Chapter 7
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Prospects for Application of Nanotechnology in Marine Industries: A Brief Review

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ABSTRACT

The advent of nanotechnology is an advancement that represents a fundamental change that will lead to the development of materials and tools in the future. The possibility of using nano-building blocks in size and composition is revolutionizing material science. Currently there are many ongoing studies of nanotechnology, its applications, benefits, and future prospects. In the marine industry, which includes a wide range of industries such as shipbuilding, submarines, and offshore platforms, nanotechnology is providing many uses. In fact, nanotechnology has valuable applications in various sectors of the marine industry where it can revolutionize the marine industry. Studies have shown that nanoparticles added to fuel can reduce fuel consumption in diesel engines and can reduce pollutants. The addition of these nanoparticles to the fuel leads to the decomposition of burnt hydrocarbons and soot, which improves efficiency. Consequently, the amount of soot, HC and CO decreases. The results of physical testing have confirmed the role of nanoparticles for increasing efficiency and reducing pollution. In this study, some applications of nanotechnology in the marine industry are discussed. For example, nanoparticle matrices in battery electrodes can drastically increase their ability to store lithium ions, increasing the storage density of the battery. Graphene can be used as a self-lubricating solid or as an additive for lubricating oils. Application of nanotechnology for the fabrication of cellular ceramic can improve its thermal stability and mechanical strength. Overall, nanotechnologies seem to have huge potential in areas as diverse as drug development, water decontamination, information and communication infrastructures, and the production of stronger, lighter and perfect nanomaterials. The benefits of nanotechnology to marine applications is no less significant.

Keywords: Chemistry; nanotechnology; nanomaterials; nano additives; marine industries; submarines.

1. INTRODUCTION

Nanotechnology has received a lot of attention in the last decade. At the same time, the maritime industry has undergone fundamental changes and huge investments have been made in it. Nanotechnology offers a potential to open a large scope of novel application in the fields of biotechnology and agricultural industries due to unique physicochemical properties. Nanoparticles can be used in herbicides, nano-pesticide, nano-fertilizers, or genes, which target specific cellular organelles in plants to release their content. It can potentially play an instrumental role in minimizing the application losses of agrochemicals due to their more stable emulsion, higher coverage on leaf surfaces, precision application, etc. [1,2]. The presence of nanomaterials is not in itself a threat; it is only certain aspects that can make them risky, in particular their mobility and their increased reactivity. Only certain properties of certain nano particles were harmful to living beings or the environment would be faced with a genuine hazard [3]. Today, the maritime industry is a haven for growth and development in the coastal areas of countries. Iran, with a 2900 km water border, is considered a developing country in maritime industry; while some European countries, with less than one-fifth of

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this water border, are among the most powerful countries in the maritime industry. The maritime industry includes a wide range of subsidiary industries, each of which can be a support and a cradle for the development of science and technology. The three general categories of marine industries are:

(i) Shipbuilding industries: Manufacturing various types of ships such as container ships, giant oil tankers, and submarines.
(ii) Offshore industries: Includes the construction of fixed and mobile offshore platforms and offshore pipelines that are used in large oil and gas projects.
(iii) Coastal and port industries: Including the construction of piers, breakwaters and structures near the shore or oil terminals.

Identification of the broad needs of a country's maritime industries can be a good indicator for the application of nanotechnology products and can also provide growth for those products. In this study, some applications of nanotechnology in the marine industry are discussed.

Nanotechnology is of great importance in the field of marine industry, especially in the construction of ships, and its applications can be generally considered to include the following:

(a) Creating appropriate coatings against the effects of the sea environment.
(b) Production of new materials for the construction of ship bodies and its components in order to increase the strength and reduce the noise and vibration emitted from the ship body.
(c) Production of new materials to increase the performance capability, such as new fuels and batteries with very high energy storage, and fuel cells.

2. DEFINITION OF NANOTECHNOLOGY

Nanotechnology in general refers to the use of very small scale (nanometer scale) materials or additives. Through the use of nanotechnology, it is possible to produce new materials, tools, and systems by modifying the properties of the bulk material. In practice, nanotechnology is used by manipulating atoms or molecules of a material. The behavior of nanomaterials depend on the amount of nanoparticles added to a system, on the properties of the nanoparticles, and on the orientation and arrangement of the nanoparticles [4].

The advent of nanotechnology is an advancement that represents a fundamental change that will lead to the development of materials and tools in the future. The possibility of using nano-building blocks in size and composition is revolutionizing material science. Researchers will be able to create structures of materials that do not exist in nature and conventional chemistry has not been able to create them. Some of the benefits of nanostructures include: lighter, stronger and more tailored materials, reduced cost by reducing defects, the ability to develop new tools, and use of molecular or cluster factories that have the advantage of assembling materials at the nano-scale.

Although experiments and studies of nanotechnology began in earnest in the 1980s, it took some time for nanotechnology applications to become commonplace. In the 21st century, nanotechnology is considered to be one of the most important research thrusts across many technical areas.

The use of this technology in the medical sciences, petrochemicals, materials sciences, defense industries, electronics, quantum computers, etc. has been proven to be fruitful. The potential for nanotechnology to increase technical development in these areas is great and researchers and application-based scientists should become more familiar with these nanotechnology-based advancements. Clearly, as nanotechnology penetrates a broader range of industries (such as marine industries), the impacts of the technology to society in general will continue to grow.

3. IMPORTANCE AND NECESSITY OF NANOTECHNOLOGY

Today, science and technology in many fields are approaching their real technical limits and may no longer be able to meet the growing expectations of society. The use of nanotechnology is expected to overcome some of the limitations. Consider, for instance, the following questions:

Did anyone imagine that one day nanotechnology specialists would be able to build very small machines that could travel inside the body to target and kill bacteria or other pathogens? Similarly, who could imagine small machines that break blood clots and increase life expectancy? Nanotechnology is also being used to deliver therapeutics to targeted locations within the human body [5-9].

In the field of electronics, the construction of quantum computers that are approximately 1000 times faster than today's computers require the use of nanotechnology. In medicine, nano-capsules can identify diseased tissue and deposit therapeutics directly to targeted locations. In transportation, new materials made from nanoparticles have significantly reduced the weight of vehicles, resulting in higher speeds, improved safety, and improved efficiency. Nanoparticles added to steel (or replacing steel) result in light-weight yet very strong material with a strength-to-weight ratio that is far superior to the original metal. Nanomaterials are used in automobile tires; they exhibit a very high resistance to wear and a long serviceable lifetime. In the production of solar cells, nanoparticles are used to facilitate hydrogen as a clean fuel, a new generation of batteries, and development of resistant materials and surfaces. In textiles, nanotechnology leads to resistant clothing with colors that are very stable and long-lived.

Researchers and scientists in many countries are aware of this important issue (the potential role of nanotechnology) and pay special attention to it. These countries have allocated large sums of money to research and develop nanotechnology.

Table 1 provides the U.S. National Nanotechnology Initiative (NNI) investments for 2019 through 2021 for Federal agencies with budgets and investments for nanotechnology. The President’s 2021 Budget requests over $1.7 billion for the NNI with an increased investment in foundational research that will lead to discoveries that will advance a wide range of areas including key industries of the Future. Cumulatively totaling over $31 billion (including the 2021 request), this support reflects the continued importance of research at the nanoscale and translation of this knowledge into technological breakthroughs that benefit society. The information provided in the table is obtained from [10].

Federal organizations in the USA with the largest investments are:

- **National Institutes of Health (NIH)**: nanotechnology-based biomedical research at the intersection of life and physical sciences.
- **National Science Foundation (NSF)**: fundamental research and education across all disciplines of science and engineering.
- **Department of Energy (DOE)**: fundamental and applied research providing a basis for new and improved energy technologies.
- **Department of Defense (DOD)**: science and engineering research advancing defense and dual-use capabilities.
- **National Institute of Standards and Technology (NIST)**: fundamental research and development of measurement and fabrication tools, analytical methodologies, metrology, and standards for nanotechnology.

Other agencies and agency components investing in mission-related nanotechnology research are:

- CPSC Consumer Product Safety Commission;
- DOJ Department of Justice;
- EPA Environmental Protection Agency;
- FDA Food and Drug Administration (DHHS);
- NIOSH National Institute for Occupational Safety and Health (DHHS/CDC);
- NASA National Aeronautics and Space Administration;
- USDA U.S. Department of Agriculture;
- ARS Agricultural Research Service (USDA) BIS Bureau of Industry and Security (DOC);
- FS Forest Service (USDA);

- NIFA National Institute of Food and Agriculture (USDA) NIH National; Institutes of Health (DHHS);
- USBR Department of the Interior (including the Bureau of Reclamation and the Bureau of Safety and Environmental Enforcement).

Table 1. The U.S. National Nanotechnology Initiative (NNI) investments for 2019 through 2021 for Federal agencies Budget (dollars in millions)

Agency	2019 Actual	2020 Estimated*	2021 Proposed
CPSC	0.9	0.2	0.1
DOC/INST	70.2	65.5	58.4
DOD	160.1	184.3	172.0
DOE**	385.0	362.5	352.8
DOI (total)	0.3	1.2	0.0
BSEE	0.0	0.7	0.0
USBR	0.3	0.5	0.0
DOJ/NIJ	0.9	1.6	1.6
DOT/FHWA	1.5	0.5	0.5
EPA	10.6	5.5	2.0
HHS (total)	676.4	710.4	647.1
FDA	15.4	13.6	13.6
NCEH	0.1	0.1	0.1
NIH	649.7	685.8	622.5
NIOSH	11.2	10.9	10.9
NASA	9.0	9.9	10.0
NSF	520.7	475.7	435.5
USDA (total)	22.7	22.4	25.3
ARS	3.0	3.0	3.0
FS	3.7	3.4	3.3
NIFA	16.0	16.0	19.0
TOTAL	1858.3	1839.7	1723.2

* *2020 numbers are based on appropriated levels*
** *Funding levels foe DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, and the Office of Nuclear Energy*

In Japan, the total budget for nanotechnology research was about 82.5 billion yen in 2002 and increased to about 90.4 billion in 2003. This makes Japan's budget fairly close to the national budget for nanotechnology in the US. Of the five Japanese government ministries that play a role in nanotechnology research, Ministry of Education, Culture, Sports, Science and Technology (MEXT) and Ministry of Economy, Trade and Industry (METI) are the dominant ones (Kishi and Bando, 2004). Traditionally, Japan has been very active in the field of nanotechnology. In the 14th century the golden pavilion in Kyoto was built, later, when it was coated with gold leaf, the thickness of the coating was 100 nanometers. Although that coating technique is not used anymore, it exemplifies that the Japanese are historically innovative and precise engineers. Japan has been among the top three countries in patents and publications in the field of nanotechnology, although lately Asian countries such as China and Korea are gaining momentum and surpassing Japan in many fields. The market size of the Japanese nanotech sector has ranged 29.6 billion euros in 2010 and is projected to grow extensively in the future reaching 94.4 billion euros in 2020 and should be worth 188.9 billion euros in 2030 [11].

In 2019, more than 40 percent of the world's publications relating to nanoscience were from China, followed by the United States, India, and Iran, holding 13.5, 8.5, and 6 percent of the publications, respectively. Table 2 shows the number of nanoscience articles in 2019 for 20 top countries. The five top countries are China, USA, India, Iran and South Korea.

A total of 178000 nanoscience articles were published in the journals indexed by the Journal Citation Reports (JCR) in 2019, around 74000 of which were from China; being home to the largest number of people in the world, having a multitude of universities and research centers, and more importantly, paying special attention to nanotechnology, China could achieve and hold the first rank during the past decade. China's nanoscience articles published in 2019 comprise more than 16 percent of its total scientific publications in this year.

Following China, the United States ranked second with around 24,000 nanoscience articles; and India, Iran, and South Korea took the next places, respectively. Apart from the number of nanoscience articles of different countries, the in the portion of nano-articles out of their total publications can be considered as an indication of the priority they give to this field of science. From this viewpoint, Iran, Saudi Arabia, and India, respectively, placed a higher priority on nanoscience in 2019 as compared to the other countries.

Table 2. The number and share of nanoscience articles in 2019

Rank	Country	Nano-articles	Share of nano-articles (%)
1	China	74,387	16.17
2	USA	23,999	5.47
3	India	15,083	16.45
4	Iran	10,494	21.22
5	South Korea	9,431	14.31
6	Germany	8,446	7.12
7	Japan	7,429	8.58
8	UK	5,682	4.66
9	France	5,465	7.17
10	Russia	5,392	10.52
11	Australia	4,632	6.17
12	Spain	4,554	6.45
13	Italy	4,253	5.68
14	Canada	3,756	4.85
15	Saudi Arabia	3,519	16.92
16	Brazil	3,345	5.49
17	Turkey	2,959	7.36
18	Taiwan	2,943	11.06
19	Egypt	2,726	14.9
20	Poland	2,661	8.11

Source: Statnano ISI Indexed Nano-articles Indicator

Table 3 provides a listing of past nanotechnology spending in the USA. The information is somewhat dated and it is challenging to obtain more recent expenditures. However, the information is still informative. Similarly, Table 4 provides prior spending on nanotechnology in different countries and is useful to enable comparisons.

Table 3. The U.S. national nanotechnology initiative budget ($ in million) listed by agencies

Federal Agencies	2003 Actual	2004 Estimated	2005 Proposed
National Science Foundation	221	254	305
Department of Defense	322	315	276
Department of Energy	134	203	211
National Institutes of Health	78	80	89
National Institute of Standards & Technology	64	63	53
National Aeronautics & Space Administration	36	37	35
Environmental Protection Agency	5	5	5
Transportation Security Administration	1	1	1
Department of Agriculture	0	1	5
Department of Justice	1	2	2
Total	862	961	982

Table 4. Global governmental funding in nanotechnology ($ in million/year unless indicated otherwise) in the fiscal year 2003. The order of countries is listed according to the funding size of governmental investment

Japan	$810
USA	$774
European Union	$1.2 billion/4 years
China	$280
Taiwan	$625/5 years
South Korea	$1.2 billion/10 years
Germany	$118
Australia	$93
United Kingdom	$90
France	$50
Canada	$80/5 years
Switzerland	$45/3 years

As already noted, nanotechnology has a wide area of applications. Numerous new applications are being developed across the globe. The diagram below shows commercial applications of inorganic nanoparticles, focus of research and development as well as future directions is comprehensively displayed (Fig. 1).

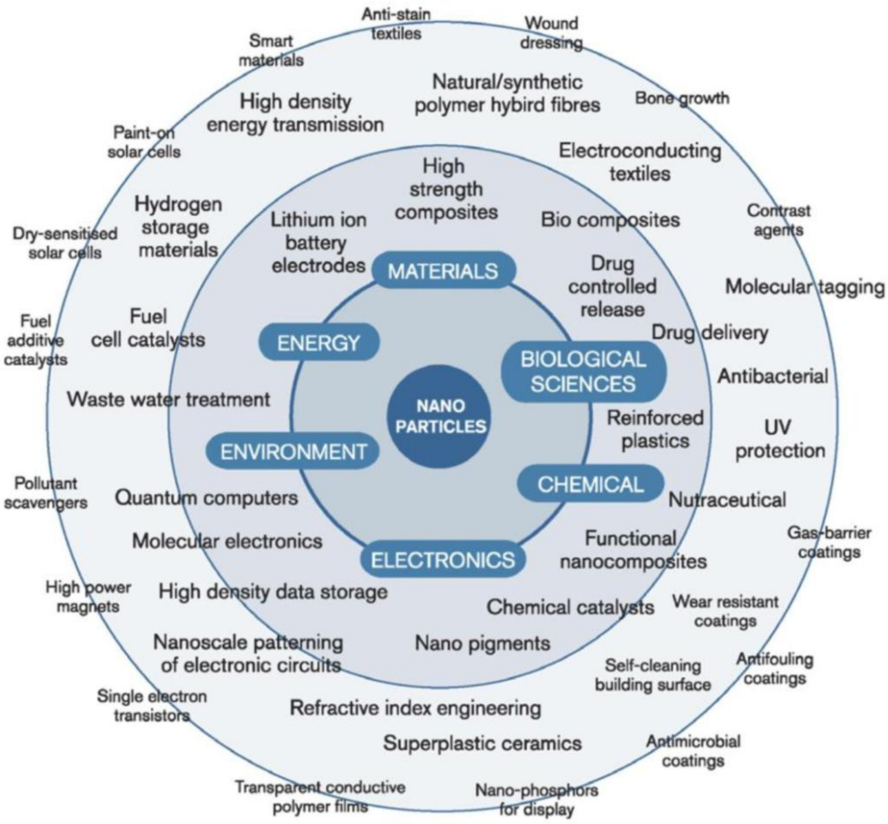

Fig. 1. Nanoparticle applications [11]

4. POTENTIALS OF APPLICATION OF NANOTECHNOLOGY IN MARINE INDUSTRY

Marine industries include a wide range of subsidiary industries, such as surface vessels (ships) and submarines (submarines) construction and operation, offshore platforms, and all sea-related industries. Some of the potentials of applying nanotechnology in the marine industry include the following:

Low temperature welding electrodes, advanced fuels, nanocomposites and nanocomposite coatings, nanofiberglass, vibration absorbers, acoustic absorbers, marine paints, sea and sunlight energy absorbers, nanofiltration, nanomorphology, evolution in fuel cell technology, marine computer applications, electronics, telecommunications, ultra-high energy storage batteries, graphite and ceramics, lubricating nanoparticles and friction reduction.

In the following discussion, more details about the above applications will be given.

4.1 Low Temperature Welding Electrodes

Nanotechnology improved electrodes have a very low operating temperature compared to existing welding electrodes. The material of these electrodes is such that, in exchange for modest heating, they form a strong molecular bond between two pieces of metal that functions like a thermal adhesive. These electrodes, which cause very little distortion, will have a tremendous impact on welding technology, especially aluminum welding.

Sokoluk et al. [12] showed that AA7075 can be safely arc-welded without hot cracks by introducing nanoparticle-enabled phase control during welding [12]. Joints welded with an AA7075 filler rod containing TiC nanoparticles not only exhibit fine globular grains and a modified secondary phase, both of which intrinsically eliminate the materials hot crack susceptibility, but also show exceptional tensile strength in both as-welded and post-weld heat-treated conditions. This rather simple modification to filler material of a fusion weld could be generally applied to a wide range of hot-crack-susceptible materials.

4.2 Fuel

Ships and boats often carry several tons of fuel while at sea, and ocean-going ships are sometimes forced to refuel along their voyage. Nanotechnology provides high-energy fuels such as hydrogen and nano-fuel additives. Nano-fuel additives, in addition to reducing fuel consumption, also reduce pollution. These fuels are high-energy molecular packets that release a lot of energy, so that one liter of this fuel is equivalent to ten cubic meters of comparative common fuels. Since nanometer particles increase the rate of burning and its uniformity, they can be used in new fuels to increase the energy release of the fuel. Nanotechnology is a suitable method for producing very large amounts of hydrogen without the production of carbon dioxide or the requirements to store hydrogen. This issue is one of the most important issues related to the use of hydrogen fuel [13].

Fuel additives are added to fuel to reduce the emission of pollutant exhaust (PM) particles and to alter the production of NOx, CO and HC. The use of some of these additives has reduced the amount of pollutant particles by 15 to 20%. Research has shown that when fuel is used in conjunction with a DPF catalyst, emissions can be reduced by nearly 99%. Some additives reduce multi-core aromatic hydrocarbons by 80%.

Additives can vary from 10 ppm (ten particles per million) to 100 ppm in fuel. Additives cause a significant reduction in smoke combustion temperature. Summarizing the published information in this field shows a reduction in fuel consumption from 5 to 7% due to the presence of fuel additives. Additives that are added to diesel fuel to reduce the outlet ignition temperature in the soot are called FDC catalysts. These additives are used with active and inactive catalysts.

One fuel additive is platinum-based nanopuffs that are always used with another metal. This additive is also produced at the nanoscale. These nanopowders have been able to reduce pollutants by 25 percent, hydrocarbons by 35 percent, carbon monoxide by 25 percent and NOx by 25 percent. These additives have also reduced fuel consumption by about 5 to 7 percent. In heavy diesel vehicles, this additive is currently used in Europe for road, off-road, and fixed applications.

Another application of nanotechnology is metal nanopowders. These metal nanopowders are very chemically active and can also show special catalytic properties. They can be melted and alloyed at lower temperatures which reduces the need for energy and the resulting pollution. Metal nanopowders can also reduce pollution. For example, a type of nanopowder containing aluminum can be added to the solid fuel of a rocket to double its energy and increase its value. This arrangement leads to less fuel consumption and less pollution [14].

Ma et al. [15] reported on a series of experimental investigations into the effect of an F_e-based homogeneous combustion catalyst on the emission characteristics from a four-stroke single cylinder diesel engine [15]. The catalyst contained ferrous picrate as the active ingredient in a composite organic solvent mixture which could be homogeneously dissolved into a commercial diesel fuel at ultra-low dosage ratios.

Table 5. A summary of important studies conducted in the field of nano-additives added to diesel fuel [16]

Nano-additive	Nano-additive concentration in fuel	CO	NOx	UHC	Soot	Power	Specific consumption of brake fuel	Temporal brake efficiency
CNT	0.01% - 30%	-	-	-	-		-	-
Nano metal oxides	-	-	-	-	-	-	-	-
Nano CeO_2 Nano ferrofluid	-	-	-	-	-	-	-	-
Nano CeO_2	-	↓	↓	-	-	-	11%	12%
Nano CeO_2	42 ppm	-	-	-	-	3.5%	-	-
Nano ionic surfactant	5%, 10%, 14 %	-	18%	-	-	-	-	-
Nano ZnO Nano CuO	250 and 500 ppm	-	-	-	-	-	-	-
Nano MnO Nano CuO	250 and 500 ppm	37%	4%	-	-	-	-	-
Nano ferrous picrate+organic composite	-	21.1%	6%	13.1%	39.5%	-	-	-

Table 6. A summary of important studies conducted in the field of nano-additives added to bio-diesel fuel [16]

Nano-additive	Nano-additive concentration in fuel	CO	NOx	UHC	Soot	Power	Specific consumption of brake fuel	Temporal brake efficiency
Nano CeO_2	40-80 ppm	25-40%	30%	25-40%	-	-	-	-
F_eCl_3 Nano fluid	20 μmol/L	52.6%	-	26.6%	6.9%	-	8.6%	6.3%
Nano Al-Mg Nano CO_3O_4	100 μmol/L	41%	30%	70%	-	-	-	-
Nano n-Al	25, 50 ppm	-	-	-	-	-	-	29%
CNT	25, 50 ppm	↓	↓	↓	↓	-	-	-
Nano emulsion	5%, 10%, 15 %	-	↓	-	-	-	-	-
CNT Nanon-Al_2O_3	25, 50 ppm	-	23.4%	-	60%	-	28.9%	-
Nano ZnO	25, 50 ppm	-	-	-	-	-	-	-

It should be noted that while some of these prior studies deal with land-based combustion, the concepts are immediately applicable to marine combustion engines as well. Using fuels like biodiesel with less emissions compared to diesel has contributed to reducing emissions produced by combustion of diesel fuel. Although pollutants such as carbon monoxide (CO), unburned hydrocarbon (UHC) and soot resulting from combustion of biodiesel are significantly less compared to diesel fuel, the low torque and power and high level of nitrogen-oxygen compounds are disadvantages of using biodiesel as an alternative for diesel fuel, even though biofuels may provide other benefits (Hoover and Abraham, 2009). Table 5 provides a summary of some of the most important studies conducted in the field of nano-additives to diesel fuel. Application of nano-additives in such fuels is one way to reduce the emissions and to enhance motor performance. Mirzajanzadeh et al. [16] discussed different types of these nano-catalysts and interested readers are directed there [16]. Information from Mirzajanzadeh et al., [16] is provided in Table 6.

5. NANOCOMPOSITES AND NANOFIBER GLASS COATINGS

Corrosion is a major problem in the marine industry. Corrosion causes extensive economic and environmental damage every year. It is caused by a variety of factors, one of which is the activity of bacteria and other microorganisms. This type of corrosion is called "microbial corrosion".

Sediments in the waters of rivers and seas are suitable environments for the growth and multiplication of microorganisms. These microorganisms can form in marine structures such as the bases of drilling rigs, ship hulls, and on metal or non-metallic parts that are in contact with water. According to recent studies, even polymers such as polyurethanes are not immune to the effects of microbial accumulation. Wood beams as natural composites can also be subject to corrosion.

As mentioned, seawater not only contains chemical compounds such as sodium chloride that causes corrosion, marine microorganisms are themselves an important cause of corrosion as the presence of oxygen, carbon dioxide and hydrogen sulfide in water provides a breeding ground for harmful microorganisms such as sulfate-reducing bacteria (SRB). The important point is that these substances are in fact sub-components of seawater and their concentration varies geographically and temporally. As an example, according to studies conducted by the Iranian Petroleum Industry Research Institute, environmental conditions have caused harmful SRB bacteria to be found in the following areas:

1- Around Qom salt lake
2- The water of the Persian Gulf (at a depth of 35 meters) and the islands of Siri and Khark
3- Caspian Sea water (in Astara and Anzali areas)
4- Water of Arvand, Bahmanshir, Karun and Qarasar rivers
5- Water wells of Kermanshah and Tabriz refineries and laboratory water and school of Abadan refinery

Some common methods of counteracting microbial food use are anti-corrosion resistant coatings, protective coatings on metal surfaces, and stainless steel.

Factors such as oxygen concentration, temperature, and pH, have a large effect on the rate at which microbial corrosion occurs. For example, if the pH of the environment can be increased by up to 10, the reduction in microbial erosion will be significant. The use of new technologies, including nanotechnology is also an approach that has recently received attention. With nanotechnology, it is possible to achieve coatings that protect the surface of metals much better than before. In this regard, we can refer to nanocomposites and nanocomposite coatings and fiberglass.

A composite is a combination of several distinct materials so that its components can be easily distinguished from each other. The nanocomposite is the same as the composite at the nanometer scale (10^{-9}). Nanocomposites are formed in two phases. In the first phase, a nano-sized crystal structure is constructed that serves as a composite matrix. This background may be made of polymer, metal, or ceramic. In the second phase, nanoscale particles are added to the matrix as reinforcements for strength, resistance, electrical conductivity, etc. Depending on the material of the nanocomposite substrate, it is divided into polymeric, metallic and ceramic groups. Polymer composites have been used in aircrafts for many years due to their strength, rigidity, and thermal and dimensional stability.

Nanocomposites include polymers reinforced with nanometer-sized particles. Composites with different molecular arrangements can be applied to a broader class of engineering problems. One of the important properties of composites is their high strength and low weight, high corrosion resistance, and radar absorption property. This feature is used to build aircraft and submarines that are difficult to detect by radar.

Nanocomposite coatings are nanostructured coatings that have better properties than conventional coatings. Excellent adhesion and very special surface properties can be obtained through these coatings. Nanocoatings are impregnated onto surfaces such as metals, glass, ceramics, and plastics with thicknesses of several microns. They are resistant to mechanical corrosion (wear and tear), chemically resistant (rust), thermally resistant, luster and self-cleaning. All of these factors lead to a reduction in the consumption of raw materials needed for replacement, a reduction in the energy consumption required to produce more raw materials, and a reduction in the need to be cleaned.

One example of a practical application of nanotechnology is the application of nanocomposite coatings on drilling rigs. Recently, Vega Tooling Company has introduced a new type of nanocomposite coating called TH coating. This coating can be used in drilling tools to increase the life of a product and improve its quality. The efficiency of drilling tools using these coatings is twice that of ordinary drills. Lower heat generation when using drills that have been upgraded with a new coating makes it possible to use these drills in dry drilling.

Fiberglass has a high strength with a matte texture. In these materials, glass fibers are produced in the form of thin fibers and under certain conditions, they are woven together in different ways. The most common types are woven fibers in the form of mats and needle fibers. Nanotechnology creates very strong, lightweight nanofibers by applying a fine-grained texture between molecules that are far superior to today's fiberglass.

6. VIBRATION ABSORBERS

Today's vibration absorbers are bulky and heavy materials. Nanotechnology will bring about a profound transformation in this field by presenting new vibration-absorbing surfaces. These nanomaterials store a very large amount of vibrational energy within their molecular lattice and reduce their specific molecular structures to a high degree of translocation. In this way the vibration is well controlled. These materials are widely used in cruise ships, military vessels and submarines and are often installed under engines and rotating components of vessels.

7. SOUND ABSORBERS

These absorbers, like vibration absorbers, absorb sound energy, despite their lightness and thinness. Today's acoustic materials have different efficiencies in terms of frequency and direction of impact sound, and they are typically heavy and bulky. Nanotechnology offers a variety of acoustic materials whose molecular structure is compatible with sound and sound frequency. They can absorb much more sound energy than previously available materials. These materials have many applications in cruise ships, military vessels and submarines, and the inner or outer part of the hull can be covered with these materials.

8. MARINE COLORS

Because ships travel through water, algae and suspended particles in the water attach to their bodies and cause them to move more slowly. Extreme corrosion of the marine environment, especially in brackish seas, and the attachment of moss and algae to hulls are major problems in the maintenance of offshore platforms and ships. The special conditions of the marine environment require that, on average, the hulls of platforms and ships be painted once every three years. One of the common methods of cleaning the hull is to take the ship to a dry sanding pool, which has high costs, extensive downtime, and other added costs. Solving this issue leads to increased carrying capacity and lifespan of the structure. Maintenance will also be improved. Nano-technology enables new colors that are highly resistant to corrosion and other deleterious environmental impacts. Furthermore, the use of nanotechnology in the paint industry prevents algae from adhering to the hull and prolongs the life of ships (Fig. 2).

An anti-fouling material invented by an Iranian company prevents undesirable accumulation of moss on the wetted surface of vessels' hulls. The coating is also environment-friendly, does not release any chemicals into the sea, and reduces the use of biocides. In addition to ship hulls, the nano-coating could be applied to coastal structures and piers, as well as military submarines. An Iranian knowledge-based company tested a new coating for five years before starting its mass-production. The anti-fouling layer lasts for at least five years and functions like shark and dolphin skin. As mentioned earlier, the problem of adhesion of moss to the vessel's hull increases frictional resistance and fuel consumption and decreases the vessel's speed.

Fig. 2. Developing a special coating with nanotechnology that prevents the growth of marine organisms, such as moss, on the outer layer of the hull of ships by an Iranian knowledge-based company [17]

9. SEA WAVE AND SUNLIGHT ENERGY ABSORBERS

Nanotechnology introduces a new generation of materials that, like photovoltaic cells, absorb sea waves and sunlight and act as a source of energy. The unique feature of these materials is that, like ordinary marine coatings, they can be attached to a body that can prevent ship body from negative effects of being in the sea water for a long time. There are also environmental benefits to using these energy sources (Fig. 3).

Fig. 3. Corrosion of a ship body [18]

Nanotechnology will play a crucial role in the future management of vessel corrosion and biofouling, according to a major maritime study. Leading European scientists are releasing details of a study on the potential of 'Nanotechnology Marine Applications' as part of the two-year KET maritime project.

10. NANOFILTRATION

One of the features of this technology is the adsorption of very small particles in the environment, which are used in the adsorption of carbon monoxide and carbon dioxide. For example, the inner surface of submarines is closed to ambient water and is suitable for using this technology. Semiconductor titanium oxide crystals, which are only 40 nanometers in size, are charged by ultraviolet light and used to remove organic contaminants. The nanofiltration method has flourished over the past few years, the separation is based on the size of the molecules.

This method involves the removal of organic components such as micron contaminants and multi-capacity ions and desalination of water. Other applications of nanofiltration include the removal of chemicals added to water to kill harmful organisms, the removal of heavy metals, the purification of wastewater, the decolorization and removal of contaminants, and the removal of nitrates. Nanofiltration can clean almost any water source and remove bacteria in the water. In addition, it allows easy use of purification methods and performs purification without chemical action. These nanofilters can be used in vessels to produce fresh water from saline seawater. The nanofilters are made of pressurized filters and function superior to ultra-filters. With apertures of 1 to 10 nm with pressure between 5 and 15 bar, these filters are capable of purification of sea saltwater with 90% less energy consumption than the reverse osmosis method. In addition, it is able to effectively eliminate bacteria, viruses, pesticides, organic pollutants and calcium and magnesium salts.

Hu et al. [19] studied a method to develop a modified activated carbon filter to remove CO_2 in indoor air [19]. Various design parameters such as removal efficiency, adsorption, breakthrough and pressure drop were investigated (Fig. 4). A method of determining these optimum operating conditions of sorption-type air filters was verified experimentally. The removal efficiency data can be used to predict removal efficiency of indoor cleaning systems. In experiments with a single contaminant (CO_2), the breakthrough time decreases with increasing inlet concentration of CO_2 and face velocity. While dense magnesium oxide impregnation of activated carbon is detrimental to adsorption, 2.5 g magnesium oxide-IAC can increase the adsorption time of CO_2 over virgin AC. Pressure drop related in the air stream can be predicted by a simple model.

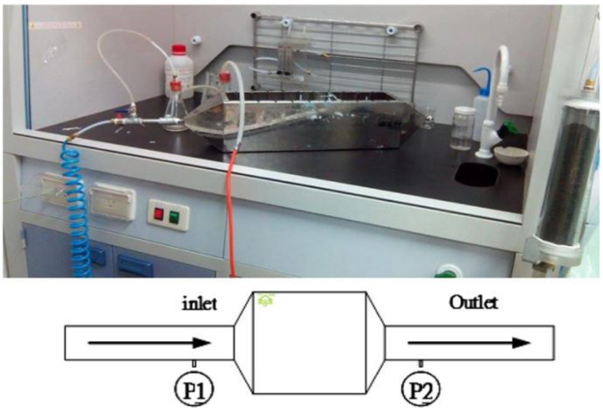

Fig. 4. Schematic diagram of combination of filtration- and sorption-type air filter system [19]

11. NANOMORPHOLOGY

Using nanotechnology, highly refractory materials can be made that are similar to soil in non-flammability. The use of these substances in boats is very important for fire safety. The risk of fire is very high in military areas, for example. Therefore, the use of this technology is vital.

12. DEVELOPMENTS IN FUEL CELL TECHNOLOGY

Fuel cells have a wide range of applications in vessels, especially submarines. Fuel cells are relatively quiet and they are suitable for generating local electricity. Their high efficiency, minimum emissions of environmental pollutants, the possibility of using clean fuel alternatives, their modularity, and the ability to produce both heat and electricity and the use in decentralized energy production are among the advantages of fuel cells. Today, various methods are used to store the hydrogen needed in the fuel cell. Hydrogen in the form of a liquid that requires very high pressure at very low temperatures, metal hydrates (which are very heavy) and activated carbon (which is very difficult to use and inefficient) are all storage approaches. Nanotechnology is a way to build a fuel cell with the ability to store hydrogen using nanomaterials. These nanomaterials include fullerenes, carbon nanotubes, carbon nanofibers, and encapsulated metal fullerenes.

Non-combustible fuel cells generate a combination of oxygen and hydrogen to create water and electricity. This process is the reverse of the electrolysis process. These batteries can be used in electronic devices, but they are subject to problems such as high cost and low stability and durability. Each fuel cell consists of two electrodes (an anode and a cathode) and a membrane. The membrane is sandwiched between the anode and the cathode. Hydrogen fuel is stored there and catalysts, such as platinum or its alloys, cause the oxidation reaction of hydrogen gas. From the oxidation of hydrogen gas, + H and electrons are formed. The + H ions pass through the membrane and reach the cathode, whereas the electrons enter the output circuit.

When oxygen enters the cathode in the form of air and, as an oxidizer, takes the electrons from the consuming device, it converts the + H ion passing through the membrane to water. Eventually, water will be the output of this system. These fuel cells, called PEM proton exchange membranes, are a leading source of clean energy.

Carbon nanomaterials have been used to store hydrogen; these materials have a high storage capacity. The use of carbon nanomaterials alone is not very efficient. After several times charging the batteries, their capacity decreases drastically. The use of platinum metal alone is also not suitable due to its high cost. For this reason, carbon nanomaterials have been used in conjunction with small amounts of platinum metal, which increases the cell's resistance to highly acidic environments. The use of activated carbon with platinum-group metals and its fusion with fullerenes has had similar results. Among the fullerenes, C60, C120, and C70 were used to make C60 more suitable. Carbon nanotubes can now be used to store hydrogen. They no longer need low temperatures, very high pressure, or heavy weight bearing. This innovation will revolutionize fuel cell technology.

13. DEVELOPMENTS IN COMPUTER TECHNOLOGY, ELECTRONICS AND TELECOMMUNICATIONS

Computer and communication innovations have had their effects felt throughout modern society, in particular in marine applications. Today's electronics industry is based on silicon. The age of this industry is ~ 50 years and now it has reached a stage that is technologically, industrially and commercially very advanced. In contrast to this technology, molecular electronics is in its infancy and this technology should be considered the future of the silicon electronics industry. Molecular electronics is a science based on nanotechnology and has a wide range of applications in the electronics industry. Due to the wide range of applications of electronics in commercial products, the market can be profitable with further investment and advancement in nanoelectronics technology in the not-too-distant future. Nanotechnology appears in the miniaturization of electronics, increased information processing speed, reduced sizes of consumer devices, expansion of sensors that collect signals, logic devices for processing, memory devices for storage, and display and transmission apparatus for communications. The production of faster and better computers with much smaller sizes, as well as nano-sized memory chips, are extremely powerful.

Other potential enhancements include:

- Nanostructured microprocessor devices that reduce energy use and lower unit costs.
- Continuing improvements to computer performance.
- Communication systems with higher transmission frequencies and more efficient use of the light spectrum leading to a tenfold increase in bandwidth.

- Dramatic improvements to small memory storage devices that have capacities in the multi-terabyte level.
- Integrated nanosensor systems capable of collecting, processing, and communicating large amounts of information with minimal size and energy use.

Nano-sensors are very small tools that are able to detect and respond to physical stimuli at the nanoscale; the signals can be biological, chemical, or motion-based. These sensors can be of the porous silicon type and can be used to detect chemical and biological reactions using spectroscopic or optical methods. They can also be nanoprobes and can be used as optical-biological, optical-chemical receptors or space-imaging sensors. They can also be electrical-mechanical sensors and can be used to measure the mass changes of absorbing materials on structures. The developments in computer, electronics, and telecommunications technologies based on nanotechnology will affect the marine industry. The marine industry, like other industries, is highly dependent on these technologies.

The ultimate goal would be the ability to create and manipulate materials at the most basic level, fabricating devices atom by atom with precise control. Scientists at MIT, the University of Vienna, and several other institutions have taken a step in that direction, developing a method that can reposition atoms with a highly focused electron beam and control their exact location and bonding orientation. The finding could ultimately lead to new ways of making quantum computing devices or sensors, and usher in a new age of “atomic engineering,” (Fig. 5).

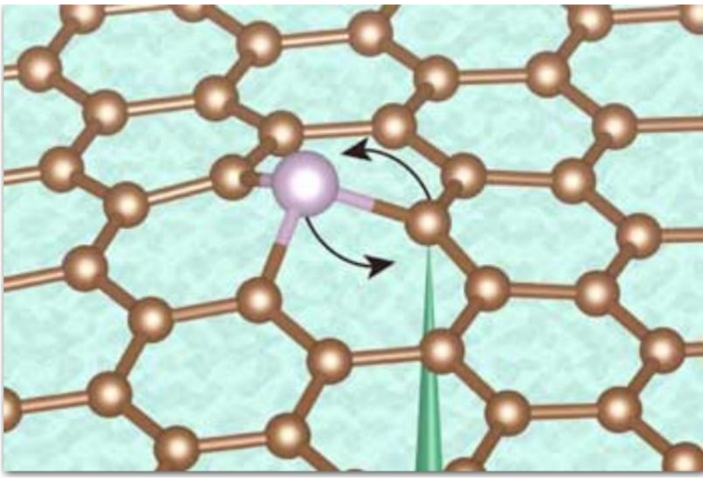

Fig. 5. Illustration of the controlled switching of positions of a phosphorus atom within a layer of graphite by using an electron beam [20]

14. BATTERIES WITH VERY HIGH ENERGY STORAGE

There are many types of rechargeable batteries available today that are heavy yet have low energy storage. These batteries have vital applications in vessels, especially for recreational boats and for submarines and ships (as an emergency source of electricity). But the small amount of energy they store limits their use. For instance, stored battery power limits the time that electric diesel submarines can stay underwater. The electrical energy generated by the diesel is stored in the batteries, and when the submarine is submerged, the energy from the batteries is drawn. Nanotechnology enables diesel-electric submarines to stay submerged tens of times their current duration by providing batteries with very high energy reserves. In addition, nanotechnology reduces the weight of battery packs. Less weight options create valuable applications in aerospace technology, drones, automobiles, and small recreational amenities, where weight is a limiting factor.

The main drivers for research in battery technology is the goal of finding materials suitable for use as electrodes with as large a surface area as possible. This allows charge to flow more freely, resulting in higher capacity and shorter charge/discharge cycles. Safety also an important concern. Liquid electrolytes, which are prevalent in Li-ion batteries, can rupture the cell and even combust when overheated. Currently, safety measures are required to prevent this from happening but they take up space inside the battery, increasing battery size, and adding cost and complexity to the manufacturing process.

These issues are being solved by nanotechnology research. Nanostructured materials can offer a huge increase in surface area for electrolyte materials, and nanoparticles could enhance the conductivity of ceramics or gels sufficiently to allow them to replace liquid electrolytes, reducing or eliminating the chance of a short circuit.

15. NANOMATERIALS FOR BATTERIES

15.1 Electrodes

Several types of nanomaterials have been explored which allow for higher storage densities of lithium than standard metal or graphite electrodes, they include:

- Carbon-coated silicon nanowires
- Carbon nanotubes
- Layered, nanostructured vanadium oxide and manganese oxide
- LiMn2O4 or LiCo2O4 nanoparticles
- Li alloy/Graphene foil
- Phosphorene-graphene hybrid material

15.2 Electrolytes

Al_2O_3, SiO_2, or ZrO_2 nanoparticles added to solid polymer gel could significantly enhance the conductivity and storage capacity of the electrolyte. Solid ceramics have also been explored, as their high-temperature resistance would suit demanding, high-stress applications like large vehicles or renewable power stations. 2D MOS_2 is used as an efficient protective layer for Li metal anodes in high-performance Li–S batteries (Figs. 6 and 7).

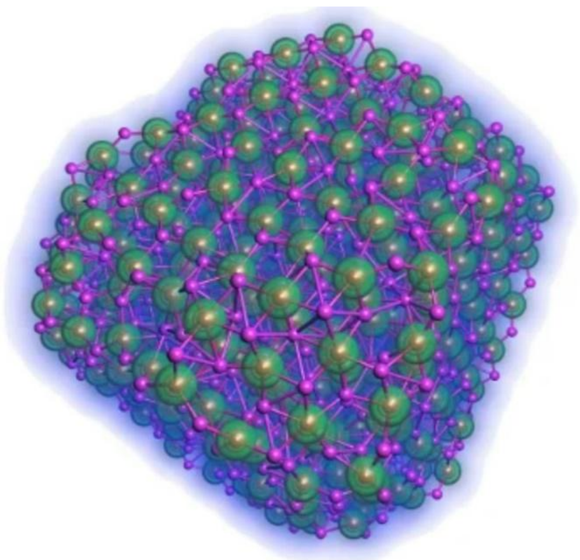

Fig. 6. Nanoparticle matrices in battery electrodes can drastically increase their ability to store lithium ions, increasing the storage density of the battery [21]

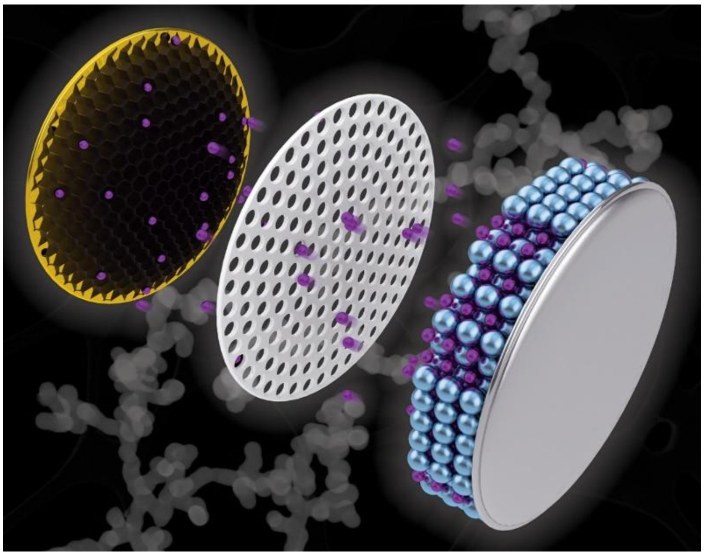

Fig. 7. Using nanochains to improve the performance of lithium batteries at Purdue University [22]

Today's lithium batteries generally use a liquid electrolyte to hold ions between the two electrodes, however scientists eyeing stable options see some thrilling alternatives in the future. Among them are cellulose derived from wood, which is paper-thin and can bend and flexed to reduce stresses during the battery cycling.

One shortcoming of the electrolytes utilized in lithium batteries is that they include risky liquids that carry a threat of fire if the system short circuits, and they might promote the formation of tentacle-like growths known as dendrites that compromise efficiency. Solid electrolytes can be made from non-flammable supplies, make them much less susceptible to dendrite formation.

One new application prospect pertains to the anode, which is currently made using graphite and copper. Some scientists see stable electrolytes as a key stepping-stone to creating batteries that work with an anode made from pure lithium steel. This advancement might break the energy-density bottleneck and allow electrical automobiles and planes to journey a much farther without charging. And of course, corresponding benefits would be realized in marine industries.

Many of the stable electrolytes developed up to now have been made from ceramics that are extremely efficient at conducting ions. However, ceramics are brittle in nature, which limits their effectiveness. Scientists from Brown University and the University of Maryland sought a substitute for ceramics and used cellulose nanofibrils present in wood as their replacement.

These wood-derived polymer tubes are mixed with copper to create a stable ion conductor with a conductivity similar to that of ceramics and between 10 and 100 times higher than polymer ion conductors. According to the group, the behavior results from the addition of copper into the space between the cellulose polymer chains for "ion superhighways". These superhighways allow the lithium ions to journey with excellent effectiveness and speed (Fig. 8).

By incorporating copper with one-dimensional cellulose nanofibrils, Yang et al. (2021) demonstrated that normally ion-insulating cellulose offers a speedier lithium-ion transport within the polymer chains [23]. In fact, they found this ion conductor achieved a record high ionic conductivity among all solid polymer electrolytes. As a result, the fabric is paper-thin and versatile, the scientists imagine that it is more tolerant of the stresses incurred during motion. They additionally say it has the electrochemical stability to accommodate a lithium-metal anode and excessive voltage cathodes. They also propose that it might act as a binder material that encases ultra-thick cathodes in high-density batteries.

Fig. 8. Copper-coordinated cellulose ion conductors for solid-state batteries

16. GRAPHITE AND CERAMICS

Nanotechnology will have a significant impact on the construction of marine structures and marine industries by providing highly robust materials that are tens of times more resistant than steel. Ceramics are among the materials that will be used by deep-water divers (about 11 thousand meters). These materials, with their extraordinary strength, light weight, very high corrosion resistance and durability in highly variable temperature conditions, are a suitable option for large marine structures, especially submarines.

Fibers are materials that have a very long axis compared to other materials and their strength in terms of length is much higher than in other directions. Demand for high-strength, high-modulus reinforcing fibers has led to the development of carbon or graphite fibers. Graphite fibers are carbon fibers that have been subjected to heat treatment above 1650 degrees Fahrenheit. Relatively good conductivity, electricity, lightness, strength, creep resistance and excellent damping are some of its advantages. One of its disadvantages is that it is fragile, has low impact resistance, and is expensive.

Marine organisms are formed with materials that have a vast range of properties and characteristics that may justify their potential application within the biomedical field. Moreover, ensuring the sustainable exploitation of natural marine resources, the development of marine residues constitute an interesting platform for the development of novel biomaterials. An increasing number of different types of compounds are being isolated from aquatic organisms and transformed into profitable products for health applications, including controlled drug delivery and tissue engineering devices.

Silva et al. [24] reviewed the scientific literature that is being developed for the isolation and characterization of some polysaccharides, proteins, glycosaminoglycans and ceramics from marine raw materials [24]. Emphasis was given to agar, alginates, carrageenans, chitin and chitosan, polysaccharides, collagen, glycosaminoglycans such as chondroitin sulphate, heparin and hyaluronic acid, calcium phosphorous compounds and biosilica.

The marine biosystem has proven to be a huge source of useful materials, even though the knowledge of marine materials and their properties is still in its infancy. Nevertheless, with recent technological developments, the appearance of new remotely operated (underwater) vehicles that allow collection of materials in deep waters, an enormous new door is being opened. In fact, marine biomaterials are of particular interest as they might have novel characteristics as well as unique biochemical properties. Moreover, the diversity of these materials and their potential, in particular polysaccharides, can be increased by physical or chemical modification; for instance, complexation with other polymeric materials, chemicals or salts, or modifications introduced in the polysaccharidic chain. The possibility of developing a wide variety of chemically modified derivatives makes these polysaccharides versatile materials that can be applied in different fields of technological interest, including biomedical. This is a continuing challenge to polymer and biomaterial scientists, but it is already possible to anticipate that these strategic approaches will open up perspectives and potential applications in the future. On the other hand, this will impact low-environmental-impact products that have a smaller carbon footprint at the end of their product cycle. The enhancement of the performance of marine-derived polysaccharides will increase their competitiveness against synthetic biodegradable polymers and polymers from petroleum sources.

In an era of increasing oil prices, global warming and other environmental problems (e.g. waste), the change from fossil feedstock to renewable resources can considerably contribute to a sustainable development in the future. It is envisaged that the biomedical field will be an area in which marine-derived materials will have major relevance, particularly with their use for tissue repair and regeneration. This multidisciplinary approach that aims to go from engineered scaffolds to clinical applications will allow regeneration of damaged or injured tissues or organs [24].

Kovarik et al. [25] is a thorough investigation of geopolymer-based ceramic foam with interconnected open-pore architecture [25]. That work aimed to study critical parameters for the fabrication of cellular ceramic via a replica technique and to define their influence on thermal stability, mechanical strength, and total porosity. Porous leucite ceramic samples were fabricated using a powder mixture of fine MK, BFS and potassium silica solution. The incorporation of chamotte filler into the potassium geopolymer slurry led to a viscosity increase, matrix reinforcement and mechanical integrity improvement. It was shown that the presence of calcium cations in geopolymer slurry through the BFS powder induced beneficial acceleration of polycondensation kinetics during the impregnation step. Furthermore, the rheological characterization of non-reinforced geopolymer slurry demonstrated that the temperature increment leads to an increase in the rate of hardening (Fig. 9).

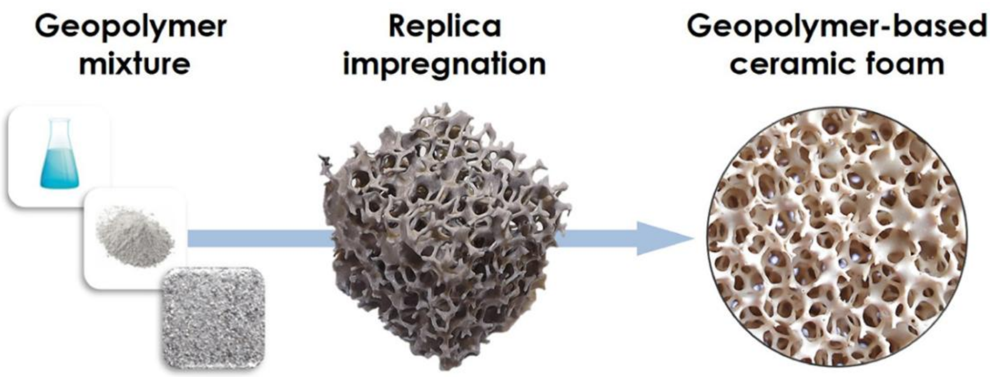

Fig. 9. Geopolymer-based ceramic foam [25]

17. LUBRICATING NANOPARTICLES AND REDUCING FRICTION

Nanotechnology-based solid lubricants, used directly or in addition to liquid lubricants, are commonly used in many industries including marine-based applications. They are non-toxic, unlike today's synthetic oils. Lubricants reduce friction and wear between contacting surfaces; most lubricants are liquid, oil, or grease. In applications such as clean-room applications, as well as in small components and devices that need to be easily repaired, solid lubricants are used instead of liquid lubricants. They are also used in high vacuums, for long-term storage periods, and in situations where a large load is required.

Solid lubricants work well at high temperatures and pressures and in radioactive situations. The lubricants can be dried as powder, coated, or added to liquid lubricants. The ultimate goal for using them is for improved lubricant performance. Solid lubricants are generally layered materials such as graphite, molybdenum disulfide, and tungsten disulfide that allow the molecular layers to rub against each other. However, these molecular layers can damage the surfaces because the chemical reaction of the layers with the surfaces causes the metal surfaces to decompose, break and bend. They accumulate on surfaces, disrupt machining and further corrode metal parts. As a consequence, there is a need for smaller, more stable solid lubricants. In drilling and marine industries, grease and oil that can be easily maintained and can reduce friction and wear are needed.

Berman et al. [26] provided an up-to-date survey of recent tribological studies based on graphene from the nano-scale to macro-scale [26]. It was shown that they are used as self-lubricating solids or as additives to lubricating oils (Fig. 10).

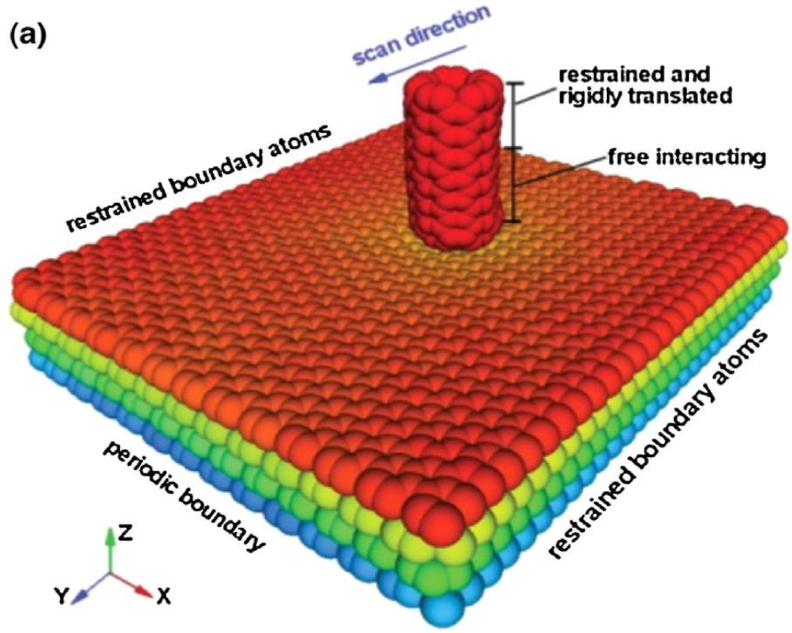

Fig. 10. Four-layer suspended graphene assembly. The color of each atom is determined by its Z-position [26]

Previous studies have confirmed the following key findings [26]:

- Theoretical simulations predicted that the low friction of graphene is highly dependent on the sliding interfaces (whether the tip is sliding on the graphene surface or two graphene surfaces are sliding against each other) and on the number of graphene layers.
- Atomic force microscopy (AFM) studies confirmed the theoretical prediction of decreasing friction when the number of layers is increased. Moreover, it was shown that friction can reach the ultra-low friction regime at specific loads when the sliding occurs without stick-slip.
- Micro-scale tribological studies show defects in graphene increase friction. Also, chemical modifications of graphene by hydrogenation, fluorination, or oxidation result in a 2, 6, and 7 fold increase in friction, respectively.
- Macro-scale tribological studies have clearly demonstrated that graphene is different from graphite in reducing friction and wear irrespective of atmospheric conditions (humid or dry). It also acts as a passivation layer inhibiting corrosion induced wear (tribo-corrosion) in the case of steel contacts.
- Macro-scale studies demonstrate that graphene layers largely suppress the friction and wear of sliding steel interfaces. The friction coefficient of steel drops from 0.9-1 for bare steel down to 0.15–0.16 for graphene coated steel in dry nitrogen and humid air environments. The wear volumes and rates are reduced by 3–4 orders of magnitude when graphene is present at the sliding interfaces.
- Overall, graphene was shown to be very effective for friction and wear reduction not only as a lubricant but also as an additive to oils, composite materials, and solvents.

Graphene is an allotrope of carbon consisting of a single layer of atoms arranged in a two-dimensional honeycomb lattice nanostructure. The name is derived from "graphite" and the suffix -ene, reflecting the fact that the graphite allotrope of carbon contains numerous double bonds (Fig. 11). Each atom in a graphene sheet is connected to its three nearest neighbors by a σ-bond, and contributes one electron to a conduction band that extends over the whole sheet. This is the same type of bonding seen in carbon nanotubes and polycyclic aromatic hydrocarbons, and (partially) in fullerenes and glassy carbon.

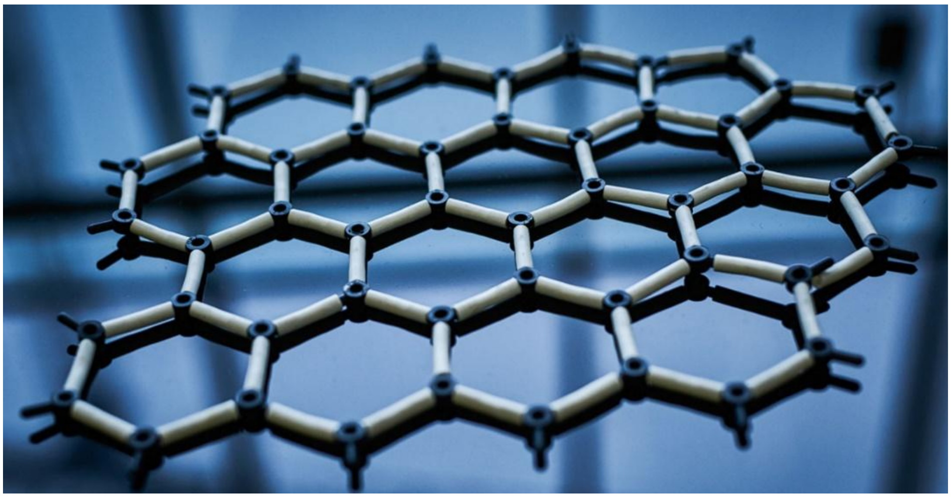

Fig. 11. Structure of grapheme: a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice nanostructure

Dry lubricants, which are produced using nanotechnology, have spherical mineral structures and their diameter is in the range of 20-50 nm. Their geometric structure is in the form of fullerene minerals which are known as IF nanoparticles. Compared to conventional wide-lubricating solid lubricating plates, these fullerene-shaped structures are considerably smaller (about 20 times or more). They act like miniature balls that rotate around surfaces, making contact pieces easy to move.

Solid lubricants based on nanotechnology are layered mineral compounds. Examples include tungsten disulfide, which can take the form of fullerene. Under certain conditions, the layers of these materials can bend on themselves and form nanoparticles.

Solid lubricants are promising for industrial production and process facilitation of industrial units. First, they reduce component friction and wear seven times better than commercial lubricants. In particular, when the loading increases, the lubrication effectiveness increases. Meanwhile, they decrease the need for lubrication, they reduce operating costs, maintain cheaper and more accurate dimensions, and are less injurious to the environment. Reducing friction will also reduce noise, vibration, and heat. Companies tend to use permanent lubricants to reduce costs. IF lubricants have been shown to reduce friction by a large amount compared to conventional lubricants and have a longer lifespan. Therefore, they are more suitable for permanent applications. The use of IF lubricants can also reduce the amount of lubrication. Adding solid lubricants to combustion engines reduces the amount of lubricant required without compromising performance.

Another advantage is that fullerene-shaped minerals are better able to withstand large forces. The special properties of these materials give them high resistance. It has been reported that tungsten disulfide nanoparticles are significantly more resistant to shock pressure than standard lubricants.

The effect of tungsten fullerene nanosphere disulfide on fatigue resistance of pressure vessels is being investigated. Some research has shown that adding a small amount of these materials can significantly reduce friction and wear and increase the life of moving parts. Use of nanotech lubricants also reduces the need for ensuring smooth surfaces and associated machining costs.

Further advances in powder metallurgy will improve the types lubricant that are available. Impregnation of cavities and joints of powdered metals with IF particles improve their abrasive properties compared to oil, tungsten sulfide, or molybdenum disulfide.

Due to the widespread industrial need for lubrication process, nanotechnology-based solid lubricants would be an ideal option. Of course, the applications encompass much more than just marine industries, but clearly marine applications will benefit significantly.

18. CONCLUSIONS

The applications of nanotechnology that have been mentioned are only a small portion of the widespread applications in marine and other industries. The future will make these applications more definite and specific. The introduction of nanotechnology into any industry has the potential to cause dramatic changes and improvements to efficiency.

Appropriate use of nanotechnology requires the recognition of the needs of every sector of industry. It is necessary for nanotechnology authorities to examine the needs of each application separately and to develop nanotechnology by identifying specific market needs. In addition, they do not provide adequate financial support for the development of nanotechnology. Because not knowing the needs means that nanotechnology is going astray in countries.

In Iran, the maritime industry is considered to be limited, i.e., the construction of fixed and mobile marine platforms, ocean-going ships, submerged vessels, submarines, etc. Nanotechnology is not very old in the world and is one of the few technologies that were introduced in Iran at the very beginning of its introduction in the world. Nanotechnology has received considerable attention due to its tremendous impact on all industries. Marine industries are in the process of reaching their evolution in Iran, and nanotechnology can also contribute to its purposeful and increasing development.

Much of the research into nano-enhanced batteries in the coming years will focus on reducing the cost of these nanomaterials and making them viable for large-scale commercial applications. The use of nanotechnology to enhance performance by increasing energy storage density has also allowed much smaller batteries to be made for applications which are less demanding but benefit from small, light and flexible rechargeable batteries. Some thin-film batteries are already available, but these have limited performance and are still relatively expensive. The advent of nano-based research and technology has improved the energy and power-density, cyclability and safety of modern batteries.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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He is an Applied Chemistry Student, Faculty of Chemistry, University of Tabriz, Tabriz, Iran. His interest topics are environmental pollutants, lithium batteries, water decontamination and nanotechnology. He works on catalytic converters and resonators in automobiles. He is working on a catalytic converter is an exhaust emission control device that converts toxic gases and pollutants in exhaust gas from an internal combustion engine into less-toxic pollutants by catalyzing a redox reaction. One of his studies on Recovery and then individual separation of platinum, palladium, and rhodium from sent car catalytic converters.

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He is a thermal sciences researcher at the University of St. Thomas, USA. His research on many aspects of heat transfer and fluid flow. The primary applications of his research are biomedical devices, burn injuries, climate change, and water resource management. He has produced approximately 400 publications, conference presentations, patents, books, and book chapters. He also has six papers that have been ranked by altmetric in the top 1% of all similar papers in terms of media interest level.

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He was born in Tehran, Iran, in 1970. He is a Professor in Department of Water Engineering, University of Tabriz, Iran. He received the B.Sc. degree in Irrigation and drainage engineering from the University of Tabriz, Iran, in 1992. He received a M.Sc. degree in Hydraulic structures engineering specializing in mathematical modeling of ground water from Shahid Chamran University (SCU), Ahvaz, Iran, 1996 and a Ph.D. degrees in Hydraulic structures engineering specializing in physical modeling of stepped spillways from Shahid Chamran University (SCU), Ahvaz, Iran, 2005. His doctoral thesis was on "Hydraulic investigation and physical modeling on stepped spillways". His main scientific interests are: physical modeling of weirs in irrigation canals, dam spillways, seepage analysis under diversion dams and through earth dams, pump stations, design of earth and gravity dams and finite element analysis with commercial software including Geo-studio (Seep/w) and ANSYS-Fluent. He has authored and co-authored about 150 national and international journal articles and participated in 20 national and international conferences. He regularly serves as a reviewer for 10 high impact-factor journals in engineering and material science, among them: Soil and Water (University of Tabriz), Civil Engineering (University of Tabriz), Journal of Irrigation and Drainage Engineering (ASCE), Journal of Hydraulic Engineering (ASCE), Flow Measurement and Instrumentation, ISH Journal of Hydraulic Engineering and Journal of Hydrology. He has performed five scientific projects supported from "University of Tabriz, Iran".