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Effect of Dryer Parameters on Drying Rate and Quality of Spent Brewers' Grain

L. A. Sanni
Senior Lecturer, Department of Agricultural and Environmental Engineering,
Obafemi Awolowo University, Ile-Ife, Nigeria
O. A. Fakunle
Graduate Student, Department of Agricultural and Environmental Engineering,
Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract:
The effect of four operational parameters (shape of flight, number of flights, vapour extraction rate and drum temperature) of a conductive rotary dryer on the drying rate and quality of spent brewers' grain was investigated in this study, with the aim of mechanizing the drying of spent brewers' grain for animal feed production. The Taguchi statistical method was used to determine the optimum levels of the parameters, at which drying rate was highest. Drying rate of 0.0746 kg/min was attained at the optimum parameter levels of curved flight shape, 2 flights, vapour extraction rate of 0.03 m^3/s and drum temperature of 190 ^0C. The four parameters contributed 1.72, 0.59, 1.45 and 89.36 % to the drying rate respectively. Drum temperature had the most significant effect with signal-to-noise-ratio difference of 2.39 andF value of 12.99.Moisture content of the spent brewers' grain decreased from 78.27 to 8.16 % and the crude fibre and crude protein contents increased from 2.4 and 7.87 % to 8.94 and 25.38 % respectively. Dehydration of the spent brewers' grain was achieved in 2.5 hours as against 72 hours of sun-drying. Deterioration and fermentation of the spent grain were totally prevented and the mechanically dried product was successfully stored for over 26 months. Considering the time spent for dehydration, the conductive rotary dryer performed better than traditional sun-drying method.

Keywords: *Rotary dryer, brewers' grain, drying rate, quality*

1. Introduction

Spent brewer's grain (SBG)is the solid residue left after the processing of germinated and dried millet grains (*Sorghum bicolor* L.) for the production of beer or other malt products. In the brewing process, the sorghum grains are soaked in water until they germinate and then dried to produce malt. The malted grain is milled and steeped in hot water for enzymatic transformation of the starch into a sugar-rich liquid (wort) which is boiled, filtered and fermented to produce beer. Once all the sugars have been removed from the grains, the remaining product is a concentrate of proteins and fibre, which is suitable for animal feed production, particularly for ruminants (Crawshaw, 2004). However spent brewers' grain contains 75-80% water and therefore deteriorates rapidly due to the growth of bacteria, yeasts and fungi. This makes its handling, transportation and storage difficult for animal feed millers (Wyss, 1997; Wadhwa et al., 1995, Aning et al., 1994).Research works have shown that when dried and mixed with other ingredients, brewers' grain is an excellent substitute to maize in livestock feed production and a wide variety of animals have been productively fed with it(Pelevina, 2007; Yaakugh et al., 1994).

There are over 49 breweries (quoted and unquoted) located in different parts of Nigeria (FMR, 2013). They engage in the production of various beer and malt drinks from locally produced grains, especially sorghum (*Sorghum bicolor* L.) and maize (*Zea mays* L.). The breweries generate large quantities of spent brewers' grain as by-product on a daily basis. The current beer production capacity in Nigeria is estimated at 15 million hectolitres per annum (Ahmed, 2010) and research shows that brewers' grain constitutes about 20 % of the beer produced (Mussatto et al., 2006). This means that about 300 million kg (300,000 tons) of wet brewers' grain is produced annually. After beer production, some breweries give out the spent brewers' grain free to livestock farmers, while most breweries dump them off as waste. Fresh brewers' grains left on the ground outside the brewery spoil quickly and often become a source of environmental nuisance, including water pollution. Using brewers grains as animal feed therefore alleviates the environmental impact of the brewing process (Crawshaw, 2004).

Because of the bulky nature of wet brewers' grains they are costly to transport and their distribution is therefore limited to a radius of 150-350 km around the brewery. Dehydration therefore facilitates the transportation and distribution of brewers' grains beyond their area of production, as dried brewers' grains are less bulky and less expensive to transport. When brewers' grains are intended for long storage, it is necessary to dry them so that they contain no more than 10% water (Crawshaw, 2004). Many local feed producers collect the wet brewers' grain and spread it out in thin layer in the sun to be dried. This method is slow, unhygienic and requires large ground surface area. Sun drying is difficult during the rainy season and the method is not adequate for commercial production of dried brewers' grain. This research work sought to investigate the drying characteristics of spent brewers' grain in a conductive rotary dryer, with a view to mechanizing and expediting the drying process for large scale production.

2. Materials and Methods

2.1. Materials

The major materials used for the investigation include spent brewers' grain mash from sorghum which was collected fresh from Nigeria Breweries Plc, Ibadan; screw press for dewatering the wet mash of spent brewers' grain and a conductive rotary dryer for drying granular agricultural materials.

2.2. Experimental Methods

2.2.1. Proximate Analysis of Spent Brewers' Grain

Fresh mash of spent brewers' grain was collected from Nigerian Breweries, Ibadan and its proximate composition was determined in the Animal Science Laboratory of the Obafemi Awolowo University, Ile-Ife. The standard method recommended by AOAC (2012) was used to determine the moisture content (%), ash content (%), crude fibre content (%), ether extract (%) and crude protein content (%). The same procedure was used to analyse the proximate composition of the spent brewers' grain after pressing for 2 hours and after drying in the conductive rotary dryer. The results of the proximate analyses were compared with reported cases in the literature.

2.2.2. Dewatering of Spent Brewers' Grain

According to the method used by Ademiluyi et al. (2006, 2010a, 2010b, 2013), two perforated polyethylene bags were each filled with 38 kg of wet mash of the spent brewers' grain. The bags were tightly sealed and placed under the ram of a vertical screw press. The threaded shaft of the press was rotated until its plunger ram pressed against the bags and the free water content was discharged through the perforations. The threaded shaft was re-tightened intermittently to apply pressure on the bags until no more free liquid was discharged. This method reported by Kolawole et al. (2011, 2012 and 2014) is popular with the pressing of grated cassava mash for *gari* production. After 2 hours of pressing, the bags were removed from the screw press and weighed, and samples were taken for proximate analysis. The compressed brewers' grain was pulverized manually into a plastic container and covered tightly to prevent moisture migration in readiness for the drying experiments.

2.2.3. Drying of Spent Brewers' Grain in Conductive Rotary Dryer

2.2.3.1. Experimental Design

The Taguchi method (Moreno, et al., 2007; Esme, 2009)was used to analyse the effects of four parameters of the conductive rotary dryer on the drying rate of spent brewers' grain. Each of the four dryer parameters was investigated at two levels as presented in Table 1. Based on the number of parameters and levels, an L8 orthogonal array was chosen for the experimental design as shown in Table 2.The degree of freedom of the orthogonal array is 7, and is greater than 4 for the four parameters at two levels each.

Symbol	Process Parameters	Unit	Level 1 (low)	Level 2 (high)
A	Flight shape	-	Straight	Curved
B	Number of flight	-	1	2
C	Vapour extraction rate	m^3/s	0.015	0.03
D	Drum temperature	^oC	90	190

Table 1: Dryer parameters investigated at two levels
Note: Degree of freedom of four parameters at two levels each = 4

Number of Experiment	Flight shape	Number of flight	Vapour extraction rate (m^3/s)	Drum Temperature (^0C)
1	Straight	1	0.015	90
2	Straight	1	0.015	190
3	Straight	2	0.03	90
4	Straight	2	0.03	190
5	Curved	1	0.03	90
6	Curved	1	0.03	190
7	Curved	2	0.015	90
8	Curved	2	0.015	190

Table 2: L8 orthogonal array for drying experiments
Note: Degree of freedom of experimental design = 7

2.2.3.2 Determination of quality characteristic and Taguchi Loss Function

The most important quality characteristic of interest is moisture content and the concern is how quickly the moisture content of the spent brewers' grain was reduced to the desired level. This was measured by calculating the drying rate of the spent brewers' grain for each of the eight experiments outlined in Table 2. According to Moreno (2007), the drying rate as affected by the combination of dryer parameters was calculated using Equation 1.

$$DR = (M_i - M_f)W_d/t_d \quad (1)$$

where DR is the drying rate (kg of moisture/minute); $M_i$is the initial moisture content (dry basis), M_f *is* the final moisture content (dry basis); $W_d$is the dry matter content (kg); $t_d$is the drying time (minutes).

Each of the eight experiments in Table 2 was run by connecting the appropriate type and number of flights to the inner surface of the rotary drum of the dryer (Sanni et al., 2015). The external surface of the drum was heated by electrical heating elements whose temperature was set and regulated by means of a set of thermocouple, 60 amps contactor and a 300 ^{0}C temperature control knob. Once the drum surface temperature reached the appropriate level, 5 kg of the pressed and pulverized spent brewers' grain[with initial moisture content of 51.6 % wet basis (1.07 dry basis)] was introduced into the drum which rotated at a steady speed of 20 rpm. By means of an air duct connected to a centrifugal suction fan and a gauge valve, the vapour in the drying chamber was removed at the appropriate vapour extraction rate. For each drying experiment the conductive rotary dryer was left to run for 35 minutes after which the spent brewers' grain was discharged, allowed to cool and weighed. Samples were taken from each batch of the dried spent grain for final moisture content determination. The initial and final moisture contents were determined using the procedure of AOAC (2012).

The Taguchi loss function (equivalent to the mean squared deviation) was determined according to the method used by Kamaruddin et al. (2004) and Esme (2009). Since it was desired that the spent brewers' grain be dried as quickly as possible, the-higher-the-drying rate-the-better, and the mathematical expression in Equation 2 was used to calculate the corresponding signal/noise ratio (S/N) for each of the eight experiments.

$$(S/N)_i = -10log(1/n \sum_{k=1}^{n} 1/y_i^2) \quad (2)$$

where $(S/N)_i$ is signal-to-noise ratio of the drying rate from the ith replicate; n =1is number of replicate(s) for each experiment in the orthogonal array;y_i is the drying rate of the spent brewers' grain from the ithreplicate.

Because the optimum combination of parameter levels did not coincide with anyone in the orthogonal array, an estimate of the drying rate of the spent brewers' grainat the optimum parameter levels was predicted using the regression equation of Equation 3(Kamaruddin et al., 2004).

$$y_{opt} = \bar{\bar{y}}_m + (\bar{y}_{Aopt} - \bar{\bar{y}}_m) + (\bar{y}_{Bopt} - \bar{\bar{y}}_m) + (\bar{y}_{Copt} - \bar{\bar{y}}_m) + (\bar{y}_{Dopt} - \bar{\bar{y}}_m) \quad (3)$$

y_{opt} = predicted value of drying rateat the optimum levels of dryer parameters

$\bar{\bar{y}}_m$ = grand mean of drying rate

$\bar{y}_{Aopt}$ = average value of drying rate for parameter A at its optimum level

$\bar{y}_{Bopt}$= average value of drying rate for parameter B at its optimum level

$\bar{y}_{Copt}$ = average value of drying rate for parameter C at its optimum level

$\bar{y}_{Dopt}$ = average value of drying rate for parameter D at its optimum level

3. Results and Discussion

3.1. Effects of Dryer Parameters on Drying Rate of Spent Brewers' Grain

The drying rate which was calculated using Equation 1, and signal-to-noise ratio (S/N) which was calculated from Equation 2 are summarized in Table 3.

Exp. No.	Code A B C D	Flight shape	No. of flight	Vapour extraction rate (m^3/s)	Drum temperature (^{o}C)	Final moisture content (% wb)	Drying rate (kg/min)	S/N ratio
1	1 1 1 1	Straight	1	0.015	90	28.08	0.0470	-26.56
2	1 1 1 2	Straight	1	0.015	190	1.22	0.0732	-22.71
3	1 2 2 1	Straight	2	0.03	90	19.65	0.0574	-24.82
4	1 2 2 2	Straight	2	0.03	190	5.34	0.0701	-23.09
5	2 1 2 1	Curved	1	0.03	90	19.55	0.0572	-24.85
6	2 1 2 2	Curved	1	0.03	190	2.86	0.0720	-22.85
7	2 2 1 1	Curved	2	0.015	90	20.11	0.0566	-24.94
8	2 2 1 2	Curved	2	0.015	190	3.87	0.0712	-22.95

Table 3: S/N responses to drying rate of spent brewers' grain

From the analysis of Table 4, the parameter level with the higher average of S/N ratio was considered optimum for drying the spent brewers' grain in the conductive rotary dryer. It follows that a curved flight (A_2), 2 flights (B_2), vapour extraction rate of 0.03 m^3/s (C_2) and drum temperature of 190 ^{0}C (D_2) were the best combination of parameter levels for efficient drying of spent brewers' grain in the conductive rotary dryer. The difference between the two levels of S/N ratios for each parameter is an indication of the effect of the parameter on the drying rate of the spent brewers' grain in the dryer.

CRD Parameter	Symbol	Average S/N Ratio		Parameter Average	Grand Mean	Difference of S/N	Strength of effect
		Level 1	Level 2				
Shape of flight	A	-24.30 0.0619	-23.90[a] 0.0643[b]	-24.10 0.0631	S/N: -24.10 DR: 0.0631	0.40	2nd
Number of flight	B	-24.24 0.0624	-23.95[a] 0.0638[b]	-24.10 0.0631		0.29	4th
Vapour extraction rate (m^3/s)	C	-24.29 0.0620	-23.90[a] 0.0642[b]	-24.10 0.0631		0.39	3rd
Drum temperature (^{0}C)	D	-25.29 0.0546	-22.90[a] 0.0716[b]	-24.10 0.0631		2.39	1st

Table 4: S/N analysis of the drying rate of spent brewers' grain in the conductive rotary dryer

[a]Higher value of S/N ratio indicate the optimum level of each parameter, i.e. $A_2B_2C_2D_2$

[b]Corresponding values of drying rate of spent brewers' grainat optimum parameter level

The ranking of the S/N differences in Table 4 therefore shows that drum temperature had the strongest effect (S/N = 2.39) distantly followed by flight shape and vapour extraction rate (0.40 and 0.39, respectively). The number of flight had the least effect (0.29) on the drying rate of the spent brewers' grain. The result of the Taguchi method (fractional factorial analysis) was confirmed by the analysis of variance (ANOVA) in Table 5. The drum temperature contributed the highest effect on the drying rate (89.36 %), distantly followed by flight shape and vapour extraction rate which contributed 1.72 % and 1.45 %, respectively. The contribution of flight number (0.59 %) was not significant. The F values however showed that a small variation in the drum temperature (F > 4) will have a significant effect on the drying rate of the spent brewers' grain with 99 % confidence. Thus, drum temperature of was most critical to the dryer's performance.

Parameter Code	Process Parameter	Degree of Freedom	Sum of Square	Mean Square	F	Contribution (%)
A	Shape of flight	1	$11.52e^{-6}$	$11.52e^{-6}$	2.50	1.72 (2nd)
B	Number of flight	1	$3.92e^{-6}$	$3.92e^{-6}$	0.09	0.59 (4th)
C	Vapour extraction rate	1	$9.68e^{-6}$	$9.68e^{-6}$	0.21	1.45 (3rd)
D	Drum temperature	1	$598.76e^{-6}$	$598.76e^{-6}$	12.99*	89.36 (1st)
	Error	3	$46.10e^{-6}$	$15.37e^{-6}$		6.88
	Total	7	$669.98e^{-6}$			100

Table 5: Result of ANOVA using the overall evaluation criterion for cassava flour
**At least 99% confidence*

The optimum parameter levels indicated by the S/N ratio analysis of Table 4 ($A_2B_2C_2D_2$) did not coincide with any of the eight combinations in the Taguchi orthogonal array of Table 3. Equation 3 was therefore used to predict the drying rate of the spent brewers' grain under the optimum parameter levels and a predicted value of drying rate of 0.0746 kg/min was attained. This value is higher than any of the experimental values of drying rate in Table 3. Running the conductive rotary dryer at the second level of each parameter will therefore increase the drying rate and more dried brewers' grain can be produced in a given time. The cost of drying can also be reduced by using one flight in the dryer without affecting the dryer's efficiency.

3.2. Effect of Conductive Rotary Drying on Quality of Spent Brewers' Grain

The proximate analysis of the spent brewers' grain at the three stages of dehydration is presented in Table 6. Reduction in the moisture content of the spent brewers' grain caused a general increase in its ash, crude fibre, ether extract and crude protein contents. After pressing for 2 hours under the screw press, the moisture content decreased from 78.27 % to 51.60 %and the crude protein increased from 7.87 % to 13.76 %. After drying for 35 minutes in the conductive rotary dryer, the moisture content decreased to 8.16 % and the crude fibre and crude protein contents increased to 8.94 % and 25. 38 %, respectively. In evaluating the inclusion of brewers' dried grain in poultry ration, Fombad and Mafeni (1989) dried fresh brewers' grain in the sun for 72 hours before using it to produce poultry feed. The proximate composition of the sun-dried spent brewers' grain was compared with corn as presented in Table 7.

Condition of Spent Brewers' Grain	Proximate Composition				
	Moisture (%)	Ash (%)	Crude Fibre (%)	Ether Extract (%)	Crude Protein (%)
Fresh	78.27	0.92	2.41	6.11	7.87
After mechanical pressing	51.59	0.92	3.49	14.79	13.76
After mechanical drying	8.16	2.76	8.94	11.22	25.38

Table 6: Proximate analyses of spent brewers' grain

	Proximate Composition			
	Ash (%)	Crude Fibre (%)	Ether Extract (%)	Crude Protein (%)
Sun-dried BDG	3.8	15.7	7.2	27.7
Corn	1.2	2.9	4.3	9.1

Table 7: Proximate analyses of BDG and corn
Source: Fombad and Mafeni (1989)

The proximate composition of the mechanically dried spent grain compared favourably well with the sun-dried BDG. The source of the variations can be attributed to the type of grain and the brewing process used. The ash, crude fibre, ether extract and crude protein contents of both mechanically dried and sun-dried spent grains were generally higher than for corn, making it a good substitute for corn in animal feed formulations. This agrees with the finding of Fombad and Mafeni (1989). The approximate time for mechanical pressing and drying of spent brewers' grain was 2.5 hours as against 72 hours required for sun-drying of BDG.The spent brewers' grain that was dried in the conductive rotary dryer was successfully stored under room condition for over 26 months without deterioration.

4. Conclusions

The use of the conductive rotary dryer proved to be an efficient method of rapidly drying spent brewers' grain. Rapid deterioration due to the growth of bacteria, yeast and fungi and fermentation of the spent grain during sun-drying were totally prevented. The large ground surface area often required for sun drying was not necessary. Unlike the product of sun-drying, the mechanically dried spent brewers' grain was free of the bad odour usually caused by improper drying and mould growth. The use of the conductive rotary dryer can make drying possible in rainy season when sun-drying is difficult. Dependence of animal feed millers on corn will be reduced and more corn can be available for human consumption. However the capacity of the dryer is a limitation for large scale drying. Re-designing the conductive rotary dryer for increased capacity and cheaper energy source is therefore necessary.

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