Ultrasound-Assisted Oxidative Desulfurization of Natural Gasoline

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Each forward-looking statement speaks only as of the date of the particular statement and we undertake no obligation to update or otherwise revise any forward-looking statement, whether as a result of new information, future events or otherwise.

References in this presentation to “we,” “us,” “our,” “our company,” and “SulphCo” refer to SulphCo, Inc., a Nevada corporation.
Outline

- Natural gasoline (NG) background and market
- SulphCo® Sonocracking™ process
- Scale-Up of NG Sonocracking™
  - Batch Scale
  - Bench Flow Testing
  - Commercial Scale Testing
- Summary
What Is Natural Gasoline?

- C$_5$+ hydrocarbon stream processed in gas plant
- Common blend-stock for on-road gasoline
- Average daily NG production in US: 271,000 BPD

Figure adapted from:
NG Market Outlets

- Gasoline blending is typically the most valuable NG market for NG producers
- Sulfur is one of the bottlenecks for NG blending
- Mandated sulfur limit in on-road gasoline = 30 ppm S
SulphCo® Sonocracking™ Process

- **Chemistry**
  - Oxidant: H₂O₂
  - Aqueous catalyst

- **Ultrasound**
  - Custom magnetostrictive driver and probe
  - 18-20 kHz, 30-100 µm (zero-peak)

- **Separation**
  - Gravity separation
  - Water wash to remove oxidized sulfur analogs
Ultrasound Enhances Reactivity

Conversion of DBT to DBTO, %

- Chemistry: petroleum product, H₂O₂ solution, catalyst, phase transfer reagent
- Original patent assigned to SulphCo

Mei, H.; Mei, B. W.; Yen, T. F. Fuel, 82, 405 (2003)
a) Ultrasound induces cavities in process fluid
b) Rectified diffusion and bubble growth over several compression cycles
c) Bubbles grow to an unstable size
d) Implosion of bubble leads to intense mixing, localized high temp and pressure

NG/aqueous phase boundary essentially eliminated in cavitation zone
SulphCo® Scale-Up Approach

- Three major steps in scale-up process
- NG stream “C”, as referenced in abstract, successfully scaled from batch to commercial flow

Batch Testing
< 200 mL NG
280 ppm S

Pilot Scale Testing
0.3 - 1.6 GPM NG
280 ppm S

Commercial Scale Testing
1000 - 2000 BPD NG
(29 - 58 GPM)
200-450 ppm S
Batch Testing

- Goal – initial screening process to understand sulfur reactivity, speciation
- Desulfurized to < 30 ppm S:
  - Sonicated in lab batch reactor with lab-scale probe
  - Held at reaction temperature for phase separation
  - Water-washed to produce final product
- Produced sulfur scans of feed and product sulfur content via GC-SCD
Sulfur Speciation

Peak height corresponds to the intensity of detected sulfur species at the given GC column retention time.
Pilot Scale Testing

- Goal – develop operating window for process in continuous flow unit
- Design of experiments around the following variables:
  - Reactor pressure, temperature
  - NG and additive flow rates
  - Probe tip amplitude
- All samples allowed to phase separate, then water washed
Pilot Scale Unit

- Ultrasound Reactor Assembly
- Additive Pumps
- NG Feed Tank
- NG Feed Pump
- NG Heater
- Product Tank
Pilot Scale Sulfur Contour
Commercial Scale Testing

- Goal – maximize NG throughput and minimize operating cost
- Multiple design of experiments to verify pilot scale operating window
- Endurance run to prove robust operation
Commercial Scale Process Scheme

Some NG streams do not require this step.
Endurance Run Background

- 42 hour continuous run, culmination of 5-6 weeks verification testing
- 1000-2000 BPD (29-58 GPM) NG processed in single ultrasound reactor
- NG product sulfur upper limit target: 45 ppm S
- Phase separation and water wash performed in vessels adjacent to MPU assembly
Handling Swings in NG Feed Sulfur

Feed sulfur increased over 50% in 12 hours

Under-dosing results in product sulfur incursion. Lag due to post-process turnover time.
Ultrasound Performance

Ultrasound operated in tight power band

Higher aqueous loading increases probe impedance

Feed flow varied due to client downstream equipment requirements

Flow reduction is one method to stabilize system

- Oil Flow GPM
- Ultrasound Input Power, %
- Probe Tip Amplitude, %
Ultrasound Probe Wear Minimal

Tip View

Side View

Probe operated at various reactor conditions for ~110 hours
Summary

- Successful commercial validation of technology
- Ultrasound-assisted oxidative desulfurization of NG was reliably scaled from lab to commercial scale
- 45 ppm S final NG product was produced under robust operating space
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