General concept of waste matrix and relating empirical value to collect reliable data

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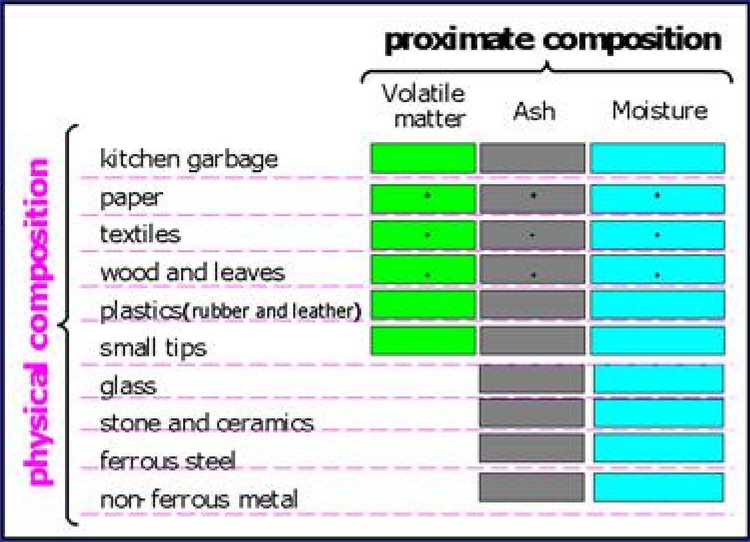
What is the problem ?

- Tonnes of data exist. However, what does it mean?
  - Reported data
    - *xx*%, *yy* kJ, *zz* m^3
  - Needed information
    - How much moisture or energy **in TOTAL**?
    - Material flow in the total waste stream
- What should be standardized is **General Concept** instead of a fixed reporting format

Reporting format is NOT fixed worldwide, however, general concept of waste matrix must be the same

- Waste consists of
  - moisture M ■, $m(i)$
  - ash A ■, $a(i)$
  - volatile matter V ■, $v(i)$

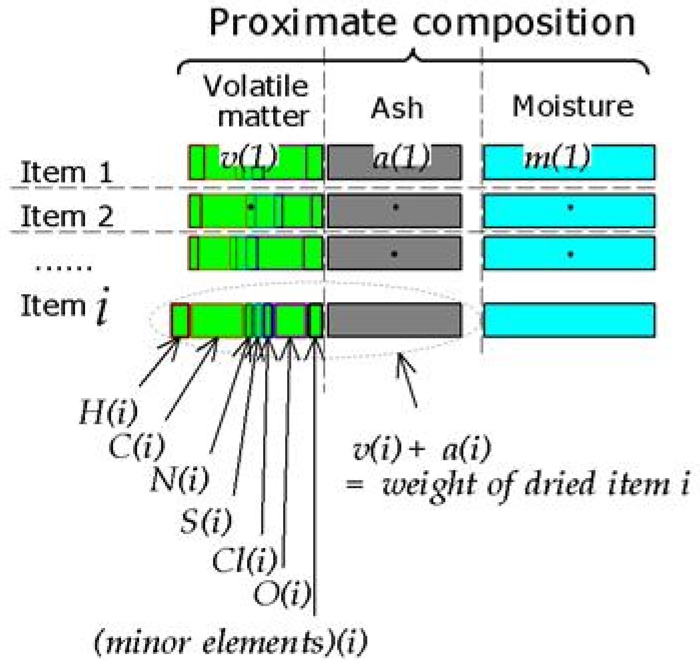
The ratio of M, A and V is Proximate Composition



- All physical components have $m(i)$, $a(i)$ and $v(i)$

The other common sense we should have: Σ Organic Elements = Volatile matter

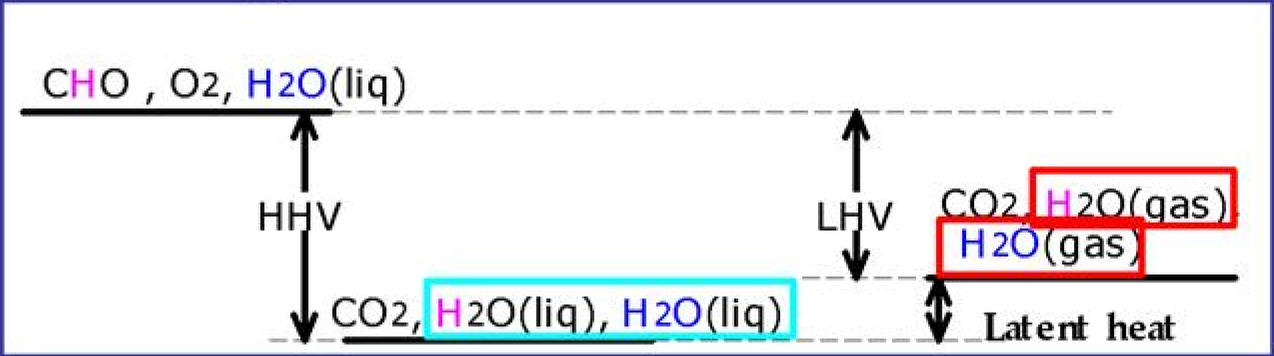
- Organic elements:
  - Hydrogen
  - Carbon
  - Nitrogen
  - Sulfur
  - Chlorine
  - Oxygen
  - minor elements



$$(\text{carbon})(i)\ (\%) = \frac{C(i)}{v(i) + a(i)} \times 100$$

Viewpoint of Energy: Heat Value

- High heat value(HHV)
  - measured value by calorie meter
    - to H_2O(liq) and CO_2
  - Biologically available energy
- Low heat value(LHV)
  - LHV = HHV - latent heat for water evap.
    - to H_2O(gas) and CO_2
  - Available energy by combustion



Example of a Reportig Format :Check Points

■ Physical composition (as received, %)

Paper	30
Kitchen garbage	30
Plastic	10
Wood and grass	5
Textile	5
Other combustibles	10
Incombustibles	10
Total	100

■ Proximate composition (%)

Volatile matter	42.5
Ash	22.0
Moisture	35.5
Total	100

same

■ Elemental analysis (%)

Hydrogen	3.5
Carbon	24.5
Nitrogen	0.43
Sulfur	0.036
Chlorine	0.52
Oxygen etc.	13.5
Total	42.5

■ Heat value (kJ/kg)

High heat value	10 915
Low heat value	9 240

$$10\,915 - (355 + 18/2 \times 35) \times 2.5 = 9\,240$$

↑ HHV ↑ moisure ↑ H_2O from H ↑ Latent heat of H_2O ↑ LHV

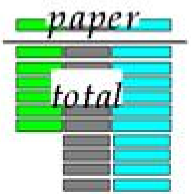
Physical Composition: "As Recieved" vs Dry Base

■ Physical composition (as received, %)

Paper	30
Kitchen garbage	30
Plastic	10
Wood and grass	5
Textile	5
Other combustibles	10
Incombustibles	10
Total	100

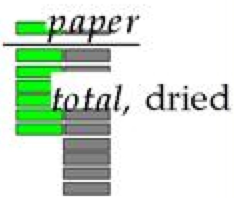
as received = wet condition

$$(paper)_{\text{as received}} = (V(1) + A(1) + M(1)) \,/\, (\text{total waste}) \times 100\ (\%) =$$



dry base = after dry

$$(paper)_{\text{dry base}} = (V(1) + A(1)) \,/\, (\Sigma V(i) + \Sigma A(i)) \times 100\ (\%) =$$



INTERPRETAION

For example, 300 grams of paper (not dried) was in 1000 g of collected waste.

Proximate Composition:

- Proximate composition (%)

Volatile matter 42.5

Ash 22.0

Moisture 35.5

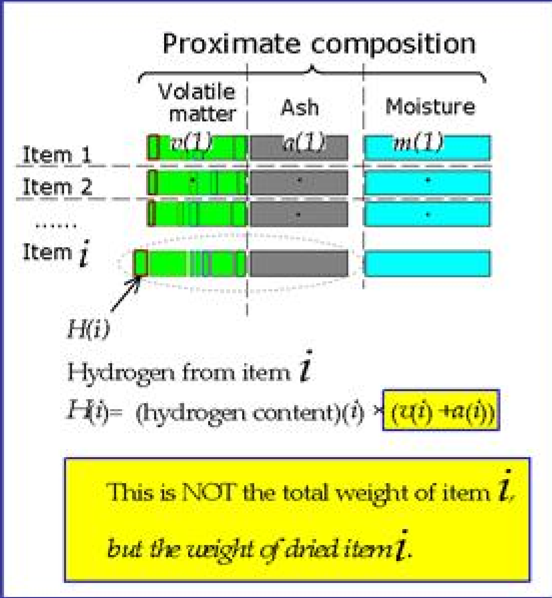
Total 100

INTERPRETAION

For example, the sum of vilatile matter from all components are 425 grams in 1000 g of collected waste.

Elemental Analysis

Elemental analysis (%)	
Hydrogen	3.5
Carbon	24.5
Nitrogen	0.43
Sulfur	0.036
Chlorine	0.52
Oxygen etc.	13.5
Total	42.5



INTERPRETAION

For example, 3.5%of hydrogen is equal to 35 grams in 1000 g of collected waste. However, it is the summation of H from paper, H from kitchen garbage etc.

The elemental analysis is performed with dried sample whose weight is $v(i) + a(i)$.

Reporting heat value

Heat value
(kJ/kg)

High heat value	10 915
Low heat value	9 240

Heat from item $i = HHV(i) \times \{v(i) + a(i)\}$

$HHV = \sum HHV(i)$

Really measured value is $HHV(i)$

= Heat per dried weight of item i

INTERPRETAION

Heat analysis is also performed with dried sample whose weight is $v(i) + a(i)$.

Empirical Value of Elemental Analysis

Estimate calculation of elemental composition of MSW

	Fractions of item *i*			From literature: Elemental composition of item *i* (dry base)		Calculated results: Element contribution from item *i*	
	v(*i*) (g/kg)	*a*(*i*) (g/kg)	*m*(*i*) (g/kg)	(*carbon*)(*i*) (%)	(*hydrogen*)(*i*) (%)	*C*(*i*) (g/kg-MSW)	*H*(*i*) (g/kg-MSW)
Paper	237	15	48	40	5.9	100.8	14.9
Kitchen garbage	60	15	225	42	5.5	31.5	4.1
Plastic	85	5	10	69	9.8	62.1	8.8
Wood and grass	22.5	2.5	25	41	5.4	10.3	1.4
Textiles	39	1	10	48	6.3	19.2	2.5
Fine waste	35	25	40	29	3.8	17.4	2.3
Incombustibles	0	100	0	-	-		

Elemental composition of MSW

$(carbon)_{MSW}$ (%)	$(hydrogen)_{MSW}$ (%)
24.1	3.4

These value are listed Table 1

Empirical value for heat analysis

Estimate calculation of heat value of MSW

	Fractions of item *i*			From literature	Calculated results
	$v(i)$ (g/kg)	$a(i)$ (g/kg)	$m(i)$ (g/kg)	$HHV(i)$ (kJ/kg)	Heat from item *i* (kJ)
Paper	237	15	48	17000	4284
Kitchen garbage	60	15	225	18000	1350
Plastic	85	5	10	33000	2970
Wood and grass	22.5	2.5	25	18000	450
Textiles	39	1	10	20000	800
Fine waste	35	25	40	12000	720
Incombustibles	0	100	0	0	0

Heat value of MSW	
HHV_{MSW}(kJ/kg)	10574
LHV_{MSW}(kJ/kg)	8909

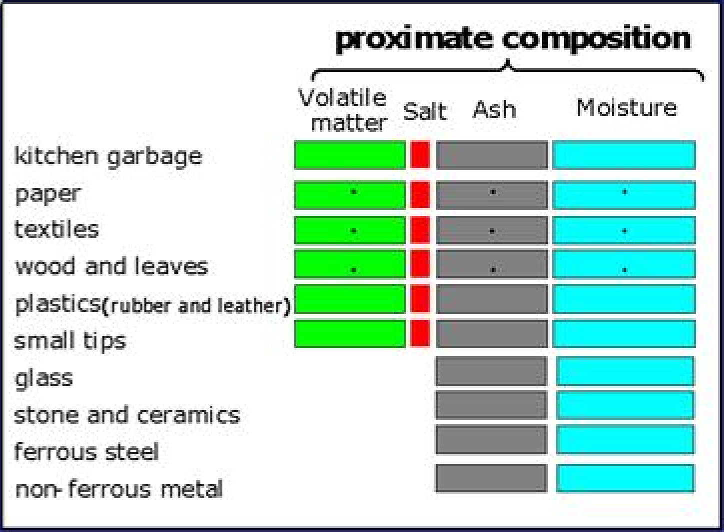
These value are listed in Table 2

Current problem 1: Chlorine in Ash

- In traditional concept of fuel analysis, Cl and S are considered to be volatile in combustion.
- However, considerable amount of Cl and S remains in ash.
- From the viewpoint of air pollution control, only volatile fraction is of concern. However, ash - remaining Cl can be PROBLEMATIC for recycling!
- Nevertheless, sufficient attention on Cl in ash is NOT payed yet.
- Reported Cl content might be underestimated.

Current problem 2: salts

- Salts(Salinity) e.g. Na, K, Mg and Cl is NOT welcome to ash recycling.
- However, no reporting format for salts in waste matrix is given.
- Salts are water soluble.
- However, they are partially volatilzed (categorized to volatile matter) and partially remains in ash (categorized to ash).



Conclusions 1/2

- Common Concept
  - All items have volatile matter, ash and moisture
  - Volatile matter consists of organic element (H, C, N, S, Cl and O)
  - High heat value(HHV) and low heat value(LHV)

Conclusions 2/2

- Practical Calculation - Using an Example Report
  - Check points
    - Volatile Matter and Elemental Analysis
    - LHV is derived from HHV, Moisutre and Hydrogen
- Two ways in physical composition description
  - “as recieved“ versus ”dry base“
- Interpretation and empirical data of
  - Proximate, Elemental and HHV
- Current problem
  - Chlorine
  - Salt

Experimental training of waste analysis in Osaka Inst Technol (3rd grade)

- Dried and crushed samples are given to students
  - plastic
  - kitchen garbage
- Experimental work
  - Proximate analysis
  - Elemental analysis
    - H, C, S and Cl (N is omitted)
  - Heat measurement by calorie meter
- Calculation
  - Waste Matrix
  - HHV and LHV
  - Incineration gas prediction

Heat value measurment

- First primitive way using a plastic beaker
- Later, pricise measuement by Neneken B calorie meter

Table 1
Empirical values of elemental compositions of individual items

		Elemental composition (dry base)				
		Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulfur (Combustible sulfur) (%)	Chlorine (Combustible chlorine) (%)
Paper	ref 1	43	5.8	0.25	0.2	
	ref 2	41-42	5.8-6.6	0.16-0.35	0.02-0.03	0.08-0.19
	ref 3	40±2	5.9±0.2			
	ref 4				0.04-**0.074**-0.17 (0.01-**0.02**-0.033)	0.06-**0.18**-0.54 (0.04-**0.12**-0.30)
Kitchen garbage	ref 1	42-45	5.8-6.4	3.0-3.3	0.25-0.52	
	ref 2	39-45	5.2-6.1	2.8-3.2	0.08-0.09	0.19-0.30
	ref 3	41±2	5.8±0.3			
	ref 4				0.1-**0.25**-0.42 (0.03-**0.14**-0.33)	0.16-**0.8**-1.8 (0.05-**0.12**-0.25)
Plastic	ref 1	60	7.2			
	ref 2	72	11	0.55	0.04	3.37
	ref 3	plastic: 78, rubber and leather: 58	plastic: 9.4, rubber and leather: 6.5	plastic: 0.19, rubber and leather: 1.6	plastic: 0.03 rubber and leather: 0.37	plastic: 3.64, rubber and leather: 3.1
	ref 3	plastic: 69±2 rubber and leather: 55±6	plastic: 9.8±0.6 rubber and leather: 6.9±0.9			
	ref 4				0.01-**0.081**-0.37 (0.01-**0.044**-0.25)	0.47-**2.4**-6.8 (0.28-**2.1**-6.2)

Table 1 continued

Wood and grass	ref 1	40	5.6	2	0.05	
	ref 2	43-49	5.4-6.4	0.8-0.95	0.01-0.03	0.14-0.18
	ref 3	41±4	5.4±0.6			
	ref 4				0.02-**0.076**-0.16 (0.007-**0.032**-0.076)	0.04-**0.2**-0.46 (0.03-**0.13**-0.29)
Textiles	ref 1	46	6.4	2.2	0.2	
	ref 2	46 - 52	6.3 - 6.6	2.8 - 3.7	0.22 - 0.30	0.21 - 0.49
	ref 3	48±3	6.3±0.4			
	ref 4				0.05-**0.73**-6.7 (0.02-**0.68**-6.7)	0.041-**0.41**-3.8 (<0.001-**0.35**-3.2)
Fine wastes	ref 4				0.1-**0.31**-0.85 (0.03-**0.088**-0.21)	0.18-**0.74**-2.6 (0.05-**0.19**-0.77)
	Estimated in this study	29	3.8			

Data from Ref 1 and Ref 2 are given by one value or in a range.
Data from Ref 3 are given by one value or by an average ± standard deviation.
Data from Ref 4 are given as "minimum - average - maximum"

1. Rhyner CR, Schwarz LJ, Wenger RB, Kohrell M (eds) (1995) Waste Management and Resource Recovery. CRC Press
2. Japan Waste Management Association (1999) Comprehensive Handbook for the Planning and Design of Waste Management (in Japanese)
3. Japan Environmental Sanitation Center (2001) Fact Book 2000 Waste Management & Recycling in Japan
4. Watanabe N, Yamamoto O, Sakai M and Fukuyama J (2004) Combustible and incombustible speciation of Cl and S in various components of municipal solid waste. Waste Manag 24: 623-632

Table 2

Empirical high heat values of individual items

		High heat value (*HHV*) (kJ/kg)
Paper	ref 1	17600
	ref 2	17300
	ref 3	17100±850 16600±730
Kitchen garbage (food waste)	ref 1	19700, 16900
	ref 2	18700
	ref 3	17900±1300 16700±540
Plastic	ref 1	33400
	ref 2	37400
	ref 3	34100±2900 32100±1300
Wood and grass	ref 1	16500
	ref 2	19900
	ref 3	17600±2000 18300±530
Textiles	ref 1	18700
	ref 2	21400
	ref 3	20500±1200 20000±1100
Fine waste	ref 3	12300±970