CHAPTER

4
NANOPARTICLE-STABILISED FOAM FOR ENHANCED OIL RECOVERY

Abdul Rahim Risal, Nur Bashirah Azli,
Muhammad Noorul Anam Mohd Norddin, and Sharul Nizam Hasan

4.1 INTRODUCTION

A solvent injection like carbon dioxide, methane, and nitrogen effectively dissolves and mobilises the residual oil (Kumar et al., 2022). Unfortunately, injecting carbon dioxide, nitrogen, and natural gas into a reservoir results in poor sweep efficiency and ineffective displacement (Hassanzadeh et al., 2023). Under normal reservoir conditions, gas is less viscous than the existing reservoir formation water and residual oil, and often, the gas fingers through the existing high-permeability channel or rises to the top of the reservoir, causing imminent gravity segregation (Li. et al., 2022; Xiaolong et al., 2021). Even when facing a critical problem, gas, especially carbon dioxide injection, is still favourable due to its achievable dynamic miscibility in most reservoir conditions (Almobarak et al., 2021; Kumar et al., 2022). Because of that, mobility control was introduced to control the low viscosity and density gas flow from fingering and segregating through the residual oil, causing premature gas breakthroughs (Massarweh & Abushaikha, 2022).

The concept of mobility control has led to increasing interest in dispersed gas-liquid or foam flooding in achieving mobility control in the displacement process (Almobarky et al., 2020; Khandoozi et al., 2023). Even compared to water alternate gas (WAG), limited research suggested that the foam flooding process performed better primarily due to effective gas impediments (Li et al., 2020). Foam flooding reduces gas mobility by increasing the gas's apparent viscosity and density, thus mitigating gravity override and fingering (Khandoozi et al., 2023). The higher gas's apparent viscosity also minimises the effect of a non-homogeneous reservoir by blocking the high permeability channel and diverting foam flow to the previously untouched zone, consequently improving the sweep efficiency (Li et al., 2020). Foam is more advantageous than using a simple fluid of the same nominal mobility because foam has greater apparent viscosity than the displaced fluids, reduces gas mobility, and improves the governing viscosity ratio.

Despite foam's favourable properties, foam is kinetically unstable and breaks easily. Even with the addition of surfactant to enhance its stability, bubble coarsening is imminent, mainly due to the coalescence, Ostwald ripening, and liquid drainage (Yu & Kanj, 2022). The surfactant-stabilised foam's instability is further aggravated by the surfactant adsorption onto reservoir grain (Yekeen et al., 2017) and degradation of a surfactant under harsh reservoir conditions such as high temperature and high pressure (He et al., 2022). Instead of opting for more uneconomical and expensive methods like increasing surfactant concentration and adding a co-surfactant or polymer, researchers have been studying the addition of nanoparticles in foam stabilisation (Briceño-Ahumada et al., 2021; Khandoozi et al., 2023).

Multiple studies (Chen et al., 2023; Liu et al., 2020; Suleymani et al., 2020; Sun et al., 2023; Xu et al., 2022) reported that the nanoparticles can stabilise foam in foam flooding. Theoretically, the properties of the nanoparticle surfaces, nanoparticle aggregation in foam lamella, the foaming agent, and the presence of a third phase, such as the oil phase in the system, strongly influence foam stabilisation (Afifi et al., 2021; Razavi et al., 2020; Tang et al., 2023). Nanoparticles' hydrophobicity has been acknowledged as one of the prominent factors influencing foam stability. The hydrophobic nanoparticle has been reported to induce foam breakage instead of stabilising, hence, it is a good de-foaming agent (Wang et al., 2020). Although it has been established that hydrophobic particles induce foam breakage, researchers have agreed to the potential of partially hydrophobic particles (contact angle 60° to 100°) in improving foam stability (Chen et al., 2023; Liu et al., 2020; Monjezi et al., 2020; Sun et al., 2023; Wang et al., 2020).

Naturally, partially hydrophobic particles are scarce. Normally, nanoparticle's partial hydrophobicity can be achieved through surface treatment or surface coating (Monjezi et al., 2020; Wang et al., 2020). The treatment includes wettability alteration through surfactant adsorption and chemical modification by a silane ligand reaction. In surfactant adsorption, the particles are dispersed in a surfactant solution with a known concentration. The surfactant adsorbed onto the particle's surface is believed to have changed the wettability of the particle. Chemical modification alters nanoparticle surface wettability by chemically reacting the hydrophobic silane ligand with the nanoparticle surface (Monjezi et al., 2020; Pal et al., 2020; Rattanaudom et al., 2021; Xu et al., 2022).

This research highlights the potential of partially hydrophobic nanoparticles in foam stabilisation for enhanced oil recovery. The conventional surfactant-stabilised foam will be used as the benchmark, where adding wettability-altered nanoparticles is expected to improve the foam's stability. The research work uncovers the nanoparticles' effectiveness in stabilising foam film in relation to the hydrophobicity or wettability of the nanoparticles.

4.2 NANOPARTICLE STABILISED FOAM

Three major mechanisms that govern the foam's long-term stability include liquid drainage, bubble coalescence, and coarsening, considering no external force was involved (Suleymani et al., 2020). The addition of surfactant is crucial to improving all the foam stability mechanisms. In a foam system, the addition of surfactant aids in overcoming liquid surface