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Design, Construction and Evaluation of Zobo Juice Processing Device

V. I. Umogbai[1*]

[1]Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria.

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

This study was aimed to develop a device which can process Zobo juice at an economic rate utilizing the principle of leaf extraction method. Four tanks were constructed using aluminium sheet and stainless steel. The boiling, heat exchanger, and homogenizing tanks were made of aluminium while the cold water tank was made of stainless steel. The volumes of the tanks are 9.0 m^3, 9.5 m^3, 9.0 m^3 and 5.0 m^3 for boiling tank, homogenizing tank, heat exchanger and cold water tank respectively. The Zobo calyces are boiled in the boiling tank and the product is exited into the heat exchanger where water from the cold water tank is allowed into the heat exchanger to reduce the temperature of the zobo juice after which it finally enters the homogenizing tank where other ingredients (sugar and ginger) are added. The homogenizing tank stirs its content to obtain the final product. Its performance showed that in an average of 32 minutes using 9 litres capacity of boiling tank with mean volume of 9.0 cm^3, the homogenizing tank with mean volume of 9.5cm^3 would produce 9 litres of Zobo juice. It takes 32 minutes total processing time per 9 litre of zobo juice. This implies that on the average, one man working at a normal rate of 8 hours 32 minutes shift could process 144 litres of zobo juice using 9 litres capacity boiling tank. The calculated volumetric flow rate was $4.69 \times 10^{-6}\ \mathrm{m^3/s}$. The microbiological quality assessment from the processed zobo juice showed $1.8 \times 10^4\ \mathrm{cfu/ml}$ of mesophilic bacteria and $2.8 \times 10^3\ \mathrm{cfu/ml}$ of yeast/mould with complete absence of coliform cells. The results implied its safety for consumption as a beverage. The zobo-juice processing device is low cost in terms of construction, easy to

**Corresponding author: E-mail: victorimolemhe@yahoo.com;*

construct, easy to assemble and requires very little maintenance. It eliminates the unhygienic manual method of producing zobo juice. It serves the purpose of quick production of Zobo juice in homes, hotels, bars and restaurants. The cost of production is eighteen thousand six hundred and ninety Naira ₦18,690:00 which is approximately $117:00 US Dollars.

Keywords: Design; construction; evaluation; zobo; juice; device.

1. INTRODUCTION

Rosselle (*Hibiscus sabdariffa*), called Zobo in Nigeria, is an annual shrub that is cultivated in the tropical and sub-tropical regions of Northern hemisphere. The crop is native to India but it has been introduced to other parts of the world such as Central America, West Indies, and Africa. Roselle is a member of the family Malvacea to which includes okra, cotton and kenaf among others [1-4]. The common names of the plant in English speaking environment are Rosselle, Sorrel, red sorrel etc. In Nigeria it is popularly known as Zobo and the juice extracted from it is simply called Zoborodo.

1.1 Botanical Charateristics

The shrub grows to 2 – 2.5 m (7 – 8 ft) tall. The leaves are deeply three-five lobed 8 – 15 cm (3 – 6 in) long, arranged alternately on the stem. The flowers are 8 – 10 cm (3 – 4 in) in diameter; white to pale yellow with red dark spot at the base center of each petal and have a stout fleshy calyces at the base, 1 – 2 cm (0.39 – 0.79 in). The fruits are about 2.5 cm in length and are surrounded by enlarged fleshy calyces containing 22 – 34 seeds per capsule. The seed is dark in colour and weighs about 0.025g. Roselle plant takes about six months to mature [2,4].

1.2 Chemical Composition

The water extracts from Rosselle Calyces is rich in carotenoids (especially betta-corotene) and ascorbic acid. The calyces has also been found to be rich in vitamins, antioxidants and minerals. It is a fair source of vitamin A. It is also rich in riboflavin, niacin, calcium and iron [2,5]. It contains antioxidants including flavonoids, gossypetine, hibiscetine and sadderetine. Some of the anthocyamins of Roselle identified by chromate graphic process include delphinidin-3-glucose [6].

Rosselle is characterized a highly acidic fruit with low sugar content. Succinic acid and oxalic acid were quantified as two predominant organic acids in the calyces. It also contain higher amount of ascorbic acid compared to orange and mango [7]. Rosselle drink had been improved nutritionally by producing fruit flavoured Rosselle drink which are richer in vitamins and minerals by additions of different fruits. The calyce contains 8.3% moisture, 4% citric acid, 1.5% pigment (mainly anthocyanin), 6.9% protein and about 9% soluble solid with a pH of about 2.7 [6].

1.3 Medicinal and Culinary Uses

Rosselle is all natural, known for its pro-health and anti-aging properties. A Flemish botanist observation of the plant and edibility of the leaves in 1576, was recorded in Java in 1687 [8]. The seeds, leaves and calyces have been employed for different uses as vegetables, source of oils, refreshing drinks and food preservatives [9].

Rosselle has been used in folk medicine as a diuretic, mild laxative and treatment for cardiac and nerve diseases and cancer. The red calyces of the plant are increasingly exported to America and Europe where they are used as food colouring. Germany is the main importer [10]. It can also be found in market (as flower or syrup) in some places such as France, where there are Senegalese immigrant communities. The green leaves are used as spicy version of spinach. They give flavour to the Senegalese fish and rice dishes [11].

In East Africa, the calyx infusion called “Sudan tea” is taken to relieve cough. Rosselle juice with salt, pepper, asafoetida and molasses is taken as remedy for blindness [12].

A 2000 USAD study shows consuming *Hibiscus sabdariffa* tea lower blood pressure in a group of pe-hypersensitive and mildly hypersensitive adults [5].

1.4 Uses in Nigeria

In Nigeria, apart from its medicinal and culinary application the juice from the calyces of Zobo (*Hibiscus sabdariffa*) popularly referred to as

Zoborodo is suitable raw material for production of soft drinks, wine, and canned juice. The juice is usually served to entertain guests during festivals or ceremonies and can also serve as income generation activity. Zoborodo has become popular among almost all the ethnic groups in Nigeria. Students in campuses of higher institutions in the country prefer Zoborodo to other beverages because of its relative cheapness [5,12].

1.5 Preparation of Zobo Juice

Zobo juice is prepared by boiling the drying calyces of *Hibiscus sabdariffa* in water for about 10 – 15 minutes during which the pigment and flavour embedded in them is extracted. After extraction the filtrate may be taken as hot tea or allowed to cool and packaged in plastic bottles and taken as refreshment drink when chilled. The sharp taste of the raw extract is usually sweetened with sugar cane juice or granulated sugar, pineapple, orange or other fruits depending on choice. The sweetness of Zobo juice drink does not last long due to spoilage by microbial activities. A shelf life is approximately twenty four hours after production if not refrigerated [8].

According to Federal Ministry of Science and Technology (FMST) Zobo juice has been in extraction locally in Nigeria for over 30 years without clear processing technology. The first technological attempt of extracting Zobo juice on record in Nigeria was the cooking pot, firewood and decanting method by Rose of the Department Food Science and Technology, University of Maiduguri, Borno State, Nigeria. This was later modified by replacing the method with sieve and firewood with either kerosene stove or gas cooker. The methods are adjudged unhygienic and of very low productivity [13]. As at 2003, the Raw Materials Research and Development Commission of Nigeria (RMRDC) reported that despite the increasing acceptance of Zobo juice its production in large quantity is yet unknown [14]. However, Joseph and Chindapi of the Federal Polytechnic, Mubi, Nigeria developed Zobo juice processing machine. The machine was found to be expensive. The heating and boiling of the calyces still relied on charcoal stove, kerosene stove and gas cooker. The process was also time consuming [15].

There are presently no industrial machines and devices for the production of Zobo juice in Nigeria. Attempts are being made by researchers in the country to produce equipment for Zobo juice. The recent example is the device by Joseph and Chindapi (2010). Locally the juice is produced by heating with fire wood in locally fabricated aluminium pots, metal tins or earthen ware pots. Filtering is carried out by use of local filters made from raffia palm fronds and leaves and in some cases from plastic filters.

The microbiological characteristics of Zobo juice consumed in Nigeria is assessed to be fit for consumption as it meets the set standard of low bacterial and yeast/mould count and absence of coliform cells as required by the international commission on microbiological specification of food [16,17].

From the above reasons it is evident that there is a need to develop a Zobo juice extracting device to eliminate the unhygienic and time consuming method of processing Zobo juice.

2. MATERIALS AND METHODS

2.1 Component Parts of the Developed Zobo Juice Extraction Device

The component parts of the device are the boiling tank, heater, filter, cold water tank, heat exchanger electric motor, homogenizing tank, homogenizer (stirrer), Zobo juice outlet tap and electric cables. Fig. 1 is a photograph of the assembled device. Fig. 2 is a pictorial drawing of the Zobo juice extraction device while Fig. 3 shows the component parts with dimensions. The boiling tank, heat exchanger and the homogenizing tank were constructed from aluminium sheet. Aluminium was chosen for its toughness, corrosion resistance and high thermal conductivity. Stainless steel was used for the cold water tank because of its lower thermal conductivity and high resistance to corrosion. It exhibits neutral taste, does not react with beverages, and there is no danger of toxins being leached into foods that may come in contact with it. All up aluminium and stainless steel are the ultimate food grade surface out performing plastics and other metals in every aspect [18].

The heater and electric motor were purchased from an electrical shop in Makurdi. They are made by Super Master Electrical Appliance Ind. Co. Japan. The company is a reliable manufacturer of electrical appliances and its brands are popular in Nigerian markets. The

specifications of the heater are, rating 100 W, current 200 V, length 180 mm, and width 50 mm. The electric motor operates at a speed of 1500 rpm, current 12 V, length 150 mm and width 75 mm.

The filter is made of fine nylon net. It provides easy filtration, free passage of juice and reduced pipe blockage. The connecting pipes are made of reinforced flexible rubber. The taps are made of plastic material.

The boiling tank, homogenizing tank, heat exchanger and the cold water tank are cylindrical in shape.

Aluminium sheet metal (guage 17) and stainless steel were used to construct the boiling tank, cold water tank heat exchanger and homogenizing tank by folding and gas welding at the Mechanical Engineering Workshop, University of Agriculture, Makurdi. A 5 mm diameter stainless steel rod was used to construct the stirrer in the homogenizing tank.

Their volumes were determined using the formula for calculating the volume of a cylinder.

$$V = \pi r^2 h \quad (1)$$

Where, *V*, *r* and *h* are respectively volume, radius and height of the cylinders.

A Celsius thermometer was used to measure the temperature in the various tanks.

2.2 Test Materials and Procedure

Zobo calyces were obtained from the North Bank Market in Makurdi. They were washed and sundried and 200g of calyces were used for evaluation of the device.

A super master electrical water heater was used for heating.

Sugar was obtained by squeezing sugar out of sugarcane stalk by pounding on mortar. Duplex pressure gauges, Bourdon Tube Series – Type 712.25DX (Range: up to 1000 Psi; Temperature = 20ºC - 100ºC) was used to measure the pressure in the boiling and homogenizing tanks.

A Celsius thermometer was used to measure the temperature in the boiling tank and homogenizing tank.

2.3 Volumetric Flow Rate

The volumetric flow rate was calculated as follows:

$$Q = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} \ \mathrm{m}^3/\mathrm{s} \quad (2)$$

i.e. the flow of volume of a fluid v through a surface per unit time t.

Since this is only the time derivatives of volume, a scalar quantity, the volumetric flow rate is also a scalar quantity. The change in volume is the amount that flows after crossing the boundary for some time duration, not simply the initial amount of volume at the boundary minus the final amount at the boundary, since the change in volume flowing through the area would be zero for steady flow [19,20].

The microbiological characteristics of the processed Zobo juice was carried out in the College of Food Scince Technology, University of Agriculture, Makurdi.

A yeast and mould principle was used for the enumeration of yeast and moulds in the processed Zobo juice.

The aerobic plate count method was used for the enumeration of mesophilic aerobic bacteria in the sample [16]. The most probable number (MPN) method was used for the enumeration of coliforms according to Health Protection Agency. Five samples were produced for microbiological analysis and the mean was used for the results [21].

2.4 Operation of the Device

The Zobo calyces are sundried to a moisture content of between 4-5% [8]. The dry Zobo calyces are sorted to remove impurities and rinsed in tap water. 200 g, 30 g and 5 g of calyces, sugar and ginger respectively were used to produce the juice. The prepared calyxes, sugar and ginger are boiled in the boiling tank to an average temperature of about 62ºC [8]. The boiling tank exit tap is opened allowing the flow by gravity through the heat exchanger into the homogenizing tank. About 50 cl of cold water is released from the cold water tank into the homogenizing tank to reduce the temperature of the juice. This increases the volume of the initial quantity of juice in the boiling tank. The shell – and – tube heat exchanger (STHE) in-flow tap is

opened to allow proper and timely cooling of the hot juice. After all the contents of the juice in the boiling tank have passed through the heat exchanger into the homogenizing tank, flavor, sugar cane juice, granulated sugar, pineapple, orange or other fruits depending on the choice is added to a required quantity (based on volume in homogenizer). The electrically powered homogenizer is operated for one minute to stir the content. The homogenizing tank exit tap is opened to empty the tank into a temporary storage tank or bottles ready for consumptions. 200 g of Zobo calyces were used for evaluating the performance of the device.

3. RESULTS AND DISCUSSION

3.1 Results

Results of calculated volumes of the boiling tank, homogenizing tank, heat exchanger and cold water tank are shown in Table 1.

Table 1. Results of calculated volumes

Item	Result (m^3)
Volume of boiling tank	9.04896
Volume of homogenizing tank	9.50141
Volume of heat exchanger	9.04896
Volume of cold water tank	5.00

Results of the tests carried out on the device are shown in Table 2.

Table 3 is the result of analysis of variance (ANOVA) using SPSS computation to compare the significant levels between Volume and Temperature.

3.1.1 Volumetric flow rate

$$Q = \lim_{\Delta t -> 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} \ \mathrm{m^3/s}$$

$$= \frac{9\ litres}{32\ minutes}$$

$$= \frac{0.009\ (m^3)}{32 \times 60\ (s)}$$

$$= \frac{0.009}{1920} \ \mathrm{m^3/s}$$

$$= 4.69 \times 10^{-6} \ \mathrm{m^3/s}$$

A comparison of the developed device was made with the Zobo juice processing machine developed by Joseph and Chindai in 2010 at the Federal Polytechnic, Mubi, Borno State, Nigeria. The comparison is shown in Table 5.

Table 4 is the result of microbiological analysis.

Fig. 1. A photograph of the Zobo juice extraction device

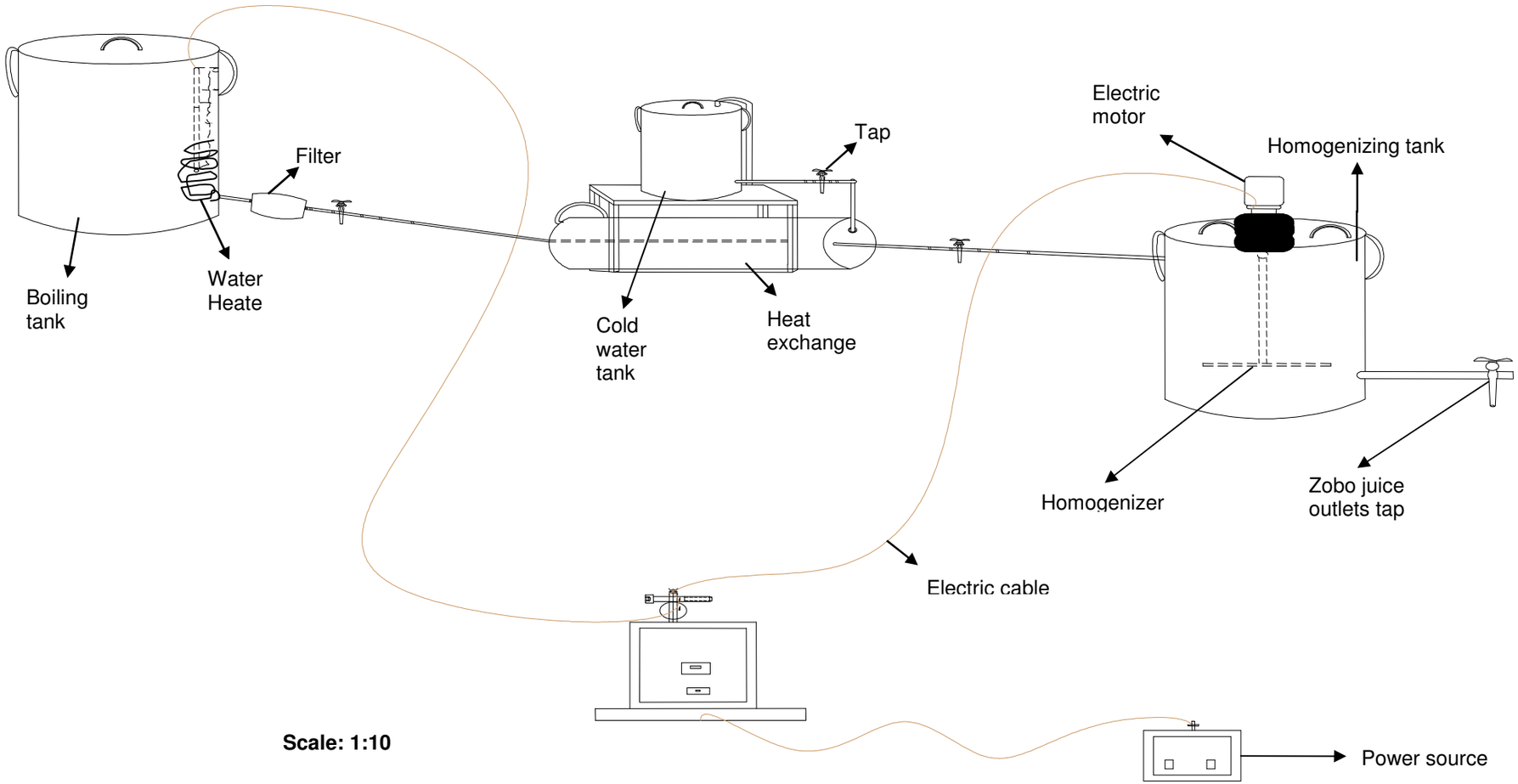

Fig. 2. Pictorial drawing of the Zobo processing device

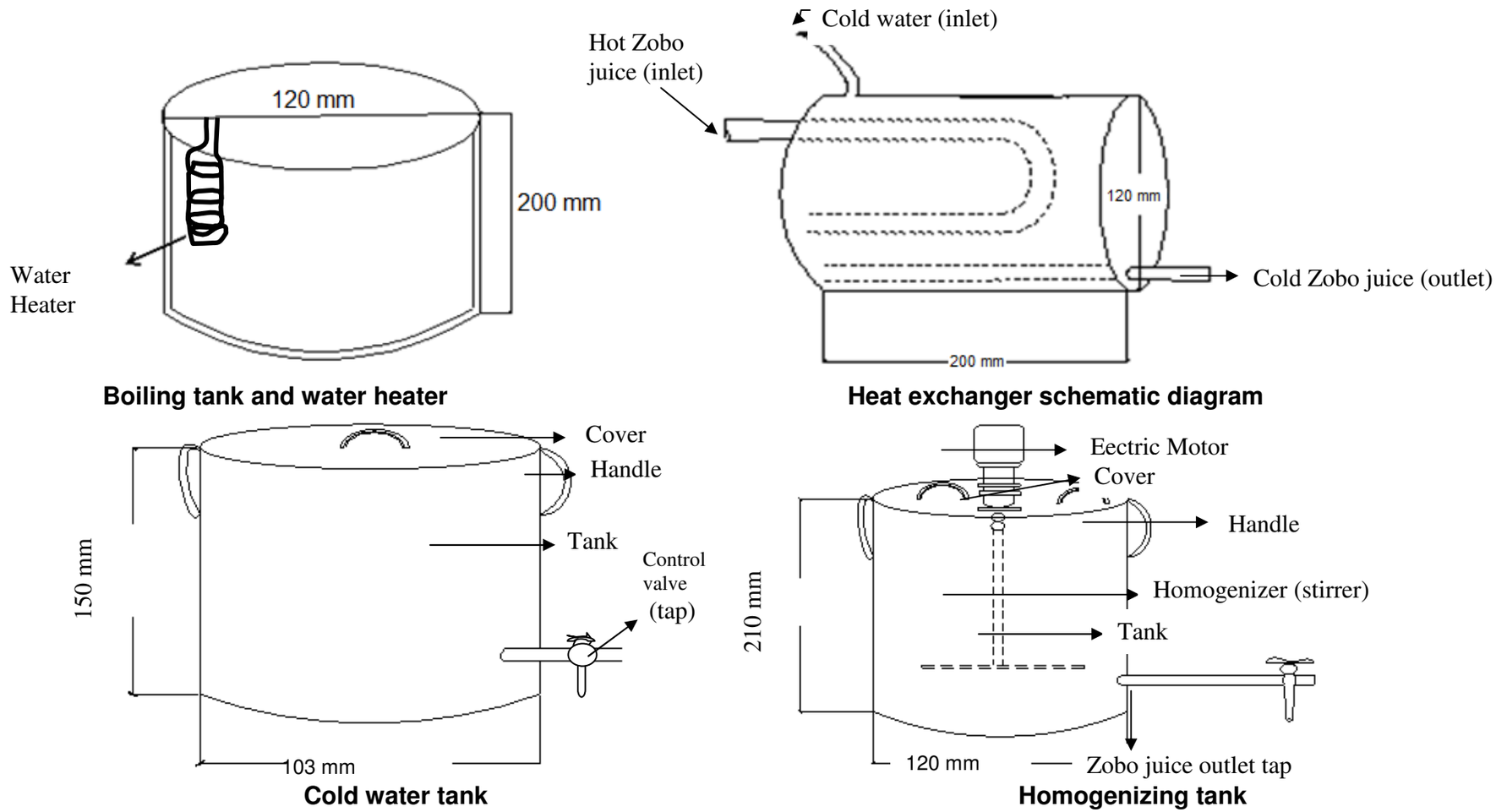

Fig. 3. Component parts of the device

Table 2. Test results

Test no	V_1 [cm^3]	T_1 (ºC)	V_2 [cm^3]	T_2 (ºC)	T_p (min)
1	9.05	62	9.50	38	32
2	9.04	63	9.51	41	33
3	9.06	61	9.53	40	35
4	9.04	60	9.51	39.5	34
Mean	**9.47**	**61.5**	**9.513**	**39.63**	**33.5**

Key:
$V_1(cm^3)$ = Volume of boiling tank
T_1 (ºC) = Extraction temperature in boiling tank
V_2 (cm^3) = Volume obtained in homogenizing tank
T_2 (ºC) = Temperature in homogenizing tank
T_p = Processing time (minute)

Table 3. ANOVA Comparison of significant levels between volume and temperature

Source of variation	SS	Df	MS	F	P-value	F crit
Rows	96.69696	3	32.23232	1.229873*	0.327833	3.159908
Columns	8677.913	6	1446.319	55.18647	1.29E-10	2.661305
Error	471.7413	18	26.20785			
Total	**9246.351**	**27**				

** = significantly different at p ≤ 0.05, Source: SPSS computation*

Key:

SS = Sum of square total
df = Degree of freedom value
MS = Mean square
F = From the analysis
P-value = Actual value (calculated value)
F crit = Critical value

Table 4. Mean result of mesophilic bacteria, yeast/mould and coliform

Bacteria countcfu/ml	Yeast/Mould count cfu/ml	Coliform count cfu/ml
1.8×10^4	2.8×10^3	zero

Table 5. Analysis of comparison of the efficiency of the production of zobo juice processing device constructed

	Zobo juice processing machine by Joseph and Chindapi (2010)	Zobo juice extraction device by Umogbai (2013)
1	It has a sump tank	It has a filter
2	Charcoal stove, kerosene stove, gas cooker is used in heating the boiling tank	Electric heating coil (water heater) is used in heating the boiling tank
3	The process waste time(45 minutes)	The process save time (32 minutes)
4	Bogus and expensive to construct (12000cm^3) (₦173,600)	Compact and cheap to construct (₦18,630) (9000cm^3)
5	It is strictly for outdoor usage	It is suitable for outdoor and indoor usage

3.2 Discussion

The volumes of the tanks are 9.05 m^3, 9.50 m^3, 9.05 m^3, 9.05 m^3 and 5.00 m^3 for the boiling tank, homogenizing tank, heat exchanger and cold water tank respectively Table 1.

From the four repetitions carried out on the device the temperature in the boiling tank

(extraction temperature) ranged from 60ºC to 63ºC with a mean of 61.5℃. The temperature recorded in the homogenizing tank was from 38ºC to 41ºC with a mean of 39.6ºC Table 2. This is as a result of the cold water added from the cold water tank. It is also observed that there is an increase in volume of the juice in the homogenizing tank as a result of the added water and the little sugar and orange juice to remove the sharp taste of the raw extract and sweeten the juice. Volume in the boiling tank was from 9.04 to 9.06 m^3 with a mean of 9.47 m^3. This increased between 9.50 and 9.53 m^3 with a mean of 9.51 m^3 in the homogenizing tank. This gave an increase in volume of about 1%. The processing time recorded for the four tests were from 32 to 35 min with a mean of 33.5 min Table 2. From the performance using 32 min and 9.50 m^3 as bench mark it would take an average of one man working at a rate of 8 hours 32 minutes to process 144 litres of Zobo juice using the developed device.

From the hypothesis test shown in Table 3 for the performance test on the Zobo juice processing device there is a significant difference at $p \leq 0.05$, where p is the level of probability. This implies that volume and temperature have significant effect on the time it takes to boil the Zobo juice.

The calculated volumetric flow rate was $4.69 \times 10^{-6}\ m^3/s$

Microbiological quality assessment results obtained from the processed Zobo juice Table 4, showed 1.8×10^4 cfu/ml of mesophilic bacteria and 2.8×10^3 cfu/ml of yeast/mould and the complete absence of coliform cells which is less than the standard set by the International Commission on Microbiological Specification of Food (ICMSF, 2002) and Health Protection Agency (2004) that set a limit of 10^6 cfu/ml for aerobic count of foods and coliform count of less than 10^2 cfu/ml. As for the instant Zobo juice, zero cfu/ml of coliforms was recorded. This implies that the drink is free of *E. coli* and safe for consumption.

The measured pressure using the Bourdon gauge in the boiling tank was 84.23 Kpa while the pressure in the homogenizing tank was 57.51 Kpa. The decrease in pressure was as a result of the lower temperature in the homogenizing tank.

The Zobo juice was heated to a temperature of about 62ºC in the boiling tank. This could be regarded as partial pasteurization. Complete pasteurization can be achieved by heating the Zobo juice in a separate container at a temperature of 100ºC.

A comparison of the developed Zobo juice device with the Zobo juice machine produced by Joseph and Chindapi (2010) at the Federeal Polytechnic, Mubi, Borno State, Nigeria shows significant improvement as indicated in Table 5. While that of Joseph and Chindapi uses charcoal, kerosene or gas as source of heating with the attendant pollution from emissions, the developed stove uses electricity with no pollution. The machine by Joseph and Chindapi takes a longer time (45 min) to process the juice as compared to 32 minutes for the developed device. The one by Joseph and Chindapi is bogus and expensive to construct (₦173,600). The developed stove is more compact, portable and much cheaper (₦18,690). That of Joseph and Chindapi is strictly for outdoor use because of emissions while the developed device is suitable for outdoor and indoor usage. The developed Zobo juice device is easy to construct, easy to dismantle and assemble, and requires very little maintenance. It would serve the purpose of fast production of Zobo juice in homes, hotels, bars and restaurants.

The cost of production of the developed device is eighteen thousand, six hundred and ninety Naira (₦18,690), which is approximately $117:00 US Dollars.

4. CONCLUSION AND RECOMMENDATIONS

A Zobo juice extraction device using electric power to heat the calyces in a boiling tank with water has been developed. The device is easy to construct, dismantle and assemble for easy cleaning and requires very little maintenance. It is recommended for hygienic and fast production of Zobo juice in homes, hotels, fast food joints and restaurants.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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