Bioethanol Production from Municipal Solid Waste

Department of Civil and Environmental Engineering
Aiduan Li
Dr Majeda Khraisheh
Dr Blanca Antizar

Department of Chemical Engineering
Professor Steffan Simons
Contents

• Background
• Previous studies
• Ongoing project
• Waste characterization
• Experiments & results
• Conclusions
• Future work
# Background: MSW - rubbish or resources?

<table>
<thead>
<tr>
<th>Composition of MSW</th>
<th>Average % Wt in MSW</th>
<th>Biodegradability Fraction (%)</th>
<th>Overall Biodegradability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and card</td>
<td>27.8</td>
<td>100</td>
<td>27.8</td>
</tr>
<tr>
<td>Organics</td>
<td>34.3</td>
<td>100</td>
<td>34.3</td>
</tr>
<tr>
<td>Fines (≤ 10 mm)</td>
<td>1.3</td>
<td>60</td>
<td>0.8</td>
</tr>
<tr>
<td>Textiles</td>
<td>2.4</td>
<td>50</td>
<td>1.2</td>
</tr>
<tr>
<td>Miscellaneous combustible</td>
<td>10.3</td>
<td>50</td>
<td>5.2</td>
</tr>
<tr>
<td>Glass</td>
<td>7.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other non-combustibles</td>
<td>1.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Plastic film</td>
<td>5.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Ferrous metal</td>
<td>0.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Non ferrous metal</td>
<td>0.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Waste electrical and electronic equipment (WEEE)</td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Household hazardous waste (HHW)</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Dense plastic</td>
<td>5.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>-</td>
<td>69.3%</td>
</tr>
</tbody>
</table>


1 Dry matter basis

- 4.4 Million tonnes MSW produced in London in 2003
- 3% rising every year
Background: MSW as Feedstock?

MSW disposal methods in London in 2003:

- Recycle, 8%
- Incineration, 19%
- Landfill, 73%

Reasons for MSW as biomass feedstock:

- Potential large biodegradable fraction: around 70% of total
- E.U. Directive 2003/30/EC requires to reduce biodegradable fraction to landfill by 25% by 2010, 50% by 2013, 65% by 2020
- Large quantity, low cost
- Economic benefits of “Rubbish to fuel (bioethanol)”

Source: Defra, UK
Background: Ethanol Market

Background: Ethanol process challenges

Improving technology to reduce cost:

- Producing ethanol from abundant and cheap waste biomass
- Improved efficient pretreatment
- Increasing use of genetically-engineered organisms with improved properties for hydrolysis and fermentation
- Integrating process steps to reduce capital and operating cost

Cost Contribution Details from Each Process Area (% of Ethanol Selling Price)

Previous Studies

• Single Substrate

Study on used newspapers, pretreated with aqueous ammonia-hydrogen peroxide solution\(^1\), stated that more than 80% enzymatic digestibility can be obtained after 72 hours hydrolysis.

Most of the previous investigations have focused on single substrates, using grass, corn stover etc

• Multi-substrates

Investigation of mixed waste, by combining construction lumber waste, almond tree prunings, wheat straw, office waste paper, and newsprint, with pretreatment method of dilute-acid hydrolysis\(^2\), reported that 80-90% theoretic of glucose yield can be obtained with enzyme loading of 66 FPU after 100 hours hydrolysis.

Sources:


On-going Project

- **MSW**: Municipal Solid Waste
- **MSW samples**: Carrot peelings, potato peelings, grass, newspaper and scrap paper
- **SSF**: Simultaneous Saccharification and Fermentation

**Diagram**:
- **Biomass** → **Pre-processing** → **Enzymatic Hydrolysis** → **SSF/Fermentation** → **Ethanol**
- **MSW** → **Pre-processing** → **Enzyme and Yeast** → **SSF/Fermentation**
- **Glucose** → **Yeast** → **Process Simulation**

**Current Stage**: Enzymatic Hydrolysis
Ongoing project aims

• Waste characterization

• Studying the possibility of MSW as biomass feedstock

• Investigation of effective pre-treatment methods

• Factorial experimental design with Design Expert software package

• Optimizing enzymatic hydrolysis process
Waste Characterization: cellulose content

**Cellulose Content of Common Lignocellulosic Materials**

- Potato peelings
- Carrot peelings
- Grass
- Newspaper
- Scrap paper
- Cellulose

**Note:** dry matter basis
Waste Characterization: CHN Analysis

Note: dry matter basis
Waste characterization: Ethanol potential

- According to our preliminary studies, 1kg of selected wastes contains 0.41 kg carbon (average carbon content is 41.05%)
  - Percentage of carbon in glucose molecule (C$_6$H$_{12}$O$_6$): 40.00%
  - If 100% of the carbon present in selected wastes was converted to glucose, then the possible potential yield of glucose from 1 kg of selected waste can be calculated.
    - Then, possible mass of glucose: 1.03 kg
  - Percentage of carbon in ethanol molecule (C$_2$H$_6$O): 52.17%

Therefore, the possible mass of ethanol that we could obtain from 1 kg of selected waste is **0.79 kg**
Current results: Pretreatment effects (24 hours)

- HCl+SE: Dilute acid (Hydrochloric acid) hydrolysis + Steam Explosion
- HNO₃+SE: Dilute acid (Nitric acid) hydrolysis + Steam Explosion
- H₂SO₄+SE: Dilute acid (sulphuric acid) hydrolysis + Steam Explosion
- H₂SO₄+MW: Dilute acid (sulphuric acid) hydrolysis + Microwave treatment
Results: cellulase effects (without pretreatment)

Hydrolysis condition: temperature 50°C, ph 4.8, enzyme loading 60 FPU, time 96 hours
Current Results: Cellulase effects (with pretreatment)

Hydrolysis condition: temperature 50°C, ph 4.8, enzyme loading 60 FPU, time 96 hours
Pretreatment: \( H_2SO_4 + SE \)
Current results: Glucose yield (after pretreatment)

Hydrolysis condition: temperature 50°C, ph 4.8, enzyme (T. viride) loading 40 FPU
Factorial experiment design

- Sample: Carrot peelings
- Factors: A, Acid concentration: 1% and 4%
  B, Temperature 121 and 134 °C
  C, Enzyme loading: 10 and 60 FPU

Time: 72 hours, pH 4.8
Treatment: H₂SO₄ + SE
Enzyme: T. viride
Hydrolysis temperature 50 °C

Experimental results

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Temperature (°C)</th>
<th>Acid concentration (%)</th>
<th>Enzyme loading (FPU)</th>
<th>Glucose yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>121</td>
<td>4</td>
<td>60</td>
<td>61.16</td>
</tr>
<tr>
<td>2</td>
<td>134</td>
<td>1</td>
<td>60</td>
<td>72.50</td>
</tr>
<tr>
<td>3</td>
<td>134</td>
<td>4</td>
<td>60</td>
<td>61.16</td>
</tr>
<tr>
<td>4</td>
<td>121</td>
<td>1</td>
<td>10</td>
<td>65.21</td>
</tr>
<tr>
<td>5</td>
<td>134</td>
<td>4</td>
<td>10</td>
<td>50.22</td>
</tr>
<tr>
<td>6</td>
<td>134</td>
<td>1</td>
<td>10</td>
<td>56.70</td>
</tr>
<tr>
<td>7</td>
<td>121</td>
<td>4</td>
<td>10</td>
<td>43.34</td>
</tr>
<tr>
<td>8</td>
<td>121</td>
<td>1</td>
<td>60</td>
<td>68.45</td>
</tr>
</tbody>
</table>

Results from DESIGN-EXPERT Plot

Cube Graph

X = A: Acid concentration
Y = B: Temperature
Z = C: Enzyme loading

- low setting
  + high setting

A: Acid concentration
B: Temperature
C: Enzyme loading
Factorial experiment design

- **Sample:** Carrot peelings
- **Factors:**
  - A, Acid concentration: 1% and 4%
  - B, Temperature: 121 and 134 °C
  - C, Enzyme loading: 10 and 60 FPU

Time: 72 hours, pH 4.8
Treatment: H₂SO₄ + SE
Enzyme: T. viride
Hydrolysis temperature 50°C

Comparison of Actual Value (AV) and Predicted Value (PV)

![Graph showing AV and PV comparison]

R² = 0.90

Results from DESIGN-EXPERT Plot

X = A: Acid concentration
Y = B: Temperature
Z = C: Enzyme loading

Table of factor effects

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Acid concentration)</td>
<td>13.12</td>
<td>47.70</td>
</tr>
<tr>
<td>B (Temperature)</td>
<td>0.04</td>
<td>0.13</td>
</tr>
<tr>
<td>C (Enzyme loading)</td>
<td>13.58</td>
<td>49.39</td>
</tr>
<tr>
<td>AB (Acid concentration*Temperature)</td>
<td>0.76</td>
<td>2.78</td>
</tr>
</tbody>
</table>
Conclusions

• Pretreatment of dilute sulphuric acid hydrolysis followed with steam explosion did increase in general the rate at which the maximum yield of glucose was formed. However, this pretreatment did not give higher yields for newspaper wastes.

• Enzyme of T. viride is more effective on the selected wastes in general as well as the multi-substrates by combining the single substrates.

• This investigation reported the glucose yields produced by multi-substrates are higher than the average yield by single substrate.

• This study proved the possibility of using multi-substrates as ethanol feedstock and encouraged the conversion of MSW to ethanol.

• The factorial experiment results showed that acid concentration and enzyme loading have a higher effect on glucose yield within the temperature range of 121-134 °C.
Future work

• Greater biomass yield
• Other sugar analysis: including xylose, mannose, galactose, and arabinose
• Feedstock from pretreated waste (directly from bin, or separated)
• Ethanol production from fermentable sugars
Acknowledgement

Engineering Conference International (ECI) Organization

Graduate School, University College London, UK

Department of Civil and Environmental Engineering, University College London, UK

Dorothy Hodgkin’s, RCUK

Natural and Environmental Research Council (NERC), RCUK