Additives for Improving CO_2 Floods

Sasol Performance Chemicals

About Us

Sasol's Performance Chemicals business unit markets a broad portfolio of organic and inorganic commodity and speciality chemicals. Our business consists of four key business divisions: Organics, Inorganics, Wax and PCASG (Phenolics, Carbon, Ammonia and Speciality Gases). Our offices in 18 countries serve customers around the world with a multifaceted portfolio of state-of-the-art chemical products and solutions for a wide range of applications and industries.

Our key products include surfactants, surfactant intermediates, fatty alcohols, linear alkyl benzene (LAB), short-chain linear alpha olefins, ethylene, mineral oil-based and synthetic paraffin waxes, cresylic acids, high-quality carbon solutions and high-purity and ultra-high-purity alumina. Our Speciality Gases business supplies its customers with high-quality ammonia, hydrogen and CO_2, as well as liquid nitrogen, liquid argon, krypton and xenon gases.

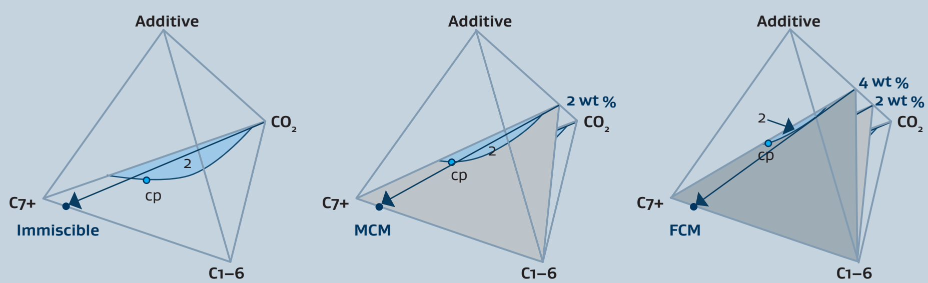
Our products are as individual as the industrial applications they serve, with tailor-made solutions creating real business value for customers. Ongoing research activities result in a continuous stream of innovative product concepts that help our customers position themselves successfully in future markets.

Our products are used in countless applications in our daily lives to add value, security and comfort. Typical examples include detergents, cleaning agents, personal care, construction, paints and coatings, leather and metal processing, hot-melt adhesives, bitumen modification and catalyst support for automotive catalysts and other diverse specialty applications including oil and gas recovery, aroma production, plastic stabilisation, and polymer production. Every day, our researchers explore ways to improve our products and develop innovations that improve the quality of people's lives.

Sasol's Additives Improve CO_2 Floods

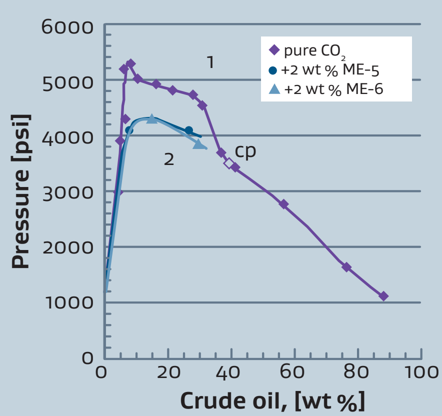
Sasol has developed a range of miscibility-enhancing additives for CO_2 enhanced oil recovery (EOR). Incorporating these additives with CO_2 injection improves the interaction between injection gas and crude oil, leading to increased miscibility and lower injection pressure. The benefits are twofold. First, it provides new opportunities to shallow reservoirs that were not previously candidates for CO_2 miscible flood applications due to miscibility pressures that were above the formation parting pressure. Second, reservoirs that are currently at near-miscible conditions could see further enhanced recovery as a result of the improved miscibility.

Influence of Sasol's Additives on the CO_2 Flooding Process Due to Reduction of the Miscibility Gap

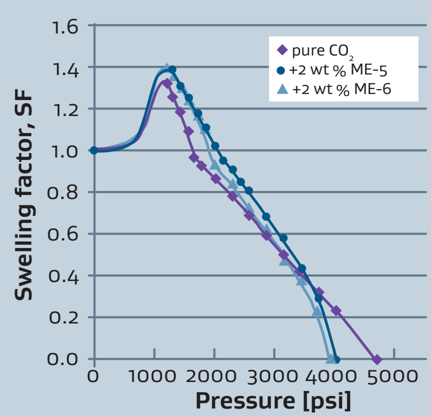


The diagrams above illustrate how Sasol additives significantly reduce the region of immiscibility at constant pressure. This enables an immiscible flood to evolve into a multiple-contact miscible (MCM) or even first-contact miscible (FCM) type condition. Ultimately, production is enhanced, costs reduced and project economics improved.

Miscibility Gap of an Asian Crude Oil and CO_2 @ 65 °C



Swelling Behavior of an Asian Crude Oil and CO_2 @ 65 °C



Due to the improved miscibility behavior by incorporating Sasol's additives into the injection gas, lower pressures are required for full miscibility. The extent of the region of immiscibility is also reduced significantly.

Additionally, the swelling factor (SF) increases due to improved condensation of the injection gas into the residual crude oil. SF of the Asian crude oil is about 20 % higher with the additives compared to pure CO_2.

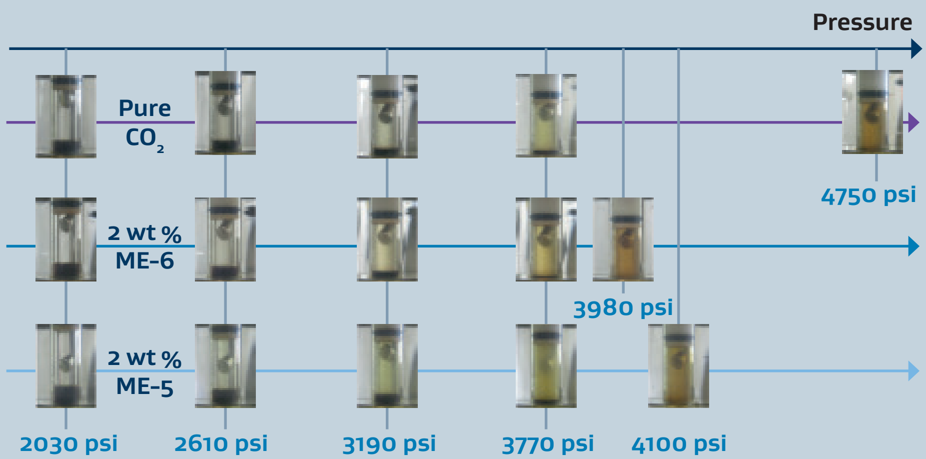
Improvement of the Swelling Behavior

Pure CO_2	+2 wt % ME-5	+2 wt % ME-5
32 %	38.5 %	39 %

Enhancing miscibility of crude oil residual saturation will improve the recovery rate through viscosity reduction and oil swelling effects. The result is a higher recovery factor, as oil in previously inaccessible pore space is displaced from the reservoir rock. Reduction in crude oil viscosity is a further benefit that also leads to an improved liberated oil mobility ratio within the reservoir.

Sasol's novel additives can make miscible CO_2 injection an economic oil recovery technique for shallow or fractured reservoirs, which would otherwise produce oil with marginal economics.

Reduction of the Miscibility Pressure for an Asian Crude Oil and CO_2 @ 65 °C Due to Incorporation of Sasol's Additives



In the phase behavior photographs above, the physical minimum miscibility pressure (MMP_p) required for FCM flooding is reduced significantly from 4750 psi with CO_2 alone to 3980 psi and 4100 psi respectively, with the addition of 2 wt % of two different additives.

Physical Properties of the Additives

Sasol's additives are easily dissolved and co-injected with supercritical CO_2, demonstrating good performance at low dosage. The additives are supplied as high active products (> 95 %) to streamline logistics, while the low viscosities (< 30 mPa·s @ 40 °C) and pour points (< −10 °C) enable easy handling. The additives are also safe for operations, with high flash points of > 65 °C.

Physical Properties of Sasol's Additives

Property	Value
Pour point	< -10 °C
Viscosity @ 40 °C	< 30 mPa·s
Flash point	> 65 °C
Activity	> 95 %

Theoretical Background

Interaction of Injection Gas with Crude Oil

The miscibility between injected CO_2 gas and crude oil at reservoir conditions is the single most important parameter in the design of a successful miscible gas flood. The recovery factors for a CO_2 EOR project strongly depend on the interaction of the injected CO_2 with the residual hydrocarbon in the formation. A broad region of immiscibility (miscibility gap) often exists, which creates phase separation and reduces the displacement efficiency causing a CO_2 flood to be less economical. There are three major processes in CO_2 floods:

First Contact Miscibility (FCM):

Optimum recovery rates are achieved when the process is in the first-contact miscible (FCM) state. In this stage, crude oil and CO_2 are miscible at all ratios and form an instant homogeneous single phase.

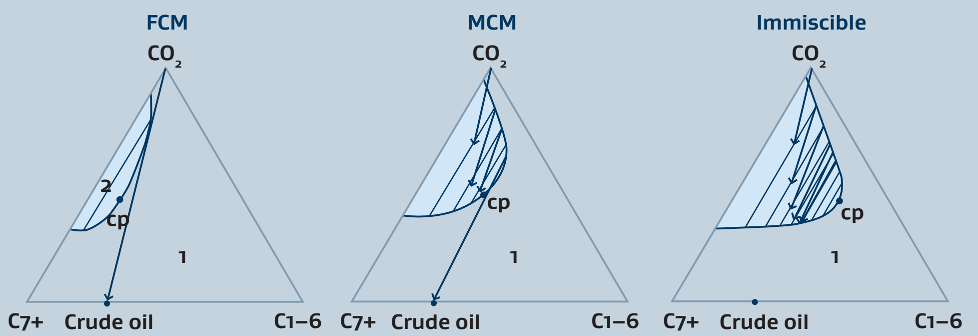
Multiple Contact Miscibility (MCM):

More commonly, the injection pathway crosses the miscibility gap where separation and remixing happens during the flood and the two phases have variable miscibility. When injected CO_2 and crude oil come into contact, vaporization and condensation processes oc-cur. Both processes lead to a modification of the two coexisting phases. Due to continuous condensation and vaporization over several steps, both phases become more and more equal until they are identical in composition, resulting in a homogeneous, fully mixed phase. CO_2 flooding in MCM state still provides increased oil recovery, even though efficiency is reduced compared to FCM processes.

Immiscibility:

If the CO_2 injection pathway never leaves the miscibility gap, crude oil and injected CO_2 will not become fully miscible during the flood and the process basically remains immiscible. Incremental crude oil recovery is therefore not enhanced and causes most projects to become economically infeasible.

Principles of the Different Flooding Processes



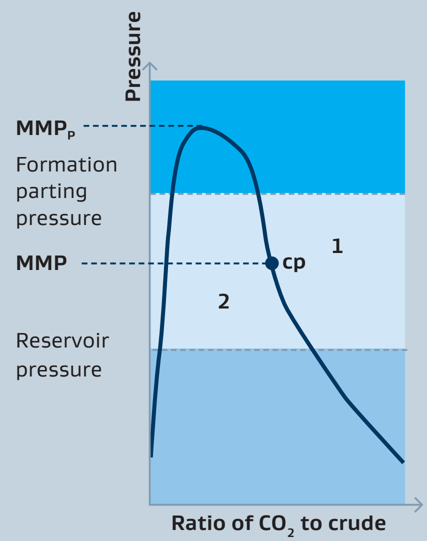
The interaction of CO_2 and crude oil, in combination with the flooding scheme, strongly depends on the injection pressure.

If the gas injection pressure is below the minimum miscibility pressure (MMP), the process remains immiscible.

As pressure in the reservoir increases, the miscibility gap becomes smaller and eventually reaches the MMP, where the flooding scheme converts from immiscible into an MCM state. From a thermodynamic point of view, the MMP strongly correlates with the critical point (cp) of the miscibility gap. The two distinct phases can only reach full miscibility if those phases become equal in composition, which is the case at the critical point. The interfacial tension (IFT) between the two fluids vanishes at cp when full miscibility is achieved.

The physical minimum miscibility pressure (MMP_p) is the lowest pressure required for obtaining instantaneous full miscibility at any ratio. When the CO_2 injection pathway bypasses the miscibility gap, phase separation no longer occurs and FCM is achieved. This is the most efficient CO_2 EOR flooding process.

Schematic View of the Miscibility Gap of a Crude Oil with CO_2



As the illustration above suggests, the applicable pressure window for injection has two limitations. The lower border is the reservoir pressure itself, while the upper limit is the formation parting pressure. Having an MMP below or as close as possible to the reservoir pressure is most desirable.

Swelling and Extraction of the Crude Oil

Especially in MCM processes, the interaction between residual crude oil and the injected gas is crucial for successful recovery. As CO_2 condenses into the liquid oil, the oil phase begins to swell. The increased volume of the swollen oil phase causes residual oil saturation to be forced out of tight pores of the formation rock, where it had previously been trapped. At the same time, the viscosity of the oil is also reduced, improving flow capability through the reservoir even in zones of low permeability. A second process involves some vaporization of the crude oil – initially its lighter components, but in time also the heavier ones – into the CO_2 phase. The oil excess phase is enriched with CO_2, while at the same time oil components are dissolved in the CO_2 excess phase. Improving the interaction between CO_2 and crude oil increases the sweep efficiency potential. This, along with a vanishing IFT as miscibility increases, allows for easy mobilization of the miscible phase through the reservoir.

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- SPE-183389-MS (presented at ADIPEC 2016, Abu Dhabi)
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