RTB Working Paper

Impact of the feeding system on pneumatic dryers' energy performance

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The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is an alliance led by the International Potato Center implemented jointly with Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Institute of Tropical Agriculture (IITA), and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), that includes a growing number of research and development partners. RTB brings together research on its mandate crops: bananas and plantains, cassava, potato, sweetpotato, yams, and minor roots and tubers, to improve nutrition and food security and foster greater gender equity especially among some of the world's poorest and most vulnerable populations.
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INTRODUCTION

For the good operation of a pneumatic dryer, solids should be fed to the equipment well dispersed and without the presence of lumps. In addition, the material should be introduced to the drying duct at a rate as uniform as possible. Rotary valve feeders and screw feeders are the most common type of feeding mechanisms used in pneumatic dryers. However, before drying, the grated and dewatered cassava is sticky, and therefore rotary valve feeders cannot be used (Figure 1). As part of RTB's 2020 activities, two feeding systems for pneumatic drying of cassava were developed. One of the feeders uses a screw mechanism (Figure 2) and the other uses a plough mechanism (Figure 3). Both feeders have hoppers with vertical walls, as for cassava grits, V-shaped hoppers, create bridges and consequently stop the material flow (Figure 4). The screw feeder requires a flow-aid-device and a disintegrator, while the plough feeder does not require either, being therefore more affordable equipment. The objective of this working paper is to compare the impact that those two feeders have on the energy performance of pneumatic dryers used for cassava processing.

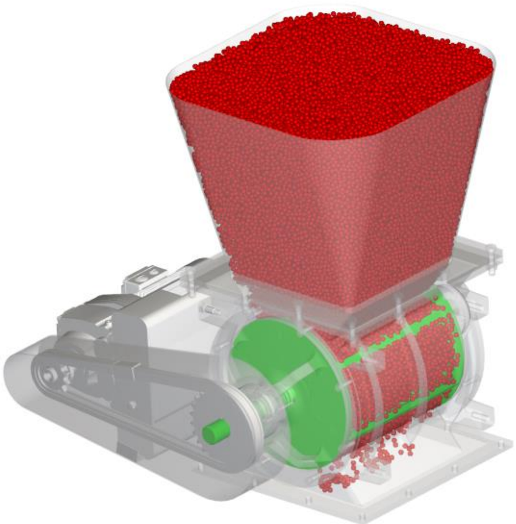


Figure 1. Rotary valve feeder, also known as star feeder, cannot be used with a sticky material like cassava.

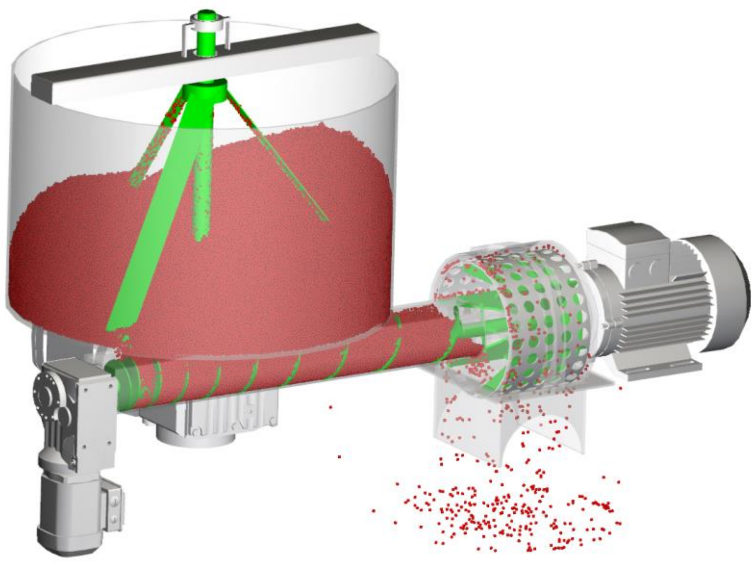


Figure 2. Screw feeder, designed for pneumatic drying of cassava, as part of RTB's 2020 activities.

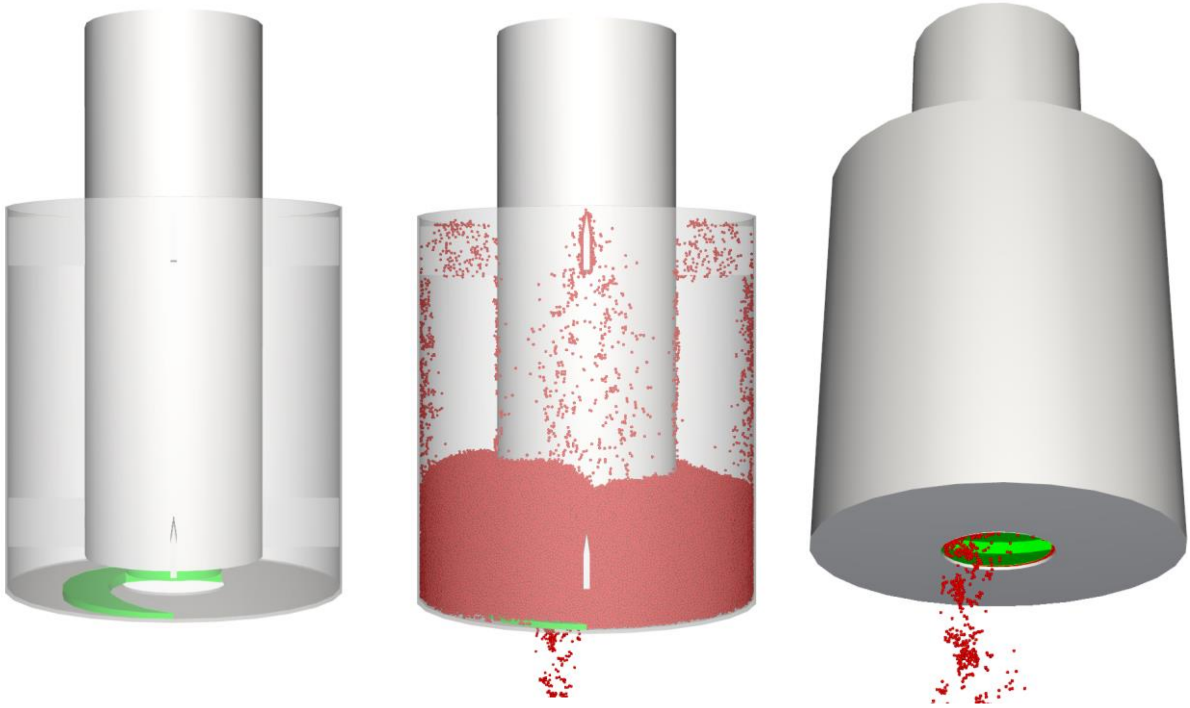


Figure 3. Plough feeder, designed for pneumatic drying of cassava, as part of RTB's 2020 activities.

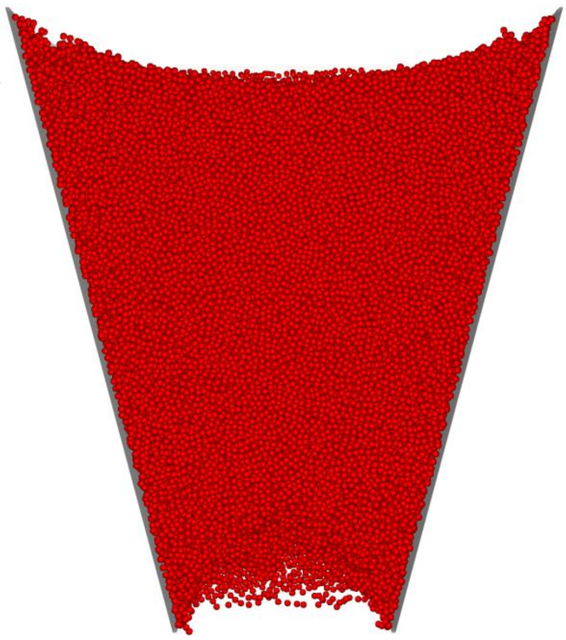


Figure 4. The V-shaped hopper cannot be used with cassava, as bridging occurs and make material flow stop.

NUMERICAL MODELLING

Numerical modelling provides design guidance for materials handling systems. It is a valuable tool to reduce costs and speed up equipment design and evaluation. For solving problems related to transport processes, including pneumatic dryer feeding systems, many numerical approaches are available, but by far, Computational Fluid Dynamics (CFD) coupled with Discrete Element Method (DEM) is the most useful one. It not only provides visualization of the gas—solids interactions but more importantly, it provides most of the critical design parameters.

POSITIVE PRESSURE FEEDING

In a pneumatic dryer, if the fan is positioned before the drying duct, it uses a positive-pressure conveying system. In those cases, if the fan is positioned before the feeding point, the material is introduced to a drying duct in which air is at pressure. This can generate solid blowback and consequence waste of energy and material. To prevent it, the static pressure at this point must be equal to or below atmospheric pressure. This is achieved using a venturi entrainment section. This device creates a reduction in the cross-section of the drying duct in the region where the material is fed, increasing entrainment velocity, and decreasing pressure. CFD coupled with DEM was used to design the venturi and assure the absence of material blowback. Figure 5a shows air velocity at the dryer and Figure 5b a close-up at the feeding point. Similarly, Figure 6a shows the pressure of the air at the dryer and Figure 6b a close-up at the feeding point. At those figures it is possible to see the negative pressure created by the venturi, preventing solid blowback. Figure 7 shows the CFD-DEM simulation of the dryer operating with the screw feeder and Figure 8 shows the CFD-DEM simulation of the dryer operating with the plough feeder. In neither of them, solid backflow was observed. The 3D CAD model of the venturi can be downloaded from https://a360.co/3t0jfyx, and Appendix 1 shows its main dimensions.

(a) (b)

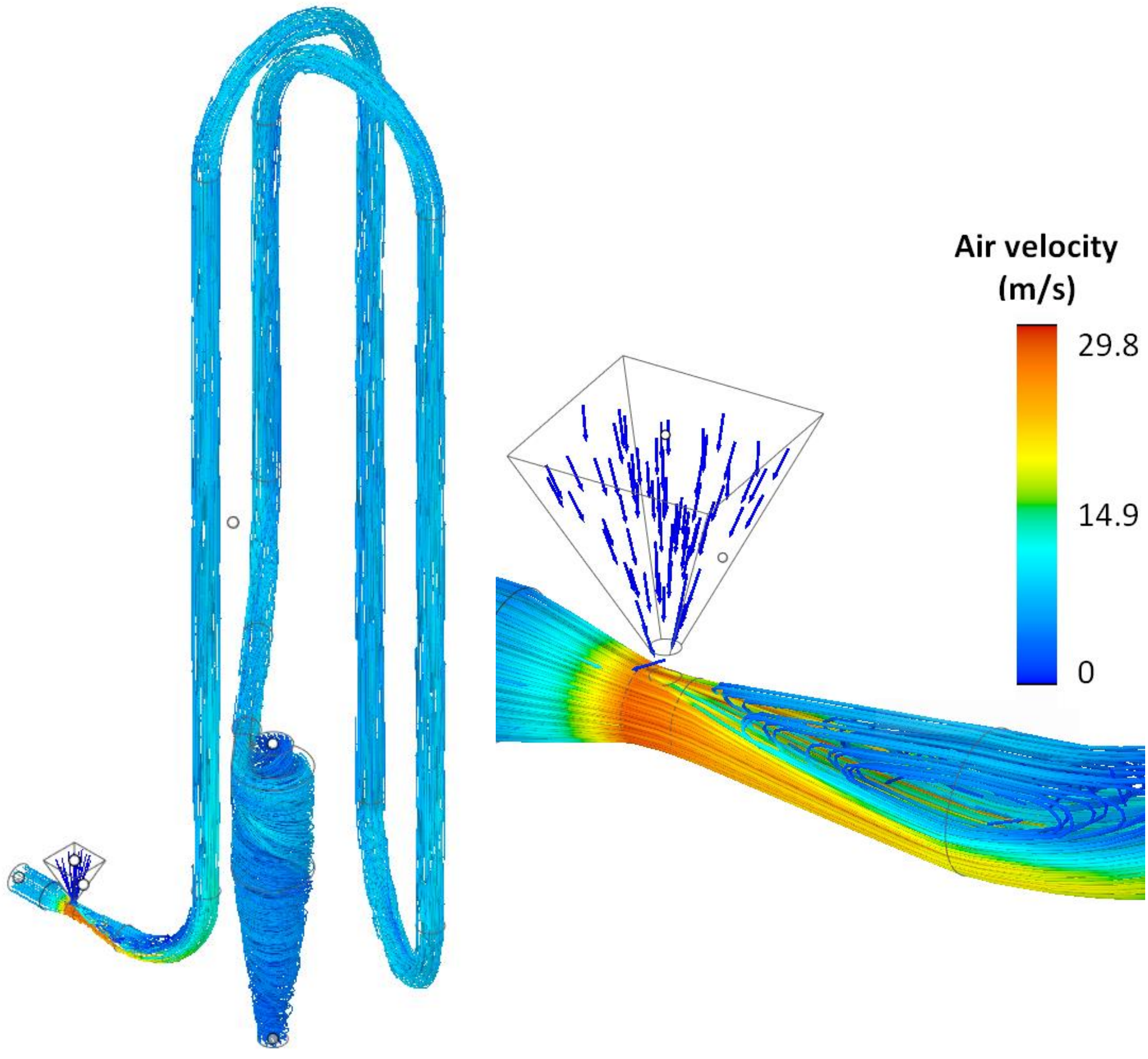


Figure 5. Air velocity (a) at the pneumatic dryer and (b) close-up at the feeding point.

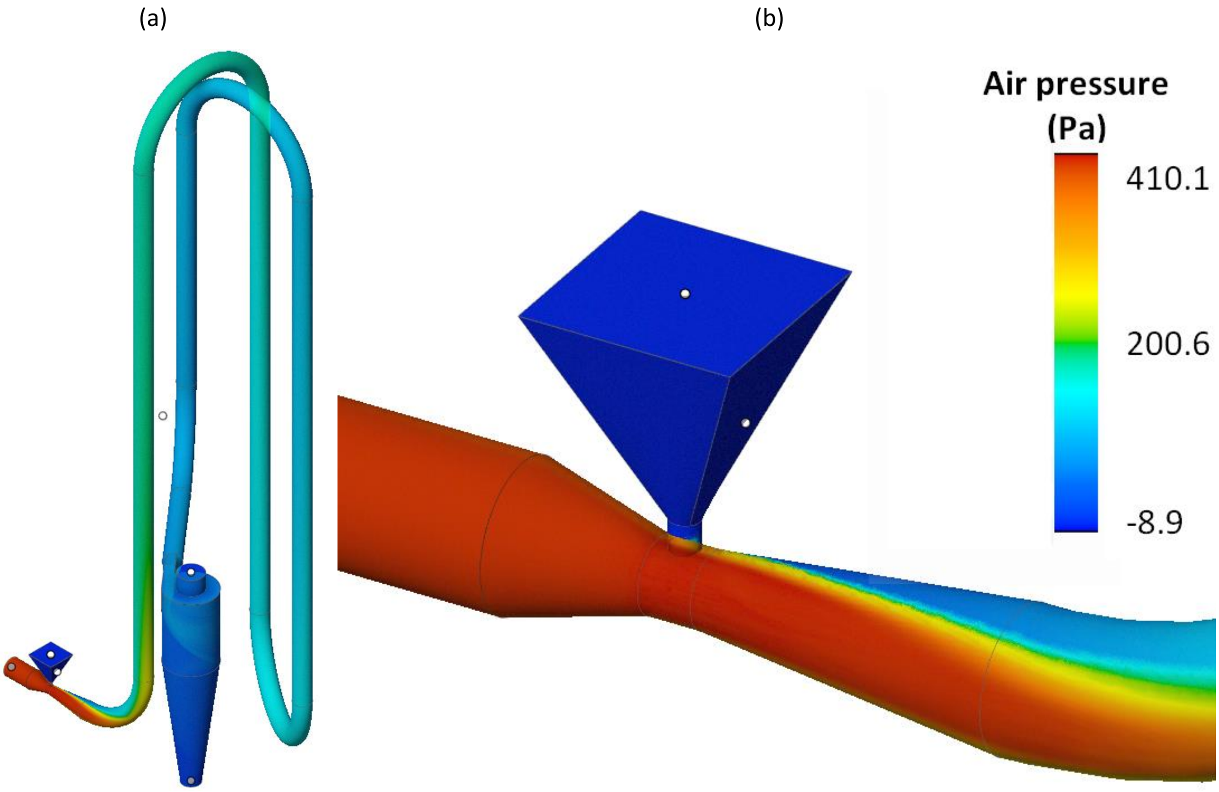


Figure 6. Air pressure (a) at the pneumatic dryer and (b) close-up at the feeding point.

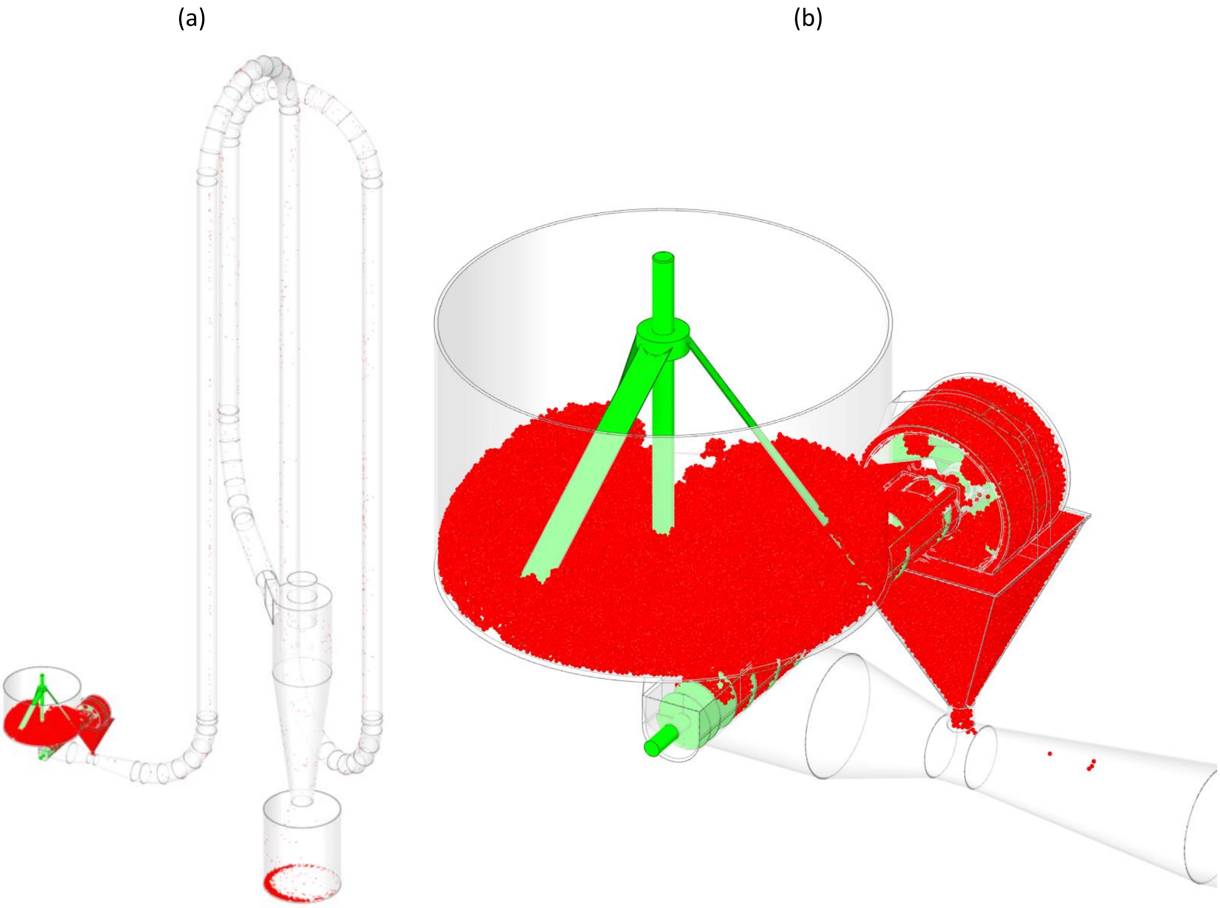


Figure 7. Simulation of the (a) dryer operating with the screw feeder and (b) close-up at the venturi.

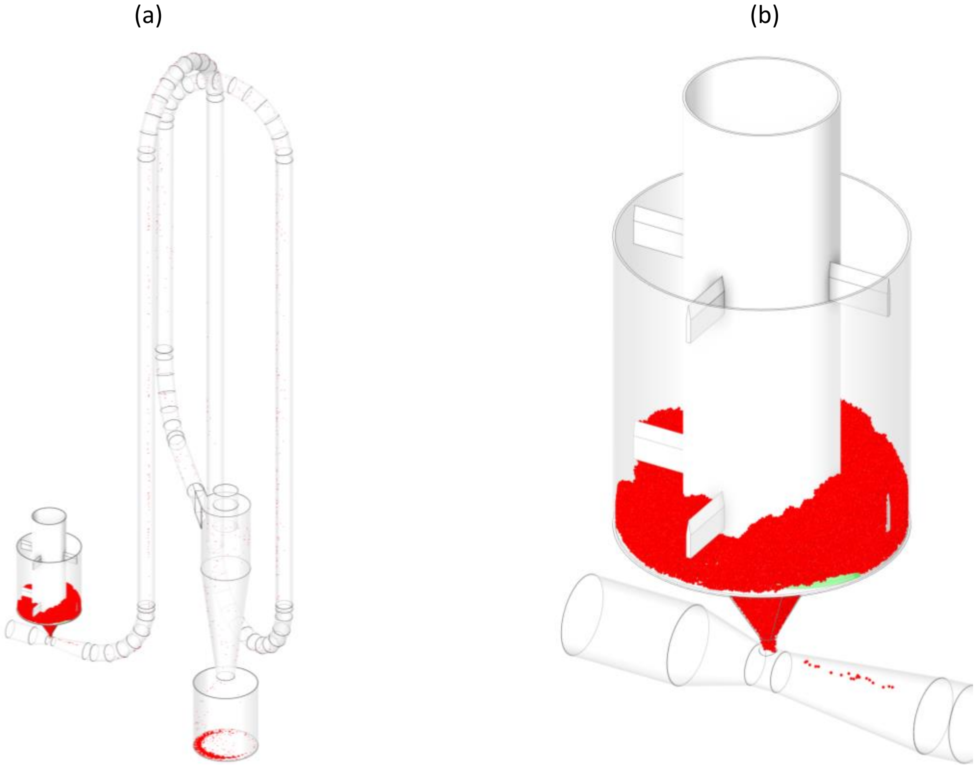


Figure 8. Simulation of the (a) dryer operating with the plough feeder and (b) close-up at the venturi.

FEEDER PERFORMANCE EVALUATION

CFD coupled with DEM was used to evaluate the performance of the feeder, specifically the degree of agglomeration of the particles being introduced to the dryer and the uniformity of the feeding rate. The degree of agglomeration was evaluated by analysing the adhesive forces of the particles leaving the feeder. The feeding rate uniformity was evaluated by analysing its coefficient of variation. Figure 9 shows particle adhesive force for both feeders and Table 1 shows the results from the feeder performance evaluation.

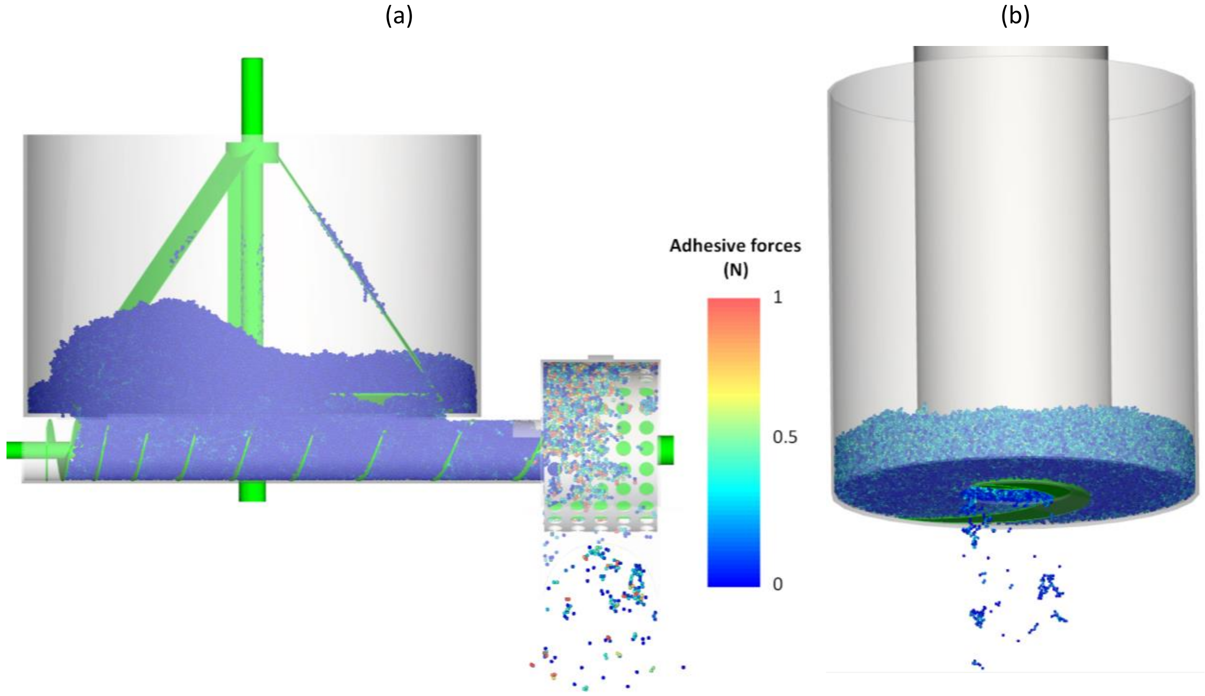


Figure 9. Adhesive forces at (a) the screw feeder and (b) at the plough feeder.

Table 1. Results from feeder evaluation using Computational Fluid Dynamics and Discrete Element Method.

	Average feeding rate (kg/h)	Feeding rate coefficient of variation (%)	Average adhesive forces (N)
Screw feeder	388.2 ± 108.5	27.9%	0.37 ± 0.06
Plough feeder	388.1 ± 148.1	38.2%	0.09 ± 0.02

The feeding rate from the screw feeder was more uniform, however, the adhesive forces of the particles leaving this feeder, was much higher, indicating that the material is more agglomerated. This is explained by the compaction and consequent agglomeration that the screw generates. As shown in Figure 10, adhesive forces were highest at the end of the screw.

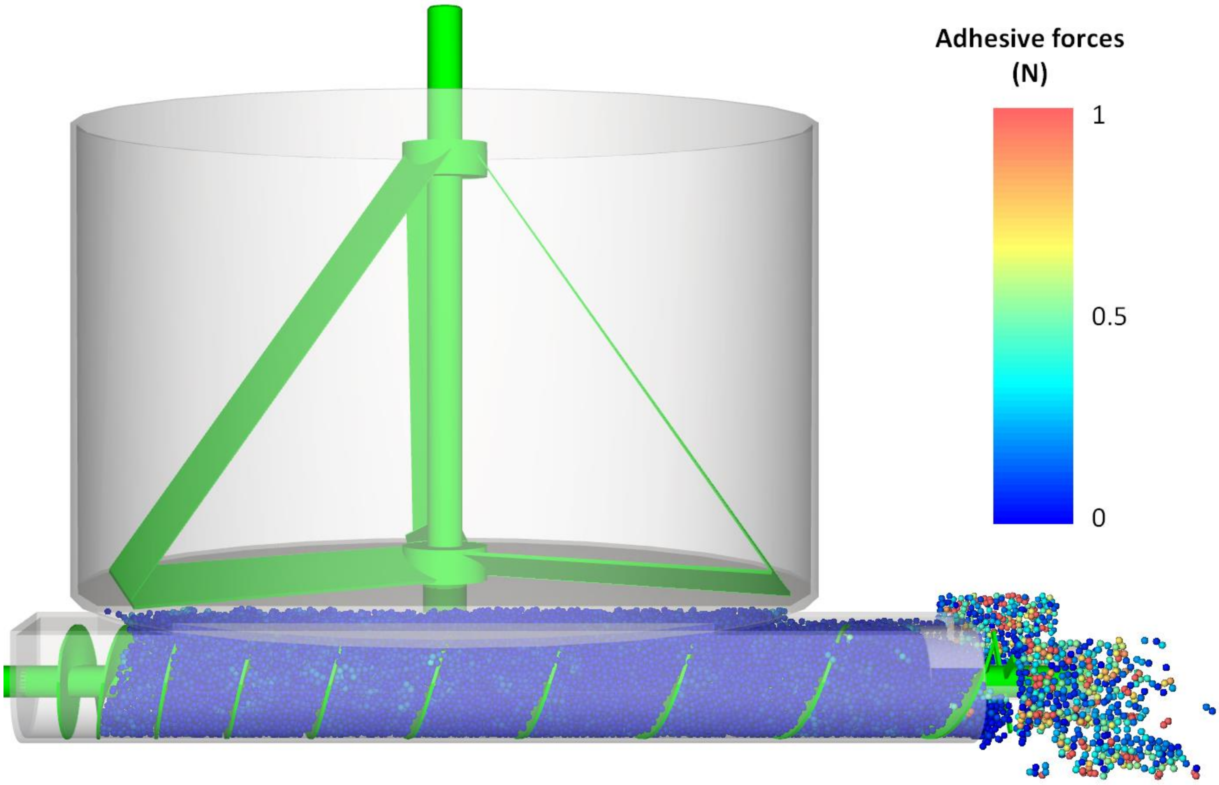


Figure 10. Particles high adhesive forces were observed at the end of the screw.

DRYER ENERGY PERFORMANCE EVALUATION

DRYING EQUIPMENT

The impact of feeder design on the energy performance of the dryer was conducted at Intermech Engineering, a manufacturer of cassava processing equipment located at Morogoro, Tanzania. Measurements were made at one of their prototype pneumatic dryers. The equipment was designed for an input of 80 kg/h of dewatered cassava grits with a moisture content of 45% on a wet basis (wb) and output is of 50 kg/h of dried cassava grits with a moisture content of 12% wb. The equipment uses a diesel burner and a heat exchanger to produce hot air, and a centrifugal fan to generate forced airflow.

MODIFICATIONS TO THE DRYER

To assist in making air velocity measurements, a 500 mm long duct at the fan intake was installed (Figure 11)

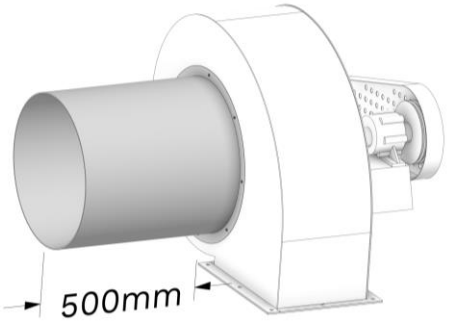


Figure 11. A duct at fan intake was added to assist air velocity measurements.

The temperature sensor of the thermostat that controls the on/off operation of the diesel burner was placed at the cyclone air outlet (Figure 12).

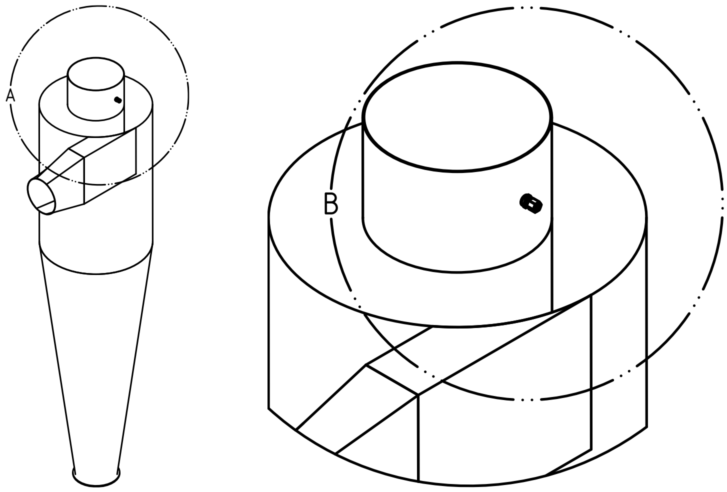


Figure 12. Location of the temperature sensor that controls the on/off operation of the diesel burner.

To monitor the air temperature at the drying inlet, a thermometer was installed between the heat exchanger and the feeding point (Figure 13).

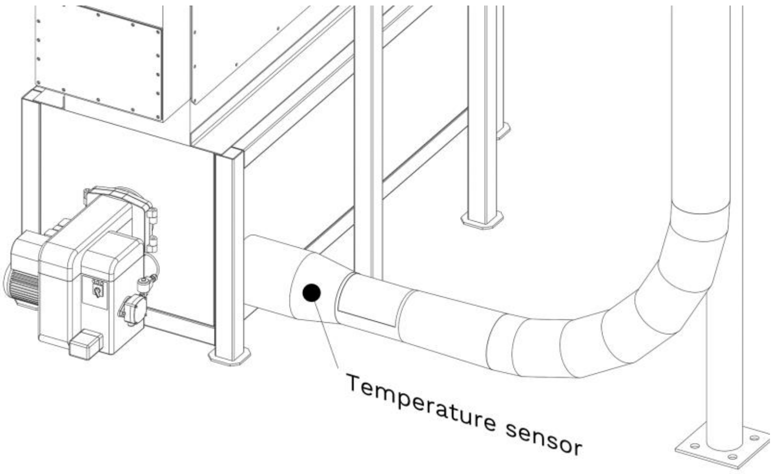


Figure 13. Location of the thermometer installed at the dryer inlet.

FEEDER CALIBRATION

On the screw feeder, the feeding rate is controlled by the rotational speed of the screw. On the plough feeder, the feeding rate is controlled by the rotational speed of the plough. On both feeders, the rotational speed that discharge 80 kg/h of material (moisture content 45%wb) was identified and used throughout the trials.

DATA COLLECTION

Data were collected on two consecutive days, on the first day the screw feeder was used and on the second day the plough feeder was used. On both days the target temperature at the cyclone air outlet was set to 60 °C (Figure 14)

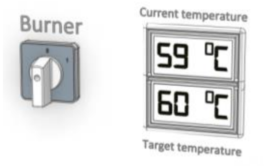


Figure 14. The target temperature at the cyclone air outlet was set to 60 °C.

On each day, data collection started only after a steady-state condition was reached. First, for 45 minutes, the dryer operated with the fan switched on, and the burner ignited, but with no material being fed. After that, the feeder was switched on and the material was added to it. The temperature at the dryer inlet and the cyclone air outlet were monitored and data collection started only when temperature fluctuation at those two locations became less than 5%. Temperature and relative humidity of the ambient air were recorded, as well as the temperature at the dryer inlet. At the fan intake, air velocity was measured at 18 points of its cross-section area (Figure 15) and samples of cassava grits before and after drying were taken for moisture content analysis.

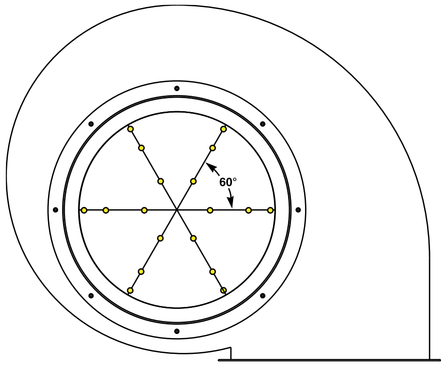


Figure 15. The air velocity was measured on 18 points at the cross-section of the fan intake.

ENERGY PERFORMANCE INDICES

The values of temperature and relative humidity of the ambient air was used to calculate the humidity of the air at the dryer inlet. With this value and the temperature of the air at the dryer inlet, the enthalpy of the air was obtained. The values of air velocity measured at the fan intake were used to calculate the mass flow of air passing through the dryer. This value together with, the value of the enthalpy of the ambient air, and the values of enthalpy of the air at the inlet, were used to calculate the heat input rate to the dryer. Based on the values of moisture content of the cassava grits before and after drying and the solid feeding rate, the water evaporation rate was calculated. This value was then multiplied to the water latent heat of vaporization, to determine the heat rate used for moisture evaporation. To find out the amount of energy needed to evaporate one kilogram of water, specific energy consumption was calculated by dividing the heat input rate to the dryer, by the water evaporation rate. Lastly, energy efficiency was calculated by dividing the heat rate used for moisture evaporation by the heat input rate to the dryer.

During the evaluation of the screw feeder, the average temperature of the ambient air was 34.4 °C and the average relative humidity was 36.4%. During the evaluation of the plough feeder, average ambient temperature was 37.1 °C and the average relative humidity was 33.5%. Moisture content before drying and after drying, plus the temperature at the inlet of the dryer is shown in Table 2 while the obtained energy performance indices are shown in Table 3.

Table 2. Drying conditions when using the screw feeder and when using the plough feeder.

	Average moisture content of cassava grits before drying (% wet basis)	Average moisture content of cassava grits after drying (% wet basis)	Average temperature of the air at the dryer inlet (°C)
Screw feeder	46	10	260
Plough feeder	47	14	255

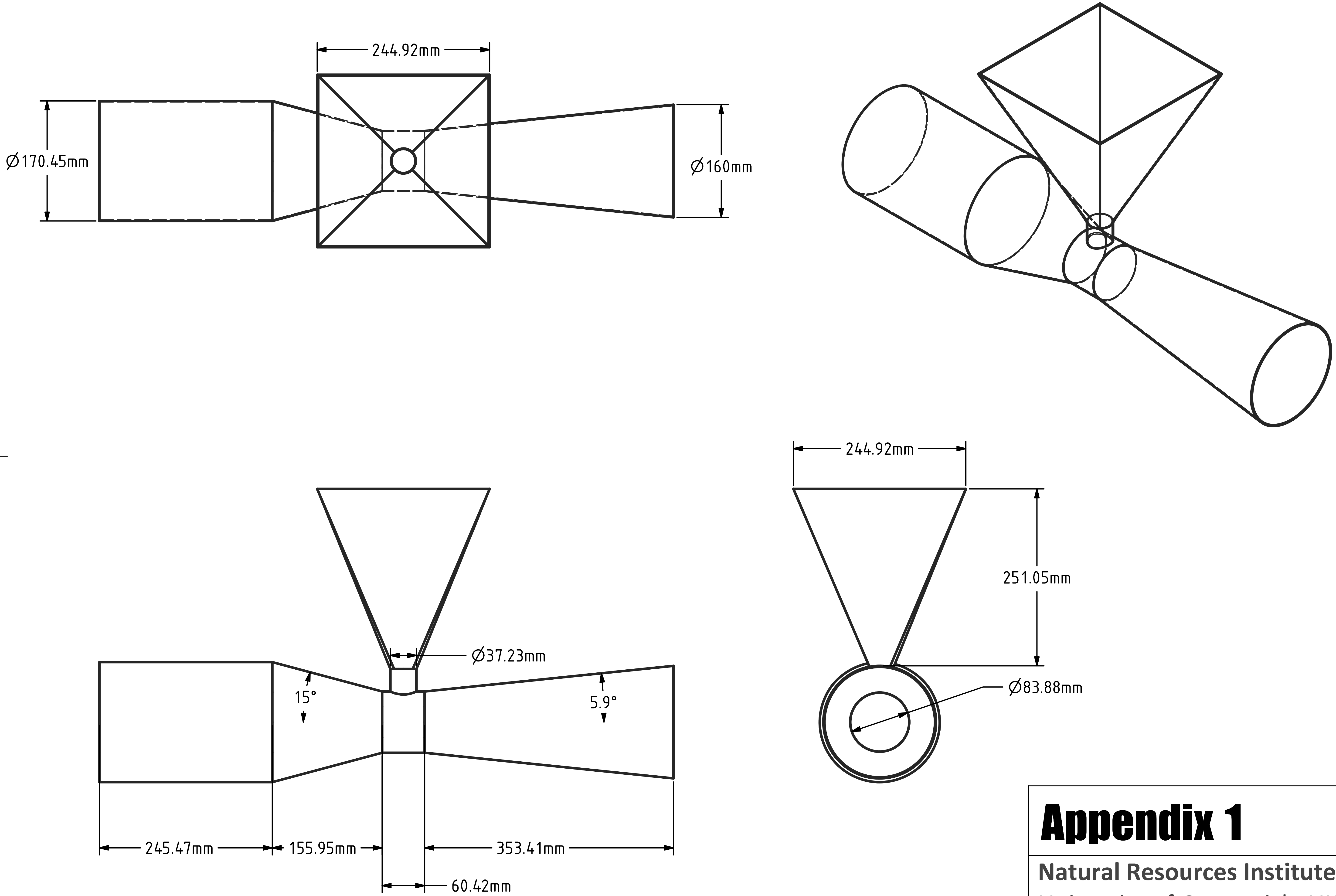
Table 3. Energy performance of the dryer operating with the screw feeder and operating with the plough feeder

	Heat input rate to the dryer (kW)	Specific energy consumption (MJ/kg)	Energy efficiency (%)
Screw feeder	41.8	4.63	53.4
Plough feeder	39.4	4.62	53.6

The data collection lacks repetitions and thus it is not possible to estimate the variability of the results and access its accuracy. In addition, the reached moisture content of the solid was different. This makes the comparison even less accurate, as the energy needed to remove moisture increases exponentially as the product dries. Nevertheless, the obtained results suggest that both feeders were able to introduce material at a uniform rate and without lumps, resulting in the observed high energy performance.

CONCLUSIONS

Pneumatic dryers have specific requirements regarding feeding, and when drying cassava, to fulfil them, a carefully designed feeding system is needed. The two feeders developed by RTB was evaluated, the simulation results indicate that the screw feeder provides a more uniform feeding rate while the plough feeder generate fewer lumps. When installed at the dryer and tested, no difference in the energy performance of the equipment was observed. Taking there into consideration and accounting that the plough feeder cost less to build, maintain and operate, it is, therefore, the recommended feeder design for pneumatic dryers used for cassava processing.



Appendix 1

Natural Resources Institute

University of Greenwich, UK

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RESEARCH PROGRAM ON
Roots, Tubers and Bananas

The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is an alliance led by the International Potato Center implemented jointly with Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Institute of Tropical Agriculture (IITA), and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), that includes a growing number of research and development partners. RTB brings together research on its mandate crops: bananas and plantains, cassava, potato, sweetpotato, yams, and minor roots and tubers, to improve nutrition and food security and foster greater gender equity especially among some of the world's poorest and most vulnerable populations. www.rtb.cgiar.org

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