Advanced Oxidation
Frac Water Recycling System

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About Bisco

• Leading global provider of soil and water remediation process systems since 1989
  • >5000 integrated systems
  • >3000 air strippers
  • 750 ozone units

• Based in Taunton, MA

• Acquired assets and IP from Kerfoot Technologies for Advanced Oxidation Technology (Perozone®)
17,500 Square Foot Fabrication/UL Panel Shop
BISCO Products & Systems

Technologies/Capabilities

1. Air Sparge/Soil Vapor Extraction
2. Dual Phase Extraction
3. Air Stripping - Low Profile
4. Controls & SCADA Design
5. Build-to-Print
6. Ozone / Peroxide Technology
7. Water Clean Up Units
Forty-foot Container Systems
Bisco/Kerfoot Background

- Bisco and Kerfoot Technologies formed a Strategic Alliance to provide ozone/Perozone® systems in 2011.
- In December 2012, Bisco acquired the key technology assets from Kerfoot for:
  - Remediation below ground
  - water/wastewater treatment
  - Frac water recycling
- Patent estate consists of >40 patents on applications/equipment, including frac applications.
Perozone Technology Overview

- Advanced Oxidation (AO) chemistry
- Aggressively oxidizes and breaks down contaminants to $\text{CO}_2$ and water, including recalcitrant materials
- Metals oxidized to filterable particulate
- Bacteria is killed
- Can be used below surface in soils and groundwater
- Primary applications are above ground to economically and efficiently clean up water

For Frac Water Applications, Enables Recycling
Extensive Ozone & Perozone® Experience

- Over 750 successful installations in Europe and the United States
- Fast, reliable remediation with difficult compounds/soils
- Perozone® has demonstrated cleanup in periods of months
- Treats numerous compounds

1,4 Dioxane
MTBE
Napthalene
TBA- Alcohols
Chloroalkanes
TPH – alkanes and alkenes
Chlorophenols – PCP, TCP

Chlordane
Heptachlor
Aldrin
Dieldrin
DDT/DDD
Creosote – Naphthalenes
Perozone® and C-Sparge Chemistry

- **C-Sparge™** (microbubble ozone)
  \[
  O_3 + 2H^+ + 2e^- \rightarrow O_2 + 2H_2O \quad \text{Clean by-products}
  \]

- **Perozone®** (peroxide-coated ozone)
  \[
  2O_3 + H_2O_2 \rightarrow 2OH^\cdot + 3O_2 \quad \text{Clean by-products}
  \]

- Chemical reaction of Perozone® releases twice the hydroxyl radicals per mole of peroxide than Fenton’s Reagent

*The key to high performance is the use of the Kerfoot Spargepoint Injector*
Perozone Injector

- Able to produce nanometer to micron sized peroxide-coated bubbles of ozone
- Generates extremely large surface area for reactions
Nanobubble Structure

5 μm
Oxidation Potentials Indicates How Aggressive Oxidant Will Be

Need Aggressive Oxidation for Frac Contaminants
C-Sparge is Different than Conventional Ozone

<table>
<thead>
<tr>
<th></th>
<th>Dissolved Ozone</th>
<th>C-Sparge Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffin hydrocarbons</td>
<td>0.0</td>
<td>95.7</td>
</tr>
<tr>
<td>Aromatic hydrocarbons</td>
<td>19.6</td>
<td>91.4</td>
</tr>
<tr>
<td>Naphthalenic hydrocarbons</td>
<td>29.3</td>
<td>92.0</td>
</tr>
<tr>
<td>Trimethylbenzenes</td>
<td>--</td>
<td>84.1</td>
</tr>
<tr>
<td>Propylbenzenes</td>
<td>--</td>
<td>75.0</td>
</tr>
</tbody>
</table>

(Brown and Ivan, 2005)
Frac-Cleanse Technology™
Frac Water- Recycling Objectives

- **Economically** and safely produce clear saline water for direct reuse, blending with fresh water, or as desalination pretreatment
- Remove hydrocarbons (free, emulsified, dissolved), gelling agents, metals, \( \text{H}_2\text{S} \), iron sulfide, bacteria, and suspended solids
- Able to handle variability of inlet water
- Compact design- minimal footprint
- Eliminate scale-up risk- use modular design with proven injectors; each module processes 1400 BPD
- Overall cost – economical compared to new water and disposal

*Bisco Frac-Cleanse™ System Meets Objectives*
Frac-Cleanse Process

Diagram showing the process flow with various components such as Ozone Gen., Peroxide Pump, Injector, “Loop” System, Recirc Pump, Pressure Tank, Atm. Reaction Tank, Gas Vent Catalyst, Continuous Filter, Residue, and Clean Saline Water Outlet.
Reactions

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>After Perozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbons (oil, grease, polymers, BTEX, MeOH)</td>
<td>CO₂, water</td>
</tr>
<tr>
<td>Iron, Manganese</td>
<td>High removal as oxides, hydroxides, sulfates; filtered out</td>
</tr>
<tr>
<td>H₂S, sulfides</td>
<td>To S, then to SO₃, removed as insoluble metal sulfates</td>
</tr>
<tr>
<td>Calcium, Magnesium</td>
<td>Removed as carbonates or sulfates; chloride not removed</td>
</tr>
<tr>
<td>Barium, Strontium</td>
<td>Removed as sulfate or carbonate</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Oxidized and effectively killed</td>
</tr>
</tbody>
</table>
Frac Water Experience: Field Units

1. Unit installed in western PA in 2008
   - Processed 60 to 100 GPM of flowback water
   - Demonstrated high efficiency on flowback water

2. Frac-Cleanse trials in Permian Basin 2013
   - Produced water applications at disposal site
   - Produced water at well sites
   - Flowback water at fracking operations

Trials at over fifteen different sites resulted in clear saline odor-free water suitable for reuse
Marcellus Test Unit
### Results of Brine Water Treatment using Perozone™

<table>
<thead>
<tr>
<th></th>
<th>Raw Water¹</th>
<th>Nanozox²</th>
<th>System End³</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volatile Organic Compounds (VOCs) (µg/L – ppb)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>240</td>
<td>ND</td>
<td>ND</td>
<td>99.6+</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>13</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>190</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Xylenes</td>
<td>110</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>n-Butylbenzene</td>
<td>2.7</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Naphthalene</td>
<td>17</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>n-Propylbenzene</td>
<td>2.5</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>1,3,5 Trimethylbenzene</td>
<td>18</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>1,2,4 Trimethylbenzene</td>
<td>35</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td><strong>Metals (alkaline and transitional) (mg/L – ppm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barium</td>
<td>175</td>
<td>69.6</td>
<td>7.65</td>
<td>95.6</td>
</tr>
<tr>
<td>Calcium</td>
<td>9800</td>
<td>6800</td>
<td>2573</td>
<td>73.7</td>
</tr>
<tr>
<td>Iron</td>
<td>20</td>
<td>ND</td>
<td>ND</td>
<td>99.5+</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1100</td>
<td>850</td>
<td>802</td>
<td>27</td>
</tr>
<tr>
<td><strong>General Chemistry (mg/L)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids, total dissolved</td>
<td>100,000</td>
<td>87,000</td>
<td>81,900</td>
<td>18.1</td>
</tr>
<tr>
<td>Chloride</td>
<td>60,000</td>
<td>53,000</td>
<td>51,688</td>
<td></td>
</tr>
</tbody>
</table>
Flowback and Produced Water - Frac-Cleanse

Marcellus Flowback Water

OK Flowback

NM Produced Water
Frac-Cleanse Demo Trailers

- Enables demonstration of the performance on-site with customer’s flowback and/or produced water

- “Mini-trailer” enables quick on-site trials (1 GPM)

- Pilot Trailer has full scale loop injector to minimize scale-up risk and long term operation
  - Capacity is 12 GPM- 400 bbl/day
  - Fully automatic operation
  - Bisco controls included for remote operation

- Simple set up – Frac water inlet/ clean water out
Mini and Pilot Frac Water Trailers

SWD site in New Mexico
3500 BPD Container Arrangement

- Designed for Safe Operation
- Suitable for Flowback and Produced Water
- Modular design minimizes scale-up risk
- Customer’s Total Cost is <$1/bbl
- Available within Four Months after Order
Frac Water Recycling Drivers

- EPA estimates that fracking uses >3 billion barrels (120 billion gal) of water per year
- Fresh make up water costs from $1/bbl to $3/bbl
- Residue disposal costs from $0.25/bbl to >$10/bbl
  - Trucking is primary cost
  - Total cost of fresh water and disposal is $1.25 to >$10/bbl; $3/bbl is typical

Frac-Cleanse™ total cost of ownership is <$1.00/bbl
Frac-Cleanse *Total cost of ownership*

<table>
<thead>
<tr>
<th>150,000 gal/day</th>
<th>3571 bbl/day</th>
</tr>
</thead>
</table>

**Variable cost per day**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>Daily cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>62.4 kw</td>
<td>$</td>
<td>0.11 per KW-hr</td>
<td>$ 164.74</td>
</tr>
<tr>
<td>Bisco Oxidant</td>
<td>141.2 gal</td>
<td>$3.56</td>
<td>per gal of 10%</td>
<td>$ 502.59</td>
</tr>
<tr>
<td>Filters</td>
<td>0.5 per day</td>
<td>$476.00</td>
<td>per filter</td>
<td>$ 238.00</td>
</tr>
<tr>
<td>Filter Disposal (tons)</td>
<td>0.5 per day</td>
<td>$70</td>
<td>per ton</td>
<td>$ 35.00</td>
</tr>
<tr>
<td>Labor, 8 hrs/day</td>
<td>1 person</td>
<td>$50.00</td>
<td>per hr</td>
<td>$ 400.00</td>
</tr>
</tbody>
</table>

**Total variable cost/day**

$1,340.32

**Daily variable cost per barrel**

$0.38

**Recovered oil Value**

0.5% oil in water recovered

18 bbl/day

$85 per barrel

$1,517.86

**Net daily variable cost**

Zero $

**Annual Cost**

<table>
<thead>
<tr>
<th>320 days</th>
<th>(Oil recovery not included)</th>
<th>$428,903.76</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 times</td>
<td>$7,700.00 ea. Time</td>
<td>$7,700.00</td>
</tr>
<tr>
<td>5 years</td>
<td>equipment cost</td>
<td>$195,000.00</td>
</tr>
<tr>
<td>2%</td>
<td>equipment cost</td>
<td>$19,500.00</td>
</tr>
</tbody>
</table>

**Total Cost for 12 months**

48,000,000 gallons processed

1,142,857 bbls

$651,103.76

**All-in Cost per barrel**

$0.57 NO OIL RECOVERY

$0.19 WITH OIL RECOVERY

Oil recovered by Bisco oil/water separator offsets operating cost; *Net cost reduced to $0.20 per barrel*
Comparison to other Technologies

Water Treatment Technologies – Cost vs. Value Add

- Frac-Cleanse
- Clean-Wave™
- Ultrafiltration
- Chemical Precipitation
- Filtration Hydroclone
- RO
- Distillation Evaporation

TDS removal Not Necessary for most water re-use for frac fluids
Small percentage removal of TSS/Hydrocarbon passing residuals to the well
Competitive Advantages of the Technology

- Economical – less than $1/bbl fully-loaded cost
- Safe design
- Able to remove multiple contaminants in one unit
- Compact
- Minimal secondary waste (not slurry)
- Suitable for mobile or fixed installations
- Proven performance
Frac-Cleanse Summary

1. Frac-Cleanse - compact, economical system to recycle produced and flowback water
2. One compact unit can treat many contaminants:
   • Effectively eliminates hydrocarbons; emulsified, gelling agents, BTEX, oils, grease and surfactants.
   • Metals are oxidized to enable filtration and removal
   • H₂S and iron sulfide are removed
   • Bacteria are killed
   • Suspended solids are removed
3. The technology can be applied in mobile units or in a fixed facility.
4. The all-inclusive cost per barrel of <$1.00/bbl is an economical solution to recycling produced water

A Demonstration Unit is available for testing
Questions?