Наносистеми, наноматеріали, нанотехнології
Nanosistemi, Nanomateriali, Nanotehnologii
2025, т. 23, № 2, сс. 363–377
https://doi.org/10.15407/nnn.23.02.0363

PACS numbers: 81.16.Hc, 81.20.Ym, 87.50.-a, 87.85.Rs, 89.60.Ec, 92.20.jb, 92.40.kc

Driving Potential of Nanotechnological 'Softening' Approaches for the Maritime Industry: Application, Preference, and Prospects

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The article discusses certain nanotechnologies' key aspects: their rapid development, purposes, and uses. The types of certain nanotechnology generation are explained. Emphasis on the use is given to the cleaning of drinking water, in particular, sewage and ballast water. The latter is discussed at the level of the publisher and organizer of the international water industry—Global Water Intelligence. The variety of ways of applying nanotechnologies to reduce pollution of aquatic environments is presented, and the disadvantages are emphasized. The article is descriptive and applied to help the reader understand the essence of the growth of the nanotechnology boom in several different technologies, ways, and distribution methods. A comparison of nanofiltration membranes with reverse osmosis (SWRO) systems is provided, concerning to processes at the nanoscale level, namely, the use of semi-permeable membranes, which allow only molecules of a certain size to pass through; the pore size in such membranes is measured in nanometers. Therefore, reverse osmosis is an example of a nanoscale technology that is widely used for water purification. The article contains, as a research part, an illustrative example of the application of the nanotechnological principle of the self-discharge filter in the innovative process of disinfection/purification of ballast water according to the quality standard D-2 of the IMO Convention, based on an experimental level by the developers of the Danube Institute of the National University 'Odessa Maritime Academy' (DI NU 'OMA'; Izmail, Ukraine). It is shown how, with the help of its effective application process, the level of final destruction of invasive foreign organisms in ballast water increases. In the discussion of the article, it is stated that this filter will significantly reduce the labour costs of the marine ships' engine crew for the production of high-quality distillate and will allow to improve the cleaning and washing of the filter working elements of the modernized ships' SWRO. In particular, shortly, these are ceramic membranes, which will be commercialized and industrialized in the areas of water purification and desalination, as opposed to the use of the SWRO and nanofiltration membranes. The application No. 1059B162300675 submitted by the applicant, Candidate of technical sciences, Docent of the Department of Management in the Transport Industry of the DI NU 'OMA' of the Ministry of Education and Science of Ukraine Nataliia Tiron-Vorobiova (2216B—TÜBITAK-TWAS Postgraduate and Postdoctoral Fellowship Programs 2024–2027), refers to the use of ceramic membranes: Ballast Water Treatment System (BWTS) using Ceramic Membrane Filtration Method, Electrooxidation (EOx) Development and Ecological Assessment. The application provides a key decision (quotation): 'Recently, research has mainly focused on improving adequate, cheap, and aquatic-safe ballast water management systems (BWTS). However, most of these treatment processes alone do not meet all the required discharge quality indicators; they require modification. Thus, there is a significant need for innovative environmental technologies and clean, cost-effective, sustainable maintenance of safe seawater sources. Recently, the integration of electrochemical (EOx) processes with improved membrane filtration processes has been considered as a means to overcome this barrier. The main idea is aimed at creating modern BWTS that meet the requirements of the quality standard D-2 of the IMO Convention. BWTS developed based on experimental research within the bilateral project Ukraine–Türkiye ('2514 TÜBİTAK ve MESU İkili İşbirliği Programı', 2021), is innovative, multifunctional, based on high nanotechnological principles.'. Against the background of the driving advantage of the use of nanofiltration, reverse osmosis, special attention is be paid to the acceptance of 'nanotechnology: the environment' (because the latter remains under threat) with the participation of the increasingly widespread use of nanotechnological approaches.

У статті розглядаються ключові аспекти певних нанотехнологій: їхній стрімкий розвиток, призначення та використання. Пояснюється певні типи ґенерації нанотехнологій. Акцент робиться на використанні для очищення питної води, зокрема, стічних вод і баластних вод. Останнє обговорювалося на рівні видавця й організатора міжнародної водної галузі Global Water Intelligence. Представлено різноманітні способи застосування нанотехнологій для зменшення забруднення водного середовища та зазначено недоліки. Стаття має описовий і прикладний характер, щоб допомогти читачеві зрозуміти суть зростання буму нанотехнологій у кількох певних різних технологіях, шляхах і методах поширення. Наведено порівняння нанофільтраційних мембран із системами зворотньої осмози (SWRO) щодо процесів на нанорівні з використанням напівпроникних мембран, які пропускають лише молекули певного розміру; розмір пор у таких мембранах вимірюється в нанометрах. Отже, зворотня осмоза є прикладом наномасштабної технології, яка широко використовується для очищення води. Стаття містить як дослідницьку частину ілюстративний приклад застосування нанотехнологічного принципу саморозрядного фільтра в інноваційному процесі дезінфікування/очищення баластних вод відповідно до стандарту якости D-2 Конвенції IMO, заснованому на експериментальному рівні розробниками Дунайського інституту Національного університету «Одеська морська академія» (ДІ НУ «ОМА»; Ізмаїл, Україна). Показано, як за допомогою ефективного процесу його застосування підвищується рівень остаточного знищення інвазійних сторонніх організмів у баластних водах. В обговоренні статті зазначено, що цей фільтер значно понизить витрати праці машинного екіпажу морського судна на виробництво високоякісного дистиляту та дасть змогу поліпшити очищення та промивання робочих елементів фільтра модернізованого суднового СООП. Зокрема, найближчим часом саме керамічні мембрани будуть комерціялізовані та промислово впроваджені в сферах очищення та опріснення води, на відміну від використання СООП і нанофільтраційних мембран. Заявка № 1059B162300675, подана заявником — к.т.н., доцентом кафедри менеджменту в транспортній галузі ДІ НУ «ОМА» Міністерства освіти і науки України Тірон-Воробйовою Наталією (2216B за Програмою стипендій для аспірантів та постдокторантів TÜBITAK-TWAS 2024–2027 років), стосується використання керамічних мембран: системи очищення баластних вод (СОБВ) з використанням методу фільтрації через керамічні мембрани, розробки електроокиснення (EOx) та екологічної оцінки. Заявка містить ключове рішення (цитата): «Останнім часом дослідження в основному зосереджені на вдосконаленні адекватних, дешевих та безпечних для водного середовища систем управління баластними водами (СОБВ). Однак більшість цих процесів очищення самі по собі не відповідають усім необхідним показникам якості скидів; вони потребують модифікації.». Таким чином, є значна потреба в інноваційних екологічних технологіях і чистому, економічно ефективному, сталому обслуговуванні безпечних джерел морської води. Останнім часом інтеґрація електрохемічних (EOx) процесів з удосконаленими процесами мембранної фільтрації розглядається як засіб подолання цього бар'єру. Основну ідею спрямовано на створення сучасних СОБВ, що відповідають вимогам стандарту якости D-2 Конвенції IMO. СОБВ, розроблена на основі експериментальних досліджень у рамках двостороннього проєкту Україна–Туреччина («2514 TÜBİTAK ve MESU İkili İşbirliği Programı», 2021), є інноваційною, багатофункціональною, заснованою на високих нанотехнологічних принципах. На тлі рушійної переваги застосування нанофільтрації, зворотньої осмози, особливу увагу буде приділено прийняттю «нанотехнології: довкілля» (оскільки останнє залишається під загрозою) завдяки все більш широкому використанню нанотехнологічних підходів.

Key words: nanofiltration, nanofiltration materials, reverse osmosis, marine environment, 'softening' membranes, self-discharging nanofilter.

Ключові слова: нанофільтрація, нанофільтраційні матеріяли, зворотня осмоза, морське середовище, «пом'якшувальні» мембрани, саморозрядний нанофільтер.

(Received 31 March, 2024; in revised form, 29 May, 2024)

1. INTRODUCTION

Water is a rich source of valuable resources, whether it is chemicals in industrial wastewater, minerals in geothermal brines, or water itself. Interest in efficiently capturing and reusing products from the aquatic environment is growing, creating opportunities for technologies such as nanofiltration. Global Water Intelligence (GWI), a leading publisher and event organizer serving the international water industry, provides an essential guide to exploring this key technology for resource recovery.

Stricter water quality standards have led to increased demand for efficient membrane filtration technologies such as nanofiltration.

1.1. Nanofiltration as a Circular Economy

Nanofiltration (NF) (Fig. 1) is a type of semipermeable membrane, a thin selective barrier used to filter liquids in many industries. Positioned between reverse osmosis and ultrafiltration, nanofiltration is the second densest membrane with a pore size ranging between 1–10 nanometers. Nanofiltration membranes are available in various configurations, with the most common being spiral membranes; however, hollow fibre membranes have gained popularity since Pentair X-Flow introduced them in 2013. While polymeric NF materials dominate the market, other options include ceramics and cellulose.

Pressure is required to push the liquid through the membrane, with the permeate passing through while the concentrate is rejected. Particles can be rejected not only by size exclusion, but also by the chemistry of the membrane surface, selectively attracting or repelling certain contaminants based on their charge or chemical affinity.

Nanofiltration can purify high-quality water with less energy consumption than reverse osmosis (RO). For applications that do not require the removal of high levels of dissolved salts, nanofiltration membranes can be a useful alternative to RO, capable of removing bacteria, viruses, organics, and divalent ions.

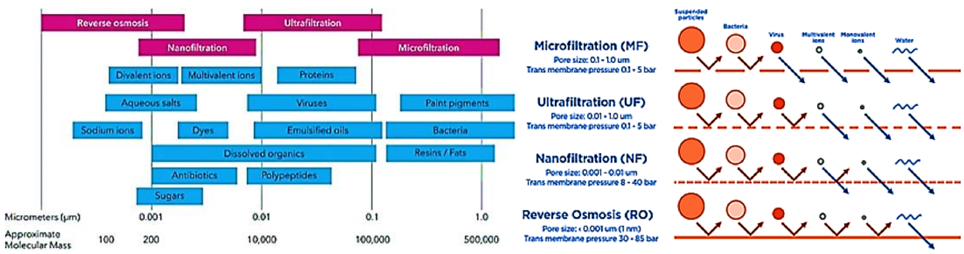

Fig. 1. Nanofiltration [1].

Nanofiltration was initially used for sulphate removal in the oil and gas sector, but now, it is applied for various purposes such as water softening, drinking water treatment, and purification of many industrial wastewater and brines. Recently, NF has also been employed for removing emerging contaminants from drinking water.

Nanofiltration aligns with the principles of the circular economy, primarily by reclaiming high-quality water suitable for reuse, but the recovery of other commodities such as biomass, minerals, and chemicals is gaining momentum in the market [1].

Nanofiltration should be used with fresh water and low-salinity brackish water if it contains heavy metals or microbiological contamination. In such situations, reverse osmosis will produce overly pure water that will need to be demineralized, increasing the cost and complexity of the purification system.

2. MAIN PROBLEMS: GOALS AND SOLUTIONS

2.1. Water Pollution and Nanotechnology [2]

How can nanotechnology be used to reduce water pollution?

Nanotechnology is utilized to address three very distinct water quality issues.

One problem involves removing industrial water contaminants from groundwater, such as a solvent used in cleaning called TCE (trichloroethylene). Nanoparticles can be employed to transform the contaminant through a chemical reaction to render it harmless. Research has shown that this method can effectively capture contaminants dispersed in underground aquifers at significantly lower costs than methods requiring pumping water from the ground for purification.

Another complex issue is the removal of salt or metals from water. The deionization method using electrodes made of nanofibers shows promise in reducing costs and energy requirements for converting saline water into potable water.

The third problem lies in standard filters being ineffective against viral cells. Currently, a filter with a diameter of just a few nanometers is being developed to be capable of removing viral cells from water.

3. MAIN TEXT. WATER POLLUTION: APPLICATION OF NANOTECHNOLOGY IN DEVELOPMENT

3.1. Research

Researchers at the University of Tokyo demonstrated the use of fluorine nanochannels for salt removal from water.

Researchers at EPFL demonstrated a water filter powered by solar panels, which utilizes nanowires of titanium dioxide (TiO_2) and carbon nanotubes for water purification.

Researchers at Brown University demonstrated the creation of water filters using short channels between graphene sheets, allowing water to pass through but blocking larger contaminants.

Researchers at North-Western University developed a nanocomposite coating that can be applied to a sponge to absorb oil but repel water.

Researchers at Nagoya University demonstrated the use of amino-modified nanocarbons for removing heavy metal ions from water.

Researchers at RMIT University and the University of New South Wales demonstrated a filter made of nanosheets of aluminium oxide, which can filter water for both heavy metals and oils.

Researchers at the University of Cincinnati demonstrated a method for removing antibiotics contaminating waterways. The method utilizes vesicle nanoparticles that absorb antibiotics.

Researchers at the Pacific Northwest National Laboratory developed a material for removing mercury from groundwater. The material is called SAMMS, which stands for Self-Assembled Monolayers on Mesoporous Supports. This involves taking a ceramic particle with many nanosize pores on its surface and lining the nanopores with molecules containing sulphur atoms on one end, leaving a hole in the centre lined with sulphur atoms, as shown in the SAMMS figure. They line the nanopores with sulphur-containing molecules as sulphur binds to mercury, trapping mercury atoms inside the nanopores.

3.2. Usage

–Nanosponges with a reactive nanoparticle layer covering a synthetic core that easily magnetizes. For example, silver nanoparticles, if bacteria are a problem, attach to pollutants or kill them. Then, when a magnetic field is applied, the nanosponges are removed from the water.

–Pellets containing nanostructured palladium and gold as catalysts for breaking down chlorinated compounds polluting groundwater. Since palladium is very expensive, researchers formed pellets of nanoparticles that allow nearly every palladium atom to react with chlorinated compounds, reducing processing costs.

–Enzyme-functionalized micromotors for removing carbon dioxide from water.

–Graphene oxide for removing radioactive material from water. Re-

searchers found that graphene oxide patches absorb radioactive ions in water. Then, graphene oxide forms clumps that can be removed from water for disposal.
–Graphene as membranes for inexpensive water desalination. Researchers have found that graphene with nanopores a nanometer or less in size can be used to remove ions from water. They believe this can be used for desalinating seawater at a lower cost than reverse osmosis methods currently used.
–Carbon nanotubes as pores in reverse osmosis membranes. This can reduce the power required to operate reverse osmosis desalination plants as water molecules pass through carbon nanotubes more easily than through other types of pores. Other researchers are using carbon nanotubes to develop small inexpensive water purification devices needed in developing countries.
–Carbon nanotubes for oil spill clean up. Researchers found that adding boron atoms during carbon nanotube growth results in the nanotubes growing into a sponge-like structure that can absorb oil many times its weight.
–Nanoparticle-like hairs (nanohairs) for capturing and measuring mercury contamination levels in water.
–Integration of nanomembranes with solar energy to reduce the cost of seawater desalination.
–Iron nanoparticles for cleaning groundwater from tetrachloroethylene contamination.
–Addition of graphene oxide to sand filters to enhance their ability to remove pollutants from water.
–Silver chloride nanowires as photocatalysts for decomposing organic molecules in polluted water.
–Electrified filter consisting of silver nanowires, carbon nanotubes, and cotton for bacteria eradication in water.
–Nanoparticles capable of absorbing radioactive particles polluting groundwater.
–Iron nanoparticle coatings allowing them to neutralize dense hydrophobic solvents polluting groundwater.
–Nanodroplet mats for absorbing oil spills.
–Iron oxide nanoparticles for arsenic removal from water wells.
–Carbon nanotubes with a gold tip for capturing oil droplets polluting water.

Antimicrobial nanofibers and activated carbon in a disposable filter as an inexpensive means of purifying contaminated water.

3.3. Nanofiltration is Sometimes Used for Wastewater Treatment

It provides higher flow rates and consumes less energy than reverse osmosis systems. The design and operation of nanofiltration are very similar to 'nanofiltration, considerably similar to reverse osmosis', with some differences.

The main difference is that the nanomembrane is not as 'tight' as the reverse osmosis membrane. It operates at a lower feed water pressure and does not remove monovalent (*i.e.*, those with one charge or valence) ions from water as effectively as the RO membrane.

While an RO membrane typically removes 98–99% of monovalent ions such as chlorides or sodium, a nanofiltration membrane typically removes 50% to 90%, depending on the membrane material and manufacturing. Due to its ability to remove effectively divalent and trivalent ions, nanofiltration is often used for water softening, leaving a smaller impact on the overall content of dissolved solids than RO. For this reason, it is called a 'softening membrane'. Nanofiltration is often used to filter water with low levels of dissolved solids, remove organic matter, and soften water.

As it is a 'looser membrane', nanofiltration membranes are less likely to foul or scale and require less pretreatment than reverse osmosis systems. Sometimes it is even used as pretreatment for reverse osmosis.

Nanofiltration can be used in various water and wastewater treatment applications for economically efficient removal of ions and organic matter.

In addition to water purification, nanofiltration is often used in the manufacturing process for pharmaceuticals, dairy products, textiles, and bakeries.

In particular, WaterProfessionals® have extensive experience in

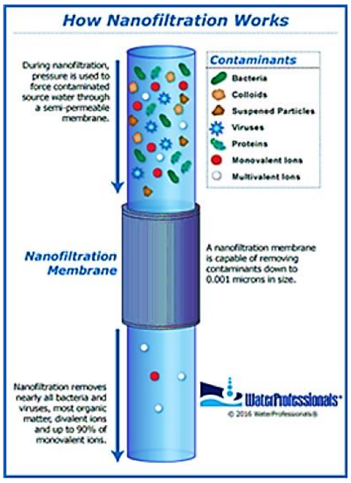

Fig. 2. How nanofiltration works [3].

applying nanofiltration systems to address water purification challenges (Fig. 2).

3.4. Sea Water Reverse Osmosis (SWRO) Systems on Maritime Vessels

Steam vacuum systems from leading manufacturers such as Alfa Laval, Mitsubishi, and others, according to design documentation, are expected to produce high-quality distillate on-board maritime vessels. However, in practice, due to changes in the operation modes of the main engine, the temperature of the water in the internal circuit of the engine, which serves as the heat carrier of the ship's desalination plant, may vary. As a result, the obtained distillate may not always meet the 1.5-ppm standard after desalination. The obtained permeate does not meet the quality standard, leading to fouling of the internal circuit of the main engine's diesel generators. This increases the deposition of solid scale and loose sludge in the engine rooms of internal combustion maritime diesel engines (ICME) and boiler drums, requiring additional use of expensive reagents for water treatment.

Currently, on new vessels, Sea Water Reverse Osmosis Systems (SWRO) are being additionally installed alongside existing steam vacuum systems, reducing energy costs for desalinating seawater.

Energy costs can be analysed using reversible thermodynamic processes. From thermodynamic principles, it follows that any water desalination method will be most efficient if it includes a thermodynamically reversible process. Energy calculation to determine a reversible system serves as the lower bound of energy for any other process [4].

To obtain large volumes of freshwater, a significant amount of seawater must be used, where, as a result of desalination, we obtain pure permeate and highly concentrated NaCl brine, which is completely drained overboard.

The ratio of produced freshwater to the volume of seawater required to obtain freshwater is called the water recovery coefficient—a.

In practice, a reverse osmosis desalination system cannot be a reversible process; there will always be losses depending on the coefficient.

$$a = \frac{V}{V + V_0}, \tag{1}$$

where V is the volume of fresh water ('sweet-water') produced; V_0 is the volume of water remaining after the desalination process has not been converted into fresh water ('sweet-water'). It is usually called brine or concentrate.

For example, if the system processes 1000 L of seawater: $V + V_0 = 1000$ L and, at the same time, receives 400 L of fresh water: $V = 400$ L, and 600 L remain as brine, then, the water recovery coefficient will be:

$$a = 400/(400 + 600) = 400/1000 = 0.4.$$

This means that 40% of the original seawater was converted into fresh water.

Actual work considering losses are in a formula, more specifically taking into account osmotic pressure and water volume. This formula takes into account that the volume of seawater exceeds the volume of fresh water ('sweet-water') by the water recovery coefficient:

$$W = PV\left(\frac{1}{a} - 1\right), \tag{2}$$

where P is the osmotic pressure, V is the volume of pumped water.

For most engineering calculations, this simplified version of this formula is used, which directly relates the volume of fresh water to osmotic pressure and water recovery coefficient.

Another example. Let us say we need to get 100 L of fresh water. Osmotic pressure P is of 5 bar (this is approximately of 0.5 MPa). The water recovery coefficient a is of 0.4 (40% of the original seawater is converted into fresh water).

The actual work done by W is of 0.075 MJ (megajoules).

To convert into more convenient units, for example, kWh, you can use the following conversion:

$$1 \text{ MJ} = 0.27778 \text{ kWh}.$$

So, to obtain 100 L of fresh water under these conditions, it is necessary to expend approximately 0.0208 kWh of energy.

It is sufficient to provide an example by comparing the Alfa Laval VSP-36-C-125 steam vacuum unit, which has a capacity of 36 m^3/day, with a permeate quality of 1.5 ppm and consumes 52 kWh/m^3 [5]. In reverse osmosis units, energy consumption will be five to ten times lower depending on the membranes used [6].

In recent years, reverse osmosis systems have gained widespread popularity for water purification and desalination, with the use of nanotechnology.

The FiiZK Aqua membrane filtration technology (see, for instance, https://fiizk.com/en/news-from-fiizk/water-purification-and-desalination-solutions-for-land-based-farming-and-parasite-control/)

Applications

Membrane Filtration	Pore Size (μm)	Raw Water Source	Desalinated	Application
Ultrafiltration (UF)	0.01 – 1.0	Sea water	No	Intake water for land-based facilities
Nanofiltration (NF)	0.001 – 0.01	Sea Water Brackish water Salty groundwater	Partially (3-22 ‰)	Prevention & treatment of parasitesIntake water for land-based facilities
Reverse Osmosis (RO)	< 0.001	Sea water	Yes (0.3 ‰)	Intake water for land-based facilities

Fig. 3. Applications (MF)/Seawater [3].

utilizes membrane filtration to stop unwanted substances. The use of membranes is intended to prevent contamination by organic and biological contaminants (parasites, bacteria, and viruses).

The membrane pore size determines the fraction that can be retained through filtration and our installations offer means for (Fig. 3):

–ultrafiltration (UF; pore size of 0.01–1.0 μm),
–nanofiltration (NF; pore size of 0.001–0.01 μm),
–reverse osmosis (RO; pore size < 0.001 μm).

A significant drawback of using SWRO systems in the maritime fleet is the high operating pressure of up to 100 bar required to achieve the quality standards of the obtained permeate. All types of installations are compelled to flush the working membranes from heavy metals, salts, and other inclusions, and discharge them overboard along with the brine, causing significant harm to the marine environment and biodiversity.

4. DISCUSSION

In earlier works, the authors proposed a catalyst capable of obtaining crystalline salt from the brine obtained during seawater desalination with minimal costs, using modern crystallizers to produce technical-grade salt in maritime conditions.

The scientific breakthrough in creating nanotubes, which subsequently found application in the production of nanomembranes for seawater desalination in SWRO installations, provided enormous potential for reducing energy consumption and operating pressure from 80 bars to 3 bars. The material used to produce nanotubes consists of sheets of carbon atoms. Their density is so high that only seven water molecules can pass through their cells, and the rate of seawater passage through nanotubes is 5000 times higher than in synthetic membranes. This effect has not found a complete explanation in science and requires further study. The quality of the obtained fresh water is 0.5 ppm, and energy consumption does not exceed 2 kWh/m^3 [7, 8].

According to the authors of the article, a decision has been made to propose the creation of a nanodischarge automated filter with disks made of nanocarbon tubes in the development and testing of a ballast water treatment/disinfection system created at the Danube Institute of the National University 'Odesa Maritime Academy' (Izmail, Odesa region, Ukraine) in accordance with the IMO Convention D-2 quality standard (Fig. 4).

Such a filter will significantly reduce the labour costs of the ship's crew for the production of high-quality distillate and improve the cleaning and flushing of the filtering elements of the modern SWRO ship system.

The advantage of the self-cleaning filter lies in providing the installation with a high level of invasive species destruction in ballast water treatment. The disc filter is used for filtering fine-dispersed suspensions; it consists of a housing in which a hollow shaft with perforated discs mounted on bearings is connected to the shaft cavity (Fig. 4).

Filtration cloth is fastened to the surface of the discs using clamps. During filtration, the shaft with the discs remains stationary, and the filtrate passes through the filtering partition inside the discs, then into the hollow shaft, and is discharged from the top. A sediment layer forms on the upper and lower surfaces of the

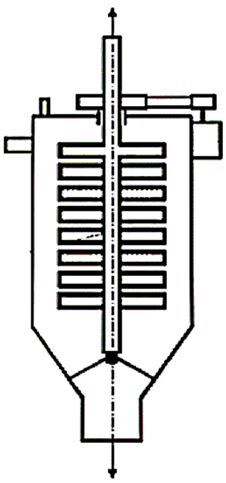

Fig. 4. View of the disc self-cleaning filter [4].

discs. After filtration is completed, the suspension is drained, and flushing liquid is supplied inside the shaft and discs, while the shaft with the discs is rotated by an electric drive.

Due to centrifugal forces, sediment is removed from the discs and discharged from the bottom of the filter. Then the filtration and flushing cycles are repeated. The positive quality of the filter is automatic sediment discharge.

The application of existing technologies from such company as CJC™ for purifying circulating lubricants and heavy fuel for ship engines provides the authors with practical experience and acquired expertise. Regarding ballast water treatment, proposed fine purification filters can be successfully applied since the density of oil is significantly higher than the density of ballast water, which increases the fluid's permeability.

5. CONCLUSION

According to experts, nanotechnologies will become a driving force of the industrial revolution and will change our way of life. Research and development in nanotechnologies are on the rise in the pursuit of original and useful things, and while there is a boom in factory production, little is being done to ensure the safety of society and the environment.

According to the National Science Foundation of the U.S.A., over the next decade, nanotechnologies are expected to 'capture' 1 trillion dollars of the world market. Nanotechnologies promise enormous potential benefits in improving almost all types of industrial products. However, on the other hand, the question arises: are they safe? The increasing number of scientific studies and government reports warns that created nanoparticles may pose a danger to human health and the environment, although there have been few studies on their toxicity.

Considerable efforts have been made to overcome the shortage of clean water, and nanotechnologies are a strong candidate for rapid development. Research and commercialization of polymer RO and NF membranes began in the early 1960s. So far, two types of membranes dominate the water desalination market: cellulose-based membranes (CA) and thin-film composite membranes (TFC). The most representative products, such as TS40, TS80, and AD-90, were developed over 30 years ago, and since then, there have been no significant changes due to low production costs and a high level of salt rejection. New research directions in barrier layers of TFC membranes include improving resistance to contamination, as well as chemical and thermal stability. Meanwhile, microporous supports can be optimized to increase mechanical strength and permeability.

Inorganic RO and NF membranes have been studied on a laboratory scale for water purification since the 1980s. The most typical ceramic membranes are metal-oxide membranes and carbon-based membranes. The main method for synthesizing metal oxide membranes is the sol–gel technique, which requires further optimization for particle size and distribution control. The efficiency of mixed matrix membranes (MMMs), made from both organic and inorganic nanomaterials, is excellent, but they are too expensive compared to other membranes. Therefore, it is important to understand the economic competitiveness of MMMs, as well as their potential application.

Although nanotechnologies are leading the way in the development of RO and NF membranes for water purification, there are still technical and scientific problems that need to be addressed before more advantages can be gained. Despite the difficulties that need to be overcome, it is very likely that ceramic membranes will be commercialized and industrialized in water purification and desalination in the near future [9].

Thus, nanotechnologies encompass a wide range of technologies for controlling the structure of matter at the atomic and molecular levels. A nanometer is one billionth of a meter, the length of a chain of 10 adjacent hydrogen atoms; the thickness of a human hair is approximately 80.000 nanometers. It is difficult to imagine something so small, let alone believe that it can be used in manufacturing processes [10].

At such a microscopic level, matter behaves differently than in our everyday life in this world dominated by 'classical Newtonian physics'. In the nanoworld, 'the properties of matter are determined by a complex and rich combination of classical physics and quantum mechanics', as stated in an exclusive online issue of Scientific American in January 2006. Moreover, in larger quantities, miniature nanomaterials can have enormous power due to their significantly higher surface area to volume ratio. As the particle size decreases and its reactivity increases, a substance that may be inert on a micro or macroscale can acquire hazardous properties on a nanoscale [11].

Regarding social and ethical issues, according to Vital Signs 2006–2007, serious concerns are not limited to safety and health impact; broader social and ethical implications need to be studied.

As with other forms of black carbon, such as carbon nanotubes, there is an increasing risk to the environment and/or public concern that graphene-based/(restored) *r*GO (GO—graphene oxide) nanomaterials will be found in natural water bodies due to their diverse applications. In addition, these nanomaterials may play an important role in biogeochemical activity due to their high mobility in the environment. These nanoadsorbents may also contain various toxic chemicals due to potential impurities.

Therefore, comprehensive research is needed to develop environmentally friendly methods for producing clean nanomaterials based on graphene/(restored) *r*GO and to assess the toxicity and biocompatibility of these nanomaterials.

‘The nanotechnological revolution is driven by profit—it is not a necessity for human development; as long as poverty and social injustice are fundamental problems, new technologies will never be a universal solution to them’, as stated in the Vital Signs report.

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