Presentation Outline

- Introduction and Powerwave Overview
- Waterflood Case History
- Conclusions and Forward Plan for this Operator/Project
- Questions and Answers
Wavefront specializes in designing and developing leading-edge techniques for oil well stimulation, improved oil recovery, and environmental groundwater remediation.
Flooding and Stimulation Issues

All porous media are heterogeneous and one of the biggest issues in maximizing flood recovery is effectively placing the injected fluids where we want them (injection conformance).
Tubing Deployment

Tubing String Detail

- Injection packer
- Tubing
- Control line
- Accumulator
- Pulsation dampener
- Wellhead
- Casing
- Flow meter
- Fluid supply
- Flow switch
- Pressure sensor
- Controller
- Powerwave tool
- Water discharge
The Powerwave Process - Forced Injectivity

• An oriented pressure pulse is created at the perforations
• As the wave travels the pore space dilates or flexes propagating the wave further in to the reservoir

\[ P_{bh} = P_{wh} + \Delta P_{hyd} \]

- Amplitude Typically ~250 psi for waterfloods
- Rise Time
- Minimum Pressure in Borehole during pulsing
- Period
- Pressure Decay Rate
Powerwave Mechanisms

Pseudosteady State Pressure vs Distance from Wellbore can be expressed as follows:

\[
p(r) = p_w + \frac{141.2 \ q_w H_w B_w}{kh} \left[ \ln \left( \frac{r}{r_w} \right) - 0.75 + s \right]
\]

Pressure increase rapidly near the wellbore and slower as distance from wellbore increase.

What controls fluid flow and determines the path of least resistance is given by the DIFFERENCE in pressure gradients.
How does Powerwave work?

Pressure gradient in the high permeability streak/viscous finger, \( \text{(1)} \) is lower than in the matrix \( \text{(2)} \), but

When looking at a very short length scale (1 inch or less), the difference between the gradient in the high perm and normal matrix is small.

The forced Powerwave pressure gradient \( \text{(3)} \) totally dwarfs the natural pressure gradient difference on this scale and water is now forcibly injected into the reservoir much more evenly than during static injection resulting in greatly improved sweep efficiency.
Powerwave Mechanisms

Conventional flooding: path of least resistance dominates flow and fluid distribution.

Powerwave™ flooding: pore-scale expansion dominates flow and provides for more uniform fluid distribution.
Powerwave Provides Superior Distribution

Powerwave works to maximize oil recovery factor

- Poor sweep efficiency
- Considerable by-passed oil
- Low oil recovery factor

- Superior sweep efficiency
- Stranded oil mobilized
- Higher recovery factor

Powerwave is a proven and cost-effective method for increasing oil production with existing infrastructure. Compared to the economic costs of drilling more oil wells, Powerwave increases overall recovery with minimal investment.
Chemical Flooding - Laboratory

- Powerwave waterflood
- Powerwave surfactant flood
- Waterflood
- Surfactant flood

Graph showing recovery factor (%) against pore volumes injected.
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Analysis Method – Simple

Pattern: Pattern 1    Well: Well 8

Oil Cut Increase, Powerwave 100%

Oil Cut Decline – Green Line
RMS curve fit of oil cut between the two red arrows.

Powerwave Benefit – Black
Shaded Area
Oil Cut benefit * Fluid potential

Oil Cut Decline – Red Line
RMS curve fit between the two red arrows.

Oil Cut Benefit – Blue Line
Defined by Oil Cut points above the oil cut trend line.

Powerwave Benefit – Black
Shaded Area
Oil Cut benefit * Fluid potential
The split between New Injector Benefit and Powerwave Benefit was determined using the Operator’s experience from previous injectors in this field along with the early Powerwave response to attribute relative benefit. In this case 40% to Powerwave and 60% to the New Injector.
Case History – Eastern Alberta
Case History – Eastern Alberta
Case History – Eastern Alberta Incr. Oil

Incremental Production – 54,000 bbls oil
Last 12 Month Average: 2,660 bbl oil/Month
Case History – Eastern Alberta Oil Cut

![Graph showing Oil Cut (%) over time from 01-Sep-05 to 02-Mar-10 with various data points and lines representing different patterns.]

Legend:
- **Red Line**: Project Oil Cut - 3 Patterns
- **Yellow Square**: Oil Cut Decline Match Points
- **Blue Line**: Project Oil Cut Decline - 3 Patterns
- **Blue Dashed Line**: Pattern 1 Powerwave
- **Red Dashed Line**: Pattern 2 Powerwave
- **Green Dashed Line**: Pattern 3 Powerwave
Case History – Eastern Alberta (Pattern 1)

Legend
- Powerwave injector
- Influencing injector
- New injector
- Pattern Producer
- Offset Producer

Pattern 1 – 14B-12
- Powerwave injector

Pattern 2 – 6C-12
- Influencing injector

Pattern 3 – 4-12
- New injector

Legend:
- Powerwave injector
- Influencing injector
- New injector
- Pattern Producer
- Offset Producer

Strong Pressure Gradient

- 14B2-12
- 14D-12
- 14A-12
- 11D-12
- 11A2-12
- 11C-12
- 14A-12
- 14B-12 Powerwave
- 13A3-12
- 12D-12
- 14C-12

Pressure response, no oil cut increase

- 250 psi
- 70 psi
- 110 psi
- 110 psi
- 250 psi

0 Kilometers 0.5
0 Miles 0.3
Case History – Eastern Alberta (Pattern 1)
Case History – Eastern Alberta (Pattern 1)
Case History – Eastern Alberta (Pattern 1)

Incremental Production – 18,800 bbls oil
Last 12 Month Average: 1,020 bbl oil/Month
Case History – Eastern Alberta (Pattern 1)
Case History – Eastern Alberta (Pattern 1)
Case History – Eastern Alberta (Pattern 1)
Case History – Eastern Alberta

Eastern Alberta Powerwave Pilot Project Results

Graph showing cumulative oil production vs. actual field production, actual incremental daily production, powerwave installation, and base decline.
Case History – Eastern Alberta

![Graph showing economic figures related to the Eastern Alberta Powerwave Project. The graph compares oil revenue and cumulative net cash flow with different price scenarios over a period of up to 25 months post-project start.](image-url)
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Conclusions

• Exceptional results have been achieved using Powerwave Technology
• 175% increase in production rate at the project level
• 70% reduction in decline rate from 3.4% to 1% per month
• The results for Pattern 1 representing a “true test” of Powerwave showcase the best results of the 3 patterns
• Powerwave has delivered significant improvements in sweep efficiency that has lead to significantly increased reserves
Forward Plan For This Operator/Project

• We are in the process of expanding from 3 systems to 53 systems for this operator.
• The expansion is a combination of:
  • electrical tools deployed on tubing and
  • mechanical tools set on wireline
• The wireline deployable Voyageur Powerwave system will cut implementation cost for project expansion from ~$40,000 to circa ~$2,000 per well
• Repair of broken wells to increase capture of Powerwave sweep benefits
• Evaluating future chemical options
Detail of landing nipple pre tool installation.

Detail of landing nipple with lock and tool set.

pulsation dampener

wellhead

Injection fluid supply

casing

packer

Landing nipple

wireline entry guide

Perforated interval

Lock set in Landing nipple

Spacing tube

Powerwave tool