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Emergence of nanotechnology in the oil and gas industry: Emphasis on the application of silica nanoparticles

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ABSTRACT

The application of nanotechnology in the oil and gas industry is on the rise as evidenced by the number of researches undertaken in the past few years. The quest to develop more game-changing technologies that can address the challenges currently facing the industry has spurred this growth. Several nanoparticles, of different sizes and at different concentrations, have been used in many investigations.

In this work, the scope of the study covered the application of nanotechnology in drilling and hydraulic fracturing fluids, oilwell cementing, enhanced oil recovery (which includes transport study, and foam and emulsion stability), corrosion inhibition, logging operations, formation fines control during production, heavy oil viscosity reduction, hydrocarbon detection, methane release from gas hydrates, and drag reduction in porous media. The observed challenges associated with the use of nanoparticles are their stability in a liquid medium and transportability in reservoir rocks. The addition of viscosifier was implemented by researchers to ensure stability, and also, surface-treated nanoparticles have been used to facilitate stability and transportability.

For the purpose of achieving better performance or new application, studies on synergistic effects are suggested for investigation in future nanotechnology research. The resulting technology from the synergistic studies may reinforce the current and future nanotechnology applications in the oil and gas industry, especially for high pressure and high temperature (HPHT) applications. To date, majority of the oil and gas industry nanotechnology publications are reports of laboratory experimental work; therefore, more field trials are recommended for further advancement of nanotechnology in this industry. Usually, nanoparticles are expensive; so, it will be cost beneficial to use the lowest nanoparticles concentration possible while still achieving an acceptable level of a desired performance. Hence, optimization studies are also recommended for examination in future nanotechnology research.

1. Introduction

Over the years, it has been discovered that the transition from microparticles to far-smaller particles will bring about a revolution in so many industries. In fulfilling this goal, the use of nanoparticles in various applications has resulted into new fields of science and technology. These fields are nanoscience and nanotechnology. Nanoscience describes the study of the phenomenon and principles governing the behavior of materials at nano-scale level [1], while nanotechnology deals with the design, characterization, production and application of materials and devices based on nanometer scale [2]. Similarly, nanoparticles are substances with dimensions in the order of

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1–100 nm (nm). Nanoparticles possess unique properties owing to their small size and greater surface area per unit volume; thus, they show a higher reactivity with other molecules. A comparison of the surface area to volume ratio of spherical particles of the same material with radius of 1 mm (mm), 1 μm, and 1 nm was presented by Ref. [3]. It is obviously from Fig. 1 that more than a millionfold increase in surface area per unit volume will be realized if a particle on a millimeter scale is converted to nano-sized particles. Nanoparticles traverse several industries, and the determination of what type to use depends on the anticipated application.

Materials that have nanoparticles embedded in their structures are termed nanomaterials. Most of the qualities of the nanoparticles are inherited by these materials, and that explains the enhancement in their properties. The nanoparticles are knitted into the structure of materials and bring about reinforcement. In conventional materials, the atoms are located in the interior of the particles; but, for a typical nanomaterial, most of the atoms are located on the surface of the particles. Reactions that produce superb chemical, optical, mechanical, electrical, thermal, magnetic properties etc., occur in nanomaterials [4]. The production of nanomaterials is mainly from six known methods, namely: chemical vapor deposition, plasma arcing, electrodeposition, sol-gel synthesis, ball milling, and the use of natural nanoparticles [4]. Chemical vapor deposition involves making nanoparticulate material from the gas phase [5], and a schematic of the process is presented in Fig. 2. The material is heated to form gas and then allowed to deposit as a solid on a surface, most times under vacuum. The deposition may be direct or by chemical reaction, forming a new product that is different from the volatilized material. In plasma arcing, gas is made to conduct electricity and it eventually gives up its electrons and thus ionizes. The resulting ionized gas is called plasma. This method is applicable in forming carbon nanotubes. Vacuum arcs is a type of plasma discharge [6], and a schematic of it is presented in Fig. 3. In this figure, an arc is initiated by contacting the cathode, while an igniter is attached to the anode for a low-voltage and high-current self-sustaining arc generation. Subsequently, the arc gives up ions and they accelerate toward the substrate. In the process, large droplets are filtered out before deposition [7]. Electrodeposition involves a controlled placement of a layer or more on a surface. An example of a template-assisted electrodeposition process is shown in Fig. 4. It is obvious from this figure that the process of electrodeposition leads to the placement of particles on the surface of the graphene sheet [8]. Sol-gel synthesis describes the process of generating networks through the formation of colloidal suspension (sol), and the subsequent gelation of the sol to form a network in a continuous liquid phase (gel) [9]. The colloids are synthesized from ions of a metal or metalloid element surrounded by different reactive ligands. A summary of the different stages and routes of sol-gel synthesis is presented in Fig. 5. In ball milling, small balls (which rotate around a drum) are allowed to drop under gravitational force on a solid in the drum; thereby, breaking the structure into nanocrystallites as depicted in Fig. 6. This method can produce fines and uniform dispersions of oxide particles [10]. The use of natural nanoparticle involves the reformation of existing nanoparticles into new materials when their crystallite bonds are broken. Nanomaterials are used in making insulation materials, machine tools, batteries, high power magnets, motor vehicles, aircraft, medical implants, etc. [4].

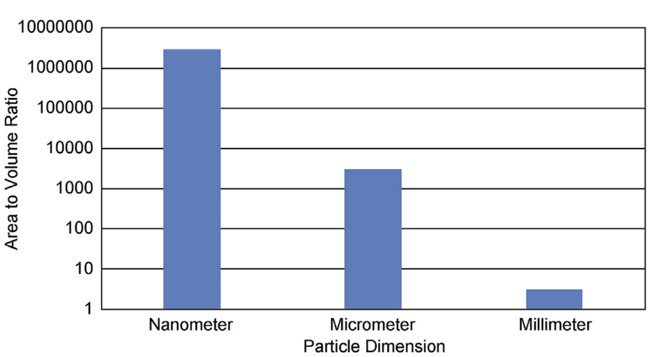

Fig. 1. Surface area to volume ratio of the same volume of materials (source: adapted from Ref. [3]).

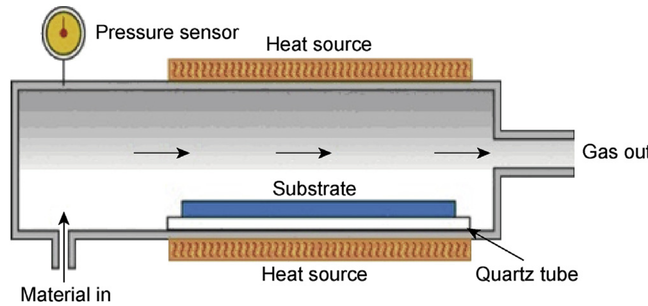

Fig. 2. A typical chemical vapor deposition reactor (source: adapted from Ref. [5]).

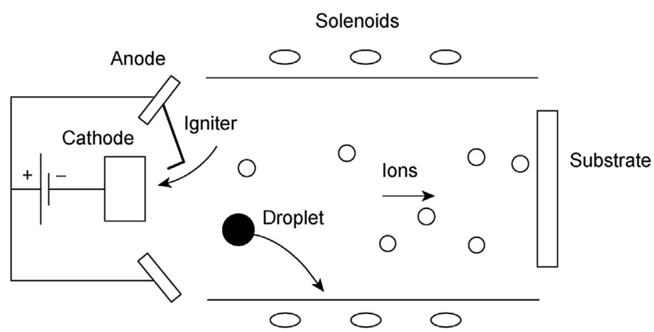

Fig. 3. Vacuum arc – a type of plasma discharge (source: [7]).

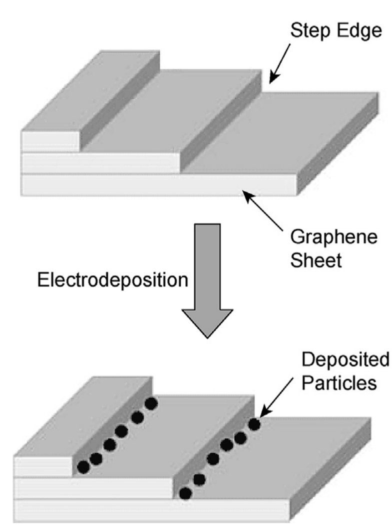

Fig. 4. Active template-assisted electrodeposition (source: [8]).

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