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Comparative Study of the Behavior of a Field Model versus a Theoretical Model in Sugar Manufacture from Sugar Cane

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ABSTRACT

A theoretical (simulation) model was developed with the objectives to predict sugar yield from sugar cane, as well as to compare the results with field production model. The model developed was used to predict the sugar, bagasse, filter cake and molasses yield from sugar cane. The predicted values from the model were compared to yield data obtained from the production of sugar cane from the Savannah Sugar Company, Numan, Nigeria for 90 days. The analysis of variance (ANOVA) at $p \leq 0.01$ was used to determine if there were significant difference in the yield predicted by the model and the measured factory yield. The least significant difference (F-LSD) at $p \leq 0.01$ was used to separate the means. The model is validated where there was no significant difference between its predicted yield and the factory-obtained yield. The sugar cane input of 2,150.52 MT was obtained from the Savannah Sugar factory. The corresponding imbibitions water pumped into the mixed juice was 673.12 MT. The predicted sugar, bagasse, molasses and filter cake yield using the theoretical model was 279.5MT (13%), 1,049.46MT (48%), 111.828MT (5.2%) and 101.1MT (4.7%) respectively. The ANOVA showed that there was no significant difference between the theoretical and the factory-based model. It is concluded that the theoretical model was capable of predicting sugar yield from a giving quantity of raw cane. Consequently, this model is recommended for use in predicting sugar and by-products yields from sugar cane.

Keywords: behavior, model, prediction, sugar, byproducts, yields, sugarcane

INTRODUCTION

Sugarcane is the world's largest crop. It was cultivated on about 23.8 million hectares, in more than 90 countries, with a worldwide harvest of 1.69 billion tons. The world demand for sugar is the primary driver of sugarcane agriculture. Cane accounts for 80 per cent of sugar produced;

most of the rest is made from sugar beets. Sugarcane predominantly grows in the tropical and subtropical regions, and sugar beet predominantly grows in colder temperate regions of the world [1].Table sugar is a global item found in the recipes and menus of the diets consumed in almost every home. It is a major product of sugarcane processing. Sugar cane contributes well about 100% of all the sugar manufactured in Nigeria. However, sugar can also be manufactured in other parts of the world from other plants such as sugar beets [2].

Industrial cultivation and processing of raw and refined sugar in Nigeria is currently being undertaken by Savannah sugar company, Numan; Bacita sugar company (now Josepdam Sugar Company), Dangote and Bua refineries in Apapa Lagos. These companies import raw sugar and manufacture white sugar from it to complement the requirements demanded by the Nigeria populace. The main knowledge gap in the study of yields from sugarcane is that the production process has not graduated from the level of using modules to that of higher techniques such as the use of special models for the prediction of sugar yields and its various byproducts. This lapse is occurring inspite of the fact that such advancements have been employed in the production of sugar for the purpose of increasing sugar output to meet the increasing demand for the product. The average yield of refined sugar from a ton of cane is estimated at approximately 0.961 or 9 percent [3]. Nigeria's sugar refining capacity is estimated at 2.1 million tons exceeds the country's current total demand of 1.45 million tons. The country's sugar refineries depend almost exclusively on brown sugar from Brazil at five percent duty. The situation has assisted with promoting investment in sugar refining rather than in production so far.

Dangote Sugar Refinery is Nigeria's sugar producer. Nigeria's consumption of sugar continues to rise, with consumption estimated at 1.34million tons, as an emerging class of consumers creates a bigger market for manufacturers and sellers of sugar products. This makes

Nigeria the second-largest consumer of Sugar in Africa, after South Africa. However, per capita sugar consumption is still very low in Nigeria, compared to South Africa on global average scale [4]. According to the National Sugar Development Council, NSDC[5], Nigeria has a land potential of over 500,000 hectares of suitable cane fields that can produce over 5 million metric tons of sugarcane that when processed, can yield about 3 million metric tons of sugar.

The process of manufacturing sugar from sugarcane is a very interesting subject given the merits of this exercise. It presents us with the advantages of realizing the production of the primary product (sugar) as well as the bye-products (bagasse, filter cake, molasses), and so on. Of greater interest and concern still is the need to have an instrument through which the sugarcane, weighed to be grinded, can be used to predict the end sugar that it can yield as well as the amount all the important bye products realizable: hence the comparative potential of the performance of the simulation model over the conventional use of factory modules.

Process modeling is an integral part of any process industry and is undertaken to simulate how things are done. The process model gives a description or prediction of what the process looks like [6]. The sugar industry is a process industry where various models have been developed to represent the different unit operation used in the industry. The milling process is primarily a unit operation used to extract juice from sugarcane. Several models have been developed to simulate the process [7], [8].

MATERIALS AND METHODS

General

This research aimed at the prediction of Sugar Yield from Sugar Cane using process modeling. Sugar value is often not known or estimated until production is completed in the factory at every given occasion. This method lacks the potential to quantify the yield of sugar from sugarcane. sugar and it's major by-products including bagasse, molasses, and filter cake which were determined in the research "Prediction of Sugar Yield from Sugar Cane using process modeling" .

The Experimental Site

Savannah Sugar Company Limited, Numan located in Adamawa State of North-Eastern Nigeria was used as the site for this research: established in 1971 by the then Federal Government of Nigeria. The North eastern state government was accordingly saddled with the responsibility of land acquisition, compensation payments and settlements of the affected communities. This responsibility devolved the then Gongola State government on creation of States in 1976. This means that Savannah Sugar Company Limited was neither involved in land acquisition or compensation. The Company is operating an integrated sugar farming and milling. It has a mill capacity of 50,000 Mt per annum and has the largest refinery in sub-Saharan Africa. The transfer of its ownership to Dangote Sugar Company took place in 2003 and since then there has been a joint ownership of the Sugar Company with Dangote possessing at least 75% of the partnership. Presently, the Company is cultivating a total landed area of 18,000 hectares and it is employing up to 20,000people made up of direct employees and farmer out growers. It was projected to produce 1million tons by 2015. The block diagram of sugar processing of the Savannah Sugar Company, Numan is shown in figure 1 below.

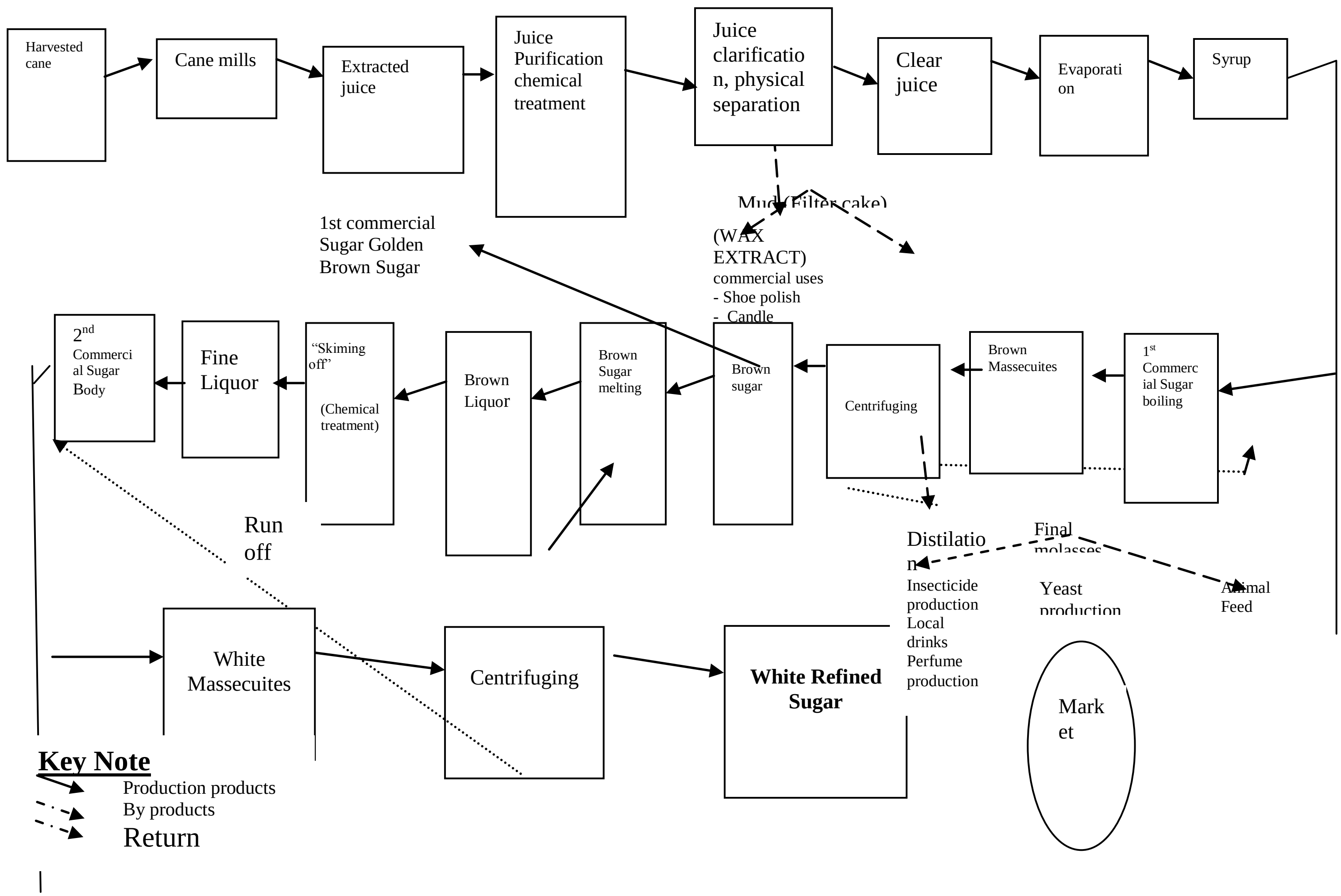

Figure 1: Block diagram of sugar manufacture process in savannah sugar company, Numan, Nigeria

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Description of Sugar Production Plant

Generally the organization is categorized into:

i) The milling department comprising of cane crushing and juice extraction unit; and

ii) Processing department.

Milling Department

This department is under the supervision of a Chief engineer and factory shift assistants. The main objective of this department is to extract the maximum of juice from the cane crushed, keeping losses of sucrose in bagasse to minimum. The staff of the milling department is also responsible for the boilers, steam production, electricity generation and the general maintenance repairs of all mechanical equipment such as motors, mills workshop etc.

Processing Department

This department is under the control of a Process Manager and shift assistants. The main objective is to extract and crystallize out the maximum amount of sucrose from mixed juice received from the milling from the milling section. Main operations are :- liming, juice heating, clarification and subsidation, mud filtration, evaporation, boiling in vacuum pans, cooling in crystallisers and centrifuging of massecuites, drying of sugar

Laboratory

The chemical and technical control of the factory – milling and processing – is done by the laboratory under the supervision of a chief chemists assisted by shift chemists and samplers working on a 24 hour basis. Sampling must be done at all the time the factory is working so the laboratory work is organised accordingly. Some products, such as bagasse, filter cake, massecuite, molasses, condensate water must be sampled at fixed frequency when need arises.

Determination of Sugar Yield

The formula to determine sugar yield is complex and so does not depend on a single equation however there are three measures of cane quality that are important, which will be briefly mentioned here. Brix is the percentage of dissolved solids on a weight per weight basis and is measured by refractometer or density meter. Pol is a measure of the passage of polarised light through the clarified juice [9]. These two measures of juice quality (corrected for fibre content of the stem) allow determination of the level of impurities in the cane (ie. Brix minus Pol equals total impurities in the cane). Furthermore this allows estimation of the sugar yield or commercial cane sugar (CCS) of a grower's cane [10].

To calculate CCS it is assumed that three quarters of the impurities remain after the juice is clarified. These impurities end up in the final molasses, which in turn consists of ~40% non-recoverable sugar and 60% impurities. Therefore:

CCS = Pol of juice (corrected for fibre content of stem) – $\frac{3}{4}$ (impurities in cane x 40/60)

= Pol in cane - $\frac{1}{2}$ (impurities in cane)

CCS is a measure of how much pure sucrose can be extracted from the cane. The final return that the grower receives is determined by additional factors [10].

Determination of Bagasse Yield

It consists of two types of fibre, which constitute 55% of bagasse dry weight. These are the cellulose fibre of rind, vascular tissue and the pith of the cane stem. Bagasse weight is therefore determined by integrating the concepts of [11] which states that every 1000kg of cane, there are between 350 – 750kg extractable bagasse.

Determination of Filter cake Yield

Filter cake weight in process juice is determined when impurities contained in the juice are precipitated by treatment with lime and heat and after removal filtration they form filter muds. It is integrated in the model using the relationship:

$$Fc = Mm + Ml \quad (1)$$

Where
Fc is filter cake,
Mm is mud mixture,
Ml is molasses fraction

Determination of Molasses Yield

Molasses is a residual syrup form which no crystalline sucrose can be obtained following evaporation, crystallization and fugalling of the massecuite. Between 27kg to 40kg of molasses are produced per ton of cane. Its average composition is 20% water, 35% sucrose, 20% reducing sugar, 15% sulphated ash and 10% others. Molasses is mainly used as animal feed or transformed into rum; alcohol or ethanol fermentation and distillation [12; 13]. Thus clarified sugar juice is boiled and centrifuged the first time to produce 'A' sugar and 'A' molasses. 'A' molasses is then boiled again to produce 'B' sugar and 'B' molasses. The 'B' molasses is boiled a third time to produce 'C' sugar which is mixed with water and is used to seed the next round of crystallization. The 'C' molasses is referred to as 'final' or 'blackstrap' molasses [10].

Development of Model

There are various processes or methodologies that are being selected for the development of the project depending on the project's aims and goals. Many development life cycle models have been developed to achieve different required objectives. The models specify the various stages of the process and the order in which they are carried out [14; 15].

The selection of the model has a very high impact on the testing that is to be carried out. The theoretical model was developed for the purpose of predicting sugar yield from cane sugar. The model was derived from [16] which served as the bases for the development of new set of equations. Details of the model development procedure and equations are shown in section 2.7.1 below.

The Theoretical Simulation Model

The following model analysis is based on mass balance model comprehensively represented in equation (2).

Assumptions

The efficiency of the MATLAB model determined to be 100% basically due to the following assumptions:

- Clarification Temperature, T = 102°C
- Juice pH=7
- And Exhaust pressure, P=1.5kpa
- These global parameters are defined in the var.m .
- All values were measured in metric tons.

The Model is written thus:

$$\dot{m}C + \dot{m}I = \dot{m}J_m + \dot{m}B \quad (2)$$

So

The essential components of the model include the cane, C, imbibitions water, I, mixed juice, Jm and baggasse, B.

The model was rewritten and presented thus

$$C + I = Mj + B \quad (3)$$

Bagasse $\Rightarrow$B

Mixed juice $\Rightarrow$Mj

Cane $\Rightarrow$ C

Imbibition water $\Rightarrow$ I

But Mj = A + Imp.

Where

$$A = S + Nw + Mm \quad (4)$$

A = absolute juice
Imp = Impurities in the juice
S = Sucrose (sugar)
Nw = Natural water in the juice
Mm = mud mixture
So:

$$Mj = S + Nw + Mm + Imp \quad (5)$$

Mj is mixed juice (practically including imbibitions water)
So,

$$C + I = S + Nw + Mm + Imp. + B \quad (6)$$

$$C = S + Nw + Mm + Imp. - I \quad (7)$$

But

$$S + Nw = Cj \text{ (Clarified Juice)} \quad (8)$$

i.e $Cj = S + Nw$

$$C + I = Cj + Mm + Imp + B \quad (9)$$

This equation (10) is synthesized further as the new model.

From equation (4) rewritten as equation (10)

$$C = Mj + B - I \quad (10)$$

But from equation (7) cane, C is

$$C = S + Nw + Mm + Imp - I$$

$$C = Cj + Mm + Imp - I \quad (11)$$

Apart from the bagasse (+B) in the model above, the sugar and the other remaining by products are generated from the mixed juice component in equation (3) above. This represent what takes place immediately after leaving the last (4th) mill where bagasse is exited from the manufacture process.The mixed juice(Mj) is extracted from the mills and it is the product of soluble/insoluble impurities such as tiny pieces of cane fibres wax,bagacillo, cane starch soil particle etc.

The *decision variables* used (obtained from factory data) were:

C = 2,150.542 metric tons

I = 673.12 tons

B ⇒ According to [11], for every 1000kg of cane crushed, Bagasse is 488kg

: . 1000kg = 488kg

2,150.542 = B ?

$$1000kg\ B = 2150542kg \times 488kg \tag{12}$$

$$B = \frac{2150542kg \times 488kg}{1000kg} \tag{13}$$

: . B = 1, 049.46T

From equation (3)

$$Mj = C - B + I \tag{14}$$

$= 2150.542 - 1049.46 + 673.12$

Mj = 1774.202T

$Nw = \frac{75}{100} X$ weight of cane [17]

: . Nw = 1612.90 tons

From (7)

$S + Imp = C - Nw - Mm + I = 997.862T$

$Mm = \text{approx} \frac{9.9}{100} x\ wt\ Cane$ (Based on Production parameter)[18]

: . Mm = 212.90 tons

But Mm = Fc + Ml

$$So,\ S + Imp = 997.862 \tag{15}$$

From (7)

$Cj + Imp = C - Mm + I \Rightarrow 2610.762$tons

Cj + Imp = 2610.762T (16)

From equation (15); Imp = 997.862 - S

From equation (16); Imp = 2610.762 - Cj

NB: Imp $\Rightarrow$ 997.862 –S = 2610.762 - Cj

Cj – S = 2610.926 – 997.862 (17)

718.292 = 997.862 - S

: . S = (997.862 - 718.292) = 279.57

S = 279.57 T

718.292 - 2610.726 - Cj

Cj = (2610.726 - 718.292)

: . Cj = 1333.33T

Note that;

Mud mixture, Mm is the fraction of yet to be extracted quantities of Molasses and filter cake in the absolute juice with the emergence of equation.

Mm = Fc + Mc (18)

Molasses, (M) = 111.828T: according to [18], there 40-52kg of Molasses in every one ton of crushed cane)

: . From (18)

Man of filter cake, Fc = 212.90 - 111.828

: . Fc = 101.1T

Now converting all known weights given above to percentages:

Mixed juice, Mj_p percent = $Mj_p \; \frac{Mjw}{Cw} x\, 100$ (19)

: . Mj_p = 82.54%

Where,

$Mj_{p\ is}$ percentage of mixed juice (%)

Mjw isweight of mixwd juice (tons)

Cw is cane weight tons)

Also imbibitions water added in percentages

$$I_p = \frac{Iw}{Cw} x\,100 \qquad (20)$$

Ip is percentage of imbibitions water in the mixture
Iw is weight of imbibitions water (tons)

Percent weights of Bagasse $B_p = \frac{Bw}{Cw} x\,100$ (21)

Bw is weight of bagasse tons)

Determining the percentage of filter cake (Fc): $Fc_p = \frac{Fcw}{Cw} x100$ (22)

Fcw isweight of filter cake tons)

So substituting values in equation (22)

$$FC_p = \frac{101.1}{2150.542} \times 100 = 4.7$$

$[Fc_p \Rightarrow 4.7\%]$

And also for molasses percentage, $(M_p) = \frac{Mw}{Cw} x\,100$ (23)

Mw is mass of water tons)

$[Mp \Rightarrow 5.2\%]$

Natural water (Nw) contained in the crushed weighed 1612.9T

: . Percentage of the water, NWp:

The various proportions sugar of cane, percentage of natural water in cane, bagasse percent in cane and molasses percent respectively presented as follows

$S = 13\%C \Rightarrow 0.13C$

$Nw_p = 75\% \Rightarrow 0.75C$

$B_p = 48.76\%C \Rightarrow 0.488C$

$M_p = 5.2\%C \Rightarrow 0.052C$

$Fc_p = 4.7\% \Rightarrow 0.047C$

Validation of the Models

Model validation as defined by [19] is the substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model or Validation is the task of demonstrating that the model is a reasonable representation of the actual system: that it reproduces system behaviour with enough fidelity to satisfy analysis objectives.. A model should be built for a specific purpose or set of objectives and its validity determined for the purpose.

The model in this study was based on a sufficient amount of a data of ninety (90) days each of Field and Theoretical (shown in tables 1and 2 below) simulation of four factors including sugar, bagasse, molasses and filter cake. The data used here was obtained from the Savannah Sugar Company, Numan. It was subjected to a statistical analysis of variance(ANOVA) and comparing the means using least significant difference(F_LSD) to test the validity of the field model developed.

Table 1: Field Data of sugar Production and the bye products obtained for 90 Days (all weighs are in metric tons)

DAY	CANE WEIGHT	BAGASSE	FILTER CAKE	MOLASSES	SUGAR
1	1453.75	391.31	28.9	28.8	16
2	1412.55	999.01	67	73	61
3	1565.87	831.84	57.7	60.4	70
4	872.16	454.24	30.4	32.6	50
5	1838.15	1031.01	62.5	77	80
6	880	447	29.93	36.6	18
7	1579.24	918.47	71.1	66.2	39
8	1902.01	1120	79.9	79.7	94
9	203	12.4	0.8	6.9	27
10	1631.7	903.18	65.3	68.4	98
11	1690.33	969.53	65.9	70.8	80
12	445.33	250.68	153	18.7	30

13	1288.25	725.97	435	54	50
14	193.29	114.89	8.7	8.1	21
15	1066.9	594.4	40.5	44.7	67
16	1331.09	704.59	51.9	55	20
17	1440.22	784.99	49	60.3	74
18	1537.5	829.45	52.28	64.4	70
19	907.3	487.08	38.1	38	40
20	563.04	327.24	21.4	23.6	13
21	1596.8	817.2	63.9	84	70
22	2005.08	1055.58	78.2	84	80
23	101.54	52.35	3.5	4.3	52
24	1889.14	1051.04	64.26	79.2	84
25	1368.71	746	48.91	51.3	60
26	1875.93	1063.23	84.4	78.6	32.9
27	714.26	401.13	27.1	29.9	20
28	975.39	574.35	41	40.9	56
29	1606.09	947.86	72.3	100.9	37
30	1023.61	602	34	64.3	46
31	1611.02	904.53	54	101.3	46
32	1446.07	731.26	56.4	90.9	33
33	1575.66	866.21	63	66	68
34	376.04	217.3	14.3	15.8	20
35	461.55	217.3	14.3	15.8	21
36	1689.59	970	76	70.8	43
37	1494.5	832.8	50.81	90.9	54
38	901.24	496.55	30.6	37.8	74.38
39	1870.08	1100.04	72.9	78.4	85
40	2196.48	1197.72	87.9	92	105
41	551.03	326.83	20.9	23.1	12
42	1509.63	797	63.2	63	70
43	2110.2	1169.29	95	88.4	59
44	1593.66	899.55	54.18	100.2	68
45	2150.93	1163.03	73	90.1	86
46	820.7	451.77	32	34.4	35

47	1914.16	1115.4	76.6	80.2	70
48	2004.48	1154.21	76.2	84	41
49	809.48	435.12	34	33.9	87
50	2120.64	1194.7	95.4	88.9	43
51	390.96	219.33	13.29	24.6	11
52	1928.84	1044.34	65.6	80.8	73
53	1901.43	1105.18	75	81.2	84
54	1314.24	722.75	50	52.4	73
55	912.47	625.25	50	52.4	73
56	223.51	1514.78	93.2	93	66
57	198.2	1297.37	92.2	85.8	28
58	2143.12	1180.62	72.39	89.2	54
59	1516.3	826.52	64.4	91.1	45
60	2048.16	1398.75	81.7	87.8	62
61	651.48	512.07	26.4	27.6	20
62	1169.55	744.41	48.1	48	72
63	2139.55	1297.56	96.4	89.8	107
64	757.9	398.56	26.34	32.4	81
65	1911.36	1040.4	64.4	91.1	118
66	2216.97	1316.45	84.9	91.2	65
67	378.72	235.85	15.9	16.6	21
68	259.67	151.07	10.1	10.9	0.5
69	622.87	368.87	24.9	26.1	25
70	258.01	171.71	25	27.6	0.8
71	1259.36	324.04	52.9	52.8	34
72	1474.4	853.11	50.13	61.8	18
73	1340.19	615.14	33.2	43.6	57
74	421	244.7	16.4	17.6	5
75	1051.16	603.06	47.3	44.1	67
76	885	517.38	30.09	37.1	42
77	122.05	706.12	39.1	51.2	33
78	1051.16	603.06	47.3	44.1	67
79	2255.19	1319.19	84.4	44.2	126
80	1222.75	706.12	39.1	51.2	3

81	1550.62	837.22	60.5	65	4
82	925.76	528.52	37	38.8	43
83	911.42	540	38.3	38.8	43
84	1664.5	968.14	74.9	69.7	82
85	484.48	272.68	16.47	20.3	7
86	1220.75	695.65	62.62	51.1	88
87	1463.04	848.47	55.6	61.3	45
88	1027.22	586.68	43.1	43	59
89	1610.44	859.44	72.5	67.5	72
90	1555.14	889.5	52.87	65.2	100

RESULTS AND DISCUSSIONS

Results

The results obtained in this research included the following:

- Source code as presented in section 3.1.1
- Table(2) of Simulated values from the On the theoretical model/ software
- Graphical comparisons of Field versus Theoretical values of sugar and its by-products comprising of bagasse, scum and molasses presented in Figures 2, 3, 4 and 5 respectively;
- Table of Analysis of variance (ANOVA) shown in table 4. And,
- Table of Least significant difference, as table 5

Source code of the Model Developed for the MATLAB Simulation

(a) Source code of 'var.m' MATLAB file

```
functionxVal=var(x)
%Constants and Variables for Prediction of Sugar

Eff = 0.75; %Milling efficiency of 75%

%GLOBAL PARAMETERS
T=102; % Clarification temp (between 102 and 105 degree Celsius)
```

```
pH=7; % (+-1) Juice pH
P=1.5; %(kpa) %%Exhaust pressure

if(strcmp('Eff',x)) %GLOBAL PARAMETERS
xVal(1)=Eff;
elseif(strcmp('Param',x))%GLOBAL PARAMETERS
xVal(1)=T;
xVal(2)=pH;
xVal(3)=P;
end
end
```

(b) Source Code of 'predictfxn.m' matlab file

```
function Pw=predictFxn(C,conv)
%Fetching list of Variables from var.m file
xV=var('Eff'); %Efficiency

Eff=xV(1);
Pw = zeros(size(C));

%Then computing for each component of the sugarcane extracted
in the mill
for i=1:length(C)
ifconv==1
C(i) = C(i) * 1000; %(Conversion from metric ton to kg)
end
Pw(i,1)=Eff * (48.76/100) * C(i); %Mass of Bagasse extracted (kg)
Pw(i,2)=Eff * (3.94/100) * C(i); %Mass of Filter cake extracted
(kg). Contains dirt composition
Pw(i,3)=Eff * (5.2/100) * C(i); %Mass of Molasses extracted (kg)
Pw(i,4)=Eff * (13/100) * C(i); %Mass of Sucrose extracted (kg)
Pw(i,5)=Eff * (24.4/100) * C(i); %Mass of Natural water
extracted (kg)
```

```
Pw(i,6)=Pw(i,1)+Pw(i,2)+Pw(i,3)+Pw(i,4)+Pw(i,5);
Pw(i,7)=C(i)-Pw(i,6);
end
end
```

Table (2) as shown is the results of sugar production simulated for ninety days. Two additional columns can be noticed compared to Table 1, that is the emergence the 'total' column and the 'difference' column. The total stands for the summation of sugar, bagasse, filter cake and molasses. This when subtracted from the weight of cane fed into the mills now gives us the 'difference'. The difference defines the efficient performance of the entire units in the system. At higher efficiency of the milling process, less differences may be noticed.

Table 2: Theoretical Results (data) of sugar Production and the bye products obtained From MATLAB Simulation for 90 replications.

DAY	CANE WEIGHT	BAGASSE	SUGAR	FILTER CAKE	MOLASSES	IMBIBITION	TOTAL	DIFFERENCE
1	1453.75	749.698875	56.69625	57.27775	75.595	354.715	1293.982875	159.767125
2	1412.55	728.452035	55.08945	55.65447	73.4526	344.6622	1257.310755	155.239245
3	1565.87	807.519159	61.06893	61.695278	81.42524	382.07228	1393.780887	172.089113
4	872.16	449.772912	34.01424	34.363104	45.35232	212.80704	776.309616	95.850384
5	1838.15	947.933955	71.68785	72.42311	95.5838	448.5086	1636.137315	202.012685
6	880	453.816	34.32	34.672	45.76	214.72	783.288	96.712
7	1579.24	814.414068	61.59036	62.222056	82.12048	385.33456	1405.681524	173.558476
8	1902.01	980.866557	74.17839	74.939194	98.90452	464.09044	1692.979101	209.030899
9	203	104.6871	7.917	7.9982	10.556	49.532	180.6903	22.3097
10	1631.7	841.46769	63.6363	64.28898	84.8484	398.1348	1452.37617	179.32383
11	1690.33	871.703181	65.92287	66.599002	87.89716	412.44052	1504.562733	185.767267
12	445.33	229.656681	17.36787	17.546002	23.15716	108.66052	396.388233	48.941767
13	1288.25	664.350525	50.24175	50.75705	66.989	314.333	1146.671325	141.578675
14	193.29	99.679653	7.53831	7.615626	10.05108	47.16276	172.047429	21.242571
15	1066.9	550.20033	41.6091	42.03586	55.4788	260.3236	949.64769	117.25231
16	1331.09	686.443113	51.91251	52.444946	69.21668	324.78596	1184.803209	146.286791

17	1440.22	742.721454	56.16858	56.744668	74.89144	351.41368	1281.939822	158.280178
18	1537.5	792.88875	59.9625	60.5775	79.95	375.15	1368.52875	168.97125
19	907.3	467.89461	35.3847	35.74762	47.1796	221.3812	807.58773	99.71227
20	563.04	290.359728	21.95856	22.183776	29.27808	137.38176	501.161904	61.878096
21	1596.8	823.46976	62.2752	62.91392	83.0336	389.6192	1421.31168	175.48832
22	2005.08	1034.019756	78.19812	79.000152	104.26416	489.23952	1784.721708	220.358292
23	101.54	52.364178	3.96006	4.000676	5.28008	24.77576	90.380754	11.159246
24	1889.14	974.229498	73.67646	74.432116	98.23528	460.95016	1681.523514	207.616486
25	1368.71	705.843747	53.37969	53.927174	71.17292	333.96524	1218.288771	150.421229
26	1875.93	967.417101	73.16127	73.911642	97.54836	457.72692	1669.765293	206.164707
27	714.26	368.343882	27.85614	28.141844	37.14152	174.27944	635.762826	78.497174
28	975.39	503.008623	38.04021	38.430366	50.72028	237.99516	868.194639	107.195361
29	1606.09	828.260613	62.63751	63.279946	83.51668	391.88596	1429.580709	176.509291
30	1023.61	527.875677	39.92079	40.330234	53.22772	249.76084	911.115261	112.494739
31	1611.02	830.803014	62.82978	63.474188	83.77304	393.08888	1433.968902	177.051098
32	1446.07	745.738299	56.39673	56.975158	75.19564	352.84108	1287.146907	158.923093
33	1575.66	812.567862	61.45074	62.081004	81.93432	384.46104	1402.494966	173.165034
34	376.04	193.923828	14.66556	14.815976	19.55408	91.75376	334.713204	41.326796
35	461.55	238.021335	18.00045	18.18507	24.0006	112.6182	410.825655	50.724345
36	1689.59	871.321563	65.89401	66.569846	87.85868	412.25996	1503.904059	185.685941
37	1494.5	770.71365	58.2855	58.8833	77.714	364.658	1330.25445	164.24555
38	901.24	464.769468	35.14836	35.508856	46.86448	219.90256	802.193724	99.046276
39	1870.08	964.400256	72.93312	73.681152	97.24416	456.29952	1664.558208	205.521792
40	2196.48	1132.724736	85.66272	86.541312	114.21696	535.94112	1955.086848	241.393152
41	551.03	284.166171	21.49017	21.710582	28.65356	134.45132	490.471803	60.558197
42	1509.63	778.516191	58.87557	59.479422	78.50076	368.34972	1343.721663	165.908337
43	2110.2	1088.23014	82.2978	83.14188	109.7304	514.8888	1878.28902	231.91098
44	1593.66	821.850462	62.15274	62.790204	82.87032	388.85304	1418.516766	175.143234
45	2150.93	1109.234601	83.88627	84.746642	111.84836	524.82692	1914.542793	236.387207
46	820.7	423.23499	32.0073	32.33558	42.6764	200.2508	730.50507	90.19493
47	1914.16	987.132312	74.65224	75.417904	99.53632	467.05504	1703.793816	210.366184
48	2004.48	1033.710336	78.17472	78.976512	104.23296	489.09312	1784.187648	220.292352

49	809.48	417.448836	31.56972	31.893512	42.09296	197.51312	720.518148	88.961852
50	2120.64	1093.614048	82.70496	83.553216	110.27328	517.43616	1887.581664	233.058336
51	390.96	201.618072	15.24744	15.403824	20.32992	95.39424	347.993496	42.966504
52	1928.84	994.702788	75.22476	75.996296	100.29968	470.63696	1716.860484	211.979516
53	1901.43	980.567451	74.15577	74.916342	98.87436	463.94892	1692.462843	208.967157
54	1314.24	677.753568	51.25536	51.781056	68.34048	320.67456	1169.805024	144.434976
55	912.47	470.560779	35.58633	35.951318	47.44844	222.64268	812.189547	100.280453
56	223.51	115.264107	8.71689	8.806294	11.62252	54.53644	198.946251	24.563749
57	198.2	102.21174	7.7298	7.80908	10.3064	48.3608	176.41782	21.78218
58	2143.12	1105.206984	83.58168	84.438928	111.44224	522.92128	1907.591112	235.528888
59	1516.3	781.95591	59.1357	59.74222	78.8476	369.9772	1349.65863	166.64137
60	2048.16	1056.236112	79.87824	80.697504	106.50432	499.75104	1823.067216	225.092784
61	651.48	335.968236	25.40772	25.668312	33.87696	158.96112	579.882348	71.597652
62	1169.55	603.136935	45.61245	46.08027	60.8166	285.3702	1041.016455	128.533545
63	2139.55	1103.365935	83.44245	84.29827	111.2566	522.0502	1904.413455	235.136545
64	757.9	390.84903	29.5581	29.86126	39.4108	184.9276	674.60679	83.29321
65	1911.36	985.688352	74.54304	75.307584	99.39072	466.37184	1701.301536	210.058464
66	2216.97	1143.291429	86.46183	87.348618	115.28244	540.94068	1973.324997	243.645003
67	378.72	195.305904	14.77008	14.921568	19.69344	92.40768	337.098672	41.621328
68	259.67	133.911819	10.12713	10.230998	13.50284	63.35948	231.132267	28.537733
69	622.87	321.214059	24.29193	24.541078	32.38924	151.98028	554.416587	68.453413
70	258.01	133.055757	10.06239	10.165594	13.41652	62.95444	229.654701	28.355299
71	1259.36	649.451952	49.11504	49.618784	65.48672	307.28384	1120.956336	138.403664
72	1474.4	760.34808	57.5016	58.09136	76.6688	359.7536	1312.36344	162.03656
73	1340.19	691.135983	52.26741	52.803486	69.68988	327.00636	1192.903119	147.286881
74	421	217.1097	16.419	16.5874	21.892	102.724	374.7321	46.2679
75	1051.16	542.083212	40.99524	41.415704	54.66032	256.48304	935.637516	115.522484
76	885	456.3945	34.515	34.869	46.02	215.94	787.7385	97.2615
77	122.05	62.941185	4.75995	4.80877	6.3466	29.7802	108.636705	13.413295
78	1051.16	542.083212	40.99524	41.415704	54.66032	256.48304	935.637516	115.522484
79	2255.19	1163.001483	87.95241	88.854486	117.26988	550.26636	2007.344619	247.845381
80	1222.75	630.572175	47.68725	48.17635	63.583	298.351	1088.369775	134.380225

81	1550.62	799.654734	60.47418	61.094428	80.63224	378.35128	1380.206862	170.413138
82	925.76	477.414432	36.10464	36.474944	48.13952	225.88544	824.018976	101.741024
83	911.42	470.019294	35.54538	35.909948	47.39384	222.38648	811.254942	100.165058
84	1664.5	858.38265	64.9155	65.5813	86.554	406.138	1481.57145	182.92855
85	484.48	249.846336	18.89472	19.088512	25.19296	118.21312	431.235648	53.244352
86	1220.75	629.540775	47.60925	48.09755	63.479	297.863	1086.589575	134.160425
87	1463.04	754.489728	57.05856	57.643776	76.07808	356.98176	1302.251904	160.788096
88	1027.22	529.737354	40.06158	40.472468	53.41544	250.64168	914.328522	112.891478
89	1610.44	830.503908	62.80716	63.451336	83.74288	392.94736	1433.452644	176.987356
90	1555.14	801.985698	60.65046	61.272516	80.86728	379.45416	1384.230114	170.909886

Table 4: Analysis of variance (ANOVA) calculations

***** Analysis of variance *****

Variate: BAGASSE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Factor	1	361684.	361684.	3.33	0.070
Residual	178	19328528.	108587.		
Total	179	19690212.			

Variate: FILTER_CAKE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Factor	1	2457.	2457.	1.71	0.192
Residual	178	255391.	1435.		
Total	179	257848.			

Variate: MOLASSES

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Factor	1	3183.0	3183.0	3.81	0.053

Residual	178	148755.4	835.7		
Total	179	151938.3			

Variate: SUGAR

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Factor	1	5656.5	5656.5	6.19	0.014
Residual	178	162758.6	914.4		
Total	179	168415.1			

Table 5 Least significant difference obtained from the ANOVA

Product	Data source	Mean value (tons)	LSD 1 %
Bagasse	Field	735	127.9 ns
	Model	645	
Filter cake	Field	56.7	14.70 ns
	Model	49.3	
Molasses	Field	56.7	11.22 ns
	Model	65.1	
Sugar	Field	53.8	11.74 ns
	Model	65.1	

Mean values with LSD having the superscript 'ns' indicate 'not significantly different' at the given probability level

DISCUSSION

The Comparative Behavior of Factory versus Predicted Sugar Results

Figure 2 below represents the curves of sugar generated over a period of 90 days (3months), a typical factory production results as against the sugar predicted for the same period using the same quantity as input. The values were obtained by mass balance calculations and the process did not distinguish different categories of cane received such as variety, cycle etc.

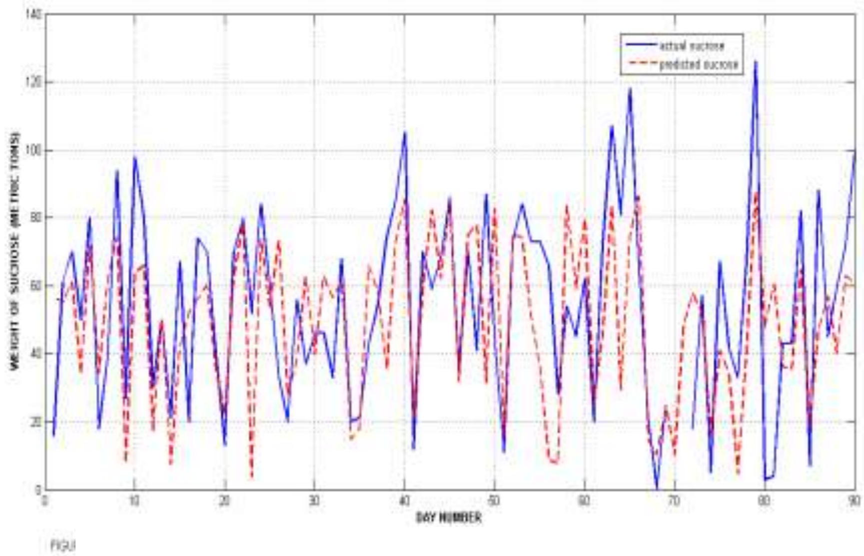

Figure 2: Sugar comparison curves between field and model predicted values

Taking a critical look at the graphs, it was observed that the model predictions and the factory-based curves were in agreement since they maintained the same pattern throughout the range of 90 day production period. However some minor cases of slight variations could be observed which are considered insignificant. The most likely reasons for these variations even though we may not expect the two curves to be naturally the same could be ascribed to:

i) Efficiency: The Model has a design efficiency of 100%; the variations in local factory conditions with respect to lower or higher efficiencies probably due to ageing machines could have been responsible for the differences., this may be responsible for the observed trend of some slight curve heights variations: a higher efficiency of the model equally project higher curves. Most machines in the factory have been operating for over thirty (30) years at a highly reduced efficiency. This fact can be accepted as evidence considering the rather relatively smaller variations in the compared values of the by- products especially that of bagasse in figure 4 as well as tables 1 and 2 respectively.

This is so in view of the fact that bagasse is a fibrous insoluble solid matter, it is classical and its value change cannot be so significant naturally. The cause may also be due to production error as these declining values always occurs in sequence of days within the same interval.

ii) Imbibition is a factor linked to the factory's milling efficiency. Low shredding/crushing of the cane at the respective mills may have resulted in more imbibitions water at the expense of partially ruptured cane cells: the result of this is that more water might have been added which some sucrose which could have been extracted by the water conveyed away as part of bagase. While the prospective sugar has been lost as sucrose in the bagasse, more imbibition has on the other hand been generated which will require more steam energy powering to extract through the evaporators in an effort to achieve the required raw sugar [20].

iii) The outstanding values of sugar generated by the model compared to those of the factory environment as reflected in the results may have also been caused by juice heating below or above the optimum temperature since it is known in principle that low temperatures often results in juice inversion or alcohol formation and excessive temperature leads to carmilization of juice.

iv) Doses of additives like lime, coagulants etc may have in some cases within the investigation period been misapplied; for instance, phosphate requirements in most cases is $\geq$ 200ppm (g/kg) and cold liming is PH of 4.5 while hot liming occurs at 8+or -2pH to achieve an optimum of 7 ± 1 PH to account for the property of clarified juice.

v) Brix entering the evaporator may have fallen outside the required range of 13-16% or brix leaving the evaporator(s) may have exceeded 60-65%. This condition is in tandem with the findings of [21].

vi) Use of module: some factories including the one within which this research work was conducted instead of using models rather use modules for predictions of sugar production. Modules work on the principle of Tons Cane per Tons Sugar(TCTS) which is an assumption index. It provided for example that given an input of 30,000tons of cane, 10tons of sugar could be expected. The empericallity of this index is therefore so much so that another TCTS value can be adopted other than 10 at some other time due to certain assumption process or systems. Hence the model guarantees a precise figure which is constant at fixed efficiency

DISCUSSION ON BY PRODUCTS OF SUGAR

Bagasse

Bagasse is a primary by product of sugar production. It is the first and only product that leaves the production line from the last mill, hence it does not go through the rigours and long processes of production; it is used to aid the process that produced it, by way of utilizing it to power steam into the boilers, heaters, evaporators, centrifuging, and eventually crystallizing and dehydration sugar to the final production stage. Bagasse generated from the field and the simulation model represented in figure 3 below.

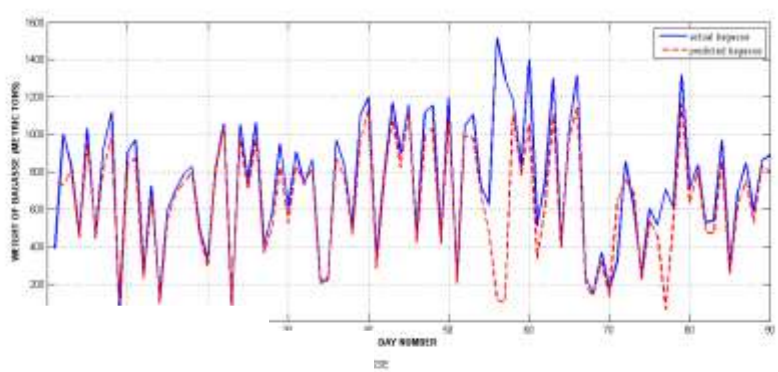

Figure 3: Bagasse comparison curves between field and model predicted values

The curves comparing the amount of bagasse through a factory process with that of a model developed in this work as presented were obtained from data shown in1 and 2 respectively. The curves indicate a close agreement between the two comparative conditions. Bagasse maintains a constant value in output; however, some little liquid might always be left trapped in the cells of the fibres. That is likely the reason for some slight rise in the amplitudes of the curves of the field module along the y-axis.

Bagasse is an essential raw material for the production of paper and boards in addition to being used as fuel for powering steam turbines. The values observed in appendix I and II agrees fully with the findings of [11] with regards to the value or proportion of bagasse that can be expected from crushing 1000kg of cane.

Filter cake (scum or mud)

Filter cake is the second by product normally extracted after bagasse and often the smallest in quantity amongst the three major byproducts of sugar. Filter cake produced from field and the simulated values are shown in figure 4 comparatively. The curves are both so low below 100 tons compared to values of bagasse and molasses. The close relationship between the graphs and similarity in pattern connotes agreement between them and suggests little or insignificant variations between the two curves, hence an indication of high compatibility between the Theoretical and Field models.

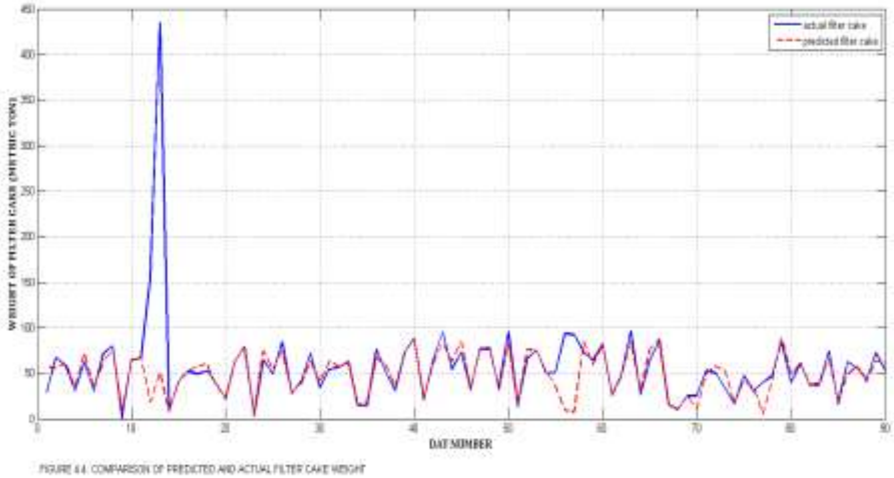

Figure 4 Comparison curves of filter cake field and model predicted values

Molasses

Molasses is the final by product of sugar that always quits the process last, but before the sugar finally comes out. It is a liquid which is known to possess a very high proportion of water in it with some traces of un-extracted sugar and other minor impurities. It is a valid raw material in the liquor production industry. It is important to note that of all the byproducts of sugar production, non is thrown away as waste but are all utilized in one thing or the other.

Molasses comparative results between factory and model simulated values are presented graphically in figure 5 below. The curves as can be seen to demonstrate a close agreement arising from the values obtained in tables 1 and 2. The graphs agree with the conventional pattern found in modern sugar factories [22]. A slight difference in the flow pattern of the graph is noticeable at the58th and 68th day of the production where the predicted which has been slightly higher generally turns to be lower at these points. This may be attributable to some factors such as error in reporting production figure arising from system failure at some intervals. Yet the overall results compromises a close correlation between the two curves

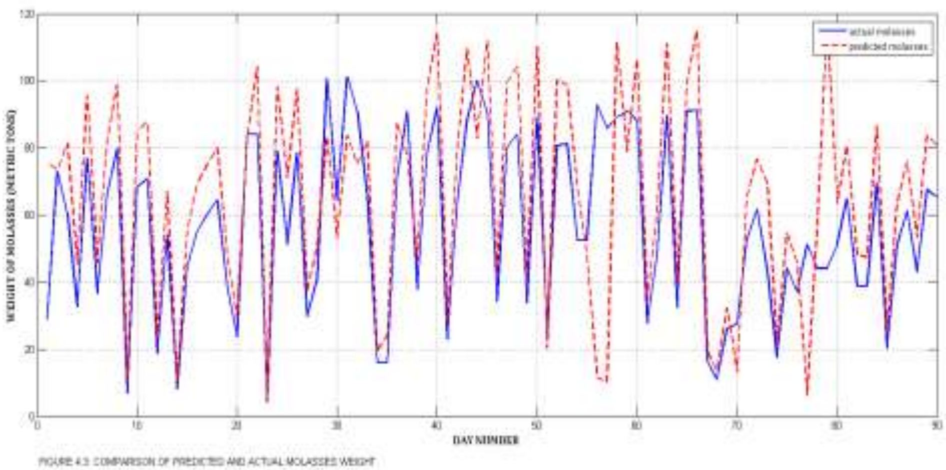

Figure 5 Comparison curves of molasses field and model predicted values

The relatively higher peaks observable in the pattern of the curves of the theoretical model is a likely indication of the model's more precise ability to extract the molasses fluid form the mixed juice.

Analysis of variance (ANOVA)

The mean values obtained from the field module and the prediction model for sugar production and the by-products which include baggase, filter cake and molasses where analysed to determine any significant difference between the means. Analysis of Variance (ANOVA) was carried out using GenStat Analytical Software (Discovery Edition 3) at 1 % ($p<0.01$) probability level.

From Tables 4 and 5, showing the Least Significant Difference (LSD) at 1 % probability level $p<0.01$), the mean value obtained for the bagasse from the field module (735 tons) and also from the developed model (645 tons) were not significantly different at 1 % ($p>0.01$) probability level. Similarly no significant differences were observed between the means obtained for filter cake and molasses at the 1 % ($p>0.01$) probability level. For the sugar product, the mean values obtained from the field and from the model were observed and means were not significantly different ($p>0.01$) at 1 % probability level.

Since the ANOVA presented in table 4 above shows no significant difference between the sugar, bagasse, filter cake and molasses obtained from Savannah Sugar Factory and the theoretical model developed, the field model is therefore validated. However the field model is fast and can be used to estimate yield ahead of the production process.

CONCLUSION

From the results of the studies the following conclusions were drawn:
1. The predicted sugar yield and that of the field data were in agreement with each other.
There was no significant difference (at 99% probability) between Sucrose (Sugar), bagasse, filter cake and molasses values obtained from Savannah Sugar Company and the values generated from the theoretical model.
2. The theoretical model is however superior to the conventional field model in the sense that it is able to predict yields given a quantity of cane, whereas the field model waits till the final products comes. The theoretical model allows room for planning which is not the case with the field model already in use.

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