Pilot plant results for advanced CO₂ capture process using AMP/PZ solvent at Tauron’s coal-fired Power Plant

Adam Tatarczuk, Institute for Chemical Processing of Coal, Poland
tatarczuk@ichpw.pl
Fuel mix in power generation - Poland

Year 2015 – 140,1 TWh
- Hard coal: 44.90%
- Lignite: 12.13%
- Natural gas: 36.47%
- Oil products: 1.78%
- Nuclear: 0.71%
- Renewables: 0.43%
- Water: 1.50%
- Others: 1.78%

Year 2030 – 201,8 TWh
- Hard coal: 35.6%
- Lignite: 18.8%
- Natural gas: 21.0%
- Oil products: 6.6%
- Nuclear: 0.5%
- Renewables: 0.3%
- Water: 15.7%
- Others: 12.13%

* "Energy Policy of Poland until 2030" (Ministry of Economy 2009)
About TAURON Group – power plants

**Electric Power – 4 671 MWe**
- Łągiska Power Plant
  - 850 MWe
  - 343.4 MWt
- Blachownia Power Plant
  - 166 MWe
  - 256 MWt
- Łaziska Power Plant
  - 1 155 MWe
  - 196 MWt
- Jaworzno Power Plant
  - 1 535 MWe
  - 369.3 MWt

**Thermal Power – 1 667,1 MWt**
- Łaziska Power Plant
  - 330 MWe
  - 465.9 MWt
- Siersza Power Plant
  - 666 MWe
  - 36.5 MWt
- Słatowa Wola Power Plant
  - 1 155 MWe
  - 196 MWt

**Group power plants**
- Stalowa Wola Power Plant
  - 330 MWe
  - 465.9 MWt
- Łaziska Power Plant
  - 850 MWe
  - 343.4 MWt
- Siersza Power Plant
  - 666 MWe
  - 36.5 MWt
Institute for Chemical Processing of Coal, Zabrze, Poland

Clean Coal Technology Centre

Institute for Chemical Processing of Coal
Clean Coal Technology Centre in Zabrze (Upper Silesia, Poland)

Pressurized gasification and oxy-combustion in circulating fluidized bed (100/50 kg/h)

Testing plant for solid fuels gasification (100 kg/h)

Chemical looping reactor (10m³/h)

Biomass gasifier (15 kg/h)

By-products station

Technological Building I

Coal preparation station

Coal storage yard

Technology Building II (experimental sets and tanks)

Testing plant for CO₂ capture in absorption process (100m³/h)
General information

- **Project name:**
  Development of a technology for highly efficient zero-emission coal-fired power units integrated with CO₂ capture.

- **Objective:**
  The main purpose of the project was to demonstrate the post combustion process in pilot plant connected to coal-fired power plant.

- **Principal:**
  National Research and Development Center (Poland)

- **Project duration:**
  1.04.2010 – 30.11.2015 (67 months)

- **Executors:**
  TAURON Polish Energy, TAURON Production, Institute for Chemical Processing of Coal (IChPW)
IChPW CO$_2$ capture process scale-up strategy

Experimental apparatus of CO$_2$ absorption kinetics and equilibriums in amine blends (2010)

Lab stand for CO$_2$ capture process – 5 m$^3$/h (2011)

The Mobile Pilot Plant – 200 m$^3$/h (2013-Tauron Power Plant)

PDU for CO$_2$ capture process – 100 m$^3$/h (2012-IChPW Zabrze)
# The Pilot Plant commissioning – 05.2014 Jaworzno Power Plant (TAURON)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column diameter</td>
<td>300 mm</td>
</tr>
<tr>
<td>Column height</td>
<td>15.0 m</td>
</tr>
<tr>
<td>Number of devices</td>
<td>40</td>
</tr>
<tr>
<td>Measurements</td>
<td>180 points</td>
</tr>
<tr>
<td>Solvent</td>
<td>amines solution</td>
</tr>
<tr>
<td>Solvent stream</td>
<td>up to 1800 dm$^3$/h</td>
</tr>
<tr>
<td>Gas stream</td>
<td>up to 200 m$^3$/h</td>
</tr>
<tr>
<td>Tested gas</td>
<td>Flue gas from hard–coal boiler</td>
</tr>
</tbody>
</table>
The Pilot Plant simplified flow diagram

Split-flow

Inter heating

Desulphurising solution
Rich amine solution
Semi-lean amine solution
Lean amine solution
Water, condensate
Gae
### Results and discussion

#### Nomenclature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ recovery</td>
<td>Amount of CO₂ captured divided by amount of CO₂ in flue gas</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Typical values: 80 – 90</td>
<td></td>
</tr>
<tr>
<td>Reboiler heat duty</td>
<td>Energy delivered to the process divided by amount of CO₂ captured</td>
<td>MJ/\text{kgCO}_2\text{ }</td>
</tr>
<tr>
<td></td>
<td>Typical values: 3 – 5</td>
<td></td>
</tr>
</tbody>
</table>
Results and discussion – selected campaign

- Effect of absorption pressure
- Effect of heating power
- Effect of desorption pressure
- Effect of absorption temp.
- CO₂ concentration [% vol.]
- L/G ratio
- CO₂ recovery
- Reboiler heat duty [MJ/kgCO₂]

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Effect of CO$_2$ inlet stream concentration on CO$_2$ recovery and reboiler heat duty

CO$_2$ recovery [\%] vs. CO$_2$ inlet stream concentration [% vol.].

- CO$_2$ recovery:
  - 90.9 at 12.17\% vol.
  - 93.3 at 9.94\% vol.
  - 96.6 at 8.14\% vol.

- Reboiler heat duty [MJ/kgCO$_2$]:
  - 3.88 at 12.17\% vol.
  - 4.50 at 9.94\% vol.
  - 5.32 at 8.14\% vol.
Standard versus advanced configuration
Effect of L/G ratio on CO₂ recovery and reboiler heat duty - 30 wt% MEA (different process configurations)
Effect of L/G ratio on CO₂ recovery and reboiler heat duty - 30 wt% MEA (different process configurations)
Effect of L/G ratio on CO₂ recovery and reboiler heat duty - 30 wt% MEA (different process configurations)
Effect of stripper internal heating on CO₂ recovery and reboiler heat duty

Solvent: AMP/PZ
L/G: 4.0
Conf.: Split Flow

CO₂ recovery drops 10%

CO₂ concentration

Reboiler heat duty increases 16 %
Effect of stripper internal heating on CO₂ recovery and reboiler heat duty

Solvent: AMP/PZ
L/G: 3,2
Conf.: Multi Abs. Feed

CO₂ recovery drops 4 %
Reboiler heat duty increases 11%
Results - stripper internal heating temperature profile

Temp. - with internal heating ON
Temp. - with internal heating OFF

Solvent: AMP/PZ
L/G: 4,0
Conf.: Split Flow

Condenser

CO₂

STRIPPER

SemHean solution

Loaded solution

Reboiler

Lean solution

29,24 kW
48,22 kW

13,6 kW
0,0 kW

4,1 kW
0,0 kW

44
42

52
51

54
53

85
78

88
77

107
104

19

INSTITUTE FOR CHEMICAL PROCESSING OF COAL
## Results - Stripper internal heating influence matrix

<table>
<thead>
<tr>
<th>Campaign</th>
<th>Solvent</th>
<th>L/G (kg/kg) (Configuration)</th>
<th>Lean loading reduction [molCO₂/mol amine]</th>
<th>Heat duty reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>MEA</td>
<td>5,7 (Split-flow)</td>
<td>0,025</td>
<td>11,2</td>
</tr>
<tr>
<td>J5</td>
<td>AMP/PZ</td>
<td>5,7 (Split-flow)</td>
<td>0,050</td>
<td>14,0</td>
</tr>
<tr>
<td>J8</td>
<td>AMP/PZ</td>
<td>4,0 (Split-flow)</td>
<td>0,054</td>
<td>16,0</td>
</tr>
<tr>
<td>J10</td>
<td>AMP/PZ</td>
<td>3,17 (Multi absorber feed)</td>
<td>0,031</td>
<td>11,6</td>
</tr>
<tr>
<td>J13</td>
<td>Multicomponent</td>
<td>4,0 (Split-flow)</td>
<td>0,051</td>
<td>16,0</td>
</tr>
</tbody>
</table>
Results – IChPW reboiler heat duty reduction road map (2013-2014)

<table>
<thead>
<tr>
<th></th>
<th>Łaziska Power Plant - 2013</th>
<th>Jaworzno Power Plant - 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reboiler heat duty (gross values) [MJ/kgCO₂]</td>
<td>4.26</td>
<td>3.16</td>
</tr>
<tr>
<td></td>
<td>3.69</td>
<td>3.32</td>
</tr>
<tr>
<td>Pilot Plant operating hours [h]</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td>950</td>
<td>1200</td>
</tr>
</tbody>
</table>

MEA 30%
Results – IChPW reboiler heat duty reduction road map (2013-2014)

Reboiler heat duty (gross values) [MJ/kgCO₂]

Łaziska Power Plant - 2013
Jaworzno Power Plant - 2014

Pilot Plant operating hours [h]

200 550 950 1200

4.26 3.69 3.32 3.16

MEA 30%
AMP/PZ

2.8 3.2 3.6 4.0 4.4

3.69

2.8

2.4
Results – IChPW reboiler heat duty reduction road map (2013-2014)

Łaziska Power Plant - 2013

Jaworzno Power Plant - 2014

Pilot Plant operating hours [h]

Reboiler heat duty (gross values) [MJ/kgCO₂]
Results – IChPW reboiler heat duty reduction road map (2013-2014)

Reboiler heat duty (gross values) [MJ/kgCO₂]

Łaziska Power Plant - 2013
Jaworzno Power Plant - 2014

Pilot Plant operating hours [h]

4.26
3.69
3.32
3.16
Results - The Pilot Plant operational difficulties

- CO₂ concentration fluctuations in inlet flue gas stream
- Inlet flue gases pipeline drainage
- Additional Venturi scrubber demister due to flue gases moisture
- Rapid corrosion in blower

Inlet flue gas stream [kg/h]

Outlet stream [kg/h]
Results - Pros and cons of the stream-splitting and internal heating

- Higher CO₂ recovery
- Lower reboiler heat duty
- Lower OPEX due to reduced steam demand

- Higher CAPEX due to stripper modification, additional piping and equipment (pumps)
Results - Simplified economic analysis

The full chain CCS demonstration plant captures and stores the CO$_2$ from 250MW (175 tonnes of CO$_2$/h) of net electricity generation unit, with 100km CO$_2$ pipeline, solvent: 30 wt% MEA, CO$_2$ recovery: ca. 90%

<table>
<thead>
<tr>
<th>Standard configuration</th>
<th>Advanced configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX: PLN 978.2 M</td>
<td>CAPEX: PLN 1000.3 M</td>
</tr>
<tr>
<td>OPEX: PLN 159.7M / year</td>
<td>OPEX: PLN 155.7M / year</td>
</tr>
</tbody>
</table>

How long will it take an advanced CCS plant to pay for itself?

CAPEX difference (PLN 22.1M) will be paid in less then 6 years!
The Pilot Plant research summary

- The pilot plant campaigns successfully demonstrated reliable operation allowing the removal of over 80,000 kg of CO₂ from real flue gas (2000h).
- The energy requirement for solvent regeneration was found about 3.16 MJ/kgCO₂ (gross value) with 90% CO₂ removal efficiency.
- Experimental data was presented to verify effectiveness of the modifications which were up to this time presented mainly through modelling.
- Presented modifications resulted in an increase of CO₂ recovery ranging from 4% to 16% while reducing the reboiler heat duty up to 16%.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of campaigns</td>
<td>29</td>
</tr>
<tr>
<td>Number of tests</td>
<td>360</td>
</tr>
<tr>
<td>Operation time</td>
<td>2000 h</td>
</tr>
<tr>
<td>CO₂ removed</td>
<td>approx. 80,000 kg</td>
</tr>
</tbody>
</table>
New project – CO₂ methanation system for electricity storage through SNG production

<table>
<thead>
<tr>
<th>Intermittent Renewable Energy</th>
<th>Several markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbine</td>
<td>Natural gas network</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Domestic uses</td>
</tr>
<tr>
<td>CO₂ Capture</td>
<td>Fuels</td>
</tr>
<tr>
<td>Coal power plant</td>
<td>Transportation</td>
</tr>
<tr>
<td>Modular structured reactor</td>
<td>Chemical market</td>
</tr>
</tbody>
</table>

**CO₂ Capture**
- Coal power plant

**Water electrolysis**
- O₂
- H₂
- Electrolyser

**Modular structured reactor**
- CO₂ hydrogenation
- SNG

**SNG Production**
- H₂O
- H₂O

**Project Consortium:**
- TAURON Wytwarzanie
- CEA
- ATMOSTAT
- AGH University of Science and Technology
- Institute for Chemical Processing of Coal
- RAFAKO S.A.
- West Technology & Trading Polska Sp. z o.o.
Research team:
- dr inż. Aleksander Sobolewski
- dr inż. Krzysztof Dreszer
- mgr inż. Józef Popowicz
- dr inż. Lucyna Więckol Solny
- mgr inż. Adam Tatarczuk
- mgr inż. Marcin Stec
- mgr inż. Tomasz Szczypiński
- mgr inż. Piotr Kolon
- mgr inż. Dariusz Śpiewak
- mgr inż. Tomasz Spietz
- mgr inż. Aleksander Krótki
- mgr inż. Andrzej Wilk

Industrial partners team:
- dr inż. Stanisław Tokarski – TAURON Polska Energia SA
- mgr inż. Janusz Tchórz – TAURON Wytwarzanie SA
- mgr inż. Sławomir Dziaduła – TAURON Wytwarzanie SA
- inż. Stanisław Gruszka – TAURON Wytwarzanie SA
- mgr inż. Jerzy Janikowski – TAURON Polska Energia SA
- mgr inż. Janusz Zdeb – TAURON Wytwarzanie SA

Project manager:
- dr hab. inż. Marek Ściażko, prof. nadzw.

E-mail: office@ichpw.pl
Internet: www.ichpw.zabrze.pl
We invite you to take a virtual tour of the Clean Coal Technology Centre: 
http://ichpw.wkraj.pl/#/65563/0

and to watch the movie about the Institute:
http://koala.ichpw.zabrze.pl/video/Institute_for_Chemical_Processing_of_Coal.mp4
Tauron’s Pilot Plant - That's one small step for [an] engineer, one giant leap for Poles.

Thank you for attention