Energy performance of a pneumatic dryer and of a flatbed dryer used for small-scale cassava processing

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This document compares the energy performance of a pneumatic dryer and of a flatbed dryer, both commonly used to process cassava on a small-scale operation in Africa. As expected, the pneumatic dryer has higher energy efficiency, attributed to the better contact between the product and the drying air. The work was funded by the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and executed by the Natural Resources Institute (NRI) of the University of Greenwich, United Kingdom, in partnership with the Food Research Institute (FRI) of the Council for Scientific and Industrial Research (CSIR), Ghana.

Background

Fixed bed dryers are widely used by smallholders in developing countries mainly because of its versatility, simplicity and low cost. In this kind of dryer, the product to be processed is placed on a perforated screen and dried by forcing hot air through it. Heat is generated by a burner, fuelled by kerosene, diesel or gas. A fan, powered by an electric motor, induces the air. Fixed bed dryers usually have a rectangular bin shape and for this reason, sometimes are called bin dryer. The most common fixed bed dryers are flatbed dryers, where the perforated drying screen is horizontal, however, inclined screen, to facilitate unloading, are also common.

Figure 1 Flatbed dryer are frequently used by small-scale cassava possessors in developing countries.

Like flatbed dryers, pneumatic dryers also use a burner to produce heat, and a fan to induce the air. However, on pneumatic dryers drying occurs during product transport and inside a duct. At this duct air velocity is high enough to make the product to suspend and to become fluidized. This improves greatly the contact between material and hot air, enhancing heat and mass transfer and consequently improving energy efficiency. For this reason, for granular materials, pneumatic dryers are a better choice over flatbed dryers. However, they are rarely used by smallholders in developing countries. That is because pneumatic dryers need to be correctly dimensioned to operate efficiently and this knowledge is not widely available. However, in Ghana, as part of RTB activities, equipment manufacturers learned how to dimension and build such dryer (Figure 2).

Figure 2 Small-scale pneumatic dryer built by equipment manufacturers in Ghana during RTB training.

The objective of this work was to compare the energy performance of a pneumatic dryer against the energy performance of a flatbed dryer, both used for small-scale cassava processing. Experiments were conducted in quintuplicate at a processing centre named Tropical Starch, located in Ghana’s Central Region.

Data collection

Data were collected over a period of 10 days, 5 days for each dryer, on a randomized order (seed=49205). Air relative humidity, temperature, pressure and velocity were recorded at different locations of the dryer as shown in Figure 3. In addition, material samples were collected, and solid mass flow measured. Also, fuel consumption and electricity consumption were monitored.

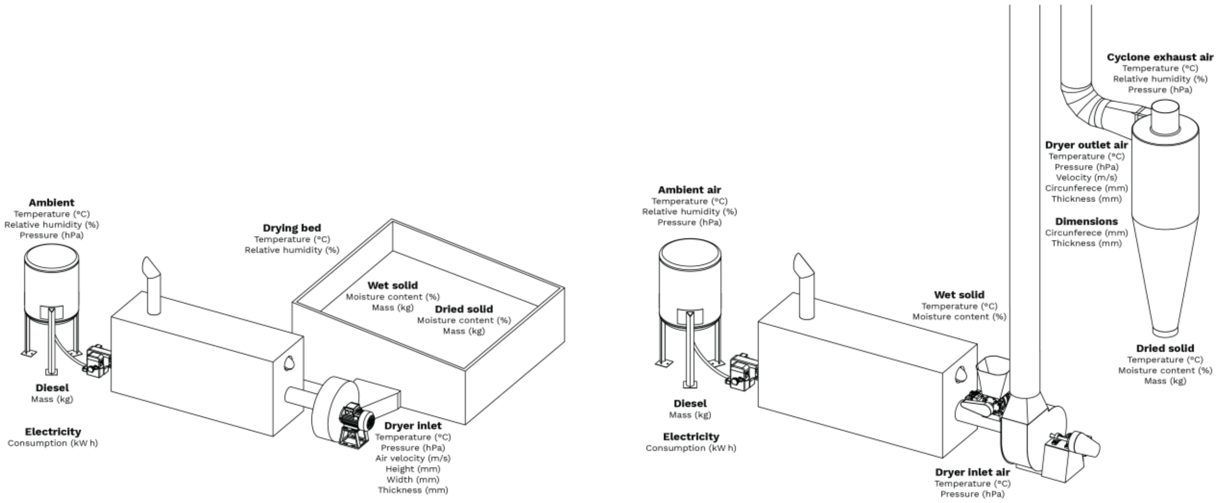

Figure 3 Data collected at the flatbed dryer and at the pneumatic dryer for energy performance evaluation.

Calculation of energy performance indices

To evaluate the energy performance of the dryer, specific energy consumption, energy efficiency and specific heat utilisation were used. Specific energy consumption (q_s) was defined as the ratio between the heat supplied to the dryer ($\dot{Q}_{in}$) and the water evaporation rate ($\dot{m}_w$), as shown in Equation 1:

$$q_s = \frac{\dot{Q}_{in}}{\dot{m}_w} = \frac{\dot{m}_{air}\left(h_1 - h_{amb}\right)}{\dot{m}_{dm}\left(X_{ws} - X_{ds}\right)} \tag{1}$$

The value for $\dot{Q}_{in}$ was obtained by multiplying air mass flow rate on a dry basis ($\dot{m}_{air}$) to the specific enthalpy of the air at the dryer inlet (h_1) but subtracting the specific enthalpy of the ambient air (h_{amb}). The value for $\dot{m}_{air}$ was obtained from the air volume flow (V_{air}) and its density (ρ_{air}). The value for V_{air} was calculated multiplying air velocity to the cross-sectional area of where the air velocity measurement was performed. The value for ρ_{air} was calculated from using the air temperature relative humidity and pressure figures recorded while air velocity was being measured. The value for h_1 and h_{amb} were calculated from the respective values of air temperature, relative humidity and pressure.

The value for $\dot{m}_w$ was calculated based on the product mass flow rate on a dry basis ($\dot{m}_{dm}$) and the difference between the wet product moisture content on a dry basis (X_{ws}) and the dried product moisture content, also on a dry basis (X_{ds}). The value for $\dot{m}_{dm}$ was calculated from the dried product mass flow rate ($\dot{m}_{ds}$) and its X_{ds}.

Energy efficiency (η) was defined as the ratio between the heat used for moisture evaporation ($\dot{Q}_{\mathrm{w}}$) and $\dot{Q}_{\mathrm{in}}$, as shown in Equation 2:

$$\eta = \frac{\dot{Q}_{\mathrm{w}}}{\dot{Q}_{\mathrm{in}}} = \frac{\dot{m}_{\mathrm{w}} \cdot Q_{\mathrm{st}}}{\dot{Q}_{\mathrm{in}}} \quad (2)$$

The value of $\dot{Q}_{\mathrm{w}}$ was obtained by multiplying $\dot{m}_{\mathrm{w}}$ to the cassava heat of sorption (Q_{st}). Q_{st} was used instead of the latent heat of vaporisation (λ), to account for the energy required to overcome capillary forces.

Specific heat utilisation (q_{U}) was defined as the ratio between the heat supplied to the dryer and the dried solid output rate ($\dot{m}_{\mathrm{ds}}$), as shown in Equation 3:

$$q_{\mathrm{U}} = \frac{\dot{Q}_{\mathrm{in}}}{\dot{m}_{\mathrm{ds}}} \quad (3)$$

Product quality indicators

Moisture content of all the samples collected was measured. For the dried and milled product, colour was measured and the Whiteness Index (WI) calculated using the Judd and Wyszecki formula, as shown in Equation 4.

$$WI = 100 - \left[\left(100 - L^*\right)^2 + \left(a^*\right)^2 + \left(b^*\right)^2 \right]^{1/2} \quad (4)$$

Furthermore, 3 members of staff that work at Tropical Starch, and are responsible for controlling product quality, were asked to evaluate the overall appearance of the product using a 7-point hedonic scale (Figure 4).

Product code ________

Do you like the appearance of this product?

1	2	3	4	5	6	7
Dislike extremely						Like extremely

Figure 4 Excerpt of the questionnaire filled by quality control staff to evaluate the final product overall appearance.

Obtained results

In Ghana, many cassava processing centres have a maximum capacity of handling 1 tonne of fresh roots per day, in an 8-hours operation. This 125 kg/h of roots becomes 60 kg/h of wet grits after it has been peeled and dewatered. Therefore, a dryer suitable to the Ghanaian small-scale operation would have a wet solid throughput of 60 kg/h and a dried solid throughput of 40 kg/h. The flatbed dryer had a wet solid throughput of 84 kg/h and a dried solid throughput of 52 kg/h. For the pneumatic dryer, the throughput was inferior, being 66 kg/h of wet solid and 41 kg/h of dried solid. While the pneumatic dryer had a capacity suitable for smallholders, the values of temperature and relative humidity at the dryer outlet, respectively 70 °C and 37%, suggest that feeding rate could be increased, without jeopardizing drying and without needing to increase heat input to the dryer. Despite the different throughputs of the dryers, no significant differences were observed regarding product initial and final moisture content, allowing the dryers to be compared (Table 1). Also, no significant difference, by Fisher's Least Significant Difference (LSD) test at 5% level, were observed on air ambient temperature and relative humidity when evaluating the dryers.

Table 1 *Operating conditions of a flatbed dryer and of a pneumatic dryer used to process cassava in Ghana.*

Dryer type	$\dot{m}_{dm}$ Throughput on dry basis (kg/h)	MC_{ws} Wet solid moisture content ($\%_{wb}$)	MC_{ds} Dried solid moisture content ($\%_{wb}$)	T_1 Dryer inlet temperature (°C)	T_{ds} Dried solid temperature (°C)	$\dot{m}_{diesel}$ Fuel consumption (kg/h)	E Electricity consumption (kW)
Flatbed	45.0^a	46.5^a	12.8^a	85.2^a	41.3^a	5.27^a	1.29^a
Pneumatic	35.9^b	46.1^a	12.2^a	226.8^b	57.2^b	2.89^b	2.24^b

Means followed by a common letter are not significantly different by Fisher's Least Significant Difference (LSD) test at 5% level of significance.

Table 1 shows that dryer inlet temperature was 166% higher at the pneumatic, but this higher temperature did not directly affect product temperature, that end up being only 38% higher at this dryer. Also, the higher temperature at the dryer inlet did not mean higher fuel consumption, as the diesel mass flow rate was 45% inferior at the pneumatic dryer. Furthermore, despite the higher inlet temperature at the pneumatic dryer, heat input to the dryer was inferior compared to the flatbed dryer, as shown in Table 2. That is attributed to the much higher air mass flow, being 3498 kg/h at the flatbed dryer and 533 kg/h at the pneumatic dryer, both on a dry basis. Notwithstanding that the blower at the flatbed dryer was producing a much higher air mass flow, electricity consumption was higher at the pneumatic dryer. The reason for that is the additional motor used by the feeder. Nevertheless, the pneumatic dryer performed better on all energy performance indices. At the flatbed dryer, for each kilogram of dried product produced, USD 0.20 was spend with diesel and USD 0.003 with electricity. For the pneumatic dryer, for each kilogram of dried product produced, USD 0.15 was spent with diesel and USD 0.007 with electricity.

Table 2 *Energy performance indices of a flatbed dryer and of a pneumatic dryer used to process cassava in Ghana.*

Dryer type	$\dot{Q}_{in}$ Heat supplied rate (kW)	$\dot{m}_{w}$ Water evaporation rate (kg/h)	q_s Specific heat consumption (kJ/kg)	η Energy efficiency (%)	q_U Specific heat utilization (kJ/kg)	WI Dried solid whiteness	A_{ds} Dried solid appearance score (7-point)
Flatbed	54.0^a	32.5^a	6005.4^a	41.3^a	3776.9^a	42.2^a	6.1^a
Pneumatic	29.9^b	25.6^b	4316.5^b	58.7^b	2716.9^b	37.1^a	6.1^a

Means followed by a common letter are not significantly different by Fisher's Least Significant Difference (LSD) test at 5% level of significance.

Regarding product appearance, Whiteness Index was higher for the Flatbed dryer, but not at a significant level of 5%, and the staffs, responsible for product control, did not notice any visual difference between the product coming for each dryer.

Derived guidelines

The pneumatic dryer at Tropical Starch has been properly dimension and its design can be replicated on other processing centres. However, improvements can still be made, particularly on the feeder and at the blower design.

The current feeder is able to introduce the material on a controlled rate and to disperse the solid well within the airstream. However, it requires an extra motor, increasing electricity consumption. A new feeding system, able to introduce the material on a controlled rate and to disperse it well, without the need of motor, should be developed.

Regarding the blowers, their current designs are suboptimal, contributing to electricity costs. Training of equipment manufacturer on its proper design and dimensioning is needed.

Finally, pneumatic dryers are more efficient than flatbed dryers for cassava processing. However, it not a panacea, and other dryer types, such as fluidised-bed dryers, should be considered and investigated.