NOx abatement in Swedish large and medium sized combustion plants
- fuelled with biomass,
- or used for co-incineration for energy production

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22nd EGTEI Meeting - Nice, 18 October 2013

Multiply mg/MJ with
2,5 (for biomass with 50 % moisture), or
2,8 (for biomass with 20 % moisture)
to get mg/Nm³ at 6 % O₂

Multiply mg/MJ with
1,8 (for biomass with 30 % moisture)
to get mg/Nm³ at 11 % O₂
Summary

• In combustion & co-incineration plants (in the Swedish Energy and Industrial Sectors) biomass and biomass waste predominate

• Primary measures to abate NOx are frequent and sophisticated

• For biomass combustion & co-incineration for energy production:
  ▪ ~ 150 units have SNCR
    – Typically 50 - 120 mg/MJ with SNCR
  ▪ ~ 20 units have, or have had SCR
    – Almost all installed SCR are either removed or are now used as slip-SCR
  ▪ 7 - 10 have Slip SCR (as high dust)
    in combination with SNCR

Combustion Plants in Sweden

• Units = mostly boilers (and some gas turbines)

• Plants = all the units at the site

• ~ 700 combustion plants EU ETS
  ~ 430 units Swedish "NOx Charge"

• ~ 140 LCP plants (with ~ 300 units)
  ~ 80 WID plants (with 135 units)

• Major product = Heat for district heating: 50 - 60 TWh annually
  + Power at CHPs & Industry: ~ 14 TWh
  + Steam at Industry: 10 TWh
  + District cooling: ~ 1 TWh
  + Condensed Power: ~ 0,3 TWh
Energy Sector:
- 400+ district heating nets
- ~ 70 CHP plants with 10 TWh power production
- 70 TWh thermal input for heat and CHP:
  - ~ 40 % biomass + ~ 25 % waste
  - ~ 9 % fossil + ~ 4 % peat
  - ~ 6 % flue gas condensation

Industry Sector:
- 15 TWh biomass for steam and power production in:
  - Pulp & Paper (10 TWh excluding recovery boilers)
  - Saw Mills (4 TWh)

Typical plant in the Energy Sector in Sweden - Today

Example:
- Boiler 4 - CHP - 2007 - base load - "co-incineration plant"
  » waste wood and other waste fuels
  » some virgin wood
- Boiler 3 - CHP - 1984 - mid merit - built for coal, but retrofitted to wood chips
- Boiler 2 - Heating Water - 1971 - peak load - bio oil
- Boiler 1 - Heating Water - 1966 - reserve load - gas oil
A typical plant (unit, boiler) for biomass in Sweden

- SNCR
- Boiler
- ESP/FF
- Flue Gas Condenser
- Turbine
- Heating Water Accumulator

Primary measures at biomass boilers in Sweden

Primary measures important Role

• Staged combustion, of course
  - Including
    ▪ Rotating Over Fire Air
    ▪ Ecotube
    ▪ ..... 

• Recirculation of Flue Gas
• Injection of water or steam in boiler
• Cooling of combustion air
• Sulphur injection
• ... and others

Together with hour to hour focus
Approx. NOx Yearly average at those biomass and waste fired boilers which have SCR

Approx. NOx Yearly average at those biomass and waste fired boilers which have SNCR
SNCR vs SCR for new biomass and co-incineration boilers

- Above 40 mg/MJ SNCR is first choice
  - since economy is determining factor
- Below 40 mg/MJ SCR is probably the best option,
  - or for lower levels: the only choice

Estimated Costs for 75 MWth Biomass Boiler

<table>
<thead>
<tr>
<th>Investment</th>
<th>Ammonia</th>
<th>Catalyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCR</td>
<td>5 million €</td>
<td>Deactivation Rate critical</td>
</tr>
<tr>
<td>SNCR</td>
<td>1 million €</td>
<td>2-3 times more than SCR</td>
</tr>
</tbody>
</table>

Estimated annual Costs in € per kg NOx

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Being installed at (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary measures</td>
<td>1 - 2</td>
<td>all units more or less</td>
</tr>
<tr>
<td>SNCR</td>
<td>1,5 - 3</td>
<td>~ 150 units</td>
</tr>
<tr>
<td>SCR</td>
<td>4 - 20</td>
<td>1 unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 units (slip-SCR)</td>
</tr>
</tbody>
</table>

Calculation method:
- Depreciation during:
  - 10 years for primary measures and SNCR
  - and 20 years for SCR
- Interest rate 10 % (!!!)
SNCR - at biomass and co-incineration boilers

- Yearly averages range from 13 to 150 mg/MJ thermal input
  - 70% of units: 50 - 120 mg/MJ yearly average
  - Upper end of interval quite high
    - Existing boilers have been retrofitted
- ~150 units (i.e. boilers) in Sweden today have SNCR
  - ~120 with ammonia
  - ~25 with urea
  - ~8 with ammonium sulphate

Conditions that must be fulfilled:

- Temperature levels
- Reaction times
- Injection at several levels
- NH$_3$ slip
High Dust SCR  - at biomass and co-incineration boilers

• Beginning at the 90:s: Some coal boilers converted to biomass Catalysts removed or now used as slip-SCR
• Biomass & Tyres/ Recycled wood/ Paper&Plastics
  Deactivation ~ 50 % per year
• Coal co-combusted with 10-15% Biomass
  Deactivation 10-20 % per year
  DK, NL, ...

SNCR and Slip SCR in High dust position  - at biomass and co-incineration boilers

• Installed at ~ 6 biomass plants since 1997
  − 15 - 55 mg/MJ
• ~ 8 - 20 % deactivation per year
  − Catalyst elements exchanged after 3 - 7 years
Low Dust SCR - after dust abatement - at biomass and co-incineration boilers

Only few installations:

- % Bio and % Peat
  since 2010 - Umeå
  15 mg/MJ yearly average
- 50 % Bio and 50 % Peat
  Deactivation < 10 % per year

1994-2000 Kiruna

Tail End - at biomass and co-incineration boilers

- Waste incineration plants: Dominating
  - Deactivation ~ 1-3 % per year
- (As far as we know) Not used in Sweden for pure biomass
- Heat exchanger cost ~ 1 million €
- Need of net extra energy
  + 1-2 MW
  for a 75 MWth boiler
Summary - Once again! 😊

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Thank you for your attention

And a special thank to:
- The colleagues at the Administration of the NOx Charge
- The Swedish Thermal Engineering Research Institute ("Värme forsk")

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The Swedish Charge on NO\textsubscript{x}

Some extra slides

The Swedish Charge on NO\textsubscript{x}
Applies to boilers & gas turbines for energy production with
Energy production > 25 GWh per year

After each year Calculation
TOTAL SUM MONEY
divided with
TOTAL SUM PRODUCED ENERGY
\( \rightarrow \sim 1 \, \text{€} / \text{MWh} \)

FIXED
5,5 € / kg NO\textsubscript{x}

SUM usually:
\( \sim 75 \text{ million €} \) per year

The Swedish EPA
Administration
\( \frac{1}{2} \text{ million €} \)

SAME SUM:
\( \sim 75 \text{ million €} \) per year
The Swedish Charge on NO$_X$

Applies to boilers & gas turbines for energy production with
Energy production > 25 GWh per year

Totally
75 TWh produced / year

14 000 tonnes NO$_X$ / year

5.5 € / kg NO$_X$

1 € / MWh produced

Benchmark "automatically" set by the performance of all plants

0.41 kg/MWh$_{\text{produced}}$ in 1992 → 0.18 kg/MWh$_{\text{produced}}$ in 2013

Yearly average NO$_X$ emissions for all units (boilers, gas turbines) subject to NOx Charge (all fuels)
Why the NOx Charge have been successful

- High charge level (5.5 € per kg)
- Every kilogram counts
  - Focus at NOx levels from hour to hour by personnel for operation of the plant
- Measures for decreasing emissions are taken at plants where the cost is least
- Reduced effect on competition due to the refund construction
- Technology development
- Winners and losers in every sector → Rather well received
- Very low administration cost (<1%)

Net yearly economic result for all ~ 400 boilers - individually under the NOx charge

Net receivers

Net payers