Electrostatic filters are used in: respirators, medical masks, industrial gas filters. Polypropylene fibers produced by meltblown technology are widely used for electrostatic filtration. Filter materials should not deform during long-term operation. Mechanical strength ensures. Long service life, resistance to high pressure, tear resistance. Factors affecting mechanical strength include. Fiber type, bonding method; fabric density; thickness. Needle-punched nonwoven fabrics possess high strength and are used in geotextiles and industrial filters. In water filtration systems, the water permeability of nonwoven fabrics is very important. This property determines: water flow rate, filtration quality, membrane efficiency. Nonwoven membranes based on nanofibers are capable of retaining: bacteria, heavy metal ions, organic pollutants. Nonwoven fabrics produced using nanotechnology can capture extremely small particles. Advantages of nanofilters: high efficiency, low energy consumption, ability to retain microorganisms. Nanofilters are used in medicine, water purification, environmental monitoring devices. Nonwoven filters are used to reduce industrial dust, automobile emissions, toxic gases. As a result, atmospheric air quality improves. In water purification systems, nonwoven membranes retain: bacteria, heavy metal ions, microplastics. This improves the quality of drinking water. The use of biodegradable nonwoven materials increases environmental safety. Environmental advantages: recyclability, natural decomposition, reduction of plastic waste. Ecological sustainability means maintaining ecological balance through the rational use of natural resources. Main indicators: atmospheric quality, water purity, energy efficiency, waste management. Nonwoven filter materials help

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improve these indicators.The main purpose of ecological sustainability forecasting models is to determine the future condition of ecological systems in advance. These models play an important role in reducing environmental risks, ensuring rational resource use, and developing environmental protection strategies. Forecasting models analyze: atmospheric pollution, water quality, waste volume, climate change, industrial emissions. Statistical models study ecological processes based on historical data. These models make it possible to determine how environmental indicators change over time.Main statistical methods: regression analysis, correlation, variance analysis, time series models.

Regression model:: Y=a+bX

where: **Y** — environmental indicator; **X** — influencing factor; **a, b** — coefficients.

The relationship between industrial waste and air pollution, as well as the connection between the number of vehicles and the amount of CO_2 emissions, can be determined. Statistical models are: simple, inexpensive, fast. However, they cannot fully represent complex ecological systems. Mathematical models describe the physical and chemical processes of ecological systems using formulas. The dispersion of harmful substances in the atmosphere is expressed as:

dCdt=−kC

where: **C** — concentration of the substance; **k** — attenuation coefficient. Mathematical models are used to predict: concentration of gases in the atmosphere, water pollution, waste dispersion, environmental risk zones. **Advantages:** high accuracy, ability to represent complex systems. **Disadvantages** require large amounts of data, computational processes are complex.

Artificial intelligence is one of the most modern directions in environmental monitoring. By processing large volumes of data, it becomes possible to predict environmental conditions with high accuracy. **Main algorithms:**

- Artificial Neural Network (ANN);
- Random Forest;
- Decision Tree;
- Deep Learning.

Using artificial intelligence, it is possible to: forecast air quality, detect water pollution, assess environmental risk zones. **Advantages:** operates in real time, processes large datasets, provides high accuracy. **Disadvantages:** requires high computational power, programming is complex. GIS (Geographic Information Systems) is widely used in environmental monitoring. GIS technologies enable the mapping and spatial analysis of environmental data.With the help of GIS: atmospheric pollution is mapped, water resources are monitored, desertification processes are assessed. Using satellite data, it is possible to monitor: deforestation, glacier melting, the condition of water bodies. GIS systems improve the efficiency of environmental management. In modern environmental forecasting systems, several models are often used together. For example: statistical model + GIS, artificial intelligence + mathematical model. Such an approach: increases forecasting accuracy, quickly identifies environmental risks, enhances monitoring efficiency. The efficiency of nonwoven filters depends on the following factors: fiber diameter, porosity, air velocity, humidity, pressure difference. Using forecasting models, it is possible to determine: filter service life, dust collection capacity, filtration efficiency. This helps to: reduce energy consumption, replace filters on time, improve environmental safety. Filtration systems are important tools for reducing environmental risks.

Their environmental benefits include: purifying air, improving water quality, reducing greenhouse gases, enabling waste recycling. The use of modern filters in industrial enterprises helps reduce: SO_2, CO_2, nitrogen oxides, dust particles. Environmental problems in Uzbekistan are associated with: the Aral Sea crisis, atmospheric pollution, water scarcity, desertification processes. Therefore, the following are being introduced water-saving technologies, environmental monitoring systems, modern filtration devices. In the future the "green economy", renewable energy, smart monitoring systems will play an important role in ensuring ecological sustainability.

Conclusion.

Filtration technologies play an important role in reducing environmental problems. Mechanical, chemical, biological, and nanofiltration methods are effective tools for reducing air, water, and soil pollution. Ecological sustainability forecasting models make it possible to identify environmental risks in advance and ensure the rational use of resources. In particular, the development of artificial intelligence and GIS technologies is increasing the efficiency of environmental monitoring systems. In the future, the widespread implementation of modern filtration technologies and the development of environmental forecasting systems will contribute to reducing global environmental problems.

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