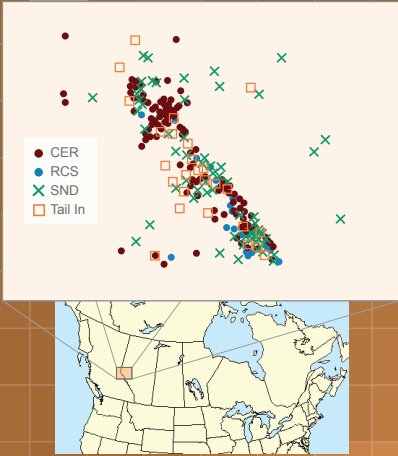


# Wanna Better Frac?



**THE SETTING**

- Western Canada Low Perm Sandstone
- Evaluated 1600 Wells
- In-depth study of 350 Fracs
- Proppant and Fluid effects contrasted


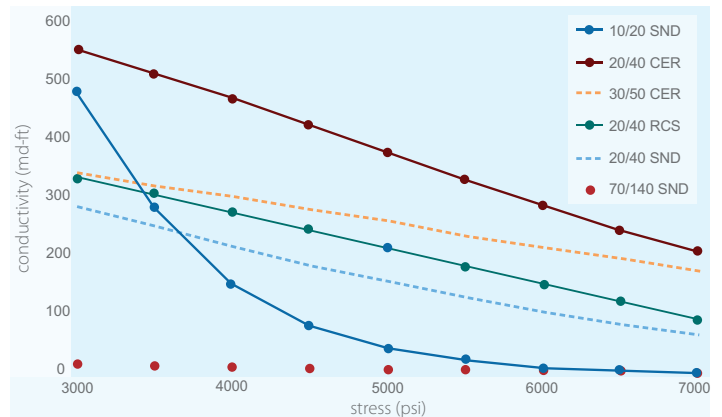
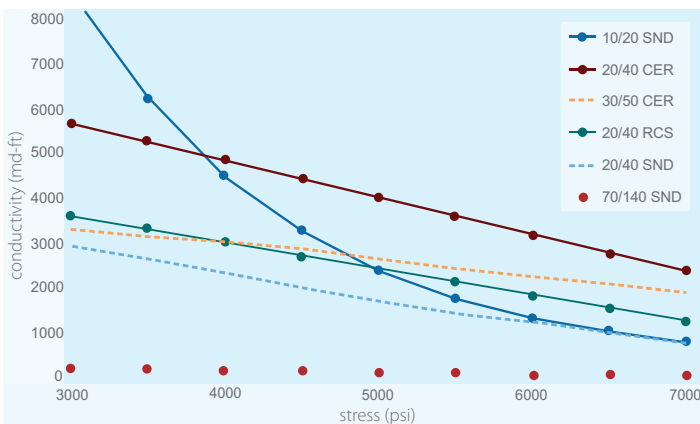


Figure 2a (lower left.) Reference conductivity (laminar flow). Figure 2b (lower right.) Conductivity under realistic conditions may be 95% lower than reference conductivities.



It has been said that in low permeability reservoirs, the only thing more important to well productivity than the hydraulic fracture treatment is your choice of the location where you drill the well. That said, how does one improve the effectiveness of a fracturing treatment? Pinnacle believes there are 3 key components that must be integrated:

## Fracture Design

The frac must be designed with the proper frac fluid for proppant transport, with the proper volume to achieve optimum fracture dimensions, and with the correct proppant and proppant concentration.

## Fracture Placement

The frac design must be properly executed to achieve the design. This requires coordination with the fracture service companies and on-site supervision of the procedure, often with a mini-frac performed to evaluate whether any changes are needed to the design.

## Fracture Conductivity

Optimum fracture conductivity is vital during the flowback/cleanup of fracture fluids and for the long term productivity of the well. This requires a combination of compatible fracture fluids, breakers and proppants.

Pinnacle engineers perform hundreds of treatment designs and on-site supervision each year for our clients. Many of these projects include substantial research into which fracturing components have improved production response in a field. Over the past decade, Pinnacle has mapped more than 10,000 hydraulic fracture treatments and in general, we see fracs that are more complex,

more confined, longer and narrower than previously thought or modeled. This leads us to believe that many fracs are likely conductivity limited. You can see the results of many of these projects and studies in the more than 200 SPE papers we've published.

This case study looks at the Cardium formation in Alberta, Canada. More details can be found in SPE 96962.

## The Background

The most frequently stimulated formation in the Western Canadian Sedimentary Basin (WCSB) is the Cardium formation of the Late Cretaceous period. More than 12,500 fracture stimulations have been performed here during the last 50 years. This study encompassed 1,600 wells operated by 96 companies. We examined productivity of hydraulic fractures propped with various materials and placed with a variety of fluid systems and found that significantly greater economic return has been achieved when fracture designs are optimized.

The Cardium hydraulic fracture treatments in the study area are conducted at modest depths of 5,700- to 8,200-ft but can exhibit higher than normal closure stress, typically from 3,500- to 5,800-psi.

## Pinnacle Performs

Proppant types examined in this study include ceramic proppants (CER), uncoated sand (SND), and resin coated sand (RCS). A variety of fracturing fluid systems have been used in gas wells in this formation, including gelled water (GW), gelled hydrocarbon (GHC), and 100% liquid CO<sub>2</sub> (CO<sub>2</sub>). More than half of the fracs studies in depth were

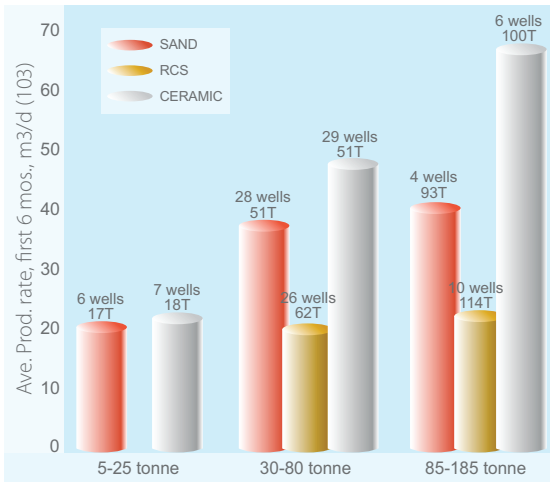


Figure 3. Effect of proppant type and mass on gas wells, GHC

performed with gelled hydrocarbon.

Figs. 2a and 2b show that fracture conductivity after adjustment for non-Darcy flow, gel damage, filter cake, and cyclic stress may be easily reduced by 90 to 95%. The incremental production increase achieved in the Cardium by substituting a ceramic proppant is typically forecast to be 5% to 15% using Stim-Lab's Predict-K model. While this incremental production can easily justify the added expense, the actual benefits observed in the field are greater than production models have predicted.

It is important to recognize that treatment sizes, proppant types, and fracturing fluid systems are not entirely independent in this dataset. Therefore, it is important to create subsets of the data to isolate as many factors as possible. The gas well populations are shown in Fig. 3 with all categories containing between 4 and 29 wells grouped by proppant type and proppant mass. In each of these categories, ceramic proppant shows an even greater benefit over sand than was predicted by models.

Interestingly, wells receiving resin-coated sand did not perform as well as uncoated sand in most comparisons in this case study. It has been demonstrated that modern resin coatings retain some chemical reactivity, and it is possible that gel breaker has been partially scavenged in fracs containing RCS. If coated proppants continue to be utilized in the Cardium, it may be appropriate to further investigate fluid cleanup and well productivity.

#### Economic Considerations

Annual revenue and incremental profit can be approximated with cumulative plots at 8,760 operating hours (one year). Incremental profit should consider the effect of increased gas processing cost and royalty payments. Differences in fracturing costs must be taken into account. However, it appears that incremental stimulation costs

are small compared to the annual cash flow from the well and should not significantly affect the project economics. For instance, the incremental cost to upgrade an 187,000 lbm [85 tonne] sand treatment from sand to ceramic proppant is approximately Cdn\$50M to Cdn\$100M. The incremental cost of an energized gelled hydrocarbon fluid versus a water-based gel is approximately Cdn\$40M. With cumulative production differences on the order of 175 MMcf/yr [ $4 \times 10^6 \text{ m}^3/\text{yr}^1$ ] between well categories, at a conservative gas price of Cdn\$5/Mcf, the incremental revenue generated of Cdn\$875M overwhelms the incremental costs of different fluid systems or proppant types, and makes the analyses relatively insensitive to original stimulation costs.

#### The Results

Results from a detailed study subset of 375 hydraulically stimulated Cardium gas wells:

1. In gelled hydrocarbon treatments, ceramic proppants have demonstrated significant gas production increases compared to sand or resin-coated sand.
2. With large stimulation treatments, gelled hydrocarbon appears to provide superior gas production rates to gelled water.
3. The incremental cost to utilize gelled hydrocarbons or ceramic proppant would typically be repaid within a month and generate over Cdn\$500,000 incremental cash flow during the first year for a typical Cardium gas well.
4. Well productivity was shown to increase with proppant mass when placed with gelled hydrocarbon.
5. Of the ceramic treatments, 73% utilized 30/50 as the largest diameter proppant. Although 30/50 ceramic is a popular product in the Cardium, this analysis suggests that increasing the conductivity of the fractures should be of benefit. Therefore, use of 20/40 or larger ceramic should be consid-

ered if it can be placed successfully.

6. Tail-in treatments were not as effective as when the entire fracture contained ceramic proppant.

The incremental cost of ceramic proppant is usually recovered within 30 days, generating a significant increase in profitability. At current gas prices, average return on investment achieved by optimizing proppant selection greatly exceeds 100%.

Production from Cardium oil wells was also found to increase with proppant concentration and with proppant size. A preliminary review suggests that oil production has been significantly improved with higher conductivity fractures and that further increases in proppant conductivity should be considered.

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