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Application of Nano-materials for Corrosion Control

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Authors' contributions

This work was carried out in collaboration between the two authors. Author RM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author AME managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This review describes some nano-technological applications concerning the corrosion incidence and protection of steel pipelines mainly used in the petroleum sector. These techniques play a major role in producing anti-corrosion coatings which enhances metal durability with high abrasion and corrosion resistances towards adverse environmental conditions. In addition the review also describes the advantages for employing nano-materials in protecting metal and other material surfaces.

Keywords: Nanotechnology; corrosion protection; coating; anti-corrosion; steel pipes.

1. INTRODUCTION

Nano-compounds possess many advantages over their micrometer scale counterparts. The main aspect of many applications of nano-materials in industry is to highlight the desired advantages in the product and to avoid the negatives. Efforts are undertaken to promote

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their effective utilization in the sector of corrosion control and protection [1]. The enhancement of materials performances in different industrial areas can be done through employing these nano-materials especially in an advanced coating [2]. More advanced studies should be performed to confirm the use of nano-materials in the area of corrosion control and prevention and also to authenticate the corrosion/oxidation performance of the nano-structured compounds. Nowadays, the application of nano-compounds in corrosion control, protection and prevention is of increasing interest to avoid the deleterious problems in many industries [3]. The large economic impact of corrosion of metallic structures is very important for all industrial societies. The cost of corrosion degradation estimates to about 270 billion dollars/year in the United States of America and 200 billion Euros/year in Europe. Both direct and indirect costs represent the annual cost of corrosion. Direct costs to provide corrosion protection are related to construction, manufacturing and design, and the indirect costs are dealing with maintenance, corrosion-related inspection and repairs.

The unique properties of nano-materials provide high resistance to metallic surfaces corrosion due to their outstanding mechanical and physical characters. Recent development is now shifting to manufacture of efficient structures and coatings that have greater corrosion resistance [4]. The preparation of microcrystalline coatings by the processes of chemical vapor deposition (CVD) and physical vapor deposition (PVD) can be modified using feedstock powders having nano-grained structure [5]. Thorpe et al. [6], also reported the enhancement of corrosion resistance of nano-crystalline Fe32-Ni36-Cr14-P12-B6 than that of its amorphous counterpart. Nano-coating materials used to protect steel pipelines have generally of better insulation and adhesion quality than traditional ones and provide superior mechanical and electronic properties [7,8]. Metallic nano-coating can be produced through electro-deposition [9,10], sputtering [11] and multi-arc-ion plating [12]. The process of metallic nano-coating can be of a pure metal such as iron (Fe), Cupper (Cu), Nickel (Ni) [13] or alloyed for the purpose to enhance properties [14].

2. ELECTROCHEMICAL INCIDENCE OF STEEL CORROSION

The electrochemical corrosion of steel occurs in nature and includes many forms such as galvanic, pitting, de-alloying, erosion, uniform, microbial influenced corrosion (MIC). The process of incidence of electrochemical corrosion is summarized in the following equations:-

$$Fe \rightarrow Fe^{2+} + 2\,\bar{e} \quad (1)$$

$$2\,H_2O + O_2 + 4\,\bar{e} \rightarrow 4\,OH^- \quad (2)$$

$$2\,Fe + 2\,H_2O + O_2 \rightarrow 2\,Fe^{2+} + 4\,OH^- \quad (3)$$

$$4\,Fe^{2+} + 8\,OH^- \rightarrow 4\,Fe(OH)_2 \quad . \quad (4)$$

$$4\,Fe(OH)_2 + O_2 \rightarrow 2\,Fe_2O_3.\,H_2O\ (Rust) \quad (5)$$

3. ADVANTAGES OF USING NANO-TECHNOLOGY TO CONTROL STEEL CORROSION

Many advantages were reported for protecting steel pipelines from corrosion as described in the following points:-

1. Nanotechnology has been employed to enhance the inherent corrosion resistance and performance of steel by achieving the finely crystalline microstructure.
2. Some materials exhibit physical, chemical and biological unique properties by modifying their chemical composition at the nanometer-scale.
3. Nano-particles are smaller than the wavelength of visible light range and consequently appear transparent to the human eye.
4. Nano-particles produce an extra-ordinary high surface energy.
5. Nano-technology reduce the potential for environmental damage of materials during maintenance and installation because they can be stronger per unit volume than conventional one.
6. The physical property of nano-particles incorporated in a coating gets altered without affecting the clarity.
7. Nanostructure coatings have excellent adhesion and toughness because their powders have grains less than 100 nm in size, which may be used to repair component parts instead of replacing them.
8. Metallic surfaces coated with nano-materials help in the process of super hardening.
9. The formation of nano-composite thin film coating on steel minimize the impact of

corrosive environment by changing of the steel/ electrolyte interface.

10. The coating's nano-molecules improve long-term corrosion protection by forming a durable covalent bond with metallic molecules on steel surfaces.
11. The nano-coatings (NCoatgs) are stable at high degrees of temperature up to 180°C.
12. The coating's nanomolecules form a smooth coating surface that provides low fluid friction to flow oil and water and consequently reduce oil pumping power losses and operation costs.
13. NCoatgs produce lower film thickness (10-12 μm) that ensures stable dimensions.
14. NCoatgs produce long lasting ceramics and nano-thermoplastics with unique abrasion and corrosion resistant properties.
15. NCoatgs can be applied on the aircraft's surfaces replacing the halogenated fire-retardants by nano-additive fillers eliminating the risk of generating heat and smoke.

4. NANOTECHNOLOGY APPLICATIONS

Nanotechnology is used in many areas and it is more specific to nano-materials which are used in various industrial processes, products and applications. Most of the current applications of nano-materials represent evolutionary development of existing technologies with many effective modifications such as the reduction in size of electronic devices. The following are some applications of nano-particles in corrosion protection (Table 1).

4.1 Nanocomposites

The utilization of nano-tubes and nano-particles in composites is one of the designed applications to exhibit the best properties of each component of the nano-composite. This multi-functionality nano-composites are applied to mechanical, electrical, optic and magnetic properties. Recently carbon fibers and bundles of multi-walled Nano-tubes (CNTs) are used in polymers to enhance and control conductivity. Applications for nano-composites include oxygen and gas barriers, thin-film capacitors for computer chips, automotive engine parts and fuel tanks, solid polymer electrolytes for batteries, impellers and blades and food packaging [15-17].

4.2 Nanopaints

The incorporation of nanoparticles to paints can improve their performance, impart them different beneficial properties for environment and making them more lighter. Examples of this application the light weighting, thinner paint coatings used on aircraft and the fouling-resistant marine paint as an alternative to tributyl tin (TBT) used in heat exchanger to save energy. The difference between nano-paint and conventional one lies in that the basic components of the conventional paint are binding organic agents, solvents and additives, however in nano-paints the binding agent is an inorganic/organic hybrid polymer which can combine between the positive characteristics of both organic and inorganic agents. Other recent applications of nano-particles might lie in paints that have reduced infra-red absorption and consequently reduce heat loss and paints that change color in response to change in temperature [18-20].

4.3 Nanolubricants

Recent studies reported the capability of nano-spheres of organic materials to serve as lubricants by acting as nano-sized ball bearings, making them more durable than conventional solid lubricants and additives. These studies indicated that nano-particles reduce friction between metal surfaces especially at high normal loads and for metal surfaces that are not highly smooth [21,22].

4.4 Nanoclays

Nanoclay is another application of nanotechnology which have a unique morphology, featuring one dimension in the nanometer range. Clay particle based composites containing plastics and nano-sized flakes of clay are also used in many applications such as in fabrication of car bumpers [23-26].

5. TOUGHER AND HARDER CUTTING TOOLS

Application of nano-crystalline materials such as nano-titanium-, nano-tantalum- and nano-tungsten carbides are more resistant to erosion and have the advantage to last longer than their conventional counterparts and are used in the drills used to bore holes in circuits boards [27,28]. The cutting tools made of nano-

Table 1. Some applications of nanoparticles in corrosion protection

Application	Example	Reference
Nanocomposites	fillers in a matrix such as carbon black used to strengthen car tyers	Gupta and Kumar, 2017 [33]
Nanopaints	Light weighting, thinner paint coatings used on aircraft	Krishnamoorthy and Kim, 2015 [34]
Nanolubricants	Metal surfaces that are not highly smooth	Shenderova et al. 2014 [35]
Nanoclays	fabrication of car bumpers	Rytwo, 2008 [36]
Tougher and Harder Cutting Tools	Drills used to bore holes in circuits boards.	Jackson and Dring, 2006 [37]
Nanocoatings and nanostructured surfaces	self-cleaning window coated with highly activated titanium dioxide	Carneiro et al, 2011 [38]

crystalline materials help the manufacturer to machine various materials much faster, thereby increasing productivity and reducing manufacturing costs.

6. NANOCOATINGS AND NANOSTRUC-TURED SURFACES

Nano-structured surfaces and nano-coatings can be applied as chemically and catalytically functionalized surfaces. In recent years, the developed applications include the self-cleaning window coated with highly activated nano-titanium dioxide, modified to be highly antibacterial, hydrophobic and coatings based on nanoparticulate oxides that catalytically degrade chemical agents [29-31]. Metallic nanocoatings include one or more of the pure metals or alloyed for the purpose of the enhancement of properties. The nanocoatings of metals improve their chemical, physical, mechanical and thermal properties [32].

7. CONCLUSION

This review article describes briefly the advantage of using nanotechnology in corrosion protection of steel oil pipelines and the development of using recent applications in enhancing nano-materials to resist corrosion damage. Nanocoating materials used in steel pipelines have generally better insulation and adhesion quality than traditional ones and provide superior mechanical and electronic properties. The development of nanotechnology in coating steel pipelines, steel tanks and other petroleum equipment enhanced greatly the insulation of these materials. Recent advances in nanotechnology play a major role in improving the control of corrosion incidence and minimize corrosion risks. More attention should be paid by specialists in this field to invent new intelligent nano-technological applications to prevent/control corrosion damage aggressive environments.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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