Making our world more productive

RECHARGE HNP™

Enhancing hydrocarbon recovery with a next-generation Huff'n Puff treatment that combines gas and nanoparticles

Contents

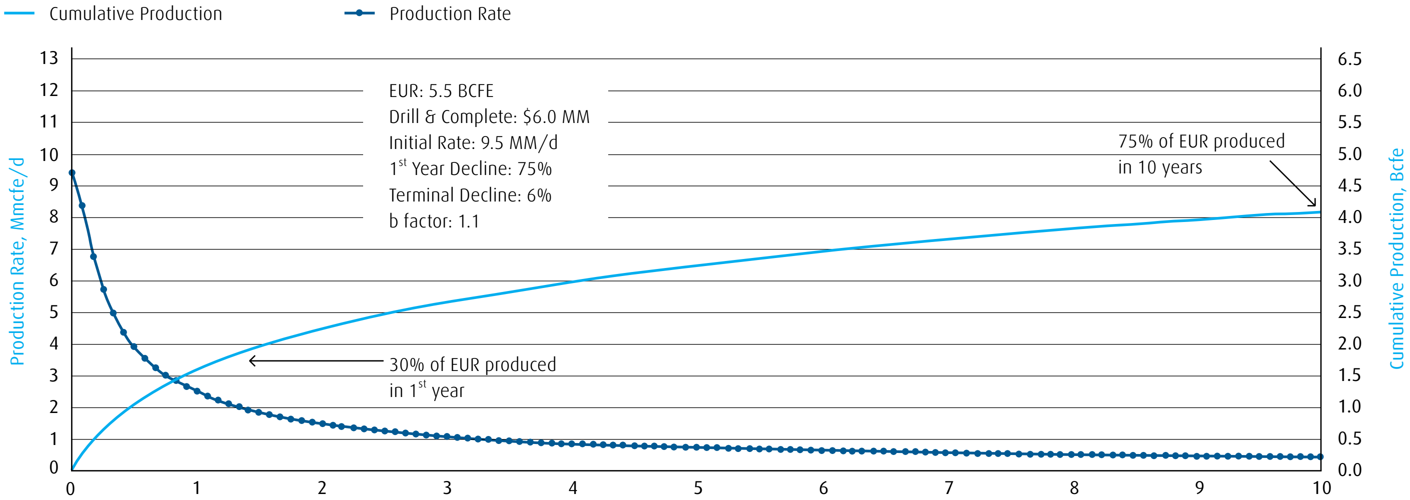
The production challenge: Damage and methods of stimulation

There are around 1.7 million active oil and gas wells in the US. However, hundreds of thousands of these have declined or been depleted to the point of being marginally economic. As wells age, multiple mechanisms contribute to the production decline. In addition to mechanical failures of a well's infrastructure, the following formation damage accelerates the production decline:

- A drop in bottom hole pressure as the well depletes, which decreases relative permeability and increases liquid loading
- Fines migration, mechanically induced by flow velocity[1]
- Scaling, precipitates, paraffins/asphaltenes and clay swelling
- Water or condensate block
- Fracturing (frac) hits

Enhancing well productivity has traditionally been done using stimulation methods that increase the permeability of the reservoir rock or lower the oil viscosity. Matrix acidising[3], as a method of stimulation, is relatively inexpensive but narrow in scope. Ideal candidates for this process typically include wells in formations with a permeability of >10 mD and where solids plug the pores near the wellbore and/or at the perforations. The refracturing process is at the other end of the spectrum. This can be used to stimulate productivity but it is a costlier option and riskier value proposition, especially for unconventionals.

Fig. 1 Example of a production decline curve[2]



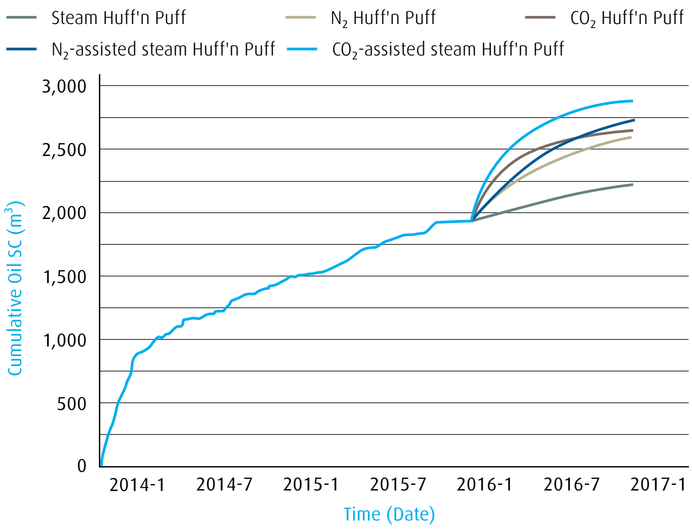
History of how CO_2 and N_2 Huff'n Puffs (HNPs) enhance recovery

CO_2 and N_2 have a long history of improving relative permeability, providing energy and drive in miscible and immiscible recovery applications. Studies have shown that HNP treatments with CO_2 have achieved particularly positive results in oil recovery and short-term production (Figure 2). N_2 HNP has also shown very beneficial results in field studies carried out in suitable formations in the Appalachian Basin.[5] HNP treatments for stimulating well production are usually individual, cyclic well treatments comprising three phases: injection, soaking and production.

HNPs also provide important information on injectivity and pressure communication with adjacent wells. As a proven, single-well stimulation method, they can dramatically increase production from stripper, depleted or low-pressure oil wells. Under certain conditions, CO_2 and N_2 can become miscible with crude, lowering its viscosity and thereby further enhancing recovery.

Over the years, CO_2 and N_2 HNP treatments have been used as an affordable, effective means of enhancing recovery. They are an ideal solution for marginal wells in advanced decline and an effective way of stimulating reservoirs with poor inter-well communications. More recently, studies have shown that HNP injection is a more effective method for enhancing oil production from shales than continuous gas flooding[6,7,8]. Treatments can be applied multiple times to a single well to support improved oil recovery (IOR) and enhanced oil recovery (EOR). Small volumes of CO_2 can generate significant increases in recoverable reserves and production that provide quick payback as a result of that increased production.

Fig. 2 Comparisons of oil recovery using CO_2, N_2, and steam HNP treatments[4]



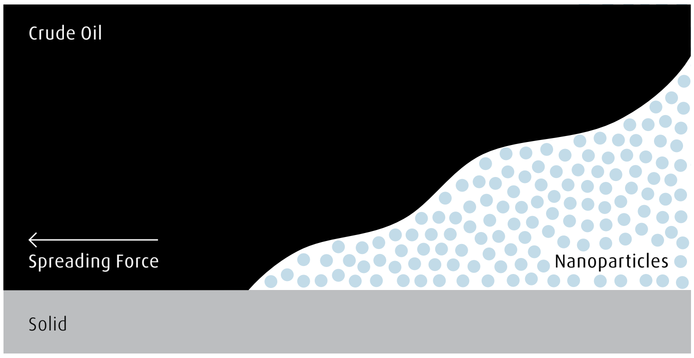
History of how nanoparticles enhance production: Theory, lab and field results

Nanoparticles have been at the forefront of research into various applications in the oil and gas industry for at least a decade now. Nanoparticles are usually particles under 100 nm in size and can be made up of various inorganic materials such as silica, alumina and oxides of iron. Nanoparticles can be structured to contain an inner core and an outer shell[9]. Their outer shell can be modified to alter their wettability. Nanoparticles (either unmodified or modified) can then be dispersed in an aqueous or organic medium such as water, methanol or isopropanol and deployed. Nanoparticles are highly versatile and can be designed for specific applications.

The true mode of action of nanoparticles in a reservoir depends on how they are designed and deployed. However, laboratory studies have shown that nanoparticles in dispersion can align themselves at the oil, aqueous, solid three-phase contact angle[10]. The alignment of the nanoparticles in a wedge between oil and rock generates what is known as structural disjoining pressure, which helps create a pressure gradient sufficient to lift an oil droplet off the surface of the rock. This phenomenon results in increased oil recovery rates and has been demonstrated in imbibition and in-core flow tests[11].

In the field, case studies have been reported that exhibit the effectiveness of nanoparticle dispersions. In one field trial, a silicon dioxide-based nanoparticle dispersion was deployed in a hydraulic fracturing application[12]. The dispersion was deployed as a pre-pad pill ahead of the pad stage in a fracture job for first contact with the reservoir in five wells in the Wolfcamp and Bone Spring formations in the Permian Basin. Field results displayed significant increases in initial production of around 20 percent compared with the type curves. These rates appeared to be sustained for the successful wells even in the presence of an offset fracture breakthrough. The results also showed a decrease in the initial effective decline rate.

Fig. 3 Nanoparticles aligned at the three-phase contact angle to support hydrocarbon recovery (Wasan et al., 2003)



Combining gas and nanoparticles for synergistic recovery enhancement

Nanoparticles + CO_2 or N_2 + Huff'n Puff Know-how

A new HNP process known as RECHARGE HNP™ combines proven, enhanced gas and nanoparticle recovery technologies to create a multi-spectrum remediation process for wells with production problems. By combining the properties of gas and nanoparticles, this solution creates a unique, synergistic process that addresses multiple potential production issues simultaneously. This is extremely useful because wells often experience a number of issues and/or operators may not know exactly what the problem is.

The gas, usually N_2 or CO_2, is used to distribute the nanoparticles more effectively and push them deeper into the formation, allowing the gas and nanoparticles to maximize their production enhancement capabilities. Successful treatment enhances production for six months or more thanks to the effective penetration and residual value of the nanoparticles. This process is extremely flexible and can therefore be used with all types of wells, including conventional, unconventional and oil and gas wells.

The gas itself delivers a range of benefits, for example:

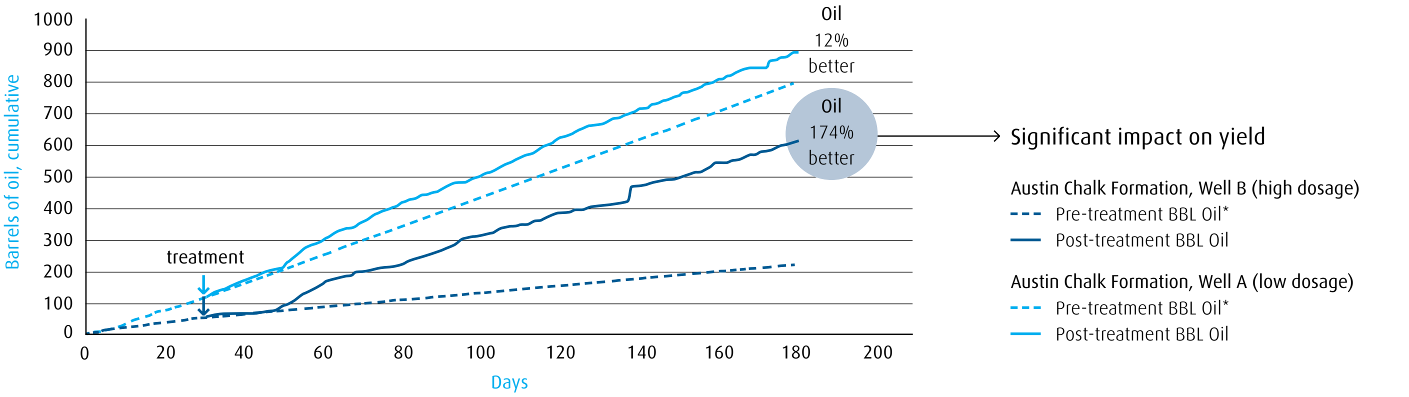
- Stimulating the well with pressure, mobilizing oil or gas to the wellbore
- Removing debris, fines and other matter (removing the well skin)
- Swelling and reducing the viscosity of the oil, facilitating mobilization of oil when miscible
- Displacing oil or gas in the reservoir, mobilizing to the wellbore
- Altering wettability characteristics, removing fluids causing blockages near the wellbore area by changing their wettability to a more neutral wet state

Nanoparticles penetrate micro/nano fractures and pores, enabling production that otherwise would not be possible. The nanoparticles also leave residual particles on the rock surfaces, which can create a wettability-neutral coating that has a lasting effect over time.

Case study: Combining N_2 and nanoparticles in the Austin Chalk and Buda formations

Fig. 4 Cumulative oil production for the Austin Chalk wells before and after treatment with N_2 and nanoparticles

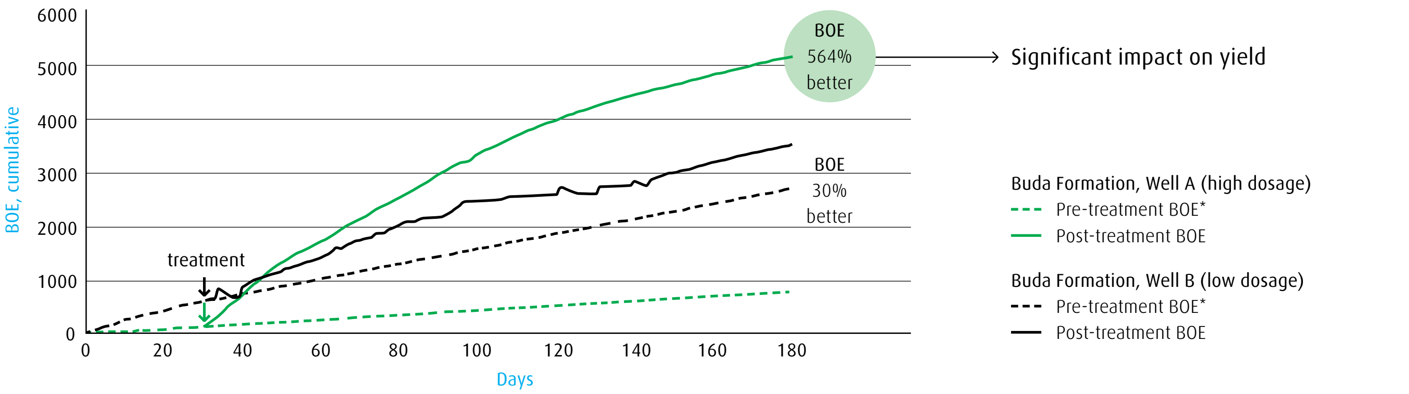
RECHARGE HNP™ (nanoparticles and Nitrogen) pre- and post-treatment comparison after 180 days of cumulative production



*Post-treatment projection based upon the trajectory from the 30-day pre-treatment actuals

Fig. 5 Cumulative BOE production at the Buda wells before and after treatment with N_2 and nanoparticles

RECHARGE HNP™ (nanoparticles and Nitrogen) pre- and post-treatment comparison after 180 days of cumulative production



*Post-treatment projection based upon the trajectory from the 30-day pre-treatment actuals

This case study focuses on a number of aged, depleted wells (some shut-in) in the Buda and Austin Chalk formations in Central Texas (USA). These wells are horizontal open-hole completions. A treatment of Nitrogen in combination with nanoparticles was suggested as a way of achieving better, longer-lasting results. Five wells were treated with various amounts of nanoparticles along with a constant volume of 60 tonnes of N_2 per well. The well candidates, N_2 volumes and stages of injection were chosen by the operator.

After monitoring production for 180 days after treatment and thoroughly analyzing the production results, several observations were recorded. All five wells responded to the treatment. Looking at the dosage of treatment relative to the treatment area, there was a direct, one-to-one correlation between dosage and treatment response. The wells that received higher doses of gas and nanoparticles produced better results. The responses of four of the five wells, two in Austin Chalk and two in Buda, are shown in Figures 4 and 5. The fifth well received the lowest treatment dosage (45 percent lower than the highest dosage) and initially the only response observed on this well was excess water removal. After approximately 160 days of production and excess water removal, a 20-percent uptick in average daily oil production was recorded.

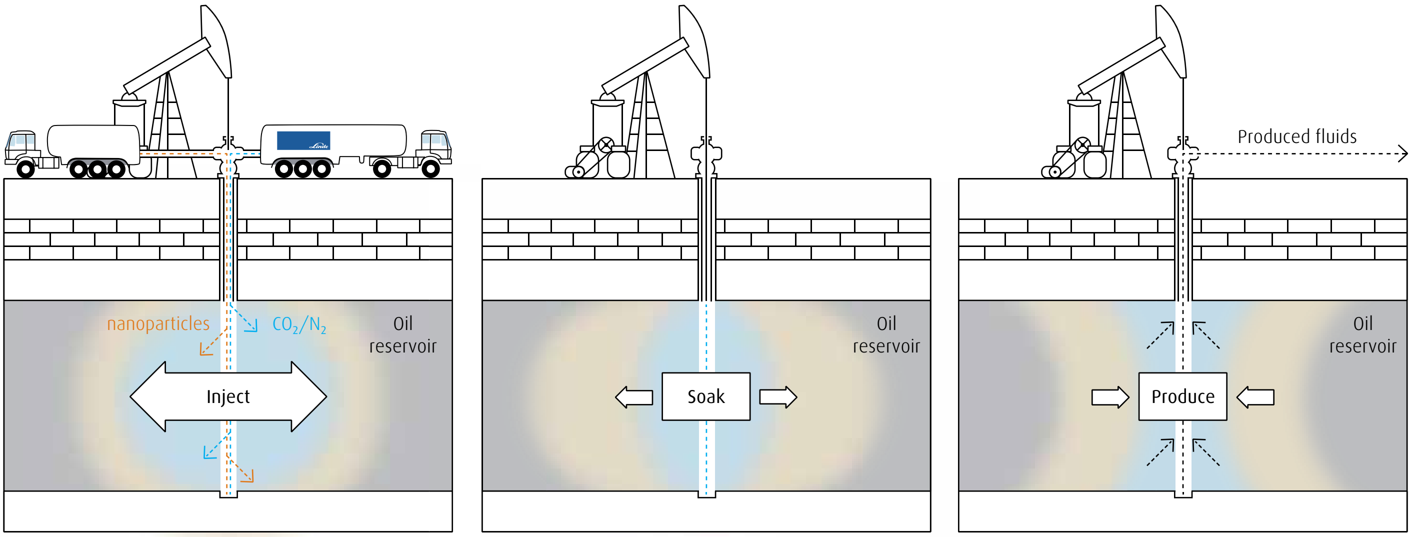
In addition to the direct correlation between the dosage applied to the wells and their responses (improvement in hydrocarbon production expressed as a percentage), there is also a direct correlation between the dosage and the duration of the treatment response. This can be seen in table 1 below.

Table 1 Correlation between the treatment dosage (N_2 and nanoparticles) in the Austin Chalk and Buda wells and the well production response and the duration of the response

	Treatment production response (days)	Treatment dosage (ranking)	Well response (ranking)
Buda, Well A	90	3	4
Buda, Well B	180	1	1
Austin Chalk, Well A	90	4	3
Austin Chalk, Well B	180	2	2

The basics of treatment

Fig. 6 The three phases of a RECHARGE HNP™ treatment



RECHARGE HNP™ is a prescribed, simple, flexible remediation treatment for wells consisting of the three HNP phases: injection, soaking and production. Thanks to the synergies between the nanoparticles and the gas, the soak times can be dramatically reduced compared with traditional HNP treatments. Depending on the type of formation, well history and identified issues, a specific treatment plan is prescribed.

RECHARGE HNP™ treatment comprises a three-phase process of 1) screening the well candidates, 2) specifying and prescribing the treatment, and 3) implementing the treatment. This also includes monitoring post-treatment production for up to 180 days to determine the most suitable next-stage treatment.

Wells must be screened and analyzed to ensure the correct treatment is applied. This is vital to ensuring the treatment has the desired effect on productivity. Table 2 highlights the current screening criteria.

Table 2 Well screening criteria for RECHARGE HNP™

Production	Good initial production (IP) with gradual decline curve that indicates continuous well depletion, wettability issues. Current production <10–20% of IP and preferably >5–10 BOPD or 20 mscfd.
Field Data	Well performance should be on par with other wells in the field; thief zones and extensive fractures need to be understood.
Treatments	Acid and other chemical treatments may negatively impact properties of the nanoparticles.
Well Equipment	Must be in good mechanical condition. Pumps, linings, gaskets. Make sure they are pressure tested or ensure that assurance for pressure treating levels is available.
Water	Excessive salt content (e.g., KCl) and TDS may negatively impact the nanoparticles.
Water Cut	<80% (N_2), <90% (CO_2) ideal, may increase with greater treatment dosages.
Net Pay Zone	<100 ft (30 m) vertical to optimize 60–90 days payback.
Porosity	Porosity/ >8% conventional, >4% unconventional.
Oil	Oil gravity <30 API, CO_2 preferred. Avoid asphaltene precipitation conditions.

Conclusion

RECHARGE HNP™ is a proprietary, multi-spectrum remediation treatment for wells with a range of production problems. Combining the properties of gas and nanoparticles creates a unique, synergistic treatment that addresses several potential production issues simultaneously, while being less cost-intensive than alternative solutions. The extended scope is extremely useful because wells often experience a combination of issues that lead to a decline in productivity or, in many cases, operators do not know the full extent of the downhole problems.

Successful treatments enhance production by six months or more, thus reducing the periodicity of repeated treatments. RECHARGE HNP™ is highly flexible and easy to implement with existing oilfield equipment and methods. It can be used with all types of wells, including conventional, unconventional and oil and gas wells.

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