Development of Drying Machine for Vegetable Extracts

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Abstract

A drying machine for selected vegetable extracts under varying temperatures and moisture content was developed. The machine consists of sub-components: belt and pulley system; dryer enclosure; conveyor assembly; air fans; heat sources; product feeder; and other accessories. The power transmitted by the belt and pulley system was designed as 72.53 W. The speed of the dryer shaft and length of the belt that connect the motor and dryer pulleys together were estimated to be 60 rpm and 957.94 mm respectively with tension values of 176.77 N (T1) and 22.46 N (T2) on tight and slack sides of the belt. The designed value for the diameter of the dryer shaft for full strength was estimated as 10.7 mm. The conveyor belt length, corrected factor, belt speed, belt capacity, belt power and pressure loss through the belt were estimated to be 1070 mm, 1.035, 0.47 m/s, 0.279 kg/s, 11.57 W and 450 Pa respectively. The mass of the load per unit length of the belt was 2.14 kg/m. While the maximum belt tension and feed flow rate on the conveyor belt which the machine can handle were 388.4 N and 1.01 kg/s (3636 kg/hr) respectively. The drying rate of 0.856 kg/s at fresh air rate of 9.51 kg/s was obtained. The thermal energy requirement of the heating chamber was 1352.3 W over the heat transfer area of $4.55 \times 10\text{-}4 \ m^2$. The electrical power of the conveyor dryer was 46.11 W while overall efficiency of the machine was estimated as 71.64 %.

Keywords
Design, simulation, drying machine, vegetable extracts

1. Introduction

Vegetable plants are important in any society for consumption and also used for natural supplement that contain substances which could be used for treatment purposes or used to produce drugs. These plants have been reportedly used in the treatment of ailments such as stomach disorder, fever symptoms and cough traditionally (Udochukwu, et al., 2015). Sequel to this, it is imperative to preserve the vegetable plants from spoilage and bacteria attack. Traditionally, most people particularly farmers expose their crops to the sun by spreading them widely to dry before storage. Example of some of these vegetables are: scent leaf and bitter leaf (Muazu et al., 2013). Sun drying still remains the most widespread method of food preservation due to its simplicity and low cost (Chua and Chou, 2013). Several drying machines have been designed and fabricated to solve the problems being experienced by traditional methods but still faced with the challenges of human intervention and their inability to dry varieties of vegetable at different drying temperature and moisture content using a single drying machine (Mujumdar, 2015). Therefore, a drying machine that will flow with vegetable extracts process plant with little or no human intervention can be implemented to simplify the existing method. This will not only reduce the labour cost but also retain the quality of the vegetable plants at required temperatures (Asaolu et al., 2012).
Vegetable plants can be dried in the sun, in an oven or in a food dehydrator by using the right combination of warm temperatures, low humidity and air current (Harrison and Elizabeth, 2009). Drying process can be classified into batch, where the material is inserted into the drying equipment and drying proceeds for a given period of time, and as continuous, where the material is continuously added to the dryer and dried material continuously removed (Ayodeji et al., 2012). There are different types of dryers for agricultural foodstuffs, among which are fluidized bed dryer; spouted bed dryer; solar drying; conveyor infrared drying; low-cost convective dryers; and desiccant drying (Desrosier,

1970). They possess the following characteristics: low initial capital costs; generate better drying kinetics and product quality than the sun-drying method; and easy to maintain all parts and components. The objectives of this work are to develop a drying machine for drying vegetable extracts and carry out simulations to investigate the temperature distributions, effective drying temperatures and maximum stress that the machine support can accommodate. The brief description of the designed drying machine is discussed in section 2 and the design analysis of the component parts is presented in section 3. Section 4 discusses the design results, while the conclusion is drawn in section 5.

2. Brief Description of the Designed Drying Machine

The drying machine is a sectional part of a process plant meant for the processing of vegetable extracts. The major components for this drying machine under discussion are: belt and pulley system; dryer enclosure; conveyor assembly; air fans; heat sources; product feeder; and other accessories which are needed for its effective functionality. For better understanding of these parts, the isometric and exploded views of the machine identifying them are as shown in Fig.1 and Fig. 2 respectively which was drawn with the aid of AUTOCAD Inventor 2018.
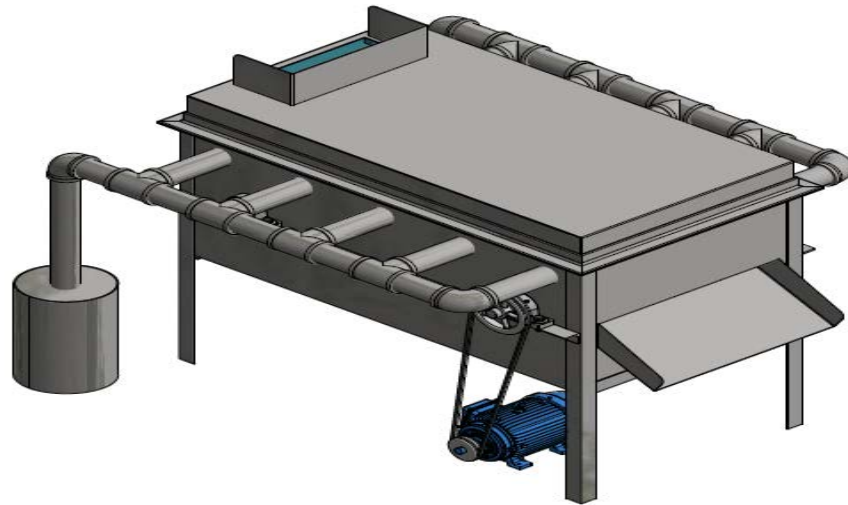

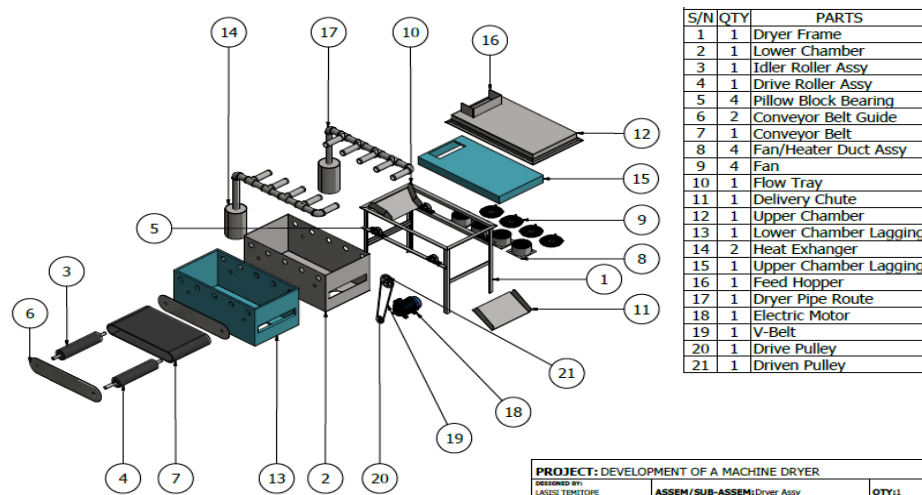Fig. 1. Isometric drawing of the drying machine

S/N	QTY	PARTS
1	1	Dryer Frame
2	1	Lower Chamber
3	1	Idler Roller Assy
4	1	Drive Roller Assy
5	4	Pillow Block Bearing
6	2	Conveyor Belt Guide
7	1	Conveyor Belt
8	4	Fan/Heater Duct Assy
9	4	Fan
10	1	Flow Tray
11	1	Delivery Chute
12	1	Upper Chamber
13	1	Lower Chamber Lagging
14	2	Heat Exhanger
15	1	Upper Chamber Lagging
16	1	Feed Hopper
17	1	Dryer Pipe Route
18	1	Electric Motor
19	1	V-Belt
20	1	Drive Pulley
21	1	Driven Pulley

PROJECT: DEVELOPMENT OF A MACHINE DRYER
DESIGNED BY:
LASISI TEMITOPE   ASSEM/SUB-ASSEM: Dryer Assy   QTY:1

Fig. 2. Exploded view of the drying Machine

3. Design Analysis of Component Parts

The component parts were all designed for using relevant design equations as discussed in the following subsections.

3.1 Determination of Belt Capacity

The general formula for belt capacity is as expressed in (1) as found in Dunlop, (2009)

$$C_b = 3.6AS\rho \tag{1}$$

Where C_b is the capacity of belt in Kg/s; A is the load cross sectional area in m^2; S is the belt speed in m/s; and ρ is the material density in Kg/m^3.

3.2 Determination of Belt Capacity

Mass of the load per unit length, Q as adapted from Dunlop, (2009) is given in (2).

$$Q = 0.278 \frac{C_b}{S} \tag{2}$$

Where C_b is the belt capacity in Kg/s and S is the speed in m/s

3.3 Determination of Material Flow

Feed flow rate, F is determined using (3) as culled from Dunlop, (2009)

$$F = QS \tag{3}$$

where S is the speed in m/s, Q is the Mass of the load per unit length in kg/m.

3.4 Determination of Absorbed Power

The amount of power required by the conveyor is expressed from the definition of power as "power equal to the product of the force applied and the speed at which the conveyor belt travels." The force applied is the effective tension and hence the power required at the shaft of the drive pulley is as expressed in (4).

$$P = T_e S \tag{4}$$

Where T_e is the effective tension in N and S is the speed in m/s.

3.5 Determination of Electrical Load on the Belt Driver and Electrical Power Requirement

The electrical load on the belt driver and its electrical power requirement for conveyor dryer are determined using (5) and (6) respectively.

$$E_b = e_1 L(1 + X_o)F \tag{5}$$

$$E = E_b + E_f \tag{6}$$

Where: E_b is the belt driver; e_1 is belt driver power equation constant; L is the dryer length in m; X_o is the initial moisture content of bitter leaf in kg/kg db; F is the material flow rate in Kg/s; E is total power requirement in Watt; E_b is electrical load on belt driver in watt; and E_f is electrical load on fan in watt.

3.6 Determination of Thermal Energy Requirement

The required thermal energy for this design is computed using (7).

$$Q = Q_{we} + Q_{sh} + Q_{ah} \tag{7}$$

Q_{we}, Q_{sh} and Q_{ah} are as defined in (8), (9) and (10) respectively as follows:

$$Q_{we} = F(X_o - X)[\Delta H_o - (C_{PL} - C_{PV})T_s] \qquad (8)$$

$$Q_{sh} = F[C_{PS} + X_o C_{PL}](T - T_o) \qquad (9)$$

$$Q_{ah} = F_a[C_{PA} + Y_o C_{PV}](T - T_o) \qquad (10)$$

Where: C_{PL} is specific heat of water in KJ/kg ^{0}C; C_{PV} is specific heat of water vapor in KJ/kg ^{0}C; ΔH_o is steam condensation in KJ/kg; X_o is the initial moisture content of bitter leaf in kg/kg db; X is the final moisture content of bitter leaf in kg/kg db; Y_o is ambient humidity in kg/kg db; T_s is steam temperature in ^{o}C; F is material flow rate in Kg/s; Fa is fresh airflow rate in Kg/s; C_{PS} is specific heat of dry material in KJ/kg ^{o}C; T is dry air temperature in ^{o}C; and T_o is ambient temperature in ^{o}C;

The resulting design values obtained are as presented in Table 1.

Table 1. Resulting Designed Values for the Drying Machine

S/n	Design Factor	Design Values
1	Belt capacity, C_b	0.279 Kg/s
2	Mass of load per unit length, Q_m	2.14 Kg/m
3	Material flow rate, F	1.01 Kg/s
4	Absorbed power, P	11.57 W
5	Electrical load on the belt driver, E_b	12.36 W
6	Electrical power requirement, E	46.11 W
7	Thermal energy requirement, Q	1000 W

4. Results and Discussion

The outcome of the results are as discussed in the following subsections.

4.1 Heat Transfer Analysis

The simulation of the designed machine was carried out to determine the temperature gradient, the heat flux and temperature distribution in the model as well as the heat exchanged between the model and its environment with the following boundary conditions: total heat generation; Q = 1000W; film coefficients representing the ambient surrounding air, h0 = 5 W/m2K; air velocity from the fan, V = 0.15 m/s; range pressure of 0 Pascal; initial ambient temperature, T0 = 20 0C; refined mesh size = 0.5 mm; inner iteration is taken to be 2; number of iteration as 700; buoyancy effect to be -1; turbulent model is assumed to be k-epsilon; and solid meshed model with number of nodes to be 576034 and number of elements as 2419712 were used as shown in Fig. 3.
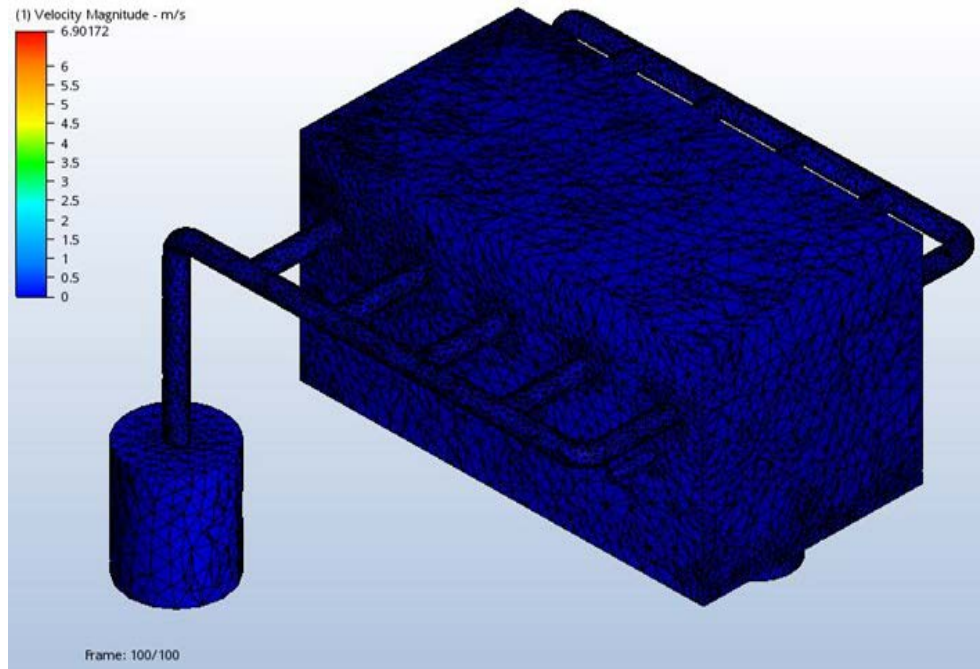
Fig. 3. Solid mesh of the dryer model

4.2 Transient Thermal Analysis

Analysis of heat flow changing with time is called transient thermal analysis. The temperature of the heating plate is controlled by a thermocouple reading the temperature of the leaves. The thermocouple turns the power on if the temperature of the leaves drops below minimum required temperature, and turn it off when the temperature exceeds a maximum present value. Thermal analysis was executed to find temperature distribution, temperature gradient and heat flowing in the model as shown in Fig. 4 to 7.
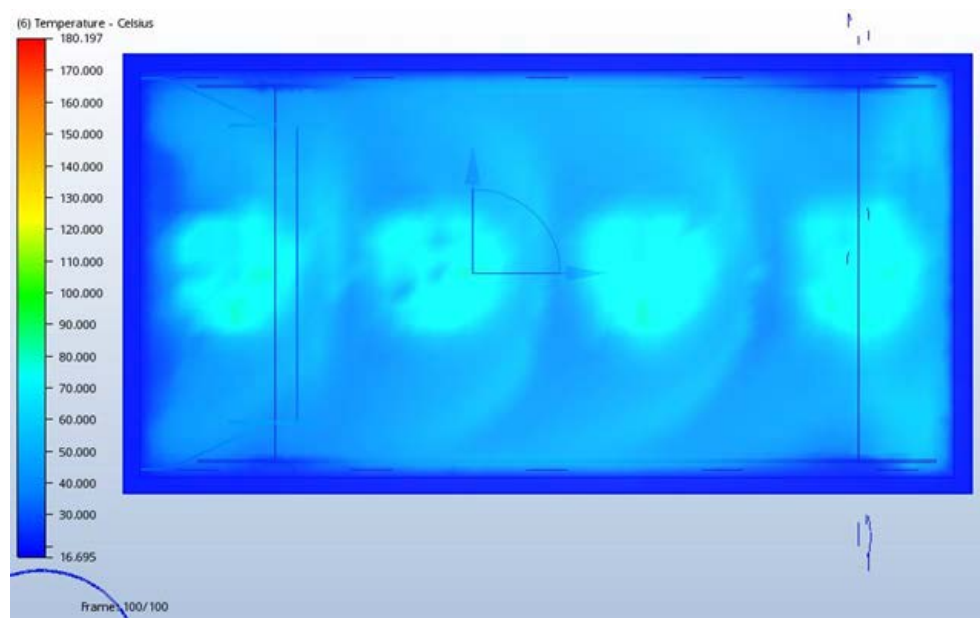
Fig. 4. Heat distribution across the bottom of the conveyor
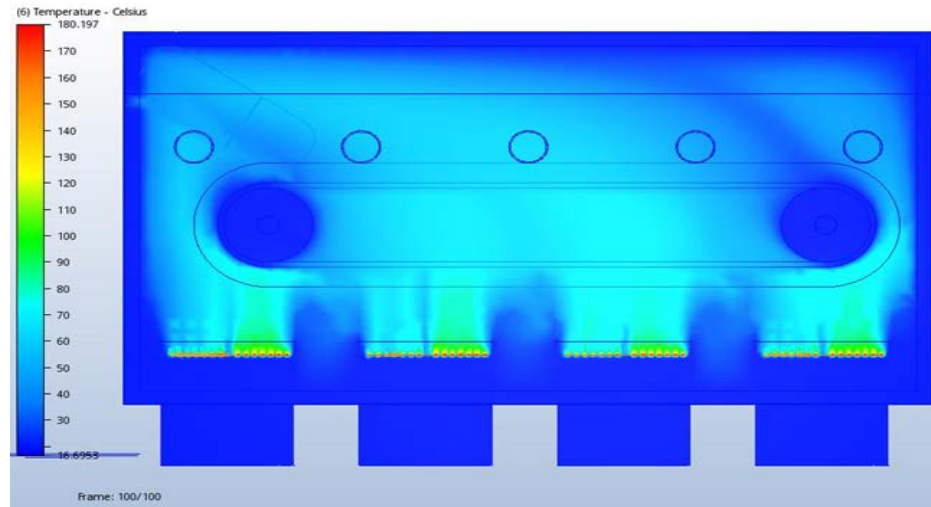
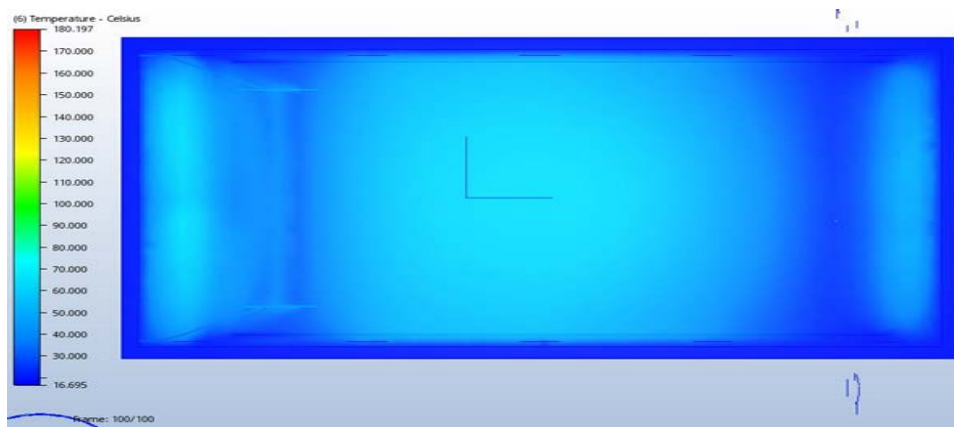Fig. 5. Heat distribution along the symmetry plane

Fig. 6. Heat distribution across the top of the conveyor drying zone
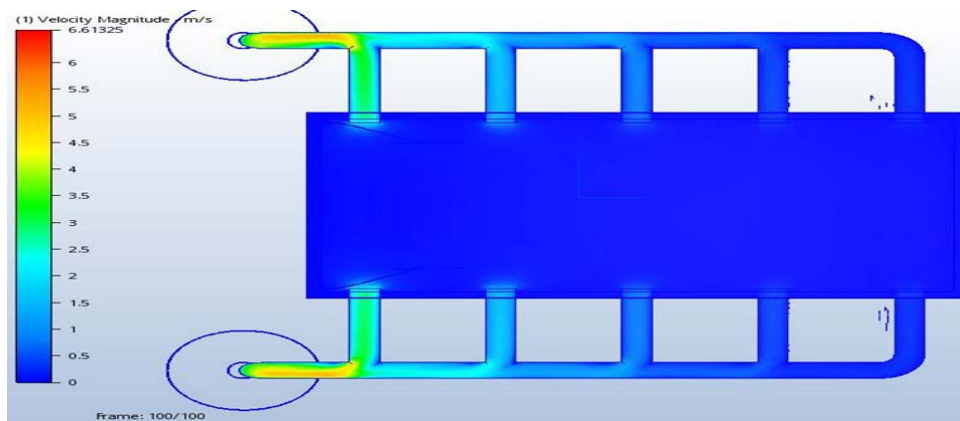

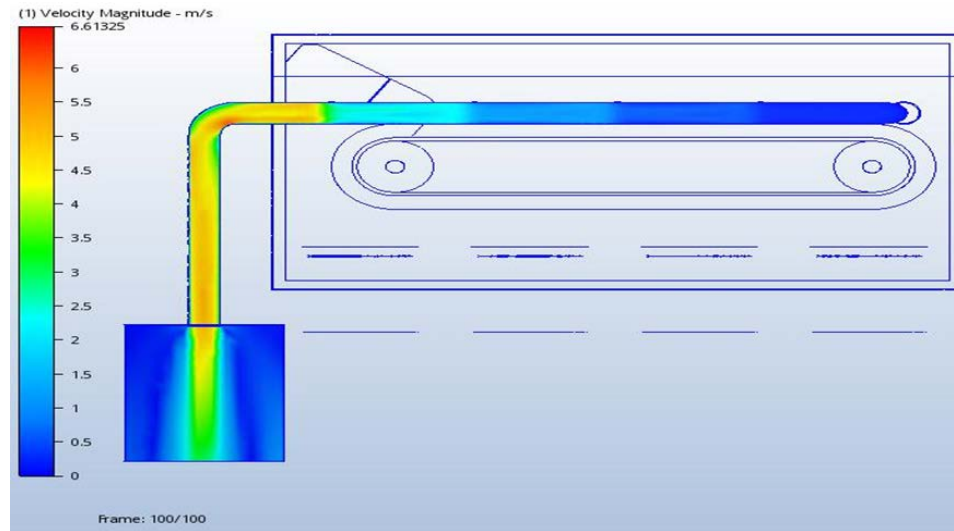Fig. 7. Flow gradient from the drying chamber into the pipe

Fig. 8. Flow velocity across the outlet pipes

The heat generated from the heating element in Fig. 4 is at the range of 80 ^{0}C. While along the peripheral of the drying chamber, the temperature range is between 16 ^{0}C and 30 ^{0}C

The range of temperature generated by the heater, as shown in Fig. 5 is between 130 ^{0}C and 170 ^{0}C, as the hot air flows into the chamber, the temperature decreases to the required range of temperature by the selected leaves. In Fig. 6, the required range of temperature by the selected vegetables extract was achieved. The temperature ranges between 50 ^{0}C and 60 ^{0}C from the result.

As it can be inferred from Fig. 7 and 8, the velocity gradient of the drying air was infinitesimally small at the small outlet pipes that linked to the long pipe, however, it increased as it travelled towards the edges of the long pipe until it got to heat sink. And from this heat sink, it is being radiated into the atmosphere.

4.3 X-Y Plot

This is the graphical representation of temperature distribution against the distance travelled by the hot air. Fig. 9 shows the plots of temperature below the conveyor while Fig. 9 shows corresponding plot above the conveyor.
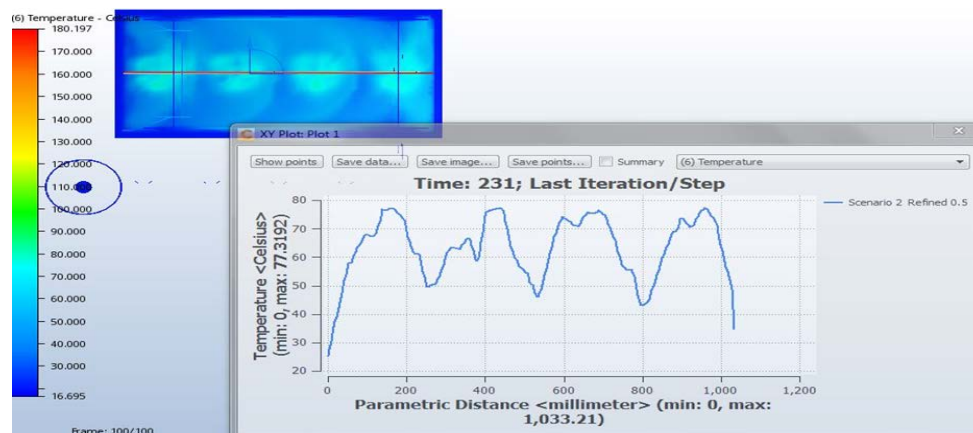

Fig. 9. XY plot below the conveyor

It could be inferred in Fig. 10 that at the drying zone (that is above the conveyor), the heat distribution for drying the selected vegetable extracts recorded was at the range of temperature is 55 0C. It is a uniform flow which does not give

rise to overheating of any region inside the drying chamber thereby effectively removing moisture through the pipes to the ambient.

Inferring from the thermal fluid simulation carried out on the heating zone of the machine in examining the temperature gradient, the heat flux and temperature distribution in the model as well as the heat exchange between the designed model and its environment, it is summarily observed that the range of temperature generated by the heater was between 130 °C and 170 °C. As the air flows into the chamber, the temperature decreases to the required range of temperatures required to dry the leaves hygienically whose values were 50 °C and 60 °C and was achievable around the dryer maximum temperature of 160 °C. Stress analysis carried out on the machine frame showed the maximum stress of 8.756 Mpa under the action of equivalent load of 409.13 N. The static analysis also revealed the maximum displacement of 0.042 mm. Thus, the machine is efficient for drying vegetable extracts and its preservation.
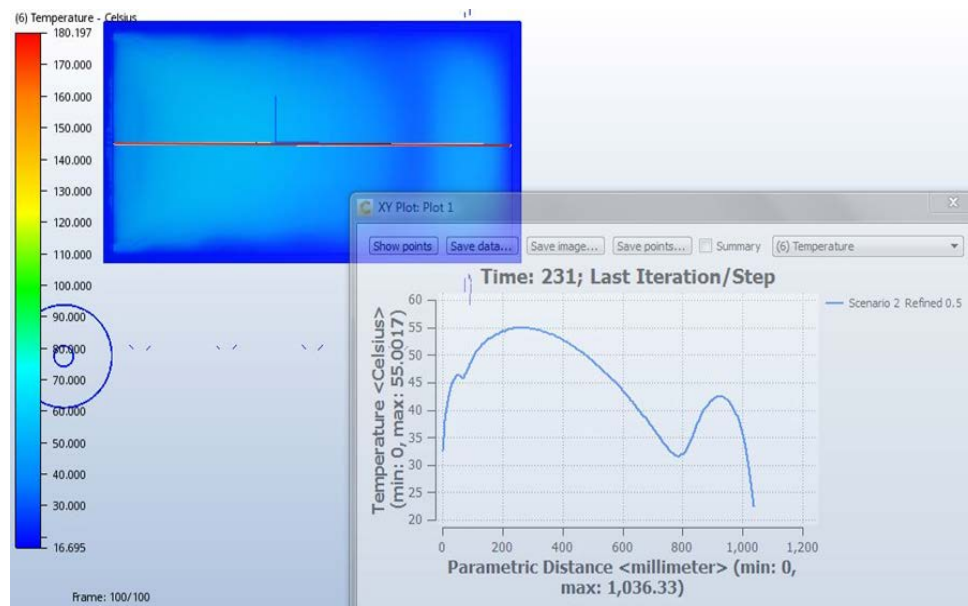

Fig. 10. XY plot above the conveyor

5. Conclusion

A robust designed drying machine for selected vegetable extracts under varying temperatures and moisture has been proposed and implemented in this paper. The designed concept has been discussed while thermal simulation was carried out to validate and verify the reality of the concept. Simulation results indicated that the proposed dryer machine's design was appropriate and suitable for fabrication.

Acknowledgements

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Biographies

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