

The Application of Nanomaterials in Energy Materials

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Abstract. With the continuous development of industry, nanomaterials had become one of the most active research fields due to their unique electronic, optical, and mechanical properties. In this review, we systematically reviewed the research progress of nanomaterials in recent years. Specifically, we explored the applications of nanomaterials in oilfield development, battery performance, and solid waste treatment. And we pointed out the existing problems in the current research.

Keywords: Nanomaterials, oilfield development, battery performance, solid waste treatment.

1. Introduction

Nanomaterials refer to a dispersed phase in which at least one dimension of a material with a size less than 100 nm was present. Nanomaterials with different structures and morphologies had their own advantages. For example, they had the performance of good conductivity, high mechanical properties, and large specific surface area. These characteristics played different important roles in different technological fields. Nowadays, population growth had brought about energy demand and social production based on fossil fuels had brought about environmental issues. The manufacturing of functional materials needed to meet the requirements of efficient production and green sustainability.

This article had introduced the application and research progress of nanomaterials in oilfield development, battery performance, and solid waste treatment in recent years. Through the above work, that promoted the reference and integration of advanced nanotechnology in multiple fields. The practical application effects of nano lotion, nano microsphere and nano cellulose were reviewed. Finally, the article pointed out the existing problems and looks forward to future development directions.

2. Application

2.1. Application in oilfield development

2.1.1. Nanomaterials as drilling fluid additives

The combination of nanotechnology and drilling fluid technology could realize reduction of leakage, reduction of friction, stabilization of the wellbore, and protection of the reservoir. Nanomaterials' unique properties were utilized in achieving these benefits. The realization of fast, high-quality and safe drilling under complex conditions had an important role in promoting the development of drilling fluid technology [1]. In laboratory experiments, Liu et al [2] analyzed the performance of a drilling fluid system containing nano emulsion. They found that nano emulsion increased the viscosity of the drilling fluid and had a certain impact on its rheological properties. The surfactant contained in the nano emulsion could reduce the surface tension and realize the rock wetting inversion. By adding various nanomaterials to the water-based drilling fluid, Liu et al [3] discovered that the viscosity and dynamic shear force of the drilling fluid increased as the amount of nanomaterials increased. However, the static shear force remained almost unchanged. Although

nanomaterials had many advantages as drilling fluid additives, there were some problems in their application, especially in the recovery and treatment of drilling fluid. Therefore, many factors needed to be taken into account when using nanomaterials as drilling fluid additives to ensure their safe and efficient application in the drilling process.

2.1.2. As a completion fluid additive

Compared with conventional cement-based materials, which had large particle size and were difficult to enter into the pores with poor consolidation, nano-materials had fine and uniform particle size. Adding nanomaterials to completion fluid could significantly improve the physical properties of cementing materials. This was achieved by imparting characteristics such as less water precipitation, non-shrinking volume, high strength, unblocking, high temperature resistance, high pressure resistance, and high salt resistance to the completion fluid. Li [4] and others evaluated the rheology, stability, thickening time, flexural strength and the impact strength of cement slurry by adding different proportions of nano-silica into the cement slurry. Experimentally, the addition of an appropriate amount of nano-silica to cement slurry improved its settling stability. And that reduced water loss and thickening time. This resulted in a thicker cement slurry system overall. There were also some problems with nanomaterials as completion fluid additives. First, the high volume of completion fluid required to consider the stability and dispersion of nanomaterials. Secondly, the performance of nanomaterials under high temperature and pressure needed further study. In addition, attention should also be paid to the effects of nanomaterials on reservoir rocks, including the dissolution and acidification of mineral particles.

2.1.3. Nanometer anti-corrosion and wear-resistant materials

In the field of oil drilling and production engineering, surface and downhole tools encountered complex environments. These environments included wear, corrosion, high temperature and pressure, and high H₂S and CO₂ content. The negative effects of these environmental factors could lead to tool damage, high costs, low production, operation risk, and environmental pollution. The high-performance nano coating was expected to solve the above problems [5]. Wang et al [6] discovered negative charges on the surface of carbon nanomaterials. These negative charges were found to be effective in inhibiting the penetration process of chloride and hydroxide ions. Furthermore, this reduced the concentration of anions between the coating and metal interface. And this minimized corrosion between them. Carbon nano-materials had their own lubricating properties, which could reduce friction and improve the wear resistance of the coating. In addition, nano-materials had strong oxidation and rust resistance properties. This made them effective in resisting oxidants in the oil field environment, preventing oxidation corrosion, and prolonging the service life of equipment. Although nano anticorrosive and wear-resistant materials showed good performance in the laboratory, the compatibility between nano materials and other materials was different. And the introduction of nano materials might affect the performance of the whole material system. So relevant research and testing should be carried out.

2.1.4. Nanosphere profile control and displacement

In recent years, nanospheres had been widely used in oil fields. The particle size of nanospheres was 5 to 120 microns, which was only 1/10 of the pore throat radius of the oil layer. They could be injected into the deep part of the oil layer to play a role. By controlling injection pressure and injection rate, nanospheres could selectively play the role of adjusting reservoir profile and displacing remaining oil. Wu et al [7] analyzed the plugging rate of microsphere profile control and flooding in Wangyao low permeability reservoir. The study found that smaller microsphere particle sizes resulted in higher mass concentrations and greater permeability reduction after injection into the formation. Additionally, smaller particle sizes led to stronger plugging performance. Small particle size microspheres tended to aggregate and block, while single large particle size microspheres blocked the large pore throat. These mechanisms achieved stepwise profile control and flooding through formation synergy. Rong et al [8] carried out different types of profile control and flooding agents for

reservoirs with high permeability bands according to the actual situation of the field. Experimental results demonstrated that combining nano-microspheres with traditional polymer gel profile control and flooding agents improved overall oil displacement efficiency. And that improved sweep volume of the reservoir. This approach was also effective in increasing oil recovery and reducing water production. However, the preparation cost of nano-microspheres was high and it was difficult to be applied on a large scale. At the same time, the microspheres were difficult to control and separate in the production process because of their tiny size.

2.2. Applications in batteries

2.2.1. Nanomaterials to improve the power conversion efficiency (PCE) of perovskite solar cells

Perovskite solar cells (PSC) were a new generation of solar cells. PSCs were considered to be a higher-quality technology for energy conversion compared to traditional monocrystalline silicon solar cells. PSCs used adjustable materials, facilitating low-cost amplification through deposition into thin films. Electron collection was ensured by applying a careful contact layer consisting of semiconductor oxides such as TiO_2 , ZnO , or SnO_2 , or graphene materials. SeckinAkin et al [9] used hydrothermal synthesized inorganic CuCrO_2 (CCO) delafossite nanoparticles as a hole transport material (HTM). After optimizing the concentration, a completely uniform and fully covered CCO layer was obtained on the surface of perovskite. It helped to quickly extract and collect carriers, achieving an optimal PCE of 16.7%. Mohammed et al [10] used carbon nanotube (CNT) materials doped with metal oxide photodiodes to replace traditional metal oxide photodiodes. Carbon nanotubes contributed to better interface contact between ZnO and perovskite, allowing perovskite to grow larger grains and pinhole-free surfaces. After adding CNT to ZnO ETL, the PCE of assembled solar cells increased from 9.12% to 15.19%. Subas Kumar Muduli et al^[11] used several layers of liquid peeled two-dimensional black (BP) nanosheets as HTMs for perovskite-based solar cells. The low valence band level of BP nanosheets was conducive to hole injection of $\text{CH}_3\text{NH}_3\text{PbI}_3$ (MAPbI_3). The work PCE of BP nanosheets HTMs was increased by about 25%. The PCE was increased to 16.4%. PSC had explored using different hole transport materials to improve efficiency, with notable success seen using CuCrO_2 nanoparticles, carbon nanotubes, black, and so on phosphorus nanosheets.

2.2.2. Nanomaterials Improving the Stability of Perovskite Solar Cells

Carbon nanostructures (CNSs), such as single-walled carbon nanotubes (SWCNTs) and graphene-based materials (GBMs), improved thermal stability of PSCs. Teresa Gatti et al [12] doped hexylthiophene hole transport materials with functional carbon nanostructures and doped HTM between adjacent layers. This improved interface contact and extended shelf-life stability. K. Ramachandran et al [13] developed inorganic copper antimony sulfide (Cu_3SbS_4) nanocrystals as HTMs for PSCs through thermal injection and spray deposition techniques. The strong hydrophobicity of Cu_3SbS_4 nanocrystals allowed the material to maintain 75% of original efficiency after 25 days of exposure to the environment. KyungminIm et al [14] improved humidity stability under solar illumination conditions ($100\text{mW}/\text{cm}^2$) by using p-i-n type planar $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite solar cells. They also used Ti doped MoO_2 inorganic hole transport materials with high moisture stability. The use of carbon nanostructures and inorganic nanocrystals as hole transport materials in perovskite solar cells showed promise in improving thermal and moisture stability. They were important factors for increasing the practicality of this technology.

2.2.3. Nanomaterials Improve Battery Life

Nanomaterials were widely used as anode and cathode materials for batteries due to excellent cycle stability and electronic conductivity. Yong Cheng et al [15] prepared nanostructured C/Sb composites through sol gel method and high-temperature carbothermal reduction process. These composites were more suitable for the volume change of Sb phase in charge discharge process. It still showed ultra-high discharge capacity after 200 cycles under current density of $100\text{mA}/\text{g}$. Yanli Zhou et al [16] prepared amorphous ultra-small MoS_3 nanoparticle nanocomposites with graphene oxide (GO/MoS_3)

using a simple acid precipitation method. GO served as a buffer layer, suppressing volume changes and exhibiting better lithium and sodium storage performance than pure MoS₃. BiaoShang et al [17] prepared TiNb₂O₇/carbon nanotube composites (TNO/CNTs) through ultrasonic dispersion and a simple solvothermal method. CNTs had a unique one-dimensional tubular structure, high electronic conductivity, and large surface area. Through the synergistic effect of TNO/CNTs combination, after 200 cycles of 50 mA g⁻¹, the reversible capacity reached 261.1 mA g⁻¹. After more than 1000 cycles, significant magnification performance could be maintained at about 110 mA g⁻¹ at 500 mA g⁻¹. The development of nanostructured composites, such as C/Sb, ultra-small MoS₃ nanoparticle with graphene oxide, and TiNb₂O₇/carbon nanotube, could improve volume changes and increase the reversible capacity. They made them potentially useful for practical battery applications.

2.3. Application in solid waste treatment

2.3.1. Synthesis of nanomaterials from plastic waste

Nowadays, plastic products had been widely used in human production and life. Its production had increased significantly, reaching an unprecedented scale. Excessive use of plastic products had seriously threatened the safety of the environment. Due to the high carbon content in plastics, waste plastics could be used as a carbon source to prepare nano carbon materials. It could not only effectively solve the problems caused by incineration. In addition, resources were abundant, recyclable, and low-cost. The prepared product was sustainable. Ma [18] prepared porous carbon nanosheets (CNS) using porous magnesium oxide as a template and waste polystyrene plastic as a carbon source. Subsequently, the performance of the material was optimized by increasing its specific surface area. Through three electrode testing, it was found that the prepared porous carbon nanosheets (CNS) could be made into high energy density electrode devices. Elessawy et al [19] mixed thermoplastic (PET) waste and urea in different proportions. Then they put the products into the autoclave and the high-temperature electric furnace in turn. The entire process reacted at a constant temperature. Finally, 3D sponge like nano nitrogen doped graphene was successfully prepared. It was measured by cyclic voltammetry and impedance spectrum. The prepared materials exhibited excellent electrode performance for supercapacitors. Although plastic waste could be converted into nano carbon materials. But toxic and harmful substances might also be generated or leaked. There were certain safety hazards.

2.3.2. Synthetic nanomaterials from agricultural and forestry wastes

China produced a large amount of organic waste every year, including about 1.14 billion tons of agricultural and forestry residues. If these solid waste could not be properly treated. It would waste resources, Even causing environmental pollution. Due to the fact that the main component of agricultural and forestry waste biomass was cellulose. Therefore, nano cellulose could be extracted from agricultural and forestry waste as the main raw material. Nanocellulose had excellent properties such as good biocompatibility and biodegradability. It could be widely used in the preparation of synthetic materials. Especially as fillers and reinforcing agents for composite materials, this had attracted the attention of the material science community [20]. Ao [21] used pine sawdust waste to load metal ions through iron salt impregnation. Three pre-treatment methods were used: acid pickling impregnation, ultrasonic impregnation, and hydrothermal treatment. And the experiment was combined with microwave pyrolysis technology. Finally, carbon based metal nanocatalysts were prepared. Through a comprehensive evaluation of its catalytic performance, it was found that this material could further improve the catalytic efficiency and durability of the catalyst without affecting its catalytic activity. This discovery helped eliminate the research on real biomass gasification tar. Jin [22] used bamboo pulp as carbon source to prepare bamboo pulp nanocellulose (BCNF) by two-step method of enzyme pretreatment and mechanical grinding. The results showed that the crystallinity of the prepared BCNF was 6.1% higher than that of the raw material. This material had good thermal stability. However, the preparation of nanomaterials required expensive equipment and processing costs. Therefore, the cost of synthesizing nanomaterials was relatively high.

2.3.3. Synthetic nanomaterials from aquaculture wastes

With the continuous development of the economy, the vigorous development of the aquaculture industry had been accelerated. But at the same time, a large amount of aquaculture waste had also caused huge pollution to the environment. It not only hindered the sustainable development of aquaculture. At the same time, it also restricted the improvement of aquaculture quality. If these aquaculture waste were used as raw materials for manufacturing nanomaterials, it could effectively solve environmental problems. And the products had high added value. Gao et al [23] used poultry feather waste as raw material. The materials were then pyrolyzed in a supercritical carbon dioxide atmosphere consisting of nickel acetate tetrahydrate (NiAcTa), dry ice and stainless steel autoclave. Finally, nitrogen rich carbon nanotubes (N-CNTs) with a nitrogen atom content of up to 6.43% were successfully synthesized. The experimental results indicated that the catalytic performance of the synthesized N-carbon nanotubes was superior to that of N-doped graphene. It could even be comparable to common precious metal catalysts. In the field of fishery, the main waste was chitosan. He [24] used carboxymethyl chitosan hydrogel (CMC) as a template. Then he fixed Fe^{3+} at the crosslinking site. Finally, in-situ nitrogen doping was carried out on the carbon material through the amino groups in the carboxymethyl chitosan molecule. He successfully synthesized iron nitrogen doped carbon nanocomposites. And he found that the composite material had the ability to effectively degrade sulfonamide antibiotics (SA) in the PMS system and excellent recovery performance. Although using aquaculture waste to synthesize nanomaterials had environmental advantages. But the technical difficulty was relatively high. The conversion of waste plastics into nanomaterials required precise chemical reactions and separation techniques. Even high-level research experts were needed for research. Therefore, the technology was still in the research stage. It could not completely replace traditional materials, resulting in limited market demand. These issues still needed to be further addressed and explored.

3. Summary

This article summarized the practical applications of nanomaterials in oilfield development, battery performance, and solid waste treatment. Nanomaterials had achieved fruitful results in various fields with their unique properties. And it would show broad application prospects in more fields in the future. Therefore, this article proposed the following suggestions, to promote the application of nanomaterials in new fields:

(1) When designing and adjusting the performance of nanomaterials, it was necessary to consider the actual needs of different fields. By drawing on the successful application of nanotechnology in other industries, we could organically apply it to the development of current practical needs.

(2) Reducing the cost of nano material preparation and modification processes was still a difficult task. The high cost of existing nanomaterials had led to many new materials only staying at the indoor research stage. How to effectively reduce costs would ultimately determine the application effect of nanotechnology.

References

- [1] Zhang Lei, Zhang Gui Cai, Jiang Ping, et al. Application of Nanomaterials in Oilfield Development [J]. Materials Guide, 2015, 29 (13): 72 - 76.
- [2] Liu Zhendong, Li Gongrang, Zhao Huaizhen. Application and Mechanism of Paraffin Nano-emulsion in Drilling Fluid [J]. Journal of Shengli College of China Shiyou University, 2022, 36 (1): 41 - 44.
- [3] Liu Xusan. Experimental Study of Enhancing Heat Capacity of Water-Based Drilling Fluid with Nano-Material [J]. Journal of Sichuan Geology, 2022, 42 (2): 331 - 334.
- [4] Li Bo, Lu Yongwei. Effect of Nano-silica on the Properties of Cement Slurry [J]. Henan Science and Technology, 2019, 0 (13): 96 - 99.

- [5] Liu He, Wook Kim, Ding Bin. Application of nanotechnology in petroleum exploration and development [J]. *Petroleum Exploration and Development*, 2016, 43 (6): 1014 - 1021.
- [6] Wang Chi-jia, Wang Zihua, Liu Shu-pei, et al. Research Progress of New Carbon Nanomaterials Used in Organic Anticorrosive Coatings [J]. *Surface Technology*, 2021, 50 (3): 1 - 1544.
- [7] Wu Tianjiang, Zheng Mingke, Zhou Zhiping. New method for plugging performance evaluation of polymeric nanospheres in low permeability reservoir [J]. *Fault Block Oil and Gas Field*, 2018, 25 (4): 498 - 501.
- [8] Rong Xinming, Zhang Yu, Du Xun, et al. Experimental study for nanosphere combination flooding technology [J]. *Petrochemical Application*, 2020, 39(5): 76-78.
- [9] Akin, Seckin, Yuhang Liu, et al. Hydrothermally Processed CuCrO₂ Nanoparticles as an Inorganic Hole Transporting Material for Low-Cost Perovskite Solar Cells with Superior Stability [J]. *Materials Chemistry*, 2018, 47 (6): 27 – 37.
- [10] Hu, Chechia, Tzer-Rung Su, et al. Yellowish and Blue Luminescent Graphene Oxide Quantum Dots Prepared via a Microwave-Assisted Hydrothermal Route Using H₂O₂ and KMnO₄ as Oxidizing Agents [J]. *New Journal of Chemistry*, 2018, 42 (6): 3999 – 4007.
- [11] Muduli, Subas Kumar, Eswaraiah Varrla, et al. 2D Black Phosphorous Nanosheets as a Hole Transporting Material in Perovskite Solar Cells [J]. *Journal of Power Sources*, 2017, 371: 56 – 61.
- [12] Gatti, Teresa, Simone Casaluci, et al. Boosting Perovskite Solar Cells Performance and Stability through Doping a Poly-3 (Hexylthiophene) Hole Transporting Material with Organic Functionalized Carbon Nanostructures [J]. *Advanced Functional Materials*, 2016, 41 (26): 43 – 53.
- [13] Ramachandran, K., C. Jeganathan, et al. Nanostructured Bilayer CuSCN@CuI Thin Films as Efficient Inorganic Hole Transport Material for Inverted Perovskite Solar Cells [J]. *Ceramics International*, 2021, 47 (13): 83 – 94.
- [14] Im, Kyungmin, Jin Hyuck Heo, et al. Scalable Synthesis of Ti-Doped MoO₂ Nanoparticle-Hole-Transporting-Material with High Moisture Stability for CH₃NH₃PbI₃ Perovskite Solar Cells [J]. *Chemical Engineering Journal*, 2017, 330: 698 – 705.
- [15] Cheng, Yong, Zheng Yi, et al. Nanostructured Carbon/Antimony Composites as Anode Materials for Lithium-Ion Batteries with Long Life [J]. *Chemistry - An Asian Journal*, 2016, 15 (11): 73 – 80.
- [16] Zhou, Yanli, Yanyan Li, et al. Ultrasmall MoS₃ Loaded GO Nanocomposites as High-Rate and Long-Cycle-Life Anode Materials for Lithium- and Sodium-Ion Batteries [J]. *ChemElectroChem*, 2019, 12 (6): 13 – 19.
- [17] Shang, Biao, Qimeng Peng, et al. TiNb₂O₇/Carbon Nanotube Composites as Long Cycle Life Anode for Sodium-Ion Batteries [J]. *Ionics*, 2019, 4 (25): 79 – 88.
- [18] Ma Changde, Waste polymers derived carbon nanomaterials and their applications in energy storage and microwave absorption [D]. University of Science and Technology of China, 2020.001702.
- [19] Elessawy N A, El Nady J, Wazeer W, et al. Development of High-Performance Supercapacitor based on a Novel Controllable Green Synthesis for 3D Nitrogen Doped Graphene [J]. *Scientific Reports*, 2019, 9 (1).
- [20] Shi Yifei, Preparation of sawdust-based ultra-pure nanocellulose and its potential biomedical functionality evaluation [D]. Jiangsu University, 2022.000482.
- [21] Ao Wenya, Preparation and catalytic performance of carbon-based metal catalysts derived from biomass waste [D]. Beijing University of Chemical Technology, 2022.000198.
- [22] Jin Hao, Optimization of preparation process of cellulose nanofibrils from bamboo pulp using enzymolysis-grinding two-step method [J] *Journal of Forest and Environment*, 2021, 41 (01): 104 - 111.
- [23] Gao L, Li R, Sui X, et al. Conversion of Chicken Feather Waste to N-Doped Carbon Nanotubes for the Catalytic Reduction of 4-Nitrophenol [J]. *Environmental Science & Technology*, 2014, 48 (17): 10191 - 10197.
- [24] He Jinkai, In situ synchronous structure of iron@nitrogen doped carbon Nanocomposite catalyst and its activation of peroxymonosulfate for antibiotic degradation [D]. Shandong University, 2022.005729.