

Drawing the Materials Balance for an MBT Cycle from Routine Process Measures in a MBT Plant located in Venice

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Darstellung der Materialbilanz aus Messungen beim Routineprozeß einer MBA in Venedig

Abstract

An observation term was carried on in an MBT plant owned and run by a public Company to treat MSW left by separate collection. All observations and measurements were made without interfering with the ordinary operation rules, in order to assess the efficiency of one process cycle for a given batch of waste. Analytical data came from both a) process instruments and b) physical analysis of a batch of waste entering / exiting from a selected *bio-cell*.

From the process mass losses (about 37% – including moisture evaporation – in that single process cycle) the theoretical amounts of water and carbon dioxide produced by biodegradation were calculated. A verification of the results was tried through a thermal balance, comparing the energy released by degradation with the energy losses from the bio-cell. The results showed a fair agreement, within 80%; what appeared critical is the knowledge of the chemical composition of fermentable waste (taken as cellulose as first attempt) and the actual amount of heat developed by biological oxidation.

Keywords

MBT, RDF, organic waste, aerobic degradation, process energy balance, process mass balance.

1 Introduction

This study is the result of an observation term carried on in November 2003 in an MBT plant sited in the industrial area of Venice (Italy), owned and run by the public Company VE.S.T.A. S.p.A.. The process investigated is a *dry type* one; it treats MSW left by separate collection of glass, plastics, aluminium cans, paper and cardboard, textiles and organic waste and is operated on the “Herhof-Ladurner” concept of forced-aeration batch fermentation cells to produce an RDF cleaned from readily degradable organics, dried and sanitized.

All observations and measurements were made without interfering with the ordinary operation rules or diverting fluxes. The aim was to assess the efficiency of the process, for

a given batch of waste fed to the unit at a given time in a given season. No general deduction should therefore be drawn about the process *per se*.

The plant is fitted with the ordinary process instrumentation; all data we used are drawn from the records. Analytical data came from both a) process instruments and b) physical analysis of a batch of mechanically pre-treated waste entering / exiting from a selected *bio-cell* out of 15 in the plant. To this aim a representative sample of each was taken out and was sorted into 7 fractions, which in turn were singularly analysed for moisture and Volatile Solids. Plastics, although *volatile* at 600 °C, were obviously excluded from the amount of biodegradable matter in the sample defined and determined in this way.

From the overall measures on the fermentation unit made by the operator for that cycle the process mass losses (37% of the introduced waste, in that single process cycle studied, normally ordinary value is lower, about 31%) were obtained. To explain them the hypothesis was made that degradable mass was made up of cellulose or starch; as discarded fruits, vegetables, bread and like. This hypothesis allowed us to calculate the theoretical amounts of water and carbon dioxide produced by biodegradation.

The results needed verification. This was attempted through a thermal balance: that is, calculating the energy released by degradation reactions (on one hand) and the energy losses from the *bio-cell* during the process cycle (on the other) and comparing them.

2 The plant

2.1 Description and overall throughput

The general block diagram of the plant is shown in Figure 1.

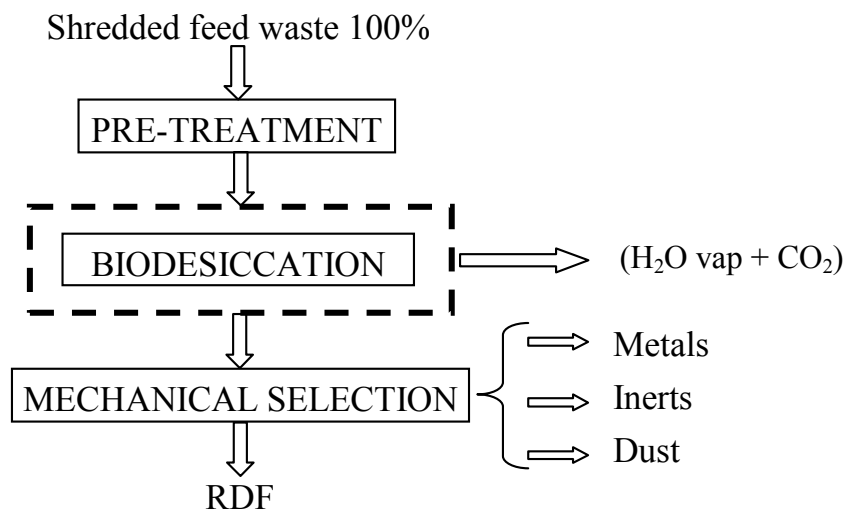


Figure 1 General block diagram of the plant for RDF at Fusina (VE) site

The dashed line identifies the phase of the process that is the object of this study. The feed is MSW left by separate collection, after shredding down to 250 mm as pre-treatment; the product is an RDF cleaned from readily degradable organics, dried and sanitized.

The process is operated after the concept of dry forced-aeration batch fermentation; it is exothermic and is completed in seven days.

The plant described here has 15 cells Herhof - Rottebox®: these are concrete vessels, parallelepiped-shaped, air-tight, 750 m³ volume each. Regulating the flows of fresh and re-circulated air makes possible to control the fermentation.

The bottom of the cells is divided in 12 parts allowing differential air flows to control the temperature of the fermenting waste: this allows to keep different temperatures for the four phases which make up a weekly cycle, distinguished as depicted in Figure 2.

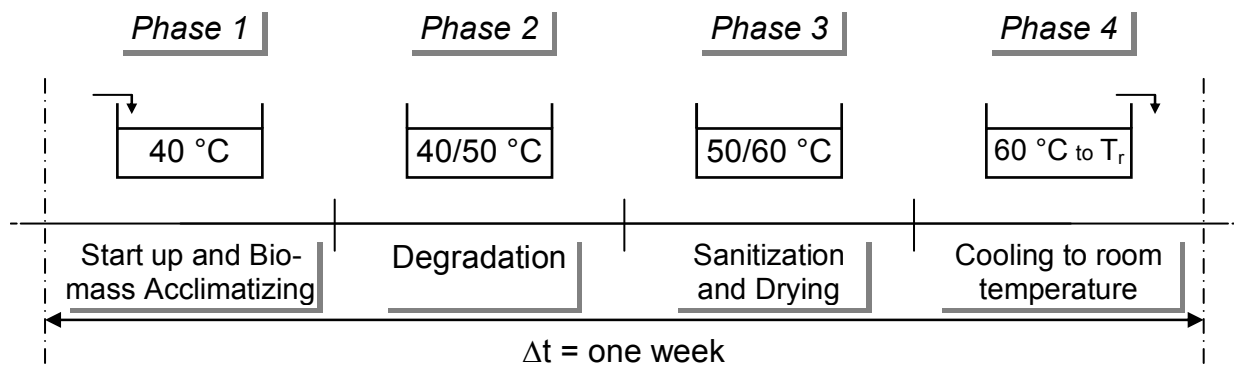


Figure 2 Block diagram of the process cycle

The process is automatically controlled by a computerized system that regulates temperature and air flow; CO₂ and H₂O are generated as principal by-products, whereas the substances with a slower degradation rate remain in the solid matrix.

Exhaust process air contains gaseous intermediate metabolites; it is therefore treated at 850°C in a combustion plant (not described here) before release to atmosphere.

2.2 Data from laboratory analysis and process measures

To get the data required to control the process and to establish the balances, both the shredded waste fed to the cell and the exiting RDF were submitted to the analysis whose sequence is described in Figure 3.

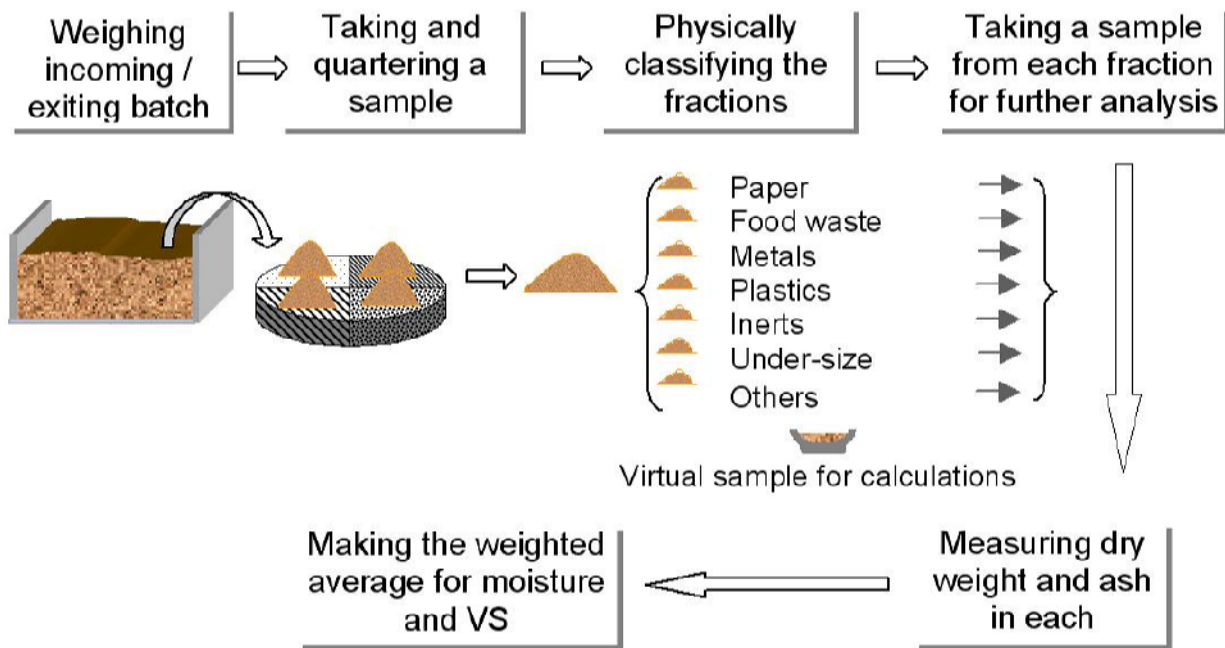


Figure 3 Analytical operations for bio-cells input and output

Figure 4 shows samples ready for laboratory.

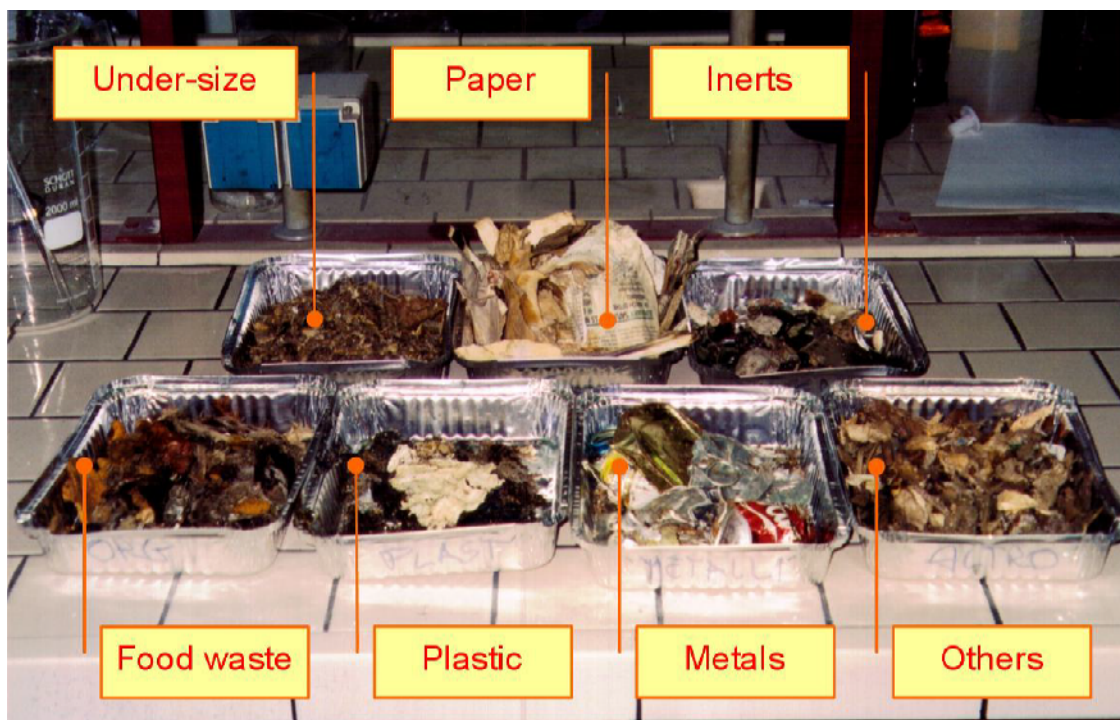


Figure 4 Samples of the 7 fractions ready for weighing and drying in aluminium trays

Results obtained from laboratory analysis are organized in Table 1. For the principle of this process to be strictly applied, the mass transformed by aerobic reactions should be only the organic, easily degradable one. The bio-stabilization process should be ended before paper and cardboard volatile solids (VS) start to react, preserving in this way their content in carbon, thus in chemical energy.

Actually, the total value of bio-desiccated waste Lower Heating Value (LHV) is fair (see par. 3.2 below), and is in good agreement e.g. with Rada's results (RADA *et al.*, 2006).

Table 1 Composition of waste fed to the cell and of product coming out, in tons

Component	Wet w.	Dry w.	Moisture	VS/TS [%]	Volatile mass	Ash
PRE-TREATED WASTE FEED TO THE CELL [t]						
Paper	57,78	34,13	23,64	87,38	29,83	4,31
Food waste	8,53	3,14	5,38	87,34	2,74	0,40
Metals	3,58	3,55	0,03	30,86	1,09	2,45
Inerts	12,64	12,52	0,12	1,88	0,24	12,28
Plastics	44,98	32,99	11,99	96,00	31,67	1,32
Undersize 20 mm	80,20	50,56	29,65	76,00	38,42	12,13
Others	13,57	7,21	6,36	69,89	5,04	2,17
Total	221,27	144,10	77,17		109,03	35,07
PRODUCT FROM THE CELL [t]						
Paper	62,09	50,07	12,02	85,86	42,99	7,08
Food waste	0,84	0,50	0,34	49,81	0,25	0,25
Metals	11,33	10,98	0,35	14,86	1,63	9,35
Inerts	6,49	6,43	0,06	9,74	0,63	5,81
Plastics	29,24	27,49	1,74	90,00	24,74	2,75
Undersize 20 mm	21,93	19,08	2,85	76,50	14,60	4,48
Others	6,96	5,58	1,39	69,89	3,90	1,68
Total	138,88	120,14	18,74		88,74	31,40

The data above are depicted in Figure 5.

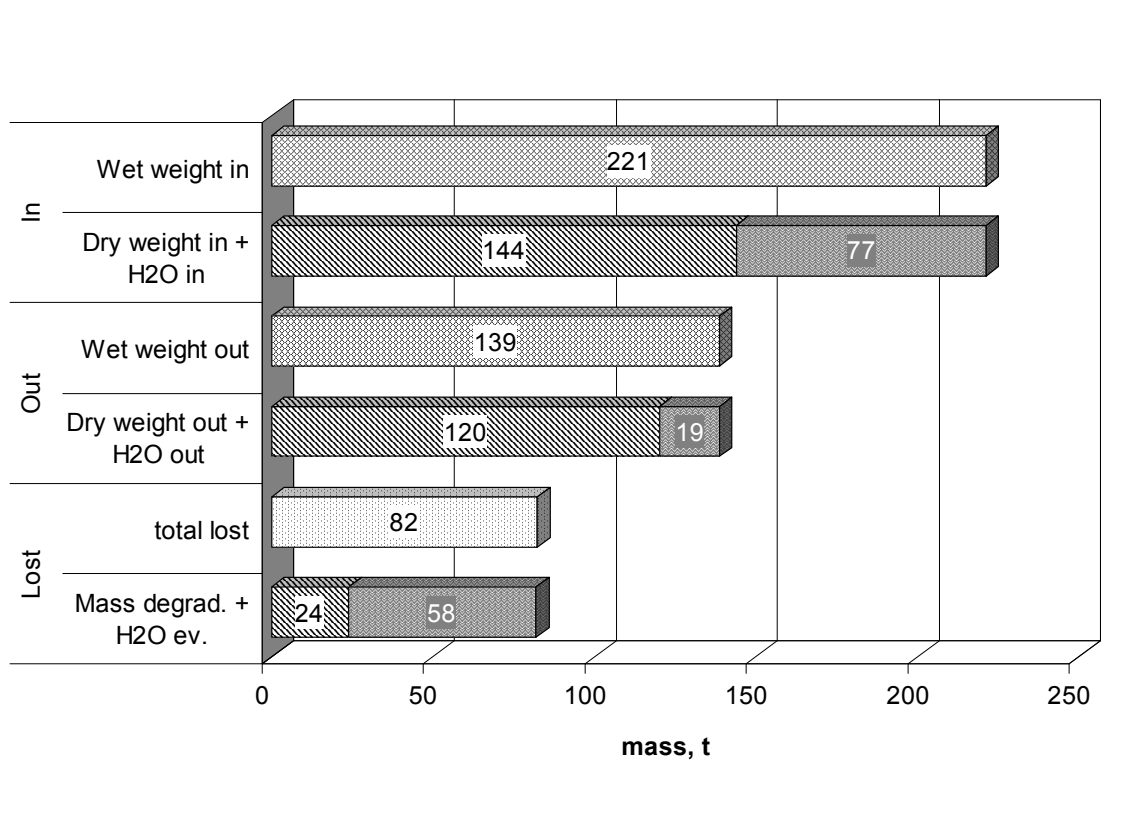


Figure 5 Visual global mass balance for the case - study bio-cell

On the whole the results shown in table 1 appear consistent and realistic although the loss in dry matter is 23,96 t whereas the loss in volatile matter is just 20,29 (a 15% difference). About metals, in the sample taken from shredded waste a piece is likely to have escaped from the proper tray into another; as for plastics, during incineration in the laboratory muffle furnace (APAT, 2003) the scraps underwent some melting, so that the operation appeared non-quantitative. It was assumed that the ratio (VS/TS) in waste was 0,96.

It should be recognized that the plant we are dealing with is not a pilot - scale one. This entails that the samples of waste and RDF taken at the start and at the end of the process are entirely different, and the errors, which unavoidably occur in forming them, are not necessarily the same. When running a laboratory plant, instead, it may be realistic to analyze the whole reacting mass, so the results (basically, for TS and VS) would probably be more precise.

3 The balances

3.1 Mass

3.1.1 Experimental data

The measures taken by process instruments and the data from laboratory analysis (see Table above) were put together to draw the balance of dry matter and water described in fig. 6. Process losses in the cycle amounted to about 37 %, slightly greater than the usual in this plant (30 %).

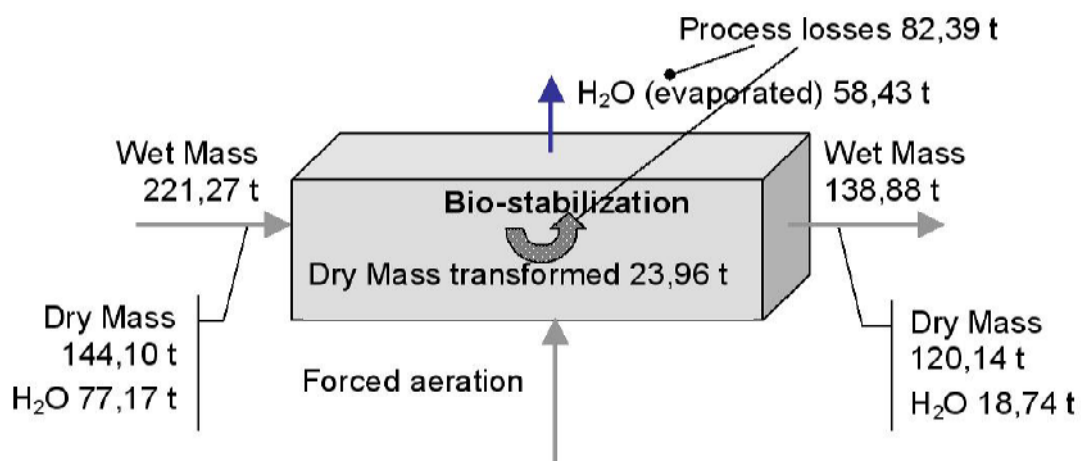


Figure 6 Mass balance of dry matter and water in the cycle

3.1.2 The mass balance

The following equations were used for mass balance:

Global wet mass balance (for one cycle):

$$m_{in} + m_{O_2} = m_{out} + m_{H_2O,v} + m_{CO_2,v} \quad [t] \quad (1)$$

Water mass balance:

$$m_{H_2O,in} + m_{H_2O,prod} = m_{H_2O,out} + m_{H_2O,v} \quad [t] \quad (2)$$

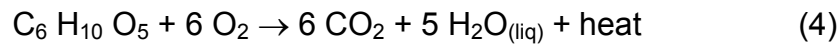
Introducing moisture (U), water mass balance can be rewritten as:

$$U_{in} \cdot m_{in} + m_{H_2O,prod} = U_{out} \cdot m_{out} + m_{H_2O,v} \quad [t] \quad (3)$$

where *in* and *out* indicate quantities introduced into and taken off from the bio-cell; *v* indicates exiting quantities in gaseous phase (process losses).

Degraded mass is transformed into H_2O e CO_2 ; to determinate their quantities (without instrumental data) mass balance calculations were made with the assumption that all organic matter was cellulose ($C_6 H_{10} O_5$). Even if the formula $C_{18} H_{26} O_{10} N$, proposed by Kayhanian e Tchobanoglous (1993), is more accurate, the presence of Nitrogen for these calculations is negligible.

Neglecting also the synthesis of biomass, the overall reaction considered is simply:



If this reaction were a combustion one, it would give the following heat of reaction:

$$\Delta H_{reaz} = - 640 \text{ kcal/mol} = - 2675,2 \text{ kJ/mol} = 16,51 \text{ kJ/g SV.}$$

Several authors however (see USDA, 1992 for all) support that the heat produced is less than that and propose a typical value of 15,5 kJ/g VS. This value will then be used in this work.

Single process losses, with the appropriate approximations, were estimated applying stoichiometric coefficients given by (4) to the dry mass degraded (already calculated: see Figure 5 and 6). Dry mass lost was assumed as all degraded, neglecting possible losses of light organics by volatilization. Should this not be exactly true, the real value of heat produced would be less than the one calculated below.

Moles of organic reactants are:

$$n \text{ mol} = \frac{\text{kg (total mass lost)}}{MW_{\text{cellulose}}} = \frac{23.960}{162} = 147,90 \text{ kmol} \quad (5)$$

Reactants and products stoichiometric masses are calculated from Eq. 4 and resulting data are summarized in the following table 2.

Table 2 Stoichiometric mass balance for oxidation reaction

		Moles from reaction (Eq. 4)	M.W.	Process kmol (Eq. 5)	Masses [t]
Reactants	C ₆ H ₁₀ O ₅	1	162	147,90	23,96
	O ₂	6	32	887,40	28,40
Products	CO ₂	6	44	887,40	39,05
	H ₂ O	5	18	739,50	13,31

Table 3 groups the masses, expressed in tons, of reactants and products in the aerobic degradation, under assumption that the organic matrix is only made of cellulose. Values shown include air; the temperature rise of the water content of air was also taken into account for energy balance.

Values reported and calculated by the authors come from a point investigation performed in a single cycle of bio-stabilization of a single batch of waste. Needless to say, results obtained could be different when considering more cycles.

Table 3 Data from mass balance, including stoichiometric air inlet

	Fraction	Input [t]	Output, flue gas [t]	Output, solids [t]	$\Delta = (i - o)$ [t]
non - Bio degradable	VS	67,86	0,00	73,89	-6,03
	Ash	22,53	0,00	26,66	-4,13
	TS	90,40	0,00	100,55	-10,15
	H ₂ O	42,14	26,58	15,56	0,00
	Total n-BD	132,54	26,58	116,11	-10,15
Biodegradable	VS	41,17	0,00	14,85	26,32
	Ash	12,53	0,00	4,74	7,80
	TS	53,70	0,00	19,58	34,11
	H ₂ O from moisture (measured)	35,03	31,84	3,19	0,00
	H ₂ O from reaction (calc.)	0,00	13,31	0,00	-13,31
	Totale BD	88,73	45,16	22,77	20,80
	CO ₂	0,00	39,05	0,00	-39,05
	O ₂	28,40	0,00	0,00	28,40
	N ₂	93,47	93,47	0,00	0,00
	TOTAL	343,14	204,26	138,88	0,00

3.2 Energy

3.2.1 Experimental data

Considering that total dry mass lost reacts, heat produced from the aerobic reaction is:

$$H_{p, \max} = 23.960 \text{ kg} \times 15.500 \text{ kJ/kg} = 371.380.000 \text{ kJ}$$

This is the maximum theoretical value of heat produced during the studied cycle.

In table 4 wet mass and moisture data for pre-treated and bio-desiccated waste, drawn from table 1, are summarized. They were used for LHV determination as shown.

Table 4 Lower Heating Value calculations for wet waste

Fractions	LHV (kJ/kg of dry fract.)	Pre- treated waste			Bio- desiccated waste		
		Wet mass %	Moisture %	Contrib. to LHV (kJ/kg of w. waste)	Wet mass %	Moisture %	Contrib. to LHV (kJ/kg of w. waste)
paper	18.640	26,11%	40,92%	2.876	44,71%	19,35%	6.721
food waste	12.540	3,85%	63,15%	178	0,60%	40,17%	45
metals	420	1,62%	0,91%	7	8,16%	3,11%	33
inerts	120	5,71%	0,93%	7	4,67%	0,89%	6
plastics	25.000	20,33%	4,65%	4.846	21,05%	5,97%	4.949
under-size	12.000	36,25%	36,97%	2.742	15,79%	13,00%	1.649
others	6.200	6,13%	46,89%	202	5,01%	19,90%	249
Total		100,00%		10.856	100,00%		13.651

3.2.2 The energy balance

To draw the energy balance an air excess value of 15 times was assumed starting from the records of head developed and power required by blowers. Incidentally, this value is in agreement with various references (BARI et al., 2000; BIOE S.r.l., 2001).

It was to be taken into account: 1) evaporation and sensible heat of water produced from the aerobic reaction; 2) evaporation and sensible heat of waste moisture and of air water content; 3) sensible heat of bio-desiccated mass; 4) sensible heat of flue gases (CO₂, O₂, N₂).

Outdoor conditions during the considered period were: average temperature, 11 °C; air humidity, 80 %. From these data water content in wet air was calculated as: 0,0086 (kg of water) / (kg of wet air). Temperature increase for sensible heat calculation was (55 – 11) = 44 °C.

Actually a closer control of air flow ratios usually allows the operator to maintain exit air temperature below 50 °C in phase 3 (figure 2 above).

Wall heat loss was assumed the 5 % of total heat generated in the bio-cell. Under this assumption total heat leaving per cycle was calculated as the sum of the different items:

$$H_{t,out} = \Sigma H_{i,out} = 287.135.647 \text{ kJ}$$

This value indeed is slightly lower (- 23 %) than the one of produced heat calculated above (371.380.000).

3.3 Checking the balances with each other

As told above, the value of 15 for air excess is not a record in itself: it was assumed from blowers head and power records. The energy balance helped us in judging whether it is realistic.

If we try, for instance, an excess value 10, the heat driven out by gases that we find is just 259.506.931 kJ; the agreement between produced and lost heat drops to 70 %. In actual operation this would lead to overheating and eventually sterilizing the vessel; once the biomass inactivated, the process would prematurely end.

If – on the other hand – we suppose air excess to rise to 20, heat escape amounts to 314.764.363 kJ; the agreement improves to 85 %, but the plant blowers actually could hardly sustain such a flow rate.

This *scenario experiment* suggests that air excess values between 15 and 20, and the associated heat transport, fit best the results of the heat generation computation. Incidentally, they confirm the good quality of the design of the plant under study and stand for a skilful operation.

4 Summary

The results of energy balance for one cycle showed fair agreement (77 %) between heat produced by oxidation and heat removed by flue gas, when the value of 15 is assumed for air excess. Actually, water evaporation enthalpy and sensible heat in exhaust gas accounted for 85 % of the losses calculated on stoichiometric values.

Enthalpy of reactions could thus be retro-calculated at full scale as demonstrated by Chang and co-workers. (CHANG *et al.*, 2001) for waste incineration.

What appeared critical in such calculations is: 1) the knowledge of the chemical composition of fermentable waste (taken as cellulose as a first approach); 2) the actual amount of heat developed by biological oxidation; 3) the effect of experimental errors in waste

analysis, particularly serious when dealing with the more heterogeneous waste fed to the bio-cell.

It appears therefore it would be worthwhile to fit the existing plant with flow meters on air delivery pipes and / or on exhaust air conduits. Additional instruments for continuous IR analysis of water vapour and carbon dioxide would also be most helpful for closer process control and for more robust data consistence verifications.

5 Acknowledgement

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6 Literature

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