Carpet as an Alternative Fuel for Cement Kilns

M. J. Realff
P. Lemieux, R. Hall
K. Bruce
P. Smith
G. Hinshaw

Georgia Institute of Technology
U.S. Environmental Protection Agency
ARCADIS G&M
Lehigh Cement Company
Environmental Assurance Monitoring
Carpet Waste Volumes

• Two basic sources of carpet waste
  – Post-manufacturing
    • Geographically concentrated in 50 mile radius around Dalton, GA, 75% of US Carpet manufacturing.
      – Rule of thumb ~ 80 tons/day at landfill.
  – Post-consumer
    • Correlated with centers of population.
      – Rule of thumb ~ 17 lbs/person/year.
Post Manufacturing: Whitfield Co. Landfill

Carpet Manufacturing Waste Monofill Area
Collection Potential Estimation

Hypothesis 1  Carpet scales linearly with population.

\[
\text{Carpet Available in Region} = \frac{\text{Current Population of Region}}{\text{Total US Population}} \times ?
\]

Hypothesis 2 – Total available carpet

1) New Sales will be partially for replacement and therefore new sales volume will be a predictor of carpet available for retirement.

- US New Sales from US Dept of Commerce Data
- Replacement Fraction ~ 0.66

2) Average carpet life in residential setting is 13 years

- US Sales 1988 from US Dept of Commerce Data provide a rough estimate

- Data is summarized in CRI Reports
Carpet Sales

Broadloom Carpet Sales 1988-1998

Area data from CRI 1999 Carpet & Rug Industry Review Appendix Table 6
Which Comes First?

Collection Infrastructure defines the cost at which raw materials can be provided.

Markets define the price at which raw materials need to be delivered.

How do we build robust, cost effective, efficient and environmentally sound systems for recycling carpet?
Food Webs - “The Bottom Feeder”

“Value Pyramid” - Werner Braun, CRI
The Potential for Cement Kilns?

In 1999

- U.S Clinker Production = 70x10^6 metric tons
- Btu/ton Clinker (av) = 5.5x10^6 btu/mton
- Btu/ton Clinker (coal only) = 3.24x10^6 btu/mton

Total U.S. Disposal lbs/year ~ [5x10^9 6x10^9] lbs
Btu/lb carpet ~ [9879 10000 10529]

For all kilns at 10% displacement of coal:
2.1x10^9 lbs of carpet ~ [35% 42%] of annual disposal

For kilns with Preheat/Precalciner at 10% displacement of coal:
1.32x10^9 lbs of carpet~ [22% 26.5%] of annual disposal

55% of Plants currently use waste fuel, 7.7% of all energy consumption
Overall Strategy

Establish overall feasibility and size reduction options

Perform Combustion Trials to establish emissions levels

• Mixed coal and carpet emissions testing
• Full system feasibility

Establish possible locations and designs of kiln feeding system

Perform volume kiln trial
Full Scale Trial Design

Raw Carpet

CarpetCycle llc, Elizabeth, NJ

107 Miles

Zwicky & Sons, Evansville, PA

Size Reduction & Shipment

Lehigh Cement Evansville Plant, PA

0.2 Miles

Arcadis Stack Testing

Documentation

Georgia Tech GT, ASME

Size Reduction Equipment

Republic Machine

Helping to preserve the environment for future generations...
Objective

- Evaluate technical feasibility of substituting carpet for coal in a cement kiln
  - Shredding/grinding
  - Transport to burner
  - Feeding into kiln
  - Kiln operation
  - **Air emissions**
Carpet Size Reduction Logistics

Shredded carpet pile

Walking Floor Trailer

Size Reduction Equipment

Throughput about 2-3000 lbs/hr

Building Edge

Raw Carpet bales
Size Reduction Rotor

Republic Machines 200HP motor machine.
Size Reduction System in Operation
Cement Kiln Operation

• Nominal Operating Conditions
  – 100 tph of raw feed
  – 10 tph of coal
  – 1900 tons/day of clinker production

• Perturbations
  – Substitution of shredded carpet for coal
  – 2.2 tons/hr of carpet feed
Pollutants of Concern

- Conventional Combustion Gases
  - $O_2$, $CO$, $CO_2$, $NO_x$, $SO_x$
- Metals
  - Sb, As, Ba, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, Ag, Tl
- Halogens
  - HCl, Cl$_2$, HBr, Br$_2$, HF, F$_2$
- Dioxins/Furans
- Total Particulate Matter
- Particle Size Distributions
Methods Used

- Combustion Gases - CEMs
- Metals - EPA Method 29
- Halogens - EPA Method 26
- Dioxins/Furans - EPA Method 23
- Total Filterable Particulate - EPA Method 5 (done on M26 train filters)
- Particle Size Distribution - CARB Method 501
Other Sampling/Analytical

- Audit samples for M29, M26 sent to analytical laboratories (passed audits)
- XRF analysis
  - Carpet
  - Coal
  - Clinker
  - Baghouse dust
## Test Matrix

<table>
<thead>
<tr>
<th>Condition 1 (Coal Only)</th>
<th>Condition 2 (Coal/Carpet co-firing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 tph raw feed</td>
<td>100 tph raw feed</td>
</tr>
<tr>
<td>100% energy input as coal</td>
<td>85% energy input as coal</td>
</tr>
<tr>
<td></td>
<td>15% energy input as carpet</td>
</tr>
</tbody>
</table>
# Sampling Scheme

<table>
<thead>
<tr>
<th>Day</th>
<th>Cond.</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (11-5)</td>
<td>2</td>
<td>CEMs, M23 x 3 (2 simultaneous), M501 x1</td>
</tr>
<tr>
<td>2 (11-8)</td>
<td>2</td>
<td>CEMs, M26 x 3, M29 x 3</td>
</tr>
<tr>
<td>3 (11-9)</td>
<td>1</td>
<td>CEMs, M23 x 3 (2 simultaneous, 1 bad run)</td>
</tr>
<tr>
<td>4 (11-10)</td>
<td>1</td>
<td>CEMs, M23 x 1 (repeat of bad run), M501 x 2 (simultaneous)</td>
</tr>
<tr>
<td>5 (11-11)</td>
<td>1</td>
<td>CEMs, M26 x 3, M29 x 3</td>
</tr>
<tr>
<td>6 (11-12)</td>
<td>2</td>
<td>CEMs, M501 x 2 (simultaneous)</td>
</tr>
</tbody>
</table>
Results: SO$_2$
Results: CO
Results: $\text{NO}_x$
Results: PM10

![Bar graph showing PM10 levels for Coal Only and Coal/Carpet conditions.]
Results: Condensable Organics
Results: Condensable Inorganics
Results: Total Filterable PM

- **Coal Only**: 4
- **Coal/Carpet**: 5
Results: Metals

![Bar chart showing metal concentrations in Coal and Coal/Carpet samples]
Results: Halogens

![Bar chart showing chloride and HCL concentrations for coal and coal/carpet conditions.]

- Coal: Chloride (7) and HCL (6)
- Coal/Carpet: Chloride (5) and HCL (5)
Results: Total PCDD/F

![Bar chart showing PCDD/F levels for Coal Only and Coal/Carpet conditions.](chart.png)
Results: PCDD/F TEQs
Overall Performance

- Process for shredding/ transportation/ feeding/ burning went well. Facility operators were able to troubleshoot minor problems.
- Carpet burns out very quickly, resulting in shorter flame overall and altered thermal profile at burner end of kiln.
- Kiln #1 was due for recast approximately a month after testing. Hot spots occurred due to shorter flame. Did not exceed 15% carpet substitution so as not to jeopardize refractory. Tuning of carpet fuel with other aux. fuels (e.g., wood chips) might help.
Conclusions: Fixed Gases

- \( \text{SO}_2 \) emissions higher while co-firing carpet – process variation considered most likely cause. Other possible cause volatilization of sulfur due to higher kiln temperature-calcium-oxygen-carbon equilibrium at hot end of kiln resulting in higher \( \text{SO}_2 \) emissions; optimization of flame length may eliminate this issue
- \( \text{CO} \) emissions largely unaffected by fuel switching
- \( \text{NO}_x \) emissions largely unaffected by fuel switching
Conclusions: Particulate

• PM$_{10}$ appears to be unaffected by fuel switching
• Addition of carpet may possibly reduce condensibles
• Total PM appears lower with carpet co-firing (largely due to lower condensibles)
• Total filterable PM appears to be unaffected by fuel switching
Conclusions: Metals

- Carpet co-firing at the levels that were done does not appear to have an effect on metal emissions
Conclusions: Halogens

• Co-firing carpet appears to slightly reduce HCl and Cl- emissions
Conclusions: PCDD/F

- Co-firing carpet appears to reduce both total PCDD/F emissions and TEQ emissions by roughly 2/3
- Reduction in PCDD/F emissions could be the result of higher SO$_2$ levels
- Reduction in PCDD/F emissions could be the result of lower halogen levels
Summary

• Co-firing carpet with coal as a substitute fuel for cement kilns appears to be at least, environmentally neutral

• Optimization of co-firing operations to maintain normal flame length and temperature distributions in the burner end of the kiln is desirable
Trial Future Plans

Complete 1000 Ton Trial Run

Jan 24th-Feb 4th
- Trommel Screen conveyor to test carpet break up
- Carpet delivered from Carpet Cycle
- Carpet size reduced at Zwicky’s

July
- Machine redesign and fabrication
- Deeper cutters (1.5 & 2x) under trial at Republic Machines
- New Machine installed and set up at Zwicky’s

May 1st
- Kiln conveyor system renovation

July
- Carpet fed to kiln at 2 Tons/hr 10hrs/day
- Burn restarts to consume 800 Tons of Carpet
Acknowledgments

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- PA DEP
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- Carpet & Rug Institute
- ASME Research Committee on Industrial and Municipal Waste