Date-Leaf Carbon Particles for Green Enhanced Oil Recovery

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Contributor: Bashirul Haq, Md. Abdul Aziz, Dhafer Al-Shehri, Nasiru Muhammed, Shaik Basha, Abbas Saeed Hakeem, Mohammed LARDHI

Carbon nanomaterials such as graphene, carbon nanotube (CNT), and carbon dots have gained interest for their superior ability to increase oil recovery. These particles have been successfully tested in enhanced oil recovery (EOR), although they are expensive and do not extend to green enhanced oil recovery (GEOR).

Keywords: carboxylic acid functionalization ; carbon nanoparticle ; green enhanced oil recovery (GEOR)

1. Introduction

The oil production processes from a reservoir are grouped into three classes: primary, secondary, and tertiary [1]. In the primary stage, oil is produced due to natural drive mechanisms, for example, water, gas cap, solution gas and so on. The secondary process is launched after the weakening of natural energy. Waterflooding and pressure maintenance are common secondary recovery methods. The tertiary oil recovery, known as the enhanced oil recovery (EOR) method, is introduced when the second technique is no longer economically feasible [2][3]. The common EOR methods are chemical, gas, thermal, and others [4][5][6]. The chemical EOR method involves injecting surfactant, polymer, alkaline, and alcohol chemicals to alter interfacial tension (IFT), wettability, phase behavior, and boost oil recovery. In the gas EOR method, gases such as CO_2, N_2, CH_4, and Flue gas are injected into the reservoir to reduce viscosity, IFT, increase the crude's mobility, and improve oil recovery. This is achieved due to gas mixing with the oil which results in expansion and thus pushes the oil toward production outlets. For the thermal EOR methods, the temperature of the reservoir region is raised to heat the crude oil in the formation to reduce its viscosity, vaporize part of the oil, increase the mobility of the oil, and finally boost oil recovery. Common examples of thermal processes include hot water, steam, and in situ combustions, which are suitable for heavy crude oil.

Microbial enhanced oil recovery (MEOR) falls under other EOR methods [1]. MEOR technology is an eco-friendly enhanced oil recovery method that involves the injection of microorganisms to produce surfactant, polymer, alcohol, ketone, acids, and gas in situ, to enhance the recovery of residual oil [7][8][9][10][11]. In 2013, Haq [12] introduced an environmentally friendly oil recovery method known as green enhanced oil recovery (GEOR). GEOR is a nature-friendly EOR process that injects specific green fluids, such as surfactants, polymers, alcohols, acids, ketones, and gas (N_2, CO_2), which boosts macroscopic and microscopic sweep efficiencies, as a result, this then increases residual oil recovery [9][10][11]. The GEOR method is divided into two types: in situ and ex-situ [11]. MEOR falls under the in situ category, whereas green chemicals (for example, surfactant, polymer, and alcohol), smart water, gas (carbon dioxide and nitrogen), and hybrid (water alternating gas (WAG), and (FOAM)) are grouped in the ex situ process.

In green surfactant flooding, the eco-friendly surfactant is injected into the reservoir to reduce interfacial tension, alter phase behavior properties, and wettability alteration to improve oil recovery whereas smart water flooding (SWF) is a developing technology that utilizes modified water chemistry in terms of salinity and composition of the ions to prepare a more suitable brine composition for a specific brine/oil/rock system to achieve better recovery. The mechanisms of SWF are fine migration, pH increase, multi-ion exchange, salting-in, and wettability alteration.

In the last decade, nanoparticles have received several applications ranging from emulsion stability [13][14] and EOR [15][16][17]. Particularly, carbon nanoparticles including carbon nanotubes (CNT), single-walled CNTs, multi-walled CNTs, and carbon dots were tested mainly in the laboratory for EOR potential. Recently, there was one test conducted in the field. While these carbon-based nanoparticles are promising, they are expensive, thus, making field applications uneconomical. As a result, the development of a cost-effective and environmentally friendly carbon nanomaterial is highly desirable. So far, date-leaf carbon nanoparticle (DLCNP) application does not extend to GEOR. It was to develop carbon nanomaterial from the date-leaf via ball milling and the pyrolysis technique and examines its potential in GEOR. The objectives are achieved through experimental processes.

2. Carbon Nanoparticle in EOR

The influence of MWCNT on IFT and surface tension was examined at room temperature by Soleimani et al. [18]. The optimum MWCNT concentration was achieved at 0.3 wt%. This solution produced 18.57% incremental oil from a glass bead experiment. The rheological properties of a mixture of an acrylamide polymer and MWCNT were tested in a high-pressure high-temperature (HP-HT) and high salinity environment [19]. Improvements in viscosity and stability in the harsh HP-HT environment were achieved by negative polyelectrolyte and polyampholytic polymers. The dispersion effects of carbon nanotubes (CNT) hybrids in foam and emulsion were known in porous media by Kadhum et al. [20]. It was found that a stable CNT dispersion was obtained using a highly polarized polymer such as Arabic gum and polyvinyl pyrrolidone. It was conducted to examine the foam stability and viscosity of a surfactant polymer and MWCNT blend [21]. Investigation reveals that MWCNT could improve flow behavior in the foam of porous media. A-Dots or Arab-D dots were applied in a giant Ghawar field in Saudi Arabia to explore EOR potential [22]. A core flood experiment was conducted at 95 °C before the field trial and was followed by a post-flood with 120,000 ppm salinity brine. The average porosity, permeability, and pore volume values of the core plug were 20.3%, 9.89 mD, and 18.74%, respectively. A concentration of 0.001% w/w (10 ppm) of A-Dots solution was injected at a rate of 0.10 cm^3/min. The solution occupied about 20% of the total pore volume (3.8 cm^3). The oil recovery factor reported was 96%. A huff-and-puff method was applied in an Arab-D field trial. The production period was two days and the shut-in time was three days. The distance between the injection and production wells was 1 to 3 km. A total of 5 kg of A-Dot particles were mixed with 255 bbl of injected water. The solution was then injected at a rate 3300 bbl/day. The injection pressure and temperature were 1500 psi and 90 °C, respectively. The overall field trial outcome reported an oil recovery of approximately 82% implying that nano agent concepts are promising in boosting the recovery amount of trapped oil.

3. Nanoparticle Preparation

Carbon-based nanomaterials (CBNs) are emerging as an essential topic in the fields of science and technology. Carbon and its allotropes have been used widely in various applications (such as fiber optics) due to unique aspects such as its excellent physical, chemical, thermal, electrical, and biological properties [23]. Other applications include electrochemical sensors [24][25], electronics [26], drug delivery [27], energy storage [28], solar cells [29], environmental pollutant removal [30], construction materials [31][32], and various materials science applications [33][34][35][36][37][38][39][40]. While these nanomaterials are receiving significant attention, the conventional preparation methods for CBNs are complicated and expensive, thus, limiting their utilization. Consequently, alternative forms of developing CBNs via relatively simple, cost-effective, and sustainable approaches are of great interest. CBN production from biomass could offer an ideal economic and sustainable system. The leaves from trees and other forestry are abundantly available and often go unused. It would be perfect to utilize this biological waste as a cheap material for conversion into value-added carbon products useful in several potential applications.

Ball milling and pyrolysis, among various methods, were adopted for nanomaterial preparation and carbonization respectively. Ball milling is a simple and economical method that allows for the synthesis of nanomaterials on a large scale. It is a top-down technique where any powdered material is mechanically milled into nanoparticles using balls of various stiffnesses. The kinetics of milling depends on the milling energy, type, and size of the balls, milling speed, temperature, and duration of the milling process. Various nanocrystalline/amorphous materials were synthesized using this methodology [41][42][43][44]. On the other hand, pyrolysis is a simple and popular controlled thermochemical treatment technique that is employed to convert waste or any other biomass into valuable products. It is commonly used to prepare biochar, charcoal, and biogas for various commercial applications. Many waste materials, such as rice husk [45], jute sticks [30], date palm [46], wood waste [47], and tree/plant leaves [48][49], were converted into value-added products using this technique.

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