State of The Art Controls
For
Particulate, SO₂, SO₃ and NOₓ
EDV® Wet Scrubbing System

Reducing Particulate, $SO_2$, $SO_3$ and NOx all in a single vessel
The EDV® Wet Scrubbing System experience extends to more than 300 installations worldwide covering many type of applications including:

- Fluid Cokers
- Heaters
- SRU Tail Gas
- Incinerators
- Power Boilers
- FCCU’s
BELCO®’s List of Scrubbing Experience in Refineries

- **North America (32)**
  - Valero (7)
  - Coastal
  - Marathon/Ashland (2)
  - Quakerstate (Pennzoil)
  - Irving Oil
  - Motiva
  - Conoco Phillips (5)
  - Premcor (4) (now Valero)
  - Shell Oil
  - Lion Oil
  - Citgo (3)
  - Sunoco (2)
  - BP
  - Placid
  - Frontier

- **India (8)**
  - IOCL (4)
  - ESSAR
  - HPCL (3)

- **Other (18)**
  - Taiwan - Formosa (2), Chinese Petroleum
  - Korea – SK, GS Caltec
  - Qatar – NODCO, Al Shaheen
  - Italy – Eni S.p.A.
  - Norway – ESSO
  - Switzerland – Tamoil
  - Saudi Arabia - SAMREF
  - Russia – GAZPROM
  - Philippines – Petron
  - Belgium – Total
  - Thailand – Star Petroleum
  - Brazil – Petrobras REFAP
  - China – Petrochina, Sinopec

67 EDV Wet Scrubbing Systems in Refineries
(58 of which are on FCCU applications)
EDV® Wet Scrubbing
(Typical Upflow Configuration)

- Stack
- Filtering Modules
- Quench Section
- Droplet Separators (built inside scrubber)
- Absorber Section
- Nozzles form Spray Curtains
EDV® Wet Scrubbing
Quench & Spray Tower

Quench Section
Absorber/Spray Tower Section
EDV® Wet Scrubbing
Spray Tower

- Coarse PM, SO₂ & SO₃ (plus NOₓ when LoTOx™ is applied)
  - High Liquid / Gas Contact Cross Sectional Dense Water/Reagent Curtains
    - SO₂ & NOₓ Absorption/PM & SO₃ Impaction
  - Staged Approach for More Reliable scrubbing
- Open Tower
- Continuously Washed Walls for Self Cleaning
- No Mist Formation
- Low Pressure Drop (No Pressure Drop Design is also Available)
EDV® Wet Scrubbing

G® Nozzle

X -Section
EDV® Wet Scrubbing
(G®-400 Nozzle) Cross Section

Creates a Dual Reagent Spray by means of a Declining Trough Design
EDV® Wet Scrubbing System

G® Nozzle

Plan View

Side View
Multiple G® Nozzle Operation
EDV® Wet Scrubbing
Filtering Modules
EDV® Filtering Module
Condensation & Filtration

- Fine PM & SO₃ Mist Collection
  - By Acceleration, Adiabatic Expansion and Super Saturation
  - Condensation
  - Particle Size Growth
  - Filtration
- Open / Self Cleaning
- Non-plugging Design
- No Mist Formation
- Low Pressure Drop
Condensation & Agglomeration of Fine Particulate & Sulfuric Acid Mist

Cleaned Gas on to Droplet Separation

Very Efficient Fine Particulate Control

EDV® 6000 Filtering Module

Fine Particulate Encased in large water droplet

Liquid to Spray

Gas Inlet

Liquid to Spray
EDV® Wet Scrubbing

Removal of Excess Water Droplets without mist eliminators
EDV® Wet Scrubbing
Droplet Separators
EDV® Droplet Separator

- Removes Droplets Carryover From Gas Stream
- Low Pressure Drop
- Non-Plugging Design
- Open /Self Cleaning
- No Mists Eliminators
- No Moving Parts
EDV® Wet Scrubbing System
Droplet Separators
EDV® Scrubbing System
Two Simple Process Flows

DIffuse Dirty flue gas from FCC

EDV® Absorber

EDV® Quench

EDV® Droplet Separators

EDV® Filtering Modules

Makeup Water

Overflow Drains

Clean Gas Out

(This loop is for EDV® 5000, 6000 and 6600 models only)

Reagent

SLipstream to Purge Treatment Unit
Treatment of Scrubber Purge
EDV® Wet Scrubbing
Purge Treatment Unit
EDV® Wet Scrubbing
Typ. Purge Treatment Unit - PFD with Settling Bin
EDV® Wet Scrubbing System
Purge Treatment Unit -- Effluent

- Discharge of Scrubber Water
  - Reduction of Suspended Solids (TSS) down to below 200 ppm
  - Reduction of Chemical Oxygen Demand from Sulfites (COD) down to below 100 ppm

- More Stringent Effluent Specifications can be met if required
EDV® Wet Scrubbing

Easily Modified for NO\textsubscript{x} Control with LoTOx\textsuperscript{TM}

- Low Temperature Oxidation

LoTOx\textsuperscript{TM} is a trademark of the BOC Group
LoTO$_x^{TM}$ Installation on an FCCU
EDV® Wet Scrubber with LoTO$_x^{TM}$

- Water Droplet Separation
- Fine Particulate Removal
- SO$_2$ & Particulate Removal
- NO$_x$ Removal
EDV® Wet Scrubbing System
With LoTOx™ injection

Ozone Injection after Quench
Conversion to N₂O₅
Conversion to Nitric Acid
Conversion to a Nitrate by contact with scrubber reagent
Nitrates removed with Scrubber Purge

N₂O₅ Conversion to HNO₃ and Scrubbing by EDV Nozzles
NO, NOₓ Conversion to N₂O₅
Ozone Injection

EDV® Wet Scrubbing System
With LoTOx™ injection
EDV® Wet Scrubbing System
With LoTOx™ injection

**Simplified LoTOx™ Chemistry**

1. $\uparrow \text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$
2. $\uparrow 2\text{NO}_2 + \text{O}_3 \rightarrow \text{N}_2\text{O}_5 + \text{O}_2$
3. $\uparrow \text{N}_2\text{O}_5 + \text{H}_2\text{O} \rightarrow 2\text{HNO}_3$
4. $\uparrow \text{HNO}_3 + \text{NaOH} \rightarrow \text{NaNO}_3 + \text{H}_2\text{O}$
LoTO$_x$™ Installation on an FCCU

Ozone Injection Piping
LoTO$_x$™ Installation on an FCCU
Ozone Injection Piping
EDV® Scrubbing System PFD
w/LoTOx  (Only Ozone Injection added)

DIRTY FLUE GAS FROM FCC

EDV® FILTERING MODULES

EDV® DROPLET SEPARATORS

MAKEnP WATER

CLEAN GAS OUT

EDV® STACK

Ozone Injection

SLIPSTREAM TO PURGE TREATMENT UNIT

(Dirty loop is for EDV® 6000)

FC

EDV® ABSORBER w/RESIDENCE TIME

EDV QUENCH

MAKEUP WATER

Ozone Injection

Reagent

FC

FC

pH

pH

pH

FC

FC

pH
<table>
<thead>
<tr>
<th>Application</th>
<th>Location</th>
<th>Capacity</th>
<th>NO\textsubscript{x} In / Out</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Fired Boiler</td>
<td>Southern California</td>
<td>400 HP</td>
<td>150-70-30ppm / 2-5ppm</td>
<td>1997</td>
</tr>
<tr>
<td>Gas Fired Boiler</td>
<td>Southern California</td>
<td>1000 HP</td>
<td>30-40ppm / 4ppm</td>
<td>January ‘02</td>
</tr>
<tr>
<td>Coal Fired Power Plant</td>
<td>Ohio</td>
<td>25 MW</td>
<td>200ppm / 10ppm</td>
<td>October ‘01</td>
</tr>
<tr>
<td>SS Pickling Process</td>
<td>Pennsylvania</td>
<td>--</td>
<td>1000-3400ppm/100ppm</td>
<td>February ‘00</td>
</tr>
<tr>
<td>Lead Smelting</td>
<td>Southern California</td>
<td>--</td>
<td>50ppm / 10ppm</td>
<td>February ‘02</td>
</tr>
<tr>
<td>Refinery FCCU (Pre-Invested for LoTOx)</td>
<td>Arkansas</td>
<td>20,000 bpsd</td>
<td>70-100ppm/10ppm</td>
<td>June, 2007</td>
</tr>
<tr>
<td>Refinery FCCU (Pre-Invested for LoTOx)</td>
<td>Ardmore, Oklahoma</td>
<td>40,000 bpsd</td>
<td>--</td>
<td>TBD</td>
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<tr>
<td>Refinery FCCU (Pre-Invested for LoTOx)</td>
<td>Three Rivers, Texas</td>
<td>28,000 bpsd</td>
<td>--</td>
<td>TBD</td>
</tr>
<tr>
<td>Refinery FCCU (Pre-Invested for LoTOx)</td>
<td>Placid Refining, LA</td>
<td>30,000 bpsd</td>
<td>--</td>
<td>TBD</td>
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<tr>
<td>Refinery FCCU (pre-invested for LoTOx)</td>
<td>Alliance – Thailand</td>
<td>40,000 bpsd</td>
<td>--</td>
<td>TBD</td>
</tr>
<tr>
<td>Refinery FCCU (pre-invested for LoTOx)</td>
<td>Linden, NJ</td>
<td>80,000lbs/hr</td>
<td>90-165ppm/10ppm</td>
<td>1st Quarter ‘08</td>
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<tr>
<td>Sulfuric Acid Regeneration with LoTOx</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Refinery FCCU-LoTOx retrofit to ext. EDV</td>
<td>Texas City, TX</td>
<td>52,000 bpsd</td>
<td>70-100ppm/10ppm</td>
<td>February, 2007</td>
</tr>
<tr>
<td>Refinery FCCU (Pre-Invested for LoTOx)</td>
<td>El Dorado, KS</td>
<td>40,000 bpsd</td>
<td>150ppm/20ppm</td>
<td>TBD</td>
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<tr>
<td>Refinery FCCU-EDV w/ Integral LoTOx</td>
<td>Houston, TX</td>
<td>58,000 bpsd</td>
<td>100-150ppm/10ppm</td>
<td>April, 2007</td>
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<tr>
<td>Refinery FCCU LoTOx retrofit to ext. EDV</td>
<td>Texas City, TX</td>
<td>60,000 bpsd</td>
<td>100-150ppm/8ppm</td>
<td>Dec. , 2007</td>
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<tr>
<td>Refinery FCCU-EDV w/ Integral LoTOx</td>
<td>Texas City, TX</td>
<td>130,000 bpsd</td>
<td>100-200ppm/10ppm</td>
<td>July, 2007</td>
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</tbody>
</table>
EDV Wet Scrubbing Performance
In a Single Process Unit

Typical Emission Values:
- Particulate: Less than 50mg/Nm3
- SO2: Less than 20ppm
- SO3: 80% removal plus
- NOx: Less than 20ppm

Performance values based on numerous Oil Industry applications
## EDV® Wet Scrubbing System
### Reagent Options

<table>
<thead>
<tr>
<th>Reagent Handling</th>
<th>Conventional Sodium or Magnesium Based</th>
<th>Conventional Calcium Based</th>
<th>LABSORB® Regenerative Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid mixing, pumping and metering</td>
<td>Solids handling with slurry mixing, pumping and metering</td>
<td>Liquid mixing, pumping and metering</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sulfur By-Product</th>
<th>Conventional Sodium or Magnesium Based</th>
<th>Conventional Calcium Based</th>
<th>LABSORB® Regenerative Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate salts in a water solution (discharge or dry/sell)</td>
<td>Dry calcium sulfate solids / gypsum (sell or landfill)</td>
<td>High Purity and Strength SO₂ (SRU feed or process/sell)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reagent Costs (operating)</th>
<th>Conventional Sodium or Magnesium Based</th>
<th>Conventional Calcium Based</th>
<th>LABSORB® Regenerative Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher</td>
<td>Medium</td>
<td>Lower</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Conventional Sodium or Magnesium Based</th>
<th>Conventional Calcium Based</th>
<th>LABSORB® Regenerative Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capital Costs</th>
<th>Conventional Sodium or Magnesium Based</th>
<th>Conventional Calcium Based</th>
<th>LABSORB® Regenerative Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>Medium</td>
<td>Higher</td>
<td></td>
</tr>
</tbody>
</table>
**LABSORB**™: a regenerative approach

A wet process that absorbs SO₂ via a recyclable solution (“buffer”)

- **Clean flue gas**
- **Flue gas from Boiler**
- **Lean buffer (regenerated)**
- **Buffer regeneration system**
- **Rich (SO₂) buffer**
- **Buffer makeup**
- **SO₂ to Sulfur Recovery Unit or Sulfuric Acid Plant or SO₂ Compressor or Disposal**

Diagram showing the process flow of a regenerative approach using LABSORB™ technology.
LABSORB™
Regenerative Wet Scrubbing: What is it?

Uses EDV® Technology to Scrub Particulates, SO₂ and SO₃ in Flue/Process Gas Streams.

Utilizes an Aqueous Solution of Sodium Phosphate as Scrubbing Buffer for the Absorption of SO₂.

Minimizes Operating Costs by Regenerating the Scrubbing Buffer Using Low Pressure Steam.

 Produces a By-Product (a greater than 90% concentrated SO₂ stream that can be used as feed to a SRU, Sulfuric Acid Plant, SO₂ Compressor or for other applications.)

Virtually Eliminates Liquid Effluent Discharge from Scrubber.

Installed at Multiple Commercial Sites
Basic LABSORB™ Regenerative Process

Scrubbing Side
- Flue Gas
- Quencher
- Absorber
- Scrubbing Side Purge

Regeneration Side
- Recovered SO₂
- Condenser
- Stripper
- Vapor/Liquid Separator
- Buffer Tank
- Sulfate Removal
- Oxidation Product Removal
- LP Steam
- Heat Exchanger
- Condensate

Make-Up Buffer Tank

Pre-Scrubber Purge
Cleaned Gas
LABSORB™ Absorber and Full Pre-scrubber - PFD

GAS IN

GAS OUT

PRE-SCRUBBER (EDV® 6000)

FILTERING MODULES

DROPLET SEPARATORS

Lean Buffer From Regeneration Plant

Rich Buffer To Regeneration Plant

Make-Up Water

Pre-Scrubber Purge to Clarifier

LABSORB™ Regeneration Plant

SO₂
Why Regenerative Wet Scrubbing?

CONVENTIONAL SCRUBBING TECHNOLOGY

- Liquid Effluent Discharge or Solids Discharge
- Relatively High Operating Cost
- Lower Investment Cost

“BELCO LABSORB” REGENERATIVE SCRUBBING

- Virtually no Liquid Effluent or Solid Waste Disposal
- Low Chemicals Cost/ Acceptable Steam Requirement
- Higher Investment Cost (Investment Payback is Short Term)
Thank You!

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