Open Journal of Applied Sciences, 2024, 14, 1604-1624
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Prediction of Low Heating Value of Sugar Cane Bagasse as a Fuel for Industrial Boilers in the High Relative Humidity Region: Case of Cameroon

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How to cite this paper: Kana-Donfack, P., Tientcheu-Nsiewe, M., Tcheukam-Toko, D. and Kapseu, C. (2024) Prediction of Low Heating Value of Sugar Cane Bagasse as a Fuel for Industrial Boilers in the High Relative Humidity Region: Case of Cameroon. *Open Journal of Applied Sciences*, **14**, 1604-1624.
https://doi.org/10.4236/ojapps.2024.146105

Received: April 23, 2024
Accepted: June 23, 2024
Published: June 26, 2024

Abstract

Many attempts have been made to estimate calorific value of bagasse using mathematical equations, which were created based on data from proximate, ultimate, physical and chemical analysis. Questions have been raised on the applicability of these equations in different parts of the globe. This study was initiated to tackle these problems and also check the most suited mathematical models for the Law Heating Value of Cameroonian bagasse. Data and bagasse samples were collected at the Cameroonian sugarcane factory. The effects of cane variety, age of harvesting, source, moisture content, and sucrose on the LHV of Cameroon bagasse have been tested. It was shown that humidity does not change within a variety, but changes from the dry season to the rainy season; the sugar in the rainy season is significantly different from that collected in the dry season. Samples of the same variety have identical LHV. LHV in the dry season is significantly different from LHV in the rainy season. According to the fact that this study was done for cane with different ages of harvesting, the maturity of Cameroonian sugarcane does not affect LHV of bagasse. Tree selected models are much superior tool for the prediction of the LHV for bagasse in Cameroon compared to others. The standard deviation of these validated models is around 200 kJ/kg compared to the experimental. Thus, the models determined in foreign countries, are not necessarily applicable in predicting the LHV of bagasse in other countries with the same accuracy as that in their native country. There was linear relationship between humidity, ash and sugar content in the bagasse. It is possible to build models based on data from physical composition of bagasse using regression analysis.

Keywords

Sugarcane Bagasse, Relative Humidity, Ash, Low Heating Value

1. Introduction

To address the energy crisis that began in 1970, special attention has been directed towards alternative fuels to overcome the global energy problem. This shift has been prompted by the rising costs of fuel oil, natural gas, and electricity. Bagasse, which was previously burnt as waste, is now being utilized for combustion in electricity generation, thus becoming a viable boiler fuel. Given the necessity to consider combustion efficiency when using it as boiler fuel, bagasse has emerged as an opportunity to serve as an energy reserve to address deficits in electricity supply ([1] [2] [3]).

Currently, Cameroon owns two (02) sugar factories, which combustion of bagasse is for co-generation steam and electricity just for the sugar process. This situation laid to the accumulation of enough quantity of bagasse around the factories (41.165 tons/year for one factory, Nkoteng), which causes many environmental problems such the accident of bagasse fired ([4] [5]). The electricity deficit in the rural region where the factory is located is less than 5%. Developing the possibility to burn total fuel in the aim to export excess of electricity to the national grid, could make socio-economic benefits and favorable environmental impact for the factory.

In recent years, studies have been carried out over the world to better understand the combustion of this fibrous residue and its calorific impact on boilers efficiency in order to obtain steam. The problem of flame stability in boilers, highlighted by several of these works, is closely linked to the physic, chemical and thermal properties of bagasse ([6]-[23]). These properties have to be studied before the study of combustion process. The previous work in the Cameroon sugar factory has shown that the increasing of water moisture content in bagasse in the raining season causes down time according to the degradation of steam quality and quantity in the rainy season [10]. A fuel having a moisture content of 50% and an ash content of 2% will have an inert to combustible material ratio of 52/48 = 1.08. If the moisture is 50% and the ash content is 5%, the ratio is 55/45 = 1.22. This ratio is important when evaluating acceptable grate heat release rates and the amount of excess air required for complete combustion [24]. Complete combustion which will help to avoid factory down time. Industrial solid fuel boilers were designed for mining coal before being modified and subsequently adapted to other fuels such as biomass. Compared to coal, sugar cane bagasse, like other biomasses, has high volatile matter and moisture content

([25]-[37]). According to the fact that moisture, ash content, and inert ratio could increase during the raining season, it is necessary to make particular research. The increasing of moisture during the raining season which causes down time is due to the fact that a lot of mud usually adheres to the harvested cane and consequently increases the inert ratio in fuel bagasse, which influences the heating value.

Heating value is also calling calorific value depending of the authors. There are two different heating values: low heating value (LHV) and High heating value (HHV). Hugo [7] empirical analysis shows that, bagasse HHV in the dry basis base is approximately HHV = 19,256 kJ/kg and varies only about two percent (2%) from different countries and region in the world. The LHV is the HHV influencing by the percentage of net hydrogen in bagasse which varies from countries to countries. These percentages of net hydrogen represent also the latent heat of the water formed by the combustion process. LHV gives a more accurate indication of heat practically obtainable. Bagasse as a fuel is usually burn in wet basis, and it's characterized by fiber, brix, ash and moisture [7]. All these parameters could vary per countries and regions in the word. There are different methods used in the literature to analyzed bagasse: physical, proximate and ultimate analyses. From theses method and parameter obtained, we find a lot of models in the literature used to predict heating value of bagasse in the world ([38] [39] [40] [41] [42]). The heating value of bagasse can also be determined experimentally (direct) by a bomb calorimeter, though this method is reliable, it is not feasible due to the equipment use and consumable cost. Then models are the most method use in the literature and could help to study the effect of extrinsic parameters of the region on these Calorific Values ([43] [44] [45] [46]). As a limitation of these Mathematical models created, performs best in the country/locality in which it is created, while producing over or under prediction when used internationally.

This work describes Cameroonian bagasse characterization, relevant models were selected in the literature used in others countries by authors to determine the most suitable one which could be used to predict the Cameroonian sugar cane bagasse LHV.

2. Material and Methods

2.1. Location

The SOSUCAM sugar complex is located approximately 129 km north of the city of Yaoundé, along national road No.1 connecting Yaoundé to Nanga-Eboko in the Mbandjock-Nkoteng region in the South of Cameroon, between the following geographic coordinates: 11˚51' - 12˚10' East longitude, 4˚20' - 4˚35' latitude North.

Soil coverage of the Mbandjock-Nkoteng region (75% of the surface area), belongs to the domain of ferrallitic soils desaturated soils of the southern Cameroonian plateau alongside soils with little evolved and raw minerals (5%) on residual massifs and soils hydromorphs (20%) which cover the shallows (**Figure 1**). The climate is subequatorial with four seasons: two dry seasons (from mid-November to mid-March and from July to August) and two rainy seasons (from September to mid-November and from mid-March to July). The temperature is moderate and most often oscillates between 23.5˚C to 26.5˚C and therefore the annual average is 24.7˚C. While the sunshine is 5h20' per day and evapotranspiration of 3.8 mm per day are relatively low yet, the hygrometry remains high (morning value greater than 90%, the rest of the day the humidity does not falling below 70% than during the long dry season). The harvest being manual, it is preceded by spreading fire which eliminates all the leaves on the harvested cane.

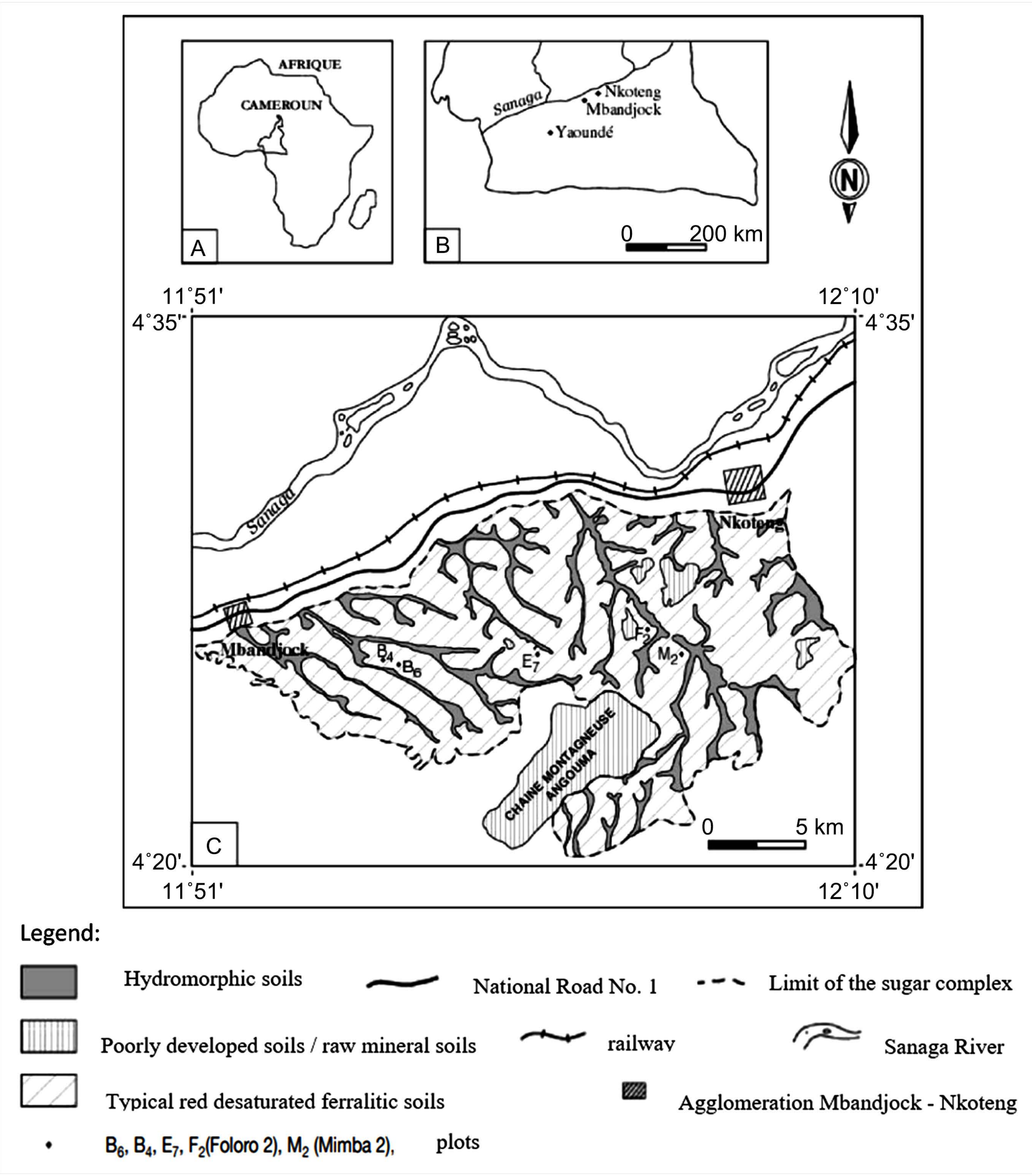

Figure 1. Localization of the Cameroon Sugar Company (SOSUCAM); A—Cameroon in Africa; B—Southern Cameroon; C—The SOSUCAM site [47].

2.2. Sampling Design

***Sample from* Table 1**

From the literature, Heating Value of sugar cane bagasse can be predicted by models based on fiber, sugar, ash and moisture content in bagasse. From these parameters, only moisture don't have heating value (**Table 2**), but it being absorbs heat in vaporized during the combustion.

Assuming that each of these parameters could be influence by cane varieties, season, age of cane, and types of soil when harvested; data were collected of historical information of the factory (**Table 1**). These data were collected over two years to make sure that these parameters could be taken during rainy and dry season. Sample from (**Table 1**) where collected according to Hugo mathematical model of heating value which depend on the proximate parameter (moisture, sugar and inert material). Means, in this table heating value were calculated by the mathematic model given by Equation (4) (**Table 3**) [7]. The effect of season, variety of can, and soil on humidity, inert ratio and heating value will be study.

***Sample from* Table 4**

Based on the hypothesis that impact of cane variety, ages when harvested, and types of soil on the calorific value of bagasse variation is not significant. The bagasse samples were taken directly from the inlet of the burner taking into account their variations in humidity level with the quality of steam produced. In the plant, when the steam quality is poor, operators often use the mixture of bagasse from storage (dry) (**Figure 2(b)**) with bagasse coming directly from the mills (**Figure 2(a)**).

Table 1. Experimental data of bagasse caracteristics according to variety and parcel types.

Season	Humidity	Sugar	Ash	LHV (kcal/kg)	LHV (kJ/kg)	Variety	Location
Rain	36.84	1.86	3.04	2394.02	10018.97	Co997	B11
Dry	35.74	2.02	3.30	2441.37	10217.13	Co997	B11
Dry	36.66	1.99	3.25	2397.95	10035.42	B46364	D1
Dry	38.19	2.20	3.58	2316.07	9692.73	B46364	M10
Dry	36.92	2.38	3.88	2370.82	9921.88	FR81258	M17
Dry	36.85	2.30	3.75	2377.22	9948.64	B46364	G1 cg
Dry	35.6	1.77	2.89	2457.52	10284.72	B46364	S2
Dry	39.95	1.92	3.14	2240.91	9378.19	Cr87339	F2/2
Dry	36.62	1.95	3.17	2401.57	10050.57	B46364	N4
Dry	34.86	1.76	2.87	2493.89	10436.93	Co997	D800
Dry	37.66	1.78	2.90	2357.37	9865.59	B46364	N3
Dry	36.8	2.06	3.36	2388.52	9995.96	Co997	A9n
Dry	40.99	2.15	3.51	2182.07	9131.94	Cr87339	F2/2
Dry	35.26	1.88	3.07	2469.81	10336.15	B46364	F2/2
Dry	36.37	1.79	2.92	2419.58	10125.92	B46364	f3/2
Dry	37.48	1.80	2.94	2365.26	9898.61	B46364	F4/1-2

Continued

Dry	37.83	1.88	3.06	2345.41	9815.52	B46364	F3/1
Dry	37.45	1.67	2.73	2371.52	9924.79	B46364	M5
Dry	40.05	1.57	2.56	2249.14	9412.63	Cr87339	M5
Dry	35.35	1.43	2.34	2482.25	10388.20	Cr87339	M6
Dry	34.45	1.47	2.41	2524.34	10564.34	Co997	M8
Dry	35.48	1.37	2.24	2478.22	10371.35	B46364	M9
Dry	36.78	1.42	2.31	2413.49	10100.46	FR81258	E10
Dry	33.75	1.30	2.12	2564.77	10733.54	Co997	M10
Dry	34.71	1.28	2.08	2519.05	10542.20	B46364	M600
Dry	34.5	1.16	1.89	2533.55	10602.91	Co997	M12
Dry	36.98	1.54	2.51	2399.23	10040.78	B46364	M300
Dry	37.41	1.09	1.78	2395.06	10023.31	B46364	D700
Dry	34.57	1.58	2.57	2514.68	10523.91	Co997	D800
Dry	35.46	1.88	3.07	2460.11	10295.56	B46364	A100
Dry	37.41	1.26	2.06	2388.58	9996.19	B46364	D10-12
Dry	38.46	0.86	1.41	2352.53	9845.34	FR81258	C7
Dry	35.56	1.57	2.56	2466.90	10323.98	FR81258	C800
Dry	38.3	1.17	1.91	2348.89	9830.10	B46364	C10-12
Dry	37.39	1.40	2.29	2384.39	9978.65	B82333	B8
Dry	35.68	1.61	2.62	2459.76	10294.10	Co997	C11
Dry	35.68	1.61	2.62	2459.76	10294.10	Co997	C800
Dry	37.76	2.36	3.85	2330.92	9754.90	FR81258	C800
Dry	35.7	1.18	1.93	2474.51	10355.82	B46364	C800
Dry	35.85	2.04	3.33	2435.44	10192.30	FR81258	C17-19
Dry	38.26	2.04	3.32	2318.67	9703.63	FR81258	M20
Dry	33.41	1.65	2.70	2568.06	10747.31	FR81258	C23
Dry	36.78	1.44	2.34	2412.77	10097.44	B46364	B6
Dry	36.33	1.60	2.61	2428.60	10163.67	B46364	N9
Dry	36.86	1.36	2.22	2411.77	10093.26	B46364	N10
Dry	39.5	1.27	2.07	2287.09	9571.47	B46364	N8
Dry	36.79	1.42	2.31	2413.01	10098.43	B46364	N12
Dry	34.61	1.04	1.70	2532.66	10599.16	B46364	N6Sud
Dry	41.63	1.40	2.28	2178.87	9118.55	B46364	N5
Dry	44.32	1.96	3.19	2027.64	8485.67	B82333	A6-8
Dry	37.81	2.15	3.51	2336.30	9777.39	Co997	A6-8
Dry	41.35	2.44	3.98	2153.81	9013.67	Cr87339	A6-8
Dry	39.97	2.02	3.30	2236.22	9358.56	FR81258	A6-8
Dry	40.23	2.13	3.47	2219.65	9289.21	Cr87339	A9sud
Dry	37.96	1.81	2.95	2341.62	9799.68	Co997	B1-2
Dry	41.99	2.71	4.43	2112.57	8841.08	B82333	B5
Dry	41.96	2.42	3.94	2125.06	8893.38	Cr87339	B9

Continued

Dry	34.94	1.04	1.69	2516.89	10533.18	B46364	A7
Rain	37.56	1.49	2.43	2372.90	9930.59	B46364	A400
Rain	34.54	0.58	0.94	2553.33	10685.69	B46364	F1
Rain	36.66	1.56	2.54	2414.03	10102.72	Co997	D11-13
Rain	41.81	0.89	1.45	2189.22	9161.86	Cr87339	D300Sud
Rain	38.51	1.49	2.43	2326.83	9737.76	Co997	F3/4
Rain	35.05	1.00	1.63	2512.88	10516.38	R570	A600
Rain	36.43	1.40	2.28	2431.07	10174.01	Co997	D5
Rain	37.53	1.11	1.81	2388.52	9995.94	Co997	D9
Rain	37.56	1.35	2.21	2378.06	9952.18	Co997	C5
Rain	41.9	1.73	2.82	2153.53	9012.52	FR81258	C1
Rain	38.6	0.94	1.53	2343.10	9805.87	B46364	C8
Rain	38.36	1.03	1.68	2351.14	9839.52	FR81258	D7
Rain	46.96	1.45	2.37	1918.44	8028.67	B82333	B10-12
Rain	38.95	1.39	2.26	2309.33	9664.53	Co997	B10-12
Rain	34.22	1.10	1.79	2549.41	10669.28	Co997	C15
Rain	38.09	1.45	2.37	2348.52	9828.54	FR81258	C22
Rain	40.48	2.23	3.63	2203.92	9223.41	Cr87339	B3
Rain	39.69	1.46	2.38	2270.80	9503.28	R585	B3

Table 2. Heating value of constituents of bagasse [7].

Constituent	Heating value (kacl/kg)
Fiber	4600
Sugar	3955
Impurities	4100
Water (humidity)	0

Table 3. Summary of models used for predicting law heating value of bagasse.

Formulas	Ref.	Country	N°
$LHV = 18309 - 207.6\omega - 196.05k - 31.14s$	[41]	South Africa	Equation (1)
$LHV = 18603 - 207.6\omega - 183.35k - 30.98s$	[42]	Mauritius	Equation (2)
$LHV = 18603 - 210.3\omega - 186.03k - 34.12s$	[37]	Australia	Equation (3)
$LHV = 4.18 (4250 - 48.5\omega - 12s)$	[7]	Combined	Equation (4)

ω: moisture content in bagasse, k: ash content, s: sugar content.

Table 4. Sample collection for analysis.

Samples	observations	moisture content
1	Bagasse from mil	59.03%
2	Mixing bagasse	---
3	Bagasse from mil	55.03%
4	Bagasse from mil	51%
5	Bagasse from mil	50.4%
6	Bagasse from storage	---

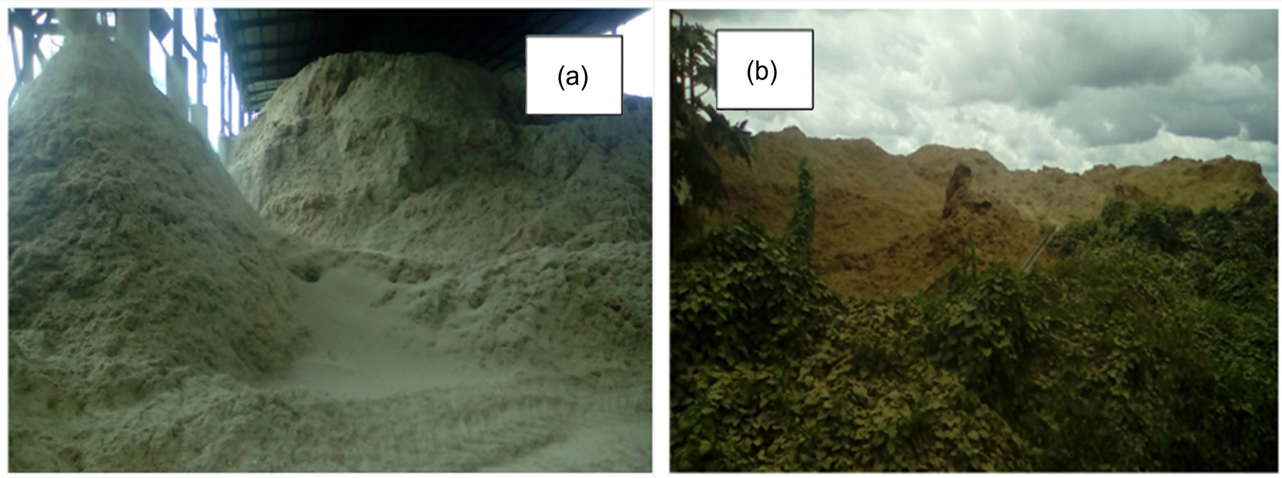

Figure 2. Bagasse of sugar factory: excess from milling (a) and storage (b).

2.3. Analytical Methods

***Effect of humidity, season, sugar Sample from* Table 2**

The relatively unknown effects of many different parameters on the LHV of Cameroonian bagasse will be tested in this study by experimentation under controlled conditions. The parameters on which the LHV depends and the LHV itself were divided into various groups which would isolate one or two controlled variables and a factorial analysis of variance (F ratio test) was applied to the samples within the groups. This is the case of the test of the effect of cane variety, season and the ages when harvested on the sugar content, humidity and LHV.

Bagasse characterization: *Sample from* Table 4

Bomb calorimeter (1520 kPa of oxygen pressure, 6 V circuit voltage, ca. 0.7 g of bagasse sample)

The experimental calculation of the Calorific value (LHV and HHV) was made according to Standard NF MO3-005/EN 14918/ISO 1928. So, the sample was first ground using the cutter mill. Then sieved through a sieve whose mesh opening is between 0.2 mm and 1mm. Before starting the analysis, the sample was mixed thoroughly for approximately one minute using a spatula. The calorimeter was conditioned by obtain a temperature difference between the thermometer of the adiabatic chamber and the calorimetric vessel thermometer less than or equal to 1˚C.

Effect of moisture, ash and sugar on the LHV of bagasse

Each bagasse corresponding sample from bomb calorimeter was analyze to determine moisture, ash and sugar content. These values were used to calculate the LHV of bagasse with the selected literature models. Results from calculations using formulas (**Table 3**) and from bomb calorimeter were statistically analyzed with multiple variable analysis method. To study the impact of inert ratio which characterized the region of culture (sludge and sand) [37], effective moisture of bagasse was evaluated and his impact on the calorific value study. in fact, if a lot of mud sticks to the bagasse during harvesting, it will not be crushed well and will arrive at the burner with a lot of mud and humidity, thus increasing the rate of inert matter. This parameter depends on the type of soil and the harvesting technique (describe in Section 2.1).

3. Results and Discussion

3.1. Effect of Variety, Season, Moisture Age and Region of Cane Harvested on the LHV

Table 5 shows the summary statistical test of the effect of season and variety change on the humidity content, sugar content and LHV. From these first three analyses, it is emerging that the constituent elements (humidity and sugar content) of the model used to calculate the LHV depend on the season and the variety, the LHV depend also on the season and the variety. The results obtained also showed that humidity does not change within a variety. It would therefore be interesting or even essential for an application data of bagasse to indicate the harvest season and the variety used.

Table 6 presents the Multiple Range Testing for Moisture Content by Variety. Five Homogeneous varieties are identified using columns of X. In each column, the levels containing X form a group of means within which there are no statistically significant differences. The results obtained showed that humidity does not change within a variety. The samples of the varieties (Co997, B46364, FR81258, Cr87339 and B82333) have identical humidity. This can also mean that the types of soil do not really have an influence because these samples of the same variety come from different types of soil.

Table 7 is the result of the multiple comparisons procedure to determine the means which are significantly different from each other, are there varieties which have similar humidity. The upper part of this table displays the estimated differences between pairs of means of two varieties. A star (*) was placed next to 12 pairs, indicating that these pairs have statistically significant differences at the 95.0% confidence level. We therefore see that the B46364 variety has the same moisture content as the FR81258 variety. Similar conclusion for B43664 and R585, B43664 and R570, Co997 and R570, Co997 and R585, Cr87339 and R570, FR81258 and R570, FR81258 and R585, R570 and R585.

In Table 8, two homogeneous groups are identified using columns of X. In each column, the levels containing X form a group of means within which there are no statistically significant differences. The conclusion from these last two tables is that the varieties in the dry season have the same humidity. In the rainy season, we also have the same observation. Then, the humidity of different bagasse in the dry season is different from the humidity in the rainy season.

Table 9, Table 10 and Table 11 gives the averages of the sugar content for each level of the factors (season and variety). The question asked here is whether the sugar content of samples collected in the dry season is different from that obtained in the rainy season.

Table 5. Summary of statistical tests of the effect of season and variety change on the sugar and humidity content in bagasse, and the LHV.

principal effect	*F value*	*Probability*
sugar	---	---
A: Season	13.45	0.0005
B: Variety	2.28	0.0457
Humidity	---	---
A: Season	9.10	0.0036
B: Variety	12.44	0.0000
LHV	---	---
A: Season	5.16	0.0263
B: Variety	12.20	0.0000

Table 6. Multiple range testing for humidity content by variety.

Variety of cane	*Count*	*Mean*	*Homogeneous groups*
R570	1	34.2688	XX
Co997	19	36.3602	X
B46364	30	37.4769	X
FR81258	12	38.0006	X
R585	1	38.9088	XXX
Cr87339	9	40.6751	X
B82333	4	43.0556	X

Table 7. Multiple comparison between cane varieties and humidity level.

Contrast	*Sig.*	*Difference*	*+/− limits*
B46364 - B82333	*	−5.57865	1.90311
B46364 - Co997	*	1.1676	1.09622
B46364 - Cr87339	*	−3.19816	1.36019
B46364 - FR81258		−0.523645	1.22698
B46364 - R570		3.0813	3.73987
B46364 - R585		−1.43187	3.73987
B82333 - Co997	*	6.6954	1.96827
B82333 - Cr87339	*	2.38049	2.14155
B82333 - FR81258	*	5.055	2.05735
B82333 - R570	*	8.8677	4.05876
B82333 - R585	*	4.14677	4.05876
Co997 - Cr87339	*	−4.31491	1,45652
Co997 - FR81258	*	−1.6404	1.3258
Co997 - R570		2.09137	3.70466
Co997 - R585		−2.54863	3.70466
Cr87339 - FR81258	*	2.7451	1.57159
Cr87339 - R570	*	6.40628	3.84125
Cr87339 - R585		1.76628	3.84125
FR81258 - R570		3.73177	3.78908
FR81258 - R585		−0.908226	3.8908
R570 - R585		−4.64	5.03947

*Denote a statistically significant difference.

Table 8. Multiple range testing for humidity content by variety.

Season	*Count*	*Mean*	*Homogeneous groups*
dry	57	37.6111	X
rainy	19	39.1735	X
Contrast	Sig.	Difference	+/− limits
rainy saison - dry saison	*	1.56236	1.03355

Table 9. Multiple range testing for sugar by cane variety.

Variety	*Count*	*Mean*	*Homogeneous Groups*
R570	1	3.73487	XX
B46364	30	4.17677	X
Co997	19	4.75923	XX
FR81258	12	4.9934	XX
R585	1	5.15487	XX
B82333	4	5.51506	X
Cr87339	9	5.56174	X

Table 10. Multiple comparison between sugar content of the cane varieties.

Contrast	*Sig.*	*Difference*	*+/− limits*
B46364 - B82333	*	−1.3383	1.27224
B46364 - Co997		−0.582463	0.73283
B46364 - Cr87339	*	−1.38497	0.909298
B46364 - FR81258		−0.816629	0.820244
B46364 - R570		0.441892	2.50013
B46364 - R585		−0.978108	2.50013
B82333 - Co997		0.755832	1.3158
B82333 - Cr87339		−0.0466736	1.43164
B82333 - FR81258		0.521667	1.37535
B82333 - R570		1.78019	2.7133
B82333 - R585		0.360188	2.7133
Co997 - Cr87339		−0.802506	0.973693
Co997 - FR81258		−0.234166	0.886307
Co997 - R570		1.02436	2.47659
Co997 - R585		−0.395644	2.47659
Cr87339 - FR81258		0.56834	1.05062
Cr87339 - R570		1.82686	2.5679
Cr87339 - R585		0.406862	2.5679
FR81258 - R570		1.25852	2.53303
FR81258 - R585		−0.161478	2.53303
R570 - R585		−1.42	3.36891

Table 11. Multiple range testing for sugar content by season.

Season	*Count*	*Mean*	*Homogeneous Groups*
rainy season	19	4.2074	X
dry season	57	5.47715	X
Contrast	*Sig.*	*Difference*	+/− *limits*
rainy season - dry season	*	−1.26975	0.690934

To compare the average sugar content of different varieties, the multiple comparison procedure was used. Table 9 shows the multiple comparison of sugar content of different varieties of sugarcane. The upper part of this table displays the estimated differences between pairs of means. A star was placed next to 2 pairs (B46364 - B82333 and B46364 - Cr87339), indicating that these pairs have statistically significant differences at the 95.0% confidence level. With the exception of these, the sugar contents are significantly equivalent.

Table 11 presents the multiple range tests of sugar cane content by season of harvest. The upper part of this table displays the estimated differences between pairs of means. A star has been placed next to one pair, indicating that this pair has a statistically significant difference at the 95.0% confidence level. At the top of the table, 2 homogeneous groups are identified using columns of X. In each column, the levels containing X form a group of means within which there are no statistically significant differences. Through this, we see that the sugar content of the samples of sugar cane varieties collected in the rainy season is not significantly different. Similar conclusion in the dry season. On the other hand, the sugar content of samples collected in the rainy season is significantly different from that of samples collected in the dry season.

Table 12, Table 13 and Table 14 give the averages of the LHV for each level of factors (season and variety). At the top of this table, 4 homogeneous groups are identified using columns of X. In each column, the levels containing X form a group of means within which there are no statistically significant differences, means that samples of the same variety have identical LHV.

From Table 12 and Table 13, part of this table displays the estimated differences between pairs of means. A star was placed next to 11 pairs, indicating that these pairs have statistically significant differences at the 95.0% confidence level. In other words, 11 pairs of varieties (B46364 - B82333, B46364 - Cr87339, B82333 - Co997, B82333 - Cr87339, B82333 - FR81258, B82333 - R570, Co997 - Cr87339, Co997 - FR81258, Cr87339 - FR81258, Cr87339 - R570 and FR81258 - R570) have significantly different LHV.

Table 14 presents the multiple range test for the comparison of LHV collected in the rainy season and the dry season. A star has been placed next to a pair, indicating that this pair has a statistically significant difference at the 95.0% confidence level. The LHV of samples collected in the dry season is significantly different from that obtained in the rainy season.

Table 12. Multiple range testing LHV content by variety.

Variety	*Count*	*Mean*	*Homogeneous Groups*
B82333	4	2095.61	X
Cr87339	9	2210.5	X
R585	1	2301.08	XXXX
FR81258	12	2347.04	X
B46364	30	2382.25	XX
Co997	19	2429.42	X
R570	1	2543.18	X

Table 13. Multiple comparisons between LHV of the cane varieties.

Contrast	*Sig.*	*Difference*	*+/− limits*
B46364 - B82333	*	286.636	97.9867
B46364 - Co997		−47.1779	56.4418
B46364 - Cr87339	*	171.746	70.0332
B46364 - FR81258		35.2112	63.1743
B46364 - R570		−160.933	192.557
B46364 - R585		81.167	192.557
B82333 - Co997	*	−333.814	101.342
B82333 - Cr87339	*	−114,89	110.264
B82333 - FR81258	*	−251.425	105.928
B82333 - R570	*	−447.569	208.976
B82333 - R585		−205.469	208.976
Co997 - Cr87339	*	218.924	74.9928
Co997 - FR81258	*	82.389	68.2625
Co997 - R570		−113.755	190.744
Co997 - R585		128.345	190.744
Cr87339 - FR81258	*	−136.535	80.9176
Cr87339 - R570	*	−332.679	197.777
Cr87339 - R585		−90.5791	197.777
FR81258 - R570	*	−196.144	195.091
FR81258 - R585		45.9558	195.091
R570 - R585		242.1	259.47

Table 14. Multiple range testing for LHV by season.

Saison	*Count*	*Mean*	*Homogeneous Groups*
rainy season	19	2299.59	X
dry season	57	2360.15	X
Contrast	*Sig.*	*Difference*	*+/− limits*
rainy season - dry season	*	−60.5589	53.215

The results obtained showed that humidity does not change within a variety, the humidity of different bagasse in the dry season is different from the humidity in the rainy season, the sugar content of samples collected in the rainy season is significantly different from that of samples collected in the dry season. Samples of the same variety have identical LHV. The LHV of samples collected in the dry season is significantly different from that obtained in the rainy season. According to the fact that this study was done for cane with different age of harvesting, the maturity of Cameroonian sugarcane does not affect LHV of bagasse.

3.2. Validity of Selected Formulas Based on Sample Analysis

Table 15 shows the minimum, maximum, average, and standard deviation (SD) of the ash contents, sugar and humidity contents, and the heating values of the normal milling operation bagasse. The ash contents of the bagasse samples covered a wide range, and the humidity contents varied in a moderate range.

A P-value statistical test was done to check the relationship between ash contents and heating value, sugar contents and heating value, and humidity contents and heating value.

Table 16 shows a P-value which tests the statistical significance of the estimated correlations. P-values below 0.05 indicate statistically significant non-zero correlations at the 95.0% confidence level. The following pairs of variables have P-values below 0.05: Ash (%) and sugar (%), Ash (%) and humidity (%), Ash (%) and LHV (kJ/kg), Ash (%) and HHV (kJ/kg); sugar (%) and humidity (%), sugar (%) and LHV (kJ/kg), sugar (%) and HHV (kJ/kg), humidity (%) and. LHV (kJ/kg), humidity (%) and HHV (kJ/kg), LHV (kJ/kg) and HHV (kJ/kg). It is means that the variability observed in HV was explained by moisture, ash and sugar.

Table 17 presents the summary statistics of LHV obtained experimentally compared to the values obtained by calculation using different models presented from the literature (Table 3). The statistical evaluations are shown namely the average, standard deviation and the range between the maximum and minimum error that occurred, which will indicate the performance of the model.

Table 17 confirms that Equation (1), Equation (2) and Equation (3) are better than Equation (4) due to a smaller standard deviation. Thus Equation (1), Equation (2) and Equation (3) are much superior tool for the prediction of the LHV values for bagasse in Cameroon. The standard deviation is around 200 kJ/kg comparing experimental values to those gives by the models. Thus, the models determined in foreign countries, such as that by the Conventional Equations above, are not necessarily applicable in predicting the LHV value of Bagasse in other countries with the same accuracy as that in their native country.

Figure 3 shows the average with the maximum and minimum LHV value, which ably shows the divergence of the averages, maximum, and minimum values from the experimental data. It's strengthening the arguments that Equation (1), Equation (2) and Equation (3) gave good prediction as compared to Equation (4).

Table 15. Characteristics of bagasse from analysis.

	Ash (%)	*sugar* (%)	*humidity* (%)	LHV (kJ/kg)	HHV (kJ/kg)
Average	4.34	4.6	48.6225	6843.88	8745.0
Standard deviation	2.93622	2.23355	9.1634	2279.01	2172.85
Coeff. of variation	67.6549%	48.5554%	18.846%	33.3%	24.8468%
Minimum	1.5	2.36	39.9	4351.5	6385.0
Maximum	7.5	7.26	59.73	8972.5	10800.0

Table 16. The statistical tests significance of the estimated correlations.

	Ash (%)	*sugar* (%)	*humidity* (%)	*LHV* (kJ/kg)	*HHV* (kJ/kg)
Ash (%)		0.9903	0.9671	−0.9995	−0.9998
		0.0097	0.0329	0.0005	0.0002
sugar (%)	0.9903		0.9637	−0.9901	−0.9901
	0.0097		0.0363	0.0099	0.0099
humidity (%)	0.9671	0.9637		−0.9744	−0.9718
	0.0329	0.0363		0.0256	0.0282

Table 17. Summary Statistics of the LHV values of final mill bagasse from experience compare to the calculation value.

	experimental (kJ/kg)	Equation (1)	Equation (2)	Equation (3)	Equation (4)
Average	6843.88	7220.87	7570.72	7413.37	7686.21
Standard deviation	2279.01	2531.3	2494.36	2533.62	1968.24
Coeff. of variation	33.3%	35.0553%	32.9475%	34.1764%	25.6074%
Minimum	4351.5	4212.6	4603.01	4398.84	5298.11
Maximum	8972.5	9492.53	9815.11	9691.38	9526.44

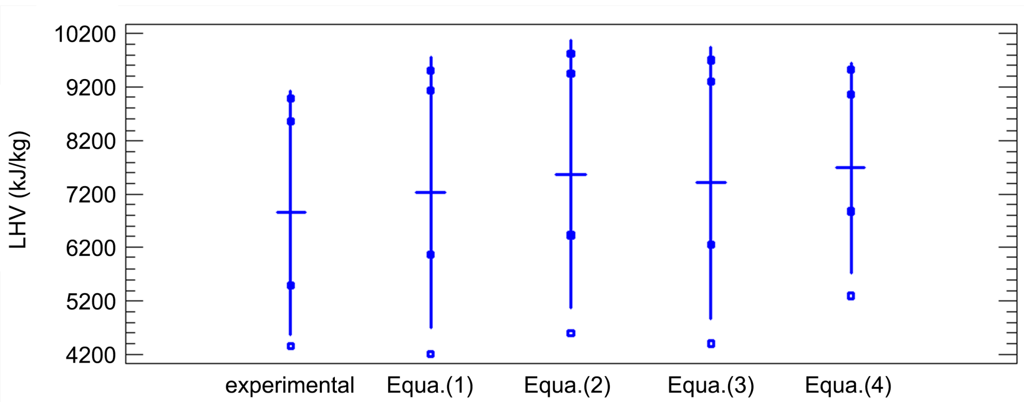

Figure 3. Average, maximum and minimum values of LHV for models and experiment.

Lastly, this finding also proves that the best suited models depend not only on the humidity and sugar content but also on the ash content. Figure 4 shows the LHV predicted by Equation (1), Equation (2) and Equation (3) decreases with the increase of ash content in sugarcane bagasse.

The previous paragraph shows that the Calorific Value of sugar cane bagasse depends on the harvest season, and the moisture content of the bagasse obtained after crushing the cane. The joint influence of the plot and the harvest season would be linked to the sand content (not studied here) which could limit the action of the mill on the cane and therefore would favor a very sandy bagasse and with a more ash after combustion. To choose the study models, it becomes important to evaluate the influence of the rate of ash on the LHV.

Table 18 shows the ash content, effective humidity content and LHV of sugar cane bagasse analyzed. From this table inert rations increases with moisture content in our factory locality. Figure 5 shows the influence of the effective humidity (inert ratio) on the LHV. When the inert ration (effective humidity) increase, LHV decrease.

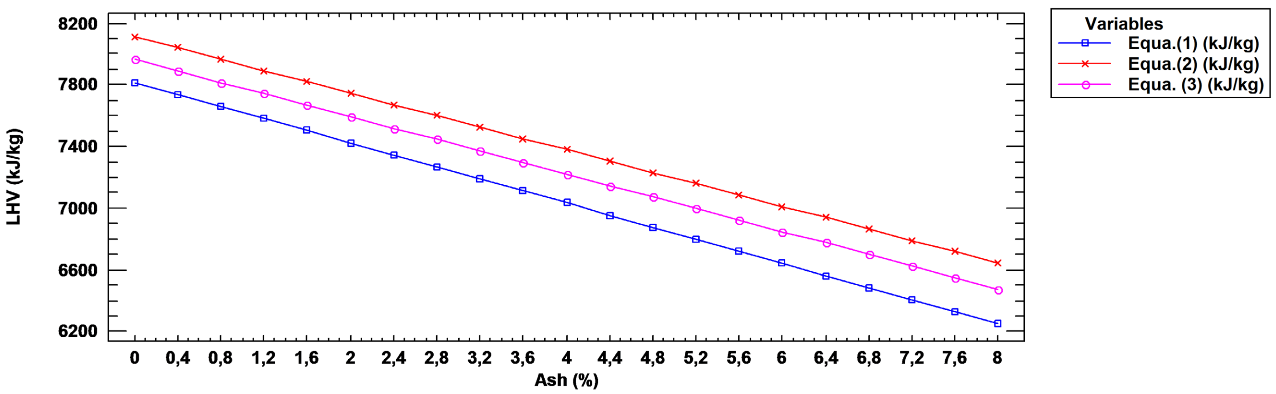

Figure 4. Comparison between LHV values estimated for literatures formulas.

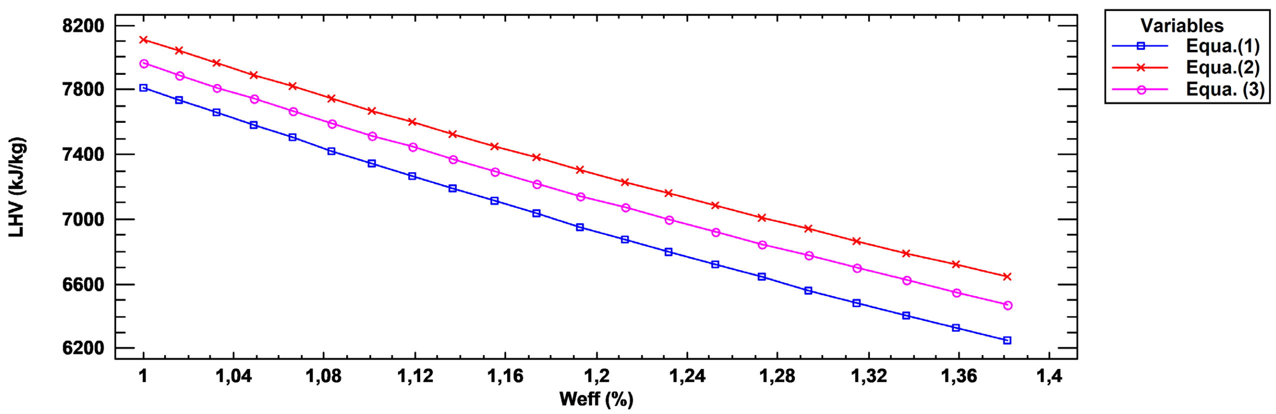

Figure 5. Profile of LHV according to the effective humidity, compared to the profiles of [40] for the rate of ash at 0% and 10%.

Table 18. Ash content, moisture and effective humidity of sugar cane bagasse.

Ash (%)	Humidity (%)	Effective Humidity Weff (%)	Experimental LHV (kJ/kg)
4.21	39.90	40.82	8570.50
1.50	42.45	42.23	8972.50
4.15	52.41	53.59	5481.00
5.50	59.73	61.94	4351.50

4. Conclusions

The objective of this work was to select the most efficient model to predict LHV of Cameroonian bagasse. We have recorded data related to the characteristics of the bagasse such as humidity rate, sugar content, different varieties of harvest plots, and a sample according to whether or not severe combustion conditions were sampled. Statements linked to characteristics of the fuel were analyzed to study the influence of the various parameters on the LHV.

It emerged from this analysis that: humidity does not change within a variety, the humidity of different bagasse in the dry season is different from the humidity in the rainy season, the sugar content of samples collected in the rainy season is significantly different from that collected in the dry season. Samples of the same variety have identical LHV. The LHV of samples collected in the dry season is significantly different from that obtained in the rainy season.

The link observed between the harvest season and the humidity rate is explained by the existence of sand on the cane during the harvest, which should reduce the work of the mills and promote the production of very humid bagasse. Consequently, the mixture of sands in the bagasse of sugarcane increased the ash content.

Equation (1), Equation (2) and Equation (3) are better than Equation (4) when using to predict the Cameroonian LHV due to a smaller standard deviation. Thus Equation (1), Equation (2) and Equation (3) are much superior tool for the prediction of the LHV values for bagasse in Cameroon. The standard deviation is around 200 kJ/kg comparing experimental values to those given by the models. Thus, the models determined in foreign countries, such as that by the Conventional Equations above, are not necessarily applicable in predicting the LHV value of bagasse in other countries with the same accuracy as that in their native country.

When the inert ration (effective humidity) and ash increase, LHV decrease thus the effect of ash in the LHV is not negligible as by those models in literature. Then, there is linear relationship between humidity, ash and sugar content in the bagasse. It is possible to build models based on data from physical composition of bagasse using regression analysis. It is therefore necessary to ameliorate the clean method of the sugarcane before processing it, or use mechanical harvesters instead of manual harvesting.

Data Availability

The article contains all the relevant data. These data, used to support the findings of this study were obtained from the Cameroonian Sugar Society, Nkoteng sugar Factory.

Acknowledgments

Authors acknowledge to Cameroon Sugar Society through Nkoteng Sugar factory for providing facilities.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Kapseu, C., Tcheukam-Toko, D. and Kana-Donfack, P. (2017) The Cogeneration in Sugar Mill: An Energetic Deposit Opportunity for Sustainable Development in Sub-Saharan Africa. Communication at Royal Academy of Overseas Sciences (RAOS) of Belgium, Uccle.

[2] Bell, J. (2005) Sweetening the Power Sector: Current Experience and Future Potential for Bagasse CHP around the World. *International Sugar Journal*, **107**, 380-387.

[3] Deepchand, K. (2002) Promoting Equity in Large-Scale Renewable Energy Development: The Case of Mauritius. *Energy Policy*, **30**, 1129-1142. https://doi.org/10.1016/S0301-4215(02)00064-2

[4] Nguedia, A.M. and Noula, C. (2012) La politique du gouvernement camerounais en matière de production et de distribution d'énergie électrique: Zoom sur le potentiel énergétique de la société sucrière du Cameroun (SOSUCAM). *Congrès Sucrier ARTAS*/*AFCAS* 2012, La Réunion, 10-14 September 2012, 1-10.

[5] Mann, A.P. (2010) Predicting the Effects of Fuel Properties on Combustion Performance. *Proceedings of the* 32*nd Conference of the Australian Society of Sugar Cane Technologists*, Bundaberg, 11-14 May 2010, 629-637.

[6] Lamb, B.W. and Bilger, R.W. (1976/1977) Combustion of Bagasse: Literature Review. *Sugar Technology Reviews*, **4**, 89-130.

[7] Hugot, E. (1986) Hand book of Cane Sugar Engineering. 3rd Edition, Elsevier, 932.

[8] Alena, A. and Sahu, O. (2013) Cogenerations of Energy from Sugar Factory Bagasse. *American Journal of Energy Engineering*, **1**, 22-29. https://doi.org/10.11648/j.ajee.20130102.11

[9] Kana-Donfack, P., Kapseu, C. and Tcheukam-Toko, D. (2016) Sugar Cane Bagasse Combustion for Steam and Electricity Generation: Literature Review. Communication at Ansolecaf, University of Bamenda, Cameroon.

[10] Kana, D.P., Kapseu, C. and Essengue, G.N. (2014) Effect of Extrinsic Fuel Moisture Content on the Performance of Bagasse Boiler for Suspension Combustion. *Journal of Energy and Power Sources*, **1**, 250-256.

[11] Luo, M., Stanmore, B.R. and Dixon, T.F. (1993) A Thermal Survey of a Bagasse-Fired Boiler. *Proceedings of the* 15*th Conference of the Australian Society of Sugar Cane Technologists*, Cairns, 27-30 April 1993, 108-118.

[12] Dixon. (1983) Combustion Characteristics of Bagasse Suspension Boiler. *Proceedings of the International Society of Sugar Cane Technologists*, Habana, February 1983, 265-267.

[13] Wibulswas, P. and Tamnanthong, N. (1988) Analyse de l'énergie thermique dans les sucreries de canne. *International Energy Journal*, **10**, 11-22.

[14] Magasiner, N. and McIntyre, P. (1984) Operating Experience on Single and Three Pass Boilers in the Cane Sugar Industry with Particular Reference to Erosion and Drum Water Level Stability. *Proceedings of the South African Sugar Technologists' Association*, Durban, Jun 1884, 123-129.

[15] Woodfield, P.L., Kent, J.H. and Dixon, T.F. (1998) Computational Modelling of a Bagasse Fired Furnace—Effects of Moisture. *Proceedings of the* 1998 *Conference of*

the Australian Society of Sugar Cane Technologists, Ballina, 28 April-1 May 1998, 458-464.

[16] Woodfield, P.L., Kent, J.H. and Dixon, T.F. (1997) Temperature Measurements in a Bagasse Fired Furnace—Experimental and Numerical Results. *Proceedings of the* 1997 *Conference of the Australian Society of Sugar Cane Technologists*, Townsville, 29April-3 May 1997, 473-478.

[17] Moor, C. (1970) Note on Air Pollution in the Sugar Industry. *SASTA* 44*th Annual Congress in Durban South Africa*, Durban, Jun 1970, 54-56.

[18] Woodfield, P.L., Kent, V.N. and Dixon. (1999) Prediction of Instable Regimes in the Operation of Bagasse Fired Furnace. *Proceedings of the Second International Conference on CFD in the Mineral and Process Industries CSIRO*, Melbourne, 6-8 December 1999, 299-304.

[19] Luo, B.R.S. and Dixon, T.F. (1993) Modeling Combustion in Corner Fired Sugar Mill Boilers. *Proceedings International Society of Sugar Cane Technolog*ists, Melbourne, April 1993, 466-472.

[20] Luo, M., Stanmore, B.R. and Dixon, T.F. (1997) Modeling Combustion in Corner Fired Sugar Mill Boiler. *Proceedings of the* 1997 *Conference of the Australian Society of Sugar Cane Technologists*, Townsville, 29April-3 May 1997, 446-472.

[21] Mann, A.P., Dixon, T.F., Plaza, F. and Joyce, J.A. (2005) Opportunities for Improving the Performance and Reducing the Costs of Bagasse-Fired Boilers. *Proceedings International Society of Sugar Cane Technologists*: *Proceedings of the XXV Congress*, 30 January-4 February 2005, Guatemala City, 241-247.

[22] Mann Anthony, P. (2013) Improving Combustion Stability in Sugar Factory Boilers. *Proceedings of the* 35*th Annual Conference of the Australian Society of Sugar Cane Technologists*, Townsville, 16-18 April 2013, 1-10.

[23] Mann, A. (2014) Improving Boiler Performance with Modified Boiler Control Systems. *Proceedings of the 36th Annual Conference of the Australian Society of Sugar Cane Technologists*, Broadbeach, 28 April-1 May 2014, 475-484.

[24] Magasiner, N. (1987) The Effect of Fuel Moisture Content on the Performance of a Typical Bagasse Fired Watertube Boiler. *Proceedings of the South African Sugar Technologists' Association*, Durban, Jun 1987, 86-88.

[25] Goudeau, J.-C. (2001) Combustion de mélanges, combustibles classiques/biomasse. Laboratoire de Combustion et de Détonique ENSMA Poitiers. https://www.record-net.org

[26] Sui1, J., Xu, X., Zhang, B., Huang, C. and Lv, J. (2013) A Mathematical Model of Biomass Briquette Fuel Combustion. *Energy and Power Engineering*, **5**, 1-5. https://doi.org/10.4236/epe.2013.54B001

[27] Magasiner, N. (1966) Boiler Design and Selection in the Cane Sugar Industry. *Proceedings of the South African Sugar Technologists' Association*, Durban, March 1966, 29-63.

[28] Tait, P.J. and Stanmore, B.R. (2000) Towards a New Generation of Bagasse Fired Boilers. *Proceedings of the* 2000 *Conference of the Australian Society of Sugar Cane Technologists*, Bundaberg, 2-5 May 2000, 482-490.

[29] Contento Gonzalez, F.O., Silva Lora, E. and Villa Nova, H.F. (2017) CFD Modeling of Combustion of Sugarcane Bagasse in an Industrial Boiler. *Fuel*, **193**, 31-38. https://doi.org/10.1016/j.fuel.2016.11.105

[30] Belosevic, S. (2010) Modeling Approaches to Predict Biomass Co-Firing with Pulverized Coal. *The Open Thermodynamics Journal*, **4**, 50-70.

https://doi.org/10.2174/1874396X01004010050

[31] Sánchez, C.Z., Gauthier-Maradei, P. and Hernández, H.E. (2013) Effect of Particle Size and Humidity on Sugarcane Bagasse Combustion in a Fixed Bed Furnace. *Revista ION*, **26**, 73-85.

[32] Shanmukhadhya, K.S. (2007) Simulation and Thermal Analysis of the Effect of Fuel Size on Combustion in an Industrial Biomass Furnace. *Energy & Fuels*, **21**, 1895-1900. https://doi.org/10.1021/ef060278y

[33] Shanmukhadhya, K.S. and Sudhakar, K.G. (2006) Investigation of Effect of Bagasse Pyrolysis Kinetic on Combustion and Boiler Performance. *Journal of the Energy Institute*, **80**, 40-45. https://doi.org/10.1179/174602207X174559

[34] Shanmukhadhya, K.S. and Ramachandran, K. (2009) Numerical and Experimental Investigations for Optimization of Plan Capacity for Bagasse Fired Furnace. *Journal of the Energy Institute*, **82**, 69-75. https://doi.org/10.1179/174602209X427051

[35] Bryden, K.M. and Ragland, K.W. (1996) Numerical Modeling of a Deep, Fixed Bed Combustor. *Fuel and Energy Abstracts*, **37**, 207. https://doi.org/10.1016/0140-6701(96)88901-6

[36] Abdallah, A.M., Hassan, T.H. and Mansour, M.E. (2018) Performance of Wet and Dry Bagasse Combustion in Assalaya Sugar Factory-Sudan. *Innovative Energy & Research*, **7**, 179.

[37] Mann, A.P. (2010) Predicting the Effects of Fuel Properties on Combustion Performance. *Proceedings of the* 32*nd conference of the Australian Society of Sugar Cane Technologists*, Bundaberg, 11-14 May 2010, 629-637.

[38] Wienese. (2001) Boilers, Boiler Fuel and Boiler Efficiency. *Production of South African Sugar Technology Association*, **2**, 275-281.

[39] Demiral, I. (2014) Pyrolysis of Sugar Beet Bagasse for Production of Liquid Fuels. *Energy Sources*, *Part A*: *Recovery*, *Utilization*, *and Environmental Effects*, **36**, 2684-2690. https://doi.org/10.1080/15567036.2011.574189

[40] Frédéric, N. (2002) Caractérisation de la biomasse, Energies Renouvelables et Cogénération pour le Développement Durable en Afrique. République du Cameroun, Yaoundé.

[41] Don, C.E. and Mellet, P. (1977) Calorific Values of South African Bagasse. *Proceedings of the South African Sugar Technologists' Association*, Durban, June 1977, 169-173.

[42] Norman, M. and Naude, D.P. (1988) Pneumatic Spreading of Fibrous Fuels and Coal in Boiler Combustion Chambers. *Proceedings of the South African Sugar Technologists' Association*, Durban, Jun 1988, 78-84

[43] Huang, C., Han, L., Liu, X. and Yang, Z. (2008) Models Predicting Calorific Value of Straw from the Ash Content. *International Journal of Green Energy*, **5**, 533-539. https://doi.org/10.1080/15435070802498507

[44] Qian, C., Li, Q., Zhang, Z., Wang, X., Hu, J. and Cao, W. (2020) Prediction of Higher Heating Values of Biochar from Proximate and Ultimate Analysis. *Fuel*, **265**, Article 116925. https://doi.org/10.1016/j.fuel.2019.116925

[45] Bourzutschky, H.C.C. (2013) Charcoal from Sugar Cane Bagasse. *Proceedings of the International Society of Sugar Cane Technologists*, **28**, 1282-1294.

[46] Kathiravale, S., Yunus, M.N.M., Sopian, K., Samsuddinb, A.H. and Rahman, R.A. (2003) Modeling the Heating Value of Municipal Solid Waste. *Fuel*, **82**, 1119-1125. https://doi.org/10.1016/S0016-2361(03)00009-7

[47] Tolale, E., Yongue-Fouateu, R., Boli Baboule, Z. and Bilong, P. (2008) Potential and

Effects of Sugar Cane Growing Residues on the Conservation of Ferralitic Soils in a Farm of the Mbandjock Region (South Cameroon). *Étude et Gestion des Sols*, **15**, 113-129.