Supplementary Material for “Analysis of attributes for industrial food waste management” - List of attributes

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**Abbreviations**

|  |  |
| --- | --- |
| ABP | Animal By-Products |
| AD | Anaerobic Digestion |
| AF | Animal Feeding |
| C | Composting |
| CFUs | Colony-Forming Units |
| COD | Chemical Oxygen Demand |
| FW | Food Waste |
| FWM | Food Waste Management |
| FWMS | Food Waste Management Solution |
| I-TEQ | International Toxic Equivalents |
| NIMBY | Not In My Back Yard phenomenon |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PCBs | Polychlorinated Biphenyls |
| R | Redistribution |
| T | Transport |
| TOC | Total Organic Carbon |
| TS | Total Solids |
| TT | Thermal Treatment with energy recovery |
| VFAs | Volatile Fatty Acids |
| VS | Volatile Solids |
|  |  |

The tables are comprised of four columns: the first column shows the attribute considered, the second column gives an example of that type of attribute or a unit commonly used to measure it, the third column presents the FWMSs that need the attribute to be defined, and the last column gives one example of published research where the attribute is used per type of FWMS listed in the third column. Consequently, the references from the fourth column, which include published research and legislation, confirm the need to consider the attribute for the FWMS assessed.

Table 1. Qualitative FW parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Example or unit** | **FWMS** | **Reference** |
| **Edibility** | Edible / Inedible | R, AF | Garcia-Garcia et al. (2017) |
| **State** | Eatable / Not eatable / Uneatable for humans, eatable for animals | R, AF |
| **Origin** | Animal based / Plant based | AF, AD, C |
| **Complexity** | Single / Mixed | AF, AD, C |
| **Animal-material presence** | Meat / Animal product / By-product from animal bodies / In contact with ABP / Not in contact with ABP | AF, AD, C |
| **Treatment** | Processed / Unprocessed | R |
| **Packaging** | Packaged / Unpackaged/separable from packaging | AF, AD, C |
| **Packaging biodegradability** | Biodegradable package / Non-biodegradable package | AD, C |
| **Stage of the supply chain** | Catering waste / Non-catering waste | AF |

**Table 2**. Quantitative primary FW parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Example or unit** | **FWMS** | **Reference** |
| **Production or flow rate** | kg or m3 / day | R, AF, AD, C, TT | R: The Commission of the European Communities (2005), AF: European Commission 2005b), AD: British Standards Institution (2014), C: British Standards Institution (2011), TT: Brunner & Rechberger (2014) |
| **Carbohydrate content and composition** | % mass | AF, AD, C, TT | AF: Parfitt, et al. (2016), AD: Batstone et al. (2002), C: Chang & Hsu (2008), TT: Caton et al. (2010) |
| **Fat content and composition** | % mass | AF, AD, C, TT | AF: San Martin et al. (2015), AD: Batstone et al. (2002), C: Chang & Hsu (2008), TT: Caton et al. (2010) |
| **Protein content and composition** | % mass | AF, AD, C, TT |
| **Vitamin content and composition** | % mass | AD, C, TT | AD: Climenhaga (2008), C: Ipek et al. (2005), TT: Caton et al. (2010) |
| **Other organic compounds** | % mass | R, AF, AD, C, TT | R: The Commission of the European Communities (2006), AF: European Commission (2002), AD: British Standards Institution (2014), C: British Standards Institution (2011), TT: Caton et al. (2010) |
| **Inorganic content and composition** | % mass | R, AF, AD, C, TT | R: WHO/FAO (1995), AF: European Commission (2002), AD: Fisgativa et al. (2015), C: Himanen & Hänninen (2009), TT: Caton et al. (2010) |
| **Moisture content** | % mass | AD, C, TT | AD: Zhang et al. (2007), C: Chang & Hsu (2008), TT: Caton et al. (2010) |
| **Biological hazard** | CFUs/g fresh matter | R, AF, AD, C, TT | R: The Commission of the European Communities (2005), AF: European Commission (2005b), AD: British Standards Institution (2014), C: British Standards Institution (2011), TT: Brunner & Rechberger (2014) |
| **pH** | 0-14 | AD, C | AD: Fisgativa et al. (2015), C: Chang & Chen (2010) |
| **Particle size** | mm | AD, C | AD: Zhang et al. (2015), C: Nakasaki et al. (2015) |

**Table 3**. Quantitative secondary FW parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Example or unit** | **FWMS** | **Reference** |
| **Density** | kg/m3 | R, AF, AD, C, TT | R: Bilska et al. (2016), AF: European Commission (2002), AD: Fisgativa et al. (2015), C: WRAP (n.d.), TT: Lee et al. (2007) |
| **Hazardous materials** | Type and % mass | R, AF, AD, C, TT |
| **Energy/nutrient value** | kcal/kg, g/kg | AF | Parfitt, Stanley, et al. (2016) |
| **Volatile solids (VS)** | % mass of TS | AD, C, TT | AD: Zhang et al. (2007), C: Chang et al. (2006), TT: Ahmed & Gupta (2010) |
| **Total solids (TS)** | % mass | AD, C, TT | AD: Kumar et al. (2015), C: Wang & Ai (2016), TT: Ahmed & Gupta (2010) |
| **Total Kjeldahl nitrogen (TKN)** | mg/g TS | AD, C | AD: Kumar et al. (2015), C: Adhikari et al. (2008) |
| **Total ammonia nitrogen (TAN)** | mg/l | AD | Fisgativa et al. (2015) |
| **Chemical oxygen demand (COD)** | mg/l | AD |
| **C:H:O:N:P:S ratio** | C:H:O:N:P:S mass | AD | Hidalgo et al. (2016) |
| **C:H:O:N:S:Cl ratio** | C:H:O:N:S:Cl mass | TT | Caton et al. (2010) |
| **C:N ratio** | C:N mass | C | Chang & Chen (2010) |
| **Ash** | % mass | C, TT | C: Chang & Chen (2010), TT: Caton et al. (2010) |
| **Porosity** | % volume | C | Cooperband (2002) |
| **Calorific value** | MJ/kg | TT | Bujak & Sitarz (2016) |

**Table 4**. FWM process and company status variables

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Example or unit** | **FWMS** | **Reference** |
| **Distance to transport FW** | km | T | den Boer et al. (2009) |
| **Type of equipment available** | E.g. Upflow anaerobic sludge blanket reactor (UASB) | AD, C, TT | AD: Mao et al. (2015), C: Cooperband (2002), TT: Defra (2013b) |
| **Volume of equipment available** | m3 | AD, C, TT |
| **Number of stages** | Number and type | AD, C, TT | AD: Mao et al. (2015), C: Chang et al. (2006), TT: Lohri et al. (2015) |
| **Temperature** | °C | AD, C, TT | AD: Mao et al. (2015), C: Cooperband (2002), TT: Caton et al. (2010) |
| **Process time** | Days / hours | AD, C, TT |
| **Treatment method** | Batch / Continuous / Semi-continuous | AD, C, TT | AD: Mao et al. (2015), C: Kwon & Lee (2004), Suler & Finstein (1977), TT: Lohri et al. (2015) |
| **Pre-treatment** | Yes (type) / No | AD, C, TT | AD: Zhang et al. (2014), C: Nakasaki et al. (2015), TT: Lohri et al. (2015) |
| **Additives / Catalysts** | Yes (type and concentration) / No | AD, C, TT | AD: Mao et al. (2015), C: Peigne & Girardin (2004), TT: Ahmed & Gupta (2010) |
| **Co-products** | Type and quantity of co-product | AD, C, TT | AD: Mao et al. (2015), C: Cooperband (2002), TT: Manfredi & Cristobal (2016) |
| **Inoculum / Seeding** | Type and % mass | AD, C | AD: Kondusamy & Kalamdhad (2014), C: Chang et al. (2006) |
| **Agitation / Stirring** | Yes (type and speed / periodicity) / No | AD, C | AD: Leung & Wang (2016), C: Cooperband (2002) |
| **pH** | 0-14 | AD, C | AD: Mao et al. (2015), C: Cooperband (2002) |
| **Organic loading rate (OLR)** | kg VS/m3 day | AD | Mao et al. (2015) |
| **Hydraulic retention time (HRT)** | Days | AD |
| **Composting of digestate** | Yes (type) / No | AD | Kondusamy & Kalamdhad (2014) |
| **Oxygen concentration / Air ratio** | % | C, TT | C: Cooperband (2002), TT: Caton et al. (2010) |
| **Pile size** | cm high, m wide | C | Cooperband (2002) |
| **Pressure** | bar | TT | Lohri et al. (2015) |
| **Steam injection** | Yes (quantity, temperature, pressure) / No | TT | Ramzan et al. (2011) |

Table 5. FWM performance factors

|  |  |  |  |
| --- | --- | --- | --- |
| **Factor** | **Example or unit** | **FWMS** | **Reference** |
| **Quantity of food redistributed** | kg/day | R | Bilska et al. (2016) |
| **Quantity animal feed produced** | kg/day | AF | Westendorf (2000) |
| **Biogas production rate** | l/day | AD | Chen et al. (2010) |
| **[CH4] in biogas** | % volume | AD |
| **Digestate flow rate** | l/day | AD |
| **Digestate composition** | % mass | AD |
| **Compost production rate** | kg/day | C | Cooperband (2002) |
| **Compost composition** | % mass | C |
| **Gas flow rate** | Nm3/day | TT | Buragohain et al. (2012) |
| **Lower heating value of gas** | MJ/m3 | TT |
| **Char production rate** | kg/day | TT | Lohri et al. (2015) |
| **Heating value of char** | MJ/kg | TT |

**Table 6**. Environmental indicators: impacts to air

|  |  |  |  |
| --- | --- | --- | --- |
| **Indicator** | **Example or unit** | **FWMS** | **Reference** |
| **Total emissions to air** | m3/day | T, AD, C, TT | T: den Boer et al. (2009), AD: Whiting & Azapagic (2014), C: Khoo et al. (2010), TT: European Commission (2006c) |
| **CO2** | mg/m3 | T, AD, C, TT |
| **CH4** | mg/m3 | T, AD, C, TT | T: den Boer et al. (2009), AD: Whiting & Azapagic (2014), C: Börjesson & Berglund (2007), TT: European Commission (2006c) |
| **N2O** | mg/m3 | T, AD, C, TT | T: den Boer et al. (2009), AD: Møller et al. (2009), C: Amlinger et al. (2008), TT: European Commission (2006c) |
| **NOx** | mg/m3 | T, AD, C, TT | T: den Boer et al. (2009), AD: Styles et al. (2016), C: Peigne & Girardin (2004), TT: European Commission (2006c) |
| **Non-methane volatile organic compounds (NMVOC)** | mg/m3 | T, AD, C, TT | T: Environmental Protection UK (n.d.), AD: Gerardi (2003), C: Amlinger et al. (2008), TT: European Commission (2006c) |
| **Total organic carbon (TOC)** | mg/m3 | T, TT | T: Wada et al. (2015), TT: European Commission (2006c) |
| **NH3** | mg/m3 | AD, C, TT | AD: Whiting & Azapagic (2014), C: Khoo et al. (2010), TT: European Commission (2006c) |
| **SOx** | mg/m3 | AD, C, TT | AD: Beylot et al. (2015), C: Zhao & Deng (2014), TT: European Commission (2006c) |
| **HCl** | mg/m3 | AD, C, TT | AD: Zhao & Deng (2014), C: Zhao & Deng (2014), TT: European Commission (2006c) |
| **Dioxins, furans, PAH, PCBs and products alike** | mg/m3 | AD, C, TT | AD: Haight (2005), C: Haight (2005), TT: European Commission (2006c) |
| **H2S** | mg/m3 | AD, C | AD: Gerardi (2003), C: Peigne & Girardin (2004) |
| **CO** | mg/m3 | AD, C, TT | AD: Gerardi (2003), C: Zhao & Deng (2014), TT: European Commission (2006c) |
| **Dust** | mg/m3 | T, TT | T: Wada et al. (2015), TT: European Commission (2006a) |
| **PM<10** | mg/m3 | T, AD, C, TT | T: den Boer et al. (2009), AD: Cherubini et al. (2009), C: Zhao & Deng (2014), TT: European Commission (2006c) |
| **PM<2.5** | mg/m3 | T, TT | T: den Boer et al. (2009), TT: European Commission (2006c) |
| **As** | mg/m3 | TT | Lee et al. (2007) |
| **Cd** | mg/m3 | TT |
| **Hg** | mg/m3 | TT |
| **Zn** | mg/m3 | TT |
| **Cr** | mg/m3 | TT |
| **Ni** | mg/m3 | TT |
| **Pb** | mg/m3 | TT |
| **Cu** | mg/m3 | TT |

**Table 7**. Environmental indicators: impacts to water

|  |  |  |  |
| --- | --- | --- | --- |
| **Indicator** | **Example or unit** | **FWMS** | **Reference** |
| **Wastewater flow** | m3/day | AF, AD, C, TT | AF: Lee et al. (2007), AD: Deepanraj et al. (2015), C: Peigne & Girardin (2004), TT: European Commission (2006c) |
| **Chemical oxygen demand (COD)** | g/m3 | AF, AD, C, TT |
| **Biochemical oxygen demand (BOD)** | g/m3 | AF, AD, C, TT | AF: Lee et al. (2007), AD: Suwannarat & Ritchie (2015), C: Peigne & Girardin (2004), TT: Abbasi & Abbasi (2010) |
| **Total suspended solids (TSS)** | g/m3 | AF, AD, C, TT | AF: Lee et al. (2007), AD: Wu et al. (2016), C: Lasaridi & Stentiford (1998), TT: Abbasi & Abbasi (2010) |
| **NH4+** | g/m3 | AF, C | AF: Lee et al. (2007), C: Peigne & Girardin (2004) |
| **P** | g P2O5/PO4-3 / m3 | AF, AD, C | AF: Lee et al. (2007), AD: Vögeli et al. (2014), C: British Standards Institution (2011) |
| **Cd** | g/m3 | AD, C, TT | AD: Xu et al. (2015), C: British Standards Institution (2011), TT: European Commission (2006c) |
| **Zn** | g/m3 | AD, C, TT |
| **Cr** | g/m3 | AD, C, TT |
| **Pb** | g/m3 | AD, C, TT |
| **NO3-** | g/m3 | AD, C | AD: Ortner et al. (2013), C: Peigne & Girardin (2004) |
| **K** | g/m3 | AD, C | AD: Levén et al. (2012), C: British Standards Institution (2011) |
| **Ca** | g/m3 | AD, C | AD: Brändli, et al. (2007), C: British Standards Institution (2011) |
| **Mg** | g/m3 | AD, C | AD: Levén et al. (2012), C: British Standards Institution (2011) |
| **S** | g/m3 | AD, C | AD: Opatokun et al. (2015), C: British Standards Institution (2011) |
| **Hg** | g/m3 | AD, TT | AD: Xu et al. (2015), TT: European Commission (2006c) |
| **Cu** | g/m3 | AD, TT |
| **Ni** | g/m3 | AD, TT |
| **As** | g/m3 | AD, TT |
| **V** | g/m3 | AD | Xu et al. (2015) |
| **Be** | g/m3 | AD |
| **Br** | g/m3 | AD |
| **Se** | g/m3 | AD |
| **Co** | g/m3 | AD |
| **F-** | g/m3 | C, TT | C: British Standards Institution (2011), TT: European Commission (2006c) |
| **B** | g/m3 | C | British Standards Institution (2011) |
| **Fe** | g/m3 | C |
| **Mn** | g/m3 | C |
| **Na** | g/m3 | C |
| **Total organic carbon (TOC)** | g/m3 | TT | European Commission (2006c) |
| **Dioxins, furans and PCBs** | mg/m3 | TT |
| **SO4-2** | g/m3 | TT |
| **Cl-** | g/m3 | TT |

**Table 8**. Environmental indicators: impacts to soil

|  |  |  |  |
| --- | --- | --- | --- |
| **Indicator** | **Example or unit** | **FWMS** | **Reference** |
| **Solid residue flow rate** | kg/day | AD, C, TT | AD: British Standards Institution (2014), C: British Standards Institution (2011), TT: European Commission (2006c) |
| **Cu** | mg/kg | AD, C, TT |
| **Zn** | mg/kg | AD, C, TT |
| **Nutrient content: N** | g N/kg | AD, C | AD: Levén et al. (2012), C: WRAP (2016) |
| **Nutrient content: P** | g P2O5/kg | AD, C |
| **Nutrient content: K** | g K2O/kg | AD, C |
| **Nutrient content: Mg** | g MgO/kg | AD, C |
| **Nutrient content: S** | g SO3/kg | AD, C | AD: Opatokun et al. (2015), C: WRAP (2016) |
| **Nutrient content: Ca** | g CaCO3/kg | AD, C | AD: Brändli, et al. (2007), C: Brändli, Bucheli, et al. (2007) |
| **Moisture content** | g/kg | AD, C | AD: British Standards Institution (2014), C: British Standards Institution (2011) |
| **Loss on ignition / VS / TOC** | g/kg | AD, C, TT | AD: British Standards Institution (2014), C: British Standards Institution (2011), TT: European Commission (2006c) |
| **pH / neutralising value** | 0-14 | AD, C | AD: British Standards Institution (2014), C: British Standards Institution (2011) |
| **Dioxins, furans, PAH, PCBs and products alike** | ng I-TEQ/kg dry | AD, C, TT | AD: Brändli, et al. (2007), C: Brändli, Bucheli, et al. (2007), TT: European Commission (2006c) |
| **Fungicides, herbicides, insecticides, acaricides** | mg/t dry | AD, C | AD: Brändli, et al. (2007), C: Brändli, et al. (2007) |
| ***E. coli*** | CFU/g fresh matter | AD, C | AD: British Standards Institution (2014), C: British Standards Institution (2011) |
| ***Salmonella spp*** | CFU/g fresh matter | AD, C |
| **Cd** | mg/kg | AD, C |
| **Cr** | mg/kg | AD, C |
| **Pb** | mg/kg | AD, C |
| **Hg** | mg/kg | AD, C |
| **Ni** | mg/kg | AD, C |
| **VFAs** | COD/g VS | AD, C |
| **Total glass, metal, plastic and any ‘other’ non-stone, man-made fragments > 2 mm** | % m/m dry matter, no sharps | AD, C |
| **Stones > 5 mm** | % m/m dry matter | AD, C | AD: British Standards Institution (2014), C: British Standards Institution (2011) |
| **Total physical contaminants (excluding stones)** | kg/t | AD | British Standards Institution (2014) |
| **Nutrient content: Na** | mg /kg | C | British Standards Institution (2011) |
| **Nutrient content: B** | mg/kg | C |
| **Nutrient content: Fe** | mg/kg | C |
| **Nutrient content: Mn** | mg/kg | C |
| **Particle size distribution** | mm | C |
| **C:N** | C:N (mass) | C |
| **Electrical conductivity** | mS/cm | C |
| **Microbial respiration rate** | mg CO2/g organic matter per day | C |
| **Germination seeds or propagule regrowth** | mean number/litre of compost | C |
| **Stones > 4 mm in grades other than "mulch"** | % mass | C |
| **Stones > 4 mm in "mulch" grade** | % mass | C |
| **Leaching value** | mg/kg | TT | European Commission (2006c) |
| **Sb** | mg/kg | TT |
| **Mo** | mg/kg | TT |
| **Cl-** | mg/kg | TT |
| **SO4-2** | mg/kg | TT |

Table 9. Economic indicators

|  |  |  |  |
| --- | --- | --- | --- |
| **Indicator** | **Example or unit** | **FWMS** | **Reference** |
| **Management cost** | £ | R, AF, AD, C, TT | R: Giuseppe et al. (2014), AF: Kim et al. (2010), AD: Gebrezgabher et al. (2010), C: Ruggieri et al. (2009), TT : Herva & Roca (2013) |
| **Economic value of solid material** | £/t | AF, AD, C, TT | AF: Parfitt, et al. (2016), AD: Styles et al. (2016), C: Rothenberger et al. (2006), TT: Bujak (2015) |
| **Heat recovered / Output power** | kJ/min | AD, TT | AD: Styles et al. (2016), TT: Ahmed & Gupta (2010) |
| **Biogas rate** | Nm3/day | AD | Styles et al. (2016) |
| **[CH4] in biogas** | % | AD |

Table 10. Social indicators

|  |  |  |  |
| --- | --- | --- | --- |
| **Indicator** | **Example or unit** | **FWMS** | **Reference** |
| **Support of local economies** | Yes (number of people benefitted / tonne) / No | R, AF, AD, C, TT | R: Buksti et al. (2015), AF: Sugiura et al. (2009), AD: Chong et al. (2016), C: Chong et al. (2016), TT: Chong et al. (2016) |
| **Job creation** | Yes (number of people benefitted / tonne) / No | R, AF, AD, C, TT | R: Buksti et al. (2015), AF: Defra et al. (2016), AD: Vögeli et al. (2014), C: Rothenberger et al. (2006), TT: Friends of the Earth (2010) |
| **Noise** | dB | T, AD, C, TT | T: den Boer et al. (2009), AD: Kythreotou et al. (2014), C: Cooperband (2002), TT: European Commission (2006c) |
| **NIMBY syndrome** | Yes (number of people affected/tonne) / No | AD, C, TT | AD: Chong et al. (2016), C: Chong et al. (2016), TT: Chong et al. (2016) |
| **Feeding people** | Yes (number of people benefitted/tonne) / No | R | Buksti et al. (2015) |
| **Traffic** | Number of vehicles / tonne of FW | T | Kijak & Moy (2004) |

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