Expandable Tubular Technology
ChevronTexaco Presentation

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April 20, 2004
Expandable Solid Casing System
Expandable Solid Tubular Myths

- Require Special, Expensive Casing
- Must Handle Casing with “Kid Gloves”
- Cannot Expand Strong Casing (P110)
- Cannot Expand Large Casing (20”)
- Cannot Expand Off-the-Shelf Casing
- Strong Threaded Connections Not Possible
- Expanding Monobore Overlap Difficult
- Monobores Must be Expensive
- Shell IP Hinders Competition
Existing Weak Connector Problems

- Major Cause of SET Failures
- Limit Ability to Expand Strong Casing (P110)
- Limit Amount Casing can be Expanded
- Reduce Burst and Collapse Strength
- Pull Apart During Expansion
- Require Special Casing
- Cannot Tolerate Casing “Dings” and Blemishes
- Require Outer Sleeve Reinforcement
- Thread Leakage Prevents Expansion
ENVENTURE Expansion System

Unexpanded Casing

Expansion Cone

Expanded Casing

High Pressure
(Δp=3000 to 4000 psi)
NOBLE 2³⁄₈” to 7⁵⁄₈” Expandable Tests (TIW)
TIW Casing Expansion Tests

Setting Up for Testing

Testing Instrumentation
7-5/8” Casing Expansion Test

7-5/8” 12 Deg Cone  16% Expansion
4-1/2” Casing Expansion Test

4-1/2” J-55 Casing 30% Expansion 20 Deg. Cone Angle
Cone Variations

- Cone Angles
- Expansion Ratios
- Cone Finishes
- Cone Material
- Casing Sizes

(Anticlockwise)
Casing Expansion Test Parameters

- Different Materials
  - Carbon Steel
  - Stainless Steel
- Cone Angles
- Different Sizes
- Solid/Perforated
- Different Hole Spacing
- Expansion Percentage
A force of 210,000 pounds was required to push the cone through the casing. Note the pressure drop when we intentionally stopped the test and then resumed with about the same force required for expansion before and after the intentional stopping.
Force/Displacement Measurements

Various Casing Material:
- J-55
- N-80
- 316 SS

Various Casing Coatings:
- Sandblasted
- Honed
- Moly-Coated
- Uncoated
TIW Test Well
NOBLE 16” & 20” Expandable Tests (Texas A&M)
20" Expander Cone being Machined
Expanding 20” X-56 - 104 lb/ft Casing
20” Casing Expanded to 23”
16” L80 – 84 lb/ft Casing (15% Expansion)
16” Casing Expanded to 18.4” (15%)
Expanded 20” Casing Bores
Smooth w/ No Galling
A&M Instrumentation
Force-Displacement Curves
Max 20” 581 kips – Max 16” 657 kips
Surface Expandable Well Design

Conventional

Wellhead & BOP

36” @200’
(Structural Pipe)

30” @600’

Trouble Zone @800’

26” @1,200’

20” @1,500’
(Surface Casing)

13⅜” @2,000’

Top-Hole Expandables ™

Wellhead & BOP

36” @200’
(Structural Pipe)

30” @600’

Trouble Zone @800’

26” @900’

20”→24” @1,200’

20”→22” @1,500’

20” @2,000’
16” & 20” Expandable Test Conclusions

- World’s first Expansion of Large Casing
- Expanded 20” to 23”
- Casing in Excellent condition
- Cone Forces Within Acceptable Limits
- Model Predictions Accurate
- Large Potential Market for Offshore Drilling
- Hydrid is Developing 20” Expandable Connection
- Will Reduce Deep Water Drilling Costs
NOBLE 7\(\frac{5}{8}\)” Pumping Tests (TIW)
TIW Pumping Test Schematic

- High Pressure Pumping System
- Safety Head
- High Pressure Flow Meter
- Gauge
- Valve
- Expandable Casing
- Tank
- Displacement Transducer
Casing Pumping Test
7-5/8”–29.7ppf–N80

6’

40’

15’

Launcher

Threaded Nut (STUB ACME)

Flow 6,000 psi

Conical Cone

Guide

Hydrid Threads

Threaded Nut

1” Thread 6,000 psi
Launchers For 7-5/8” Casing Pumping Test
TIW Pumping Test
Expander Cone Assembled on Carrier
TIW Make Up Machine

Note brass inserts used on casing to prevent scarring connections
7-5/8" Test Section Ready for Testing

Brass inserts for make-up

Note string installed to pig for displacement measurement
7-5/8” Casing Being Expanded
Severely Galled Cone  (No Coating)
Severely Galled Casing (No Cone Coating)
Improved Titanium-Nitride Coated Cone (No Galling)

Note slight marks
Hydril 723 Connection after Expansion
(8,000 psi Test Pressure)
API Casing Burst Pressure

\[ P_{br} = 0.875 \frac{2\sigma_{yield}t}{d} \]

where  
- \( P_{br} \) = Burst Pressure  
- \( \sigma_{yield} \) = Yield Strength  
- \( t \) = Thickness  
- \( d \) = Casing OD

\[ \sigma_{yield} \leq \frac{P_{br}}{2t} \]

\[ \sigma_{yield} \leq \frac{0.875 P_{br}}{d} \]

Applied Drilling Engineering  
SPE Textbook Series, Vol. 2, p308
Hydril Pin & Box Unscrewed after Expansion (Excellent Condition)
Hydril 731 Expandable Wedge Thread

- Stronger Threads Critical to SET Success
- Hydril 731 Wedge Thread 30 to 60% Stronger
- Wedge Design Holds Threads Together
- Off-The-Shelf Casing With Normal “Dings” and Defects
- Eliminates Special Handling of Casing
- Increases Reliability & Reduces Cost
- Gives Noble a Major Competitive Advantage
7-5/8” Casing Collapse Tests
Collapse Test – Expanded 7-5/8” 29.7 lb/ft. Casing
Collapse Test – Expanded 7-5/8” 29.7 lb/ft. Casing
Note bulge in pipe at 2750 psi
Mathematical Modeling
Axial Load vs Cone Angle

Axial Cone Load vs. Cone Angle

Axial Load, 1,000 lbf

Cone Half Angle, deg
Predicted vs Measured Cone Forces

Cone Force, 1,000 lbs

Casing Type

4-1/2'', 11.6 ppf, L-80
7-5/8'', 29.7 ppf, N-80
20'', 104 ppf, X-56
16'', 84 ppf, N-80
Computer Modeling
7\(\frac{5}{8}\)” N–80 Casing API Burst Pressure

**API Burst Performance of 7-5/8\” N-80 Casings**

- 47.1 ppf: 8,875 psi
- 45.3 ppf: 8,423 psi
- 42.5 ppf: 7,928 psi
- 39.0 ppf: 7,007 psi
- 33.7 ppf: 5,982 psi
- 29.7 ppf: 5,186 psi
- 26.4 ppf: 4,513 psi

**Axes:**
- Y-axis: API Burst Pressure, psi
- X-axis: Casing ID Expansion, %
7 5/8” N–80 Casing Collapse Pressure

API Collapse Performance of 7-5/8” N-80 Casings

API Burst Pressure, psi

Casing ID Expansion, %

47.1 ppf
45.3 ppf
42.5 ppf
39.0 ppf
33.7 ppf
29.7 ppf
26.4 ppf
8,281
7,487
6,619
5,003
3,356
2,448
1,680
FEA Modeling by NNC

Mandrel Push Force with Displacement along Tubular

Tool Extrusion Force (Te)

Lower Bound

Upper Bound

Lower Bound (No Friction)

Upper Bound (No Friction)

Hoop Stress across Tubular thickness (at Free End) after Expansion

FEA Modeling by NNC
Monobore Systems
Monobore Well

- Wellhead
- Expandable Liner Hanger
- Expandable Seal
- Expandable Casing
- Expandable Thread

Overlap
Advantages of Monobores

- Deeper Water Capabilities
- Faster Drilling & Lower Cost
- Less Environmental Damage
- Less Casing & Bits
- Less Mud & Cement
- Smaller Rigs & Risers
- Smaller Work Boats
- Fewer Cuttings
Monobores Require Smaller Rigs

- Smaller, Lower Cost Rigs
- Smaller Risers & BOPs
- Lower Hook Loads
- Lower Horsepower & CO₂ Emissions
- Less Deck Space
- Reduced Riser Tensioning
- Reduced Mooring Requirements
Tubular Expansion System

Unexpanded Casing

Expansion Cone

Expanded Casing

Pressure
Expander Pressure in Casing Expansion

- Burst Pressure
- Critical Pressure

Pressure, psi vs Casing ID Expansion, %

- Expander Pressure
Monobore Expansion Pressure
8.835” Monobore ID, 9⅝” Expandable Casings

8.835” ID

7⅝” ID

0.605”

Expand Casing

Required Liquid Pressure

5,417 psi

Expand Casing & Overlap

4,851 psi

ID Expansion 28.5%
Monobore Expansion Pressure
8” Monobore ID, 7\(\frac{5}{8}\)” Expandable Casings

Required Liquid Pressure
- Expand Casing: 1,978 psi
- Expand Casing & Overlap: 5,756 psi
ID Expansion 16%
Existing Monobore System I
Single-Stage Expansion (Top-down)

Start to Expand
Base Casing
9\(\frac{5}{8}\)”, 40 ppf, L–80
Expandable Liner Hanger (Overlap)

Expand Overlap
Cone
15,166 psi
Burst 5,745 psi

Cone
7,386 psi
Burst 5,491 psi

(A) (B) (C)

Expand Casing
Cone

Expandable Casing
7\(\frac{5}{8}\)”, 29.7 ppf, L–80
Existing Monobore System II
Single-Stage Expansion (Bottom-up)

Start to Expand

Expand Casing

Expand Overlap

Base Casing
9⅝", 40 ppf, L–80

Expandable Liner Hanger (Overlap)

Expandable Casing
7⅝", 29.7 ppf, L–80

Cone

15,166 psi Burst 5,491 psi

Cone (A) (B) (C)

7,386 psi Burst 5,491 psi

Cone (A) (B) (C)
Existing Monobore System III
Dual-Stage Expansion (Bottom-up & Top-down)

Start to Expand

Stage I
Bottom-Up

Stage II
Expand Overlap

Stage II
Expand Casing

Base Casing
9\(\frac{5}{8}\)”, 40 ppf, L–80

Exp. Liner Hanger
(Overlap)

Expandable Casing
7\(\frac{5}{8}\)”, 29.7 ppf, L–80

Cone 1

Cone 2

Cone 2

(A) (B) (C) (D)

5,416 psi Burst 5,885 psi

4,816 psi Burst 5,745 psi

2,200 psi Burst 5,427 psi
NOBLE Monobore System I
Dual-Stage Expansion (Single Expandable Cone)

Start to Expand

Stage I Expand Casing

Lower and Expand Cone

Stage II Expand Casing

Stage II Expand Overlap

Base Casing
9 5/8", 40 ppf, L-80

Expandable Casing
7 5/8", 29.7 ppf, L-80

Original Cone

5,416 psi
Burst 5,885 psi

Expanded Cone

2,200 psi
Burst 5,427 psi

Expanded Cone

4,816 psi
Burst 5,427 psi

(A) (B) (C) (D) (E)
NOBLE Monobore System II
Dual-Stage Expansion (Expandable & Non-Expandable Cones)

Expand Cone 2 and Start to Expand Casing
Stages I and II
Latch Cone 2 and Expand Casing
Lower Work String and Cone 1
Expand Overlap

Base Casing
9 5/8", 40 ppi, L–80

Expandable Casing
7 5/8", 29.7 ppi, L–80

Cone 1
Expanded Cone 2

5,416 psi
Burst 5,885 psi

2,200 psi
Burst 5,427 psi

4,816 psi
Burst 5,427 psi

(A) (B) (C) (D) (E)
NOBLE Monobore System III
Dual-Stage Expansion (Dual Expandable Cone)

Start to
Expand Casing

Stage I
Expand Casing

Expand
Cone 2

Stage II
Expand Casing

Stage II
Expand Overlap

Base Casing
9\(\frac{5}{8}\), 40 ppf, L=80

Expandable Casing
7\(\frac{5}{8}\), 29.7 ppf, L=80

Cone 1

Cone 2

5,416 psi

Burst 5,885 psi

Cone 1

Expanded
Cone 2

2,200 psi

Burst 5,427 psi

(A) (B) (C) (D) (E)
Monobore Casing Burst Problem

- Larger Diameter Casing is Better
- Thinner Casing is Better
- Casing Strength has Minimal Effect
PROPOSED NOBLE MONOBORE JIP
Noble Drilling DEA Monobore Project

- 6 to 8 Operators
- $0.5 to $1 Million Fee
- Drill Wilcox Monobore Test Well
- Each Operator Drills One 7-5/8” or 9-5/8” Monobore Well
- Complete Monoboires with Production Strings
- Participants – Share Field Data, Observe Field Tests
- Noble – Manage Project, Engineering, Well Planning
- TIW – Equipment Design, Field Tools
- Hydril - Expandable Wedge Connections
- IP – To Service Companies to Allow Commercialization
- Operator Benefit – Accelerate Monobore Implementation
Monobore Wilcox Test Wells

- $1 million JIP Funding
- 5000 to 6000 ft Wilcox Wells
- Fayette County, Texas Area (near Houston)
- No Well Control Problems
- No Borehole Stability Problems
- 7-5/8” Monobore Sections (1000 – 3000 ft)
- Test Expansion Tools & Procedures
- LEXXUS OIL Contributes Well, Assumes Risk
JIP Candidates

International Oil Companies

- BP
- ChevronTexaco
- ConocoPhillips
- ExxonMobil
- Shell
JIP Candidates

National Oil Companies

- Abu Dhabi – ADNOC
- Argentina/Spain – REPSOL
- Brazil – Petrobras
- China – CNPC, CNOOC, SINOPEC
- Denmark – Maersk
- France – Total, Gaz de France
- India – ONGC
- Indonesia – PERTAMINA
- Italy – ENI/AGIP
- Japan – JNOC
- Malaysia – Petronas
- Mexico – Pemex
- Norway – Statoil, Norsk Hydro
- Russia – Lukoil, Tatneft, GAZPROM
- Venezuela – PDVSA
JIP Candidates

Large Independents

- Amerada Hess
- Anadarko
- Chesapeake
- Devon
- Dominion
- El Paso
- Kerr-McGee
- Murphy

- Newfield
- Oxy
- Pioneer
- Samedan
- Spinnaker
- Unocal
- Vastar
Solid Tubular Conclusions

- Expandable Tubulars will have major impact
- Solid Expandable Tubulars reduce costs
- Expandable Screens increase production
- Expandable Screens Eliminate Sand Production
- Monobore wells “Holy Grail” of Expandables
- Monobores hindered by lack of field tests
- Noble monobores ready for commercialization
- Noble forming monobore JIP
- JIP will drill shallow test monobore
- 6 to 8 JIP Participants will each drill one monobore
- JIP will accelerate monobores by 5 to 10 years
Expandable Sand Screens
Expandable Sand Screen Myths

- Difficult to Expand Screens Over 30%
- Compliant Sand Screens Must be Weak
- Cannot Rotate Unexpanded Compliant Screens
- Compliant Screens Apply Low Contact Pressure
- Connection Failures a Major Problem
- Require Short-Life Roller Expanders
- Screens Difficult & Expensive to Manufacture
- Liner Hangers a Major Problem
- High Reliability & Low Cost Difficult to Achieve
Time Savings with Expandable Screens (Weatherford)

The bar chart shows the time savings in days for different zones with Expandable Screens. The chart compares the time taken for Gravel Pack + (CNL) Pack Evaluation and ESS across Single Zone, Dual Zone, and Triple Zone.

- Single Zone: 3.1 days for Gravel Pack + (CNL) Pack Evaluation and 2.4 days for ESS.
- Dual Zone: 6.8 days for Gravel Pack + (CNL) Pack Evaluation and 2.3 days for ESS.
- Triple Zone: 10.4 days for Gravel Pack + (CNL) Pack Evaluation and 2.3 days for ESS.
Cost Savings with Expandable Screens (Weatherford)
Expandable Sand Screen Applications

- Increase Flow Area
- Eliminate Hot Spots
- Reduce Sand Production
- Increase Drawdown & Flow Rate
Pressure Drops in Sand Screen

Equation

\[ \Delta P \propto \frac{v}{d^2} \propto \frac{Q}{A d^2} \propto \frac{Q}{d^4} \]  
(Laminar Flow in Pipe)

Example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Screen (inches)</th>
<th>Expanded Screen (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole ID</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Screen OD</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Base Pipe OD</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Base Pipe ID</td>
<td>4.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

\[ \frac{\Delta P_{ES}}{\Delta P_{CS}} = \left( \frac{4.1}{5.1} \right)^4 \times 100\% = 42\% \]

Remarks

• Expanding a 5” screen in a 6” hole reduces pressure drop in base pipe by 58%

• Significantly increases production rates in high flow rate wells (1,000 to 10,000 BPD) and with long screens (1,000 to 5,000 ft)
Eroded Screen and Base Pipe
(World Oil, 2001)

Packer

Screen Plugging

Hot Spot (erosion)

Formation

Annulus Open
Eroded Screen and Base Pipe
(World Oil, 2001)
Expandable Screen Packers
Eliminate Hot Spots

Packer

Formation
Sand Screen Mechanics
Particle Size Sand Distribution Plot
(World Oil, 2001)

Fig. 2.9. Extended range particle size sand distribution plot from sieve analysis
Sand Formation

Prior to Drilling

Flowing (Fines Migration)

Coarse Grains

Fine Grains

Fluid Flow

Sand Screen
Excessively-Fine Screen

Low $\Delta P$

High $\Delta P$

Fluid Flow

Plug (Fines)

Sand Screen
Optimum Size Screen

- High $\Delta P$
- Low $\Delta P$

Sand Screen
Fines
Reservoir Radial Fluid Flow

Steady-State Flow

\[
Q = \frac{2\pi k h (p_e - p_w)}{\mu \ln(r_e / r_w)}
\]

where

- \( Q \) = Flow rate
- \( k \) = Formation permeability
- \( h \) = Formation thickness
- \( p_e \) = Pressure at boundary
- \( p_w \) = Pressure at wellbore
- \( \mu \) = Fluid viscosity
- \( r_e \) = Radius at boundary
- \( r_w \) = Radius at wellbore
Sand Cementation

- Sand Grain
- Cement
- Oil
- Formation
Excessive Drawdown

Medium Drawdown ($Q < Q_C$)

High Drawdown ($Q > Q_C$)
Effect of Formation and Screen Damage on Flow Rate

- Undamaged Reservoir
- Damaged Reservoir

Distance from Wellbore
Formation Pressure

Formation Damage

△P Formation

Flow Rate Q

Drawdown Pressure (p_e - p_w)
Critical Flow Rate

Low Flow Rate
\( Q < Q_c \)

High Flow Rate
\( Q > Q_c \)

Sand Formation
Flow
Sand Grain
Wellbore
Sand Screen
Sand Grain
Flow
Sand Grain

\( F_p \)
Sand Grain Mechanics
(Conventional)

Failure: \( F_P > F_S \)

\( F_P \) = Pressure Force
\( F_S \) = Shear Resistance
Gravel Packing

Medium Drawdown ($Q < Q_C$)

- **Sand**
- **Gravel Pack**
- **Sand Screen**

Medium $\Delta P$

Low $\Delta P$

Low $\Delta P$
Compliant Sand Screens
Compliant Sand Screen

High Drawdown ($Q < Q_C$)
Sand Grain Mechanics
(Compliant Screen)

Failure: \( F_P > F_S + F_{SC} \)

- \( F_P \) = Pressure Force
- \( F_S \) = Shear Resistance
- \( F_{SC} \) = Screen Force

Reservoir Radial Fluid Flow

Steady-State Flow

\[ Q = \frac{2\pi k h (p_e - p_w)}{\mu \ln \left( \frac{r_e}{r_w} \right)} \]

where
- \( Q \) = Flow rate
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- \( h \) = Formation thickness
- \( p_e \) = Pressure at boundary
- \( p_w \) = Pressure at wellbore
- \( \mu \) = Fluid viscosity
- \( r_e \) = Radius at boundary
- \( r_w \) = Radius at wellbore
Production Increases with Expandable Screens (Weatherford)
Commercial Sand Screens
## Sand Screen Systems

### Unexpanded

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Fixed Cone</th>
<th>Compliant Cone/Rollers</th>
<th>Compliant Screen Fixed Cone</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**Numberous Companies**

- Baker Hughes
- Halliburton
- Noble
- Schlumberger
- Weatherford

**Cone**

- Noble Rollers
  - Tatneft
  - Weatherford

**Screen**

- Noble
Conventional Sand Screen System
(No Cone)

Conventional

Wellbore and Screen

Completion Fluid

Gravel Pack (Optional)

Numerous Companies
Expandable Sand Screen System
(Fixed Cone)

Completion Fluid

Wellbore

Fixed Cone

Expanded Screen

Large Flow Area

Gap

Unexpanded Screen

Baker Hughes  Halliburton  Noble  Schlumberger  Weatherford
Hydraulic piston can provide sufficient force down hole in horizontal applications.

Anchor | Piston | Cone

Expandable Screen hanger | Blank Pipe | Openhole packer | Expandable screen
Baker-Hughes Screen Components

Base Pipe

- Hole pattern optimized for maximum expansion and production

- Perforated base pipe provides *greater strength* for expanded screen
Halliburton Screen Expansion System

1-piece 360° premium screen (more reliable)

Threaded expandable connections (faster make-up and higher torque ratio)

Dual expansion methods - mechanically or hydraulically on the same trip with the same tool (installation flexibility for wellbore conditions)

Perforated base pipe (higher burst and collapse strength)
Expandable Sand Screen System
(Compliant Rollers)

Completion Fluid

Expanded Screen

Residual Pressure

Wellbore

Unexpanded Screen

Weatherford

Tatneft
Weatherford Screen Expansion System

Pros
- Wellbore face compliance
- Initiate expansion anywhere
- Seamless tubulars
- Low friction
- Inexpensive system

Cons
- Limited roller life
- Hard on tubular connections
ESS Expandable Sand Screen Joint
## EXPRESS vs. Slotted Base Pipe

<table>
<thead>
<tr>
<th>Feature</th>
<th>Weatherford Slotted Basepipe</th>
<th>Baker Perforated Basepipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crush Resistance</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Filtering Unexpanded</td>
<td>Poor (little inflow area)</td>
<td>Excellent</td>
</tr>
<tr>
<td>Rotational Performance</td>
<td>Cannot rotate</td>
<td>+/- 4,000 ft-lbs</td>
</tr>
<tr>
<td>Collapse Resistance</td>
<td>&lt; 400 psi (weave has no support)</td>
<td>&gt; 1,000 psi</td>
</tr>
<tr>
<td>Burst Resistance</td>
<td>&lt; 400 psi (weave has no support)</td>
<td>&gt; 1,000 psi</td>
</tr>
<tr>
<td>Maximum Expansion</td>
<td>40-50%</td>
<td>20-30%</td>
</tr>
</tbody>
</table>
NOBLE Sand Screen Tests (TIW)
Noble Sand Screen Expansion Tests

4-1/2" 316 - SS - 20% Expansion & 20 Deg. Cone Angle

Note cat eyes beginning to form
Noble Sand Screen Tests

4-1/2” – 316 Sand Screen Expanded with 12º/20% Cone

12º/20% Cone expanded in 4-1/2” SS screen (Shroud not welded on either end)

12º/20% Cone expanded in 4-1/2” SS screen (Shroud welded on both ends)
4-1/2" OD. - 316 Stainless Steel Perforated Basepipe

Note pressure drop as cone moves thru perforations.
Section 2 was cut along the horizontal axis approximately in halves, to allow disassembly and analysis. Every effort was made to keep the sample in a state as close as possible to the state it was in immediately after the expansion test. However, it should be noted that the horizontal cut released the mesh sandwich and no tension was present in the mesh construct. (Sample 3 was left intact to show the compressing effect of expansion.)

This 10 Power Magnification of the polished edge of piece 4 illustrates the efficient and effective capture of the mesh layers into a unified and well supported filtration package. The uniformity of the expansion inherent in using a cone expander results in a uniformly compressed mesh package within the construct.
NOBLE Sand Screens
NOBLE Expandable Sand Screen System

- Liner Hanger (TIW)
- Piston Tool (TIW)
- Expandable Threads (TIW)
- Expandable Packer (TIW)
- Expanded Sand Screen
- Cone Expander (NOBLE)
- Expandable Sand Screen (STREN)
- Bottom Sub (TIW)
Noble Sand Screen Thruster System
Single-Acting Piston

- Run to bottom
- Expand wall anchor, pump piston and cone down
- Retract wall anchor
- Push housing down with drillpipe weight
- Expand wall anchor and repeat process

Drillpipe → Liquid → Swivel (optional) → Wall Anchor → Housing

- Run to bottom
- Expand wall anchor, pump piston and cone down
- Retract wall anchor
- Push housing down with drillpipe weight
- Expand wall anchor and repeat process

Drillpipe → Liquid → Swivel (optional) → Wall Anchor → Housing
STREN Expandable Sand Screen
Noble Sand Screen Expansion Tools
Sand Screen Expansion Tools
Retractable Sand Screen Cone (Collapsed)
Sand Screen Collapsible Cone and Mandrel (Expanded)
Tubular Thread Expansion

Unexpanded Casing

Expansion Cone

Expanding Thread

Expanded Casing

Force
Noble Sand Screen Connection

Non-Upset Connection (Conventional)

After Expansion →
Before Expansion →

25%

Upset Connection (Invention)

After Expansion →
Before Expansion →

25% 0% 25%
4-1/2" 316 SS Casing Swaged to 5-1/2" with Buttress Threads
NOBLE Expandable Sand Screen System
(Compliant Cone)
NOBLE Compliant “Cone” Expander

- Non-Compliant Head
- Compliance Member
- Actuator
- Push Force
- Expanded Screen
- Unexpanded Screen
- Rock Formation
- Completion Fluid
NOBLE Compliant “Cone” Expander Concepts

1. Gas Pressure

2. Liquid Pressure

3. Rollers (optional)

4. Spring
NOBLE Compliant “Cone” Expander Concepts (cont’d.)

1. Spring
2. Hollow Spheres
NOBLE Compliant “Cone” Expander Concepts (cont’d.)

- Solid Spheres
- Memory Alloy

- Explosive
- Propellant
NOBLE Compliant “Cone” Expander Concepts (cont’d.)

- Screw Expander
- Swellable Material
- Heat
- Percussion Device

Bi-Metal
Spring
NOBLE Expandable Sand Screen System
(Compliant Screen)
NOBLE Compliant Screen Material
(Elastic or Plastic)

Uncompressed

Solid
Voids

$\phi = 60\%$
$k = 3$ darcies

Compressed

Pressure

$\phi = 20\%$
$k = 1$ darcy

Noble
NOBLE Expandable Sand Screen System
(Compliant Screen)

- Expanded Shroud
- Completion Fluid
- Wellbore
- Fixed Cone
- Compressed Material
- Expanded Screen
- Residual Pressure
- Uncompressed Material
- Unexpanded Screen
- Unexpanded Shroud
NOBLE Compliant Sand Screen

Before Expansion
Perforated Base Pipe
Filter Medium
Compressible Member
Wellbore
Formation

After Expansion
Pressure
Compressible Member
Formation

Compliant Sand Screen
NOBLE Expandable Sand Screen System
(Neutrally-Buoyant Particles)
NOBLE Expandable Sand Screen System
(Neutrally-Buoyant Particles)
Noble Expandable Sand Screens

- High-Torque, Rotatable Screens (> 4000 ft–lbs)
- High Collapse Strength (>2000 psi)
- Fast, Strong Piston Expansion System
- Strong Upset Connections
- Retractable Expander Cones
- Tri-Screen Filtration
- Up to 35% Expansion
- Strong Cone-Expandable Compliant Screens
- High-Strength Liner Hangers
The End
Patent 1
Combined Tubular Expansion/Cementing System

Ready to Expand Casing

Casing and Liner Hanger Expanded

Lower Cone to Bottom with Drillpipe

Stab Cone into Cementing Shoe

Squeeze Cement through Drillpipe

(A) Unexpanded Casing

(B) Expanded Casing

(C) Cement Slurry

(D) Plug

(E) Cement Slurry
Patent 2
Single-Piston Tubular Expander

Diagram:
- Drillpipe
- Fluid Pressure
- Piston
- Casing
- Liner Hanger
- Drill Collar
- Expanded Screen
- Cone or Compliant Expander
- Unexpanded Screen
Patent 3
Multiple Pass Expansion System

Single-Stage

Dual-Stage

Cone

Cone

F

F/2

F/2
Patent 3
Multiple Pass Reduce Cone Pressure
Patent 4
Expandable System Utilizing Swivel

Expandable Sand Screen
Expandable Threads
Non-Rotating Cone Expander
Expandable Screen
Swivel
Expandable Liner Hanger

Rotating Work String
Bottom Sub
Patent 5
Honing Casing to Reduce Cone Pressure
Patent 6
Multiple Expansion Sand Screen

Expandable Base Pipe
Expandable Inner Member
Completion Fluid
Sand Screen
Patent 7
Compliant Sand Screen Expander

Completion Fluid

Wellbore

Compliant Cone

Expanded Screen

Residual Pressure

Unexpanded Screen
Patent 7
Compliant Sand Screen Expander
Patent 8
Compliant Screen Utilizing Neutrally-Buoyant Particles in Annulus

- Expandable Liner Hanger
- Work String Weight
- Expandable Screen
- Expandable Threads
- Cone Expander
- Barrier
- Unexpandable Screen
- Near Neutrally-Buoyant Particles
- Bottom Sub (TIW)
Patent 8
Compliant Screen Utilizing Neutrally-Buoyant Particles in Annulus

Before Expansion

After Expansion
Patent 9
Compliant Sand Screen Utilizing Compressible Element

Completion Fluid
Wellbore

Compressed Material
Expanded Screen
Residual Pressure
Uncompressed Material
Unexpanded Screen
Patent 9
Compliant Sand Screen Compressible Element

Before Expansion

- Perforated Base Pipe
- Outer Shroud
- Compressible Member
- Filter Medium
- Formation
- Wellbore

After Expansion

- Pressure
- Compressible Member
- Formation

Compliant Sand Screen
Conventional

36” @200’ (Structural Pipe)
30” @600’
Trouble Zone @800’
26” @1,200’
20” @1,500’ (Surface Casing)
13⅜” @2,000’

Top-Hole Expandables ™

36” @200’ (Structural Pipe)
30” @600’
Trouble Zone @800’
26” @900’
20”→24” @1,200’
20”→22” @1,500’
20” @2,000’
Patent 10
20” Casing Expanded to 23”
Patent 11
Expandable Tubular Connection

Non-Upset Connection (Conventional)

After Expansion

Before Expansion

Upset Connection (Invention)

After Expansion

Before Expansion

25%
0%
25%
The End