Introduction

- Philosophy / Mission
- Complexity of Resource Cycles
- Role of metallurgical reactors
- Modelling/Simulation/Control of metallurgical reactors
Complexity of Resource Cycles

Primary metal/material = p(t)

Product Manufacture

m(t) Car inflow

Market

x(t) Car outflow

Losses (e.g. Export)

Physical Separation

Secondary metal/material = s(t-τ)

Stockpile

z(t-τ) Delay

Secondary metal/material = s(t-τ)

Losses (e.g. Export)

Metallurgy & Thermal Treatment

Losses (flue dusts/slags)

Optimisation Model

The Comet Sambre Plant (Belgium)

1153 ELV’s

The Comet Sambre Plant

The Comet Sambre Plant

Grade of products
- Un-liberated material -

Mass balance
- Before data reconciliation -

Mass = 100 t/h
Error = 0.5%

Mass = 84 t/h
Error = 1%

Our approach used in arguments by Audi to the EU to challenge recycle rate legislation

Mass balance
- After data reconciliation -

Mass = 101.3 t/h
Error = 0.5%

Mass = 18.7 t/h
Error = 5%

Recovery = 82.7 / 101.3
= 0.82
Recycling calculation with statistics

Primary metal/material = \( p(t) \)

Product Manufacture

\( m(t) \) Car inflow

Market

\( x(t) \) Car outflow

\( (1-a) \) Losses (e.g. Export)

Feed forward control?

Dynamics!

Stockpile

Secondary metal/material = \( s(t-\tau) \)

Metallurgy & Thermal Treatment

Losses (e.g. Export)

Optimisation Model

Sampling? Modelling Statistical Mass balancing!

Recycling rate

EU definition of recycling rate

\[ RR_{EoL}(t) = \frac{\text{average weight of recycled/recovered material per vehicle and year}}{\text{average weight per vehicle and year}} \times 100\% \]

Where is the error margin in this definition?

- The Comet Sambre test for the first time provides a value with an associated statistic.
- This suggests that the RR value can never be a single value but should always be reported as
  - \( RR_{EoL} = 89.4\% \pm y\% \)
- All tests up to Comet Sambre are strictly speaking useless!

The Comet Sambre Plant

High Temperature Furnaces

Complexity of Resource Cycles

Primary metal/material = p(t)

Product Manufacture

m(t) Car inflow

Market

x(t) Car outflow

(1-a)

Losses (e.g. Export)

Secondary metal/material = s(t-τ)

Stockpile

z(t-τ) Delay

Metallurgy

Losses (flue dusts/slag)

Optimisation Model

TU Delft
Complexity of Resource Cycles

**Complexity of Resource Cycles**

- Interconnected process
- Copper Smelter
- \(\text{Pb Blast Furnace}\)
- \(\text{LEW Plant}\)
- \(\text{Lead Refinery}\)
- \(\text{PM Refinery}\)
- \(\text{Special Metals Refinery}\)
- High Recoveries
- Low Emissions

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**Umicore’s Integrated Metals Smelter**

- Complex Feed
- High Temperature
- Three products
  - Off gases
  - Pb Slag
  - Blister Copper
- Focus point for calculation

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Recycling of Electronic Goods

• HOW?

• 4 Step Approach

  • Incorporate Metallurgical & Operational Perspective

  • Is able to predict effects of changing strategies

  • Gives insight into deviations, and confidence levels of predictions

Grade of products

Steel ca. 650 t
From 1153 ELVs

Al/Mg/Cu/Zn

Steel
Al/Mg/Cu/Zn
Plastics
Electric Arc Furnace

Complexity of Resource Cycles

Primary metal/material = \( p(t) \)

Product Manufacture

\( m(t) \) Car inflow

Market

\( x(t) \) Car outflow

Losses (e.g. Export)

(1-a)

Stockpile

\( s(t-\tau) \) Secondary metal/material

Losses

\( z(t-\tau) \)

\( z(t) \)

Delay

Physical Separation

Physical Processing

Optimisation Model

Losses

(fluue and soaks)
### Amount and Percentage of Recycled Waste in The Netherlands (2002)

<table>
<thead>
<tr>
<th>Category of Waste</th>
<th>Amount</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSW</td>
<td>6,831 Mio. t</td>
<td>49</td>
</tr>
<tr>
<td>Household Waste</td>
<td>4,082 Mio. t</td>
<td>46</td>
</tr>
<tr>
<td>Glass</td>
<td>0,343 Mio. t</td>
<td>80</td>
</tr>
<tr>
<td>Paper, Cardboard from households</td>
<td>1,070 Mio. t</td>
<td>55</td>
</tr>
<tr>
<td>Biodegradable Waste (2000)</td>
<td>3,560 Mio t</td>
<td>49</td>
</tr>
<tr>
<td>Small chemical waste from households</td>
<td>0,021 Mio t</td>
<td>70</td>
</tr>
<tr>
<td>Packaging</td>
<td>1,980 Mio. t</td>
<td>70</td>
</tr>
</tbody>
</table>

Source: AOO, CBS

### Total Amount of Thermally treated Waste in The Netherlands

<table>
<thead>
<tr>
<th>Year</th>
<th>Tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>4,855 Mio. t</td>
</tr>
<tr>
<td>2002</td>
<td>5,087 Mio. t</td>
</tr>
<tr>
<td>2003</td>
<td>5,180 Mio. t</td>
</tr>
<tr>
<td>2004</td>
<td>5,200 Mio. t</td>
</tr>
<tr>
<td>2005</td>
<td>5,350 Mio. t</td>
</tr>
<tr>
<td>2006</td>
<td>5,850 Mio. t</td>
</tr>
</tbody>
</table>

Source: WAR 2004 / AOO 2004
### Energy Produced at Dutch WtE Plants

(affiliated to Vereniging Afvalbedrijven ca. 80%)

<table>
<thead>
<tr>
<th></th>
<th>Electricity [GWh]</th>
<th>Heat (delivered) [TJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 MSW (or similar waste) WtE-Plants 2000</td>
<td>3.161</td>
<td>2.216</td>
</tr>
<tr>
<td>11 MSW (2001)</td>
<td>2.971</td>
<td>2.948</td>
</tr>
<tr>
<td>11 MSW (2002)</td>
<td>3.049</td>
<td>3.538</td>
</tr>
<tr>
<td>11 MSW (2003)</td>
<td>3.192</td>
<td>4.004</td>
</tr>
</tbody>
</table>

#### AVR-Chemie: hazardous waste incinerator

- DTO 8 & DTO 9: ~100,000 t/y
- Figures in 2002:
  - 81,000 tons waste
  - 290,000 tons steam
  - 52 GWh electricity

(www.bhassoc.com)
Solid waste flow model

- Gas phase: non-isothermal
  - Estimated from previous combustion model as inlets
  - K-ε turbulence model
- Particle phase
  - Eulerian treatment
  - Particles as continua fluid
  - Solved velocity field and solid volume fractions


Dispersion of solid particles: effect of injection velocity

Volume fraction of solid particles transient models: \( d_p = 20 \text{ mm} \)
Dispersion of solid particles: particle flow development

- Flow behaviour of the solid waste particles through the furnace system
- Accumulation behaviour
  - Bottom of the kiln
  - Front side
  - Corners
  - Joint areas of the vertical walls (SCC)
  - Ash sump

Afval Energie Bedrijf (AEB), Amsterdam
Present Situation for Bottom Ash

- No market left for bottom ash (million tons/year)
- Does not satisfy N1 category of the Dutch Building Materials Decree
- Has to be land filled (ca 30 euro/ton)

Potential of Bottom Ash

- Clean it to category N1 (cost 19 euro/ton)
- Recover all the metal from it (profit 10 euro/ton)
- Net cost 9 euro/ton
Wet processing of bottom ash

Major Results

• Granulates and sand that satisfy category 2 of the Dutch Building Materials Decree
• Non-ferrous metals recovery: 17 kg/ton input
• Sludge: 7-10% of input
• Cost: 9 euro/ton input

<table>
<thead>
<tr>
<th>Metal</th>
<th>Western World kton</th>
<th>Netherlands kton</th>
<th>Dutch bottom ash kton potential</th>
<th>now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>16200</td>
<td>130</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Copper</td>
<td>10800</td>
<td>86</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Zinc</td>
<td>5500</td>
<td>42</td>
<td>1.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Silver</td>
<td>12.6</td>
<td>0.10</td>
<td>0.01</td>
<td>0</td>
</tr>
</tbody>
</table>
Metals from bottom ash

<table>
<thead>
<tr>
<th>Metal</th>
<th>PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>2467</td>
</tr>
<tr>
<td>Pb</td>
<td>115</td>
</tr>
<tr>
<td>Ag</td>
<td>4</td>
</tr>
<tr>
<td>SS</td>
<td>13</td>
</tr>
<tr>
<td>Zn</td>
<td>282</td>
</tr>
<tr>
<td>Brass</td>
<td>466</td>
</tr>
<tr>
<td>Cu</td>
<td>739</td>
</tr>
</tbody>
</table>

Complexity of Resource Cycles

Product Design

Market

Physical Separation

Metallurgy & Thermal Treatment

Optimisation Model

Losses (e.g. Export)

Losses (flue dusts/slags)

Optimisation Model
Relationship product design & recycling

- We now have the models to link the CAD of car design to:
  - Shredding / Liberation / Product Grades
  - Recycling plant performance
  - The calculation of Recycling Rate
- This is all within the boundaries of rigorous statistical models.
- *These can all be referred back to design heuristics providing the designer with a statistic for the effect of his/her design choices on recycling rate!*
- Statistics gives the car designer space to operate in! Also 85% is meaningless without the error margin.

6th Framework EU project led by VW to design super light car (will apply our models to evaluate recyclability of new car concepts).

**Design model**

- Interface to CAD
- Links CAD, material choices, recycling model, liberation model to recycling rate calculation
- Opel (GM), VW, Volvo etc.
Relationship product design & recycling
-poor liberation and large distribution in products-
-improved by better design-
Relationship product design & recycling
-good plant operation produces good products with narrow distributions-

Our Group at TU Delft...

Primary metal/material = p(t)

Product Manufacture

Stockpile

Our Expertise
Technology and Theory of the Material Cycle

Optimisation Model

Losses (e.g. Export)

Losses

Losses (flue dusts/slags)

Losses (e.g. Export)

Delay

Our Expertise
Technology and Theory of the Material Cycle