Design, Construction and Performance Evaluation of Citrus Fruits' Juice Extractor

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***Abstract*:- Juice extraction from fruits has been a worrisome problem to local farmers in Nigeria due to their perishable nature. The inability of local farmers to afford the high cost of imported juice extractor has worsened the problem. Hence, the need to look for an alternative juice extractor from locally available materials in order to reduce or eliminate the difficulty encountered in extracting juice by local means from citrus fruits like orange, tangerine, lime, etc. The machine is made up of hopper, a cylindrical main housing, a shaft carrying well-arranged pressers, a perforated screen and an outlet. The cylindrical main housing consists of an upper and a lower chamber units; the upper chamber consists of a shaft and two bearings while the shaft was constructed using stainless steel plate of 1.5mm thickness with the presser properly welded on it. The machine is powered by 5Hp electric motor with the aid of V-belt and pulleys. The motor and shaft run at 1200rpm and 600rpm respectively for effective pressing. The results showed that the fabricated juice extractor has extraction efficiencies of 84%, 87% and 89% for orange, tangerine and lime respectively. In addition, the machine was allowed to run for six hours per day and it was able to extract juice from an average of 3.36, 10.85 and 10.47tonnes of orange, tangerine and lime respectively.**

Keywords: Citrus Fruit, Juice, Hopper, Cylindrical Main Housing, Shaft, Presser, Perforated Screen, Electric Motor

INTRODUCTION

Production of fruits in Nigeria can be estimated at hundreds of thousands of metric ton per year. Unfortunately, over 50% are lost due to perishable nature of fruits occasioned by high moisture content and poor post-harvest handling and marketing strategies (Otterloo, 1997). This shows that fruits juice is the next best thing to fresh fruits, and can be packaged in aseptic, easily transported containers that are less susceptible to damaged and have a relatively long storage life. Juice extraction and separation therefore open up new market opportunities for tailoring fruit products to modern consumer. Hygienic problems due to local methods of preservation and juice extraction, time and energy wastage in hand squeezing the fruit singly or manually and economics loss due to lack of affordable extracting and processing machines will be something of past with introduction of this machine to the market at an affordable price to an average farmer or medium scale industrialists (Bamigbade, 2002).

The juice extractor is made up of power unit (electric motor, belt, pulley and bearing etc.), a hopper through which the fruit will be introduced to the machine compressing chamber, a housing or compressing chamber with a shaft incorporating a set of specially arranged presser, a perforated screen (meant to sieve off pulp, seeds and skin), a separate juice receiver and an incorporated exit-where the orange waste will be evacuated. Fruit juices are categorized as those with and without pulp. Other classification includes natural juice (product obtainable from fruit) and mixed juice (obtainable from the mixing of two or more fruits of different fruit species or by adding sugar).Juice obtained by removal of a major part of their water content by vacuum evaporator or fractional freezing are defined as concentrated juice (Wills et al, 1998).

Juice is the liquid extracted from the cells of mature fruits. Fruit cell wall is made of cellulose, hemicelluloses, peptic substance and proteins (Ashurt, 1991). Fruit juice extractor is an agricultural technology implement that involves the pressing of some fruit in order to get juice. Fruit juice extractor involves the process of crushing, squeezing and pressing of whole fruit in order to obtain the juice and reduce the bulkiness of the fruit to liquid and pulp. Hand extraction of juice is slow and tedious and also not hygienic enough. The merits of using machine for extraction are: time saving, improved efficiency, increase capacity and reduction in spoilage and waste (Tressler and Joslyn, 2005).

Ruteceae is a large family of trees and occasional herbs, which are of great economic importance yielding the citrus fruits (lemon, orange, limes, and grape fruits) as well. The family name is called Ruteceae while the botanical name is called citrus spp. (Otterlo, 1997). Although, there are wide variations in size and shape of different citrus fruit, there is surprisingly little basis difference in types of extraction operation used to remove juice from them.

DESIGN ANALYSIS

Volume of the hopper 'V_h' is calculated thus,

$$V_h = V_1 + V_2 + V_3 \quad (1)$$

Where; V_1= lenght × breadth × height

$$= 210 \times 165 \times 50 = 1732500 mm^3$$

$$V_2 = \frac{1}{2} \times base \times lenght \times height$$

$$= \frac{1}{2} \times 165 \times 210 \times 85 = 1472625 mm^3$$

Also, $V_3 = A \times h$, where $A = A_r - A_c$, A_r = Area of rectangle, and A_c = Area of sector

Then; A= $(24150 - 8660.1375)mm^2 = 14859.86mm^2$
Therefore; Volume, $V_3 = 14859.86 \times 85 = 1263088.1mm^3$
Volume of the hopper, V_h = 1472625 + 1593900 + 1263088.1 = $4329613.1mm^3$

Determination of Shaft Diameter
ASME code states for commercial steel shafting, S_s (allowable) = 600Psi for shaft with key way = 40MN/m^2 (Bamigbade, 2002)
The diameter of the shaft, d_s was determined using standard procedure and equation (Khurmi and Gupta, 2005)

$$d_s^3 = \frac{16}{\pi S_s}\sqrt{[(K_b M_b)^2 + (K_t M_t)^2]} \quad (2)$$

Where Maximum bending moment (M_b) = 49.3N/m, Maximum twisting moment (M_t) = 16.23 N/m, Combine shock (K_b) = 1.5, Shock fatigue factor (K_t) = 1.0 and Allowable shear stress (S_s) = 40 MN/m^2 for shaft with key way (Adelegan, 1999).

$$d_s^3 = \frac{16}{3.142x40x10^6}\sqrt{[(1.5x49.3)^2 + (1x16.23)^2]}$$

$$d_s = 0.029401\text{m}$$

The suitable diameter will be 1¼ inches = 32.0mm (Aluko, 1999)

Power Transmitted by Shaft
Let N = Number of revolution per minute

$$T = \text{average torque in KNm}^{-1} = \frac{power\ \ transmitted}{2\pi N} \quad (3)$$

Power = design horse power x 0.746 KW (Khurmi and Gupta, 2005)
The electric motor used is 5horse power

Therefore, power = 5 x 0.746 = 3.73KW = 3730W

$$\text{Torque} = \frac{3.73}{2x3.142x1200} = 0.00049\text{KNm}^{-1} = 0.49\text{Nm}^{-1}$$

Designs for the Number and Spacing of Presser Spike on the Shaft
The number and spacing of blade on the shaft was determined using the expression given by equation below

$$S_n = \frac{L_s}{S_t} \quad \text{(Ohimijie, 2005)} \quad (4)$$

Where S_n = number of blade on the shaft, L_s = length of blade on the shaft = 150mm and
S_t = desired thickness of lump (spacing and space) = 20mm

$$S_n = \frac{150}{20} = 7.5$$

S_n = 8 (Vialle and Juliano, 1993)

Determination of Pulley Diameter and Speed
Speed ratio = 2:1, motor pulley: shaft pulley. Speed of motor (N_A) = 1200 rpm diameter of pulley (motor).
Motor's pulley diameter, D_A = 105mm, Speed of pulley B (N_B) = 1200/2 = 600rpm
Taking the transmission efficiency of pulley as 95%

$$\text{Recall, Efficiency}(\varepsilon) = \frac{\text{Output}}{\text{Input}} \text{ (Aluko, 2009)} \quad (5)$$

$$= \frac{D_B \times N_B}{D_A \times N_A}$$

$$D_B = \frac{0.95 \text{ x } 105 \text{ x}1200}{600} = 199.5$$

Bigger pulley diameter ≈200mm

Determination of Center Distance
The center distance between the two pulleys can be calculated using the equation adapted from Khurmi and Gupta (2005) as

$$C = \frac{(D+d)}{2} + d \quad (6)$$

Where Diameter of the bigger pulley (D) = 200mm and Smaller pulley diameter (d) = 105mm.

$$C = \frac{(200 + 105)}{2} + 105 = 257.5mm$$

In determining the length of belt, the equation by (Khurmi and Gupta, 2005) below was used

$$L = 2C + 1.57(D + d) + \frac{(D-d)^2}{4C} \quad (7)$$

$$L = 2 \text{ x } 257.5 + 1.57(200 + 105) + \frac{(200-105)^2}{4 \text{ x } 257.5} = 1002.61\text{mm}$$

Design of Number of Oranges, Tangerines and Limes to be fed into the Hopper
Number of orange 'n' in the hopper is gotten by dividing the volume of hopper by the volume of an orange
Thus; $n = \frac{Vh}{Vo} = \frac{4329613.1}{212149.25} \approx 20\ oranges$. Hence, a batch contains twenty oranges.
Similarly, a batch of tangerines and limes contains ninety one and one hundred and twenty respectively.

MACHINE DESCRIPTION

The Hopper
This is the inlet in which the halved peeled fruits are admitted into the pressing chamber. It is square in shape at the top and slanting as it enters through the upper chamber into the compressing unit. This is located at the left top side on the upper housing. Galvanized material is used for the "hopper" nevertheless stainless steel or aluminum alloy can also be used as alternative.

The Main Housing
This is the chamber in which the main operation of the juice extraction is carried out. It houses the shaft on which the pressers are arranged along its length alternatively. It consists of the two points upper and lower halved cylindrical shape chambers. They are made of 1.5mm thick stainless plate. The upper chamber will withstand pressure from the shaft and presser while the lower chamber (perforated sheet) will not; it will only act as the juice sieve. The lower chamber is situated below the upper chamber and it is almost exactly of the same size with the upper chamber except that it is perforated to allow passage of the extracted juice.

The Driven Shaft
This is a rotating member of the system. It is of circular cross sectional bar. The material can be steel or galvanized steel. The pressing accessories which are of the same material (stainless steel) with the shaft (except the rubber tips) were mounted upon the shaft, arranged alternatively and uniformly at equal intervals along its length. The

driven shaft has diameter 32mm and of length 1040mm. It was machined at one end to diameter 30mm by 50mm and step turned to diameter 25mm by length 45mm in other to admit the industrial bearing and the pulley respectively. The shaft was firmly bolted to the machine base with the aid of two sets of bearings.

Pressers

They are made up of stainless steel but galvanized steel can also be used. They consist of 22mm diameter round stainless steel bar, a flat rubber material pieces was securely fixed to its ends with the aid of bolts and nuts. The length of the presser depends on the size of the compressing chamber. For effective pressing, four pairs were employed.

Machine Base and Support

The weight of the shaft, the housing and the hopper are carried by the machine based and supports, they were made of 2inches by 2inches angle iron mild steel material. The base is of dimension 1020mm × 440mm × 1060mm.

The Motor Base

The motor base is equally made of angular bar of mild steel material. The bars were cut to required sizes and welded carefully to require shape.

The Pulley

The pulley is a two-way V-grooved type. It is made of cast iron of diameter 200mm and thickness of 40mm.The ready-made type was obtained for this construction.

Method of Construction

The following constructional operations were carried out on the components before the machine was finally assembled. These are: marking out, drilling of components, bending and folding of metal sheet, welding of components, machining – pulley and shaft, filling and smoothening, painting and assembly.

RESULTS AND DISCUSSION

Tests were carried out on the juice extractor with a batch of different types of citrus fruits like orange, tangerine and lime. It takes 19.95seconds, 10.25seconds and 11.09seconds to extract juice from a batch of oranges, tangerines and limes respectively as shown in Table 1. Juice can be extracted from an orange and one tone of oranges which contains 6452 oranges within 1second and 6435.87seconds (1hr47min16secs) respectively, a tangerine can be extracted within 0.11secs and one tone of tangerine which contains 18092 tangerines within 33mins10secs while a lime can be extracted within 0.09secs and one tone of lime which contains 22923 limes can be within 34mins23secs as shown in Table 3 and Fig. 2.

It takes a longer time to extract juice from an orange than it takes to extract either a tangerine or lime as shown in Fig. 2. This is due to the fact that an orange has greater geometrical volume than either of the two. In addition, the time it takes to extract juice from one tone of orange is much greater than that of tangerine or lime of the same quantity.

Lime has the highest extraction efficiency of 89% as shown in Table 2 and Fig. 3 followed by tangerine (87%) while orange has the least extraction efficiency of 84%. This could be attributed to its thicker skin, bigger size and geometrical volume. The capacity of the machine was tested on each of the sample, hence, it was allowed to run for six hours per day and it was able to extract juice from an average of 3.36, 10.85 and 10.47tonnes of orange, tangerine and lime respectively as shown in Fig. 1.

It was also observed that more than half of the fruit weights were obtained for the juice. This could be attributed to the efficiency of the machine and time of harvesting (i.e. raining season) of the fruits. It is believed that more juice is obtained during the raining seasons than dry seasons.

Filtration may be required to remove the tissue particles and care should be taken not to over press the fruits to avoid crushing the seeds.

CONCLUSION

This paper has made it possible to design and construct a device that can extract juice from citrus fruits easily and faster. The total cost of producing the machine with and without electric motor are ₦102,500 and ₦82,600 respectively. The mass production of this locally produced juice extractor will further reduce its cost and therefore make it relatively cheaper, affordable and available to both small and medium scale food industries to purchase compared to the imported ones. This will no doubt enhance the economic development of our country.

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Table 1: Time taken to Extract Juice from a Batch of Each Sample

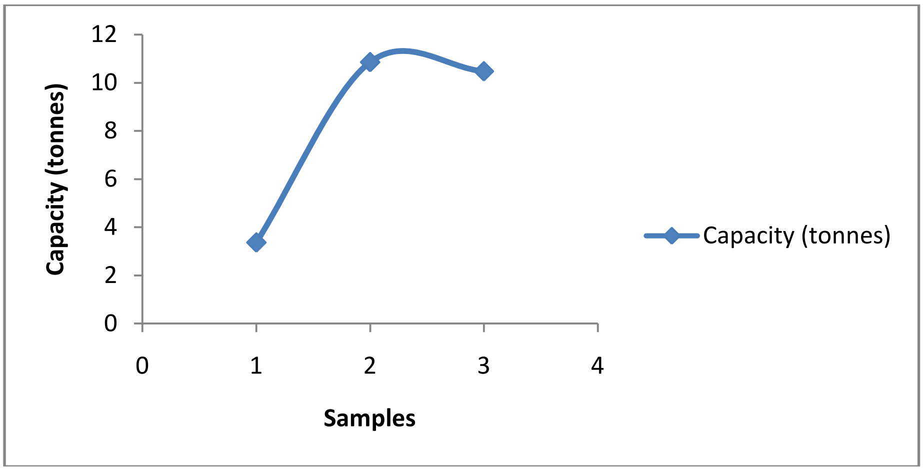
SAMPLE	NUMBER OF FRUITS IN A BATCH	TIME OF EXTRACTION(SECONDS)
Orange	20	19.95
Tangerine	91	10.25
Lime	120	11.09

Table 2: The Juice Extractor's Efficiency for Each Sample

SAMPLE	EFFICIENCY (%)
Orange	84
Tangerine	87
Lime	89

Table 3: Time taken to Extract Juice from One Tonne of Each Sample

SAMPLE	TIME (sec.) / Tonne
Orange	6436
Tangerine	1990
Lime	2063



1-Orange
2-Tangerine
3-Lime

Fig. 1: The Juice Extractor's Capacity in 6hrs for each Sample

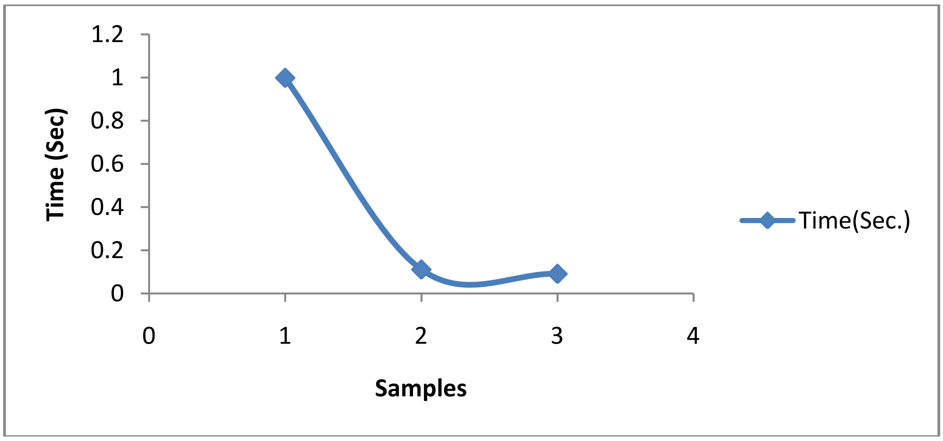


Fig. 2: Time taken to Extract Juice from a Fruit in each Sample

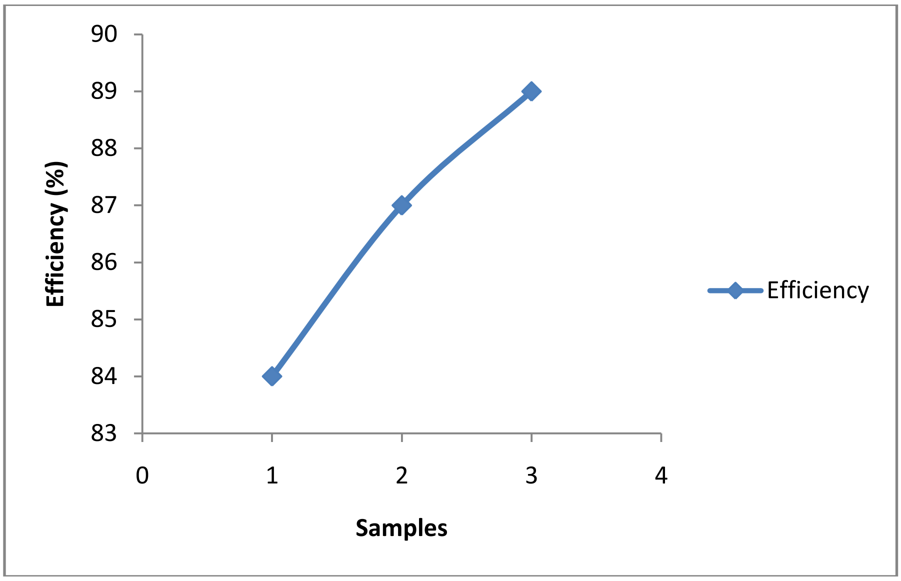


Fig. 3: The Juice Extractor's Efficiency for each Sample

1-Hopper
2-Main Housing
3-Presser
4-Perforated Sheet
5-Shaft
6-Industrial Bearing
7-Belt
8-Shalve Exit
9-Standing Bar
10-Juice Exit
11-Bracing Bar
12-Electric Motor
13-Motor Table
14-Handle
15-Locking Nut

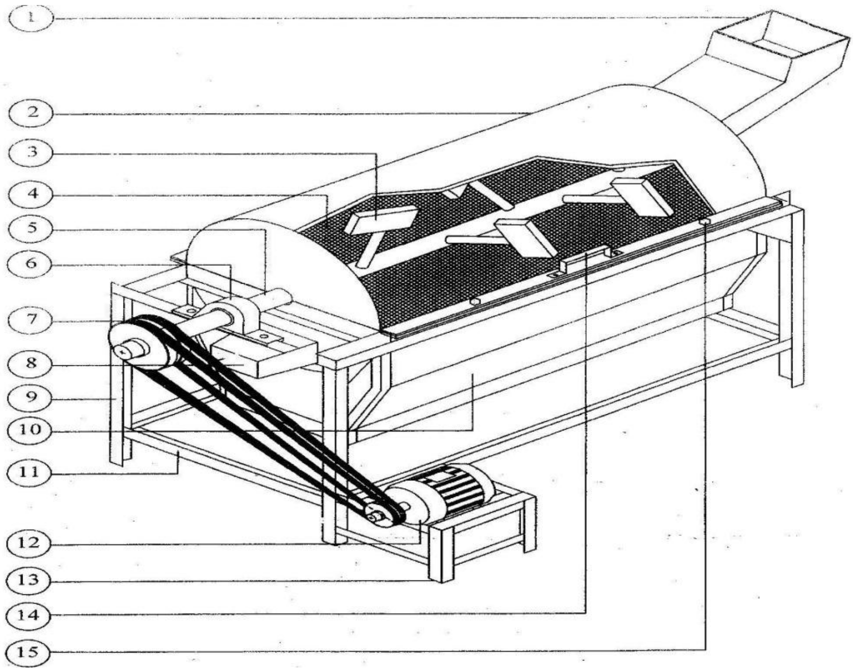


Fig. 4: Isometric Projection of Citrus Fruits' Juice Extractor

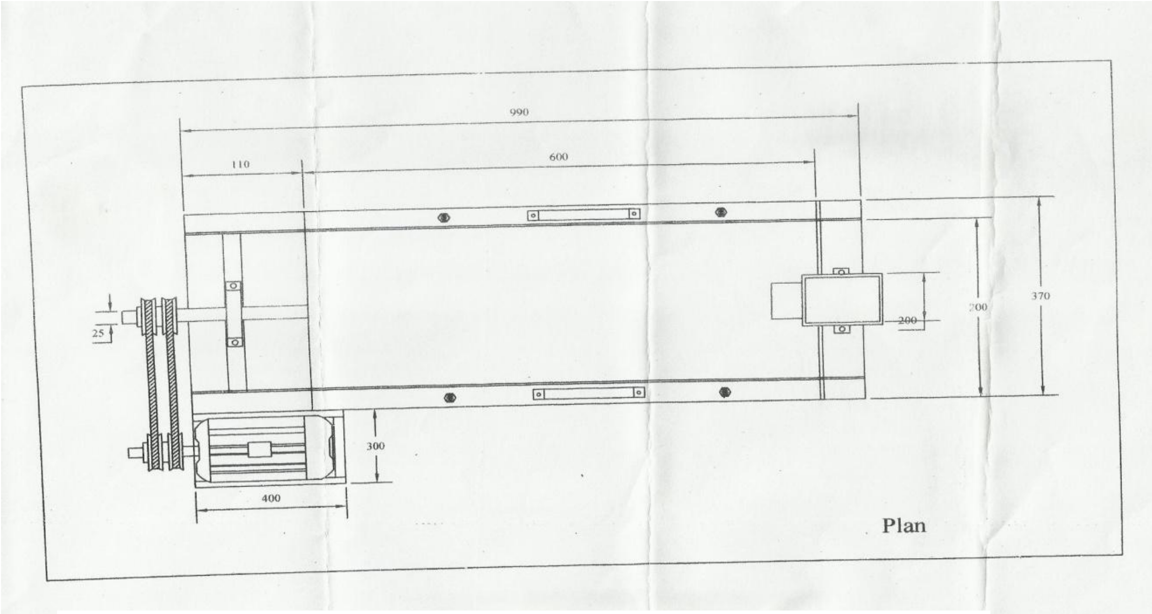


Fig. 5: Plan View of the Citrus Fruits' Juice Extractor

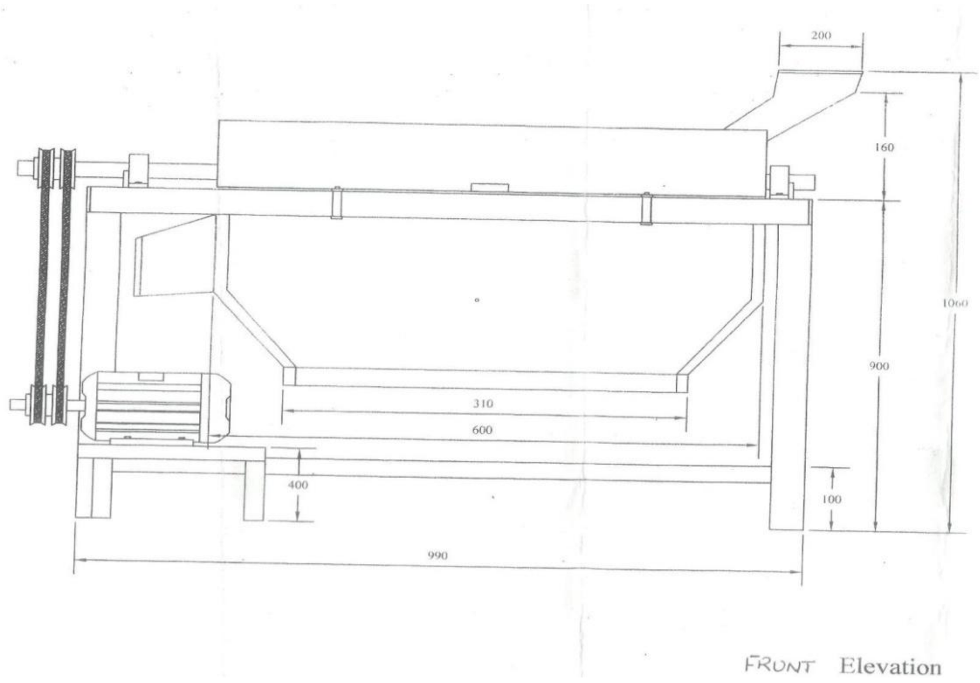


Fig. 6: Front Elevation of the Citrus Fruits' Juice Extractor

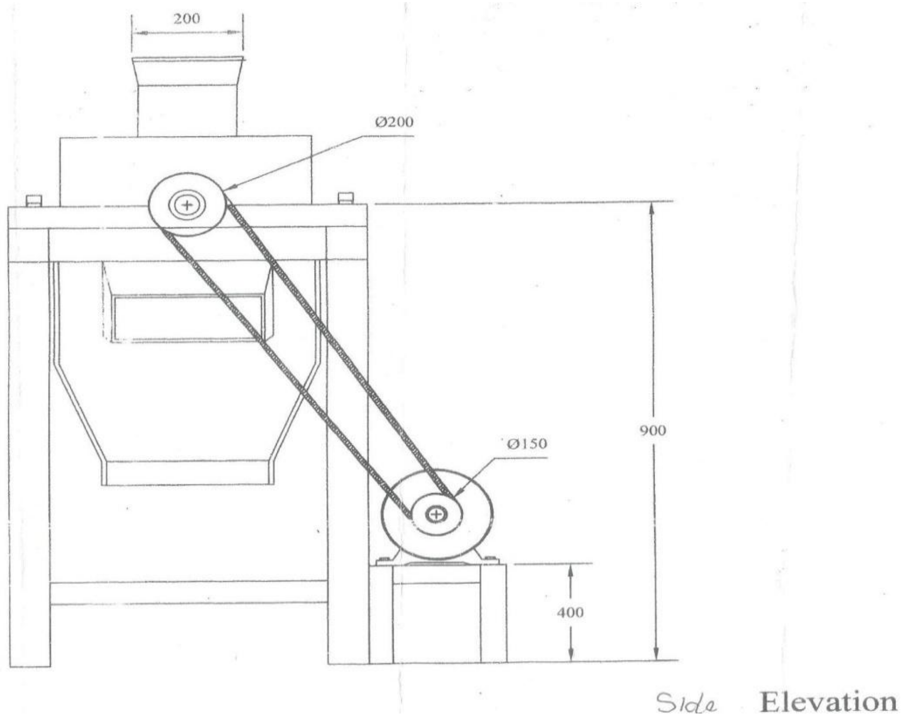


Fig. 7: Side Elevation of the Citrus Fruits' Juice Extractor