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ENERGY EFFICIENT REFUSE DERIVED FUEL (RDF) FROM MUNICIPAL SOLID WASTE REJECTS: A CASE FOR COIMBATORE

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Abstract

In this paper production of energy efficient Refuse Derived Fuel (RDF) from municipal solid waste rejects was carried out during August 2012 – April 2013 in Coimbatore City India. Municipal Solid wastes rejects (paper, plastics with exception of polyvinyl chloride, textiles) were collected from waste dump yard of Coimbatore City. Sawdust, coir dust, water hyacinth and rice husk were mixed with the collected wastes at a fixed amount of 20 percent. After grinding, cassava starch was used as a binder to produce RDF briquettes with the help of uniaxial piston briquettes making machine. Physical, chemical and thermal characteristics of the RDF were studied to assess their potential use as energy efficient material. The analyses were divided into three categories namely, physical, proximate and ultimate analyses. Results indicated that, under physical and proximate analyses; impact resistance index (IRI) for all the RDF samples were 200, density were less than 1 kg $cm^{-}3$, moisture were less than 10 % wt, ash content varied from 2.8 to 9.2 % wt, whilst volatile mater had mean value of 83.1 % wt and fixed carbon which is by subtraction ranged from 1.4 to 9.2 % wt. With respect to Ultimate analysis, Oxygen, carbon, hydrogen varied from 27.01 to 39.78 % wt, 44.8 to59.7 % wt, 5.9 to 8.1 % wt respectively. On the other hand nitrogen, sulfur and chlorine ranged from 0.18 to 0.87 % wt, 0.27 to 0.71 % wt and 0.339 to0.521 % wt respectively. Calorific values (high heating values) ranged from 5085 to 6474.9 kcal kg^{-1}. The results were compared with Energy research Centre for the Netherland database and noted that with exception to moisture, fixed carbon and hydrogen other parameters had a significant lower or higher differences. From the study, RDF from municipal solid wastes rejects along with the additives produced high energy efficient materials.

Keywords: Municipal Solid Waste, Waste to Energy, RDF, Calorific value.

Introduction

Energy is one among the human basic needs that drives human life hence extremely crucial for continued human development. It has been pointed that providing adequate and affordable energy is essential for eradicating poverty, improving human welfare and raising living standards worldwide (Chakravarty, 2013). Population increase, rapid industrialization and urbanization significantly increases demand for energy as standard of living improves with rising in average household's income, particularly in developing countries (Adefeso *et al*., 2012). Rural to urban migration in India has caused generation of municipal solid waste to thousands tones daily. In Indian cities, per capital generation of wastes ranges between 0.2 to 0.6 kilograms per day equivalent to 42 million tons annually (ADB, 2011). These wastes are disposed in low-lying areas without taking any precautions or operational controls and these varied between 60 to 90 per cent (Kaushal *et al*., 2012). Energy to waste technologies have been tested and utilized in many countries, developed and developing countries. In India this technology had been tried with very little performance (Asnani, 2006). Therefore to solve both the problems of waste disposal and energy shortages simultaneously, in the present study, the refuse derived fuel (RDF) approach is assessed. The study was undertaken to explore skills, knowledge, standards and techniques for producing energy efficient RDF from municipal solid wastes rejects which will be utilized in cement kilns, power plants and other beneficiaries.

Material and Methods

Description of the study Area

The study was carried out in Coimbatore city between August 2012 - April 2013. Coimbatore is the third largest city in the Indian State of Tamil Nadu after Chennai and Madurai. It is an inland district in the Southern part of Peninsula. The city lies between $10^{o}\,10'$ and $11^{o}\,30'$ of the Northern latitude and $76^{o}\,40'$ and $77^{o}\,30'$ of the Western longitude in the extreme West of Tamil Nadu. The area experience an average of 600 mm of rainfall in an annually. It receives high rainfall from north east monsoon of 444.3 mm and its distribution is also good. Temperature varies from 18.6 to 35.7 ^{o}C.

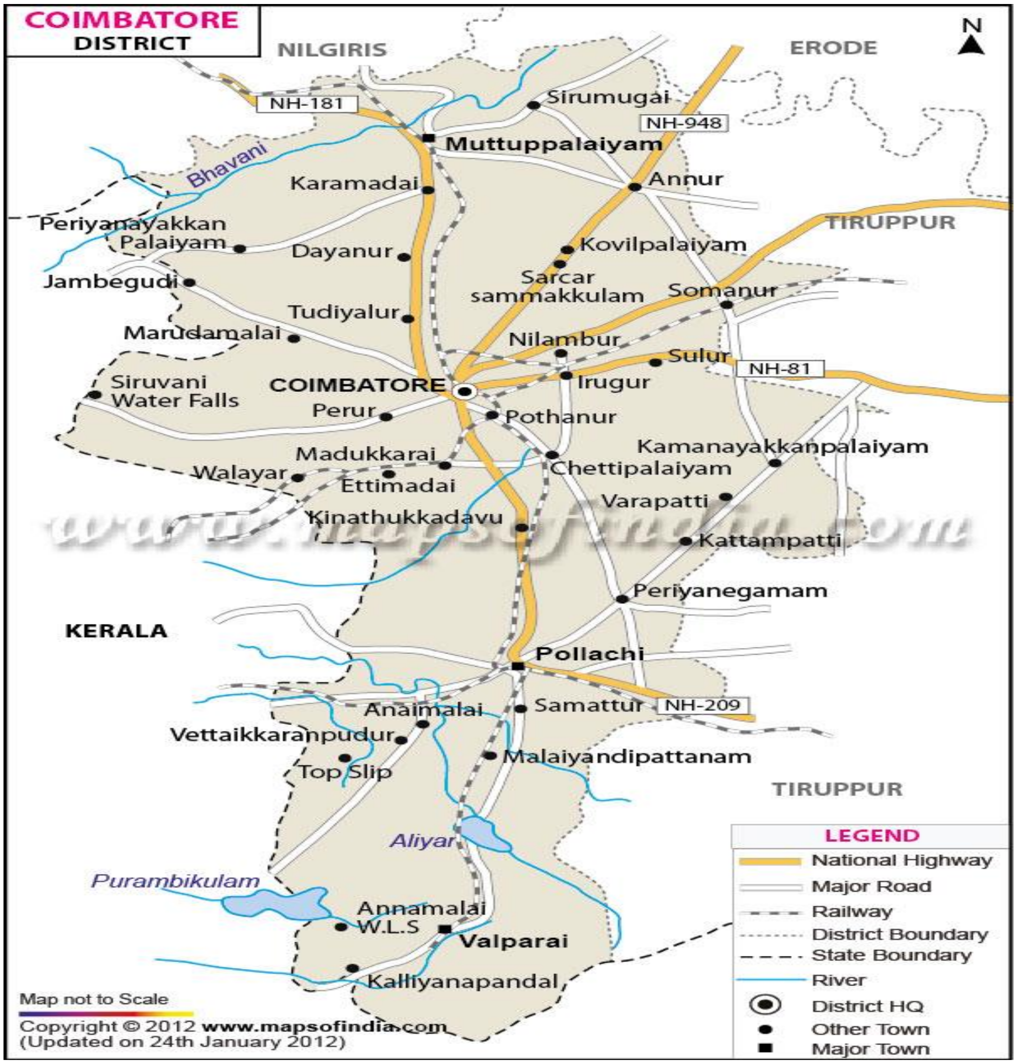


Figure 1: A map showing location of the Coimbatore District (Source: http://www.mapsofindia.com)

Data collection methods

Sample Preparation

Along with municipal solid waste (papers, plastics with exception of Polyvinyl Chloride and textiles) rejects, other materials (coir dust, rice husk, sawdust and water hyacinth) in this study termed as additives were collected, grinded and mixed with cassava starch as binder. Additives were selected based on their availability, transportation costs, and theoretical calorific values and identified as wastes intended for disposal. On the other hand cassava starch (paste) selection was based on its cost, able to be locally processed, available at large scale production, clean combustion and final characteristics of the fuel. With the help of fabricated uniaxial piston machine for making briquettes (Figure 2) RDF were prepared under room temperature and dried before they were taken to laboratory.

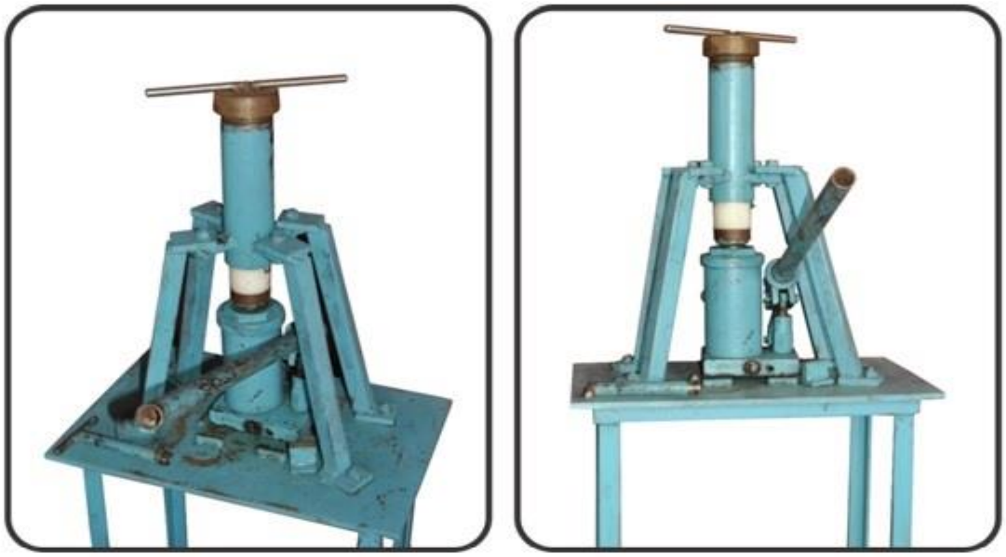


Figure 2: Different views of machine used for making briquettes

In this study a statistical experiment used was completely randomized design (CRD) and a layout of five treatments (T1, T2, T3, T4, T5) with four replications.; T1: 100 % MSW, T2: 80 % MSW +20 % sawdust, T3: 80 % MSW +20 % coir dust, T4: 80 % MSW +20 % rice husk and T5: 80 % MSW + 20 % water hyacinth. The analysis was divided in three categories i.e. physical assessment (dimensions, impact resistance and density), proximate and ultimate analyses (see table 1).

Sample Characterization

Length, diameter and then from weight and volume of the briquettes true density was obtained. Moisture content was determined by drying the known weight of sample in an electrical oven at 103 ± 5^{o}C for one hour until the constant weight was reached (Browning, 1967). Volatile matter and ash content were calculated numerically by using American Standards for Testing and Material (ASTM), (2006) whilst fixed carbon was found out by subtracting the sum of percentages of ash content, volatile matter content from the total percentage (Cordero *et al*. 2001). Carbon, hydrogen, nitrogen and sulfur were determined according to standard CENT/TS 15407, (2006). CHNS analyzer (Model – Vario EL III) in Cochin University of Science and Technology, Kerala with a sensitivity of 0.001 mg was used. On the other hand chlorine in RDF samples was determined by ASTM Method E776-87 (2004) (Watanabe, 2004), Oxygen was determined by subtracting the percentages (estimation by difference) of carbon, hydrogen, nitrogen and sulfur from the whole percentage (100 %). ASTM D440-86 method was used to determine Impact Resistance Index (IRI) (Saikia and Bamah, 2013). Gross Calorific values were experimentally measured using bomb calorimetry method. Data for comparisons were obtained from Energy research Centre for the Netherland ECN database. (Phyllis 2, nd)

Results and Discussion

In the following table are mean values obtained in the present study.

Table 1: Mean values for all the analyses in all the treatments

Parameter	Results (Mean Values)					
	T1	T2	T3	T4	T5	Standard Deviation
Physical Analyses						
Density (g cm^{-3})	0.665	0.627	0.606	0.664	0.605	0.03877
Impact resistance index (IRI)	200	200	200	200	200	0.0
Proximate Analysis						
Moisture % wt	5.33	4.98	5.30	5.08	5.00	0.2026
Volatile matter % wt	86.75	86.75	80.25	81.25	78	4.0962
Ash % wt	3.1	3.65	7.95	5.45	7.85	2.1462
Fixed Carbon. % wt	4.82	4.62	6.50	8.22	9.15	2.5499
Ultimate Analysis						
Nitrogen % wt	0.27	0.21	0.26	0.50	0.61	0.1801
Carbon % wt	57.45	54.95	49.20	49.58	47.71	4.3372
Sulfur % wt	0.695	0.424	0.544	0.459	0.442	0.1474
Hydrogen % wt	7.7	7.7	6.9	7.2	6.6	0.5373
Chlorine % wt	0.487	0.420	0.392	0.392	0.378	0.0449
Oxygen % wt	30.3	32.7	34.7	36.4	36.4	3.2717
HHV* (kcal kg^{-1})	5763	6475	5622	5548	5085	665.73
LHV** (kcal kg^{-1})	5008	5710	4917	4847	4443	620.95

*High heating value, **Low heating value

Physical Assessment

RDF produced had dimensions of 60 mm length, 50 mm diameter with hole of 15 mm at the centre which agrees with (Park *et al.*, 2008) and densities ranging from 0.558 to 0.733 g cm^{-3} which also compares well with study by (Krizan *et al.*, 2011; & Chiemchaisri *et al.*, 2010). In this study IRI for all the samples was 200 which is the maximum value. IRI assess the potential of RDF to resist any pressure and breakage during transportation and when emptying the tracks.

Proximate Analyses

Moisture content is one of the main parameter that determines the quality of RDF. Lower moisture content implies higher calorific values; otherwise material will burn at lower temperatures and thus increasing likelihood of harmful gas emissions (EPA, 2010). Produced RDF had moisture less than 10 % wt which corroborate with reports from similar findings (Koukouzas *et al.*, 2008; Park *et al.*, 200; and Kara *et al.*, 2009). With respect to ash content, T5 reported maximum value of 7.9 % wt which might have been contributed by the nature of the additive (water hyacinth) which agrees with (Park *et al*., 2008, Poespowati and Mustiadi 2012) and standards reported by (Kara *et al.,* 2008). On the other hand, volatile matter in T1 and T2 had highest values of 86 % wt and fixed carbon which remains after volatile matter and by difference varied from 4.6 to 9.2 % wt and mean value of 6.7 % wt (Figure 3).

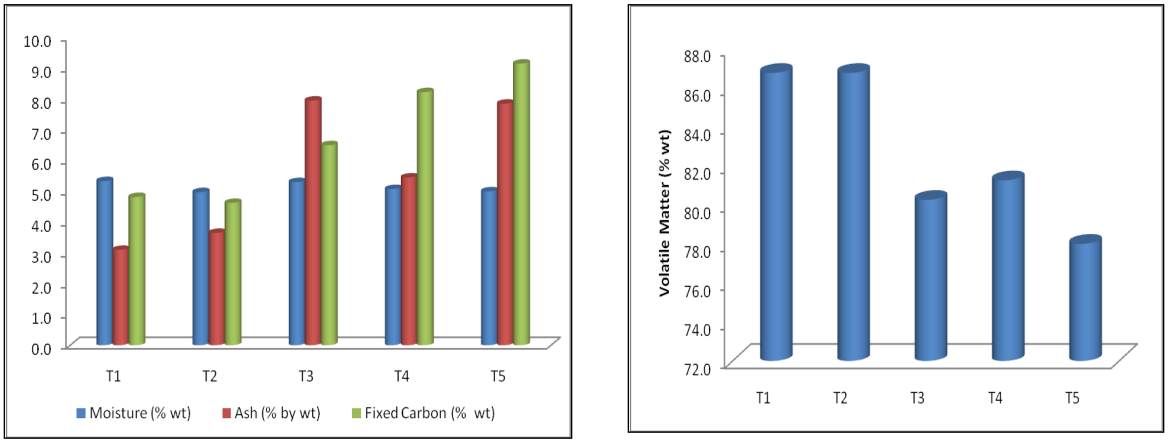


Figure 3: Graphs for proximate analyses for the produced RDF

Ultimate Analyses

For major components (Carbon, hydrogen and oxygen) the values are responsible for classification of heat values, calculating heat balances in boilers efficiency test (Rees, 1996). In present study hydrogen, carbon and oxygen had values ranging from 47.71 to 57.45 % wt, 6.7 to 7.70 % wt, and 30.30 to 36.41% wt respectively. The values for example oxygen are much comparable with other findings (Koukouzas *et al.* 2008; Garg *et al.* 2009 and Chyang *et al.* 2010). The parameters are important as the environment and technical aspects are being assessed based on the chemical composition of RDF.

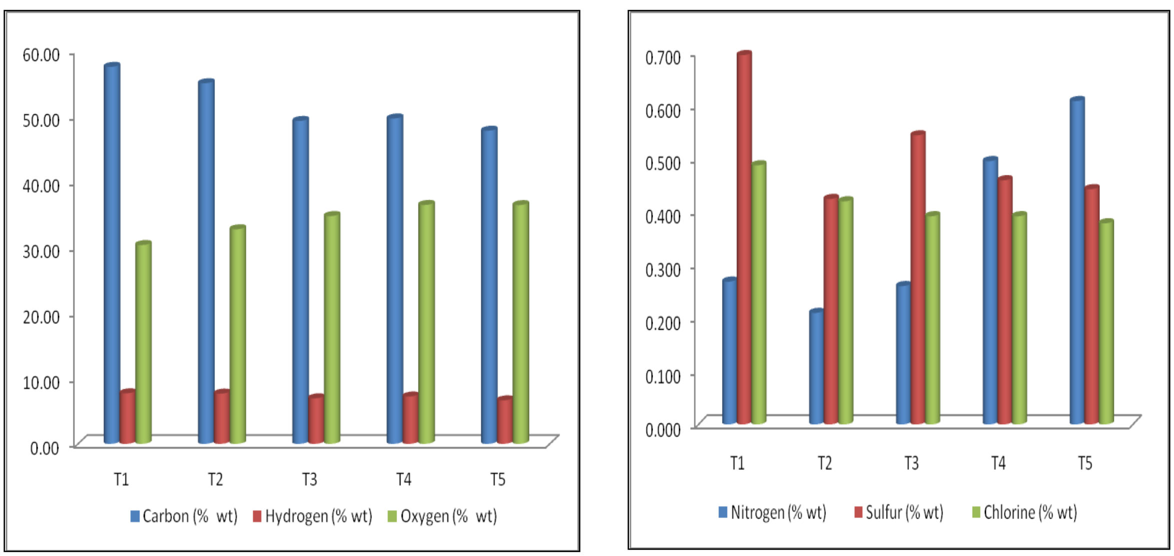


Figure 4: Graphs for ultimate analyses (minor and major constituent) for the produced RDF

Minor component (sulfur, nitrogen and chlorine) is responsible for the formation of harmful gases when combusting the RDF for example nitrogen for the formation of Nitrogen Oxides. Lower values of 0.3 to 0.5 % wt lead to lower formation of harmful products (Genon and Brizio, 2008). In this study nitrogen varied from 0.21 to 0.61 % wt(as shown in Fig. 4) which agrees and within the range reported by (Moran et al. 2009; Genon & Brisio, 2011; and Surroop & Mohee, 2011). Sulfur values varied from 0.42 to 0.69 % wt and mean value of 0.51 % wt. According to (Kara *et al*. 2008) 0.50 % wt is the maximum value set as standard for sulfur in RDF. On the other hand, chorine had values ranging from 0.38 to 0.49 % wt which is below 1 % wt a European Union (EU) standard according to (Partner, 2008).

Caloric Values

High and Low heating values (HHV and LHV) in the presents study were ranging from 5085 to 6474 kcal kg^{-1} and 4442,7 to 5709.5 kcal kg-1 (figure 5) which compares well with Indian imported coal which has calorific values ranging from 6200 to 6500 kcal kg^{-1} according to Indian Ministry of Coal (MoC, 2005).

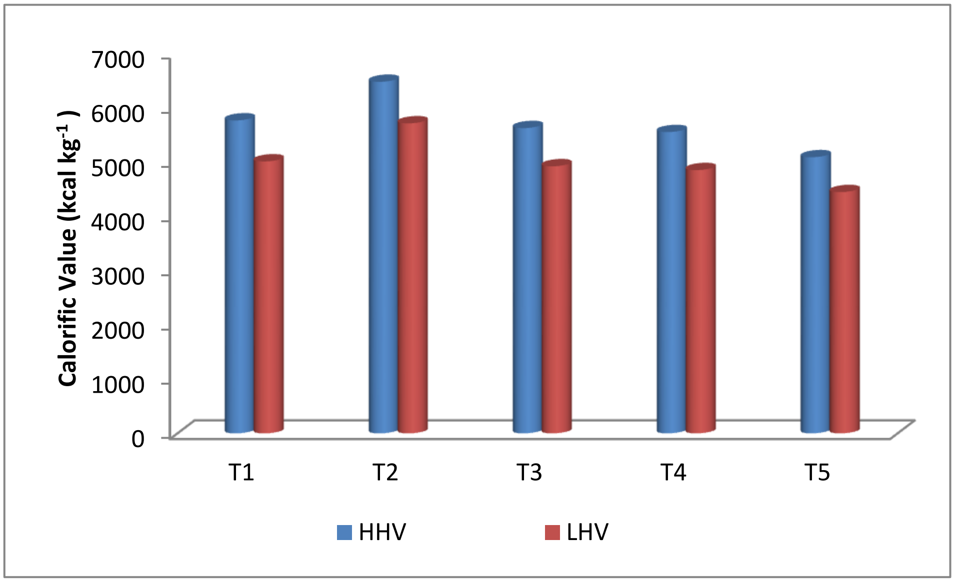


Figure 5: A graph of high and low heating values for the RDF

Comparison between produced RDF and ECN database values

Data from RDF produced were compared with known fuel data from Energy centre for the Netherland (ECN). Statistical tests were performed for all the parameters; the results indicated with exception of moisture, fixed carbon and hydrogen which showed no significant difference, other parameters had significant lower or higher differences. Ash content, nitrogen and chlorine had a significant lower values whilst carbon, oxygen had a significant higher values. Despite the differences between the mean values in the present study all the parameters were within the minimum and maximum values recorded from ECN database (Figure 6 - 8).

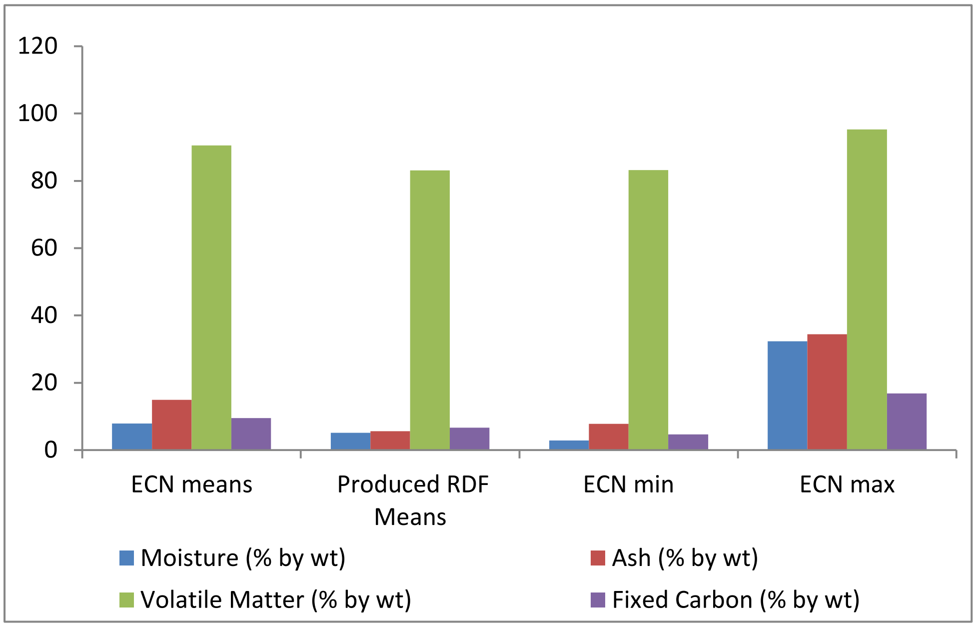
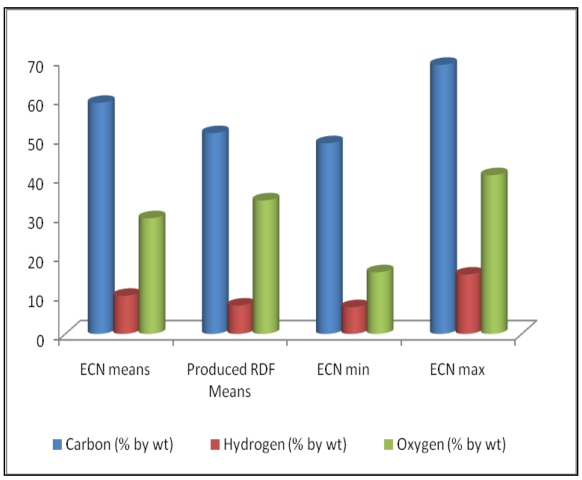


Figure 6: A comparative plot of proximate analysis between observed values and the available ECN database



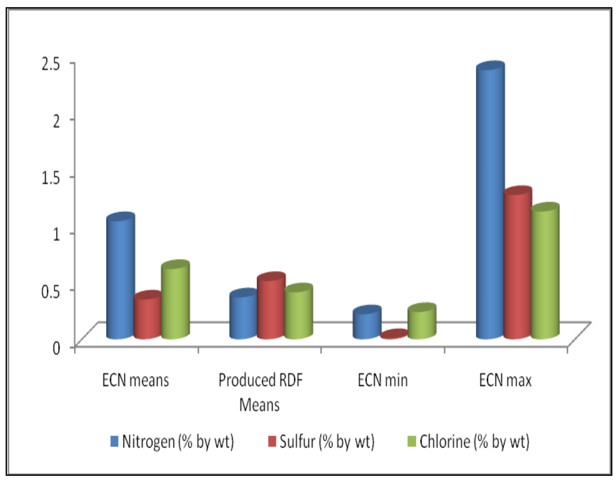


Figure 7: Comparative graph of ultimate analysis (minor and minor constituents) between the observed values and the available ECN database

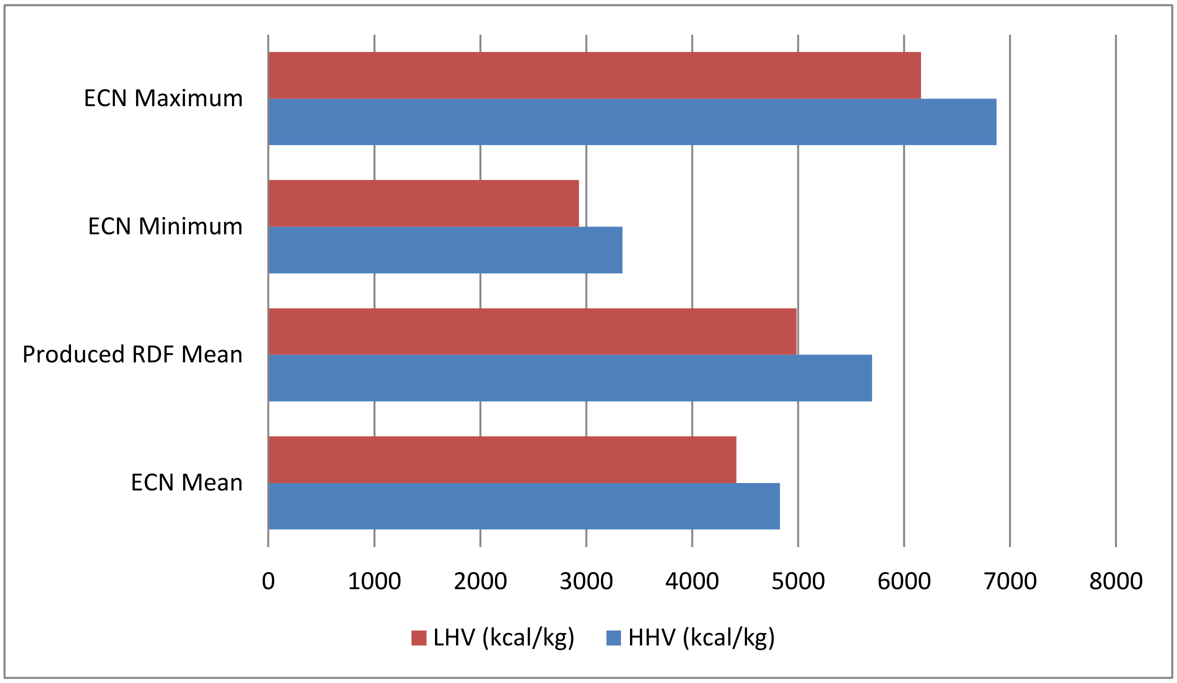


Fig. 8: Comparative bar graph of high heating values and Low heating value between observed values and the available ECN database

Conclusion

Energy demand, natural resource depletion and municipal solid waste management problems have been identified as major challenges and part of our life. Utilizing wastes can help to reach a goal of MSW no longer a wasted resource but a source from which to extract raw material and energy on an industrial scale. In this paper production of energy efficient RDF from municipal solid waste rejects proved sorting of wastes typically produce a residual fraction of high calorific value.

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References

Adefeso, I., Daniel Ikhu-Omoregbe and Ademola Rabiu., 2012. Sustainable Co - generation Plant. Refuse derived fuel (RDF) gasification integrated with high temperature PEM fuel cell System, 2012 International Conference on Environmental Energy and Biotechnology, IPCBEE Vol. 33, IACSIT Press - Singapore.

Asian Development Bank (ADB). 2011. Towards Sustainable Municipal Organic Waste Management in South Asia. A Guidebook for Policy Makers and Practitioners. Philipines.

Asnani, P.U., India Infrastructure Report. 2006. Solid Waste Management. Available Online at http://www.iitk.ac.in/3inetwork/html/reports/IIR2006/Solid_Waste.pdf as of 08/09/2011 accessed on August, 28th 2012

ASTM E711- 87, 2004. Standard test method for gross calorific value of refuse derived fuel by the bomb calorimeter. Annual book of ASTM standard. 11. 04.

ASTM E-872, 2006. Standard method for estimation of volatile matter in Refuse Derived Fuel

Browning B. C., 1997. Method of Wood Chemistry, Interscience Publishers, New York, USA. Vol. 1 and 2.

CENT/TS 15407, 2006. Solid Recovered Fuels - Methods for the determination of carbon (C), Hydrogen (H), Nitrogen (N) content.

Chakravarty, S., 2013. Energy poverty alleviation and climate change mitigation In: Is there a trade off? Centro Euro-Mediterranno sui-Cambiamenti Climatici (CMCC). Issue: RP0169.

Chiemchaisri, C., Boonya Charnok and Visvanathan, C., 2010. Recovery of plastic wastes from dumpsite as refuse derived fuel and its utilization in small gasification system. Bioresource Techn. 101: 1522-1527.

Chyan, C. S., Yu-Long Hau, Li-Wei Wu, Hou-Peng Wau, Hom-Ti Lee and Ying-His, C., 2010. An investigation on pollutant emissions from co-firing of RDF and Coal. Waste Mgt. 30: 1334-1340.

Cordero, T., F. Marquez, J. Rodriguez - Mirasol and Rodriguez, J. J., 2001. Predicting values of lignocellulosics and carbonaceous material from proximate analysis. Fuel 80: 1567-1571

Environmental Protection Authority (EPA). 2010. Standard for the production and use of refuse derived fuel. South Australia, ISBN: 978-1-921495-07-6.

Garg, A., R. Smith, D. Hill, P.J. Longhurst, S.J.T. Pollard and Simms, N.J., 2009. An integrated appraisal of energy recovery options in the United Kingdom using solid recovered fuel derived fuel from municipal solid waste. Waste Mgt. 29:2289-2297

Genon, G. and Brazio, E., 2008. Perspectives and limit for cement kilns as a destination for RDF, Waste Mgt., 28: 2375-2385.

http://www.mapsofindia.com Accessed March 3, 2013

Kara, M. EsinGunay, YeseminTabak, SenolYildiz, and Volkan, ENC., 2008. The Usage of RDF from Urban Solid waste in cement industry as alternative fuel In: 6th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering and Environment (THE'08). Greece.

Kara, M. Esin Gunay, Yusemin Tubak and Yildiz, S., 2009. Perspectives for pilot scale study of RDF in Istanbul, Turkey. Waste Mgt., 29: 2976-2982.

Kaushal, R. K., George K. Varghese and Chabukdhra, M., 2012. Municipal Solid Waste Management in India-Current State and Future Challenges: A Review, Int. J. of Eng. Sci.and Techn. (IJEST), ISSN: 0975-5462 Vol. 4 No.04.

Koukouzas N., A. Katsiadakis, E. Karlopolos and Kakaras, E., 2008. Co-gasification of solid waste and lignite- A case study for Western Macedonia. Waste Mgt. 28: 1263-1275

Moran, J. C., J.L. Miguez, J. Porteiro, D. Patino, E.Granada and Collazo, J., 2009. Study of the feasibility of mixing Refuse Derived Fuel with wood pellets through the grey and Fuzzy Theory, Renewable Energy 34:2607-2612

Park, K.J., Byoung, J. Ahn and Hyun, C.S., 2008. A study on producing Refuse derived fuel Using Waste Plastic film and sewage sludge. The Usability of Raw material for RDF, EAEF 2(1): 57-62.

Partner, L.D., 2008. Alternative fuels in developing countries. MVW Lechtenberg, Reprint from World Cement, Germany.

Phyllis 2, database for biomass and waste, http://www.ecn.nl/phyllis2, Energy research Centre of the Netherlands, access date March 2013.

Poespowati, T., and Mustadi, L., 2012. Municipal solid waste densification as an alternative Energy. J. of Energy Techn. and Policy. Vol. 2 Issue No. 4 ISBN: 2224-3232.

Rees, O.W., 1966. Report of Investigations 220. Chemistry, Uses, and Limitation of Coal Analyses. Illinois State Geological Survey, Department of Registration and Education. USA.

Saikia, M. and Baruah, D., 2013. Analysis of physical properties of biomass briquettes prepared by wet Briquetting method. Inter. J. of Eng. Research Development. Vol. 6. Issue 5. pp 12-14.

Surroop, D., and Mohee, R., 2011. Power generation from refuse derived fuel. 2011 2nd International Conference on Environmental Engineering and Applications IPCBEE Vol. 17

Watanabe, N., Yamamoto, O., Sakai M and Fukuyama, J., 2004. Combustible and incombustible speciation of Cl and S in various components of municipal solid wastes. Waste Mgt., 24: 623–632.