# PARAMETRIC DESIGN OF A SOLID DRYER FOR PROCESSING CASSAVA STARCH USING SIMPROSYS 2.0 PROCESS SIMULATION SOFTWARE

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**Abstract:** Natural sun drying is one of the most common ways to preserve agricultural products. Many agricultural products are spread on the ground to be dried by sun and wind. This results to poor quality products due to contamination and high loss caused by uneven or incomplete dehydration. Parametric design of a drying system for processing cassava starch was carried out using Simprosys 2.0 Process simulation package specifically designed for drying systems. The units considered in this design includes; the air filter, blower, heater unit, solid dryer, input feeder, cyclone and product collector, a process flow diagram consisting of all the units was assembled. The drying system was designed on the basis of 20 kg/h of wet cassava starch with moisture content of 40%. From the results generated, the air particle loading for the air filter and filter area were found to be 0.038 kg/h and 0.267 m$^2$ respectively, the blower suitable for the drying operation has a total discharge pressure of 3.296 kPa and power output of 0.505 kW. The heating unit has a total heating duty of 11.447 kW. Also from the process simulation results, for all range of temperature between 90$^o$C to 120$^o$C, an air flow rate of 450 kg/h has the highest values of drying efficiencies averaging 83.2%. Considering a circular transverse section, the suggested dryer diameter and length are 0.296 m and 2.366 m, respectively. Therefore, a total of 11 minute with an optimum temperature of 120$^o$C can reduce the moisture content of cassava starch from 40 % wet basis to equilibrium moisture content of 10 % wet basis suitable for storage.

**Keywords:** Design, moisture content, process simulation, simprosys, solid dryer

## Introduction

Food dehydration is a traditional method for food preservation, removal of water from food material is usually accomplished by thermal evaporation, which is an energy intensive process, about two thousand five hundred (2500) joules of energy is required to evaporate one gram (1 g) of water. Diverse drying equipment and processes are used for the various food products. Food dehydration is a heat and mass transfer process that requires a significant amount of energy (Maroulis *et al*., 2003).

Nigeria is currently the largest producer of Cassava, amounting to about 34.8 million metric tons per annum, most of which is converted to starch (Maziya-Dixon, 2010). Production of starch in the country is currently at 20 million tonnes per annum and demand estimated at 230 million tonnes per annum (Maziya-Dixon, 2010). Though there are local producers of starch in country, but the demand for starch is far beyond production rate. One of the major unit operations in cassava starch processing is drying. Drying cassava starch locally by exposing the starch material to direct sunlight exposes it to atmospheric contaminant and Pest infestation, therefore the need to mechanize the process to encourage commercial production and reduce contamination caused by direct exposure to sunlight (Babalis *et al*., 2006).

Simprosys was used to carry out detailed design of the drying operation based on the physico-chemical properties of the wet cassava starch. Simprosys was developed by Simprotek Corporation, a Windows-based process simulator specifically designed for drying can simulate almost any drying and evaporation related processes. Parameters generated from simprosys simulation result will aid the fabrication of the solid dryer. With the availability of this drying device; there will be improved rate of drying leading to better product quality and the cost associated with the importation of a mechanical dryer abroad will be significantly reduced.

## Material and Method

***List of materials***

Simprosys simulation software package (version 2.0)

Computer system (2Gigabite Ram and 250HDD)

***Design model equations for drying processes***

Over a small interval of time, ∂t, a certain amount of moisture evaporates from the cassava starch into the drying air, resulting in change in the humidity ratio. The moisture balance can be written as (Strumilo *et al*., 2007):

$$w_f = R(m_i - m_f) + w_{in} \qquad (1)$$

**Where;**

$W_f$= exhaust humidity ratio of air kg water/kg dry air

$W_{in}$ = inlet humidity of air kg water/kg dry air

$M_i$= average moisture content at time t, in dry basis

$M_f$ = average moisture content at time t

R= Ratio of dry mass of cassava starch to dry air

The exhaust air temperature can be determined using the equation below (Strumilo *et al*., 2007):

$$T_p = \frac{C_aT_{in} + w_{in}(h_{fg} + C_vT_{in}) - w_ih_{fg} + RC_{pw}\theta_{in}}{C_a + w_fC_v + RC_{pw}} \qquad (2)$$

**Where;**

$T_f$ = exhaust air temperature $^o$C

$T_{in}$ = inlet air temperature $^o$C

$\Theta_{in}$ = inlet feed temperature

$C_a$= specific heat of dry air kJ/kg$^o$C

$C_v$= specific heat of water vapour kJ/kg$^o$C

$C_{fw}$= specific heat of moist cassava starch kJ/kg$^o$C

$H_{fg}$= latent heat of moisture evaporation J/kg

At inlet, the grain temperature is equal to the ambient air temperature (Strumillo *et al*., 2007)

**Drying kinetics**

The drying kinetics of starch could adequately be described by a zero order reaction

$$\frac{c(t)}{C_o} = kt \qquad (3)$$

Where c(t) is the mass flow rate of dried starch (kg/h) at time t (s)

k is the rate constant (s$^{-1}$) and t is the drying time (s). The rate constant was related to the depth and drying temperature through the correlation (Sachin *et al*., 2011);

$$k = -30.34026 + 3.1920113H_{bed} - 0.109836H^2{}_{bed} \exp\left(\frac{-1518.626}{T}\right) \qquad (4)$$

**Where** $H_{bed}$ = static bed depth (cm)
T (K) is the drying temperature
From the equation, drying rate can be increased by increasing the bed temperature or reducing the bed depth.

***Determination of dryer cross-sectional area***
In design mode, the required solids throughput F, and the inlet and outlet moisture content $X_I$ and $X_o$ are known, as is the ambient humidity $Y_I$. If the inlet gas temperature $T_{cl}$ is chosen, the outlet gas temperature $T_{co}$ and humidity $Y_o$ can be found using constant enthalpy lines on psychometric chart, Cross sectional area of the dryer can be determined from the expression (Sachin *et al*, 2011):

$$A = \frac{G}{\rho_{cl}U_c} = \frac{F\ (X_I - X_O)}{\rho_{cl}U_c\ (Y_o - Y_I)} \quad (5)$$

$G = \rho_{cl}U_cA$= gas flow rate
F= particle throughput
$U_c$ = gas velocity
$\rho_{cl}$= density of gas

***Rate of water /moisture removal***
The estimation of the amount of water to be removed from the solid material is obtained using the expression below (Mujumdar, 1995).

$$X = w\frac{(M_1 - M_2)}{(100 - M_2)} \quad (6)$$

**Where;**
$M_1$ = initial weight before drying
$M_2$ = final weight after drying.
X= moisture evaporation rate
W= weight of water removed.

The process flow sheet containing the air filter unit, the blower, the heating unit, the solid dryer and the cyclone was assembled as shown in Fig. 1.

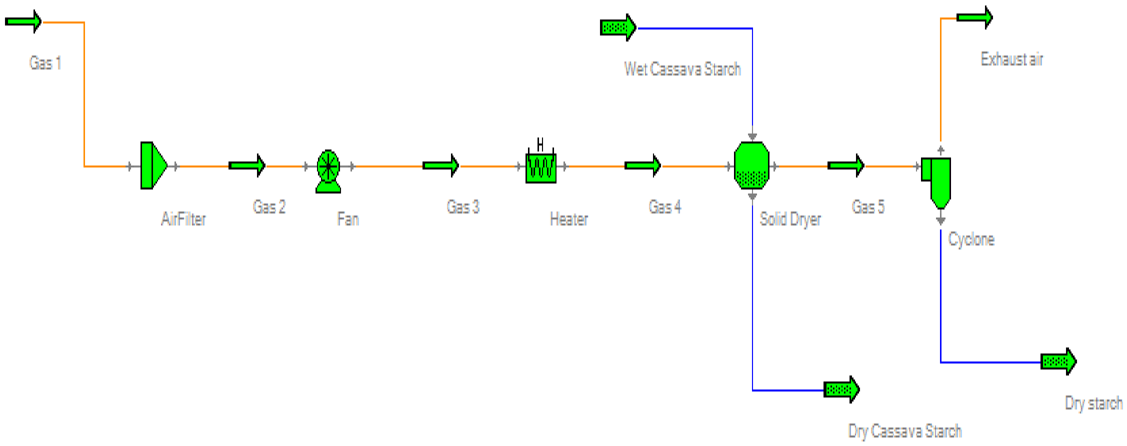



**Fig. 1: Process flow diagram for the drying operation**

**Input Parameters**
The input variables were based on the assumption as stated below for the feed;
Feed type: Cassava Starch
Feed moisture content = 40 % wet basis
Feed temperature = 27°C.
Product temperature = 50°C
Product moisture content = 10 % Suitable for storage
Specific heat of the absolute cassava starch material = 1.26 kJ/kg°C
Mass flow rate of cassava starch = 30 kg/h
Drying air was assumed to have the following laboratory conditions at the start of the experiment:
Initial pressure = 101.3 kPa
Initial temperature (dry-bulb) = 20 °C
Initial absolute humidity = 0.009 kg/kg of air
Mass flow rate of air for solid material between (400 kg/h - 700 kg/h)
Drying air goes through an air filter first. Pressure drop in the air filter was assumed to be 0.3 kPa. Assuming a dust volume concentration in the air filter is 0.1 g/m$^3$, collection efficiency of the air filter is 98.0% and filtration velocity is 2.5 m/s. Drying air then goes through a blower (the efficiency of the blower is 0.7) to gain 3 kPa static pressure, then through a heater to be heated to 120°C before going to the dryer. Pressure drop of air in heater is 0.8 kPa. Pressure drop of air in dryer is 1.2 kPa. The exhaust air entrains 0.1% of the total material. The powdered feed then passes through a cyclone where entrained dust material will be collected. Collection efficiency of the cyclone is assumed to be 95%. The process flow diagram for the above situation is shown in figure 1; vvariables to be determined in this design includes the drying air velocity, the volumetric airflow rate of air and the drying temperature.

**Results and Discussion**
***Simulation step for the fan***
One of the design variable determined was the volumetric air flow rate of air necessary for the drying operation, reviewing Sokhansanj and Jayas (2007), the recommended mass flow rate of air necessary for safe drying of starch products ranges from 700 kg/hr to 400 kg/hr. To determine the range of air velocity, all process variables were set constant and the mass flow rate of air varied from 700 kg/h to 400 kg/h. The results for the air velocities are shown in Table 1.
In order to find the optimal mass flow rate of air for drying, and knowing that the air velocity ($u_g$) is directly related to air mass flow rate ($W_{bw}$), process variables were set constant with $W_{bw}$ varying from 400 to 700 kg/h and its influence compared to the air velocity values. To do this calculation, the software Simprosys 2.0 was used as shown in Fig. 2. This Figure shows how the software works. In this dialogue window, the software shows the required input process variables in a white background box, and the output values presented in the grey

colour box. The column Gas 1 represents the ambient air going in the fan, and the Gas 2 column shows the process variables of the air coming out from the fan. The result obtained from this variation of the air flow rate compared with air velocity is shown in Fig. 2, for an air flow between 400 to 700 kg/h, air velocity result is between 19.934 to 34.885 m/s, which are the recommended range to dry starch materials. Fig. 2 shows the parameters generated for the blower, choosing a rectangular outlet cross section, the suggested air outlet diameter is 7.80 cm, and the air velocity is 22.426 m/s, while the power rating for the fan was evaluated as 0.505 kW. Fig. 3 also show the relationship between the air velocity and mass flow rate of air for the drying system.

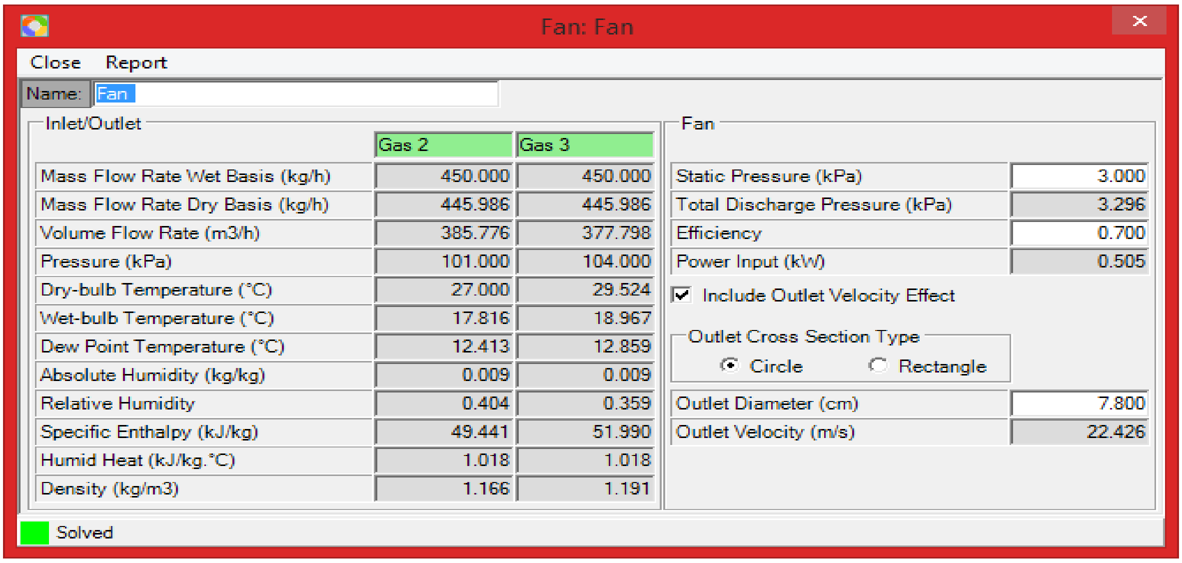



**Fig. 2: Dialogue window for the blower showing input/output variables**

**Table 1: Summary of simulation results at a fixed temperature of 90°C**

| Mass flowrate of air (kg/h) | Velocity of air (m/s) | Thermal efficiency (%) | Specific heat consumption (kJ/kg) | Moisture evaporation rate (kg/h) | Heater Heat Duty (kW) |
|---|---|---|---|---|---|
| 400 | 19.934 | 111.70 | 2151.645 | 11.818 | 6.793 |
| 450 | 22.426 | 99.90 | 2420.60 | 11.818 | 7.643 |
| 500 | 24.918 | 90.30 | 2689.556 | 11.818 | 8.492 |
| 550 | 27.410 | 82.40 | 2958.511 | 11.818 | 9.341 |
| 600 | 29.901 | 75.80 | 3227.467 | 11.818 | 10.190 |
| 650 | 32.393 | 70.20 | 3496.422 | 11.818 | 11.039 |
| 700 | 34.885 | 65.30 | 3765.378 | 11.818 | 11.888 |

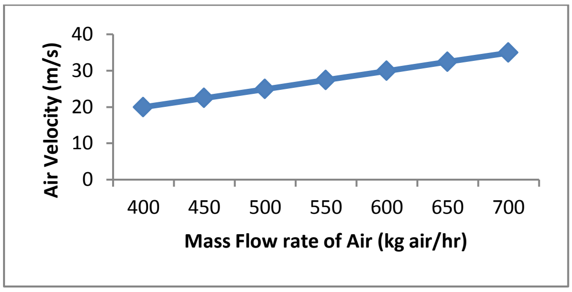



**Fig. 3: Air flow rate versus gas velocity at the fan**

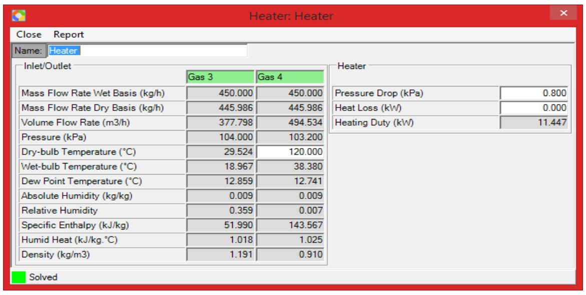



**Fig 4: Dialogue window showing Simulation results for the heater**

***Simulation step for the heater***

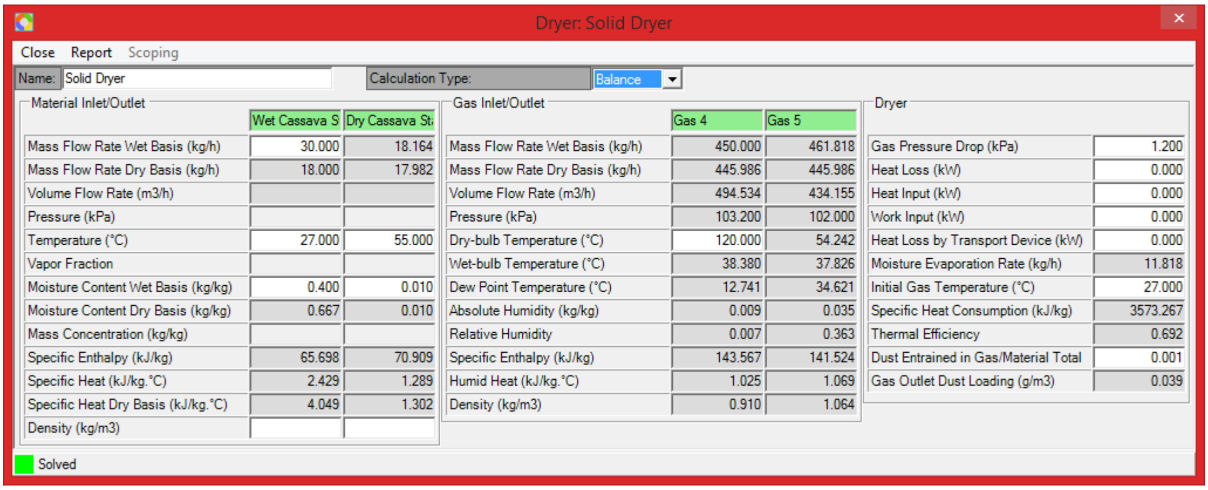
The heating unit is meant to heat up the air flowing at 450 kg/hr from initial ambient temperature of 20°C to an optimal drying temperature of 120°C. Fig. 4 shows the dialogue window for the heater, the heating duty for the heater was evaluated as 11.447 kW.

**Simulation Step for the Dryer**

So far, the range of the design variables (air velocity, drying air temperature, and Air mass flow rate) has been found; however to determined their optimal values, it is necessary to observe their behaviour compared to a performance index, such as thermal efficiency.

To do this, a simulation of the process is run, in which process variables are set constant, then each of the design variables are varied and their influence on the thermal efficiency for the dryer is observed. Fig. 5 shows the dialog window operating the dryer simulation software, the columns wet cassava starch and dry cassava starch show the values of the process variables for the cassava starch to be dried, before and after passing through the dryer, respectively. The columns named Gas 4 and Gas 5 are respectively for the heated air coming from the heater and the drying air exiting the dryer. Fig. 6 shows the performances indexes for the dryer (thermal efficiency, moisture evaporation rate, specific heat consumption) that are calculated by the software for the given conditions.

Tables 2, 3 and 4 show the variation of air temperature with thermal efficiency, heater heating duty and moisture evaporation rate. From Figs. 6 and 7, it can also be seen that the thermal efficiency decreases as the drying air temperature rises, from this behaviour, it can be deduced that the most suitable temperature for the drying process is in the range proposed and is dependent on the material temperature requirements for drying. To determine an exact value, practical experimentation is required.




| Material Inlet/Outlet | Wet Cassava S | Dry Cassava St |
|---|---|---|
| Mass Flow Rate Wet Basis (kg/h) | 30.000 | 18.164 |
| Mass Flow Rate Dry Basis (kg/h) | 18.000 | 17.982 |
| Volume Flow Rate (m3/h) | | |
| Pressure (kPa) | | |
| Temperature (°C) | 27.000 | 55.000 |
| Vapor Fraction | | |
| Moisture Content Wet Basis (kg/kg) | 0.400 | 0.010 |
| Moisture Content Dry Basis (kg/kg) | 0.667 | 0.010 |
| Mass Concentration (kg/kg) | | |
| Specific Enthalpy (kJ/kg) | 65.698 | 70.909 |
| Specific Heat (kJ/kg.°C) | 2.429 | 1.289 |
| Specific Heat Dry Basis (kJ/kg.°C) | 4.049 | 1.302 |
| Density (kg/m3) | | |

| Gas Inlet/Outlet | Gas 4 | Gas 5 |
|---|---|---|
| Mass Flow Rate Wet Basis (kg/h) | 450.000 | 461.818 |
| Mass Flow Rate Dry Basis (kg/h) | 445.986 | 445.986 |
| Volume Flow Rate (m3/h) | 494.534 | 434.155 |
| Pressure (kPa) | 103.200 | 102.000 |
| Dry-bulb Temperature (°C) | 120.000 | 54.242 |
| Wet-bulb Temperature (°C) | 38.380 | 37.826 |
| Dew Point Temperature (°C) | 12.741 | 34.621 |
| Absolute Humidity (kg/kg) | 0.009 | 0.035 |
| Relative Humidity | 0.007 | 0.363 |
| Specific Enthalpy (kJ/kg) | 143.567 | 141.524 |
| Humid Heat (kJ/kg.°C) | 1.025 | 1.069 |
| Density (kg/m3) | 0.910 | 1.064 |

| Dryer | |
|---|---|
| Gas Pressure Drop (kPa) | 1.200 |
| Heat Loss (kW) | 0.000 |
| Heat Input (kW) | 0.000 |
| Work Input (kW) | 0.000 |
| Heat Loss by Transport Device (kW) | 0.000 |
| Moisture Evaporation Rate (kg/h) | 11.818 |
| Initial Gas Temperature (°C) | 27.000 |
| Specific Heat Consumption (kJ/kg) | 3573.267 |
| Thermal Efficiency | 0.692 |
| Dust Entrained in Gas/Material Total | 0.001 |
| Gas Outlet Dust Loading (g/m3) | 0.039 |

**Fig. 5: Dialogue window showing simulation results for the dryer**

**Table 2: Summary of simulation results at a fixed temperature of 100°C**

| Mass flowrate of air (kg/h) | Velocity of air (m/s) | Thermal efficiency (%) | Specific heat consumption (kJ/kg) | Moisture evaporation rate (kg/h) | Heater Heat Duty (kW) |
|---|---|---|---|---|---|
| 400 | 19.934 | 97.10 | 2493.175 | 11.818 | 7.920 |
| 450 | 22.426 | 86.80 | 2804.822 | 11.818 | 8.909 |
| 500 | 24.918 | 78.50 | 3116.459 | 11.818 | 9.899 |
| 550 | 27.410 | 71.70 | 3428.116 | 11.818 | 10.889 |
| 600 | 29.901 | 65.90 | 3739.763 | 11.818 | 11.879 |
| 650 | 32.393 | 61.00 | 4051.410 | 11.818 | 12.869 |
| 700 | 34.885 | 56.80 | 4363.057 | 11.818 | 13.859 |

**Table 3: Summary of simulation results at a fixed temperature of 110°C**

| Mass flowrate of air (kg/h) | Velocity of air (m/s) | Thermal efficiency (%) | Specific heat consumption (kJ/kg) | Moisture evaporation rate (kg/h) | Heater Heat Duty (kW) |
|---|---|---|---|---|---|
| 400 | 19.934 | 86.00 | 2834.706 | 11.818 | 9.047 |
| 450 | 22.426 | 76.90 | 3189.045 | 11.818 | 10.178 |
| 500 | 24.918 | 69.60 | 3543.383 | 11.818 | 11.308 |
| 550 | 27.410 | 63.50 | 3897.721 | 11.818 | 12.439 |
| 600 | 29.901 | 58.40 | 4252.059 | 11.818 | 13.570 |
| 650 | 32.393 | 54.00 | 4606.398 | 11.818 | 14.701 |
| 700 | 34.885 | 50.30 | 4960.736 | 11.818 | 15.832 |

**Table 4: Summary of simulation results at a fixed temperature of 120°C**

| Mass flowrate of air (kg/h) | Velocity of air (m/s) | Thermal efficiency (%) | Specific heat consumption (kJ/kg) | Moisture evaporation rate (kg/h) | Heater Heat Duty (kW) |
|---|---|---|---|---|---|
| 400 | 19.934 | 77.30 | 3176.237 | 11.818 | 10.175 |
| 450 | 22.426 | 69.20 | 3573.267 | 11.818 | 11.447 |
| 500 | 24.918 | 62.50 | 3970.296 | 11.818 | 12.719 |
| 550 | 27.410 | 57.10 | 4367.326 | 11.818 | 13.991 |
| 600 | 29.901 | 52.50 | 4764.356 | 11.818 | 15.263 |
| 650 | 32.393 | 48.60 | 4888.385 | 11.818 | 16.535 |
| 700 | 34.885 | 45.20 | 5558.415 | 11.818 | 17.807 |

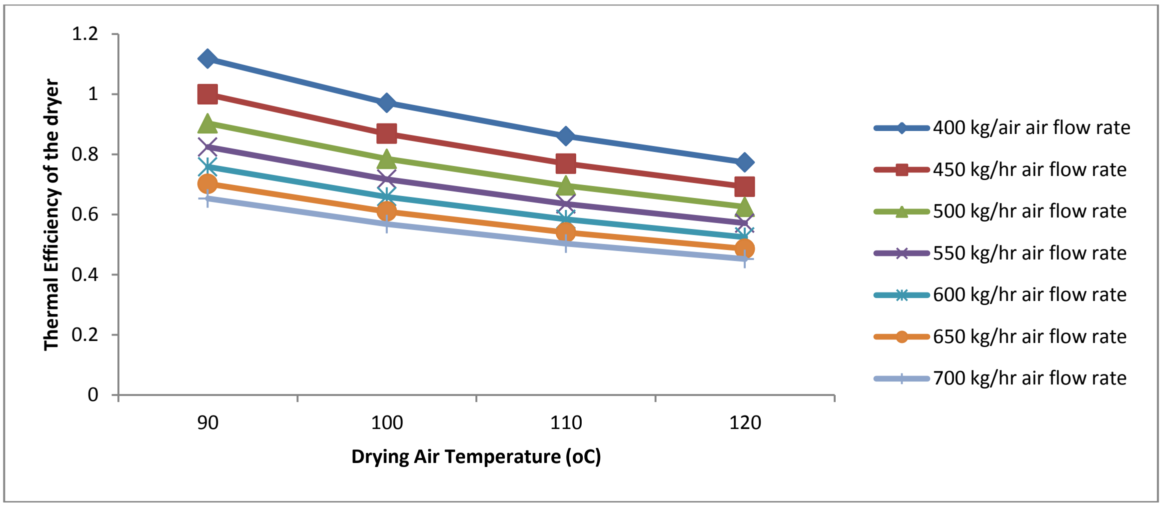



**Fig. 6: Thermal efficiency versus Drying Air temperature at different air flow rate**

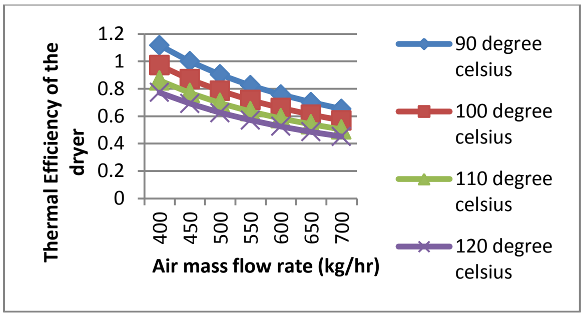



**Fig. 7: Thermal efficiency versus Air mass flow rate at different temperature**

Another performance index of the dryer that can be useful to analyse the dryer behaviour is the heat consumption, as Fig. 8 illustrates the specific heat consumption in the dryer increases as air flow rate is higher, this shows that for these drying conditions, increasing air flow means that more heat is used to evaporate each kilogram of water in the material, thus thermal efficiency of the dryer decreases. The moisture evaporation rate is the amount of moisture that is necessary to evaporate in one hour to reach desired final humidity in the product, thus it is only affected by the mass of fruit placed in the dryer, and the initial and final levels of humidity that is seek to be reached, this means that a variation in air flow rate, or the drying air temperature does not affect the moisture evaporation rate.

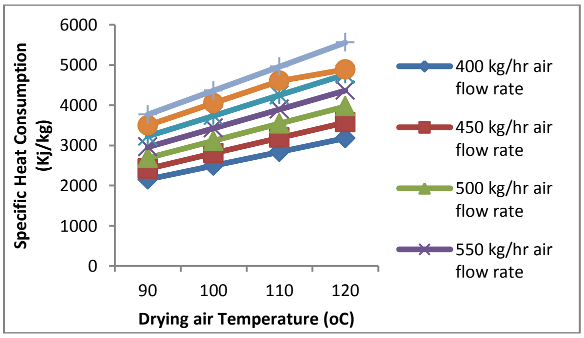



**Fig. 8: Specific heat consumption versus drying air temperature at different air flow rate**

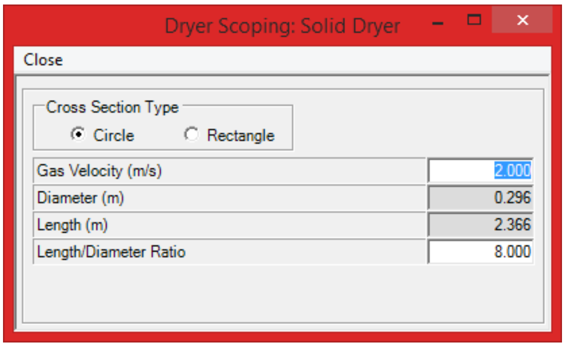



**Fig. 9: Dialogue window for dryer scooping model, showing dimensions**

Once the drying air velocity has been determined, it is possible to calculate the drying chamber dimensions using the Simprosys 2.0 software, these tool allows selection of the cross section type of the dryer chamber and determination of its dimensions, considering a circular transverse section, the dryer chamber diameter and length are 0.296 and 2.366 m, respectively as shown in Fig. 9.

## Conclusion

The following conclusions were deduced after the design: A solid dryer for processing cassava starch was successfully designed using Simprosys 2.0 simulation software package using basic physico-chemical properties of cassava starch. The quantity of heat required to heat air flowing at 450 kg/hr from initial ambient temperature of 20$^{o}$C to drying temperature of 120$^{o}$C is 11.447 kW, The length and diameter of the dryer were evaluated as 2.366 m and 0.296 m, respectively. The dryer was able to dry cassava starch from an initial moisture content of 40% to a moisture content of 10% suitable for storage.

## Acknowledgement

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