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Research Article

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Optimization of Energy Contents on Municipal Solid Waste in Auchi Metropolis using Response Surface Methodology

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Abstract Municipal solid waste management and low electric energy supplied are two major problems affecting the development of Auchi metropolis. This work is aimed at optimizing the heat energy from municipal solid waste in Auchi, Nigeria and its potential for electricity generation.

A sample was measured into analytical balance and muffle furnace for experimental analysis to determine the weight of input parameters from the various municipal solid waste components. Statistical design of experiment (DOE) using central composite design (CCD) matrix version (13.0.5.0) was employed to determine the optimum value of each input parameters that will minimize the rate of solid waste disposal and generate heat energy responses using Response Surface Methodology. Reliability was produced to test the networks adequacy.

The central composite design (CCD) matrix produced heat energy value of 26,102.6kJ/kg with a reliability plot of 80.6% was obtained from response surface methodology (RSM). The study established the heating values for energy potential of the municipal waste components in the area. The results showed that energy recovery is a feasible option as part of an integrated municipal waste management plan in Auchi metropolis, Nigeria.

Keywords Solid waste, heat energy, and response surface methodology

1. Introduction

Municipal solid waste management is one of the major environmental problems of Nigeria cities. Improper management of municipal solid waste causes hazards to inhabitants. Massive volume of solid waste is generated every day in the municipal areas and unfortunately solid waste management is deteriorating day by day (Vergara and Tchobanoglous, 2019)

According to Egwurube, (2020) stated that rapid urbanization, industrialization and population growth have led to severe waste management problems in several cities of developing or under developed world like Nigeria. The uncontrolled urbanization has left many Nigerian cities devoid of many infrastructural services such as water supply, sewerage and municipal solid waste management. Most of urban centers in Nigeria are overwhelmed by severe problems related to solid waste due to lack of low efforts by town/city authorities, garbage and its management. Great increase in the amount of municipal solid waste has been reported in the cities due to an improved lifestyle and social status (Oji *et al.*, 2020). Kumar *et al.*,, (2019) stated that quickening urbanization accompanied with increasing per capita incomes have also led to rapid increases in MSW generation that have dramatically expanded the burden on local governments in Nigeria for collection, processing, and disposal of MSW in efficient ways. Municipal corporations in Nigeria are unable to handle increasing quantities of waste, which results in uncollected waste on roads and in other public places.

Statement of the Problem

Auchi metropolis has serious problem on municipal waste management and electricity, load shedding is now impractical as living standards now become a great barrier in socio-economic growth in the metropolis. Hence there is need for an alternative source of energy to boost electric energy supply in Auchi metropolis. Recovering energy from municipal solid waste is feasible by means of a number of energy generation processes such as combustion, pyrolysis and gasification.

Aim and Objectives of the Study

The aim of this work is to optimize the energy contents of municipal solid waste as a potential for electricity generation in Auchi metropolis using response surface methodology.

In order to fulfill the aim of this study, the following objectives were pursued. They include to:

1. carry out site-specific study to determine waste collection points in the metropolis under investigation;
2. characterize the generated municipal solid wastes into their various component;
3. determine the range of input parameters from the characterized waste using analytical balance and muffle furnace
4. estimate the potential of waste for electricity generation using statistical design of experiment (DOE) with central composite design (CCD) matrix version (13.0.5.0)
5. optimize and predict the target responses of the classified municipal solid wastes using Response Surface Methodology model.

Limitation to the Study

This research study is limited to characterization and energy estimation of the municipal waste in Auchi metropolis using Response Surface Methodology models for electric energy optimization. This tool is a starting point to help with integrated waste management planning, not the end point.

Methodology

The generated municipal solid waste in the metropolis was classified into four (4) groups namely due to their energy behaviors; food waste, wood waste, plastic waste, and cotton waste (Aliu and Ogbeide, 2021). The central composite design (CCD) of RSM was used for the statistical analysis for heat energy prediction and optimization of the heating energy responses. The statistical model help to reduce the volume of municipal solid waste generated in the metropolis as well as estimated and optimizes the heat energy responses from various municipal solid wastes in the area.

Results and Discussion

Results Presentation

In the process of this research work, a sample was measured for Laboratory experiment to determine the range (kg) of input parameters from the various characterized waste in the metropolis under investigation using analytical balance and muffle furnace. The results are depicted in Table 1. Statistical design of experiment (DOE) using the central composite design method (CCD) was done. Central composite design (CCD) is unarguably the most acceptable design for response surface methodology (RSM). The design and optimization was done using statistical software and for this particular problem, Design Expert 13.0.5.0 was employed as presented in Table 2.

Table 1: The range of process Input parameters

Categories	Factors	Units	Minimum	Maximum
A	Food waste	Kg	11	14
B	Wood waste	Kg	18	26
C	Plastic waste	Kg	140	170
D	Cotton waste	Kg	130	170

Table 2: Build information for the CCD design was presented in Table 4 3, having a quadratic behavior

File Version	13.0.5.0		
Study Type	Response Surface	Subtype	Randomized
Design Type	Central Composite	Runs	30
Design Model	Quadratic	Blocks	No Blocks
Build Time (ms)	2		

The Central Composite Design and Design of Experiment for the range of process input parameters of the municipal waste components with coded responses to determine the optimum value of each input variable namely: food waste, wood waste, plastic waste, and cotton waste that will minimize the rate of solid waste disposal and generate heat energy from the municipal waste in the metropolis under investigation resulting to about 30 experimental runs was generated. The real values are presented in Table 3.

Table 3: Central Composite Design and Design of Experiment for the municipal waste

	Factor 1	Factor 2	Factor 3	Factor 4
Run	**A:Food waste**	**B:Wood waste**	**C:Plastic waste**	**D:cotton waste**
	Kg	Kg	Kg	Kg
1	13	22	160	150
2	13	22	160	150
3	13	22	160	150
4	13	22	160	150
5	13	22	160	150
6	13	22	160	150
7	13	26	160	150
8	11	22	160	150
9	13	22	140	150
10	13	22	160	170
11	13	22	160	130
12	13	22	160	150
13	13	18	160	150
14	13	22	160	150
15	12	20	170	140
16	12	24	150	160
17	12	20	170	160
18	14	24	170	140
19	14	24	150	140
20	12	24	170	140
21	14	24	170	160
22	12	24	150	140
23	12	24	170	160
24	12	20	150	160
25	14	20	150	140
26	14	20	170	140
27	12	20	150	140
28	14	20	150	160
29	14	24	150	160
30	14	20	170	160

The histogram plot on Figure 1 presented the frequency against heat energy of the municipal waste fraction from Auchi metropolis that was subjected to about 30 experimental runs for heat energy generation.

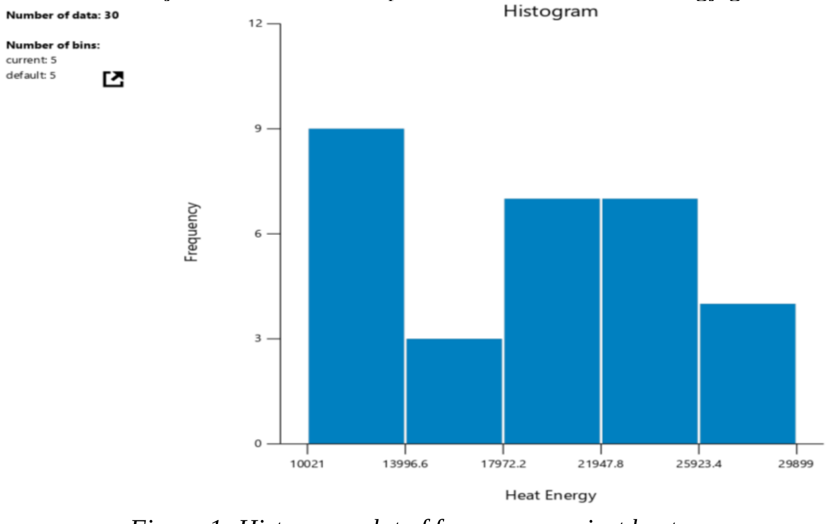

Figure 1: Histogram plot of frequency against heat energy

The heat responses analysis as generated from the histogram, the upper and the lower heating limit was considered and subjected into response surface methodology (RSM) for prediction and optimization of electricity estimation from the municipal solid waste in the metropolis under investigation.

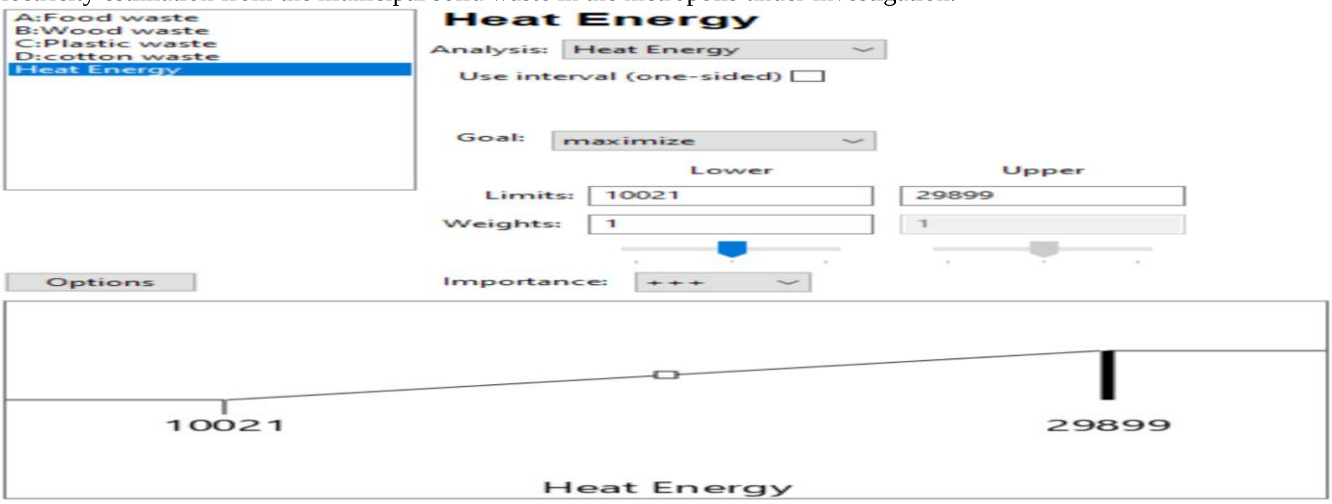

Figure 2: Optimization of Factors to obtained best yields of Heat Energy

The optimization analysis results as generated from the (RSM) network, is presented in Table 4 below:

Table 4: 20 Optimum solutions for the generated heat energy

Number	Food waste	Wood waste	Plastic waste	cotton waste	Heat Energy	Desirability	
1	**12.000**	**20.000**	**170.000**	**140.000**	**26102.576**	**0.809**	**Selected**
2	12.000	20.274	170.000	140.000	26002.378	0.804	
3	12.001	20.000	170.000	140.160	26002.084	0.804	
4	12.000	20.406	170.000	140.000	25953.119	0.801	
5	12.001	20.221	169.784	140.000	25901.711	0.799	
6	12.002	20.603	170.000	140.000	25861.973	0.797	
7	12.000	20.764	170.000	140.000	25817.921	0.795	
8	12.000	20.843	170.000	140.000	25788.517	0.793	
9	12.000	20.888	170.000	140.000	25771.044	0.792	
10	12.000	20.934	170.000	140.067	25714.522	0.789	
11	12.000	20.000	150.000	140.000	25712.215	0.789	
12	12.000	20.014	150.000	140.014	25676.696	0.788	
13	12.001	20.000	150.116	140.000	25650.435	0.786	
14	12.000	21.251	169.992	140.001	25625.089	0.785	
15	12.000	21.316	170.000	140.000	25604.658	0.784	
16	12.000	20.015	150.000	140.145	25603.896	0.784	
17	12.000	20.000	150.000	160.000	25570.507	0.782	
18	12.000	21.446	169.993	140.000	25549.346	0.781	
19	12.009	20.000	150.004	159.997	25478.685	0.778	
20	12.000	20.083	150.170	140.000	25472.022	0.777	

From the results of Table 4, it was observed that the input data of the waste components will produce a heating value of 26102.756. This solution was selected by design expert as the optimal solution with a desirability value of 0.809.

The Results of the optimum solutions for the generated heat energy is presented in Figure 3.

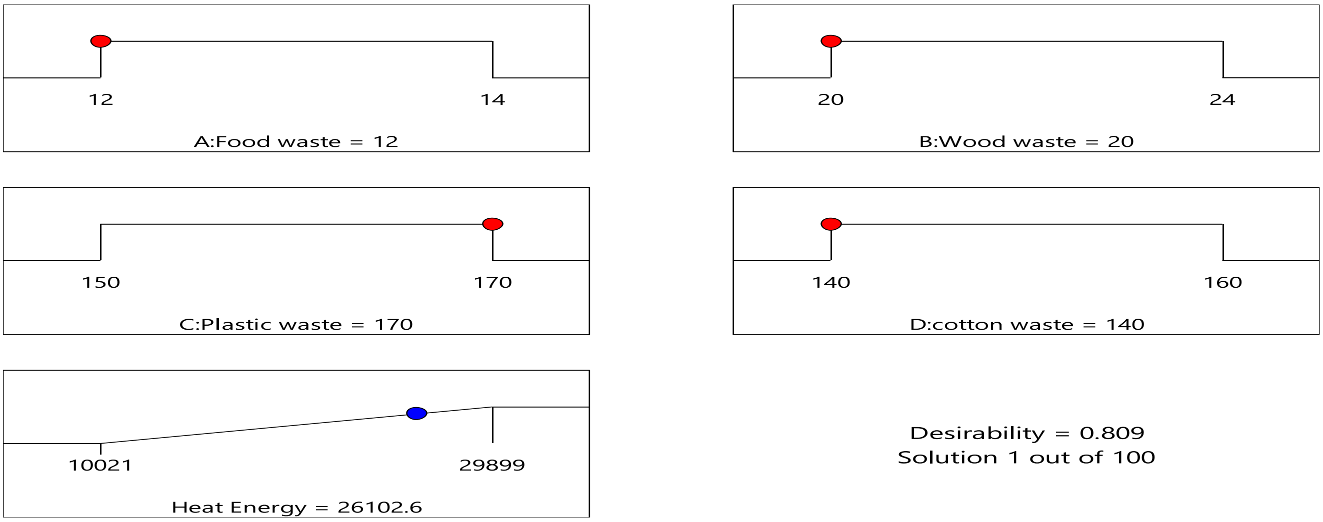

Figure 3: Results of the optimum solutions for the generated heat energy

The desirability bar graph for the generated heat energy which shows the accuracy with which the model is able to predict the values of the selected input variables and the corresponding responses is presented in Figure 4.

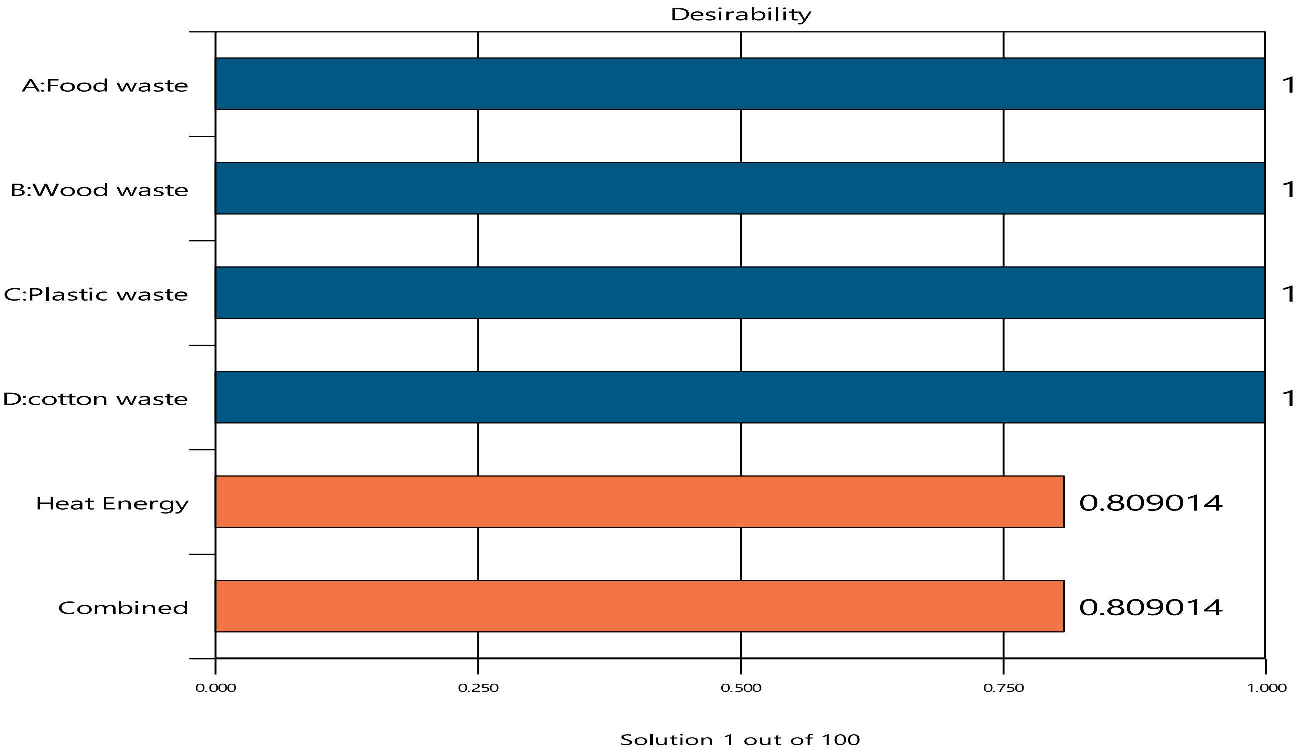

Figure 4: Desirability solutions for the generated heat energy

It can be deduce from the result of Figure 3, that the model developed based on response surface methodology are optimized using numerical optimization method and predicted the heat energy of 0.809014 as indicated in peturbation curve shown in figure 5.

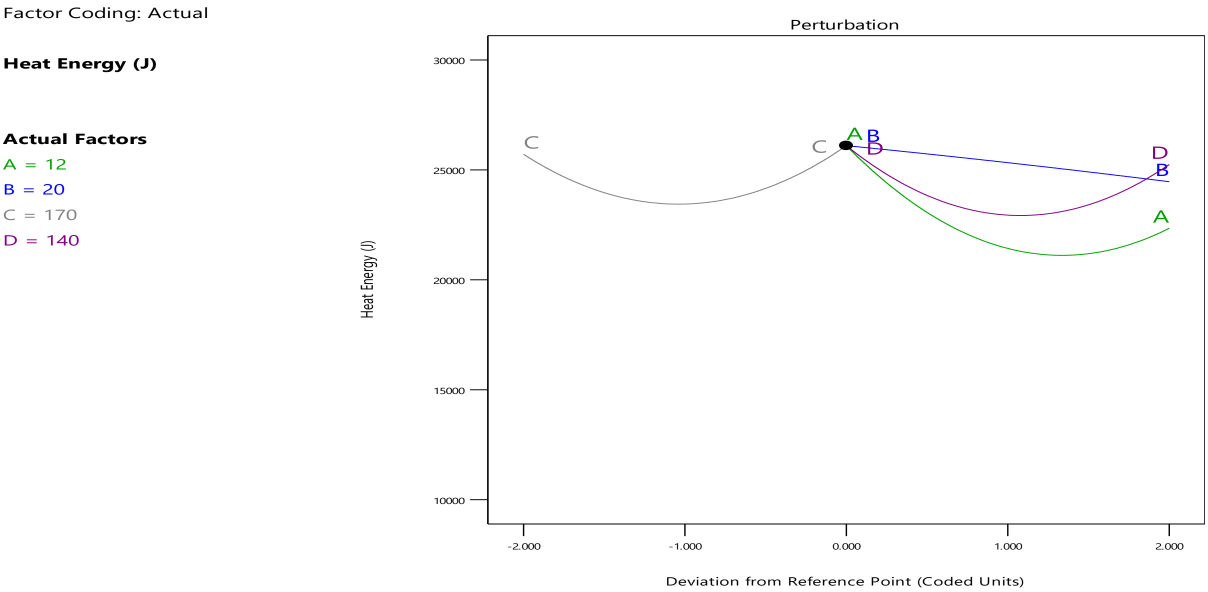

Figure 5: Perturbation Curve

Table 5: RSM in Comparison with the Experimental Heat Energy

S/N	EXP Heat energy (J)	RSM Heat energy (J)
1	10324	13017.9
2	10326	13017.9
3	10323	13017.9
4	10324	13017.9
5	10325	13017.9
6	10323	13017.9
7	10021	9897.8
8	29899	29003.4
9	22015	21119.4
10	20005	19468.6
11	28765	28405.8
12	21325	13017.9
13	16534	15761.6
14	20873	13017.9
15	27276	26102.6
16	15454	18020.2
17	23843	25244.6
18	23438	24030.2
19	21037	20230.3
20	21552	24463.8
21	16371	15234.7
22	19965	17750.2
23	26262	24017.6
24	25862	25570.5
25	22322	24867.1
26	24315	22343.7
27	23981	25712.2
28	18693	16376.1
29	10677	12151.1
30	10621	13136.5

A regression plot of output between the experimental values of heat energy and the predicted values of heat energy was generated using RSM. Coefficient of determination (r^2) was calculated for RSM predicted values of heat energy as presented in figure 6. The rule of higher the better was employed to select the best model for predicting the surface tension.

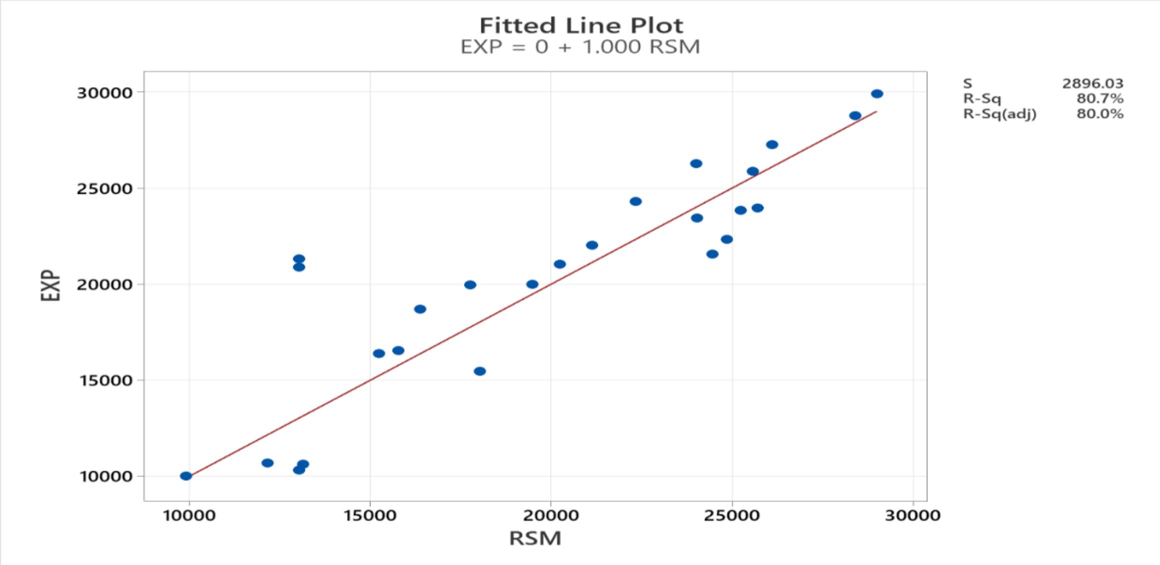

Figure 6: Fitted Line Plot for EXP vs RSM

Worksheet I

Regression Analysis: EXP versus RSM

The regression equation is EXP = 0 + 1.000 RSM

Table 6: Model Summary for the Regression Analysis of EXP versus RSM

S	R-sq	Rq(adj)
2896.03	80.69%	80.00%

Table 7: Analysis of Variance of EXP versus RSM

Source	DF	SS	MS	F	P
Regression	1	981251637	981251637	117.00	0.000
Error	28	234835182	8386971		
Total	29	1216086819			

Discussion

The response surface methodology neural network was used to optimize the input parameters such as food waste, wood waste, plastics waste and cotton waste. A model was developed using the Response surface methodology (RSM), the Result revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The diagnostic case statistics actually give insight into the model strength and the adequacy of the optimal second order polynomial equation.To asses the accuracy of prediction and established the suitability of response surface methodology using the quadratic model, a reliability plot of the observed and predicted values of each response were obtained.

In the optimization phase, the optimum value of the municipal waste was determined. From the results, it was observed that from the 30 optimum solutions from the generated heat energy, food waste is 12, wood waste is 20, plastic waste is 170, and cotton waste is 140 respectively. It also has a desirability of 0.809 and Heat Energy of 26102.6. Response surface methodology using numerical optimization was effective in predicting the municipal solid waste in the metropolis. It was also relevant in determining the exact mathematical relationship between the input parameters and the response variables.

Findings

Arising from the outcome of this study, the following are the findings.

1. The average composition of the municipal solid waste was 33.3% of food waste, 17.2% of plastic waste, 16.9% of paper waste of 10.3%, textile waste of 13.3% of garden trimming waste, 5.9%, wood waste, and 3.0% tin cans waste were determined.
2. Ultimate analysis to determine the amount of carbon, hydrogen, oxygen, nitrogen, sulphur, and ash content from the municipal solid waste properties in the metropolis were performed.
3. Dulong's model was suitable for the determination of heat energy value of 145,831.49kJ/kg for electricity estimation in the metropolis.

4. Statistical design of experiment (DOE) using central composite design (CCD) matrix version (13.0.5.0) that were employed gave optimum heat energy value of 26,102.6kJ/kg for electricity estimation as well as minimizing the rate of municipal solid waste disposal in the Auchi metropolis.
5. The overall performances of the developed models for heat energy estimation from the municipal solid waste disposal problem shows R^2 value of 93% for training, 91% for validation, 81% for testing, and 90% for overall with a reliability plot of 80.6% for response surface methodology (RSM), and 81.7% for artificial neural network (ANN).

Conclusion

Auchi metropolis produces large quantity of municipal solid waste. Statistical design of experiment (DOE) using central composite design (CCD) matrix was employed to determine the optimum value from the waste parameters that will minimize the rate of solid waste disposal as well as generating heat energy to boost the electric power supply in the metropolis using RSM model. Reliability was produced to test the networks adequacy. A reliability plot of 80.6% was obtained for (RSM). The study established the heating values for energy potential of the municipal waste components in the area. The results of this research showed that waste to energy solves the problem of municipal solid waste disposal while recovering the energy from the waste materials with the significant benefits of environmental quality, increasingly accepted as a clean source of electric energy recovery in the metropolis.

Contribution to Knowledge

In view of this, the following are highlighted as the contributions to the knowledge

(i) First time solid waste collection points and characterization was achieved in Auchi metropolis.

(ii) Determination of range of input parameters (kg) using analytical balance and muffle furnace was experimentally determined.

(iii) Response Surface Methodology (RSM) model for optimization and prediction of heat energy response from municipal solid waste to boost the electric energy generation in Auchi metropolis has been successfully developed.

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