Two stage pyrolysis/split product gasification of refused-derived fuel (RDF)

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Gasification

**DIRECT GASIFICATION**

- **Gasifier**
  - **Feed**: Air ($O_2$), Steam, $CO_2$
  - **Producer gas**: $CO$, $H_2$, $CH_4$, $CO_2$, $N_2$, $H_2O$, $C_xH_y$, Tar
  - **Ash**

**INDIRECT GASIFICATION**

- **Gasifier**
  - **Feed**: Steam or $CO_2$, $N_2$
  - **Producer gas**: $CO$, $H_2$, $CH_4$, $CO_2$, $N_2$, $H_2O$, $C_xH_y$, Tar
  - **Heat**
  - **Ash (char)**
Challenges for waste and biomass gasification

Technical challenges:
• Highly heterogeneous feed with variable composition
• Produced gas tar content and content of other contaminants
• Conversion efficiency in some gasifiers
• Requirement for specific turbine and combustion engine design

Economic challenges:
• High capital costs of gasification plants, particularly given the low capital investment required for natural gas combined cycle

Social challenges:
• Poor public-perception and understanding of the technology
• Complex permitting issues for any type of thermal waste processing technology
Gas tar content

- Complex mixture of condensable hydrocarbons and their derivates
- Causes fouling, corrosion and catalyst poisoning in downstream processing units

- Allowed gas tar content depends on its use propose
- For a fuel quality gas used in gas engines:
  - 1-ring (M < 110 g/mol) < 1500 mg/MJ
  - 2-ring (110 < M < 152 g/mol) < 200 mg/MJ
  - 3-ring (152 < M < 200 g/mol) < 3 mg/MJ
  - 4-rings and more (200 < M g/mol) not allowed
Tar removal technologies

Generally two approaches:

- **Primary methods**
  - Proper selection of gasification technology and operating parameters (temperature, gasifying agent, equivalence ratio, residence time, catalyst)

- **Secondary methods**
  - Physical methods
    - Wet cleaning
    - Organic scrubbers
    - Ventury scrubbers
    - Electrostatic precipitator (ESP)
    - Solid bed filters, etc.
  - Chemical methods
    - Thermal cracking
    - Thermo-catalytic cracking
    - Catalytic hydrocracking

Using cheap available catalysts
Gasifiers

- Fixed bed (moving bed)
- Fluidized bed
- Intrained flow

Commercialised In Coal Gasification

- Updraft
- Downdraft

Newer technologies:
- Plazma
- Dry feed
- Slurry feed
- Multistage gasifiers
- Others
Two stage pyrolysis/split product gasification (PSPG)

Big potential for complete conversion of highly heterogeneous waste solid mixtures to a low-tar combustible gas
PSPG

Gas route
Coke (solid) route

Air 1
Air 2
Equivalence ratio

$$ER = \frac{\text{Air 1} + \text{Air 2}}{\text{Air}_{\text{stochiometric}}}$$

Air split ratio

$$AS = \frac{\text{Air 1}}{\text{Air 1} + \text{Air 2}}$$

Feeding rate: 10 g.min$^{-1}$

RDF pelets 1.4 – 2.0 mm
Raw materials

RFD pellets (diameter 5mm, average height: 10mm)

Hammer mill screen

Pellet machine

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (wt. %)</td>
<td>0.50</td>
</tr>
<tr>
<td>Carbon (wt. %)</td>
<td>55.3</td>
</tr>
<tr>
<td>Hydrogen (wt. %)</td>
<td>7.90</td>
</tr>
<tr>
<td>Sulphur (wt. %)</td>
<td>0.45</td>
</tr>
<tr>
<td>Chlorine (wt. %)</td>
<td>0.89</td>
</tr>
<tr>
<td>Oxygen¹ (wt. %)</td>
<td>18.85</td>
</tr>
<tr>
<td>Ash (wt. %)</td>
<td>16.00</td>
</tr>
<tr>
<td>Moisture² (wt. %)</td>
<td>0.50</td>
</tr>
<tr>
<td>Volatile matters (wt. %)</td>
<td>77.5</td>
</tr>
<tr>
<td>Fixed carbon (wt. %)</td>
<td>6.00</td>
</tr>
<tr>
<td>Lower heating value (MJ.kg⁻¹)</td>
<td>23.85</td>
</tr>
</tbody>
</table>
Catalysts characterized and used

Methods of characterisation:

Method
- Analysis of pore structure and specific surface area
- Thermogravimetric (TG) analysis
- X-ray diffraction (XRD) analysis
- X-ray fluorescence (XRF) analysis
- Scanning electron microscope (SEM) analysis

Previously used catalysts

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>( S_{\text{BET}}, \text{m}^2 \text{g}^{-1} )</th>
<th>( \nu_p, \text{cm}^3 \text{g}^{-1} )</th>
<th>( \alpha_p, \text{nm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pristine</td>
<td>511</td>
<td>0,772</td>
<td>16,4</td>
</tr>
<tr>
<td>Impregnated</td>
<td>485</td>
<td>0,716</td>
<td>15,6</td>
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</table>

Pristine and Ni-impregnated beta zeolite

Red clay mineral (RC)
- RC/Calcined
- RC/Calcined/Ni

Pyrolytic char
- Carbonized
- Carbonized/Ni

Natural zeolite
- Calcined
Product distribution

Absence of catalyst

In present of catalyst
Gas composition

Absence of catalyst

In presence of catalyst

Gas LHV: 7-9 MJ/Nm³
Gas tar content

<table>
<thead>
<tr>
<th>RDF feed</th>
<th>Equivalence ratio</th>
<th>Tar yield [mg/g]</th>
<th>Gas tar content [g/Nm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without catalyst</td>
<td>0.15</td>
<td>13.06</td>
<td>8.33</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>10.20</td>
<td>5.87</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>4.72</td>
<td>2.42</td>
</tr>
<tr>
<td>With catalyst</td>
<td>0.15</td>
<td>5.32</td>
<td>4.08</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>3.46</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>4.66</td>
<td>2.44</td>
</tr>
</tbody>
</table>
Distribution of Cl and S

**Chlorine in solid product**

- Equivalence ratio: 0.15, 0.2, 0.25
- Yield [%]: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90
- Graph showing yield vs. equivalence ratio for different char sources.

**Chlorine in condensate**

- Equivalence ratio: 0.15, 0.2, 0.25
- Yield [%]: 0, 1, 2, 3, 4, 5, 6, 7, 8
- Graph showing yield vs. equivalence ratio for different condensate sources.

**Chlorine in gas**

- Equivalence ratio: 0.15, 0.2, 0.25
- Yield [%]: 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4
- Graph showing yield vs. equivalence ratio for different gas sources.

**Sulphur in solid product**

- Equivalence ratio: 0.15, 0.2, 0.25
- Yield [%]: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90
- Graph showing yield vs. equivalence ratio for different char sources.

**Sulphur in liquid condensate**

- Below the measurable range

**Sulphur in gas**

- Equivalence ratio: 0.15, 0.2, 0.25
- Yield [%]: 0, 3, 6, 9, 12, 15, 18, 21
- Graph showing yield vs. equivalence ratio for different gas sources.
Conclusion

- Pyrolysis/Separate Product Gasification (PSPG) unit is efficient in increasing gas LHV, reducing gas tar content and increasing CGE and CCE.

- Combination of a pyrolysis reactor with two gasification reactors for separate pyrolysis product gasification and their mutual integration has been proven as a convenient way to improve waste and biomass gasification performance.

- Catalytic effect of Ni/Beta zeolite was only on the range of catalytic effect of natural clay and char catalyst studied in previous works.

- The majority of contaminant like S and Cl remained in solid char; by increasing the equivalence ration the content of contaminants in gas product increased.