# Appendix 1

**Telemark University College**
**Faculty of Technology**

## FMH606 Master's Thesis

**Title**: Alternative fuels in cement kilns – characterization and experiments

**Student**: Hiromi Ariyaratne Wijesinghe Kaluarachchige

**TUC supervisor**: Assoc. Prof. Lars-André Tokheim

**External partners**: Norcem AS (Knut-Erik Nielsen)

**Task description**:

The work should include the following tasks:

1. A literature study on the use of alternative fuels in cement kilns, with emphasis on (partly) $CO_2$ neutral fuels; aspects that should be evaluated are: amounts available, physical characteristics, chemical characteristics, feeding and dosing systems as well as impact on process conditions, emissions and product quality
2. Characterization of one or more alternative (waste) fuels by thermogravimetric analysis (using TUC's TGA instrument).
3. Possibly characterization of TGA exhaust gas by FTIR analysis (using one of TUC's FTIR instruments)
4. Further development of a fuel characterization procedure using a combined TGA/FTIR technique (based on a TUC master project work from Fall 2008)
5. Thorough documentation of the results in a report

**Task background**:

Many different types of fuels can be combusted in cement kilns. This is due to the special process conditions prevailing in these kilns: high temperature, high residence times and favourable flow conditions in an oxidizing atmosphere.

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Alternative (waste) fuels are used to replace fossil fuels like coal. Hence, the use of alternative fuels, some of which may be $CO_2$ neutral, is in general advantageous environmentally as well as from an economic point of view.

However, not all alternative fuels are suitable, and some are more interesting than others. Hence, alternative fuels should be characterized based on its impact on the production process.

**Student category**:

PT or EET students

**Practical arrangements**:

The work will be carried out in cooperation with Norcem AS. Some of the experimental work may be carried out at the Norcem plant in Brevik.

**Signatures**:

Student (date and signature): 23/01/09

Supervisor (date and signature): 23 Jan 2009 Lars Andre Tokheim

# Appendix 2

Properties of fuels

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Petroleum-based waste | | | | | | | | | | | | | | | |
| Coal | 2.80 | 31.60 | 45.50 | 20.10 | 82.60 | 5.80 | 2.90 | 7.60 | 1.10 | | <0.1 | 24.7 | | | Axelsen, 2002 |
| Petroleum coke | 0.60 | | | 4.78 | 83.87 | 7.09 | 0.24 | 2.17 | 1.23 | | | 28.7 | | | Hansen, 2003 |
| Petroleum coke | | | | | | | | | | | | 33.9 | | 3.10 | Tokheim, 2008 |
| Petroleum coke | 1.50 | 9.85 | 88.20 | 0.49 | 88.16 | 3.03 | 1.68 | 1.09 | 3.94 | | | 33.7 | | | Kääntee et al., 2002 |
| Petroleum coke | | | | | | | | | | | | 33.7 | | | Tsakalakis, 2003 |
| Petroleum coke | 0.40 | | | | 78.24 | | | | | | | 18.9, 33.7 | $SO_2$, $No_x$, CO | 1.83-3.30 | Murray & Price, 2008 |
| Petroleum coke | | | | | | | | | | | | 37.5 | | | Conesa et al., 2008 |
| Petroleum coke | 0.00 | 0.00 | 98.50 | 1.50 | 95.00 | 1.00 | | | 2.50 | | | | | | Ottoboni et al., 1998 |
| Petroleum coke | 1.50 | 9.85 | 88.16 | 0.49 | 88.16 | 3.03 | 1.68 | 1.09 | 3.94 | | | 33.7 | | | Ka¨a¨ntee et al., 2004 |
| Petroleum coke | 0.39 | 13.90 | 85.22 | 0.50 | | 3.90 | 1.70 | | 4.90 | | <0.01 | 34.3 | | | Prisciandaro, Mazziotti & Veglio´,2003 |
| Petroleum coke | 0.38 | 14.05 | 85.06 | 0.51 | | 3.80 | 1.70 | | 4.90 | | <0.01 | 34.7 | | | Prisciandaro, Mazziotti & Veglio´,2003 |
| | | | | | | | | | | | | | | | |
| Waste oil | 0.00 | 100.00 | 0.00 | 0.00 | 86.00 | 12.00 | 0.00 | 0.00 | 2.00 | | <0.1 | 41.6 | | | Axelsen, 2002 |
| Waste oil | | | | | | | | | | | | 34.0 | | 2.50 | Tokheim, 2008 |
| Waste oil | | | | | | | | | | | | 33.0 | | | Tsakalakis, 2003 |
| Waste oil | | | | | | | | | | | | 33.0 | | | Tokheim, 2004 |
| Waste oil | 9.10 | | | 2.37 | 68.30 | 10.50 | 4.40 | | 0.04 | | 0.60 | 25.9 | | | Prisciandaro, Mazziotti & Veglio´,2003 |
| Waste oils | 5.00 | | | | 43.70 | | | | | | | | Zn, Cd, Cu, Pb | 1.61 | Murray & Price, 2008 |
| Waste oil/oiled water | | | | | | | | | | | | 33.0 | | | CEMBUREAU, 2009 |
| Waste lubricant oil | | | | 0.05 | 85.30 | 13.20 | 0.99 | | 0.50 | | | 48.2 | | | Conesa et al., 2009 |
| Residual oil & solvent | | | | | | | | | | | | 34.0 | Pb, Zn, Cl | | Willitsch et al., 2009 |
| Used automotive oil | | | | | | | | | 0.21-0.65 | 0.05-0.20 | | | | | Berry & MacDonald, 1975/76 |
| Oil mud | | | | | | | | | | | | 13.0 | | | Tsakalakis, 2003 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tyre | | | | 7.30 | 83.50 | 7.80 | 0.39 | | 1.50 | | | 35.6 | | | Conesa et al., 2009 |
| Tyres | | | | | | | | | | | | 26.0 | | | CEMBUREAU, 2009 |
| Tyres | 0.30 | | | | | | | | | | | 27.8, 37.1 | $No_x$, $SO_2$, CO | 2.05 | Murray & Price, 2008 |
| Tyres | 0.30 | 6.50 | 71.00 | 22.20 | 78.24 | 7.50 | 0.58 | | 1.05 | | 0.05 | 33.9 | | | Prisciandaro, Mazziotti & Veglio´,2003 |
| Tyres | 0.00 | | | 3.50 | 71.00 | | 0.26 | | 0.50-2.00 | | 0.07-0.13 | 28.5-35.0 | | | Twigger et al., 2001 |
| Waste tyres | 0.90 | 65.50 | | | | | | | 1.71 | | 0.50 | 33.1 | | | Conesa et al., 2008 |
| Waste tyres | 0.10 | | | 15.25 | 74.92 | 7.05 | 0.50 | 0.90 | 1.30 | | | 31.5 | | | Hansen, 2003 |
| Scrap tyres | | | | | | | | | | | | 27.0-31.0 | | | Tsakalakis, 2003 |
| Car tyre scrap | 0.66 | 68.94 | 30.40 | 6.31 | 79.07 | 6.95 | 0.43 | 4.97 | 1.53 | 0.01 | 0.06 | 35.5 | | | Ka¨a¨ntee et al., 2004 |
| Car tyre rubber | 0.73 | 66.11 | 30.87 | 2.18 | 86.36 | 7.76 | 0.33 | 1.80 | 0.79 | | | 35.6 | | | Ka¨a¨ntee et al., 2004 |
| Car tyre rubber | 0.73 | 66.11 | 30.87 | 2.18 | 86.36 | 7.76 | 0.33 | 1.80 | 0.79 | | | 35.6 | | | Kääntee et al., 2002 |
| Tyre, rubber waste | | | | | | | | | | | | 25.0 | Zn, S | | Willitsch et al., 2009 |
| | | | | | | | | | | | | | | | |
| Polyethylene | 2.10 | | | 27.40 | 69.51 | | | | | | | | Cl | 2.57 | Murray & Price, 2008 |
| Polyethylene | | | | | 85.30 | 14.70 | | | | | | 43.0 | | | Conesa et al., 2009 |
| Polyethylene | 0.00 | 99.70 | 0.10 | 0.20 | 84.30 | 15.40 | 0.00 | Traces | 0.00 | | Traces | | | | Cozzani, Petarca & Tognotti, 1995 |
| Polyethylene | | | | | | | | | | | | 44.0 | | | Tokheim, 2000 |
| Low density polyethylene | 0.10 | 97.60 | 2.30 | 0.00 | 84.02 | 12.14 | 0.00 | | 0.00 | | | | | | Grammelis et al., 2009 |
| Low density polyethylene | 0.00 | 99.60 | 0.00 | 0.40 | 85.16 | 14.24 | | | 0.20 | | | | | | Aboulkas et al., 2008 |
| High density polyethylene | 0.10 | 97.30 | 2.50 | 0.10 | 85.31 | 11.36 | 0.09 | | 0.00 | | | | | | Grammelis et al., 2009 |
| High density polyethylene | 0.00 | 99.40 | 0.00 | 0.60 | 84.99 | 14.11 | | | 0.30 | | | | | | Aboulkas et al., 2008 |
| Polypropylene | 2.10 | | | 27.40 | 69.51 | | | | | | | | Cl | 2.57 | Murray & Price, 2008 |
| Polypropylene | 0.00 | 99.10 | 0.00 | 0.90 | 83.34 | 14.27 | | | 1.49 | | | | | | Aboulkas et al., 2008 |
| Polypropylene | | | | | | | | | | | | 44.8 | | | Tokheim, 2000 |
| Polypropylene | 0.00 | 100.00 | 0.00 | 0.00 | 84.40 | | 0.28 | | 0.00 | | | | | | Grammelis et al., 2009 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Polystyrene | | | | | | | | | | | | 39.4 | | | Tokheim, 2000 |
| Polystyrene | 0.00 | 100.00 | 0.00 | 0.00 | 90.70 | 7.70 | 0.05 | 1.55 | 0.00 | | | | | | Grammelis et al., 2009 |
| Polyvinyl chloride | | | | | | | | | | | | 18.0 | | | Tokheim, 2000 |
| Polyvinyl chloride | | | | | 38.40 | 4.80 | | | 1.40 | | | | | | Conesa et al., 2009 |
| Polyvinyl chloride | 0.20 | 85.90 | 6.30 | 7.60 | 35.83 | 4.39 | 0.11 | | 0.00 | | | | | | Grammelis et al., 2009 |
| Polyamide | 1.10 | 98.40 | 0.20 | 0.30 | 62.01 | 9.59 | 10.55 | 5.06 | 0.00 | | | | | | Grammelis et al., 2009 |
| Polycarbonate | 0.10 | 83.50 | 16.30 | 0.10 | 74.03 | 5.49 | 0.22 | 6.49 | 0.00 | | | | | | Grammelis et al., 2009 |
| Plastic | | | | | | | | | | | | 38.0 | | | Tokheim, 2004 |
| Plastic | | | | | | | | | | | | 37.7 | | 2.80 | Tokheim, 2008 |
| Plastics | | | | | | | | | | | | 25.0 | | | CEMBUREAU, 2009 |
| Plastics | | | | | | | | | | | | 29.0-40.0 | | | Twigger et al., 2001 |
| Plastics | | | | | | | | | | | | 21.0 | | | Tsakalakis, 2003 |
| Plastic waste | | | | | | | | | | | | 29.0 | Cc, Cd, Pb, Zn | | Willitsch et al., 2009 |
| Plastic (PP+PET) | 0.40 | 95.90 | 1.70 | 2.00 | 80.20 | 13.40 | 0.10 | 3.70 | 0.20 | | | 37.0 | | | Tokheim, 1999 |
| Polyethylene terephthalate | | | | | | | | | | | | 23.0 | | | Tokheim, 2000 |
| Tetra pack | 1.20 | 83.40 | 8.90 | 6.50 | 47.42 | 6.22 | 0.08 | 38.57 | 0.00 | | | | | | Grammelis et al., 2009 |
| Packaging | | | | | | | | | | | | 22.0 | | | Tsakalakis, 2003 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical & hazardous waste | | | | | | | | | | | | | | | |
| Liquid hazardous waste | 45.70 | 54.30 | 0.00 | 0.00 | 48.20 | 10.40 | 2.70 | 35.70 | 2.10 | | 1.00 | 17.9 | | | Axelsen, 2002 |
| Liquid hazardous waste | 16.00 | | | 4.00 | 62.83 | 13.19 | 0.82 | 2.90 | 0.25 | | | 22.6 | | | Hansen, 2003 |
| Liquid hazardous waste | | | | | | | | | | | | 15.7 | | 1.2 | Tokheim, 2008 |
| Liquid hazardous waste | | | | | | | | | | | | 17.0 | | | Tokheim, 2004 |
| Solvent | | | | | | | | | | | | 26.0 | | 0.07 | CEMBUREAU, 1999 |
| Solvents | | | | | | | | | | | | 24.0 | | | Tsakalakis, 2003 |
| Spent solvent | 10.30, 16.50 | | | | 42.80-39.80 | | | | | | | | dioxins | 1.47 | Murray & Price, 2008 |
| Paint residues | 9.00 | | | 34.00 | 37.31-46.41 | | | | | | | 16.3 | | 1.54 | Murray & Price, 2008 |
| Varnish | | | | 8.00 | 64.00 | 7.20 | 3.31 | | | | | 25.3 | | | Conesa et al., 2009 |
| Obselete pesticides | | | | | | | | | | | | 33.3 | $No_x$ | | Murray & Price, 2008 |
| Coal slurries/ distillation residues | | | | | | | | | | | | 24.0 | | | CEMBUREAU, 2009 |
| Organic distillation residues | | | | | | | | | | | | 13.0 | | | Tsakalakis, 2003 |
| Solid hazardous waste | 10.70 | 46.30 | 7.70 | 35.30 | 65.20 | 9.80 | 2.00 | 21.80 | 0.70 | | 0.50 | 15.8 | | | Axelsen, 2002 |
| Solid hazardous waste | | | | | | | | | | | | 14.9 | | 1.10 | Tokheim, 2008 |
| Solid hazardous waste | | | | | | | | | | | | 17.0 | | | Tokheim, 2004 |
| Hazardous waste | | | | | | | | | | | | 22.0 | | | CEMBUREAU, 2009 |
| Hazardous waste | | | | | | | | | | | | | dioxins, heavy metals | 0.51 | Murray & Price, 2008 |
| Anodes/ Chemical cokes | | | | | | | | | | | | 28.0 | | | CEMBUREAU, 2009 |
| Fuller earth | | | | | | | | | | | | 11.0 | | | Tsakalakis, 2003 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt %) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-agricultural bio mass | | | | | | | | | | | | | | | |
| Sewage sludge | 5.20 | 80.58 | 4.74 | 16.97 | 40.67 | 8.53 | 1.74 | 25.79 | 0.11 | | | 15.8 | | | Kääntee et al., 2002 |
| Sewage sludge | | | | | | | | | | | | 8.0 | Pb, Cd, Hg | | Willitsch et al., 2009 |
| Sewage sludge | | | | 26.20 | 29.60 | 4.70 | 1.40 | | 1.00 | | | 15.5 | | | Conesa et al., 2009 |
| Sewage sludge | | | | 14.80 | 42.20 | 6.50 | 7.70 | | 0.80 | | | 17.5 | | | Conesa et al., 2009 |
| Sewage sludge | 10.00 | 27.60 | | | | | | | 1.24 | | 0.18 | 17.0 | | | Conesa et al., 2008 |
| Sewage sludge | 7.03 | 31.20 | | | | | | | 1.78 | | 0.39 | 11.8 | | | Conesa et al., 2008 |
| Sewage sludge | 5.20 | 80.58 | 4.74 | 16.97 | 38.39 | 6.64 | 0.80 | 23.89 | 0.11 | | 0.95 | 15.8 | | | Ka¨a¨ntee et al., 2004 |
| Sewage sludge | | | | | | | 4.20 | | 0.60 | | | 16.0-17.0 | | | Twigger et al., 2001 |
| Dewatered sewage sludge | 75.00 | | | 21.80 | 13.48, 7.50 | | | | | | | | heavy metals | 0.77-1.43 | Murray & Price, 2008 |
| Heat dried sewage sludge | 10.00 | | | | | | | | | | | | heavy metals | | Murray & Price, 2008 |
| | | | | | | | | | | | | | | | |
| Paper | 4.00 | 72.96 | 12.29 | 10.75 | 34.56 | 4.80 | 0.10 | 45.79 | ND | | Traces | | | | Cozzani, Petarca & Tognotti, 1995 |
| Paper | | | | 8.33 | | | | | | | | 12.5-22.0 | Cl | 1.54 | Murray & Price, 2008 |
| Paper | | | | | | | | | 0.10-1.50 | | 0.15-9.00 | 12.5-22.0 | | | Twigger et al., 2001 |
| Copy paper | 4.00 | 79.40 | 10.10 | 6.40 | 39.17 | 5.47 | 0.20 | 44.76 | 0.00 | | | | | | Grammelis et al., 2009 |
| Magazine paper | 2.10 | 66.70 | 8.20 | 23.00 | 34.75 | 4.50 | 0.44 | 35.20 | 0.00 | | | | | | Grammelis et al., 2009 |
| Recycling paper | 7.50 | 75.80 | 4.81 | 11.90 | 38.76 | 5.09 | 0.25 | 36.51 | 0.00 | | | | | | Grammelis et al., 2009 |
| Newspaper | 5.40 | 76.90 | 8.75 | 8.90 | 41.72 | 5.30 | 0.16 | 38.52 | 0.00 | | | | | | Grammelis et al., 2009 |
| Paper waste | | | | 43.00 | 27.00 | 3.30 | 0.40 | | 0.20 | | | 9.4 | | | Conesa et al., 2009 |
| Paper sludge | | | | | | | | | | | | 8.5 | | | Twigger et al., 2001 |
| Paper sludge | 70.00 | | | 26.00 | | | | | | | | 8.5 | Cl | 0.73 | Murray & Price, 2008 |
| Papers/ sewage sludges | | | | | | | | | | | | 6.0 | | | CEMBUREAU, 2009 |
| Cardboard | 5.00 | 82.10 | 6.02 | 6.80 | 40.09 | 5.32 | 0.19 | 42.60 | 0.00 | | | | | | Grammelis et al., 2009 |
| Pulp/paper & cardboard | | | | | | | | | | | | 17.0 | | | Tsakalakis, 2003 |
| Paper/ card board/wood | | | | | | | | | | | | 18.0 | | | CEMBUREAU, 2009 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wood | | | | | | | | | | | | 15.7 | | 1.70 | Tokheim, 2008 |
| Wood | 7.00 | 76.07 | 15.16 | 1.77 | 42.59 | 5.49 | 0.00 | 44.73 | 0.00 | | Traces | | | | Cozzani, Petarca & Tognotti, 1995 |
| Wood | | | | | | | | | | | | 13.0 | | | Tokheim, 2004 |
| Scrap wood | | | | | | | | | | | | 13.0 | | | Tsakalakis, 2003 |
| Scrap wood | 18.00 | | | 5.30 | 0.44 | | 1.00 | | | | 0.00 | 12.7 | | | Twigger et al., 2001 |
| Forest wood | 7.38 | 72.98 | 17.64 | 2.00 | 46.16 | 5.77 | 0.80 | 37.87 | | | | | | | Reina, Velo & Puigjaner, 1998 |
| Old furniture wood | 3.79 | 77.46 | 17.55 | 1.20 | 44.59 | 6.32 | 1.57 | 42.83 | | | | | | | Reina, Velo & Puigjaner, 1998 |
| Used pallets | 2.59 | 79.98 | 15.03 | 2.40 | 45.37 | 5.69 | 0.07 | 43.88 | | | | | | | Reina, Velo & Puigjaner, 1998 |
| Waste wood | 33.30 | | | 0.90 | 33.35 | | | | | | | | Cl, toxics if treated or painted | 1.21, 1.80 | Murray & Price, 2008 |
| CCA waste wood | | | | | | | | | | | | 12.6 | | 1.40 | Tokheim, 2008 |
| Contaminated wood & process waste from wood | | | | | | | | | | | | 9.0-18.0 | Cl, Cd, Pb, Zn | | Willitsch et al., 2009 |
| | | | | | | | | | | | | | | | |
| Animal meal | 4.50 | 59.70 | 7.50 | 28.30 | 56.30 | 8.30 | 11.60 | 14.40 | 0.60 | 8.30 | 0.50 | 15.8 | | | Axelsen, 2002 |
| Animal meal | | | | | | | | | | | | 16.8 | | 1.50 | Tokheim, 2008 |
| Animal meal | | | | | | | | | | | | 12.0-16.0 | Pb, Cl | | Willitsch et al., 2009 |
| Animal meal | | | | | | | | | | | | 18.0 | | | Tokheim, 2004 |
| Meat & bone meal | | | | 28.70 | 40.40 | 6.40 | 7.80 | | 0.50 | | | 17.0 | | | Conesa et al., 2009 |
| Meat & bone meal | 8.09 | 59.28 | 6.62 | 26.01 | 38.69 | 5.36 | 6.91 | 14.06 | 0.35 | 37.87 | 0.18 | 16.2 | | | Ka¨a¨ntee et al., 2004 |
| Meat & bone meal | 8.09 | 59.30 | 6.62 | 26.01 | 38.69 | 5.36 | 6.91 | 14.06 | 0.35 | | | 16.2 | | | Kääntee et al., 2002 |
| Animal meal/bone meal/animal fat | | | | | | | | | | | | 24.0 | | | CEMBUREAU, 2009 |
| Meat bone meal & animal fat | | | | | | | | | | | | 19.0 | | | Tsakalakis, 2003 |
| Animal waste (bone meal/ animal fat) | 15.00 | | | | 28.90 | | | | | | | 16.0-17.0, 19.0 | | 1.06 | Murray & Price, 2008 |
| Animal waste | 2.00-14.00 | | | 13.00-30.00 | | | | | | | | 16.0-17.0 | | | Twigger et al., 2001 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Saw dust | 20.00 | | | 2.60 | 37.52 | | | | | | | | Cl (if from treated wood) | 1.39 | Murray & Price, 2008 |
| Saw dust | 17.05 | 65.06 | 14.27 | 3.61 | 38.14 | 5.22 | 0.37 | 35.96 | 0.23 | | | 14.0 | | | Wang et al., 2009 |
| Saw dust hog fuel | 6.30 | | | 0.50 | 51.80 | 6.30 | 0.10 | 35.00 | 0.00 | | | 19.7 | | | Hansen, 2003 |
| Impregnated saw dust | | | | | | | | | | | | 12.0 | | | CEMBUREAU, 2009 |
| | | | | | | | | | | | | | | | |
| Agricultural bio mass | | | | | | | | | | | | | | | |
| Bio fuel | | | | | | | | | | | | 16.0 | | 0.11 | CEMBUREAU, 1999 |
| Rice husk | 10.00 | | | 20.60 | 34.92 | | | | | | | 13.2-16.2 | Cl | 1.28 | Murray & Price, 2008 |
| Rice husks | | | | | | | | | | | | 12.5 | | | Twigger et al., 2001 |
| Wheat straw | 14.20, 7.30, 12.00 | | | 4.50, 3.00-5.00, 8.90 | 38.52-45.20 | | | | | | | 15.8, 18.2 | | 1.54 | Murray & Price, 2008 |
| Wheat straw | 9.00 | 66.80 | 15.00 | 9.28 | 36.90 | 5.52 | 1.01 | 37.90 | 0.40 | | | 13.9 | | | Wang et al., 2009 |
| Wheat straw | 7.35 | 68.28 | 15.43 | 8.92 | 38.20 | 5.56 | 0.71 | 39.00 | 0.31 | | | 14.3 | | | Wang et al., 2009 |
| Corn stover | 9.41, 35.00, 11.00 | | | 7.46, 3.25 | 27.60-38.50 | | | | | | | 15.4 | | 1.03 | Murray & Price, 2008 |
| Sugarcane leaves | <15.00 | | | 7.70 | >33.83 | | | | | | | 15.8 | | 1.25 | Murray & Price, 2008 |
| Sugar cane (bagasse) | 10.00-15.00 | | | 4.20 | 37.50-39.70 | | | | | | | 14.4, 15.6, 19.4 | | 1.43 | Murray & Price, 2008 |
| Rapeseed stems | 12.60 | | | 5.90 | 39.50 | | | | | | | 16.4 | | 1.43 | Murray & Price, 2008 |
| Hazelnut shells | 9.20 | | | 3.50 | 48.03 | | | | | | | 17.5 | | 1.76 | Murray & Price, 2008 |
| Palm nut shells | 10.00 | | | | | | | | | | | 11.9 | | 1.32 | Murray & Price, 2008 |
| Oil palm, coconut shells | | | | | | | | | | | | 12.5 | | | Twigger et al., 2001 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt %) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Miscellaneous waste | | | | | | | | | | | | | | | |
| Refuse derived fuel | 25.00 | 53.00 | 10.50 | 11.50 | 52.30 | 6.60 | 1.00 | 39.00 | 0.30 | | 0.80 | 18.0 | | | Axelsen, 2002 |
| Refuse derived fuel | 8.30 | 71.10 | 10.30 | 10.30 | 44.20 | 6.60 | 1.00 | 29.10 | 0.50 | | | 18.4 | | | Tokheim, 1999 |
| Refuse derived fuel | | | | | | | | | | | | 13.5 | | 1.20 | Tokheim, 2008 |
| Refuse derived fuel | | | | | | | | | | | | 11.0 | | | CEMBUREAU, 2009 |
| Refuse derived fuel | 4.00 | 74.69 | 9.50 | 11.81 | 44.06 | 6.53 | 1.06 | 32.35 | ND | | Traces | | | | Cozzani, Petarca & Tognotti, 1995 |
| Refuse derived fuel | 4.50 | 70.10 | 14.33 | 11.08 | 46.13 | 7.26 | 0.57 | 30.18 | 0.10 | | 0.19 | | | | Cozzani, Petarca & Tognotti, 1995 |
| Refuse derived fuel | 15.50 | 57.54 | 17.32 | 9.63 | 34.48 | 5.66 | 0.76 | 32.87 | 0.51 | | 0.59 | | | | Cozzani, Petarca & Tognotti, 1995 |
| Refuse derived fuel | 4.00 | 73.34 | 12.58 | 9.98 | 40.51 | 5.86 | 0.77 | 38.30 | 0.10 | | 0.48 | | | | Cozzani, Petarca & Tognotti, 1995 |
| Refuse derived fuel | | | | | | | | | | | | 13.0 | | | Tokheim, 2004 |
| Refuse derived fuel | 0.99 | 79.10 | 9.60 | 10.40 | 50.79 | 7.43 | 0.76 | 29.43 | 0.21 | | | | | | Grammelis et al., 2009 |
| Refuse derived fuel | 1.30 | 71.90 | 10.70 | 16.10 | 55.57 | 4.64 | 1.63 | 19.95 | 0.13 | | | | | | Grammelis et al., 2009 |
| Refuse derived fuel | 3.20 | | | 0.77 | 45.21 | 6.00 | 1.16 | 42.69 | 0.48 | | | | | | Dalai et al., 2009 |
| Refuse derived fuel | 9.50 | | | 1.00 | 39.82 | 5.16 | 1.27 | 42.72 | 0.63 | | | | | | Dalai et al., 2009 |
| Refuse derived fuel | 2.90-34.00 | | | | | | 0.52 | | 0.10-0.20 | | 0.28-0.70 | 13.0-22.0 | | | Genon & Brizio, 2008 |
| Refuse derived fuel | 3.00-35.00 | | | 8.00-25.00 | | | | | 0.10-0.50 | | 0.10-1.00 | 12.5-15.0 | | | Twigger et al., 2001 |
| Thermal fraction of domestic waste | | | | | | | | | | | | 22.0 (humidity<10%) | Cl, Cd, Cr, Hg | | Willitsch et al., 2009 |
| Municipal solid waste | 10.00-35.00 | | | | 26.00-36.00 | | | | | | | 12.0-16.0 | Cl, $No_x$, heavy metals | 0.95-1.32 | Murray & Price, 2008 |
| Municipal solid waste | 15.00-50.00 | | | 18.00-30.00 | | | | | 0.10-0.50 | | 0.10-1.00 | 8.0-11.0 | | | Twigger et al., 2001 |
| Municipal waste | 19.70 | | | 18.00 | 40.20 | 6.30 | 0.30 | 15.40 | 0.10 | | | 13.3 | | | Hansen, 2003 |
| Mixed fraction from municipal waste | | | | | | | | | | | | 15.0 | | | Tsakalakis, 2003 |

| Description | Moisture (Wt%) | Volatiles (Wt%) | Fixed carbon (Wt%) | Ash (Wt%) | C (Wt%) | H (Wt%) | N (Wt%) | O (Wt%) | S (Wt%) | P (Wt%) | Cl (Wt%) | LHV (MJ/kg) | Contaminants or emission | Gross $CO_2$ emission factor (t $CO_2$/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Textile waste | 2.40 | 91.46 | 3.50 | 2.64 | 53.60 | 7.28 | 0.30 | 38.80 | 0.01 | | | 22.6 | | | Miranda et al., 2007 |
| Textile waste | | | | | | | | | | | | 21.0 | | | Tsakalakis, 2003 |
| Cotton | 5.00 | | ND | 0.10 | 45.50 | 6.60 | 0.30 | 47.50 | 0.10 | | | 17.1 | | | Miranda et al., 2007 |
| Cotton | | | | <0.10 | 45.50 | 6.60 | 0.30 | | <0.10 | | | 17.1 | | | Conesa et al., 2009 |
| Polyester | | | | <0.10 | 62.60 | 4.60 | 0.40 | | <0.10 | | | 22.9 | | | Conesa et al., 2009 |
| Nappy manufacturing waste | | | | | | | | | 0.04 | | 0.10 | 35.0 | | | Twigger et al., 2001 |
| Carpets | | | | | | | | | 0.10-0.20 | | 0.10-0.20 | 19.0-25.0 | | | Twigger et al., 2001 |
| Carpet fibre | 0.80 | 91.60 | 0.00 | 7.70 | 59.10 | 9.30 | 8.50 | 14.50 | 0.10 | 0.02 | 0.06 | 29.3 | | | Lemieux et al., 2004 |
| Carpet fines | 1.50 | 69.20 | 0.05 | 29.20 | 38.30 | 4.40 | 4.00 | 22.30 | 0.24 | 0.04 | 0.11 | 13.0 | | | Lemieux et al., 2004 |
| Polypropylene carpet residues | 0.20 | | | 21.20 | 56.79 | | | | | | | 28.1 | Cl, Sb, Cr, Zn | 2.09 | Murray & Price, 2008 |
| Nylon carpet residues | 0.90 | | | 25.40 | 41.82 | | | | | | | 17.2 | Cl, Sb, Cr, Zn, $NO_x$ | 1.54 | Murray & Price, 2008 |
| Automotive shredder residues | 2.20 | | | 36.20 | 45.18 | | | | | | | 16.5 | Cl, heavy metals | 1.61 | Murray & Price, 2008 |
| Demolition and commercial waste | 18.80 | | | 20.60 | | | | | | | | 25.0 | | | Murray & Price, 2008 |
| Landfill gas | | | | | | | | | | | | 19.7 | | 1.10 | Murray & Price, 2008 |

Elemental analysis of fuels (ppm)

| Description | Ag | Al | As | B | Ba | Be | Br | Ca | Cd | Cl | Co | Cr | Cs | Cu | F | Fe | Hg | I | K | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pet coke | | | | | | | | | 0.005 | 25 | | 1 | | | | | 0.2 | | | Willitsch et al., 2009 |
| Waste oil | | | | | | | | | 13 | 8400 | | | | | | | 2 | | | Willitsch et al., 2009 |
| Waste oil | | | 0.006 | | | 0.04 | | | 0.21 | | | 0.22 | | 14.3 | | | 0.004 | | | Prisciandaro, Mazziotti & Veglio´,2003 |
| Used automotive oil | 1 | 10-800 | | 3-20 | 10-2000 | 6 | 1500 | 700-3000 | 4 | | | 8-50 | | 5-348 | | 50-2000 | | | | Berry & Macdonald, 1975/76 |
| Tyres | | | 8 | | | | | | 3 | 24 | | 53 | | <100 | | 0.12 | <1 | | | Twigger et al., 2001 |
| Plastic | | | | | | | | | 2-8 | 12800 | | 9 | | | | | 0.3 | | | Willitsch et al., 2009 |
| Hazardous waste fuel | 0.339 | | 2.324 | | 690.6 | 0.24 | | | 5.359 | | | 199.6 | | | | | 0.282 | | | Woodford, Gossman R. & Gossman D., 1992 |
| Sewage sludge | | | <0.5 | | | | | | 13.4 | | 1.6 | 178.1 | | 217.7 | | | <0.5 | | | Conesa et al., 2008 |
| Sewage sludge | | | 2.4 | | | | | | 2.9 | | 4.5 | 572.7 | | 562.3 | | | 1.2 | | | Conesa et al., 2008 |
| Sewage sludge | | | 2.9 | | | | | | 1.3 | | 4.4 | 42 | | 294 | | | 1.7 | | | Twigger et al., 2001 |
| Paper | | | | | | | 0-700 | | | | | | | | 110-300 | | | | | Twigger et al., 2001 |
| Scrap wood | | | | | | | | | | | | | | | | 0.0021 | 0.3 | | | Twigger et al., 2001 |
| Animal meal | | | | | | | | | 8 | 2100-7240 | | | | | | | | | | Willitsch et al., 2009 |
| Refuse Derived Fuel | | | 0.87-5.81 | | | | | | 0.17-1.72 | | 0.58-2.64 | 10.97-92.4 | | 43.7-175.56 | | | 0.1-0.26 | | | Genon & Brizio, 2008 |
| Prepared domestic waste | | | | | | | | | 3.3 | 1.23 | | 7.6 | | | | | 0.15 | | | Willitsch et al., 2009 |
| Nappy manufacturing wastes | | | | | | | 28 | | | | | | | | 152 | | | | | Twigger et al., 2001 |
| Carpets | | | | | | | 0-50 | | | | | | | | 300 | | | | | Twigger et al., 2001 |
| Carpet fibre | | 473 | | | | | 122 | 10100 | | 443 | 17 | ND | 13 | 27 | 240 | 184 | | 18 | 233 | Lemieux et al., 2004 |
| Carpet fines | | 2500 | | | | | 25 | 98400 | | 1840 | ND | 6 | ND | ND | ND | 713 | | ND | 572 | Lemieux et al., 2004 |

| Description | Mb | Mg | Mn | Mo | Na | Ni | Pb | Sb | Se | Si | Sn | Sr | Te | Ti | Tl | V | Zn | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pet coke | | | | | | | | | | | | | | | 0.2 | | 5 | Willitsch et al., 2009 |
| Waste oil | | | | | | | | | | | | | | | | | 3000 | Willitsch et al., 2009 |
| Waste oil | | | | | | | 1.2 | 20 | 0.004 | | | | 1.11 | | 2 | | | Prisciandaro, Mazziotti & Veglio´,2003 |
| Used automotive oil | | 10-1108 | 5-10 | 2-3 | 16-300 | 3-30 | 800-21700 | | | 10-875 | 5-112 | 10-30 | | 5-30 | | 3-39 | 300-3000 | Berry & Macdonald, 1975/76 |
| Tyres | | | 145 | | | 9 | 48 | <1 | | | <10 | | | | 42 | 8 | 14000 | Twigger et al., 2001 |
| Plastic | | | | | | | | | | | | | | | | | 114-177 | Willitsch et al., 2009 |
| Hazardous waste fuel | | | | | | | 668.2 | 17.23 | | | | | | | 0.733 | | | Woodford, Gossman R. & Gossman D., 1992 |
| Sewage sludge | | | 128.1 | | | 35.8 | 69 | 4.2 | | | <0.5 | | | | <0.5 | 11.3 | | Conesa et al., 2008 |
| Sewage sludge | | | 182.2 | | | 223.2 | 72 | 0.15 | | | 55.5 | | | | 0.1 | 17.4 | | Conesa et al., 2008 |
| Sewage sludge | 4 | | | | | 35 | 203 | 4.6 | | | | | | | | | | Twigger et al., 2001 |
| Paper | | | | | | | | | | | | | | | | | | Twigger et al., 2001 |
| Scrap wood | | | | | | | | | | | | | | | | | 535 | Twigger et al., 2001 |
| Animal meal | | | | | | | | | | | | | | | | | 124 | Willitsch et al., 2009 |
| Refuse Derived Fuel | | | 27.19-138.6 | | | 0.83-13.86 | 24.28-103.62 | 8.74-9.7 | | | 3.88-330 | | | | 0.02-0.33 | 0.29-4.62 | 218.48-224.4 | Genon & Brizio, 2008 |
| Prepared domestic waste | | | | | | | | | | | | | | | | | 378 | Willitsch et al., 2009 |
| Nappy manufacturing wastes | | | | | | | | | | | | | | | | | | Twigger et al., 2001 |
| Carpets | | | | | | | | | | | | | | | | | | Twigger et al., 2001 |
| Carpet fibre | | 169 | 6 | | 717 | | | ND | | 266 | | ND | | 1260 | | | 18 | Lemieux et al., 2004 |
| Carpet fines | | 3220 | 40 | | 2800 | | | 51 | | 2660 | | 83 | | 1160 | | | 83 | Lemieux et al., 2004 |

ND- Not Detected

Inorganic properties of coal & some agricultural fuel samples (Demirbas, 2004)

| Fuel sample | $Si_2O$ | $Al_2O_2$ | $TiO_2$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | $P_2O_5$ | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal type 1 | 42.0 | 20.0 | 1.2 | 17.0 | 5.5 | 2.1 | 1.4 | 5.8 | 5.0 | – | – |
| Coal type 2 | 59.7 | 19.8 | 2.1 | 8.3 | 2.1 | 1.8 | 0.8 | 2.1 | 2.0 | 0.2 | – |
| Coal type 3 | 51.5 | 22.6 | 2.0 | 14.9 | 3.3 | 0.9 | 1.0 | 2.0 | 3.5 | 0.2 | – |
| Red oak wood | 49.0 | 9.5 | – | 8.5 | 17.5 | 1.1 | 0.5 | 9.5 | 2.6 | 1.8 | 0.8 |
| Wheat straw | 48.0 | 3.5 | – | 0.5 | 3.7 | 1.8 | 14.5 | 20.0 | 1.9 | 3.5 | 3.6 |
| Walnut shell | 23.1 | 2.4 | 0.1 | 1.5 | 16.6 | 13.4 | 1.0 | 32.8 | 2.2 | 6.2 | 0.1 |
| Almond shell | 23.5 | 2.7 | 0.1 | 2.8 | 10.5 | 5.2 | 1.6 | 48.5 | 0.8 | 4.5 | 0.2 |
| Sunflower shell | 29.3 | 2.9 | 0.1 | 2.1 | 15.8 | 6.1 | 1.5 | 35.6 | 1.3 | 4.8 | 0.2 |
| Olive husk | 32.7 | 8.4 | 0.3 | 6.3 | 14.5 | 4.2 | 26.2 | 4.3 | 0.6 | 2.5 | 0.2 |
| Hazelnut shell | 33.7 | 3.1 | 0.1 | 3.8 | 15.4 | 7.9 | 1.3 | 30.4 | 1.1 | 3.2 | 0.1 |

wt% of ash

Properties of sewage sludge and cement raw meal (Ga´lvez et al., 2007)

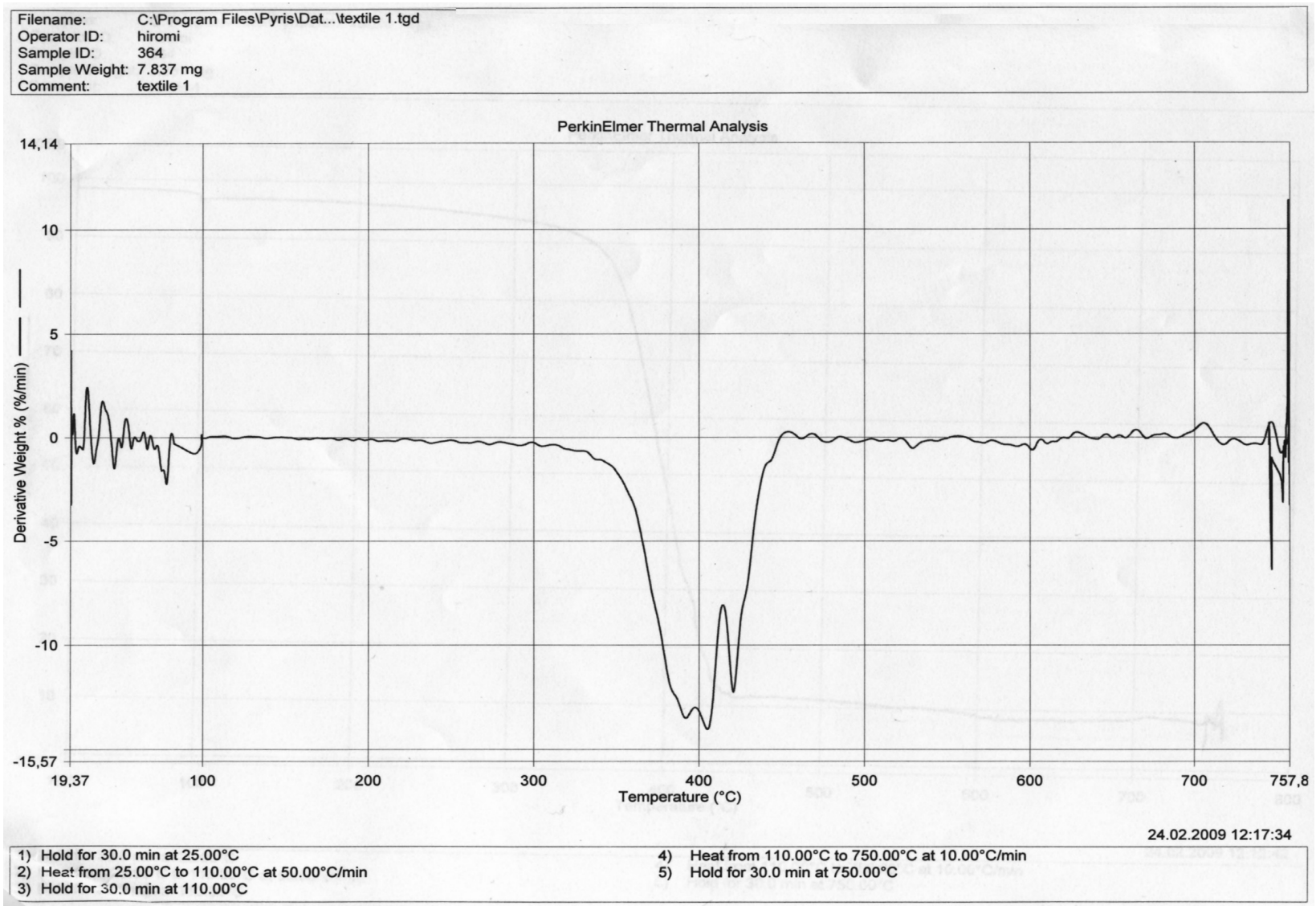
| | CRM | Sewage sludge |
|---|---|---|
| Humidity | – | 10% |
| Ash content | – | 26.2% |
| Low calorific value | – | 16984.1 MJ $kg^{-1}$ |
| $Cl^-$ | – | 1804 mg $kg^{-1}$ |
| $SO_4^{2-}$ | – | 12408.5 mg $kg^{-1}$ |
| Total hydrocarbon content | 15.8 mg $kg^{-1}$ | – |
| Particle size | 4.5 μm | – |
| *Metals (mg $kg^{-1}$)* | | |
| Cd | 3.1 | 13.4 |
| Cr | 47.7 | 178 |
| Cu | 318 | 217 |
| Mn | 474 | 128 |
| Ni | 55.4 | 35.8 |
| Pb | 316 | 69 |
| Co | 35.5 | 1.6 |
| Tl | 8.4 | <0.5 |
| V | 85.7 | 11.3 |
| Sb | 23.8 | 4.2 |
| Sn | 11.7 | <0.5 |
| Zn | 568 | – |
| Hg | <0.5 | <0.5 |
| *PAH (mg $kg^{-1}$)* | | |
| Naphthalene | 1.49 | 0.12 |
| Acenaphthylene | <0.01 | <0.01 |
| Acenaphthene | <0.01 | 0.25 |
| Fluorene | <0.01 | 0.21 |
| Phenanthrene | 0.53 | 0.27 |
| Anthracene | 0.01 | 0.19 |
| Fluoranthene | 0.07 | 0.21 |
| Phenanthrene | 0.11 | 0.31 |
| Benzo(*a*)anthracene | 0.03 | 0.14 |
| Chrysene | 0.15 | 0.06 |
| Benzo(*b*)fluoranthene | 0.06 | 0.1 |
| Benzo(*k*)fluoranthene | 0.08 | 0.08 |
| Benzo(*a*)pyrene | 0.02 | 0.05 |
| Indeno(1,2,3-*cd*)pyrene | 0.01 | 0.28 |
| Dibenz(*a,h*)anthracene | 0.01 | 0.09 |
| Benzo(*g,h,i*)perylene | 0.05 | 0.25 |
| *PCDD/F (pg $g^{-1}$)* | | |
| 2,3,7,8-TCDF | 0.15 | 2.76 |
| 1,2,3,7,8-PeCDF | 0.13 | 1.25 |
| 2,3,4,7,8-PeCDF | 0.16 | 1.91 |
| 1,2,3,4,7,8-HxCDF | 0.14 | 2.12 |
| 1,2,3,6,7,8-HxCDF | <0.11 | 1.33 |
| 2,3,4,6,7,8-HxCDF | <0.96 | 1.42 |
| 1,2,3,7,8,9-HxCDF | <0.08 | 0.46 |
| 1,2,3,4,6,7,8-HpCDF | 0.24 | 23.56 |
| 1,2,3,4,7,8,9-HpCDF | <0.11 | 1.25 |
| OCDF | 3.24 | 104 |
| 2,3,7,8-TCDD | 0.09 | Nd |
| 1,2,3,7,8-PeCDD | 0.13 | 1.84 |
| 1,2,3,4,7,8-HxCDD | <0.14 | 0.62 |
| 1,2,3,6,7,8-HxCDD | <0.14 | 4.21 |
| 1,2,3,7,8,9-HxCDD | <0.14 | 2.09 |
| 1,2,3,4,6,7,8-HpCDD | 4.28 | 71.86 |
| OCDD | 204 | 673 |
| Total pg i-TEQ/g | 0.52 | 5.15 |

Metal, PAH and PCDD/F content.

Major constituents of two SPL cuts (Constans, 1998)

| **Oxide Weight %** | **Typical first cut** | **Typical second cut** (non hazardous) |
|---|---|---|
| $SiO_2$ | 1.5-8 | 14-45 |
| $Al_2O_3$ | 8 - 20 | 21-50 |
| $Na_2O$ | 10 - 15 | 15 - 24 |
| $K_2O$ | 0.05-0.1 | 0.4-1.1 |
| MgO | 0.05-0.25 | 0.3-0.6 |
| CaO | 1.5-2.25 | 1.5-4.2 |
| $Fe_2O_3$ | 0.3-1.0 | 2 - 15 |
| $TiO_2$ | 0.04-0.25 | 0.4-1.4 |
| $P_2O_5$ | ND | ND-0.2 |
| $SO_3$ | 0.3-1 | - |
| C | 54-66 | 1.3 - -4.5 |
| F | 9 - 12 | 9 - 15 |
| **Metals as mg/kg** | | |
| As | ND-8 | 3 --5 |
| Ba | 28-101 | 90-180 |
| Cd | ND-0.6 | ND-5 |
| Cr | 12-69 | 30-340 |
| Pb | 5 -13 | 6 --15 |
| Hg | ND | ND |
| Se | ND | ND |
| Ag | ND-0.5 | ND-3 |

# Appendix 3


Filename: C:\Program Files\Pyris\Dat...\textile 1.tgd
Operator ID: hiromi
Sample ID: 364
Sample Weight: 7.837 mg
Comment: textile 1
PerkinElmer Thermal Analysis
14,14
10
5
0
-5
-10
-15,57
Derivative Weight % (%/min)
19,37
100
200
300
400
500
600
700
757,8
Temperature (°C)
24.02.2009 12:17:34
1) Hold for 30.0 min at 25.00°C
2) Heat from 25.00°C to 110.00°C at 50.00°C/min
3) Hold for 30.0 min at 110.00°C
4) Heat from 110.00°C to 750.00°C at 10.00°C/min
5) Hold for 30.0 min at 750.00°C

# Appendix 4

## Calculation of concentrations for calibration gases in FT-IR spectrometer

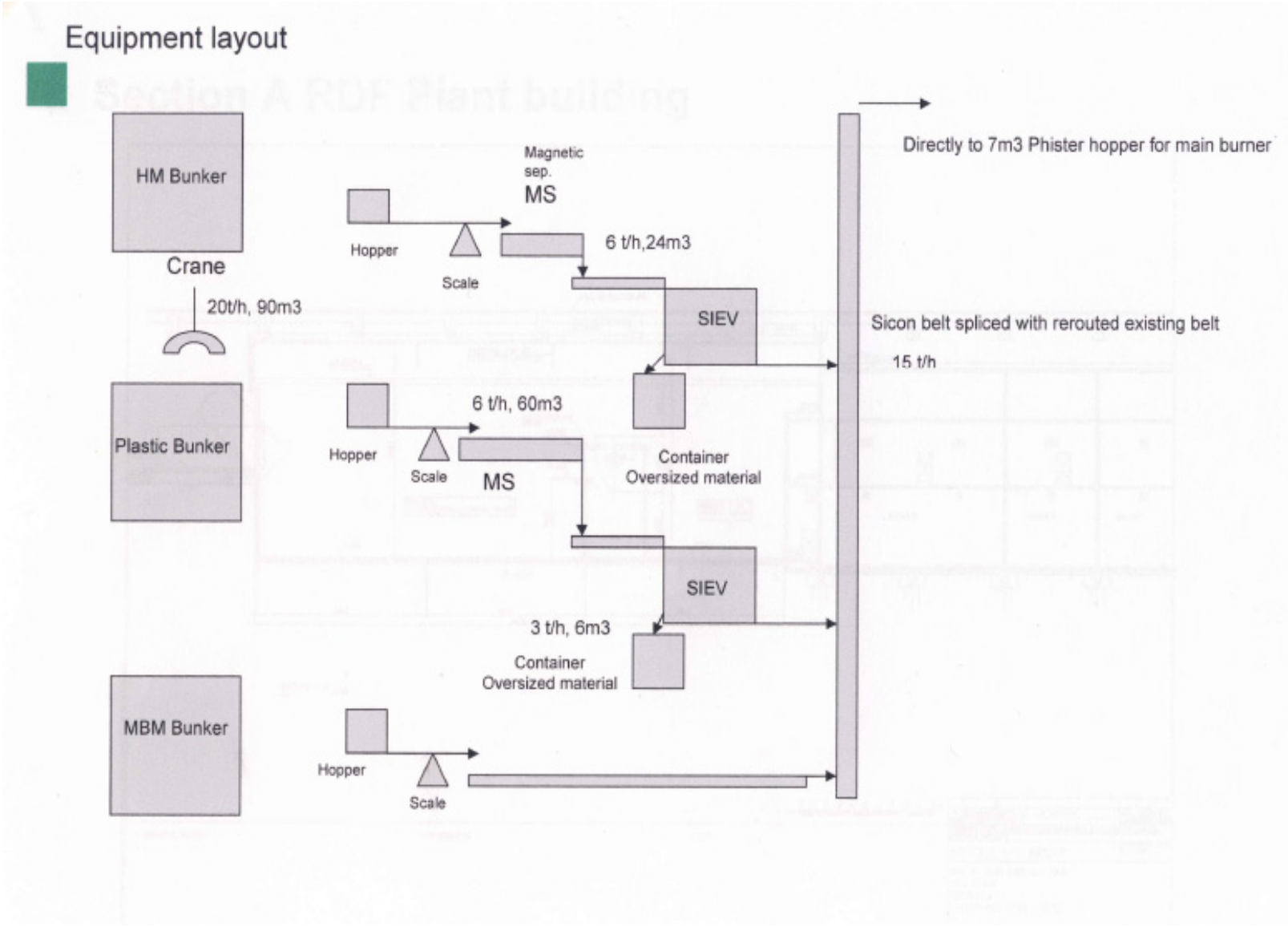
| | |
|---|---|
| Diameter of gas cell | = 0.039 |
| Length of gas cell | = 0.1 m |
| Total volume of gas cell | $= \pi \cdot 0.039^2 \cdot 0.1/4$ |
| | $= 0.0001195\ m^3$ |

The ideal gas law can be applied to calculate concentrations assuming the gases are in atmospheric pressure and temperature in the gas cell. Assume volumetric fraction of specific gas (what is going to be analyzed quantitatively) in standard gas mixture is "x". Let's fill the gas cell with $V_1$ ml volume of the standard gas mixture.

| | |
|---|---|
| The volume taken for the analysis | $= V_1$ ml |
| Volume of specific gas | $= V_1 \cdot x$ ml |
| No. of moles taken from specific gas | = PV/RT |
| | $= 101325 \cdot V_1 \cdot x \cdot 10^{-6}/8.314/298$ |
| | $= n_1$ mol |
| Concentration of specific gas in the gas cell | $= n_1/0.0001195/1000$ |
| | $= C_1$ mol/l |

Similarly, the calculations can be carried for different experiments by filling the gas cell with different volumes of standard gas mixture and then the calibration curve (absorbance Vs. concentration) can be plotted along with the FTIR analysis data.

# Appendix 5


Equipment layout
HM Bunker
Crane
20t/h, 90m3
Plastic Bunker
MBM Bunker
Magnetic sep.
MS
Hopper
Scale
6 t/h,24m3
SIEV
Directly to 7m3 Phister hopper for main burner
Sicon belt spliced with rerouted existing belt
15 t/h
6 t/h, 60m3
Hopper
Scale
MS
Container
Oversized material
SIEV
3 t/h, 6m3
Container
Oversized material
Hopper
Scale