Natural Resources, 2016, 7, 205-213
Published Online April 2016 in SciRes. http://www.scirp.org/journal/nr
http://dx.doi.org/10.4236/nr.2016.74019

Combustion Characteristics of Sewage Sludge and Algae

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Received 7 March 2016; accepted 18 April 2016; published 21 April 2016

Abstract

Sewage sludge is a good source of energetically desirable compounds and green algae in developing country like India. In this work, the combustion characteristics of sewage sludge and green algae are described. The calorific value (CV) of dried sewage sludge (n = 7) and green algae (n = 11) was ranged from 1800 to 6250 and 3700 to 6280 kcal/kg with mean value of 3999 ± 1347 and 4428 ± 547 kcal/kg, respectively. The effect of proximate variables and water quality parameters in the CV of sludge and algae are discussed.

Keywords

Sewage Sludge, Algae, Water Quality, Caloric Value

1. Introduction

Sewage sludge includes black and grey water and semi-solid precipitates released at the household levels. Total sewage generated from urban centres in India is ≈4.0×10^{10} L/day. The sewage sludge is a source of nutrients and pathogenic microbes. The sewage sludge is covered by the algal bloom in urban sectors of India. Algal bloom causes tastes and odors in the water. Some algae produce an aromatic odor resembling to that of particular flowers or vegetables. In addition, a spicy, a fishy odor and a grassy odor can also be produced by algae [1]. Sewage is a source of biomass energy that is very similar to the animal wastes. The caloric value of the sewage and algae was reported by many researchers [2]-[11]. In this work, the caloric value of sludge and algal bloom of sewage reservoirs of Raipur city, CG, India is described for their further uses in energy generation.

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How to cite this paper: Sahu, Y.K., Sahu, P.K., Chakradhari, S. and Patel, K.S. (2016) Combustion Characteristics of Sewage Sludge and Algae. *Natural Resources*, **7**, 205-213. http://dx.doi.org/10.4236/nr.2016.74019

2. Material and Methods

2.1. Study Area

Raipur is a capital city of Chhattisgarh state of India, growing rapidly in unsustainable order due to being commercial center for steel, cement and forest products. At least two million habitants are living in this city over ≈1.0 × 10^3 km^2 area by discharging ≈3.0 × 10^7 L/day waste water. They are dumped into seven open reservoirs constructed in the outer of city, **Figure 1**. The area of sewage reservoirs is ranged from 2 - 4 km^2. Among them, two reservoirs *i.e.* Urla and Siltara lie in the industrial area.

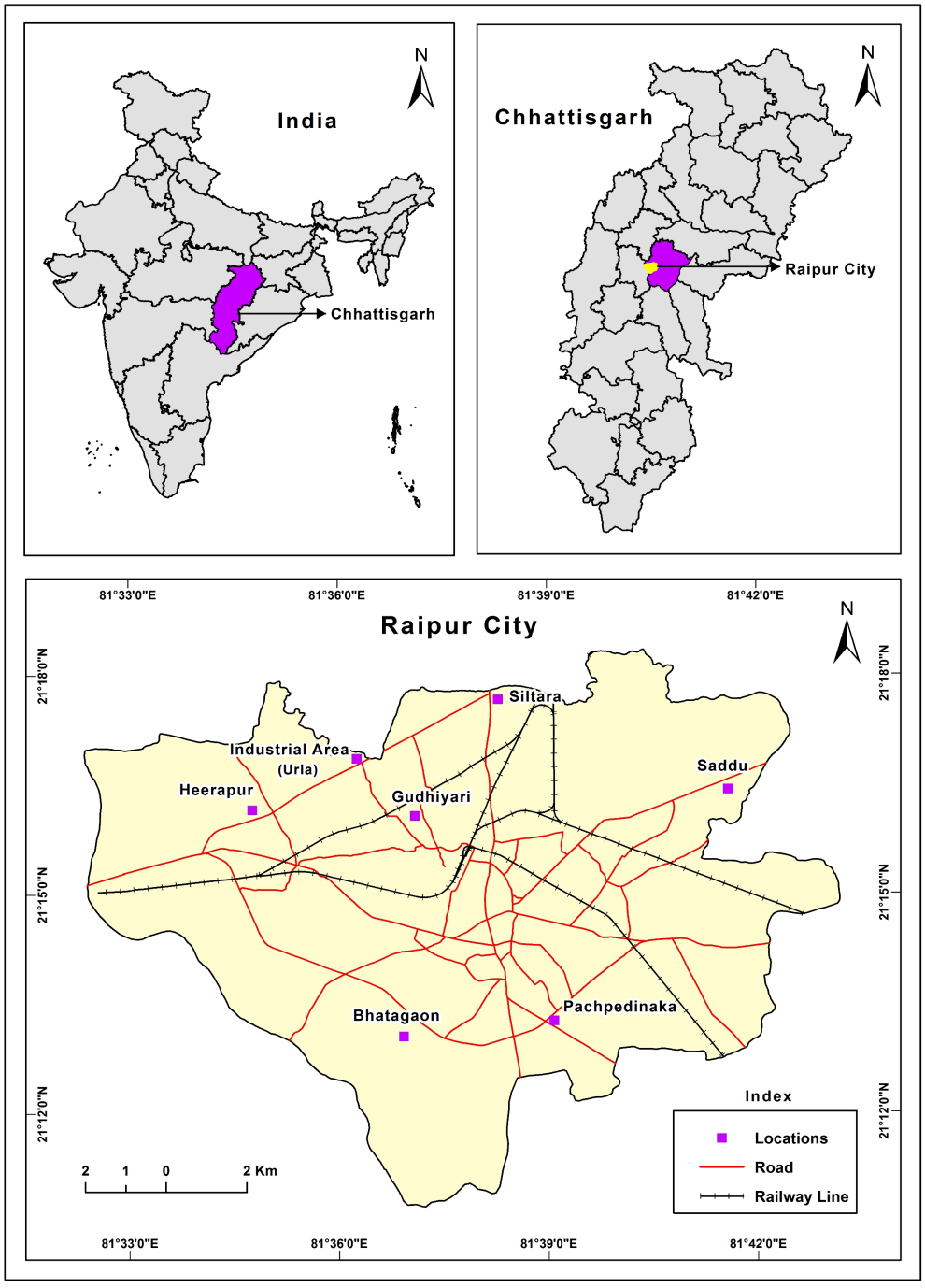

Figure 1. Representation of location of sewage ponds in Raipur city, India.

2.2. Sample Collection

The composite water sample (100 × 5 mL from five points of each location) was collected into glass bottles (500-mL) in January 2016 as prescribed in the literature [12]. The floating algal biomass was collected manually by use of knife in a 1-L glass beaker from the waste water by subsequent washing with deionized water thrice. One kilogram of the top composite sewage sludge from five points of each location (0 - 10 cm) was taken from seven reservoirs in January 2016 by use of a stainless steel spoon and stored in a glass jar [13]. The sewage sludge and algal biomass were dried for 2 days. Thereafter, they were dried in an oven for 2 days at 50˚C to remove the moisture. The dried mass was crushed and sieved out particles of <0.25 mm for the combustion studies.

2.3. Analysis

The physical parameters *i.e.* temperature (T), pH, electrical conductivity (EC), dissolved oxygen (DO) and reduction potential (RP) values of the water were measured at spot by Hanna made sensors. The total hardness (TH) and total alkalinity (TA) values of the filtered water were determined by the titration methods in the laboratory. The F^- content of water was analyzed by using the Metrohm-720 ion selective electrode in the presence of the buffer. The content of ions *i.e.* Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+ and K^+ in water and sludge were analyzed by Dionex-1100 ion chromatography. A 0.25 g of the sludge sample was digested with acids (3 mL HCl and 1 mL HNO_3) in a closed system with P/T MARS CEM (Varian Company) microwave oven for use of metal analysis. The metals (*i.e.* Cr, Fe, Mn, Ni, Cu and Zn) in the extract were analyzed by the Varian ICP-OES-700-ES.

The bulk density (BD) was measured by the water replacement method [14]. The moisture content of the tree samples were analyzed by heating it at 105˚C ± 2˚C till constant weight is observed. The ash content of the materials was determined by heating the sample at 600˚C for 4 hr [15]. The calorific value (CV) of the sample was determined experimentally using a Digital Microprocessor Based Bomb Calorimeter UTS 1.34, Advance Research Instruments Co., New Delhi as described in the literature [16]. The calorific value was calculated by using the following equation:

$$\mathrm{GCV} = \left[\left\{\mathrm{We}\Delta\mathrm{T}\right\} - \left\{\mathrm{W}_1\left(4.18\right) + \mathrm{W}_2\left(0.335\right)\right\}\right] / \mathrm{M}$$

where, GCV, M, We, W_1, W_2 and ΔT represent gross calorific value of species (kcal/kg), water equivalent, weight of sample, weight of cotton thread, weight of fuse wire and rise in temperature, respectively.

The content of volatile compounds including moisture was analyzed by using a Metller thermogravimetric analyzer-TGA-2 at heating rate of 20˚C/min.

The value of non-volatile (fixed) carbon (FC) was computed by subtracting the fraction (%) of moisture (MC), volatile compounds (VCs) and ash residue (AR) to the 100.

$$\mathrm{FC}\% = 100 - \left\{\left(\mathrm{MC} + \mathrm{VCs} + \mathrm{AR}\right)\%\right\}$$

3. Results and Discussion

Algae are main primary byproducts in all kinds of water bodies due to eutrophication, and being indicators of water pollution in a number of significant ways due to availability of contained nutrients. Algae are among the fastest-growing plants in the world and have much faster growth-rates than terrestrial crops. All sewage sludge reservoirs of country like India are floated with different types of algal blooms due to variations in the topology and exposure extent of sun light and nutrient levels.

3.1. Water Quality

The water quality of seven sewage reservoirs of Raipur city is shown in **Table 1**, **Table 2**. The water of all reservoirs is colored with bad smell due to loading of biodegradable organics. The value of T, pH, EC, DO and RP of the water bodies (n = 7) was ranged from 28 - 33˚C, 6.6 - 9.4, 720 - 1543 µS/cm, 5.9 - 7.4 mg/L and 90 - 220 mV with mean value of 30 ± 2˚C, 7.2 ± 0.7, 1108 ± 262 µS/cm, 7.0 ± 0.4 mg/L and 137 ± 34 mV, respectively. The concentration of F^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, NH_4^+, Na^+, K^+, Fe, TH and TA was ranged from 0.9 - 1.7, 48 - 84, 22 - 56, 490 - 690, 4.5 - 8.4, 7 - 13, 90 - 167, 27 - 70, 0.3 - 0.6, 240 - 360 and 340 - 720 mg/L with mean value of 1.3 ± 0.2, 62 ± 9, 41 ± 9, 606 ± 63, 6.6 ± 1.2, 10 ± 2, 136 ± 22, 46 ± 13, 0.4 ± 0.1, 299 ± 34 and 505 ±

101 mg/L, respectively. The highest value for the most of chemical parameters was seen in the water of reservoirs lie in the industrial area *i.e.* Urla and Siltara, **Figure 2**. These water bodies are bloomed with multiple algal biomass *i.e.* microcystis, hydrodictyon and phithophora.

3.2. Combustion Characteristics of Sewage Sludge

All sewage sludge was colored with bad smell as shown in **Table 3**. The dried surface sewage sludge were found to be contaminated with nutrients *i.e.* P, S, Cl, K, Cr, Mn, Fe, Ni, Cu and Zn at elevated levels, ranging from 455 - 718, 941 - 1415, 328 - 471, 8474 - 10,286, 210 - 355, 1206 - 1521, 50,837 - 57,931, 57 - 113, 204 - 449 and 472 - 837 mg/kg with mean value of 570 ± 60, 1191 ± 128, 381 ± 37, 9203 ± 431, 272 ± 36, 1370 ± 81, 54,779 ± 1688, 80 ± 13, 294 ± 63 and 623 ± 93 mg/kg, respectively. The bulk density (BD), moisture content

Table 1. Physical characteristics of sewage water.

S. No.	Location	Smell	Color	T, ˚C	pH	EC	RP	DO	Algal species in encountered
1	Gudhiyari	Fishy	BG	29	7.3	730	170	7.3	*Lyngbya* spp., *Phithophora* spp.
2	Bhatagaon	Unpleasant	BBr	28	6.6	824	150	7.4	*Microcystis* spp.
3	Saddu Mowa	Unpleasant	BBr	29	6.8	1120	120	6.5	*Phithophora* spp.
4	Urla	Fishy	BG	33	6.6	1543	90	5.9	*Microcystis* spp., *Hydrodictyon* spp., *Phithophora* spp.
5	Siltara	Unpleasant	BG	33	9.4	1380	100	7.2	*Hydrodictyon* spp., *Phithophora* spp.
6	Heerapur	Fishy	BG	30	6.6	1440	220	7.4	*Lyngbya* spp.
7	Pachpedinaka	Rotten egg	BG	28	7.1	720	110	7.2	*Phithophora* spp.

Table 2. Chemical characteristics of sewage water, mg/L.

S. No.	F^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	NH_4^+	Na^+	K^+	Fe	TH	TA
1	1.6	71	40	490	4.5	13	90	27	0.3	250	340
2	0.9	60	22	510	5.4	10	156	39	0.4	270	470
3	1.2	54	51	610	8.1	9	132	33	0.5	360	568
4	1.2	84	48	690	8.4	8	167	70	0.6	320	720
5	1.4	53	56	680	7.8	13	149	65	0.5	340	624
6	1.0	66	31	690	7.2	7	158	57	0.4	310	412
7	1.7	48	38	570	5.1	13	101	32	0.4	240	403

Table 3. Energy characteristics of dried sewage sludge.

S. No.	Location	Color	Smell	BD, kg/m^3	MC, %	CV, kcal/kg	AR, %
1	Gudhiyari	LBr	Dirty	830	4.6	1800	49
2	Bhatagaon	LBr	Dirty	870	3.5	2280	45
3	SadduMowa	B	Dirty	980	2.8	4920	43
4	Urla	B	Dirty	1050	2.4	6030	42
5	Siltara	B	Dirty	1080	2.1	6250	41
6	Heerapur	DG	Dirty	950	2.9	4120	44
7	Pachpedinaka	BrB	Dirty	880	3.9	2590	47

B = Black, BrB = Brownish black, LBr = Light brown, DG = Dark grey.

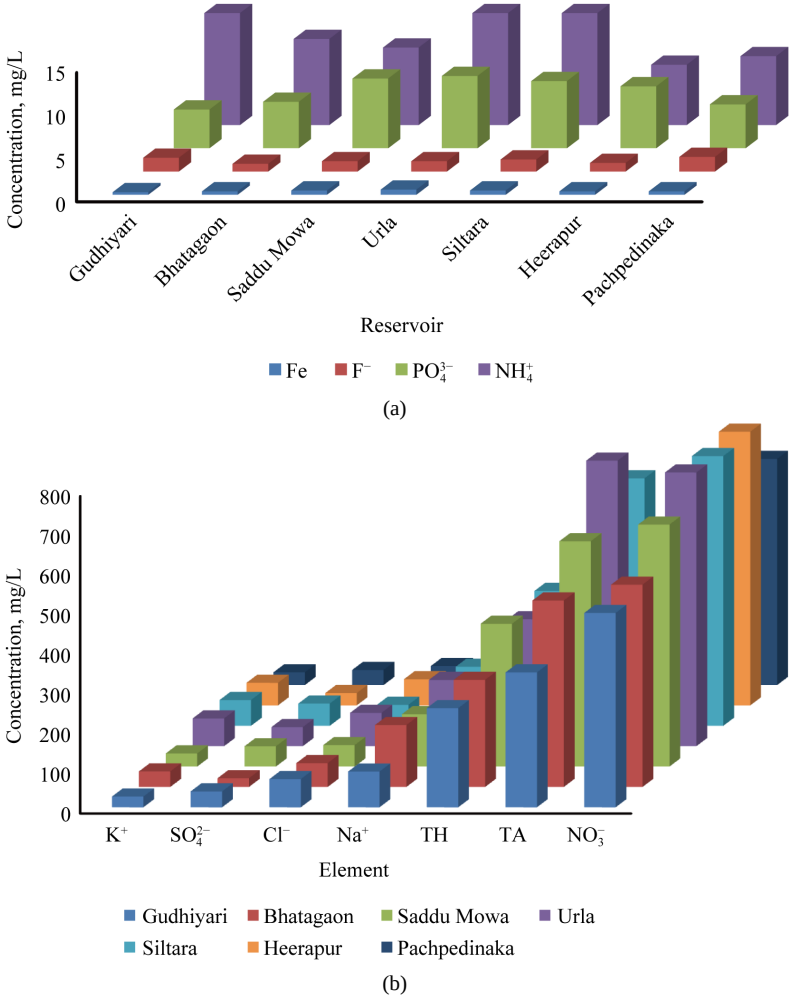

Figure 2. Spatial variation of concentration of elements in sludge reservoirs.

(MC), calorific value (CV) and ash residue (AR) of sewage sludge of seven reservoirs were ranged from 830 - 1080 kg/m^3, 2.1% - 4.6%, 1800 - 6250 kcal/kg and 41% - 49% with mean value of 949 ± 94 kg/m3, 3.2% ± 0.9%, 3999 ± 1818 kcal/kg and 44% ± 2%, respectively. Among them, the highest calorific value of sludge located in the industrial area *i.e.* Siltara and Urla was observed, may be due to higher nutrient loading. The CV of the sludge was correlated well (r = 0.99) with the nutrient levels and BD unlikely to the MC and AR value, **Figure 3**. The N, P, S, Na, K, Fe, TH and TA content of the water had fair correlation with CV of the sludge unlikely to halides *i.e.* F^- and Cl^-, as shown in **Table 4**.

3.3. Combustion Characteristics of Algae

The combustion characteristics of four algae *i.e.* hydrodictyon, lyngbya, microcystis, and phithophoragrown in seven reservoirs is shown in **Table 5**. The value of BD, MC, CV and AR was ranged from 910 - 1070 kg/m^3, 1.5% - 4.6%, 3700 - 6280 kcal/kg and 1.4% - 3.8% with mean value of 963 ± 32 kg/m^3, 3.4% ± 0.6%, 4428 ± 587 kcal/kg and 2.8% ± 0.5%, respectively. The higher CV for hydrodictyon and lyngbya algae was observed, may be due to higher BD value, **Figure 4**. The CV of algal bloom was correlated well with BD unlikely to the MC and AR, **Figure 5**. The TGA chromatogram for hydrodictyon algae is shown in **Figure 6**. The light and heavy volatile compounds (VCs) content of the dried hydrodictyon algae was found to be 5.2% and 27.4%, respectively. The nonvolatile (fixed) carbon and ash residue content of the algae was computed and found to be 64.8%.

The CV of the dried sewage sludge and algal biomass of the studied area was found to be comparable to other regions of the World [2]-[11].

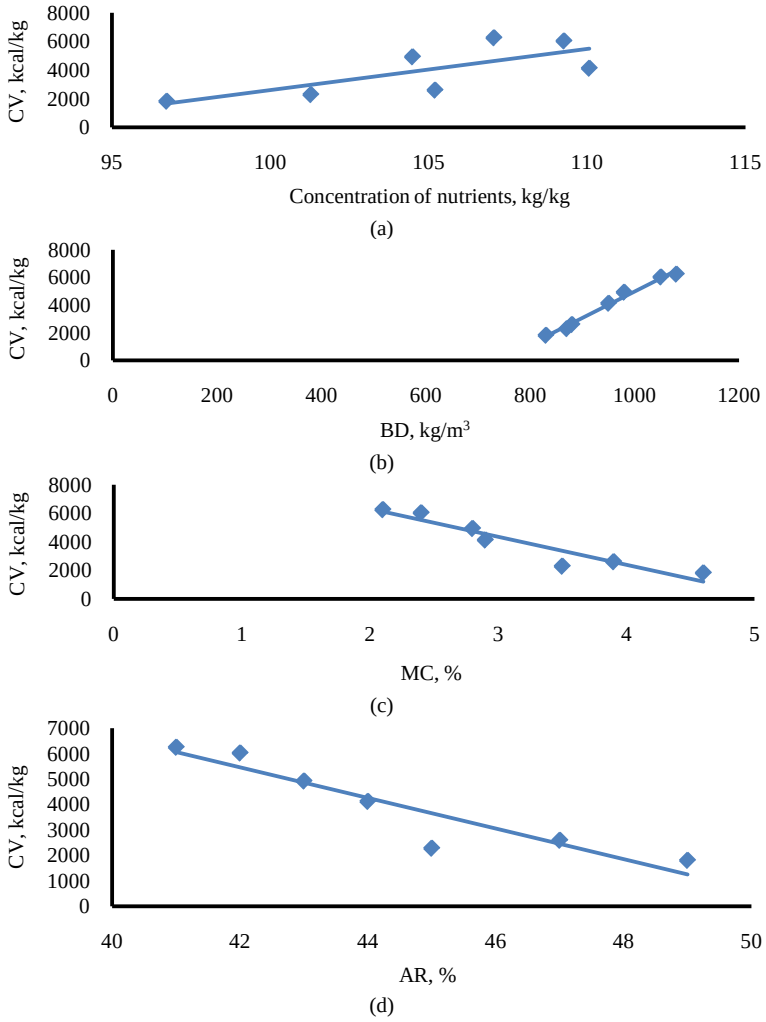

Figure 3. Correlation of nutrient content, bulk density (BD), moisture content (MC) and ash residue (AR) with calorific value of sewage sludge.

Table 4. Correlation matrix of water parameters and CV.

	F^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	NH_4^+	Na^+	K^+	Fe	TH	TA	CV
F^-	1.00											
Cl^-	−0.25	1.00										
SO_4^{2-}	0.42	−0.03	1.00									
NO_3^-	−0.25	0.18	0.49	1.00								
PO_4^{3-}	−0.40	0.2	0.61	0.87	1.00							
NH_4^+	0.80	−0.47	0.22	−0.50	−0.58	1.00						
Na^+	−0.82	0.32	−0.04	0.66	0.71	−0.71	1.00					
K^+	−0.35	0.42	0.33	0.86	0.73	−0.41	0.80	1.00				
Fe	−0.26	0.24	0.58	0.73	0.88	−0.42	0.67	0.71	1.00			
TH	−0.42	0.03	0.62	0.70	0.93	−0.47	0.67	0.53	0.72	1.00		
TA	−0.26	0.27	0.62	0.65	0.85	−0.31	0.67	0.73	0.97	0.73	1.00	
CV	−0.20	0.15	0.73	0.88	0.95	−0.34	0.64	0.81	0.89	0.86	0.88	1.00

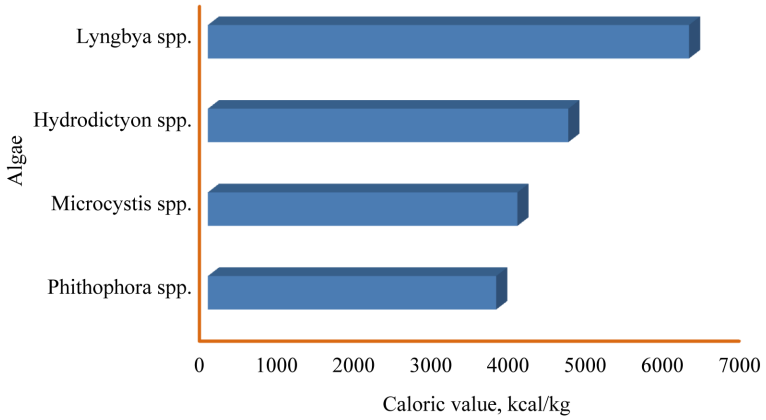

Figure 4. Calorific value of various algal bloom.

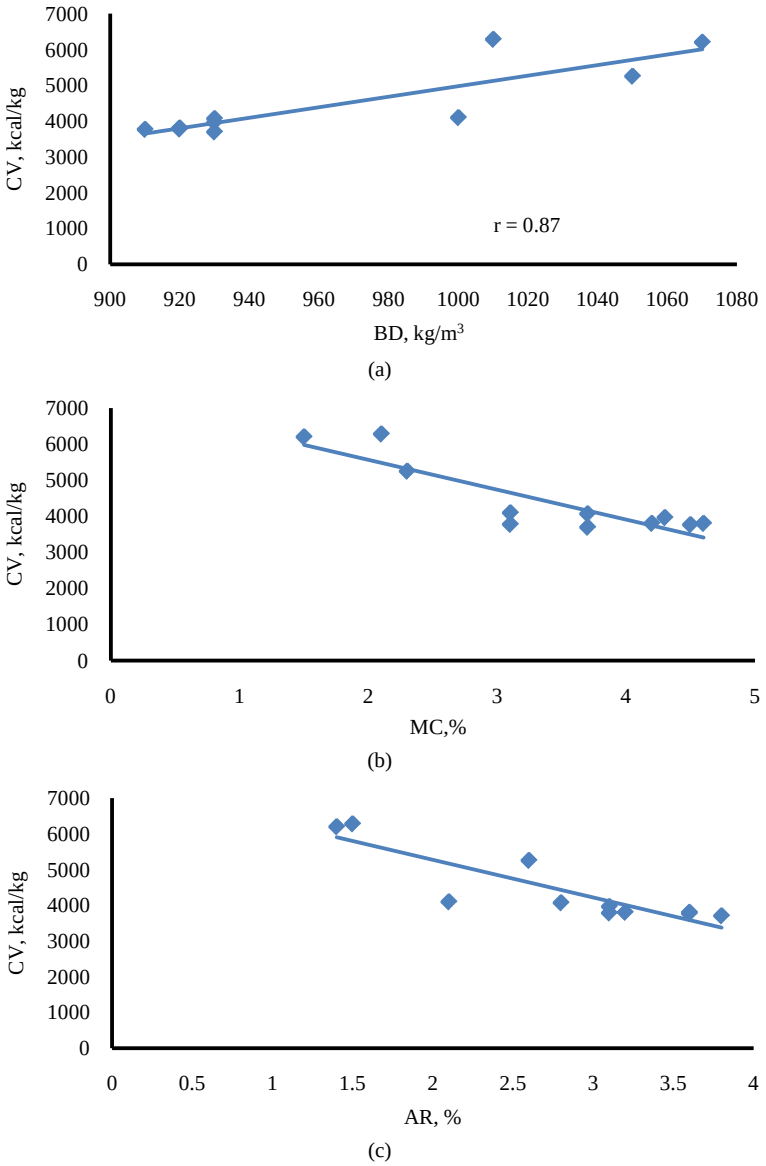

Figure 5. Correlation of BD, MC and AR with calorific value of algal bloom.

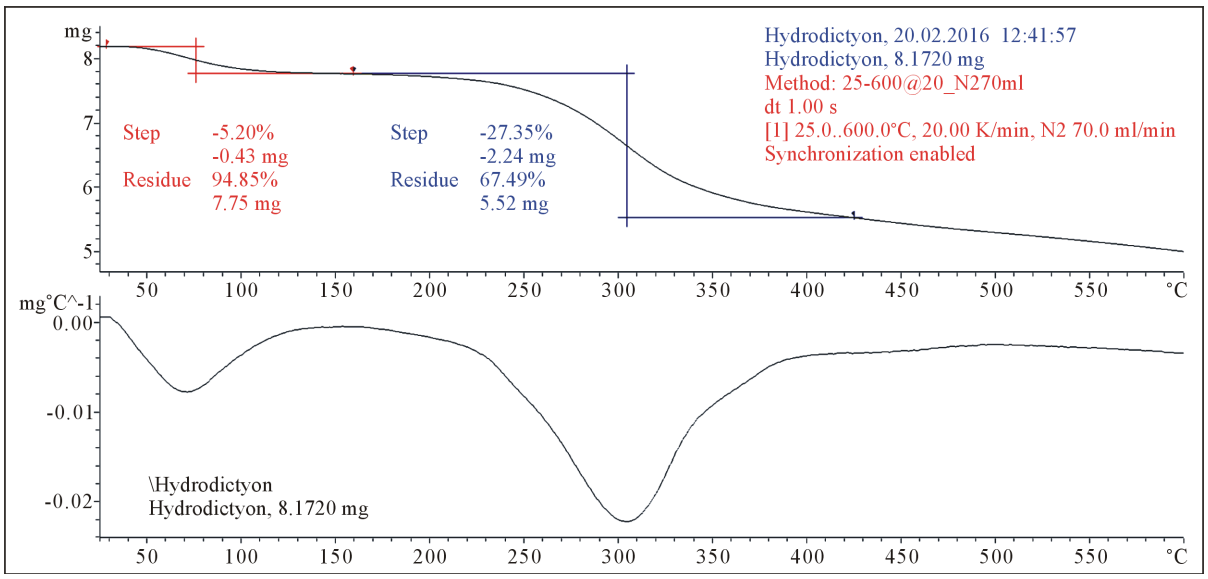

Figure 6. TGA chromatogram of *Hydrodictyon* spp.

Table 5. Energy characteristics of dried algae.

S. No.	Location	Algae	Color	Type of AB	BD, kg/m^3	MC, %	CV, kcal/kg	AR, %
1	Gudhiyari	*Lyngbya* spp.	Gr	MF	1010	2.1	6280	1.5
	Gudhiyari	*Phithophora* spp.	Gr	MF	920	4.2	3800	3.2
2	Bhatagaon	*Microcystis* spp.	BGr	SF	930	4.3	3960	3.1
3	SadduMowa	*Phithophora* spp.	Gr	MF	910	4.5	3770	3.6
4	Urla	*Microcystis* spp.	BGr	SF	930	3.7	4070	2.8
	Urla	*Hydrodictyon* spp.	Gr	MF	1000	3.1	4100	2.1
	Urla	*Phithophora* spp.	Gr	MF	920	3.1	3780	3.1
5	Siltara	*Hydrodictyon* spp.	Gr	MF	1050	2.3	5250	2.6
	Siltara	*Phithophora* spp.	Gr	MF	920	4.6	3800	3.6
6	Heerapur	*Lyngbya* spp.	Gr	MF	1070	1.5	6200	1.4
7	Pachpedinaka	*Phithophora* spp.	Gr	MF	930	3.7	3700	3.8

Gr = Green, BGr = Blue green, AB = Algal bloom, MF = Mate form, SF = Scum form.

4. Conclusion

The calorific value of the sewage sludge is found to be similar to biomass and animal waste. The heat value of the sludge and algae was found to be comparable. The heat value of algal boom is seemed to be independent of quality of the sludge because it is produced by process of eutrophication.

Acknowledgements

We are thankful to our University for providing equipment grant to the SOS in Environmental Science.

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