Modelling of Gasification of Refuse-derived fuel (RDF) based on laboratory experiments

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Institute of Chemical and Environmental Engineering

Reactor Engineering Research Group

- Experimental study and mathematical modeling of fuel thermal processes
- Pyrolysis, gasification and combustion of solid fuels
- Biomass, polymer waste, MSW, and coal thermal and catalytic processing for production energy and materials

National center for research and application of renewable energy sources
Refuse-Derived Fuel (RDF)

MSW

Biodegradables
Metals
Inorganics
Hazardous wastes

RDF
## RDF composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>$w_i$ [kg/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>White paper, recycled paper</td>
<td>0.6317</td>
</tr>
<tr>
<td>Foil</td>
<td>LDPE, HDPE</td>
<td>0.1578</td>
</tr>
<tr>
<td>Plastics</td>
<td>Rigid plastics, polystyrene, polyurethane</td>
<td>0.1910</td>
</tr>
<tr>
<td>Textile</td>
<td>Polyamide, polyester, cotton, wool</td>
<td>0.0194</td>
</tr>
</tbody>
</table>
### Proximate and Elemental Composition of RDF

<table>
<thead>
<tr>
<th>Com.</th>
<th>Mois.</th>
<th>VM*</th>
<th>FC*</th>
<th>ASH*</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>S</th>
<th>O**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. %</td>
<td>10</td>
<td>75.5</td>
<td>8.9</td>
<td>15.6</td>
<td>51.7</td>
<td>5.9</td>
<td>0.9</td>
<td>0.4</td>
<td>25.5</td>
</tr>
</tbody>
</table>

*moisture free basis  
**calculated to 100%
Behaviour of Thermal decomposition

![Graph showing the behaviour of thermal decomposition over time and temperature for different materials.]

- Recycled paper
- White paper
- Rigid plastic
- Foil
- Polystyrene
- Textile
- Polyurethane
- RDF
- Temperature

Time (min)

Mass loss (%)
Behaviour of Thermal decomposition

![Graph showing thermal decomposition behavior with TG, DSC, and temperature over time.](image-url)
### Heating value of RDF

<table>
<thead>
<tr>
<th>Component</th>
<th>Heating value [kJ/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>13410</td>
</tr>
<tr>
<td>Foil</td>
<td>43860</td>
</tr>
<tr>
<td>Plastics</td>
<td>33570</td>
</tr>
<tr>
<td>Textile</td>
<td>19770</td>
</tr>
<tr>
<td>Mixed RDF</td>
<td>20810</td>
</tr>
</tbody>
</table>
Tar content measurement

- Reactor
- Condensers
- GC
- Air
- Flow measurement

Graph showing the relationship between Tar content (mg/g RDF) and Temperature (°C):

- Tar content decreases as Temperature increases.
- The graph shows a clear downward trend from 90 to 20 mg/g RDF as the Temperature goes from 1200 to 600 °C.

In the diagram, there are test tubes labeled as Glass particles and izopropanol.
Gasification Model

Assumptions:
• Steady state flow is considered inside the gasifier
• No temperature and concentration gradient exist inside the reactor
• The residence time is enough long to reach complete decomposition of RDF and unreacted part of RDF is only carbon.
• Only the major species are considered in the product gases, i.e CO, CO$_2$, H$_2$, CH$_4$, H$_2$O, NH$_3$, H$_2$S, N$_2$ and Tar

Global material balance of RDF gasification

\[ CH_b O_c N_d S_e + x_1 O_2 + x_2 H_2 O \rightarrow x_3 CO + x_4 CO_2 + x_5 H_2 + x_6 CH_4 + x_7 H_2 O + x_8 NH_3 + x_9 H_2 S + x_{10} CH _{b1} O_{c1} N_{d1} S_{e1} \]

Reactions:

\[
\begin{align*}
C + 0.5 O_2 & \rightarrow CO \\
CO + 0.5 O_2 & \rightarrow CO_2 \\
H_2 + 0.5 O_2 & \rightarrow H_2 O \\
CH_4 + 2 O_2 & \rightarrow CO_2 + 2 H_2 O \\
C + H_2 O & \leftrightarrow H_2 + CO \\
C + CO_2 & \leftrightarrow 2 CO \\
CH_4 + H_2 O & \leftrightarrow 3 H_2 + CO \\
C + 2 H_2 & \rightarrow CH_4 \\
CO + H_2 O & \leftrightarrow CO_2 + H_2
\end{align*}
\]

Equilibrium constant:

\[
K_a = \left( \frac{P}{P_0} \right) ^ {\sum \nu_i} \prod \phi_i^{\nu_i} \prod x_i^{\nu_i}
\]

\[
k_{298}^a = e^{- \frac{\Delta_r G_{298}^{298}}{RT}}, \quad \Delta_r G_{298}^{298} = \Delta_r H_{298} - T \Delta_r S_{298}
\]

\[
\Delta_r H_{298} = \sum \nu_i \Delta_f H_i^{298} \quad \Delta_r S_{298} = \sum \nu_i \Delta_f S_i^{298}
\]

\[
\Delta_r H = \Delta_r H_{298} + \sum \nu_i c_{pi} \cdot (T - 298) \quad \Delta_r S = \Delta_r S_{298} + \sum \nu_i c_{pi} \cdot \ln \frac{T}{298}
\]
Enthalpy balance:

\[ H_{RDF} + H_{O2\text{air}} + H_{\text{steam}} + Q_R = H_{\text{gas}} + H_{\text{ash}} + H_C + Q_{\text{loss}} \]

\[ Q_R = m_{RDF} \sum w_i Q_i - \sum (-\Delta_c H_i) n_i \]

\[ T = T_{\text{ref}} + \frac{m_{RDF} \sum w_i Q_i - \left( \sum (-\Delta_c H_i) n_i \right) - Q_{\text{loss}}}{\left( \sum n_i c_{pi} \right) + m_c \overline{c}_{pC} + m_{\text{ash}} \overline{c}_{pash} - m_{\text{steam}} \overline{c}_{steam}} \]

- \( Q_s \) – heat of reaction [J],
- \( H_{RDF} \) – enthalpy of RDF feed [J],
- \( H_{O2\text{air}} \) – enthalpy of oxygen and air respectively [J],
- \( H_{\text{steam}} \) – enthalpy of water steam [J],
- \( H_{\text{gas}} \) – enthalpy of gas [J],
- \( H_{\text{ash}} \) – enthalpy of ash [J],
- \( H_C \) – enthalpy of unreacted carbon [J],
- \( Q_{\text{loss}} \) – heat losses from the reactor [J]

- \( m_{RDF} \) – mass flow of RDF feed [kg]
- \( n_i \) – mole flow of component i in the products [kmol]
- \( w_i \) – mass fraction of component i in the feed (paper, foil, plastics, textile)
- \( Q_i \) – lower heating value of component i in the feed (paper, foil, plastics, textile) [Jkg\(^{-1}\)],
- \( \Delta_c H_i \) - heat of combustion of component i in the products [Jkmol\(^{-1}\)]

- \( m_{\text{ash}} \) – mass flow of ash [kg]
- \( m_{\text{ash}} \) – mass flow of remaining carbon [kg]
- \( m_{\text{steam}} \) – mass flow of steam [kg]
- \( \tau_{pash} \) – specific heat capacity of ash [Jkg\(^{-1}\)K\(^{-1}\)]
- \( \tau_{pC} \) – specific heat capacity of remaining carbon [Jkg\(^{-1}\)K\(^{-1}\)]
- \( \tau_{psteam} \) – specific heat capacity of steam [Jkg-1K\(^{-1}\)]
Results of modelling RDF gasification

**Observed parameters:**
- Conversion of RDF
- Reactor Temperature
- Gas composition
- Content of pollutants (NH3, H2S, TAR)

**Variables:**
- Oxygen (air) to RDF mass ratio
- Steam to RDF mass ratio
Air Gasification

Mole fraction

Temperature (°C)

Conversion (%)

m(air)/m(RDF)

H2
CO
CH4
CO2
N2

Air Gasification

Mole fraction

Temperature (°C)

Conversion (%)

m(air)/m(RDF)

H2
CO
CH4
CO2
N2

Air Gasification

Mole fraction

Temperature (°C)

Conversion (%)

m(air)/m(RDF)

H2
CO
CH4
CO2
N2
H2S and NH3 mole fraction

Tar mass fraction

$m(\text{air})/m(\text{RDF})$
Gasification of RDF Using $O_2$

Graph showing mole fraction of gases such as $H_2$, $CO$, $CH_4$, $CO_2$, and $N_2$ against $m(O2)/m(RDF)$.

Graph showing temperature in Kelvin and conversion against $m(O2)/m(RDF)$. 

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Graph showing temperature in Kelvin and conversion against $m(O2)/m(RDF)$.
Effect of RDF composition

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Effect of Steam in RDF Gasification

- Mole fraction vs. m(Steam)/m(RDF)
  - H2
  - CO
  - CO2

- Temperature (K) vs. m(Steam)/m(RDF)
  - Temperature
  - Heating value

- Heating Value (MJ/kg) vs. m(Steam)/m(RDF)
Conclusion

- For RDF studied in this work, 100% of RDF conversion in gasification by air was reached at $\text{m}_{\text{air}}/\text{m}_{\text{RDF}}=2.2$. However, the gas heating value was 4.4 MJ/Nm$^3$

- Gasification of RDF using Oxygen enables production of a gas with heating value around 10 MJ/Nm$^3$ at $\text{m}_{\text{O2}}/\text{m}_{\text{RDF}}=0.45$

- Elemental Composition of RDF has a crucial effect on required $\text{m}_{\text{air}}/\text{m}_{\text{RDF}}$

- Raw untreated gas tar content was 3.3 mass %; tar fraction content a solid phase insoluble in isopropanol

- By increasing the $\text{m}_{\text{steam}}/\text{m}_{\text{RDF}}$ the content of H2 and CO$_2$ increased, However, the content of CO, reactor temperature and gas heating value decreased
Thank you for attention