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CONTACTS

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PRODUCTION AND APPLICATION OF NATURAL FIBER-BASED COMPOSITE FILTER MATERIALS FOR THE OIL AND GAS INDUSTRY

Ungarova Sohiba Isomiddin kizi

Tashkent State Technical University

PhD Student of the Department of Ecology and Environmental Protection

Sheranova Feruza Atabekovna

Tashkent State Technical University

Independent Researcher, Department of Ecology and Environmental Protection

Ayubova Indira Xamidovna

Tashkent State Technical University

Acting Professor, Department of Ecology and Environmental Protection

Sodikjonov Samandarbek Kaxramonjon ugli

Tashkent State Technical University

Master's Student, Department of Ecology and Environmental Protection

Abstract. The increasing demand for efficient and environmentally responsible filtration technologies has created a growing interest in natural fiber-based materials. Among renewable resources, cellulose is particularly attractive because of its abundance, relatively low cost, biodegradability, fibrous structure, and the presence of functional groups that can be modified according to the intended application. These properties make cellulose-based composites promising candidates for the production of filtration materials used in the oil and gas industry. This article examines the development of natural fiber-based composite filters and their potential application in the treatment of oily wastewater, separation of oil and water, and removal of suspended particles and other contaminants.

Keywords: cellulose, natural fibers, composite filter, filtration material, oil and gas industry, oily wastewater, oil-water separation, adsorption, biomass, sustainable materials.

Annotatsiya. Samarali va ekologik jihatdan mas'uliyatli filtrlash texnologiyalariga bo'lgan talabning ortib borishi tabiiy tolalar asosidagi materiallarga qiziqishni kuchaytirmoqda. Qayta tiklanuvchi resurslar orasida selluloza o'zining ko'pligi, nisbatan arzonligi, biologik parchalanuvchanligi, tolali tuzilishi hamda mo'ljallangan qo'llanish sohasiga muvofiq o'zgartirilishi mumkin bo'lgan funksional guruhlarining mavjudligi sababli alohida ahamiyatga ega. Ushbu xususiyatlar selluloza asosidagi kompozitlarni neft va gaz sanoatida qo'llaniladigan filtrlash materiallarini ishlab chiqarish uchun istiqbolli nomzodga aylantiradi. Mazkur maqolada tabiiy tolalar asosidagi kompozit filtrlarni ishlab chiqish hamda ularni neftli oqova suvlarni tozalash, neft va suvni ajratish, shuningdek, muallaq zarrachalar va boshqa ifloslantiruvchi moddalarni olib tashlashda qo'llash imkoniyatlari ko'rib chiqiladi.

Kalit so'zlar: selluloza, tabiiy tolalar, kompozit filtr, filtrlash materiali, neft va gaz sanoati, neftli oqova suvlar, neft-suvni ajratish, adsorbsiya, biomassa, barqaror materiallar.

Аннотация. Растущий спрос на эффективные и экологически ответственные технологии фильтрации вызывает повышенный интерес к материалам на основе природных волокон. Среди возобновляемых ресурсов целлюлоза представляет особый интерес благодаря своей распространённости, относительно низкой стоимости, биоразлагаемости, волокнистой структуре и наличию функциональных групп, которые могут быть модифицированы в соответствии с предполагаемой областью применения. Эти свойства делают композиты на основе целлюлозы перспективными материалами для производства фильтрующих материалов, используемых в нефтегазовой промышленности. В данной статье рассматриваются разработка композитных фильтров на основе природных волокон и возможности их применения для очистки нефтесодержащих сточных вод, разделения нефти и воды, а также удаления взвешенных частиц и других загрязняющих веществ.

Ключевые слова: целлюлоза, природные волокна, композитный фильтр, фильтрующий материал, нефтегазовая промышленность, нефтесодержащие сточные воды, разделение нефти и воды, адсорбция, биомасса, устойчивые материалы.

INTRODUCTION

The oil and gas industry generates a variety of liquid streams containing suspended solids, oil droplets, hydrocarbons, salts, metal ions, and other contaminants. These pollutants can enter process water during oil extraction, drilling, transportation, storage, and refining. Consequently, filtration and separation technologies are an essential part of maintaining process efficiency and reducing the environmental impact of petroleum-related activities. Conventional filtration materials are commonly manufactured from synthetic polymers, inorganic fibers, or other non-renewable materials. Although many of these materials provide good mechanical and chemical stability, their production and disposal may create additional environmental concerns [1–2]. The growing interest in sustainable technologies has therefore encouraged researchers to investigate renewable materials that can provide adequate filtration performance while reducing the environmental burden associated with conventional materials. Cellulose is one of the most abundant natural polymers and is widely available in wood, cotton, agricultural residues, plant stems, straw, and other biomass resources. Its molecular structure contains numerous hydroxyl groups, which provide opportunities for chemical and physical modification. Cellulose-based materials have already been investigated for wastewater treatment in the petroleum industry, including oil spill cleanup, adsorption, flocculation, and oil-water separation. Their performance can be improved by introducing specific surface wettability, including hydrophobic/oleophilic or hydrophilic/underwater oleophobic characteristics [3].

LITERATURE REVIEW

In recent years, considerable attention has been devoted to the development of cellulose-based materials for wastewater treatment and oil-water separation. The increasing interest in these materials is mainly associated with the renewable nature of cellulose, its biodegradability, relatively low production cost, and the possibility of modifying its surface and structural characteristics. Peng et al. reported that cellulose-based materials have significant potential for wastewater treatment in the petroleum industry and can be applied as adsorbents, flocculants, and oil-water separation membranes. Their review demonstrated that cellulose materials can be used at different stages of petroleum wastewater treatment, including the removal of suspended solids, heavy metals, chemical contaminants, and oil components.

RESEARCH METHODOLOGY

Raw Materials

Natural lignocellulosic biomass can be considered the primary raw material for the production of cellulose-based filtration materials. Depending on local availability, potential sources include cotton residues, wood waste, agricultural straw, plant stems, and other cellulose-rich biomass. The use of agricultural and plant residues is particularly attractive because these materials are widely available and can serve as inexpensive sources of cellulose. In addition to reducing the amount of biomass waste requiring disposal, their conversion into functional filtration materials can increase the added value of locally available resources.

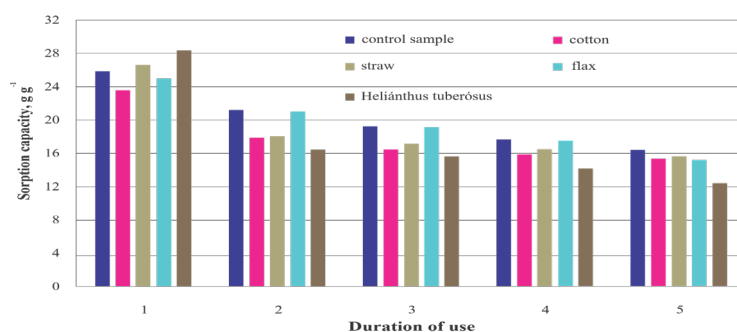


Figure 1. Indicators of semi-synthetic Addinol 10-40 oil refined using cellulose-based filter materials and duration of use of filter material

Fabrication of Composite Filter Materials

A cellulose-based composite filter can be prepared in several forms depending on the intended application.

These may include fibrous sheets, porous membranes, multilayer filters, compressed fiber structures, and cellulose-based porous composites. The filtration properties can be adjusted by controlling fiber diameter, fiber concentration, packing density, pore size, thickness, and surface chemistry. Additional components may also be introduced to improve mechanical strength, chemical resistance, adsorption capacity, or selectivity. For oil-water separation, surface modification is particularly important. Unmodified cellulose is generally hydrophilic because of its abundant hydroxyl groups. Consequently, chemical modification or incorporation of hydrophobic components can be used when selective oil capture or oil-permeable filtration is required. Previous research has shown that cellulose surfaces can be modified to control wettability and improve oil-water separation performance. For example, silanized cellulose has been investigated as a porous hydrophobic material for rapid oil-water separation [4].

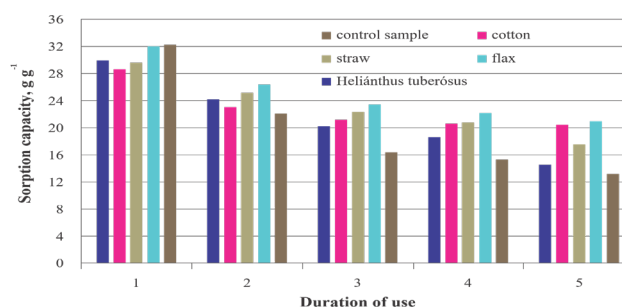


Figure 2. Indicators of synthetic Liqui Moly 5-40 oil refined using cellulose-based filter materials and duration of use of filter material

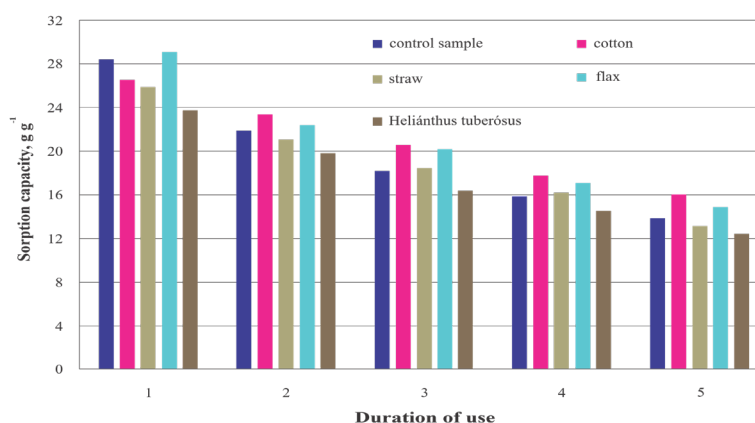


Figure 3. Indicators of mineral oil purified using cellulose-based filter material and the duration of use of the filter material

Characterization of the Filtration Materials

The structure and properties of cellulose-based composite filters can be evaluated using several analytical methods. Fourier-transform infrared spectroscopy (FTIR) can be used to identify the main functional groups and monitor chemical changes resulting from cellulose purification or surface modification. Scanning electron microscopy (SEM) can provide information about fiber morphology, pore structure, and surface changes.

Water contact angle measurements can be used to evaluate surface wettability, which is particularly important for oil-water separation. Mechanical properties should also be considered because filtration under pressure can cause deformation or structural failure of weak materials.

Filtration experiments can be performed using model oil-water mixtures or contaminated water containing suspended particles. The main parameters may include filtration efficiency, permeate flux, pressure resistance,

oil removal efficiency, water rejection, adsorption capacity, and reusability [5].

ANALYSIS AND RESULTS

Structural Characteristics of Cellulose-Based Filter Materials

The filtration behavior of a natural fiber-based composite is strongly related to its internal structure. The interconnected network formed by cellulose fibers provides channels for fluid transport while simultaneously creating sites where suspended particles can be physically retained. A denser fiber network generally provides greater resistance to particle passage, whereas a more open structure allows higher fluid flow [6]. Therefore, the design of a practical filter requires a balance between contaminant retention and fluid permeability.

The structure of cellulose also provides an advantage for composite design. The hydroxyl groups present on the cellulose surface can interact with other components and provide sites for further functionalization. This makes it possible to develop cellulose-based materials with properties that are not available in untreated natural fibers.

Filtration and Adsorption Mechanisms

The removal of contaminants by cellulose-based composite filters may occur through several mechanisms simultaneously. The first is physical filtration, in which suspended particles are retained because their dimensions exceed the effective pore size of the material.

The second mechanism is adsorption. Functional groups on cellulose and other components of the composite can interact with dissolved contaminants or oil components. This means that a properly designed cellulose composite can perform both filtration and adsorption. This combination is especially relevant for petroleum wastewater, where contaminants may occur simultaneously as suspended particles, dispersed oil droplets, dissolved organic compounds, and inorganic species [7]. Previous research has identified cellulose-based materials as potential adsorbents, flocculants, and oil-water separation membranes for petroleum wastewater treatment.

The results indicate that, when the sorbent is intended for single-use application with Addinol 10W-40, cellulose samples obtained from waste paper and combined with flax or *Helianthus tuberosus* cellulose are suitable for increasing the sorption capacity of the material. For Liqui Moly 5W-40, samples containing flax cellulose can be reused several times.

When repeated use of the sorbent is required, compositions containing flax or cotton cellulose are more suitable. Flax cellulose-based compositions can be used as sorbents for Addinol 10W-40 and Liqui Moly 5W-40, whereas all investigated compositions can be used for the sorption of mineral oil.

Current Limitations and Future Research

Despite their considerable potential, cellulose-based composite filters still face several challenges before widespread industrial implementation. The first challenge is water and chemical resistance. Since cellulose contains numerous hydrophilic hydroxyl groups, prolonged exposure to water can cause swelling and changes in dimensional stability. Surface modification and composite formation can help address this limitation [8].

The second challenge is mechanical durability. Industrial filtration systems may operate under pressure and require materials capable of maintaining their structure during long-term operation. The third challenge is fouling. Oil droplets and suspended particles can accumulate on the filter surface and inside the pores, gradually reducing permeability. Therefore, antifouling behavior and regeneration should be considered during material design (Table 1).

Table 1. Relationship Between Filtration Mechanism and Target Contaminants

Filtration mechanism	Main target	Cellulose-based material function	Relevant oil and gas application
Physical filtration	Suspended solids	Retention within fiber network and pores	Produced-water pretreatment
Size exclusion	Fine particles	Separation according to pore size	Process-water filtration
Adsorption	Dissolved contaminants	Interaction with functional groups	Petroleum wastewater treatment
Oil adsorption	Oil droplets/hydrocarbons	Interaction between modified cellulose surface and oil	Oil spill and oily-water treatment
Oil-water separation	Oil and water phases	Controlled surface wettability	Produced-water treatment
Multistage filtration	Mixed contaminants	Combination of filtration and adsorption	Advanced wastewater treatment

The fourth challenge is scale-up. A material that performs well under laboratory conditions may behave differently when produced in larger dimensions or operated under continuous flow. Recent literature continues to identify durability, regeneration, and large-scale manufacturing as important barriers to the broader application of cellulose-based oil-water separation materials [9].

CONCLUSION AND SUGGESTIONS

Natural fiber-based cellulose composites represent a promising platform for developing sustainable filtration materials for the oil and gas industry. Their renewable origin, fibrous structure, relatively low cost, and chemically modifiable surface make them suitable for a wide range of filtration and separation processes.

The potential of these materials is not limited to simple mechanical filtration. Through appropriate structural design and surface modification, cellulose-based composites can combine particle filtration, adsorption, and selective oil-water separation within a single material. This multifunctional behavior is particularly relevant to petroleum wastewater treatment, where several types of contaminants may be present simultaneously.

The use of agricultural and plant-based residues as cellulose sources also provides an opportunity to develop locally available raw materials into value-added filtration products. Such an approach can contribute to waste valorization while reducing dependence on conventional synthetic filter materials.

Further research should focus on optimizing pore structure, surface wettability, mechanical stability, chemical resistance, antifouling properties, regeneration, and long-term performance under realistic oil and gas industry conditions. In particular, experiments using real petroleum wastewater rather than only model systems will be important for evaluating the practical applicability of cellulose-based composite filters.

Overall, the development of natural fiber-based cellulose composite filters provides an intersection between sustainable materials science, environmental protection, and petroleum wastewater management. With appropriate material engineering and process optimization, these composites have the potential to become useful components of more sustainable filtration technologies.

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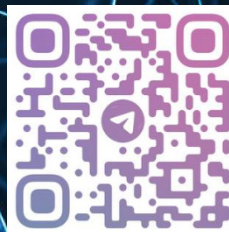
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