Estimation of Energy Potential from Organic Fractions of Municipal Solid Waste by Using Empirical Models at Hyderabad, Pakistan

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ABSTRACT

MSW (Municipal Solid Waste) now-a-day is considered as a precious renewable energy resource for various purposes. In view of above fact, one hundred samples of MSW were collected from different locations of study area. Quantities of each organic waste component were determined by using physical balance and also their proximate analysis was performed by using oven and muffle furnace. In this study, nine empirical models were used for estimating the energy value in terms of heat from OFMSW (Organic Fractions of Municipal Solid Waste), namely two of them were based upon physical composition, four of them were on the basis of its proximate analysis and remaining three of them was according to ultimate analysis of OFMSW. From comparison of all energy models, the empirical Model No. 3 and No. 4 based upon proximate analysis have highest energy recovery potential than all of others. Moreover, the result of Model No.3 on the basis of proximate analysis is closer to the calorific value of mixed OFMSW than the values obtained by rest of models. Therefore, this is the best model to be used. From the outcomes of this study it can be realized that the energy recovery from the OFMSW plays a vital role for economical growth of the country. On that account, a systematic approach should be performed in detail before making a decision on such option.

Key Words: Composition of OFMSW, Energy Potential, Empirical Models, Organic Fractions of Municipal Solid Waste, Proximate and Ultimate Analysis.

1. INTRODUCTION

A limited supply of natural resources combined with continuously growing demand for energy and raw materials has promoted the development of recovering latent energy resources from MSW. Generation of MSW and its accumulation is progressively increasing due to human activities. There are serious environmental issues like air pollution, land pollution, surface water pollution and underground water quality deterioration due to applying improper waste management plan. Solid waste management is one of the critical concerns that are being faced by the developing countries because of the social, economic and environmental implications once not properly managed. Studies show that only 30-50% of the waste generated in developing countries is collected and managed properly [1]. Nowadays, Pakistan is seriously facing energy crisis.

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Therefore, the extraction of all renewable energy sources plays very significant role especially energy from OFMSW. Various energy forms like heat energy, electricity, production of chemicals including H_2 and CH_4 may be obtained from solid wastes by adopting different treatment methods of MSW. There are various points of importance i.e. conversion efficiencies, energy transport, technology type, economic and environmental impacts which should be considered before selection of a product for conversion process. Mostly heat energy has great importance for power generation and heating purpose [2]. The recovery of energy from the combustion of MSW is also known as waste to energy. This is encouraged by the national policies which are supported by the solid waste processing division of the American Society of Mechanical Engineers. Therefore, MSW is usually considered as a renewable energy source in most of the countries. Traditionally, open dumping and burning are most popular disposal practice for MSW in Pakistan. These both practices of MSW has generated many environmental issues like air pollution due to open burning of MSW, ground water quality deterioration due to leaching from open dumping of MSW and so many other environmental as well as social issues. Energy is recovered from MSW by using variety of technologies including combustion, RDF (Refuse Derived Fuel), pyrolysis etc. For evaluation of energy recovery feasibility, it is quite important to estimate an energy value of the OFMSW. Energy content of OFMSW is stated as producing the number of heat units during burning of unit mass of a sample material. It is measured in joules per gram or British thermal units per pound. The energy value of solid wastes is a function of various factors such as moisture content, volatile matters, ash content and composition of wastes [3]. The energy content of materials like solid wastes is determined by applying different available empirical as well as experimental approaches. From which, one common technique for determination of energy value of OFMSW is known as calorimetric measurement [4]. This technique is further divided into two types; one is open calorimeter method and second is bomb calorimeter method. In the former method, pressure is maintained at the atmospheric pressure. The combustion heat is escaped under condition of constant pressure which is equal to the change of enthalpy for a reaction. Under constant volume conditions, combustion is conducted in second type of calorimetric measurement. According to the empirical approaches, varieties of mathematical models are adopted for prediction of energy value from materials like MSW. Mostly theses are on the basis of physical composition and proximate and ultimate analysis of OFMSW [5]. In this study about nine empirical models have been used in order to estimate energy potential in terms of heat from OFMSW, generated in Hyderabad city of Pakistan. Two of them were based upon physical composition, four of them were on the basis of its proximate analysis and remaining three of them was according to ultimate analysis of OFMSW.

2.   STUDY AREA

Hyderabad city was selected for this study which is said as a former capital city of the province Sindh. Until the reforms of 2000 abolished the third tier of government, it was considered as an administrative division of the Sindh namely the Hyderabad Division. After Karachi, it is the second most urbanized district of a Sindh according to the 2012 census of Pakistan. A map of the city is given in Fig.1. Administratively, it has four talukas namely Hyderabad City, Hyderabad Rural, Qasimabad and Latifabad. On globe its location lies between 25º 22´ 45" North and 68º 22´ 6" East [6], positioned at about an elevation of thirteen meter above the sea level and is 150km away from Karachi [7].

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3. METHODOLOGY

3.1 Physical Composition of OFMSW

The physical composition of wastes is defined as the distribution of various wastes components according to their percent weight of the total weight of mixed solid wastes. One hundred samples of MSW were collected from both residential as well as commercial areas of each talukas of Hyderabad city. In order to find out the percentage of organic components (i.e. cardboard, food waste, leather, paper, plastic rubber, textile, wood and yard wastes) of MSW, wastes were manually sorted. Whereas other inorganic waste components (i.e. metals, glass, dirt, bricks, repair and demolition wastes) were discarded. Then the percentage by weight of each organic component was calculated by using physical balance. Empirical models were used for predicting an EV (Energy Value) of MSW sample on the basis of its physical composition as given in Table 1.
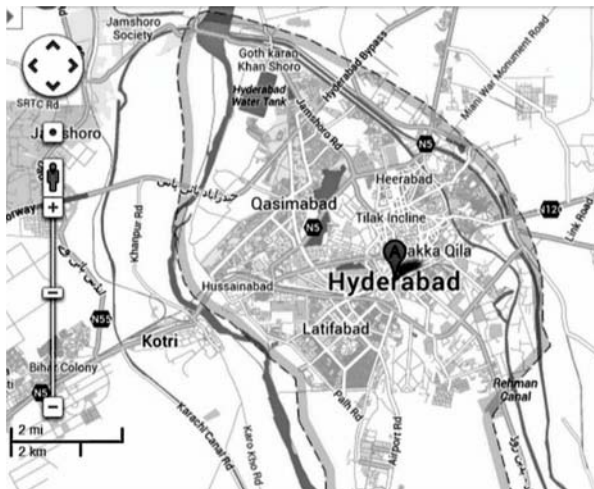

FIG. 1. MAP OF HYDERABAD CITY

3.2 Proximate Analysis of OFMSW

Proximate analysis (i.e. determination of moisture content, volatile matters, ash contents and fixed carbon) of all selected organic waste components of MSW was conducted by using Oven Dry and Muffle Furnace. Sample size of 50 gms of each food and yard wastes and 100 gm of each other waste components (i.e. cardboard, leather, paper, plastic rubber, textile and wood) were taken for analyzing [11]. For moisture content, samples of food and yard wastes in a ceramic crucible were first weighted and put in an oven at 105ºC for 24 hours according to the ASTMD 3173. Then weights after heating were also recorded. For the other waste stream components, the heating time was 1hr; because the waste samples were dry [11]. The moisture content percentage was determined as a percentage loss in weight before as well as after drying by using Equation (1) [12].

$$MC(\%) = [(a-b)/a]100 \qquad (1)$$

Where MC is the moisture content and a and b are the wet weight and dry weight of the sample, respectively. According to the ASTMD3175, the ignition method was used for determining the volatile matter of OFMSW in percentage. After calculating the percentage of moisture content, triplicate samples were weighed and heated in a muffle furnace at 950ºC for seven minutes in a covered crucible [13]. The samples were placed in decicator for cooling purpose after combustion. After that, it was again weighed for determination of the dry weight of the sample. Volatile matters were determined on wet and dry basis by using Equations (2-3), respectively.

TABLE 1. SOME EMPIRICAL MODELS FOR PREDICTING EV OF MSW ON THE BASIS OF ITS PHYSICAL COMPOSITION

Name	Equation
EM(Ph-Comp.)-1	EV= [88.2 Ppl + 40.5 (Pfo + Ppa) [(100 - W)/W] - 6W [8,9]
EM(Ph-Comp.)-2	EV = 2229.91 + 7.90Ppa + 28.16Ppl + 4.87Pga - 37.28W [8,10]
EM(Ph-comp.) = Empirical Models on the basis of physical composition, EV = Energy value (kJ/kg), Ppl: plastics (wt %), Pfo: food waste (wt %), Ppa: paper and cardboard (wt %), Pga: garbage (wt%; textiles, wood, food waste, leather waste, rubber waste, yard waste), W: moisture content (%) wet basis	

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$$VM_{(wb)} = [(b-c)/a]\ 100 \qquad (2)$$

$$VM_{(db)} = [(b-c)/b]\ 100 \qquad (3)$$

Where $VM_{(wb)}$ and $VM_{(db)}$ are the volatile matter on wet and dry basis, respectively. Whilst, a, b and c are the wet weight, weight after oven and weight after furnace, respectively. After burning of waste sample, the non-combustible residue is left which is the natural material after carbon, sulfure, water and oxygen, called as ash content. According to ASTMD 3174, analysis of ash content includes the triplicate samples of solid wastes were put into a muffle furnace at 750ºC for one hour after drying oven. Similarly, the material that is left after volatile test is known as fixed carbon. Both ash and fixed carbon content of solid wastes were determined on wet and dry basis by using Equations (4-5):

$$AC_{(wb)}\ or\ FC_{(wb)} = (c/a)\ 100 \qquad (4)$$

$$AC_{(db)}\ or\ FC_{(db)} = (c/b)\ 100 \qquad (5)$$

Where $AC_{(wb)}$ or $FC_{(wb)}$ and $AC_{(db)}$ or $FC_{(db)}$ stand for ash content or fixed carbon on wet and dry basis, respectively. Whilst, a, b and c are the wet weight, dry weight of sample after oven & weight of sample after furnace, respectively. Some empirical models for predicting EV of MSW on the basis of its proximate analysis were used as given in Table 2.

3.3 Ultimate Analysis of OFMSW

For the ultimate analysis of OFMSW, the standard procedure was adopted according to the BBOT23122013 method. Ultimate analysis of waste aims to analyze percent of carbon, hydrogen, nitrogen, oxygen, sulphur and ash. It is an important parameter in the selection of various wastes processes. Percent of carbon, hydrogen, nitrogen and sulphur was calculated by FleshEA 1112 Elemental Analyzer whereas percent of oxygen was determined by difference method as in Equation (6).

$$0(\%) = 100 - C(\%) - H(\%) - N(\%) - S(\%) - Ash(\%) \qquad (6)$$

Flesh EA 1112 Elemental Analyzer is a simple, precise and cost effective technique for ultimate analysis of solid wastes. This works on the basis of the dynamic flash combustion (modifies Dumas method) of sample for the determination of carbon, hydrogen, nitrogen and sulfur. Samples were weighted in a tin capsule before inserting into the combustion reactor by using an autosampler. Pure oxygen was added to the system in order to promote the burning of organic substance as well as inorganic substance for converting the sample into gases. After that, element concentrations were determined through separation column and detector without using a complex splitting system. Empirical models for the prediction of energy value of MSW on the basis of its ultimate analysis were used as given in Table 3.

TABLE 2. SOME EMPIRICAL MODELS FOR PREDICTING EV OF MSW ON THE BASIS OF ITS PROXIMATE ANALYSIS

Name	Equation
EM(Pro-Anal.)-1	EV = 45VM-6W [3,8,9]
EM(Pro-Anal.)-2	EV = 44.75VM-5.85W+21.2 [3,8,14,9]
EM(Pro-Anal.)-3	EV = 356.248VM - 6998.497 [14]
EM(Pro-Anal.)-4	EV = 356.047VM - 118.035FC - 5600.613 [14]
EM (Pro-Anal.) = Empirical Models on the basis of Proximate Analysis, EV = Energy Value (kJ/kg), VM = Volatile Matter (%) dry basis, W = Moisture Content (%) wet basis and FC = Fixed Carbon Content (%) Dry Basis	

4.2 Empirical Models Based Upon Proximate Analysis of OFMSW

Proximate analysis of OFMSW includes determination of moisture content, volatile matter, fixed carbon and ash content. The results of all parameters on wet as well as on dry bases are given in Table 4. Generally, the components having high moisture content possess low volatile matters and vice versa.

From Table 4 it is clear that there are different values of proximate analysis of OFMSW, which indicates that organic components of MSW consist variety of physical and chemical constituents. The percentage of MC
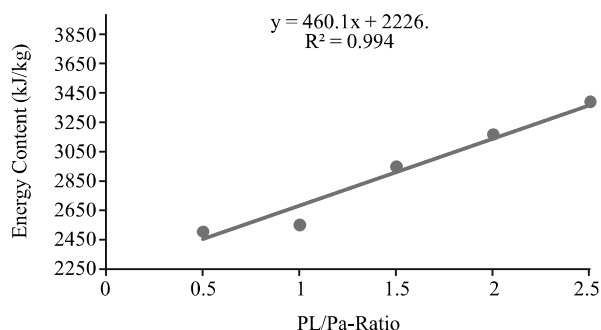

$y = 460.1x + 2226.$
$R^2 = 0.994$

FIG. 4. RALATIONSHIP BETWEEN EV OF OFMSW AND PLASTIC TO PAPER RATIO.

(Moisture Content) in all OFMSW samples lies in between 0.24 and 75.02%. The minimum and maximum moisture content value is for plastic and food wastes, respectively. The value of VM (Volatile Matter) on the dry basis in all OFMSW samples is in the range of 76.44-97.01%. The minimum is for the cardboard and maximum is for the plastic. The result of VM on the wet basis in all OFMSW samples is in the range of 19.12-96.21% for food wastes and plastic, respectively. The minimum FC on the dry basis is shown in plastic about 4% and the maximum in leather about 27%. The minimum FC (Fixed Carbon) on the wet basis is shown in plastic about 3% and the maximum in leather about 26.30%. Similarly the AC (Ash Content) on the dry basis in all OFMSW samples lies in between 3 and 27% which shows as 3% is for wood wastes and 7% is for rubber wastes. The AC on the wet basis in all OFMSW samples is represented from 2.26-26.45%. The lower value and higher value of AC is shown in wood and rubber wastes, respectively. The results regarding proximate analysis of present study show approximately similarity with the study conducted by [12] on the identification of the MSW characteristics and potential of plastic recovery at Bakri Landfill, Muar, Malaysia. in

TABLE 4. RESULTS OF PROXIMATE ANALYSIS OF OFMSW SAMPLES

No.	Waste Components	Moisture Content (%)	Volatile Matter (%)		Fixed Carbon (%)		Ash Content (%)	
		Wet Basis	Wet Basis	Dry Basis	Wet Basis	Dry Basis	Wet Basis	Dry Basis
1.	Cardboard	3.91	73.3	76.4	22.6	23.6	22.2	23.1
2.	Food	75.0	19.1	83.1	4.1	17.1	2.36	9.9
3.	Leather	0.71	72.9	73.5	26.3	27.0	20.2	21.4
4.	Paper	4.82	80.8	85.1	14.1	15.0	12.4	13.0
5.	Plastics	0.24	96.2	97.1	3.7	4.0	4.43	5.1
6.	Rubber	0.18	90.1	91.0	9.7	9.0	26.4	27.4
7.	Textile	1.34	92.1	93.0	6.1	7.1	5.04	6.13
8.	Wood	4.71	84.3	88.4	11.0	12.0	2.26	3.1
9.	Yard waste	30.4	65.3	91.9	5.7	8.1	6.43	9.1

which, the MC, VM, FC and AC of cardboard/paper, food waste, rubber/leather, plastic, yard waste and textile are 3.1-4.3, 75-82, 1.5-3.2, 0.54-0.82, 13-38 and 5.5-9.5, 84.0, 80.0, 65.0, 97.0, 75.0 and 74.0, 7.0, 6.0, 8.0, 12.0, 7.0 and 18.0 and 9.0, 14.0, 22.0, 1.4, 20.0 and 7.0, respectively.

Based upon proximate analysis of OFMSW, the results of emprical models is shown in Fig. 5 along with CV_s of each component. From Fig. 5, the results of $EM_{(Pro-Anal.)}$-1 and $EM_{(Pro-Anal.)}$-2 show that there is little bit difference between the energy values, obtained by both models which are lower than other models. This is because of including moisture content in both models whereas $EM_{(Pro-Anal.)}$-3 and $EM_{(Pro-Anal.)}$-4 are free from moisture content. The energy value by $EM_{(Pro-Anal.)}$-3 of cardboard, food waste, paper, leather and wood waste is higher than the energy value by $EM_{(Pro-Anal.)}$-4 and near to the CV_s of corresponding waste components. Whereas the result by $EM_{(Pro-Anal.)}$-4 of plastic, cloth wastes, a rubber and yard waste is higher than the result by $EM_{(Pro-Anal.)}$-3 and near to the CV_s for, respectively waste components. From the results of all models, the EV of $EM_{(Pro-Anal.)}$-3 and $EM_{(Pro-Anal.)}$-4 is higher than the energy value of others, which represents that these empirical models are beneficial for estimation of energy potential in the terms of heat from OFMSW. From Fig. 5, it is also clear that the plastic, rubber and textile have high EV in terms of heat so these are very useful for thermal conversion treatment process of MSW. All PCs (Putrescible Components) including food and yard wastes along with other components are currently either dumped or burned in most of cities of the country. Only some quantity of PCs and MSW are disposed off by composting and landfill in improper way. Because of unawareness regarding basic rules of recycling, about 20-30% of waste is recycled in the country. This paper reveals that PCs of MSW are more suitable for either composting or anaerobic digestion. Whereas, rest of MSW components like paper, plastic, rubber, leather, wood, cardboard, textile etc have capacity to generate huge quantity of heat. This means, thermal treatment such as incineration, pyrolysis, gasification or any other is favorable for their treatment in order to extract energy in terms of heat from them. By doing this, not only energy shortage facing by the country but also dumping as well as burning of MSW which leads to pollute environment would be overcomed to some extent.

Also the EV based upon proximate analysis of mixed OFMSW alon with CV_s is shwon as shown in Fig. 6. From Fig. 6, it is clear that $EM_{(Pro-Anal.)}$-3 and $EM_{(Pro-Anal.)}$-4 have high energy potential based upon proimate analysis and nearest to the CV_s of mixed OFMSW.
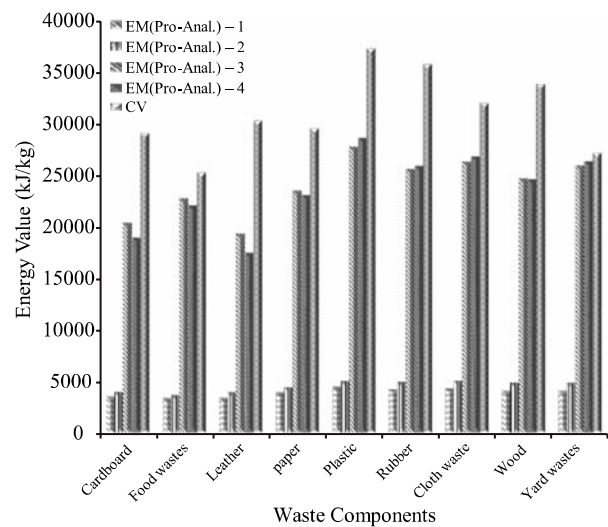

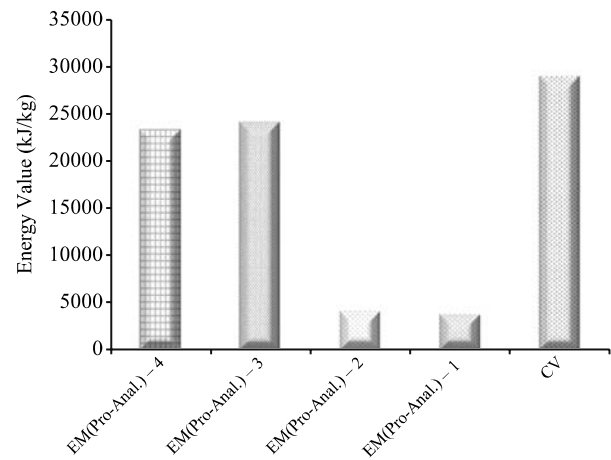*FIG. 5. EV OF EMPIRICAL MODELS BASED UPON PROXIMATE ANALYSIS OF OFMSW*

FIG. 6. EV OF EMPIRICAL MODELS BASED UPON PROXIMATE ANALYSIS OF MIXED OFMSW

4.3 Empirical Models based upon ultimate analysis of OFMSW

The result regarding percent of carbon, hydrogen, nitrogen, oxygen, sulfur and ash of OFMSW is given in Table 5.

By using the typical data of percent by weight, moisture content and ultimate analysis of the OFMSW, revised chemical composition mixed of OFMSW corresponding to 100kg of sample was determined as shown in Fig.7. From Fig. 7 it is observed that percentage of oxygen and carbon are the first and second dominant components upon other chemical constituents of the waste. By converting mass composition of elements of OFMSW into the molar composition, the approximate molecular formula for the mixed OFMSW with and without sulfur was determined as $C_{1288}H_{3379}O_{1852}N_{10}S$ and $C_{124}H_{326}O_{179}N$, respectively.

After that the EV based upon ultimate analysis of mixed OFMSW was determined by using three emprirical models as shown in Fig. 8. From Fig. 8, it is clear that $EM_{(Ult-Anal.)}$-2 has highest energy potential whereas, $EM_{(Ult-Anal.)}$-1 has lowest energy potential than all of others.

4.4 Comparison between Empirical Models for Estimation of Energy Potential from OFMSW

All empirical models for estimation of energy potential from OFMSW were compared as shown in Fig. 9 along with CV. From comparison of all energy models, it is
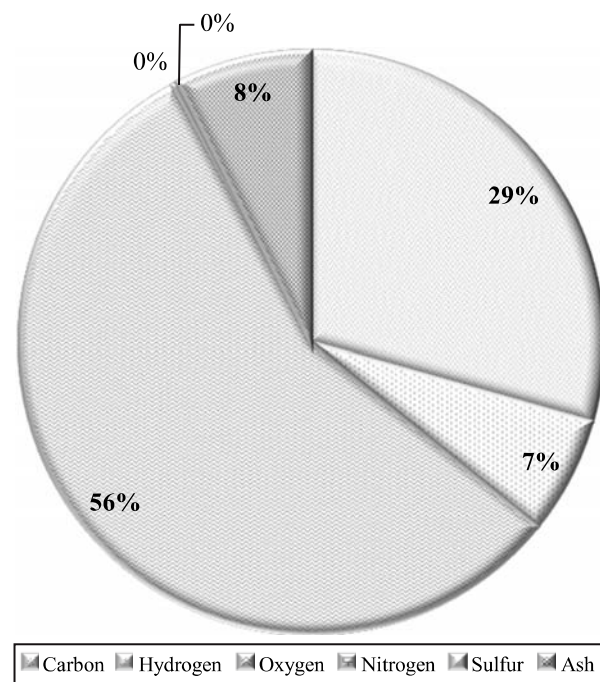

FIG. 7. CHEMICAL COMPOSITION OF MIXED OFMSW

TABLE 5. RESULTS OF ULTIMATE ANALYSIS OF OFMSW SAMPLES

Components	C (%)	H (%)	O (%)	N (%)	S (%)	Ash (%)
Cardboard	20.9	0.0	56.02	0.0	0.1	23.02
Food Wastes	35.6	6.43	46.49	1.53	0.18	9.81
Leather	38.9	5.48	33.89	0.15	0.26	21.36
Papers	41.0	7.44	38.5	0.0	0.08	13.00
Plastics	71.9	0.0	23.02	0.0	0.0	5.06
Rubber	58.3	0.0	14.06	0.0	0.17	27.43
Textiles	49.5	6.45	37.92	0.0	0.0	6.13
Wood	44.7	2.92	49.77	0.0	0.15	3.06
Yard Waste	45.4	8.03	36.32	1.04	0.12	9.13

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observed that empirical models based upon proximate analysis of OFMSW have highest energy recovery potential than all of others. It is inverse of a comparison of the EV with the determined EV of MSW by empirical models. These models resulted in excellent agreement with that of models on the basis of physical composition of MSW which is not in the case of other models regarding proximate analysis of MSW [3].

Fig. 9 shows that the result of $EM_{(Ult-Anal.)}$-2 is also higher than that of empirical models on the basis of physical composition and $EM_{(Pro-Anal.)}$-1 and $EM_{(Pro-Anal.)}$-2 according to proximate analysis of OFMSW. One reason behind the higher and lower results of models is either the presence or absence of moisture content.
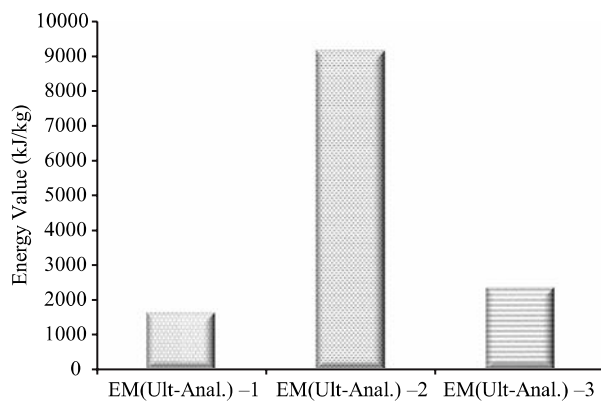

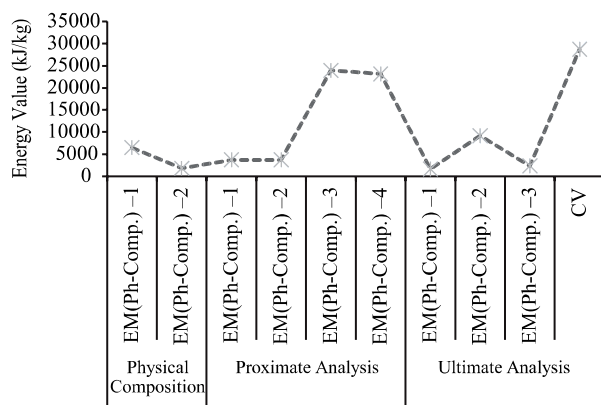*FIG. 8. EV OF EMPIRICAL MODELS BASED UPON ULTIMATE ANALYSIS OF MIXED OFMSW*

FIG. 9.COMPARISON BETWEEN EMPIRICAL MODELS FOR ESTIMATION OF ENERGY POTENTIAL FROM OFMSW

From Fig.9, it can be observed that the $EM_{(Pro-Anal.)}$-3 shows closer results to the CV of OFMSW as compared to other models. The CV of OFMSW was obatined to be 28,673 kJ/kg that is higher than the CV of MSW (i.e. 23,000kJ/kg) generated in Malaysia studied by [13]. This is due to presence of higher contribution of plastic in the composition of OFMSW as compared to the MSW of malaysia. Also the EV of MSW varies from country to country because of various factors including climate condition, season of year, types of component etc. Another reason of having higher CV of present study is that the study area is mostly facing hot and dry climate across the year [18] and CV was calculated without including moisture content as determined by [19].

5. CONCLUSION

Waste reduction and minimization are only possible by adopting integrated solid waste management plan. Energy recovery potential from OFMSW is one of the most important aspects of waste minimization technique. So for that different energy potential models were examined based upon various characteristics of MSW. Estimation of energy potential by empirical models according to physical composition of OFMSW was observed in the range of 1790-6455 kJ/kg. The energy potential of empirical models on the basis of proximate and ultimate analysis of OFMSW was observed in the range of 3676-23907 and 1626-9126 kJ/kg, respectively. From comparison of all energy models it is concluded that $EM_{(Pro-Anal.)}$-3, $EM_{(Pro-Anal.)}$-4 and $EM_{(Ult-Anal.)}$-2 have highest energy recovery potential than all of others. Moreover, the energy value of $EM_{(pro-Anal.)}$-3 also has been observed as closet to the CV of mixed OFMSW. Therefore, this model is best to be used as compared to the rest of models. Moreover, the energy recovery from the OFMSW plays significant role for economic growth of the country. Therefore, a detailed study is the need of time on such option of energy recovery from waste.

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