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Optimization of MSW Feed for Waste to Energy Practices

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The rapid growth rate in the world population along with economical development is creating an environmental burden through energy consumption and solid waste generation. As a result of bulk solid waste generation, many countries are confronted with disposal problems. Countries are drafting policy frame works for reducing, reusing, recycling and treating waste, and to use the landfills as a final repository. But with treatment process inefficiencies and the proven negative environmental impacts of landfills, developing further landfills for treated waste disposal can't remain as the only option. Alternative ways for solid waste management need to be identified. Energy recovery from solid waste known as waste-to-energy (WTE) is one such alternative. Waste to Energy technologies such as modern incineration and gasification processes have been gaining popularity as they can significantly reduce the volume of solid wastes and at the same time produce a combination of heat and electricity. Any carbon rich solid waste can be burned to produce energy. But due to variability of properties, uneven combustion in the chamber can hamper the operation of incinerator. The unsteadiness of the combustion process can be adjusted by making appropriate solid waste blend that meet the specification of combustor feed. Due to variations of physical and chemical properties, appropriate blend feeds of incinerator previously are made by applying extensive trial and error methods accompanied with laboratory and pilot scale testing of simulated synthetic wastes for stable combustion. In this work typical industrial origin solid waste is considered and optimum feed stock blending amount with its gross calorific value was predicted and was cross checked with the specific values given in literature.

1. Introduction

The recovery of energy from waste is one of the viable methods for converting wastes from potential hazard to a valuable asset. The present day conversion paths include conventional Waste-to-Energy (WTE) technologies, where Municipal Solid Waste (MSW) is fully oxidized in a single-step combustion process, and gasification and pyrolysis technologies where MSW is partially oxidized in a reactor under limited oxygen conditions.
Energy content and elemental composition are the two parameters used for characterization of solid wastes during the waste to energy practices. While energy content is quantified by the Lower or Higher Heating Value (LHV or HHV), the latter is usually expressed in terms of mass fractions of the main atomic species that compose the waste. During waste combustion processes the energy content and the elemental composition of the waste furnish important information for estimating the mass and energy balances of the treatment process during which the waste undergoes chemical changes. MSW contains a mixture of waste streams mainly containing a single material or a class of materials, like wood, glass, plastics, etc depending on the upstream process that generates the waste. Municipal solid

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waste combustion is used for heat and power production consequently resulting in reduction of the volume of the waste that have to be disposed in landfills. The operation of combustion plants is subject to both economic and environmental objectives. Maximization of both the waste throughput and the energy output are among the economic objectives for revenue maximization and cost minimization of such plants. The environmental objectives consists issues that are related with environment and public health caused by the emissions associated with the operation of the plants (Leskens et al., 2005). The direct combustion difficulties of MSW emanated due to its heterogeneity in moisture content, particle size and heating value can be tackled by changing it in to more densified and easy to handle solid fuel called refuse derived fuel (RDF) (Shen and Qinlei, 2006).

Taking the granted environmental benefits offered by combustion processes, emissions containing highly toxic dioxins and furans, difficulty of controlling metal emissions for inorganic wastes containing heavy metals and requirement of supplementary fuels to achieve the necessary high combustion temperatures are among the problems associated with it (McKay, 2002).

The study carried out by Liang et al. showed that moisture and ash contents have great impacts on net calorific value and combustion properties of MSW. Combustion phenomena of five simulated MSW were experimentally investigated by changing the moisture content from 8.8 % to 49.2 % and the net heat value was observed to drop from 9710 kJ/kg to 4390 kJ/kg (Liang et al., 2008). The effect of moisture content in the MSW on the carbon combustion efficiency was studied by Patumsawad et al. and a drop in efficiency with increasing moisture content was observed (Patumsawad and Cliffe, 2002).

Due to the difference on social and economic status and way of living of people, the corresponding compositions of generated solid wastes vary markedly across the globe. Hence the research related to municipal solid waste combustion in incinerators is versatile and time consuming. Most researchers carried out combustion studies by formulating synthetic fuel as representative of municipal solid waste (MSW). Thipsea et al. studied methods of heat content evaluation of MSW incineration using syntactic fuel as representative of municipal solid waste (MSW) found in the US waste-stream (Thipse et al., 2002).

The burning characteristics of MSW are affected by so many interacting parameters that need to be optimized. Moisture content is one of the most important properties of MSW in determining the burning characteristics. The higher the level of moisture the longer it will take the material to burn and also it affects the useful energy obtainable from the waste. In addition Ash content and ash composition have impact on smooth running of a combustor. Melting and agglomeration of ashes in reactor causes slagging and clinker formation. To avoid the obstacles and provide suitable working conditions for incinerators most countries set some quality guidelines for using solid wastes as fuels in combustion process. For example In most countries of the EU the heating value of the RDF varies from 15 MJ/kg to 31.4 MJ/kg and the corresponding moisture content is between 15-34 % (wt%) and the ash content is between 10 % to 22 %(w%) (EC-GGE, 2003). The most debatable issue in discussions of energy recovery from solid wastes is that of emissions related to sulphur and nitrogen compounds to the atmosphere. For such issues related to emissions some European countries set limit values of Nitrogen and Sulphur that should present in the RDF and according to this standard the maximum limit for Nitrogen and sulphur in such recovered fuel is 1.5 % and 0.5 % (% w) respectively (EC-GGE, 2003) . The limiting values for Carbon, hydrogen and oxygen are not uniform. Gui Qing Liu et al. studied the combustion characteristics of RDF to provide data for development of high efficiency power generation (Liu et al., 2001).

The optimization model proposed here aims at producing a suitable blend of MSW having maximum heating value by making use of experimentally determined values of Energy content and elemental compositions of known set of wastes. A typical waste of a pulp paper industry was considered for analysis. The optimization procedure is used to produce a fairly uniform fuel of high heating value that is ready for combustion in WTE plants. In order to produce consistently high quality mixed fuel the characteristics of the MSW is essential. The calorific value of a mixed sample can be formulated using mathematical models. These mathematical models are based on data from the physical composition, proximate or elemental analysis data of the MSW. Experimental determination of the calorific value is usually carried out in a bomb calorimeter.

2. Waste materials characteristics

While most waste management systems deal with waste as an aggregate material, an understanding of the behaviour of individual waste streams along with chemical analysis is extremely useful when optimizing the design of WTE systems. A representative sample set of seven solid wastes of Pulp and paper mill was selected in order to accurately represent the main fractions of the waste. Proximate and Ultimate analysis of the components are shown in Table 1 along with the moisture content in as received bases and calorific values. The inorganic fraction of waste, including metals and glass, was not included because they are not common in the solid wastes of the selected industry.

Table 1: Availability data (Gebreegziabher, 2006)

	Coal Fine	Machine Sludge	Tertiary Rejects	Screw press sludge	Chip Dust	Plastic-A,B,C	Sorted Plastic
Kg/hr	30.56	4166.67	961.11	1115.28	725.00	694.44	347.22
Moisture (wt %) as received	2.7	78	70	82	36	60	10
Proximate analysis (wt %) – dry basis							
Moisture	2.68	5.37	3.5	1.82	3.24	0.25	0.25
Volatile matter	19.86	54.22	61.23	54.22	76.56	96.54	96.54
Ash	26.49	28.04	15.78	28.04	2.81	1.73	1.73
Fixed carbon	50.97	12.37	19.49	12.37	17.39	1.48	1.48
Ultimate Analysis (wt %) – dry basis							
Moisture	2.68	5.37	3.5	1.82	3.24	0.25	0.25
Mineral matter	29.14	30.84	17.36	31.37	3.09	1.9	1.9
C	55.9	29.6	34.2	30.8	42.8	40.5	40.5
H	3.8	3.2	3.6	3.4	4.6	4.8	4.8
N	1.12	1.4	0.63	0.91	0.7	0.35	0.35
S	0.78	0.28	0.15	0.17	0.13	0.24	0.24
O	6.58	29.31	40.56	1.53	45.44	51.96	51.96
GCV(Kcal/Kg)	5376	2520	3040	2750	3780	3520	3520

3. Blending problem formulation

We assume an industrial waste origin with almost constant properties throughout the year and the blend was modelled as a linear combination of source heating values as in Equation 1. To utilize some energy for drying we incorporate the amount of energy required for moisture removal and the equation was modified as in Equation 2.

$$Heating\ value = \sum_{j=1}^{7}(a_j X_j) \quad (1)$$

$$Heating\ value, total = \sum_{j=1}^{7}(a_j X_j) - \sum_{j=1}^{7} \mathrm{E_j} \quad (2)$$

Where

X_j=flow rates of the waste stream j,

j= (coal fines, machine Sludge, Tertiary rejects, screw press sludge, chip dust, plastics-A, B, C, Sorted plastics), (Kg/h) and a_j=heating value of j

E_j=Energy needed to change the moisture content from M_{1j} to M_{2j} of j, (KJ/h),

M_{1j}, M_{2j}=Initial and final moisture contents of j .

The constraint functions are developed based on specific standard values set for high quality fuel derived from MSW where product limits are often restricted by law. In order to produce a high quality fuel that meets the prescribed quality standards it is mandatory to have the ultimate and proximate analysis of the waste at hand. This ultimate and proximate analysis of each waste streams are used thoroughly for developing the constraint functions.

The Constraints are:

1. Flow rate and moisture constraint

$$X_j \leq X_{jmax} \tag{3}$$

$$M_{2j} \leq M_1 j \tag{4}$$

X_{jmax}=maximum flow rate of jth stream from the availability data.

2. Drying of Wet Wastes

The energy consumption for drying operation changes with the moisture content. The energy demand of thermal or mechanical drying operations increases with decreasing the residual moisture content of a solid. Based on published data for drying in (Chu et al., 2005, Wang and Xi, 2005), we derived a mathematical relation for estimating the heat demand as in equation 5.

$$E_j = 2031.587 * \left(M_{1j} - M_{2j}\right) - 7458.1 \left(M_{1j}^{-0.10924} - M_{2j}^{-0.10924}\right) \tag{5}$$

$$\mathrm{E_{total}} = \sum_{j=1}^{7} \mathrm{E_j} \tag{6}$$

E_j=Energy required for drying (kJ/h) from jth stream

E_{total}=Total Energy required for drying

3. Total amount of dried waste

The amount of dried waste of each stream and the total dried amount are represented by X_{dj} and $X_{dj,total}$ respectively and the corresponding values are calculated as:

$$X_{dj} = M_{dj}\,(1 + M_{1j} - M_{2j}) \tag{7}$$

$$X_{dj,total} = \sum_{j=1}^{7} M_{dj}\,(1 + M_{1j} - M_{2j}) \tag{8}$$

M_{dj}=Dry mass of j other than moisture, (kg)

4. Heat value constraint

The heating value post to drying of the waste streams, HHV, is calculated by dividing the total heat content of the mixed streams to the weight of the dried mass of the waste streams and as to be feasible for waste to energy process the minimum value is considered to be 15 MJ/kg in reference to (EC-GGE, 2003) .

$$HHV = \frac{Heating\ value, total}{X_{dj,total}} \geq 15 \tag{9}$$

5. component constraints

$$f_i = \sum_{j=1}^{7} \left(b_{ij} X_j\right) \leq \mathrm{C_i} \tag{10}$$

Where

f_i= (Moisture, Nitrogen, sulphur), b_{ij}=fraction of f_i in waste stream j, and C_i=limiting values of f_i

The fraction values b_{ij} of f_i in waste stream X_j are calculated from the availability data and proximate and ultimate analysis of the wastes and are given in the following Table 2.The limit values of the constraints are taken from (EC-GGE, 2003).

Table 2: Values of b_{ij} and C_i

Constraint	Coal fines	Machine sludge	Tertiary rejects	Screw press sludge	Chip dust	Sorted plastics	Plastics A,B,C	C_i
Moisture, M_{1j} (kg/kg db*)	0.0275	3.5486	2.333	4.556	0.5625	1.5	0.1111	34
Nitrogen (W %)	0.01	0.02	0.01	0.01	0.01	0.0035	0.0035	1.5
Sulphur (W %)	0.01	0.0029	.0016	.0016	0.0014	0.0025	0.0024	0.5

*dry basis

In most energy recovery processes the useful heat recovered in combustion process is directly related to boiler efficiency. Usually the Boiler efficiency drops with increasing the moisture content (SIMONS-LTD., 1996). We assume all the solid wastes to behave as sludge and derived a boiler efficiency, η_{boiler} , expression as function of moisture content according to the data given in (SIMONS-LTD., 1996).We found a linear relation as in equation 11.The importance of this equation is to analyze the moisture sensitivity of heat recovery process.

$$\eta_{\text{boiler}}(\%) = 82.29 - 17.9 * \text{Moisture content total} \quad (11)$$

Moisture Content total=moisture of final blend, (kg/kg-wet basis)

4. Results and Discussions

As the objective is to produce a high quality solid waste mix by using as much as possible all the components of the waste streams, first an attempt was made without considering the drying step to assess the quality of the mixed waste and its degree of moisture removal requirement. According to the analysis of the first attempt if we mix all the available waste streams according to their hourly based availability flow rates, the resulting mixed solid waste will have a calorific value of 12.01 MJ/kg and is with 69.01 % moisture content. Both the heating values and the moisture content of the preliminary analyzed blend are not within the limits of feedstock property requirements for WTE application. From the point of view of combustion efficiency and maximization of energy recovery per kg of the solid wastes, it is clear that it would be preferable to remove moisture from some of the solid wastes. This will increase the heating value of the proposed mix being burned and therefore will generate more energy per kilogram of waste burned. Hence to examine how the reduction of moisture content of the SW affects the available heat in Waste-To-Energy (WTE) plants drying of the solid waste prior to mixing was assumed. At this stage the drying equation is Incorporated to the already formulated Linear programming problem and the inclusion of drying equation makes the feedstock blending problem to be nonlinear and was solved in Excel .The importance of adding the drying equation to the blending problem is very important in deciding how much fractions of moisture should be removed for enhancing the heating value of the mixture. Even though there is energy demand for removing moisture from the solid waste, the corresponding heating value and quality will be enhanced and can be used as solid fuel feed.

For the assigned limits of the constraint functions the maximum energy of the blend is found out to be $96.55 \cdot 10^6$ kJ/h and have a heating value of 25.6 MJ/kg, moisture content of 34 %, Nitrogen content of 0.62 % and Sulphur content of 0.16 % .For achieving a blend of the above mentioned characteristics the energy requirement for drying is calculated to be $10.82 \cdot 10^6$ kJ/h. The corresponding final moisture content of each stream is given in Table 3 .The final heating value, moisture content and sulphur content are consistent with the values given in (EC-GGE, 2003).

Table 3: Final Moisture content of each waste stream (kg/kg db)

	Coal fines	Machine sludge	Tertiary rejects	Screw press sludge	Chip dust	Sorted plastics	Plastics A,B,C
M_{2j}	0.0275	0.5875	0.5849	0.5855	0.5625	0.5868	0.111

In order to visualize the effect of moisture content of feed on boiler efficiency we included the boiler efficiency equation to the optimization model. We found out that for attaining higher efficiencies the blend should be dried up to final moisture content of 15 % and the corresponding heating value is 32.7 MJ/kg .These values are attained after the efficiency equation is integrated with the optimization model. The moisture content of the blend is within the range of values given by the EU for the responsible incineration and treatment of special waste (EURITS) given in (EC-GGE, 2003).

The analysis employed for the determination of a suitable feed stock along with levels of moisture reduction requirement of moist solid wastes of pulp and paper industry uses a dynamic blending of experimental results and mathematical models. The ultimate and proximate analysis was used for the determination of constraint compositions in each waste streams. The steps followed in this analysis can be employed in any waste to energy process containing so many waste streams and accordingly an exact moisture reduction level and the corresponding heating value of the blend can be predicted.

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