Low Pressure Atomization
Oil Reservoir Treatment Technology

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Kerui-Global Trusted Expert in Integrated Oil & Gas Solution

High-End oil equipment R&D manufacturer across the industrial chain

Integrated oil & gas field service and solution provider

Oil & Gas EPC construction building expert

Technology development system covering the world

Perfect global marketing and service network

Excellent capacity for global service delivery

Integrated Ecological Landscape for Oil & Gas Field
Kerui-World Class Equipment Research and Manufacture

High-end petroleum equipment industrial park

2.4MM m²

Oil & Gas Stimulation equipment production base

Oil recovery machinery production base

Wellhead and well control production base

Oil & Gas process production base

Houston coiled tubing equipment production base

Drilling equipment production base

Natural gas compressor production base

Nitrogen generator in China

70% market share of nitrogen generator in China
Kerui-General Contractor of Oil & Gas EPC Projects and System Solution Provider

### Wellhead Gas Treatment Modules
- Wellhead heating and throttling
- Wellhead methanol injection
- Wellhead gas purification (sweetening, dehydration demercuration)
- Wellhead metering
- Modular wellhead gas treatment equipment
- Wellhead gas to CNG
- Wellhead gas to LNG

### Natural Gas Gathering and Processing
- High-pressure gas gathering
- Multi-phase transportation
- Sour gas gathering and transportation
- Natural gas processing plant
- Condensate recovery equipment
- Sulfur recovery equipment

### Oil & Gas Storage and Transportation
- Oil & Gas pipeline
- Crossing engineering
- Hydraulic protection
- Pumping
- Compressor station
- Off-take stations and facilities
- Digital pipeline
- Oil & Gas tank farm

### Natural Gas Liquefaction Plant
- Natural gas liquefaction plant
- LNG receiving terminal

### LNG, L-CNG, CNG Refueling Station
- LNG refueling station
- L-CNG station
- CNG station and skid-mounted equipment

### Natural Gas Utilization
- Natural gas power generation,
- Natural gas chemical processing: Natural gas to ammonia and urea, Syngas to methanol, MTO,MTA,MTP,MTG,GTL.

### Environment Engineering
- Associated gas utilization
- Coke oven gas utilization
- Coal tar treatment
- Waste water treatment
- Oil-based drilling mud treatment
- Soil remediation

### Equipment Financial Leasing
- Wellhead gas treatment equipment
- CNG station
- LPG station
- Mini LNG station
1. Stimulation technology for high permeability reservoir

**Oilfield name**: CHD oilfield  
**Lithology**: Fine sandstone  
**Buried depth/m**: 1125  
**Permeability/\(10^{-3}\)um²**: 2304  
**Porosity/%**: 37  
**Initial oil saturation/%**: 62  

**Daily oil production before (t/d)**: 75.1  
**Daily oil production after (t/d)**: 137.1  
**Water cut before %**: 93.8  
**Water cut after %**: 88.7

**Application**

- Combination foam system is combination system of foam and polymer solution.
- Adding polymer into foam system can improve foam stability, reduce adsorption loss of foaming agents.
- Foam can strengthen plugging ability and selectivity of polymer.

![Graph showing performance improvement with combination foam system](image)
2. Stimulation technology for carbonate reservoir

Dig potential of remaining oil in type of reservoir space

Application case

<table>
<thead>
<tr>
<th>Oilfield name</th>
<th>Buried depth /m</th>
<th>Daily oil production before /(t/d)</th>
<th>Daily oil production after /(t/d)</th>
<th>Average single well oil increment /t</th>
<th>Highest oil increment /t</th>
<th>Operation well times</th>
<th>Accumulative oil increment /t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tahe oilfield</td>
<td>4500-7000</td>
<td>0.9</td>
<td>10.7</td>
<td>1750</td>
<td>13000</td>
<td>460</td>
<td>$43 \times 10^4$</td>
</tr>
</tbody>
</table>

Low water cut, stable oil production, good coning control effect, with the oil increment in this stage 1413t.
3. Stimulation technology for low permeability reservoir

(1) Water alternate gas (WAG) flooding technology

**Application advantages:**
- High-usage of nitrogen
- Displacement front keeps stable;
- Water enters high permeability zone and gas enters low permeability zone;
- Gas breakthrough is inhibited.

(2) Acidizing plug removal technology

**Acidizing plug removal technology**
- sandstone reservoir
- carbonate reservoir

**Chemicals used:**
- Conventional mud acid
- Self-generating mud acid
- Fluoboric acid
- Diversion acid
- Multi-hydrogen acid
- Nitric acid powder
- Hydrochloric acid
- Organic acid
- Hybrid acid system
- Retarded acid
- Solid acid

**Gases used:**
- N\textsubscript{2}, air, flue gas, CO\textsubscript{2}
3. Stimulation technology for low permeability reservoir

(3) Pseudo horizontal well development technology

Radial drilling technology improves the injection-production pattern. By radial drilling technology, flow channel with 100m horizontal section can be formed between wells. Which can connect reservoirs, increase drainage radius and water swept area, thus improve the development effect and reduce drilling workload.

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Layer No.</th>
<th>Permeability $10^{-3}\text{um}^2$</th>
<th>Length of lateral hole (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Formula method</td>
<td>Limit control method</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C17-5X1</td>
<td>C41</td>
<td>11.2</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>C42</td>
<td>21.2</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>C51</td>
<td>20.9</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>C52</td>
<td>24.9</td>
<td>52</td>
</tr>
</tbody>
</table>

Production curve for XX well

Water cut
Daily fluid production
Daily oil production

By radial drilling technology, flow channel with 100m horizontal section can be formed between wells. Which can connect reservoirs, increase drainage radius and water swept area, thus improve the development effect and reduce drilling workload.
4. Stimulation technology for heavy oil reservoir

(1) HDCS thermal recovery technology for ultra-heavy oil

Application scope

1) high crude oil viscosity (20~100×10⁴ mPa·s), poor mobility;
2) deep buried depth (>1000 m), thin thickness (4~15 m);
3) strong sensitivity, easy to be damaged (shale content: 6~20%);
4) loose cemented, fine lithology;
5) thin interlayer (2~6 m), complicated oil-water relation.

Field application

HDCS application in SL oilfield

<table>
<thead>
<tr>
<th>Operation well number</th>
<th>Operation well times</th>
<th>Accumulative steam injection /t</th>
<th>Accumulative CO₂ injection /t</th>
<th>Accumulative oil increment /t</th>
<th>Accumulative oil increment for single well /t</th>
<th>Average accumulative oil increment in one cycle /t</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>213</td>
<td>53.24×10⁴</td>
<td>2.24×10⁴</td>
<td>47.1×10⁴</td>
<td>6038</td>
<td>2210</td>
</tr>
</tbody>
</table>

Reduce oil viscosity

Viscosity field after steam injection

Viscosity field after CO₂+steam injection

Kerui-Oil Recovery Enhancement Project Solution Provider
4. Stimulation technology for heavy oil reservoir

(2) Foam temporary plugging profile control technology

Existing problem for steam injection well

Steam-crude oil density difference causes gravitational differentiation, and steam gathers at the top of the reservoir, steam overlay occurs, resulting in serious heat loss and low steam efficiency.

Field application

Oil increment statistics of XX well in Girasol oilfield

- Steam: 5500MMBTU, Nitrogen: 65500m³, Foaming agent: 5t;
- Oil increment in one cycle: 2666 bbls.

Steam-crude oil density difference causes gravitational differentiation, and steam gathers at the top of the reservoir, steam overlay occurs, resulting in serious heat loss and low steam efficiency.
4. Stimulation technology for heavy oil reservoir

(3) Heavy oil energization cold recovery technology

Application scope

1) Medium-deep well, poor steam stimulation effect;
2) Low oil phase permeability and high water cut;
3) Underground crude oil viscosity $\leq 20,000\text{ mPa}\cdot\text{s}$;
4) Formation temperature $\leq 80^\circ\text{C}$;
5) salinity of formation water $\leq 20,000\text{ mg/L}$.

Fluid characteristic

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Dynamic viscosity (mPa·s)</th>
<th>Freezing point ($^\circ\text{C}$)</th>
<th>Sulin classification</th>
<th>Salinity (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-3</td>
<td>16329</td>
<td>28</td>
<td>MgCl$_2$</td>
<td>11658</td>
</tr>
<tr>
<td>7-27</td>
<td>16451</td>
<td>20</td>
<td>NaHCO$_3$</td>
<td>10366</td>
</tr>
<tr>
<td>9-27</td>
<td>4587</td>
<td>38</td>
<td>NaHCO$_3$</td>
<td>9225</td>
</tr>
<tr>
<td>9-31</td>
<td>16840</td>
<td>36</td>
<td>NaHCO$_3$</td>
<td>10890</td>
</tr>
<tr>
<td>11-31</td>
<td>21203</td>
<td>32</td>
<td>NaHCO$_3$</td>
<td>10607</td>
</tr>
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Technology Introduction

1. Low-pressure Atomization oil Reservoir Treatment Technology

Taking advantage of high-pressure gas (nitrogen, carbon dioxide, natural gas), use atomization apparatus to disperse acid solution to become micro-droplets with diameter of less than 2μm, then atomized acid enters into micro pores and fractures in deep formation or crude oil under fracturing pressure, entered acid etches micro pores and fractures or changes wettability of rocks, to improve permeability of flow channels or reduce the viscosity of crude oil.
Atomization can be in wellhead or/and in bottom hole. Wellhead atomization is suitable for shallow well, while bottom hole atomization is for middle and deep well.
3. Stimulation Mechanism

Forming air-film by the adsorption effect of matrix on gas, help acid mist penetrate to the deep reservoir.

Before treatment

Preposed nitrogen

Treatment process
Technology Introduction

4. Application Scope

- Transforming deep microfracture in carbonate reservoir
- Transforming deep micropore in tight sandstone reservoir
- Transforming deep reservoir during the process of heavy oil huff and puff
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Superiority

1. Simple Construction, Low Engineering Cost

Atomization acid treatment technology does not need much equipment and treatment procedure is simple.

Conventional acidizing and acid fracturing requires matched borehole operation, with high cost of operation and complex construction procedure.
Superiority

2. Less Acid Consumption and High Effective Utilization

The consumption of Conventional acidification acid pressure acid dosage is from dozens of to hundreds of squares of acid fluid, atomized acid can totally diffuse with gas, less acid consumption, Only 10-20 m³ (site), low material cost.

Atomized acidizing diffusion simulation inside reservoir body

Cavernous fissure reservoir body oil reservoir profile

Model size: length 80cm, width 60cm, thickness 10cm, made from organic glass after acid etching.
Superiority

3. No Flowback Fluid, Eco-Friendly

Vaporific acid etching treatment, Less acid consumption, Reaction efficiency, to avoid reacted acid massively, flowback after acidification.

Acid fluid flowback site

Conventional acid treatment / pressurize flowback fluid treatment system.
Superiority

4. Into the Deep Reservoir, and Gradually Reform the Reservoir

Atomized acidizing formation treatment technology for micro-fracture and matrix constantly etching, While improving fracture conductivity may form a new flow channel.

Acidizing fluid fully atomized, the diameter of droplet is 0.1~10μm. Nitrogen gas takes along acid-droplet enter into micro-fracture. Acidizing fluid etches micro-fracture to increase its conductivity. Connect with Ⅱ,Ⅲ type holes.
4. Into the Deep Reservoir, and Gradually Reform the Reservoir

Atomized acid treatment Technology continue acid etching micro-fracture and matrix and new flow channel will be formed at the same time to improve the flow conductivity of fracture.
5. Nitrogen overlap to Improve Upper Reservoir

Enter the upper reservoir, selective reform for attic style oil enrichment region of carbonate

Seam hole type of carbonate reservoir production tail, residual oil distribute in top and side.

Atomized acidizing reformed, form a gas cap at the same time, advantage to the residual oil develop in the top.
6. Reduce the Damage in the Process of Water Sensitive Reservoir Acidification

Low-permeability sandstone reservoir with small pores, incompatibility between injection fluid and formation can cause swelling of clay minerals and formation damage with water lock phenomenon.

Development trend began to deteriorate after the water sensitivity of reservoir acidification.

Superiority

Water cut stepped up

Water cut spiky up

Water cut incremental up
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Application

1. Carbonate Reservoir

After atomization acid treatment, the initial production capacity is high, and the effective period is long.

Fracture cavity type carbonate reservoir is the most widely used, Nitrogen stimulation process with atomized acid formation processing technology may significantly enhance the cycle of oil increase, the effective period also increased.

![Well number comparison chart]

![Cycle oil increment comparison chart]

![The validity of the production chart]
1. Carbonate Reservoir

Deal with atomized acidizing, at early stage with high production, long period of validity.

Before treatment, cumulative fluid is 154869t, cumulative oil 116630t, cumulative water 38240t; After gas injection production for 468 days, cumulative fluid is 14960t, cumulative oil 9537t, cumulative water, average daily oil production 20t.
Application

1. Carbonate Reservoir

Only gas injection huff and puff, cumulate oil production is low, short period of validity.

**Application**

**Cumulate gas** $10^4 m^3$

**Application**

First inject gas

500000 m$^3$, may 14, cumulative oil 1284t

Flowing about 27 days, oil production 822t, daily oil output 30t

Pressure test 1.8Mpa

Second inject gas

500000 m$^3$, increase oil 635t

Flowing about 29 days, oil production 965t, daily oil output 34t

Pressure test 7.5Mpa

**Daily production curve**

**The first cycle curve of gas injection**

**The second cycle gas injection curve**
Application

2. Low-permeability Sandstone Reservoir

Reservoir thickness map of C103

Injection curve

Effect of atomization acid treatment with C103X7

Five wells implemented in the block. Average single well initial daily oil production is 3.7t. The average single well with the amount of acid is 5.3m³.
Aim: improve water injection ability of water injection well

Gas injection volume: $4.5 \times 10^4 m^3$
Acid injection volume: $5 m^3$
Application Effect

3. Deep Heavy Oil Reservoir

Reservoir parameters for YD961 Block

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (Km²)</td>
<td>1.43</td>
</tr>
<tr>
<td>Formation temperature (°C)</td>
<td>89</td>
</tr>
<tr>
<td>Reserves (10⁴t)</td>
<td>525</td>
</tr>
<tr>
<td>Temperature gradient (°C/100m)</td>
<td>3.0</td>
</tr>
<tr>
<td>Buried depth (m)</td>
<td>2300</td>
</tr>
<tr>
<td>Underground oil density (g/m³)</td>
<td>0.9826</td>
</tr>
<tr>
<td>Permeability (10⁻³μm²)</td>
<td>510</td>
</tr>
<tr>
<td>Surface oil viscosity (mPa·s)</td>
<td>15233</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>33.4</td>
</tr>
<tr>
<td>Freezing point (°C)</td>
<td>-7.2</td>
</tr>
<tr>
<td>Formation pressure (MPa)</td>
<td>16.7</td>
</tr>
<tr>
<td>Formation water salinity (mg/l)</td>
<td>187300</td>
</tr>
<tr>
<td>Pressure factor</td>
<td>0.98</td>
</tr>
<tr>
<td>Water type</td>
<td>CaCl₂</td>
</tr>
</tbody>
</table>

Top structure map for YD961 Block

Carry out cold recovery huff and puff stimulation treatment on single well at the structural high part, the initial daily oil increment is 8.2t.

Monthly production curve for YD961X8 well

- Accumulative nitrogen volume: 250000m³
- 800ppm viscosity reducer: 500m³
Conclusions

1. Treated area of typical acidizing / frac-acidizing in fracture-cavity carbonate reservoir is very small. The discharge capacity and operation speed are very high, resulting in serious acid fluid leakage. The whole reservoir is not fully stimulated, and the operation can easily connect the bottom water, so the single well water cut will increase rapidly. After being atomized, the acid can enter deep formation with nitrogen and reaction occurs very slow, so it can stimulated the typical acid unswept micro-fractures.

2. Acidizing radius is usually very small in low permeability reservoir, and unthorough flow-back can easily cause formation damage. Atomized acidizing technology can enlarge acid swept area, stimulate small pore-throat. With nitrogen to increase formation energy, the flow-back is thorough.

3. Thermal recovery efficiency in deep heavy oil reservoir is low. During cold recovery process, this technology can take oil displacing agent into deep formation to increase the stimulation radius, thus improving the cold recovery effect.
More Efficient in Oil & Gas Extraction