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REGULAR ARTICLE

DESIGN AND CONSTRUCTION OF A TUNEL DRYER FOR FOOD CROPS DRYING

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ABSTRACT

Conventional sun drying of tropical crops often result in low quality product due to unpredictable nature of weather. Utilizing mechanical dryer such as tunnel dryer can improve the quality of the products as well as increasing the acceptability of such crop in global market. In this study, a tunnel dryer in two modes of operation (co-current and counter-current) with a capacity of 35 kg of chips per batch was designed, fabricated and tested. The dryer had a chamber volume of 0.408m^3; the number of trucks in the tunnel was 6, each truck contained 6 trays. The operating temperature of the pilot dryer ranged from 50 to 150 °C and air velocity ranged from 2 to 8 m/s, respectively. Cassava chips was used to test the dryer and the results showed that the dryer reduced the moisture content from 75 to 14% in 8 h with drying constant of 2.42/h.

Keywords: Tunnel dryer, Design, Construction, Food crops

INTRODUCTION

In post harvest, the drying of the harvested products is a major step for efficient horticultural production. This is not a mere removal of water contents [1]. In post harvest technology, there are a number of methods including mechanical or manual drying.

Not only the problem of capital to import high technology dryers faces the farmers and processors in developing countries but the problem of maintaining such dryers is a critical issue. Hence construction of such dryers with locally available material (such as wood, bricks and steel) will help the farmers' affordability of such equipment. Therefore, the objective of this work is to develop a general purpose tunnel dryer for dehydration of agricultural product.

MATERIALS AND METHODS

Design features of the model tunnel dryer constructed

The diagrammatic feature of this dryer is as shown in fig. 1

- It has both counter-current and co-current mode of drying
- Expected Production rate: 32.5 kg/batch
- Expected number of trucks: 6
- Expected number of trays per truck: 6
- Initial moisture content of raw cassava chips: 75% wet basis [2]
- Desired final moisture content: 14% wet basis
- Air temperature before entering dryer: 32 °C
- Bulk density of cassava: 416 kg/m^3[2]

Description of major components and materials of construction

The dryer consists of the following components

- ***Drying Chamber (Tunnel)****:* This is the action chamber for drying. It contains six (6) trucks which were loaded periodically. The trucks are loaded in counter-current and co-current modes. The inside was constructed with aluminum frame which served as the skeletal frame of the dryer which was then covered with a aluminum sheet because of its corrosion resistance property, availability and medium cost. The outer covering was made from aluminum sheet because of its malleability, ductility, lightness and relative low cost. The length of the tunnel was 3.25m with a breadth of 0.35m and a height of 0.30m.
- ***Electric heater****:* The electric heater supplies heat to the drying chamber for drying the product (cassava). Selection of heater was based on several factors like loading mass of the product to be dried, the optimum moisture content of the product and temperature difference in the chamber. Three heaters of 3kW were used in the dryer to supply the heat needed for the drying operation. A heater was placed at both end and the third was put in the middle as supplementary.
- ***Blower (fan):*** The fans were used to circulate heated air in the drying chamber. For effective drying system, three centrifugal fans that each can deliver 5 m/s at 0.75kW was employed at both ends and 0.375 kW at the middle.

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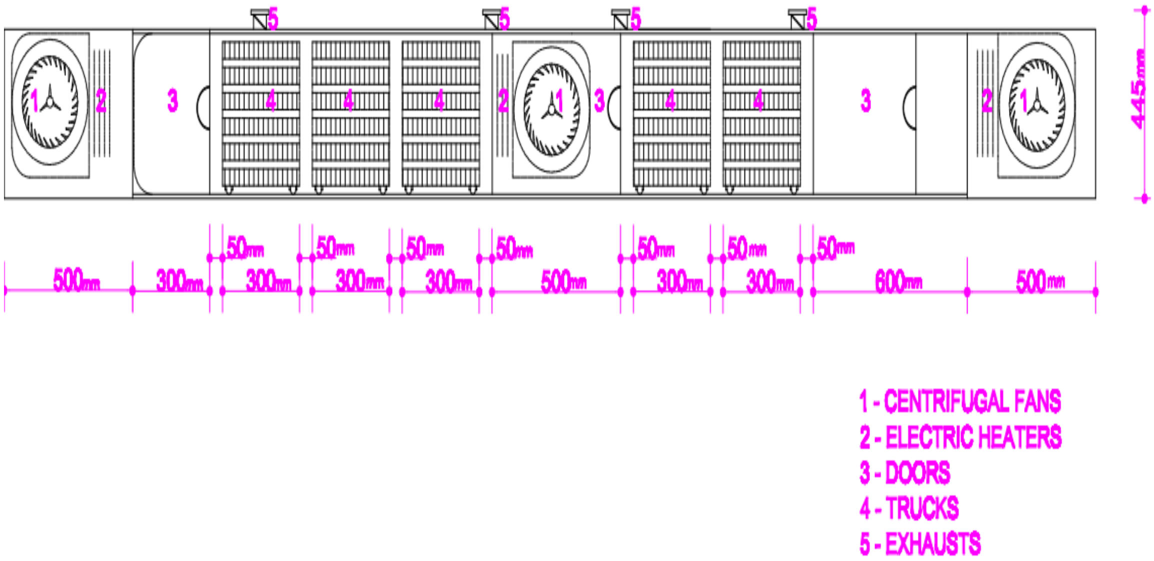

Fig. 1: Front view of the tunnel dryer with six trucks

- ***Trucks:*** The tunnel consists of six (6) trucks with each truck containing six (6) trays. The trucks were made from aluminum angles and contained roller-wheels for easy movement in and out of the chamber. It has a length and breadth of 0.30m and a height of 0.30m.

- ***Trays:*** These are flat, square–shaped containers which contain the product to be dried. They are made from aluminum plate, so that the water from the product will not corrode the surface. The dryer had thirty-six (36) trays in total. The tray had a length and breadth of 0.25mx 0.20m and a height of 0.015m.

- ***Fastener (Bolts and Nut)****:* Bolts and nuts are used for coupling different components or parts together especially for rails in the chamber which allows easy movement of trucks.

- ***Lagging Material (Hard foam)****:* Hard foam material was used for lagging tunnel dryer because of its ability to reduce heat losses in the dryer to a greater extent.

- ***Electrical and electronic components****:* Wires were used to connect the heater and the blower to an electrical power source. The thermocouples were used for sensing the temperature rise in the dryer and also regulate temperature at the desired temperature of drying.

Centre Exhaust*:* These are provided by small round-shaped perforated openings for allowing the passage of wet hot air out of the drying chamber. They are situated on the top of the tunnel in four places.

Design calculations

(a) Calculation for the volume of cassava chips on the trays

From the relationship

Volume = Mass/Density

= 0.8/416

$=0.001m^3$

Each tray will carry $0.001m^3$ of raw cassava chips

(b) Design of Trays

Length of tray=0.25m

Breadth of the tray= 0.20m

Height of the tray= 0.015m

Area of the tray = LxB

= 0.25x0.0.3

$= 0.075m^2$

Volume of the tray =LxBxH

=0.075x0.015

$=0.001125m^3$

Height of the truck = Height of the tray trays+height of roller

Wheel

= (0.025)6+5(0.015)+0.025

= 0.25m

Length of the truck = length of the tray+allowance for easy movement

= (0.25+0.05)

= 0.30m

Breadth of the truck =0.2m

Area of each truck = L x B

$= (0.3 \times 0.2)\ m^2$

$= 0.06m^2$

Volume of each truck = Lx B x H

=0.30 x 0.20 x 0.25

=0.017m^3

(d) Design for drying chamber of the tunnel

Length of the drying chamber = length of each truck x number of trucks+spaces

between the truck

=3.25m

Breadth of the drying chamber =0.35m

Area of the drying chamber = LxB

= 3.25 x 0.35

=1.1375m^2

Volume of the drying chamber = LxBxH

= (1.05 x 0.35 x 0.49) m^3

=0.18m^3

(e) Design space for components of the tunnel

Length of the whole tunnel = length of each truck x number of trucks+interspaces

+spaces for heating chamber

= 4.25 m

Breadth of the whole tunnel = Breadth of the truck+allowance for clearance

= {0.30+0.05} m

= 0.305m

Height of the whole tunnel = Height of the truck+height of the roller wheel+

clearance between trucks' height and tunnel's roof

= (0.275+0.04) m

= 0.315 m

Area of the whole tunnel = L x B

= (4.25 x 0.305) m^2

= 1.296 m^2

Volume of the whole tunnel = L x B x H

= (1.296 x 0.315) m^3

= 0.408 m^3

(f) Selection of the heater

Feed rate (m_w) = 32.5 kg/hr

Intended drying time = 6 h

Initial moisture content of the cassava chips = 75%

Desired final moisture content = 14%

Therefore, weight loss from wet to dried chips is calculated thus

$$m_d = m_w(\frac{100 - m_0}{100 - m_f})$$

where m_w is the mass of wet cassava chips, m_o =initial moisture content (%)

m_d is the mass of dried cassava chips, m_f =final moisture content (%)

$$m_d = 32.5(\frac{100 - 75}{100 - 14})$$

m_d = 9.447 kg

Mass of water to be removed during drying = mass of wet cassava chips–mass of dried cassava chips

= (32.5-9.447) kg

=23.05 kg

Quantity of heat required to remove the water = quantity of heat on the cassava

chips+latent heat of evaporation of

water inside the chips

Specific heat of cassava chips = 3.41kJ/kg °C [3]

Latent heat = 4.186 x10^3 {(597-0.56(T_{pr})} [4]

where T_{pr} is the product temperature

Q = mass of cassava chips x specific heat of the chips x temperature difference+

Mass of water x 4.186 x10^3 {(597-0.56(T_{pr})}

= 32.5 x 3.41 x (80-30)+23.05 x 4.186 {(597-0.56 (60)}

= (5541.25+57485.81) kJ

= 63025.06kJ

Power of heater to be used = Quantity of heat/Time

= 63025.06/(6 x 3600)

= 2.905 kW

From the above calculation, a heater of about 3kW was used.

(g) Selection of fan

Length of the drying chamber (previously calculated) = 3.25 m

Breadth of the drying chamber (previously calculated) = 0.35m

Height at which chips fill each tray = 0.05m

Total depth of chips for 36 trays = 36 x 0.05

=1.8m

Volume of the material in the tunnel (m^3) = 3.25 x 0.35 x 1.8

= 1.134m^3

Minimum required range of air velocity necessary for drying food products as recommended is 0.5 m/s [5], [6].

In this design, a minimum velocity of 0.5 m/s was used

Air flow rate = air velocity x area of drying

=0.5x3.25x0.35=0.56875m^3/s

It is necessary to convert the value of the volumetric flow rate to cubic per minute (cfm) for standard fan selection

1 cfm = 4.91747 x 10^{-4} m^3/sec [7].

Therefore, 1.365m^3/s = 1156.607cfm

Static pressure of cassava has moisture content close to that of potato, so a static pressure of 1.2 inches per foot depth is taken [8].

From previous calculation,

Total depth of chips = 1.8m = 5.91ft

Static pressure loss equation = total depth of chip x static pressure per foot

= 5.91 x 1.2

= 7.092 inch of water

If there are foreign materials in the chips, the static pressure is multiplied by 1.5 as reported by [7].

Therefore, the static pressure due to resistance of air flow by chips = 1.5 x 7.092

=10.638 inches of water

Fan horse power (P) = volume air flow rates x total static pressure

6320 x fan efficiency

Most industrial fan have efficiency between 70-85% as reported by [7].

Hence,

$$P = \frac{1156.607x10.638}{6320x0.85}$$

= 2.29 Hp

A centrifugal fan with 2.5 Hp and 3.64 inches water pressure was used. A centrifugal flow fan is used to ensure proper distribution of air to the drying chamber and for effective heat distribution as reported by [9]

(h) Design for insulation

Assuming a loss of 1% of the quantity of heat produced through the wall as reported by [7].

Quantity of heat per second= 3kW (from previous calculation)

1% of 3kW =31.65w

$$\Delta T = \frac{q}{A}[\frac{\Delta x_g}{k_g} + \frac{\Delta x_s}{k_s} + \frac{\Delta x_a}{k_a}]$$

$\Delta T = T_1 - T_2$ is the change in temperature (°C)

T_1 = Outside temperature = 32 °C

T_2 = Temperature in the drying chamber =100 °C (inlet)

q = Quantity of heat loss from the chamber = 31.65W

A = Area of the drying chamber = 0.28m^2

Δx_g = Thickness of the aluminium plate = 0.26mn = 2.6 x 10^{-4}m

Δx_s = Thickness of the fibre glass = ?

K_f = Thermal conductivity of the fibre glass = 0.048W/m °C

K_a = Thermal conductivity of the aluminium sheet = 204w/m °C

$$80 - 30 = \frac{31.65}{0.28}[\frac{2.4x10^{-3}}{56} + \frac{\Delta x_s}{0.048} + \frac{2.4x10^{-3}}{204}]$$

$$48 = 113.03\{4.29x10^{-6} + \frac{\Delta x_s}{0.048} + 1.27\ x10^{-6}]$$

Δx_s = 0.016m =16 mm

Hence fibre glass of 0.02m thick was used for safety reason.

RESULTS AND DISCUSSION

Observation of drying rate profile in the dryer

Cassava chips were used to test the dryer, co-current form of drying was used throughout the drying operation. Fig. 2 shows the drying rate pattern in the dryer. The drying rate exhibits a falling rate profile. It is obvious from the graph that at the 4th hour, it exhibits a second falling rate before it stops at the 8th hour. Some agricultural products occasionally second falling rate period was as a result of the plane of evaporation which slowly receded from the surface and all evaporation occurred at the interior of the foods reported by [10].

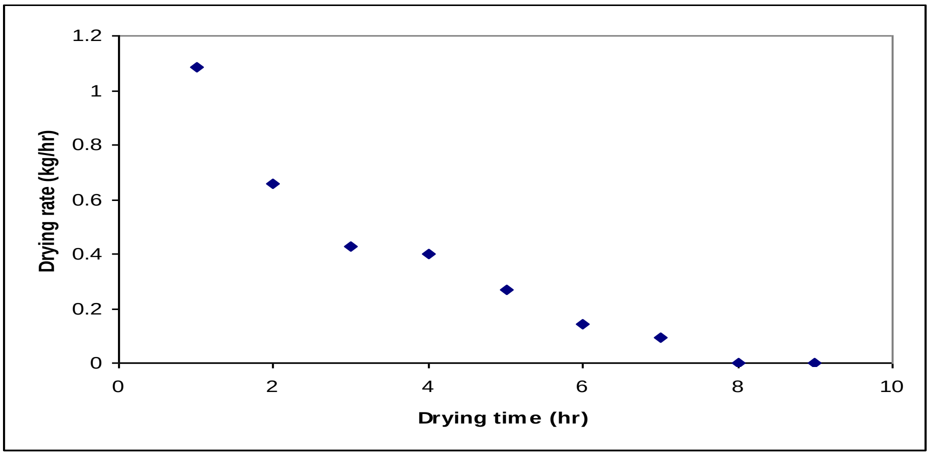

Fig. 2: Drying rate against temperature

According to [11], drying rate is the amount of water removed in a specific time interval from a food product and is affected by size, shape and thermo-physical properties of the product. Slicing and dicing into smaller pieces expose more surface area for heating and evaporation and may address the problem of case hardening and spoilage. Drying a large quantity of material means more evaporative cooling, higher humidity and lower air temperature in the dryer. Unless drying time is increased, the product being dried will have higher moisture content at the end of the process. High moisture content can lead to mould spoilage.

Observation of truck movement pattern in the dryer

The location of the truck in the tunnel varies from one point to another as the truck advanced in the tunnel. Fig. 3 shows the traveling pattern of each truck. Initially, the truck enters with fresh cassava chips at the inlet end of the dryer and advanced through the tunnel until it exits at the other end at 81/2 h. The prevailing factors affecting residence time of the truck depends on the loading density; dimensions of the food material, initial moisture content, temperature regime and air velocity as reported by other authors such as [12], [13] and [5].

Observation of temperature profile in the dryer

Temperature is an important factor in drying operation. At higher temperatures, water molecules get excited and break away from their active site thereby resulting in lower moisture content termed as drying process as reported by [14]. In this dryer, temperature regime lies between 70 (the heating side) and 55 °C (the exits side) as shown in fig. 4. This means that temperature differential of 15 °C lies between heating and exiting section. For any effective dryer, temperature gradient regime must not be too steep (large) otherwise drying would be difficult to achieve. The natural problem of convective dryer is temperature fluctuations within the drying chamber, hence there is a need to maintain consistent temperature in the tunnel otherwise there is a tendency for samples to pick up moisture especially at the low temperature end. Researcher such as [15] reported that poor insulation may reduce the effectiveness of the tunnel such as increasing the temperature differential in order to reduce the productivity of the dryer. Higher temperature and inadequate insulation mean more radiant heat loss and energy wasting.

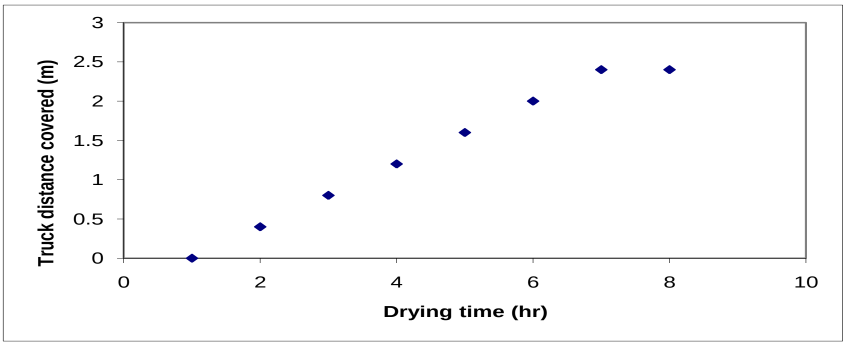

Fig. 3: Truck movement against residence time

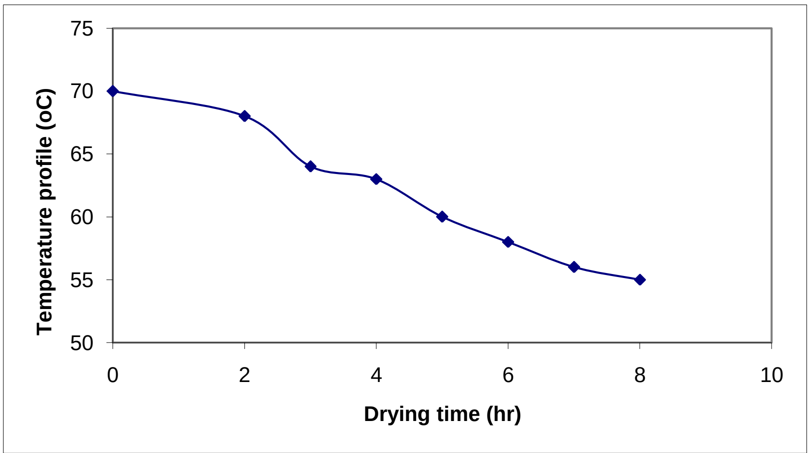

Fig. 4: Temperature profile against drying time

Elucidation on air velocity in the dryer

The drying characteristics of a tunnel are strongly influenced by its general design and arrangement, especially the direction of progression of the trucks relative to the direction of the airflow as reported [16]. Evaporation rate increases linearly as air velocity increases in the dryer. Maximum useful air speed is estimated at 3.0m/s flowing parallel to the tray surface. This is based on the recommended speed for a wet bulb thermometer on a sling psychrometer; regardless of the humidity in the air [17]. Fig. 5 shows the air velocity pattern in the dryer. The highest values of the 5 m/s were observed at the inlet end but reduced to 2.5 m/s at the exits end.

This is as a result of obstacles/resistance caused by the trucks to the air movement. For any effective drying in the tunnel, the fan should deliver enough velocity pressure to drive the heat across the trucks otherwise it would result into a localized heating. There are fans and blowers (axial and centrifugal design) for dryers but the best for tunnel dryer is centrifugal fan/blower which can generate enough velocity pressure to deliver the air across the bed length of the dryer.

Evaluation of drying constant K_m

Fig. 6 shows the drying constant (K_m) which was determined by the plot of natural logarithm of moisture ratio (logMR) against the drying time (t). The gradient of the curve gave the value of drying constant to be 2.42/hr. According to [18], the drying rate constant is an important parameter reflecting the rate at which water from the food is removed. It is affected by size, shape and thermo-physical properties of the product. Slicing and dicing into smaller pieces expose more surface area for heating and evaporation and may address the problem of case hardening and spoilage. Drying a large quantity of material means more evaporative cooling, higher humidity and lower air temperature in the dryer [19-21] The value of drying constant in this study is greater than the value reported by [18] with value of 0.5/h for rice, 0.033/hr for grapes as reported by [22]. The differences in values may be as a result of the types of food being dried.

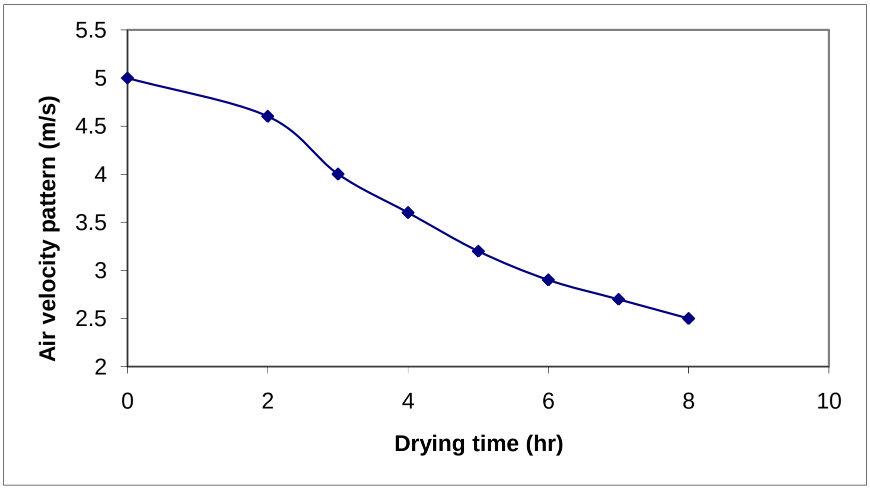

Fig. 5: Air velocity against drying time

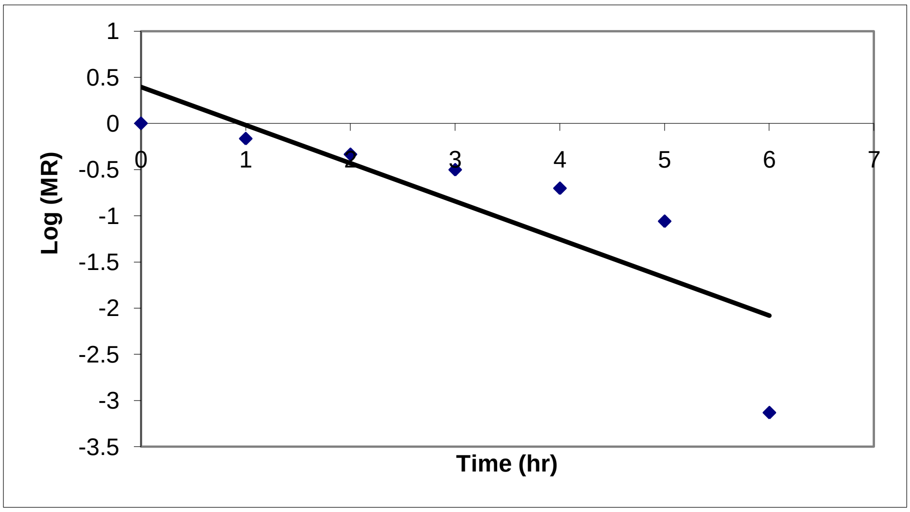

Fig. 6: Graph of the plot of log MR against time

Advantages of using this tunnel dryer

(i) It can process relatively large volume of product at a time for medium scale food processors.

(ii) Better control leading to uniformity distribution of air in regard to heat transfer as a function of temperature and air velocity even distribution.

(iii) Cost effective drying and maximum product quality.

(iv) Adaptable to drying tubers, fruits and vegetables

(v) Simplicity in construction

CONCLUSION

Drying is an essential part of unit operation and a cogent means of food processing and preservation in the tropics. The common method of drying in Nigeria is open sun drying with a lot of deficiencies in the products. The design and fabrication of this dryer has catered for most deficiencies experiences with sun drying. It can efficiently dry about 35 kg per batch with a less maintenance cost. More studies are required in the aspect of machine automation.

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