Biomass in steel industry

CASR-tutkijaseminaari
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Hannu Suopajärvi
Content of the presentation

• Background
• Bioreducer-project
• Research objective
• Topics discussed in this presentation
  – Availability of biomass
  – Conversion routes of biomass to reducing agent
  – Evaluation of the effect of charcoal use in plant scale
  – Production cost of charcoal
  – The yearly need of biomass
• Conclusions
• References
Background

• CO₂ problem in steel industry
  – Contributes 5-7 % of world’s fossil CO₂ emissions
  – In Finland Ruukki produces around 4 to 5 Mt CO₂ yearly
    (around 6-7 % of CO₂ emissions in Finland)

• Political actions and Steel industry’s response
  – Energy efficiency plans with producers
  – Emission trade
  – Increasing material and energy efficiency
  – Adopting new technologies
  – By-product usage of other industries
  – Increasing recycling
  – Adopting new raw materials (biomass…)

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Bioreducer-project

- Funding mainly from Tekes (2010-2012) and companies
- Biomass-based reducing agents for the use of metallurgical industry
- Objectives
  - To evaluate the availability of raw materials
  - To evaluate the technical potential of biomass-derived reducing agents in metallurgical processes
  - To determine the suitable conversion technologies to produce biomass-derived reducing agents
  - To estimate plant-wide effects (BF-BOF steel plant) of biomass introduction
  - To assess sustainability of biomass use in iron and steelmaking industry
- Methods
  - Availability assessments
  - Process modeling and simulation
  - Sustainability assessment
  - Laboratory experiments
- Project manager Mikko Angerman
  - mikko.angerman@oulu.fi

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Thesis work

- Evaluation of sustainability of domestic biomass use in iron and steelmaking with embedded approach
  - Evaluation of process and plant site effects of charcoal use and production
  - Evaluation of needed amount of biomass with different and contribution to Finnish renewable energy targets
  - The availability of biomass
  - The cost of charcoal production
  - The environmental burden of charcoal production
Availability of biomass

- Large acquisition area was assumed
  - Seven forest centers
  - Production of charcoal could be done in decentralized manner
  - The main interest was in wood-based biomass because of the large volumes
  - Also other biomass and alternative feedstocks were evaluated
    - Peat
    - Waste wood
    - Plastic
    - Energy crops
Availability of biomass

- Evaluation is based on the 2009 figures
- The use of forest chips in heat and power 2.7 Mm$^3$ (0.4 Mm$^3$ households)
- Several forest chip potential studies have been conducted
  - The assumptions behind estimations differ
  - The use of forest chips can be increased significantly
- Techno-economic estimations up to almost 7 Mm$^3$
- Techno-ecology potential (Kärhä et al. 2010) 13.3 Mm$^3$
- The current use (2009) of forest chips enables substantial increase
  - The potential increase of forest chips use even 10 Mm$^3$ year
- The whole energy wood potential is not earmarked to certain industry

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Conversion routes

• Biomass derived reducing agent could be introduced to blast furnace in solid, gas or liquid form

• Conversion routes:
  – Slow pyrolysis (charcoal)
  – Fast pyrolysis (bio-oil)
  – Gasification (reducing gases (H₂, CO), synthetic natural gas)

• Charcoal case examined more closely
Evaluation of the effect of charcoal use in plant scale

• Prior research done by other researchers has shown that charcoal is suitable blast furnace injectant (reducing agent)
• The effect of charcoal production and use in integrated steelworks was examined
  – The evaluation is based on the process modeling approach with mass and energy balances
  – The most important unit process to be modeled was blast furnace
• Different simulations were performed and compared to base case with traditional blast furnace reducing agents
  – In Base case coke and specific heavy oil are used as reducing agents
  – In CC case 1 the specific heavy oil is replaced by charcoal produced outside the integrated steelworks
  – In CC case 2 the amount of charcoal is further increased and the production of charcoal is integrated to steelworks structure
Blast furnace model

- Based on mass and heat balances
  - Calculation of reduction and heating energy requirements, slag formation, etc.
  - Basically based on RIST diagram
- Chemical and thermal reserve zone between upper and lower active zones
  - In chemical reserve zone CO/CO$_2$ and H$_2$/H$_2$O ratios are fixed with thermodynamic equilibrium at certain temperature of TRZ (1200 K)
- Developed for evaluating the performance of different input materials
  - Special emphasis on tuyère injected fuels
- Calculates e.g. the needed coke and blast amount, slag amount and the composition of top-gas
- All the process specific simulations are performed against one ton of hot metal
Plant site model

- The major integrated steelwork unit processes (with Factory Simulation tool)
- Mass and heat balances
- The material and energy flows between unit processes form a complex entity
- Plant site model includes also pyrolysis plant that produces charcoal and by-products that are used in energy production
- All the plant site simulations were performed against functional unit (FU) of one ton of hot rolled plate

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Results: BF simulation

• Blast furnace operation
  – Changes in blast volume
  – Slag volume decreases
  – Top-gas composition and amount change

• How charcoal can substitute coke:
  – Coke replacement ratio RR is 1.12 for oil
  – RR for charcoal is 0.97
  – To replace 1 kg oil, 1.15 kg charcoal is needed

• The temperature of the blast must be increased to maintain adiabatic flame temperature (AFT) when charcoal amount is increased to 150/t HM

• Charcoal injection could be even higher if lower AFT is allowed
Results: Plant site simulation

- The environmental burden of plant system is smaller when charcoal is used
- The fossil CO₂ emissions decrease in plant scale
  - With 2.6 Mt (Ruukki capacity) hot metal production the reduction is:
    - From 4.63 Mt → 3.92 Mt (15.4 % decrease) (CC case 1)
    - From 4.63 Mt → 3.41 Mt (26.4 % decrease) (CC case 2)
- The use of coking coal decreases in CC case 2, which further decreases the environmental burden and cost of raw materials
Results: Plant site simulation

• Gas balance and use of energy changes when charcoal is introduced
• Minor changes when only specific heavy oil is replaced with charcoal
  – The BF top-gas energy decreases
  → The energy going to power plant decreases
• Significant changes when pyrolysis process is integrated to steelworks infrastructure
  – The production of gases per FU (without converter gases)
    • Base case: 7.8 GJ/FU, CC case 1: 7.3 GJ/FU, CC case 2: 10.5 GJ/FU
  – Almost all the electricity could be produced internally with energetic by-product off-gases
  – Would require major investments to power plant capacity
  – The acquisition area of feedstock would be reduced
Production cost of charcoal

- The price of the charcoal is critical factor for industry
- The price of charcoal from different feedstock derived from the literature
- Calculated:
  - Assumptions
    - 100 000 t charcoal
    - Yield 35 % (from 20 % moisture wood)
    - Investment cost 40 M€
    - Cost of energy wood 5 €/m³
    - Cost of timber 50 €/m³
    - Other cost taken from literature
    - Handling and transportation costs assumed to same with energy wood and timber
- The price of charcoal could range from 330 to 610 €/t
- The by-product benefit not taken into account!
- More in depth assessment is needed!
- Different feedstock
  - Waste wood

<table>
<thead>
<tr>
<th>Production cost</th>
<th>Biomass cost</th>
<th>Country</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>254.60 US$/ton</td>
<td>91.6 US$ (euc.)</td>
<td>Brazil</td>
<td>Noldin (2011)</td>
</tr>
<tr>
<td>162 €/ton</td>
<td>ND (euc.)</td>
<td>Brazil</td>
<td>Fallot et al. (2008)</td>
</tr>
<tr>
<td>272 US$/ton (calc)</td>
<td>83$/ton (corn stover)</td>
<td>US</td>
<td>Brown et al. (2011)</td>
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</tbody>
</table>

Calculations updated from: Suopajärvi H & Angerman M (2011)
Layered sustainability assessment framework. METEC InSteelCon. Proc. of 1st Int. Conference on Energy Efficiency and CO2 reduction in the Steel Industry, Düsseldorf, Germany
The amount of needed biomass: Case injection

- The needed biomass in charcoal in injection is high
- The injection of 200 kg/t hot metal should be possible
  - Charcoal yield 30 % (20 % moisture wood)
  - Density of green wood 750 kg/m$^3$ (50 % moisture)
  - The yearly hot metal production 2.6 Mt

$\rightarrow$ The amount of green biomass 3.7 Mm$^3$

$\rightarrow$ To replace the oil injection (100 kg/t hot metal) approximately 2.1 Mm$^3$ of biomass is needed

$\rightarrow$ Even though the figures are large, there are available biomass that hasn’t been yet earmarked to certain industry
Laboratory experiments in Lab. of Process Metallurgy

- **In progress:**
  - Reactivity tests (with TGA) on different biomasses (charcoal)
    - Mikko Iljana
  - Viscosity tests with specific heavy oil, coal tar, (effective viscosity with solid particles: coal-, coke and charcoal dust)
    - Antti Salo

- **Planned:**
  - Metallurgical coke production including different biomass raw materials to coal mix
  - Evaluation of coke quality
    - Basic coke quality tests CRI, CSR
    - TGA (reactivity)
    - Gleeble (hot strength)
    - Electrical conductivity
    - Wavelet-texture analysis
      - Microscope images evaluated with mathematical algorithms (pores, isotropic, mosaic, banded coke)
  - Biocoke in process conditions e.g.
    - Blast furnace simulator
      - Behavior of Biocoke in different gas atmospheres

Conclusions

- Biomass is available, the potential increase in biomass feedstock use is not earmarked yet
- Charcoal use can decrease the environmental burden of steelmaking and thus increase the sustainability
- Integration of charcoal production to integrated steelworks would change the gas balance and external energy need quite much
- Integration possibilities of charcoal production should be further evaluated
  - Centralized or decentralized production
  - Chemical production, heat and power production
- The evaluation of life cycle emissions of charcoal production have to be evaluated
- More in-depth economic calculations are needed with by-product utilization and CO$_2$ emission costs
- Production and use of reducing gases derived from biomass
  - Gasification route would make it possible to utilize variety of fuels (biomass, coal, etc.)
- Laboratory experiments with biomasses (charcoals) have been started and will be increased in the future
References

Thank You