Carbon Capture, Utilization and Storage (CCUS)

Actions in CHNG and China

China Huaneng Clean Energy Research Institute
July 7, 2017
Overview of CERI

- Huaneng Clean Energy Research Institute (CERI) is a clean energy R&D institution directly under China Huaneng Group (CHNG).

- China Huaneng Group (CHNG) is a state-owned power company with an installed capacity of 165 million kW by the year of 2016, which is the largest in the world.
Overview of CERI

Research Focuses in CERI

- Clean Coal Technology: Coal Gasification, IGCC, Coal to Clean Fuel
- Circulating Fluid Bed (CFB) Technology
- Carbon Capture, Utilization and Storage (CCUS)
Overview of CCUS in CERI

- A family of 20 members, with 60% PhDs and with multidisciplinary educational background.

- 2 “Thousand Talents Program” experts; 1 “State Council allowance” experts; 1 “Beijing Outstanding Youth” expert

- Dr. Gao is the leader of CERI CCUS team. He is the project manager of both “3000 tpa CO₂ Capture Demo Project in Huaneng Beijing Thermal Power Plant” and “120,000 tpa CO₂ Capture Demo Project in Huaneng Shanghai Power Plant”.

CCUS R&D Team
Overview of CCUS in CERI

Research Focuses:

- 燃煤/气烟气碳捕集技术开发
  Coal and Gas-fired Flue Gas CO₂ Capture

- 新型吸收剂开发与性能评价
  Novel Absorbent Development and Evaluation

- 工艺优化模拟和中试验证
  Process Modeling, Optimization and Pilot Testing

- 二氧化碳与其它污染物协同脱除技术
  Integrative Removal of CO₂ and Other Pollutant

- 捕集装置设计与工程总包
  Design and EPC of Capture System
Overview of CCUS in CERI

Research Focuses:

- Enhanced Coal-bed Methane Recovery
- CO₂ Mineralization Utilization
- CO₂ Fracturing Technology
- CO₂ Chemical Conversion Utilization
Overview of CCUS in CERI

R&D Platform

- State key laboratory of coal-based clean energy
- Beijing key laboratory of CO2 Capture and Process
- NEA R&D Center of Clean Coal and Low-Carbon Power Generation
- Beijing International Cooperation Base for Clean Coal Technology Development
Overview of CCUS in CERI

Laboratory Facilities

Advanced Equipment

HPLC, GC, FTIR, MS, AAS, Calorimeter, TOC, etc.

Multi-scale Test Setups
Overview of CCUS in CERI

Fundamental Research

- Solvent Development
- Process Development
- System Integration

- Absorbing-Desorbing Characteristics Study
- Degradation and Corrosion Study
- Biphasic Solvent Development
Overview of CCUS in CERI

Pilot Plant

Coal-fired Flue Gas Carbon Capture Pilot Plant
- Real coal-fired flue gas
- 1000 ton/year 1000 TPA
- Changchun Thermal Power Plant
- Test novel solvent and process

Gas-fired Flue Gas Carbon Capture Pilot Plant
- Simulated gas-fired flue gas
- 1000 ton/year 1000 TPA
- Beijing
- Gas-fired CO₂ Capture Technology Verification
Overview of CCUS in CERI

Demo Projects

In 2009, world’s largest CO$_2$ capturing facility, with capturing capacity of 120,000 t/a, was put into operation in Huaneng Shanghai Shidongkou Power Plant.

In 2008, China’s first CO$_2$ capturing facility, with capturing capacity of 3,000 t/a, was put into operation in Huaneng Beijing Cogeneration Power Plant.
Overview of CCUS in CERI

Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>China’s first PCC project in power plant (Beijing, 3,000 t/a)</td>
</tr>
<tr>
<td>2008</td>
<td>China’s first PCC project in power plant (Beijing, 3,000 t/a)</td>
</tr>
<tr>
<td>2009</td>
<td>China’s first PCC project in power plant (Beijing, 3,000 t/a)</td>
</tr>
<tr>
<td>2011</td>
<td>World’s largest PCC project at the time (Shanghai, 120,000 t/a)</td>
</tr>
<tr>
<td>2013</td>
<td>China’s first gas-fired carbon capture pilot plant (Beijing, 1,000 t/a)</td>
</tr>
<tr>
<td>2014</td>
<td>China’s first feasibility study on million ton scale PCC project</td>
</tr>
<tr>
<td>2016</td>
<td>Coal-fired carbon capture pilot plant under extreme cold conditions (Changchun, 1,000 t/a)</td>
</tr>
</tbody>
</table>
Overview of CCUS in CERI

Research Projects

- Key Technology and Equipment Development and Demonstration of CCUS Technology (China NEA)
- Demonstration of CO₂ Capture and ECBM Utilization (China MOST)
- China-US Joint-research on CCS Technology (China MOST)
- Optimization of Coal Utilization under Carbon Constraint (China CAE)
- Novel Absorbent Development and Application for Post-combustion CO₂ Capture (Beijing MSTC)
- Key Technology Development for CO₂ Capture Performance Improvement (Shanghai MSTC)
- R&D on CO₂ Mineralization by Coal Ash (Shanxi DOST)
- The Application of Membrane Concentration Technology in CO₂ Capture (CHNG)
- R&D on Novel Low Energy Penalty CO₂ Absorbent (CHNG)
- R&D on 1 MTPA CO₂ Capture System (CHNG)
- R&D on Rich-solvent Leaching Technology in CO₂ Capture (CHNG)
- Cooperation Action within CCS China-EU (COACH)
- EU- China The Near Zero Emissions Coal (NZEC) Project
- Scope Study of Technological Options for SOx treatment for CTSCo Project (ANLEC)
Overview of CCUS in CERI

Technology Application

- 3,000 tpa CO₂ Capture Demo Project in Huaneng Beijing Thermal Power Plant
- 120,000 tpa CO₂ Capture Demo Project in Huaneng Shanghai Shidongkou Power Plant
- 1,000 tpa Coal-fired Flue Gas CO₂ Capture Pilot Platform in Huaneng Changchun Power Plant
- 1,000 tpa Gas-fired Flue Gas CO₂ Capture Pilot Platform in Beijing Miyun County
- 120,000 tpa CO₂ Capture Project in Shenhua Jinjie Power Plant (Design)
- 50,000 tpa CO₂ Purification Project in Shanxi Yanchang Coal Chemical Plant
- Australia-China PCC Feasibility Study Project of 1 mtpa CO₂ PCC in Changchun Power Plant
- Australia-China PCC Feasibility Study Project of 120,000 tpa CO₂ PCC in Millmerran Power Plant
- Pre-design of Norway 1 mtpa PCC Project
- Feasibility Study of 1 mtpa PCC Project for Canada Saskpower
- China-Italy Joint Research on 1 mtpa PCC Project
- Pre-feasibility Study of 1 mtpa PCC Project for US Duke Energy
- Feasibility Study of 300,000 tpa PCC Project for Huaneng Taicang Power Plant
Overview of CCUS in CERI

Achievements & Honors

Honored by several ministerial level awards

授权发明专利 20 余项，发表论文 30 余篇
More than 20 Patents and 30 Papers
Overview of CCUS in CERI

International Cooperation

So far, we have developed tight relationship with companies, research Institutes and universities in US, Canada, Australia, Germany, British, Italy, Norway, France, Spain, South Korean and Brazil.
Overview of CCUS in CERI

Social Influence

Former Secretary of US DOE Steve Chu visits Shanghai Shidongkou PCC Project

Former Australia Premier Kevin Michael Rudd visits Beijing PCC Project
Outline

Overview of CCUS in CERI

Overview of CCUS in China

Absorbent Development

Pilot and Demo Plants
Overview of CCUS in China

China Power Investment Corporation (CPIC)

10kt/a PCC from a 300MW Unit in Chongqing Shuangkui Power Plant

- Commission in Dec 2009, put into operation in Jan 2010
- Capture rate 95%, CO2 purity 99.5%
- CO2 utilization: shielding gas for welding
Sinopec CCUS Project (Shengli Oil)

EOR & Storage: Shengli Oilfield G89

- Project Scale: 40,000t/a
- CO₂ resource: Flue gas of Shengli Power Plant
- CO₂ capture: Post-combustion capture, chemical absorption
- CO₂ Transportation: 80km, truck
- Utilization: CO₂-EOR
- Low Permeability: 4.7mD

- Initial gas injection: Jan., 2008
- By 2015, about 250,000 tons has been injected
- Estimated oil recovery can be increased by 17.2% in 15 years.
Overview of CCUS in China

PetroChina CCUS Project (Jilin Oil)

CO2-EOR & Storage with CO2 captured from Natural Gas

122,000 tons of CO2 were injected and 80,000 tons of CO2 were stored. 51,000 tons of oil were recovered by May 2010.
China Shenhua CCUS Project (Erdos)

- China Shenhua is China’s largest coal mining company and 5th coal-fired power company.
- 100,000tons/a CCS demo project
- CO₂ came from CTL (coal to liquid) Process
- Over 300,000tons had been injected

**Overview of CCUS in China**

Evaluation the storage potential of different reservoirs.

CO₂ moving area are within 350m
Overview of CCUS in China

China CBM CO2-ECBM Project

- Shanxi Qinshui Basin
- 4,000 tons CO2 has been injected by 2015
- China CBM and Huaneng CERI are currently work on a 1,000 ton CCUS full chain demo project.
Overview of CCUS in China

Yanchang Petroleum

- Shanxi Yulin
- Phase I: 50,000 TPA project (2012, CERI's technology)
- Phase II: 360,000 TPA Project (planning)
- CO2 captured from coal chemical plant utilizing rectisol method
- CO2 is used for EOR
Overview of CCUS in China

Oxy-combustion

Huazhong University of Science and Technology

1995

300kWt PC small pilot study
Burner development
Data collection and Optimization
Thermal Design

2005

50kWt Oxy-CFB small pilot study

2008

2.5MWt CFB oxyfuel boiler
In-bed heat exchanger

2011

35MWt pilot plant
0.1 million ton capture
ASU-CPU-power generation integration and optimization

2012

2013

3MWt PC large pilot study
7000T/a full chain validation
ASU-CPU coupling
FGC and drying

2014

40MWt pilot plant
Commercial scale burner
Long-term operation demonstration

2015-2020

200-600MWe full demo.
Millions ton CCS-EOR

Huazhong University of Science and Technology

Overview of CCUS in China
Overview of CCUS in China

CTSA-CCUS

China Technology Strategic Alliance for CO₂ Capture, Utilization and Storage (CTSA-CCUS) was founded in Nov 2013.

- Develop highly efficient and low-cost CCUS technology
- Constantly improve the level of technology and engineering on CCUS
- Promote the demonstration and commercialization of CCUS projects
- Provide technical support for the government on climate change mitigation
In Nov. 2009, President Barack Obama and President Hu Jintao announced the establishment of the Clean Energy Research Center (CERC).
Outline

- Overview of CCUS in CERI
- Overview of CCUS in China
- Absorbent Development
- Pilot and Demo Plants
高性能CO₂捕集溶剂研发
High-performance CO₂ Absorbent Development

- 二氧化捕集与处理北京市重点实验室（Beijing Key Laboratory of CO₂ Capture and Storage）

- 实验室研发设备 Instrument

  - Reaction Heat Calorimeter
  - Ionic Chromatography
  - FTIR
  - UV-vis-NIR
  - TOC
  - Drop Shape Analyzer
  - GC-MS
High-performance CO₂ Absorbent Development

Single & blended amines
Novel Solvents

Thermo-dynamics & kinetic studies

Optimized regeneration temperature & energy consumption

Anti-degradation inhibitor

Antioxidant/ degradation studies

Anti-corrosion inhibitor

Modeling

Pilot test

Industrial application
复配型醇胺吸收剂（Blended Amines）

吸収、解吸性能测试  Performance test of absorption & desorption

测试条件：N\textsubscript{2}:CO\textsubscript{2}=85:15(V/V)，吸収在40°C，再生在110°C

<table>
<thead>
<tr>
<th>Solvent</th>
<th>NAC</th>
<th>Increased</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA</td>
<td>1.051</td>
<td>109.9%</td>
<td>MEA</td>
</tr>
<tr>
<td>MA</td>
<td>0.956</td>
<td>100%</td>
<td>Was used at BJ and SH</td>
</tr>
<tr>
<td>C1</td>
<td>1.182</td>
<td>123.6%</td>
<td>Higher NAC</td>
</tr>
<tr>
<td>C2</td>
<td>1.357</td>
<td>141.9%</td>
<td>higher NAC</td>
</tr>
<tr>
<td>C3</td>
<td>1.405</td>
<td>147.0%</td>
<td>higher NAC; fast absorption</td>
</tr>
<tr>
<td>C4</td>
<td>1.542</td>
<td>161.3%</td>
<td></td>
</tr>
</tbody>
</table>
复配型醇胺吸收剂（Blended Amines）

吸収、解吸性能测试  Performance test of absorption & desorption

吸収、解吸热效应测评  Energy analysis of absorption & desorption by Calorimeter

EAC: Equivalent Absorption Capacity
EDC: Desorption Capacity
NAC: Net Absorption Capacity  NAC=EAC-EDC
复配型醇胺吸收剂（Blended Amines）

- 降解损耗分析评估
  Analysis of solvent degradation and solvent loss

开发出HNC1~HNC5系列溶剂(Developed commercial solvents: HNC1~HNC5)

- 2015年新型HNC5吸收剂在上海石洞口二厂12万吨/年捕集装置完成了超过3000小时的连续运行验证。
  In 2015, the new HNC5 solvent was tested for more than 3000 hours in shanghai CO₂ capture plant.

- 溶液有效成分浓度下降速度为MEA的40%，再生能耗为3.0GJ/tCO₂。该吸收剂可减少捕集成本约20%。
  Solvent loss is 40% of MEA; Regeneration energy is 3.0GJ/tCO₂; Reducing 20% CO₂ capture cost.
高性能CO₂捕集溶剂研发
High-performance CO₂ Absorbent Development

- 稠浆型CO₂吸收剂（Slurry-based CO₂ absorbent）
  - 传统吸收剂中水的比例较高（一般>70wt%），在CO₂解吸过程中水的升温与挥发消耗大量的能量，占再生消耗热量的50%以上。
  - High water content in traditional solvent (usually >70%), a large part of energy (about 50%) is consumed by heating and evaporating the water in the solvent.
  - 在CO₂富液进入再生塔前进行浓缩预处理，实现CO₂在富液中的再分配，浓缩相进入再生塔解吸，从而降低高温解吸过程中水的参与度。
  - Developing new absorption solvent and process to reduce the water involvement in regeneration is effective approach to lower energy cost.
高能性能CO₂捕集溶剂研发
High-performance CO₂ Absorbent Development

- 稠浆型CO₂吸收剂（Slurry-based CO₂ absorbent）

  开发出基于碳酸钾溶液的稠浆型CO₂捕集吸收剂和过程工艺。

  Potassium carbonate slurry-based CO₂ capture absorbent and process were developed.

富液直接解吸的加热量和冷凝量曲线
Energy curves of desorption without slurry

富液制浆解吸的加热量和冷凝量曲线
Energy curves of CO₂-riched slurry desorption
High-performance CO₂ Absorbent Development

- Slurry-based CO₂ absorbent
  - Lab-scale pilot plant was built, tested and run for slurry-based CO₂ capture

- Regeneration energy is 2.6GJ/tCO₂; absorbent cost is 20% that of MEA. Solvent loss cost is 22%~50% that of MEA;
高性能CO₂捕集溶剂研发
High-performance CO₂ Absorbent Development

自浓缩相变型CO₂吸收剂（self-concentrated biphasic CO₂ absorbent）

- 由胺、萃取剂和水混配而成
  Blended by amine, extractant and water.
- 该类型吸收剂负载CO₂后可自动分层为液-液两相，实现CO₂的再分配。
  After absorbing CO₂, the absorbent can split into two liquid/liquid phase by itself, and almost all absorbed CO₂ transfer into the rich phase (more than 95%).
- 该分相过程无需额外能耗，可有效实现CO₂在富相中的浓缩。
  No extra energy is needed for this process.

吸溶剂载CO₂后的动态分层情况（2min、4min和10min）
Solvent phase separation upon CO₂ absorption after 2min, 4min, 10min
High-performance CO₂ Absorbent Development

- Self-concentrated biphasic CO₂ absorbent
  - Absorption rate and CO₂ loading are higher than those of MEA solutions.
  - Calorimeter experiments show that the desorption of CO₂ rich phase can reduce 20%~30% regeneration energy.
高性能CO₂捕集溶剂研发
High-performance CO₂ Absorbent Development

自浓缩相变型CO₂捕集工艺
Designed capture process for biphasic CO₂ absorbent
Outline

- Overview of CCUS in CERI
- Overview of CCUS in China
- Absorbent Development
- Pilot and Demo Plants
Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

- The 100kg/h PCC pilot plant is based in Changchun coal-fired plant
- Purpose: (1) to evaluate the screened solvents;
  (2) to evaluate the operation of PCC plant under extreme cold conditions.
- Completed on May 2014 and have tested 3 solvents with 1000hrs for each solvent.
Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

<table>
<thead>
<tr>
<th>Columns</th>
<th>Pipe size</th>
<th>Packing height, m</th>
<th>Packing materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCC</td>
<td>DN450</td>
<td>3.055</td>
<td>316L</td>
</tr>
<tr>
<td>Absorber</td>
<td>DN350</td>
<td>8</td>
<td>316L</td>
</tr>
<tr>
<td>Wash</td>
<td>DN350</td>
<td>1.88</td>
<td>316L</td>
</tr>
<tr>
<td>Stripper</td>
<td>DN250</td>
<td>8.56</td>
<td>316L</td>
</tr>
</tbody>
</table>
Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

Control Interface

Absorber

Stripper
Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

Data Acquisition

- All data are stored in the database every 5 seconds;
- Access files are generated day by day;
- Data recorded include flue gas composition (GASMET), pressure/temperature of gas and liquid flow, liquid level in columns, PH value of solvent, etc.
Pilot and Demo Plants
(1) 1000 t/a coal-fired pilot plant

Pretreatment Performance

- SO2 concentration is below 5 ppm after pretreatment;
- NOx removal rate is limited due the insoluble NO.

SO2 concentration in flue gas before and after pretreatment

NOx concentration in flue gas before and after pretreatment
Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

Test on MEA

Specific reboiler duty as a function of liquid/gas flow ratio

MEA concentration in absorbent circuit and wash-water circuit through-out the campaign
Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

The pilot test is an important part of the Australia-China PCC Feasibility Study which is conducted by CERI in 2016.
Pilot and Demo Plants
(2) 1000 t/a gas-fired pilot plant

- China’s first CO₂ capture pilot plant for gas-fired NGCC plant with a capacity of 1000t/a; installed in Miyun county of Beijing in 2012.
- Simulated flue gas by industrial burner
  - CO₂ in flue gas: 6 vol% (11% for coal fired)
  - O₂ in flue gas: 12 vol% (5% for coal fired)
  - Flue gas temperature: 90C (50C for coal-fired)
- This plant is served as a verification plant for Norway CO₂ Capture Mongstad (CCM) project
- Verification plant has been running stably for 3000 hours with capture efficiency >85% (85%~92%)
- Win the bidding of Norway Statiol CO₂ Capture Mongstad Project (Huaneng CERI-Powerspan JV)
## Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

### Major Specs of NGCC plant

<table>
<thead>
<tr>
<th>Absorber and Wash Section</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information</strong></td>
<td>CCM Full scale design</td>
</tr>
<tr>
<td>Column ID</td>
<td>[Image]</td>
</tr>
<tr>
<td>CO₂ Absorber Packed Beds</td>
<td>15.2 m total packing – 2 beds with 7.6 m in each bed Inter-cooler between beds</td>
</tr>
<tr>
<td>Packing type</td>
<td>Raschig RSP 250 316 SS, 250 m²/m³</td>
</tr>
<tr>
<td>Materials of construction (vessel walls and internals)</td>
<td>316 SS Vessel walls 304 SS, internals 316 SS</td>
</tr>
<tr>
<td>Absorber Gas Velocity and Liquid Load</td>
<td>2.7 m/s (gas) 3.9 kg/m²-s (liquid)</td>
</tr>
<tr>
<td>Wash Section Packing and Liquid Load</td>
<td>3.0 m in single bed, Raschig RSP 250, 316 SS, 4.2 kg/m²-s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regenerator</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information</strong></td>
<td>CCM Full scale design</td>
</tr>
<tr>
<td>Column ID</td>
<td>[Image]</td>
</tr>
<tr>
<td>Packing</td>
<td>12.2 m total 2 beds with 6.1 m per bed</td>
</tr>
<tr>
<td>Packing type</td>
<td>Raschig RSP 250 316 SS, 250 m²/m³</td>
</tr>
<tr>
<td>Materials of construction (vessel walls and internals)</td>
<td>316 SS</td>
</tr>
<tr>
<td>Liquid Load</td>
<td>18.6 kg/m²-s</td>
</tr>
<tr>
<td>Reboiler types</td>
<td>Kettle</td>
</tr>
</tbody>
</table>
Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant
Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

- Automatic Data Collection Every 5 Seconds, and Generating Performance Curves

Flue gas content analysis real-time data

溶�PH值及密度曲线 Solvent PH level and density
Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

- Daily Solvent sampling
- Three solvent additions added during the operation from Mar. 7 to Apr. 2.
- Estimate Solvent consume (0.3~0.45) kg / tCO₂

Solvent concentration variation during 3000 hours test

\[ Y = \frac{\text{Actual concentration}}{\text{Design Concentration}} \]
## Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

### Emissions

<table>
<thead>
<tr>
<th>气相排放组分</th>
<th>Gas emissions component</th>
<th>尾气浓度</th>
<th>Stack concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>溶剂 Solvent</td>
<td>0.17ppmv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>总亚硝胺 Total Nitrosamine(TONO)</td>
<td>3 μg/Nm³ as NDMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>氨 Ammonia</td>
<td>12.7ppmv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>乙二胺 ETHYLENE DIAMINE</td>
<td>&lt; 0.001 ppmv</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

Corrosion Analysis

<table>
<thead>
<tr>
<th>Location</th>
<th>M</th>
<th>Rate, 0.001 \times \text{in/year}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercooling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>0.0232</td>
<td>304</td>
</tr>
<tr>
<td>316L</td>
<td>0.0189</td>
<td>316L</td>
</tr>
<tr>
<td>2205</td>
<td>0.0219</td>
<td>2205</td>
</tr>
<tr>
<td>2507</td>
<td>0.0198</td>
<td>2507</td>
</tr>
<tr>
<td>EPDM70</td>
<td>-8.4795</td>
<td>EPDM70</td>
</tr>
<tr>
<td>TFE PFA</td>
<td>-0.0134</td>
<td>TFE P FA</td>
</tr>
<tr>
<td>Hot Lean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>0.0619</td>
<td></td>
</tr>
<tr>
<td>316L</td>
<td>0.0634</td>
<td></td>
</tr>
<tr>
<td>2205</td>
<td>0.0561</td>
<td></td>
</tr>
<tr>
<td>2507</td>
<td>0.0455</td>
<td></td>
</tr>
<tr>
<td>EPDM70</td>
<td>-19.3614</td>
<td></td>
</tr>
<tr>
<td>TFE P FA</td>
<td>-0.0422</td>
<td></td>
</tr>
</tbody>
</table>

- Materials tested: 316L, 304, 2205, 2507, EPDM-70 and TFE P (PFA);
- Total exposure time is 3888 hours.
- For all Alloys, lower than 0.0016 mm/year
- TFE P (PFA) perform fine, while EPDM experience swelling in hot location
Pilot and Demo Plants

(3) 3,000 t/a Demo plant

- China’s first post-combustion CO2 capture plant with a capacity of 3000 t/a.
- Designed by CERI, completed in 2008 and still in scheduled operation.
- CO2 product was sold to food industry such as Yanjin Beer.
- R&D platform of CERI.
## Pilot and Demo Plants

### (3) 3,000 t/a Demo plant

<table>
<thead>
<tr>
<th>Items</th>
<th>Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture Process</td>
<td>Amine-based Post combustion Capture</td>
</tr>
<tr>
<td>Feature</td>
<td>PC power station, CO2 12-15% in flue gas</td>
</tr>
<tr>
<td>Scale</td>
<td>3,000tpa CO₂</td>
</tr>
<tr>
<td>Solvent</td>
<td>MEA</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>&lt;3.5GJ/t CO₂</td>
</tr>
<tr>
<td>Capture Ratio</td>
<td>&gt;85%</td>
</tr>
<tr>
<td>CO₂ Purity</td>
<td>Food Grade, &gt;99.997%</td>
</tr>
<tr>
<td>Others</td>
<td>New solvent developed by CERI was put in use since 2011, Energy consumption&lt;3.2GJ/t CO₂</td>
</tr>
<tr>
<td></td>
<td>Stable running over 5 years, tests on corrosion, solvent purification and energy saving technologies</td>
</tr>
</tbody>
</table>
Pilot and Demo Plants

(4) 120,000 t/a Demo plant

- Designed by CERI and ECEPDI, completed in 2009.
- Capacity: 120,000 t/a; it was word’s largest PCC plant. (boundary dam,
- Cost: 100 million RMB (16 million USD)
Pilot and Demo Plants

(4) 120,000 t/a Demo plant
The 30MWth pre-combustion CO₂ capture facility is being installed and will go into operation in 2016.

The first pre-combustion CO₂ capture with EOR and storage in China

200m³/h palladium membrane H₂/CO₂ separation system
Pilot and Demo Plants

(5) Tianjin IGCC Based Pre-combustion Capture

<table>
<thead>
<tr>
<th>Items</th>
<th>Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture Process</td>
<td>Amine based Pre-combustion Capture</td>
</tr>
<tr>
<td>Feature</td>
<td>IGCC based full chain CCS</td>
</tr>
<tr>
<td>Scale</td>
<td>60,000-100,000tpa CO₂ (30MW&lt;sub&gt;th&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>&lt;2.5GJ/t CO₂</td>
</tr>
<tr>
<td>CO₂ Transportation</td>
<td>Tanks</td>
</tr>
<tr>
<td>CO₂ Storage</td>
<td>≥60,000tpa CO₂ EOR+</td>
</tr>
<tr>
<td></td>
<td>≥60,000tpa CO₂ storage</td>
</tr>
<tr>
<td>Others</td>
<td>Shift reaction heat power ≥50kW</td>
</tr>
<tr>
<td></td>
<td>CO/H₂/CO₂ tunable</td>
</tr>
<tr>
<td></td>
<td>H₂/CO₂ membrane separation capacity ≥6Nm³/h</td>
</tr>
<tr>
<td></td>
<td>10-15% reduction in energy consumption</td>
</tr>
</tbody>
</table>