Conformance control has been a perennial challenge facing oil producers. Unwanted water production has plagued oil companies since the beginning of the petroleum era, except that in the early days oil companies simply walked away from wells with high water cuts and looked for easier pickings.

Commodity prices have changed dramatically since the late 20th century. Now, in some fields, water cuts as high as 90% are accepted, mainly because the remaining 10% of the fluid produced still is valuable. Nevertheless, even if water production cannot be shut off completely, it would be beneficial to have a way to reduce the percentage and accompanying disposal expense.

The trick is to reduce the fraction of water produced, thus increasing the oil fraction. Historically, this was achieved by treating formations with low-viscosity relative permeability modifiers (RPMs), also called disproportionate permeability modifiers. Essentially, these polymers increase the irreducible water in pore spaces, which in turn decreases the effective permeability of the formation to water. For the past 20 years or so, this was accomplished by performing matrix treatments where polymer containing RPM was injected into the formation to a depth of 5 to 10 ft (1.5 to 3 m) radially around the borehole. The polymer adsorbed onto the pore surfaces, tying up mobile water. This increased the residual water saturation and decreased the relative permeability to water without affecting the relative permeability to oil. While this approach was reasonably effective in matrix treatments, the results were less than optimal when applied in hydraulic fracturing applications.

A better solution

The addition of RPM to oilfield brine used in fracturing treatments results in a fluid of relative low viscosity, unable to suspend proppant or create adequate fracture geometry due to high fluid leakoff. Accordingly, a viscous disproportionate permeability modifier (VDPM) has been developed using a viscosity enhancer package.

The biggest advantage of VDPM is that it has sufficient viscosity to create the required fracture geometry in formations with permeability ranging from 2 mD to more than 2 D. Through the use of proprietary chemistry, the non-crosslinked viscous fluid does not interfere with RPM adsorption onto pore surfaces. In addition, the RPM is unaffected by the high shear stress the fluid is subjected to while being pumped at high rates down tubing in the well bore.

By adjusting the concentration and ratio of the RPM polymer to the viscosity enhancer, it is possible to optimize the viscosity of the VDPM for any application. It is the perfect mixture.

Proven versatility

The VDPM has been used successfully in a number of fracturing applications. The most common application has been as a pre-pad to limit water production when fracturing layered reservoirs with widely different water saturations or formations with a known oil/water contact.

However, more recently the VDPM fluid has been used as the main fracturing fluid in frac-pack completions in highly permeable formations with known water contacts. These treatments are not a “silver bullet,” but rather a combination of a rigorous candidate selection process and the use of an innovative fluid.

When VDPM treatments are used, all wells treated show dramatically improved Magdalena oil production with little change in water cut. (Charts, Source: SPE138926)
VDPM in the field

With 83 MMbbl of original oil in place, Colombia’s Caballos formation’s two producing units are in a faulted anticline structural trap. The field is divided into three blocks with differing petrophysical properties and pressure regimes. The Upper Caballos is the principle producer, accounting for 90% of production from its 82 ft (25 m) of net pay. Drive is a combination of gas-cap expansion and a limited water drive. Today the field produces 2,000 b/d of oil with a 74% water cut.

Historically, fracturing was not considered to enhance production due to the proximity of the water contact. However, with production declining and water cut increasing, a five-well pilot project was performed using VDPM as a pre-pad.

A typical treatment consisted of four steps:
1. A step-rate test with an organic solvent pumped above fracturing pressure.
2. A step-down test with bottomhole sensors pumping VDPM at maximum rate.

Dramatic results were achieved. The productivity index (PI) of the wells treated with VDPM fluid increased 3.5 times on average. Water cut decreased by as much as 13%, and average oil production increased by 10%.

A second brownfield application was carried out in the Magdalena Upper Valley Basin in the State of Huila, Colombia, also in the Caballos formation. The field is under waterflood and presently has 76 producers and 32 injectors. Average water cut exceeds 80%. Average gross pay in the field is 400 ft (122 m), while net pay averages 100 ft (30 m).

Each sand lens has a different permeability and porosity, varying from 0.2 to 514 mD permeability and 4.3% to 14.1% porosity. Meanwhile, the sand barriers are poorly defined. Any fracturing treatment will intersect more than one barrier and can communicate with several sands. This results in greatly increased water/oil ratio following treatment.

By incorporating VDPM as a pre-pad in the fracture treatments, it was possible to consistently boost oil production while reducing the water/oil ratio.

In a third application, two offset wells had been completed in shallower intervals, bypassing a lower interval known to be close to the water contact. There was virtually no chance that a fracture treatment of either well could avoid penetrating the oil/water contact in the lower interval.

Before and after treatment, both wells were produced, commingling production from all producing intervals.

The first well was treated conventionally. The result was disappointing, with a dramatic increase in the water/oil ratio from 22% to 66% and a decrease in oil production.

The second well was treated using a VDPM fluid as a pre-pad. Oil production increased by 300 b/d, and water cut increased only 20%, even though it was known at the outset that the oil/water contact could not be avoided in either well.

A different situation was encountered in the CaraCara field in Colombia’s Llanos Basin. The field produces from the Carbonera formation, a zone of alternating high-permeability sands and shales. Pays range from 4 to 20 ft (1.2 to 6.1 m) in thickness, and both sanding and water production are known issues.

Typical completions consisted of gravel packs, but high water production affected the economic life of the wells. When stacked frac-pack completions were initiated using low-viscosity VDPM fluid with a geomechanical model to limit fracture height growth into the aquifers, water production was greatly reduced compared to conventional completions.

VDPM fluids prove their worth

The use of VDPM fluid in fracturing treatments dramatically improved production results in each case by decreasing the effective permeability to water production in the fracture faces. It can be used as a pre-pad or as the main treatment fluid. In high-permeability reservoirs, the reduction in the effective permeability to water due to the VDPM decreases fluid leakoff during the treatments, resulting in improved propped fracture geometry.