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Application of chemical engineering principles in development of nanomaterials (review)

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ABSTRACT: Nanotechnology can be applied as a common-purpose technology, as it has important impacts on almost all industries and all areas of science. In those early days, scientists and engineers have confirmed their study on the development of nanomaterials and their applications in various fields. Nanoparticles have a wide range of applications, since it incorporate knowledge from the fields of Physics, Chemistry, Biology, Medicine, and Engineering. Nanomaterials have some special properties due to their small size. The basic applications in the chemical engineering field are catalyst, sensor, coating, and adsorption and drug delivery. Notwithstanding many advantages, preparation and preserving the proper size of nanomaterials are the most desperate job. Chemical engineers play a fundamental role in the modeling and development of nanomaterials. The advances in nanomaterials necessitate parallel progress of the nanometrology tools and techniques to characterize and manipulate nanostructures. In the energy generation, compete where the conventional fuel resources cannot stay the dominant energy source, considering the increasing consumption request and the CO_2 emissions further renewable energy sources based on maiden technologies have to be promoted. The present reviews clarify the different nanomaterials using in chemical engineering, their applications and procurement methods. Moreover, results of various patents and research articles have been summarized in this paper.

Keywords: *Catalysts; Chemical engineering; Energy reservoir; Nanomaterials; Petroleum*

INTRODUCTION

The world is presently observing the advancement and development of a novel multidisciplinary technology, nanotechnology. Renowned physicist Richard Feynman in his word first discussed the concepts that seeded nanotechnology in 1959: "There's Plenty of Room at the Bottom" (Feynman, 1961). Nanoscience studies the phenomena, properties, and responses of substances at atomic, molecular, and macromolecular measures, and in general at sizes among1 and 100 nm. Nanomaterials with unparalleled properties such as nanoparticles carbon nanotubes, fullerenes, quantum dots, nanofibers, and nanocomposites allow completely new applications to be discovered. Products including engineered nanomaterials are already in the market. The area of commercial products available today is very vast, comprising metals, ceramics, polymers, smart textiles, cosmetics, electronics and varnishes. Therefore, new methodologies and instrumentation have to be extended in order to increase the knowledge and information

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on their properties (Simonis and Schilthuizen, 2006).

Nanomaterials have a broad range of application based on their size, physical and chemical properties. Because of high surface to volume part, nanoparticle can be applied as an efficient adsorbent. In chemical engineering industry nanomaterials are used as catalyst and also used as a filter or absorber (Sousa, *et al.*, 2011). Peter *et al.* created a smoke filter for smoking system with porous masses having active nanoparticles (Burke, *et al.*, 2012).

In addition, energy segments cause environmental pollution in various ways. However, renewable and green energy resources are very much favorable in recent years. Nanomaterials are carried out to produce and acquire renewable resources like hydrogen (Norton and McIIRoy, 2010) and play a competing role in solar energy producing (Chen, *et al.*, 2019).

Nanomaterials are very much beneficial in the medical science; there are several nanomaterials used for drug delivery and modeling of release pattern (Flanagan, *et al.*, 2011).

Nanotechnology suggests the potential way to design, synthesize, and control at nanometer scale (Kung and Kung, 2004). Moreover, many researches show that protective ligand can be applied for stabilizing the nanoparticles (Brust, *et al.*, 1994). Research is very much needed in this field to find the economical production methods of nanomaterials for industrial application. Researchers in chemical engineering and federate departments from several reputed institutes are largely included in research work on nanotechnology (Kouvaris, *et al.*, 2012, Yoo, *et al.*, 2009, Wang, *et al.*, 2010, Yu, *et al.*, 2003a, Yu, *et al.*, 2012b).

There is an increasing matter on the development of systems for nanostructures production, that require different aspects of chemical engineering such as transport phenomena, kinetic, thermodynamic process modeling and simulation and so on. In a process related to nanomaterials synthesis or production, distribution of scales, shapes and their purity relates to their capacity to perform diverse functions in specific applications (Roxworthy and Toussaint 2013).

In this present review, various aspects of nanomaterials and nanotechnology in the field of chemical engineering have been illustrated.

Chemical engineering in Nanostructured Materials Manufacturing

Engineering research and education, including chemical engineering, play a key role in nanomaterials manufacturing, and this role will even expand in the future because of its integrative, system approach-oriented and transforming characteristics (Roco, 2011). Chemical engineers are playing impressive roles in developing a new science based on phenomena, structures and potential applications where understanding at nanometer length scales is crucial. The areas in nanotechnology that chemical engineers are making major contributions are addressed as:

- Development of new and novel products like; catalysts, multicomponent composites, natural nanostructures, sorbents for environmental contaminants.
- Innovation in processes for synthesis of nanotechnology-based products

(Recall that nanotechnology-based products include both synthesis of nanostructures and incorporation of these nanostructures to produce new products like nanocomposites and nanosensors)

- Process optimization for nanotechnology-based products
- Mathematical modeling, kinetic study and thermodynamic study of processes involved in synthesis of nanostructures
- Transport phenomena investigation

Whether this new science base leads to important technological developments depends even more on chemical engineers.

Petroleum industries

Nanotechnology is offering new and improved methods in different areas of the oil and gas industries from exploration and well drilling to refining and distribution. Properties of nanostructures such as lightness, corrosion resistance and mechanical strength make them significant elements to be used in the oil industry machines, specially drilling machines (Singh, *et al.*, 2010). Conventional sensors and other measuring tools are unreliable in hostile high-temperature and high-pressure conditions. Improved performance sensors for imaging, measuring and controlling reservoirs and oilfields will improve all activities in the area of oil industry, from exploring oil well and drilling to oil transporting and reserving (Matteo, *et al.*, 2012). In addition, nanostructures were used for reduction in the viscosity of heavy oil, thus benefiting the oil exploitation and upgrading transportation (Nassar, *et al.*, 2011).

Chemical reactors

A chemical reactor is the heart of chemical processes, and it is a device in which the feedstock (reactants) is converted to the desired product by chemical transformations or chemical reactions. Reactors are not only involved in producing chemical products but also in energy production like combustor and in certain electrochemical cells like fuel cells (Missen, *et al.*, 1999). The capabilities of batch reactor are important from the nanotechnology viewpoint, and therefore, the batch reactors are generally selected. However, a challenge in using a batch reactor for rate determination is the ability to obtain good conversion data as a function of time.

Catalysts

Maintaining the particle size and surface properties is a challenging job for the nanotechnologist.

One of the major applications of nanomaterials is in chemical industry for catalytic reacting system. Due to its high surface area, nanomaterials can be used as catalyst.

Using nanostructures in catalysts provides several advantages that ultimately increase the economics of the upgrading process. The catalyst-improved characteristics include (Missen, *et al.*, 1999):

(a) High surface area-to-volume ratio, which results in improved catalytic performance for processing purposes

(b) Increased probability of contacts between reactants because of their high mobilization inside the reactor

(c) Long run times for conversion as there is no need of catalyst replacement because of nanocatalysts implementation inside the medium

(d) Stable long-term high activity

Son *et al.* prepare nanohybrid catalysts that comprised montmorillonite (Mt) matrix and embedded zerovalent Fe nanoparticle (Son, *et al.*, 2012). The zero valence and large surface areas of Fe nanoparticles improve their catalytic efficacy very much. Some researcher (Umegaki, *et al.*, 2008) developed steam reforming catalyst which exhibit high hydrogen production rate from ethyl alcohol at low temperatures. Nanocatalyst is also available for polymerization reaction. Li *et al.* (Li, *et al.*, 2007) synthesized a nano-sized silica supported bis(cyclopentadienyl) zirconium (IV) dichloride catalyst for ethylene polymerization. At the optimum temperature of 600C, nano-sized catalyst's has 4.35 times activity than the micro-sized catalyst. This fact was attributed to the large specific external surface area, the absence of internal diffusion resistance, and the better active site dispersion for the nano-sized catalyst (Vuillaume, 2010).

Energy reservoir

Energy is one of the most challenging needs of humanity, and is highest on the list of priorities and requisites for human welfare (Ghoniem, 2011). Taking in account the CO_2 emissions and the global climate change impact on life and the health of the planet renewable energy sources will have to play a central role in moving the world onto a more secure, reliable, and sustainable energy path (Parida, *et al.*, 2011). Plastic electronics technologies are aimed at producing significant improvements in device efficiency-to-cost ratios. This necessitates significantly improving efficiency or reducing cost or ideally both. To realize these goals, many of these technologies will need to utilize nanostructured materials and composite systems that can be tailored to have optimized electronic and optical properties (Shaheen and Ginley, 2004, Contescu and Putyera, 2009).

Membrane-Filtration

With respect to environmental issues, the vast majority of literature on nanotechnology deals with possible applications in the field of filtering and remediation. Even though this subject does not fall strictly within the scope of the project, some nanotechnology applications are listed due to the fact that they are related to the overall objective of this project, reducing environmental load and threats to human health. An important field of application is membranes combined with catalysts; therefore, new membranes for fuel cells based on nanotechnology are developed. A field where nanotechnology will change process technology is the use of membranes for the separation of different substances. Here, it is conceivable that such membranes could reduce the use of hazardous substances used for separation purposes.

Safety and environmental science

As explained in the previous sections, nanotechnology has great applications in many fields. The quantity of engineered nanostructures is expected to grow significantly in the next several years (Roco, 2011). On the other hand, as nanotechnology progresses toward manufacturing and commercial stages, more concerns are being raised about the potential risky effects of nanostructures on human health and environmental media. For example, CNTs, due to their superior mechanical, electronic and thermal conductive properties, are currently used in consumer and industrial products like sports tool or flexible displays and touch screens (Maynard and Pui, 2007). Similar reports have been also published for other nanostructures that they can potentially lead to new hazards or increase risks to the environment (Maynard, *et al.*, 2006, Oberdörster, *et al.*, 2007).

Nanoadsorbents and nanomembranes indicated their effective role in water and air purification as well as wastewater treatment by removal of various types of pollutants including heavy metals, synthetic dyes and biological contaminants (Bora and Dutta, 2014). Nanostructures act as an adsorbent or photocatalyst and have indicated high sensitivity, selectivity and efficiency for removal of these contaminants. Common nanostructures with potential applications for adsorbing pollutants include dendrimers and zeolites (Li, *et al.*, 2013).

As far as, large numbers of novel nanotechnology-based products are continuously being produced, it is necessary to develop a robust scientific platform to obtain health, safety and environments (HSE) results of these products. A comprehensive study on HSE studies associated with nanostructures will resolve questions by toxicologists, the community, and regulators. Nanostructures may enter human body through different pathways, and they may act by reacting with surface receptors or by passing into cells and reacting with intracellular receptors (Hashemi, *et al.*, 2014).

Food industries

Applications of nanotechnology in food technology are going to affect the vital aspects of food and depended industries from food safety to the molecular synthesis of new food additives and ingredients (Chen, *et al.*, 2006). Engineered nanomaterials (ENMs) have been applied to control the texture and quality of foods and affect the way such food structures are broken down during digestion (Morris, 2011). The principals' functions of food packaging are to protect and preserve the food, to retain its quality and safety, and to decrease food waste (Bradley, *et al.*, 2011). The basic advantage of nanomaterials for food packaging is that, it uses less packaging material but with the alike technical performance. This could give a less carbon footprint from the manufacture and transport of the packaging and the packaged food waste (Bradley, *et al.*, 2011). Although nanotechnology has a huge potential to fabricate novel products and processes in the food sector, there are several challenges to overcome in food science and technology. The principal challenges are to generate edible delivery systems applying economic processing operations with impressive formulation for human consumption and safety (Labrune and Palmino, 2004). In this base, nanostructures are produced from food gauge ingredients using simple and economic approaches.

Pharmaceutical science

Nanomaterials have some noteworthy chemical and physical properties; the area properties of nanomaterials, like easy modification and functionalization, make them interesting as drug carriers and drug delivery of active compounds (Kumar, 2000).

Among nanotechnology, there exist many attempts to improve the efficiency of pharmaceuticals by causing them directly to the cells where they are needed. For sure, the main goal is to diminish the side effects of the therapy, therefore making the therapy more tolerable and effective. Nonetheless, a suitable scheme to join the drug and the nanostructure is required to make nanostructures into permanent delivery vehicles (Endo, *et al.*, 2008).

Another critical stage is to conjugate the nanostructures in such a method that the functionality of the biomolecules is retained. Nowadays, nanomedicine initiatives contain a range of successful and evolving technologies circumambient targeted drug delivery leveled at minimizing side effects, development of implantable materials as scaffolds for tissue engineering, creation of implantable devices, area modification and designing optimal topology for biomaterial implants, surgical supports, nanorobotics, as well as high efficiency drug screening and medical diagnostic imaging (Pankhurst, *et al.*, 2003, Papazoglou and Parthasarathy, 2007).

Polymer nano-base in the form of micelles (Cammas, *et al.*, 1997), inorganic nanoparticles, such as magnetic nanoparticles (Zhang, *et al.*, 2005, Alexiou, *et al.*, 2000), Au nanoparticles (Ghosh, *et al.*, 2008), silica nanoparticles (Zhao, *et al.*, 2009), etc. have also demonstrated to be useful in drug delivery systems (Zhang and Olin, 2012). Aiden Flanagan *et al.* created a medical device for delivering therapeutic factors to the body tissue of a patient (Flanagan, *et al.*, 2011). Hsing-Wen Sung *et al.* devised a novel, unique nanoparticle system and procedures of preparation for protein/peptide drug or bioactive agent delivery (Sung and Tu, 2011).

An Industrial outlook Research Challenges in Nanotechnology

Nanotechnology is not just an industry or one a new phenomenon, but offers new possibilities that will likely happen at industrial giants. Any activity in the field of nanotechnology falls in one of the areas as below (Mehra, *et al.*, 2014):

1. Synthesis of nanoscale constructing blocks, called nanostructures such as nanoparticles, nanotubes and nanofibers
2. Fabrication and/or processing of nanoscale constructing blocks for a desired aim like nanofluids
3. Incorporating nanoscale constructing blocks into final product, such as nanocomposites, nanodevices and nanosensors.

Each process included in producing nanotechnology-based outcomes is strongly essential to be commercialized regarding producing materials with unique performance and customer profits at a reasonable cost. For instance, CNTs have been found a vast range of applications. Nanofluids including CNTs have been illustrated enhanced thermal heat transfer; therefore, the effects of parameters, containing viscosity of fluid, dispersion model of nanotubes, etc., are still under research (Leong, *et al.*, 2014, Jajja, *et al.*, 2013).

Conclusion and Future Perspective

Nanotechnology is a maiden technology with applications in various scientific and research fields. The present review demonstrates that chemical engineers play a significant and key role in the preparation of nanomaterials; therewith, nanomaterials also have vast range of application in the chemical engineering field such as heterogeneous catalysis, environmental applications etc. Lately, environmental friendly biological route has been tracked to synthesize some metal nanoparticles. Notwithstanding many advantages, economic and environmental amicable production of nanomaterials is a challenge for researchers. Indeed, researches may be conducted in this direction.

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