DEVELOPMENT OF LOCUST BEAN PROCESSING PLANT

(DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A LOCUST BEAN COOKER).

BY

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DECLARATION

I hereby declare that this project is a record of research work that was undertaken and written by me Alabi Osisieneto Babatunde. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished work of others were duly referenced in the text.

.... 01/01/2006

Alabi Osisieneto Babatunde — Date

2000/9484EA

CERTIFICATION

This project entitled "Development of Locust Bean Processing Plant (Design Fabrication and Performance evaluation of a Locust Bean Cooker)" by Alabi Osisieneto Babatunde meets the regulations governing the award of the degree of Bachelor of Engineering (B.ENG.) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

I dedicate this work to my parents; Tony Durojaiye Alabi PhD and Mrs Olufunmilayo Alabi. I'm forever indebted to you.

ACKNOWLEDGEMENT

First and foremost, I must mention God who has been there for me all through my programme.

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ABSTRACT

The work entails developing a locust bean processing plant. It attempts to mechanize the entire process of producing the food condiment *Iru* from the raw seeds. This project centres on the locust bean boiler, which attempt to mechanize the existing traditional method of locust bean cooking to reduce drudgery, and enhance timeliness of operation. The machine operates electrically. The machine has the capacity of boiling 33.75 kg within 1 hour. The cooker consists of three composite drums, each with a cylindrical upper part and conical lower part. The cooking chamber, made of galvanized steel has heating elements attached to its outside, while fibre-glass is lodged in between the middle and outer mild steel.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the work.

The African locust bean tree belongs to the family of *mimesaceease* of *Leguminosae* group, has a variety of names, like *Parkia bicolour, parkia clappertoniana, parkia fillicoida* and *parkia biglobasa.*

The locust bean fruit consist of bunches of pods which form the edible part of the plant. Each pod contains a yellow pulp which envelopes the thin membrane that covers the brownish-black seed coat. It is known that locust bean contains 39-40% protein, 31-40% oil, 11.7-15.4% carbohydrate (Campbel-Platt, 1980).

The seeds are of high quality, and very nutritious for human and animal feed. Processing would entail, threshing, decortication, washing, and cooking (boiling), all of which can be mechanized. Locally, the pulp is subjected to soaking to remove the sweetened yellowish tissue from the seed, after which the dry beans are subjected to cooking to soften the hard seed coat. After softening the seed coats are removed by finger pressure to release the cotyledons which are reheated for up to two hours.

1.2 Aims and objective of the work.

The overall aim of this work is to reduce the drudgery associated with obtaining the food condiment from the locust bean seed and to improve the efficiency of the process through mechanization of the cooking process.

Specifically, the objectives are;

(i) To design and fabricate a locust bean cooker,

(ii) To do (i) above using locally available materials,

(iii) To evaluate the fabricated boiler in terms of capacity and efficiency.

1.3 Justification.

The design of a cheap, affordable and easy to operate electric cooker/boiler to neatly cook the locust bean is necessitated by the desire to discontinue the manual method which is grossly inefficient and time consuming. The recovery of seeds from locust bean in the preparation of fermented food condiment would be impossible without a continuous and intensive cooking to soften the hard seed coat in order to obtain the highly nutritive indigenous condiment. The adhesive strength that binds the coat to the seed is quite high, such that ordinary soaking is inadequate.

This work attempts to further prepare the locust bean for decortication, by the use of a clean, quiet and easy to install and compact boiler. Because there are no combustion considerations, an electric boiler has minimal complexity (no fuels or fuel handling equipment) with easily replaceable boiling element.

Easy movement of water through the coat is restricted since the adhesive strength that bonds the coats to the seed is quite high. Industrial scale production of this food condiment is limited if a cooker is not developed.

1.4 Scope of the work.

The scope of the study is limited to the design, construction and performance evaluation of an electric cooker using locally-sourced construction materials.

1.5 Limitations

The limitations encountered in the course of this work generally bordered on ensuring the use of convenient and economic features, use of standard parts, minimizing cost of production such as not to compromise safety of the boiler.

The time of construction coincided with the SWEP period, when students were working in the workshop and the facilities were stretched. This drastically affected the construction time of the boiler. Some materials intended for use in construction were unavailable while some were too expensive. Therefore, other suitable materials were used.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction to food processing.

Some processes are carried out under reduced pressure to boil off moisture at reduced temperature. This is used in jam making to achieve a fresh fruit flavour. All reduced pressure processes require the measurement and control of vacuum. Conversely, some processes operate at elevated pressures, for instance, the process of pasteurization. This is achieved by raising the temperature very rapidly in a continuous process by, for instance steam injection under pressure, holding for a closely defined time in a delay tube and them quickly dropping the temperature by reversing the pressure through a relief valve and hence 'flashing off ' the steam again.

Pressure cooking is also used to hasten normal cooking processes in food preparation. (Allan, 1987)

Cooked food is food that has been changed in various ways by heating treatment. The heat may be applied in a number of ways; it may be dry or moist, it may be applied by means of fat or by infrared radiation.

1. Dry - Heat methods: includes

a). baking b). roasting c). grilling d). infrared grilling

2. Moist heat methods: Although cooking with water involves using low temperature, it is a relatively quick method of cooking because water has a big capacity for holding heat and for transferring this heat rapidly to food by means of convection. Here food is heated by steam.

Boiling uses boiling water, summering uses water near but below boiling temperature and is similar to both stewing (for meat and fruit) and poaching (for fish).

In steaming, steam is used directly to heat the food or indirectly to heat the container. Increase in pressure raise the temperature at which water boils, so the cooking temperature is increased and the cooking time reduced.

3. Frying is done with hot fat.

Heat transferred by three methods namely;

i. Conduction: Heat flows in materials from hot areas to cooler ones. Some materials such as metals are good conductors and allow heat to pass through them easily.

ii. Convention: Hot gases and liquids rise, cold ones sink, for instance in ovens.

When food is cooked in hot water, the water circulates and the heat is carried to the food by convection (though the food absorbs this heat by conduction)

iii. Radiation: Hot bodies such as sun, send out heat by radiation. This radiant heat passes through space (like light) and heats objects in its path.

A boiler is a closed vessel in which water under pressure is transferred into steam by the application of heat in the boiler furnace, the chemical energy in fuel is converted into heat and it is the function of the boiler to transfer this heat to the contained water in the most efficient manner.

A boiler must be designed to absorb the maximum amount of heat released in the process of combustion. The heat is transferred to boiler content through radiation, conduction and convection. The relative percentage of radiation, conduction and convection is dependent upon the type of boiler, the designed heat transfer surface and the fuels.

2.2 LOCUST BEAN PROCESSING

Locust bean has distinct physical and mechanical properties when compared to other legumes. The bean is encased in a hard, tough and relatively thick coat that has semi - permeable characteristics. Easy movement of water through the coat is restricted. The adhesive strength that wind the coat to the seed is relatively higher, hence decoating the bean is necessary. Decoating the bean in a dry condition is difficult if not impossible.

The local production processes subject the pulp to soaking to remove the sweeten yellowish tissue from the seed, after which the dry bean are subjected to one or two days of continuous and intensive cooking to soften the hard seed coat. After softening the seed coats are removed by finger pressure releasing the cotyledons which are reheated for up to two hours.

The seeds are then left for two to three days to ferment in the natural heat of the tropics (Campbell,. 1980). Processing of locust beans by fermentation is done by submerging and boiling cleaned beans in adequate amount of water for at least 18 hours until soft. The cooked locust bean is then allowed to cool down completely before Dehulling (that is processing between the palms to remove the tough fibrous testa). The Dehulled seeds are then washed and cooked for another 30 minutes after which they are drained, cooled and prepared for fermentation by packing into various incubation materials and weighed down to keep the cover in place.

The beans are then allowed to ferment under incubators of ones choice.

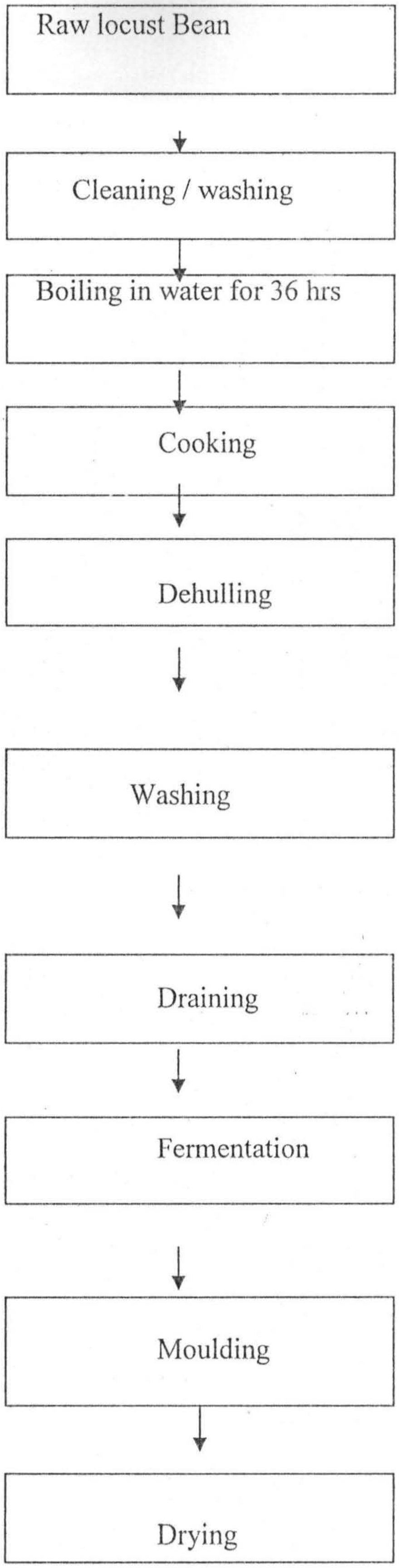


Fig 1.1; flow chart for preparation of locust bean

2.3 Locust bean boiling.

Interest in thermal properties of foods appears to mirror our capacity to predict heat transfer rates in foods. Heat transfer analysis for heating or cooling food products require constant uniform values of properties. These analysis are usually oversimplified and inaccurate.

Present day analytical techniques such as the finite element method are much more sophisticated and can account for non-uniform thermal properties, which changes with time, temperature and location as a food product is heated or cooled. This greatly increases the demand for more accurate thermal property data and more sophistication in the sense that now it is necessary to know how thermal properties change during a process.

Improvements in our ability to measure the composition of foods more precisely have increased the need to know the effects of composition on thermal properties. In fact, ideally one could predict the thermal properties of a food material for a given heating or cooling process, knowing only the composition, temperature and density and or porosity of the product.

Variability in composition and physical characteristics is typical for all food products. The thermal properties considered include

1) specific heat 2)thermal conductivity 3)thermal diffusivity 4)enthalpy 5)surface heat transfer coefficient (Sweat, 1976).

This is usually done using fire-wood and metal pots. Usually cooking 33.75 kg would take as long as 12 hours. A lot of fire wood is involved and this has adverse effects on the environment as it encourages felling of trees. Some northern states are grappling with the e problem of desert encroachment. Moreover the method is usually unhygienic.

2.5 Electrically powered boiling of locust bean.

Electric boilers are noted for being clean, quiet, easy to install, and compact. Because there are no combustion considerations, an electric boiler has minimal complexity (no fuels or fuel handling equipment) with easily replaceable heating elements. An electric boiler may be the perfect alternative to supply hot water where the customer is restricted by emission regulations. In areas where the cost of electric power is minimal, the electric boiler could be the best choice.

A heating element converts electricity into heat through the process of Joule heating. Electrical current running through the element encounters resistance, resulting in heating of the element. Most heating elements use nichrome wire or ribbon as the conductor. Nichrome is an ideal material as it is inexpensive, has relatively high resistance, and does not break down or oxidize in air in its useful temperature range.

2.6 Treatment of water

The basic assumption with regard to the quality of feed water is that calcium and magnesium hardness, migratory iron, migratory copper, colloidal silica and other contaminants have been reduced to a minimum, consistent with boiler design and operation parameters. External treatment, as the term is applied to water prepared for use as boiler feed water, usually refers to the chemical and mechanical treatment of the water source. The goal is to improve the quality of this source prior to its use as boiler feed water, external to the operating boiler itself. Such external treatment normally includes: clarification, filtration, softening, de-alkalization, demineralization, de-aeration and heating.

Once feed water quality has been optimized with regard to soluble and particulate contaminants, the next problem is corrosive gases. Dissolved oxygen and dissolved carbon dioxide are among the principal causes of corrosion in the boiler and pre-boiler systems. The deposition of these metallic oxides in the boiler is frequently more troublesome than the actual damage caused by the corrosion. Deposition is not only harmful in itself, but it offers an opening for further corrosion mechanisms as well.

Contaminant products in the feed water cycle up and concentrate in the boiler. As a result, deposition takes place on internal surfaces, particularly in high heat transfer areas, where it can be least tolerated. Metallic deposits act as insulators, which can cause local overheating. The impact of trace amounts of contaminants remaining in the feed water. The presence of dissolved gas such as oxygen, carbon dioxide and ammonia could cause corrosion

The importance of eliminating oxygen as a source of pitting and iron deposition cannot be over-emphasized. One of the most serious aspects of oxygen corrosion is that it occurs as pitting. This type of corrosion can produce failures even though only a relatively small amount of metal has been lost and the overall corrosion rate is relatively low. The degree of oxygen attack depends on the concentration of dissolved oxygen, the pH and the temperature of the water.

Elevated temperature in itself does not cause corrosion. Small concentrations of oxygen at elevated temperatures do cause severe problems. This temperature rise provides the driving force that accelerates the reaction so that even small quantities of dissolved oxygen can cause serious corrosion. Localized attack on metal can result in a forced shutdown. This must be prevented.

Most of the iron found in the boiler enters as iron oxide or hydroxide. Any soluble iron in the feed water is converted to the insoluble hydroxide when exposed to the high alkalinity and temperature in the boiler.

These iron compounds are divided roughly into two types, red iron oxide (Fe_2O_3) and black magnetic oxide (Fe_3O_4). The red oxide (hematite) is formed under oxidizing conditions that exist, for example, in the condensate system or in a boiler that is out of service. The black oxides (magnetite) are formed under reducing conditions that typically exist in an operating boiler.

Table 1; Boiler Troubleshooting Guide

Symptom	Remedy
Excessive oxygen content in deaerator effluent	1. Insufficient venting-increase vent rate by opening the manually operated air vent valve.
	2. Check steam pressure reducing valve for improper operation and hookup. Check valve for free operation, and see that control line is connected to the connection provided in the deaerator and not to the piping downstream of the valve.
	3. Check water and, if possible, steam flow rates vs. design. Trays or scrubber and inlet valves are designed for specific flow ranges.
Temperature in storage tank does not correspond within 5°F of saturation	1. Improper spray from spray nozzle. Check nozzle for sediment or deposit on seat or broken spring.

temperature of the steam	
	2. Excessive free air due to leaking stuffing boxes on pumps upstream of deaerator that have negative suction head. Repair stuffing box or seal with deaerated water.
Excessive consumption of oxygen scavenger	1. Trays collapsed-possibly from interrupted steam supply or sudden supply of cold water causing a vacuum.
	2. Condensate may be too hot. Water entering the deaerating heater must usually be cooled if the temperature is within 20 ° F of saturation temperature of the steam. Check the design specification to determine what inlet water temperature was originally intended.
High or low water level	1. Improper operation of inlet control valve. Adjust as necessary.
	2. Check faulty operation of steam pressure reducing valve.
	3. Check relief valves on the deaerator and in the main steam supply system for proper operation.
Low pressure	1. Check for improper operation of steam pressure reducing valve.

Boiler deposits result from hardness salts, metallic oxides, silica and a number of other feed water contaminants that can enter the system. In industrial boilers, it is cost prohibitive to eliminate all forms of contaminants in a pretreatment system. A controlled amount of contamination passes into the boiler with the feed water. Minimizing the adverse impact of these contaminants is the role of the boiler water treatment program.

Even the best controlled systems occasionally have upsets that cause excessive amounts of contamination to pass into the boiler. Some examples would be:

1. Carryover from a softener

2. Excess leakage from an ion exchange system

3. Contamination from leakage into condensate systems

4. Inadequate steam condensate protection programs resulting in high levels of corrosion products returning to the boiler

Mechanism of Deposition

Three basic conditions exist:

1. A circulation pattern is developed in the boiler due to steam bubbles, which alter the density of the boiler water. The hottest area of the boiler (where nucleate boiling occurs) is where the boiler water mixture is the least dense. A rolling circulation pattern is developed.

2. Based on convective, conductive and radiant heat transfer, thermal gradients are experienced throughout the boiler. The hottest areas become primary deposition points due to high heat flux.

3. Flow patterns, velocities and concentrations of contaminants also follow the laws of gravity. Thus, any area of the boiler considered to be low flow may exhibit significant deposition.

In conclusion, the boiler is a natural vessel for creating deposition of either precipitated soluble salts or migratory particulate contaminants. The ensuing discussions deal with both types of deposition.

Precipitated Soluble Salts. Here Calcium sulfate is the principal scale product. The principal scaling and fouling ions are calcium, magnesium, iron and bicarbonate and carbonate alkalinity. Silica is also a potential foulant.

Scale formation is a function of two criteria:

1. The concentration and solubility limits of the dissolved salt

2. The retrograde solubility (inversely proportional to temperature) characteristic of some salts

In a boiler, both of these conditions are met. While the boiler water is raised to a high temperature, the concentration of the dissolved salts is also increased. As steam is produced, dissolved salts remain in the boiler and continue to concentrate. Some salts may be soluble in the bulk boiler water. However, the boiler water immediately at the tube surface is considerably hotter than the bulk boiler water. As steam bubbles form near the tube wall, the soluble salts remain with the boiler water. This creates a localized high concentration of salts, even though the bulk boiler water may be well below saturation levels. The precipitation normally formed under these conditions has a crystalline structure and is relatively homogeneous.

In actuality, the crystallization of salts is a relatively slow process. A well-defined crystal is formed and often results in a dense and highly insulating deposit. From a chemical equilibrium standpoint, reversibility of this reaction is quite low. Table 2 is a partial list of scaling and fouling deposits.

As deposition begins, the localized temperature of the tube metal and deposit begins to increase. This temperature increase accelerates the deposition process. Depending

on the type of particulate, a non-scale commonly known as baked-on sludge can form. This can be very hard. It forms dense deposits, particularly in high heat transfer areas.

Regardless of the type of deposition, two very serious problems can occur:

1. Unscheduled shutdown due to tube failures from excessive deposition

2. Severe energy losses due to deposits retarding heat transfer in the critical areas of the boiler

Each of the above can be controlled through a sensible and well-applied internal boiler water program.

Why Some Corrosion in the Boiler is Necessary

Water will rapidly corrode mild steel; as the temperature increases, the reaction accelerates. The following reaction is typical of iron corrosion in a boiler:

$3\ Fe + 4H_20$ » $Fe_3O_4 + 4H_2$ (Iron + Water/Steam » Magnetite + Hydrogen gas)

Table 2: A List of Likely Boiler Deposits

Name	**Formula**
Acmite	$Na_2O{\cdot}Fe_2O_3{\cdot}4SiO_2$
Analcite	$Na_2O{\cdot}Al_2O_3{\cdot}4SiO_2{\cdot}2H_2O$
Anhydrite	$CaSO_4$
Aragonite	$CaCO_3$
Brucite	$Mg(OH)_2$
Calcite	$CaCO_3$
Cancrin	$4Na_2O{\cdot}CaO{\cdot}4Al_2O_3{\cdot}2CO_2{\cdot}9SiO_2{\cdot}3H_2O$
Hematite	Fe_2O_3
Hydroxyapatite	$Ca10(OH)_2(PO_4)_6$
Magnetite	Fe_3O_4
Noselite	$4Na_2O{\cdot}3Al_2O_3{\cdot}6SiO_2{\cdot}SO_4$
Pectolite	$Na_2O{\cdot}4CaO{\cdot}6SiO_2{\cdot}H_2O$
Alpha-Quartz	SiO_2
Serpentine	$3MgO{\cdot}2SiO_2{\cdot}2H_2O$
Thenardite	Na_2SO_4
Wallastonite	$CaSiO_3$
Xonotlite	$5CaO{\cdot}5SiO_2{\cdot}H_2O$

The magnetite produced is black iron oxide. Under normal operating conditions, this is the typical product of corrosion. However, it is also this reaction that inhibits excessive corrosion in steaming boilers. In a new or clean boiler, the initial corrosion process produces this magnetite film as a tenacious layer at the steel surface. This magnetite layer prevents any further contact with the steel or water surface. Consequently, the corrosion reaction is self-inhibiting.

This magnetite layer grows to an approximate thickness of 0.0004-0.001 inches, at which point any further corrosion process ceases. Periodic weakening or damaging of this protective shell does occur, and proper internal boiler water treatment can repair this layer. The normal corrosion in a clean boiler system progresses at approximately 1 mm per year. The appropriate pH levels for maintenance of the magnetite layer is approximately 8.5-12.7, with most systems operating at a pH level of 10.5-11.5.

Other Causes of Corrosion

Variations from the levels that are considered optimum for maintenance of the magnetite layer can cause general corrosion. a pH of 10.5-11.5 was identified as ideal for boiler operation

Acidic Attack. If boiler water pH has dropped significantly below 8.5, a phenomenon called waterside thinning can occur. The normal manifestation of acidic attack is etching. In addition, any stressed area would be a principal area for attack.

Caustic Attack. Caustic attack or, as it is more commonly known, caustic corrosion, is often encountered in phosphate treated boilers in which deposits occur in high heat transfer areas. In particular, boiler water can permeate the porous deposit. When it is coupled with significant heat flux, concentration of the boiler water occurs. Caustic soda (NaOH) is the only normal boiler water constituent that has high solubility and does not crystallize under these circumstances. This caustic concentration can be as high as 10,000-100,000 ppm. Localized attack due to the extremely high pH (12.9 +) will occur, as will the formation of caustic-ferritic compounds through the dissolving of the protective magnetite film. Once the process begins, the iron in contact with the boiler water will attempt to restore the protective magnetite film. Caustic corrosion (typically in the form of gouging) continues until the deposit is removed or the caustic concentration is reduced to normal.

Steamside tracking or blanketing is a direct corrosive attack, similar to the acid or caustic attack. The other normally encountered form of corrosion is stress-related corrosion.

Proper corrosion control is a function of several factors.

1. Proper boiler chemistry for operating pressures and conditions.
2. Close scrutiny and control of boiler water chemistry.
3. Frequent testing of boiler water chemistry.
4. Thorough inspection of all waterside areas during shutdown.

Embrittlement

Embrittlement of boiler metal is normally referred to as caustic embrittlement or intercrystalline cracking. Failure of a boiler due to caustic embrittlement is normally undetectable during operating conditions; it generally occurs suddenly, with catastrophic results.Three major factors must be present to cause intercrystalline cracking in boiler metal:

1. Leakage of boiler water must occur so as to permit the escape of steam and subsequent concentration of boiler water.

2. Attack of the boiler metal by concentrated caustic soda occurs from the concentrated boiler water.

3. There is high metal stress in the area of caustic concentration and leakage. the caustic embrittlement failures have normally been associated with riveted seams in boiler drums. The actual phenomenon of caustic embrittlement is through high caustic concentrations traversing the grain boundaries within the crystalline structure of the metal. The caustic does not attack the crystals themselves, but rather travels between the crystals.

Water treatment program must include this formula for calculating the proper sodium nitrate/sodium hydroxide ratio in boiler water is as follows.

$$NaNO_3/NaOH \text{ ratio} = \frac{(\text{ppm Nitrate as } NO_3) \times 2.14}{(\text{ppm M.O. Alkalinity as } CaCO_3) - (\text{ppm Phosphate as } PO_4)}$$

Causes of Foaming generally, are linked to the following:

1. High dissolved solids concentrations in the boiler water

2. High suspended solids concentrations

3. High alkalinity concentrations

Although, the requirement for water purity is a function of plant operation, it is important to define the causes so the proper corrective action can be taken. Part of this problem definition must be accomplished through the measurement of water purity.

Carbon Dioxide Corrosion. Carbon dioxide can enter a condensate system as a dissolved gas or it can be chemically combined in the bicarbonate or carbonate alkalinity of the feed water. The following reactions show the breakdown of naturally occurring bicarbonate and carbonate alkalinity to carbon dioxide.

Reaction 1:

$NaHCO_2 + heat \pm NaOH + CO_2$

Reaction 2:

$Na_2CO_3 + H_2O + heat \pm 2\ NaOH + CO_2$

Reaction #1 proceeds to completion. Reaction #2 is only about 80% complete.

The manifestation of carbon dioxide corrosion is generalized loss of metal, typified by grooving of the pipe walls at the bottom of the pipe: attack occurs at the threaded or stressed areas. This is the most common form of condensate system attack.

Introduction To Steam Boilers And Steam Raising **(www.nembusinesssolutions.com)**

CHAPTER THREE

3.0 DESIGN CALCULATIONS.

3.1 Preambless

The locust bean cooker was designed based on the concentric cylinders.

3.2 Design considerations.

The following factors were considered during the design of locust bean cooker.

1. The machine is a food processing unit which requires hygienic and non corrosive material for construction e.g. stainless steel and galvanized steel.

2. Leakages must be highly minimized.

3.3 Assumption

1. The thickness of all the three shells are 1.5mm

2. The heating element is either Nichrome or Constantan.

3. That the ideal heating element, wire or ribbon would be inexpensive, would have relatively high resistance, and would not break down or oxidize in air in its useful temperature range.

4. That there would be minimal steam and water loss or leakage as well as minimal heat transfer losses.

5. That electrical supply would be uninterrupted in the course of performance evaluation and subsequent operation.

The conductance (C) is equal to k/ x C = k/ x (1)

For ambient air.

k_1T_1	k_2T_2	k_3T_3	k_4T_4	k_5T_5
Boiler shell galvanized steel	Heating Element	Inner Mild Steel	Insulator	Outer Mild Steel

Ta ← Δx_1 ↓ Δx_2 Δx_3 Δx_4 ↓

→Tb

t_1 t_2

Ta – 90°C

Tb – 30.0°C

t_1 – 200°C

t_2 – 26.15°C

Δx_1= 1.5mm. Δx_2=1.5mm. Δx_3= 5mm. Δx_4=1.5

k_1,k_2,k_3, k_4 –thermal conductivity

Thermal conductivity of water = 0.7 $Jm^{-2}S^{-1}\ {}^{o}C^{-1}$

Thermal conductivity of steel = 50.2 W/m°C

C – Conductance $Jm^{-2}S^{-1}\ {}^{o}C^{-1}$

C=K/X =$Jm^{-1}S^{-1o}C^{-1}$ / m

The rate of heat transfer is given by;

$$\frac{dQ}{dt} = \frac{kA.dT}{dx} \qquad (2)$$

but $\frac{dT}{dx}$ unit length of path is given by $\frac{T_1 - T_2}{x} = KA\frac{T_1 - T_2}{x} = \frac{kA\Delta T}{x} = \left(\frac{k}{x}\right)A\Delta T$ (3)

This is the basic equation for heat conduction and could be used to calculate the rate of heat transfer through a uniform wall, if the temperature difference and thermal conductivity of materials are known.

Heat available to locust bean $q_1 = \left(\frac{A_1\Delta T_1 K_1}{x_1}\right) = \frac{6126.11 \times 110 \times 50.02}{1.5} = 22471388.2J$

Heat lose to environment

$$q_2 = \left(\frac{A_2\Delta T_2 K_2}{x_2}\right) = \frac{7355.75 \times 173.85 \times 50.02}{8} = 7995679.10J$$

Calculating for length of heating element.

Emmissivity (e) = 0.9

Radiating Efficiency (K) = 0.5

Resistance (R) 49×10^{-8} Khurmi R.S & Gapta J.A (2004)

Length of heating element L

Diameter of heating element (d)

Specific resistance or resistivity P

Power input (P)

Heat dissipated (H)

Voltage (V) =230V

Area of heating element (A)

Temperature of hot body in $^\circ K(T_1) = 200^\circ C + 273 = 473^\circ K$

Temperature of cold body or surrounding in $^\circ K(T_2) = 25^\circ C + 273 = 298^\circ K$

$$L \div d^2 = AV \div AP$$

$$L \div d^2 = AV \div 4PP = \frac{[\pi \times (230)^2]}{4 \times 49 \times 10^{-8} \times 2{,}500} = \frac{[3.142 \times 52900]}{49 \times 10^{-8} \times 10000}$$

$$= \frac{166106}{0.0049} = 33{,}899{,}183.67 \quad (4)$$

$$H = 5.72eK[(T_1 \div 100) - (T_2 \div 100)4]N/m^2 \quad (5)$$

$$5.72 \times 0.9 \times 0.5\ [(4.23)^4 - (2.98)^4]$$

$$2.574[411.6] = 1085.42\ W/m^2$$

P=2.5Kw

$$\pi \text{ x Lx}1085.42 = 2.5\text{Kw} \quad (6)$$

$$dL = \frac{2500 \times 7}{1085.42} = 0.062024 \quad (7)$$

$$d^2L^2 = 0.0038469 \quad (8)$$

From (6) and (7) L^3 would be

L^3=33, 899183.67 × 0.0038469 = 130,406,769

L = 50.71m

Then d (diameter) $= \frac{0.062024}{50.71} = 0.00122m \approx 1.22mm$

To determine the required current

$$V^2 \div (4PP \div \pi d^2) = (\pi d^2 V^2) \div 4PL \quad (9)$$

Or

$$(L \div d^2) = (\pi V^2) \div 4LP \quad (10)$$

V=IR

V=230V

$$R = P\frac{L}{A} \quad (11)$$

Assume $L = 1m$

$$\frac{49\times10^{-2}\times1m}{1.0\times10^{-6}m^2} = \frac{49\times10^{-2}}{0.1} = 490\times10^{-2}ohm$$

$$230 = I\times490\times10^{-2}$$

$$I = \frac{230}{490\times10^{-2}} = 46.93amps$$

Laws of resistance.

The resistance R offered by a conductor depends on the following factors

1) It varies directly as its length l
2) It varies inversely as the cross-section A of the conductor
3) It depends on the nature of the material
4) It also depends on the temperature of the conductor

Neglecting the last factor the time being, we can say that

$$R = \frac{1}{A} or R = P\frac{1}{A}$$

Where P is a constant depending on the nature of the conductor and is known as its specific resistance or resistivity.

If in equation (12)

L=1 meter and A=1meter^2, then, R=P

Hence, specific resistance of a material may be defined as the resistance between the opposite faces of a metre cube of that material

Units of Resisitivity

From equation ---- (1) we have $P = \frac{AR}{L}$

In the S.I system of units

$$P = \frac{Ametre^2 \times Rohm}{1metre} = \frac{AR}{L} \text{ ohm-metre}$$

The resistivities of commercial materials may differ by several percent due to impurities. The commercial heating elements considered are:

- Bare nichrome or constantan wire or ribbon: Either straight or coiled.

Table 3; Showing constantan properties.

Material	Resisitivity in ohm-metre at 20°C(x10^{-8})	Temperature coefficient 20°C(x10^{-4})
Constantan or Euraka	49	+0.1 to -0.4

Both nichrome and constantan have the quality of a good heating element which include.

1. High specific Resistance, thus only a short length of it will be required for a particular resistance (and hence heat).
2. High melting temperature thus enabling higher operating temperatures.
3. Low melting temperature thus enabling higher operating temperatures.
4. High oxidizing temperature, this ensures longer life.
5. Positive temperature coefficient of Resistance thus forestalling decrease in resistance with rise in temperature or drawing more current which will produce more wattage and hence heat.
6. Ductile- this enhances flexibility, transformation to convenient shapes and sizes.
7. Mechanical strength-As the maximum temperature of constantan (45% Ni, 55% Cu) is 400°C.

   With the passage of time, every heating element breaks open and becomes unserviceable. Some of the factors responsible for its failure are;

1. Formation of hotspots which shine brighter during operation.
2. Oxidation.
3. Corrosion.
4. Mechanical failure.

3.4 Design of heating element

Normally, wires of circular cross-section or rectangular conducting ribbons are used as heating elements. Under steady state conditions, a heating element dissipates as much heat from its surface as it receives the power from the electric su pply.

If P is power input and H is the heat dissipated by radiation, then P=H under steady state conditions.

As per Stefan's law of radiation, heat radiated by a hot body is given by

$$H = 5.72eK\left[(T_1 \div 100)^4 - (T_2 \div 100)^4\right] W/m^2$$

Where T_1 is the temperature of hot body in ^{0}K and T_2 the temperature of the cold body (or cold surroundings) in ^{0}K

$$P = V^2 \div R$$

$$R = Pl \div A = l \div P\pi d^2 \div 4 = 4Pl \div \pi d^2$$

Therefore $P = V \div 4PL \div \pi d^2 = \pi d^2 V^2 \div 4PL$ or $L \div d^2 = \pi V^2 \div 4LP$ P - (13)

Total surface area of the wire of the element $= (\pi d) \times L$

If H is the heat dissipated by radiation per second per unit surface area of the wire, then heat radiated per second

$$= (\pi d) \times L \times H \qquad (14)$$

Equating ---- (1) and ----- (2) we should have;

$$P = (\pi d) \times L \times H \text{ or } \pi d^2 V^2 \div 4PL = (\pi d) \times HorL^2 = V^2$$

(15)

We can find the values of L and d from equation (13) and (15)

Ribbon type element.

If w is the width of the ribbon and t it's thickness then;

$$P = \frac{V^2}{R} = \frac{PL}{A} = \frac{wtVL}{PL}$$

Heat lost from surface $= 2wlH$ (neglecting the side area $2H$)

$$\frac{wtVL}{PL} = 2wlHorL^2 \frac{t2PH}{V^2} \qquad (16)$$

3.5 Machine component design and calculation.

Machine design involves among others considerations for the proper sizing of a machine member to safely withstand the maximum stress which is induced within the member when subjected separately or to any combination of axial or transverse load.

Hence, the need to properly design and construct a machine that could be able to provide the services required during operation, putting all factors into consideration.

The upper part of the boiler is cylindrical in shape while the lower part is conical.

Aside of the aesthetics, the cylindrical and conical shape enhances offloading of the locust bean by natural gravitational principle. It also disallows sludge pockets at the edges of the boiler. This conforms to modern conventions in the food processing industry.

General consideration in machine design (boiler design)

1. Type of load and stresses caused by the load.

The load on a machine component may act in several ways due to which the internal stresses are set up. When a thin cylindrical shell is subjected to an internal pressure, it is likely to fail in the following two ways

i. it may fail along the longitudinal section (i.e. circumferentially) splitting the cylinder into two troughs.

ii. it may fail across the transverse section (i.e. longitudinally) splitting the cylinder into two cylindrical shells.

. Thus the wall of a cylindrical shell subjected to an internal pressure has to withstand tensile stresses of the following two types.

a. Circumferential or Hoop stresses

b. Longitudinal stress.

3.4 Capacity of the machine.

Given major dimensions

Diameter of cooking chamber (Galvanized Steel) D_1= 39cm

Radius $r_1 = \frac{diameter}{2} = \frac{39}{2}$ =19.5cm

Diameter of Inner Mild Steel D_2 = 46cm

Radius $r_2 = \frac{diameter}{2} = \frac{46}{2}$ =23cm

Diameter of Outer Mild Steel D_3 = 51cm

Radius $r_3 = \frac{diameter}{2} = \frac{52}{2}$ = 25.5cm

Volume of a cylinder = $\pi r^2 h$

Volume of a cone = $\frac{1}{3}\pi r^2 h$

Volume of each composite unit of the boiler =

The Volume of a cylinder $(\pi r^2 h)$ cm^3 + The Volume of a cone $\left(\frac{1}{3\pi r^2 h}\right)$cm^3

. (17).

For the Boiler chamber (Galvanized Steel)

$\pi = 3.14$, $r_1 = 19.5$cm, $h = 30$cm, $r_1^2 = 380.25$

Thus $\pi r^2 h = 35{,}842.3cm^3$

And $\frac{1}{3}\pi r^2 h = 17{,}921.1cm^3$

Total Volume for the Boiler shell (Galvanized Steel) =

$35{,}842.3cm^3 + 17{,}921.1cm^3 = 53{,}763.4cm^3$.

For Inner Mild Steel

$\pi = 3.14$, $r_2 = 23cm$, $h = 30cm$, $r_2^2 = 529$

Thus $\pi r^2 h = 49{,}863.54cm^2$

And $\frac{1}{3}\pi r^2 h = 24{,}931.71cm^3$

Total Volume for the Inner Mild Steel $= 49{,}863.54cm^3 + 24{,}931.71cm^3 = 74{,}795.31cm^3$

For Outer Mild Steel shell

$\pi = 3.14$, $r_3 = 25.5cm$, $h = 30cm$, $r_3^2 = 650.25$

Thus $\pi r^2 h = 61{,}292.5cm^3$

And $\frac{1}{3}\pi r^2 h = 30{,}646.28cm^3$

Total Volume for the Outer Mild Steel shell

$= 61{,}292.5cm^3 + 30{,}646.28cm^3 = 91{,}938.84cm^3$

For Area of cooking chamber= Area of cylinder with two open ends+ Area of curved surface of cone = $2\pi rh + \pi rl$ (18)

3.5 Determination of power requirement.

$$P = \frac{Energytransferred}{Timetaken}$$

$$P = \frac{IVt}{t} = IV$$

I = 46.938amps

V = 230V

Thus $IV = 46.938 \times 230$

$= 10,795.74J$

$W = QV = IVt$

Heat energy $(H) = IVt$

Heat in a Resistor I^2Rt or IVt or Vt/R

T = 5hrs $\times$ 60 = 300minutes

IVt = 46.938 $\times$ 230 $\times$ 300

=32387722 J

= 3.2 MJ

CHAPTER FOUR

4.0 FABRICATION OF LOCUST BEAN BOILER

4.1 Material selection.

The condition a machine part is subjected to make proper selection very important. It is not enough to use a material but that the material should withstand service condition. In the design of this product, strength, list of material, serviceability of parts and most importantly the availability of material were considered. This consideration and material specification led to the selection of mild steel and galvanized steel which is the most available and easy to machine and can withstand heat, finally the painting of machine was essential to reduce rusting.

The best material is one which serve the desired objective at the minimum cost. This was one of the most difficult problems.

The following factors were taken into cognizance while selecting materials.

1. Availability of materials
2. Suitability of the materials for the working conditions in service
3. The cost of the material

The important properties, which determine the utility of the materials, are physical, chemical and mechanical properties.

One must note and have a through knowledge of the properties of the materials and their behaviour under working conditions. Some of the important characteristics taken into consideration include:

1. Strength. 2. Durability. 3. Weight. 4. Resistance to and corrosion.

5. Electrical and heat conductivity.

4.2 Cost analysis.

The cost of producing the Locust bean Boiler is grouped into three;

They are; 1. Material Cost.

2. Labour Cost.

3. Overhead Cost.

Material Cost

Table 4; Material cost

S/no	Material/Part	Quantity	Unit Price (₦)	Amount(₦)
1.	Galvanized Steel	1200mm / 1200mm	2,000	2,000
2.	Mild Steel	2400mm / 1200mm	3,100	3,100
3.	Heating element	3	600	1,800
4.	Square Pipe	1 Length	800	800
5.	Control Valve	1	3000	3000
6.	Insulator (fiber glass)	1kg	1,500	1,500
7.	Electrical Cable	2.5mm/7Length	80	560
8.	Plug	1	180	180
9.	Indicator	1	150	150
10.	Bolt and Nut	4	40	160
11.	Electrode	10	10	100
Total				13,350

2. Labour Cost,

Labour cost involves the cost of the machining, cutting, welding and painting. It is taken as 25% of the material cost.

Therefore, labour cost = 25/100 X 13,350

= ₦ 3,337.5

3. Overhead Cost,

This cost includes cost incurred in course of production such as transportation as well as the consumables. It is taken as 12% of material cost.

Therefore, overhead cost = 15/100 X 13,350

= ₦ 2,002.5

Total Cost = ₦ 13,350 + ₦ 3,337.5+ ₦ 2,002.5= ₦18,690

4.3 Machine fabrication procedure

The machine component parts were fabricated in a workshop using appropriate equipment, machines and tool. The procedures carried out in the fabrication of the machine component are highlighted below in the table.

Table 5; Fabrication procedure

Component	Fabrication procedures	Machine or tools used
Boiler Shell	1. Measure out dimension on Galvanized sheet 1,220mm x 1220mm	Steel tape
	2. Mark out measured dimension on Galvanizes sheet.	Try-square and scriber
	3. Cutting of Galvanized sheet to marked out lines.	Tin-snip
	4. Rolling of the sheet into cylindrical shape	Rolling machine
	5. Joining cylinder to Delivery Valve	Hammer and Anvil
	6. Connection of heating elements.	Drilling machine
	7. Drilling of pipe hole on tank.	Bolt and Nut
	8. Connect pipe to Inner casing	Drilling machine
	9. Connect pipe to boiler shell	
Inner Casing	1. Measure out dimension on Mild sheet 1,220mm x 2480mm	Steel tape and Try-square
	2. Mark out measured dimension on Mild sheet.	Scriber
	3. Cutting of Mild sheet to marked out lines.	Tin-snip
	4. Rolling of the sheet into cylindrical shape	Rolling machine
	5. Joining cylinder to Delivery Valve	Hammer and Anvil
	6. Drilling of pipe hole on tank.	Drilling machine
	7. Connect pipe to boiler shell	Bolt and Nut
	8. Connect pipe to outer casing	Drilling machine
Outer Casing	1. Measure out dimension on Mild sheet 1,220mm x 2480mm	Steel tape and Try-square
	2. Mark out measured dimension on Mild sheet.	Scriber
	3. Cutting of Mild sheet to marked out lines.	Tin-snip
	4. Rolling of the sheet into cylindrical shape	Rolling machine
	5. Joining cylinder to Delivery Valve	Hammer and Anvil
	6. Drilling of pipe hole on tank.	Drilling machine
	7. Connect pipe to Inner casing	Bolt and Nut
	8. Setting fibre-glass	Drilling machine
Top Cover	1. Measure out dimension on Mild sheet 250mm x 200mm	Steel tape
	2. Mark out measured dimension on Mild sheet.	
	3. Cutting of Mild sheet to marked out lines.	Try-square and scriber
	4. Setting fibre-glass	
	5. Welding of plates.	Tin-snip

		Welding Machine
Square Bar (frame)	1. Measure out the dimension on a mild steel sheet iron of 1.5mm thick.	Steel tape
	2. Cutting of angle iron into measured length.	Hacksaw
	3. Welding of cut angle iron into a frame structure	Arc Welding
	4. Drilling of bolts and nut holes (17mm)	Drilling machine

Table 6; Standard components used.

Name	Description
Water Valve	A 2 inches water gate valve to regulate water flow from the tank
Bolts $ Nuts	17mm diameter bolts and nuts used for joining parts together in the machine.
Three Heating Elements	Concentric conductors.
Fibre glass Insulator	2Kg

4.4 Operational principles

A boiler is a closed vessel in which water under pressure is transformed into steam by the application of heat. A boiler must be designed to absorb the maximum amount of heat released in the process of combustion. This heat is transferred to the boiler water through radiation, conduction and convection. The relative percentage of each is dependent upon the type of boiler, the designed heat transfer surface. The Locust Bean boiler was constructed to be operated manually.

Using the batch system. The general features of the machine are

1). safety value 2). petcocks for stream weeding. 3). pressure gauge.

4). thermometer. 5). insulator (fibre-glass). 6). electrical wire.

7). capture and delivery slide. 8). water Inlet and Outlet. 9). top cover.

10. heating element (conductor). 11). cooking drum.

The cooked Locust Bean is to be collected manually after every batch operation.

Operations accommodates minimal hazard, since locating the starting, controlling and stopping levers were positioned taking cognizance of with convenient handling.

The power required to operate the machine is obtained electrically.

4.5 Performance evaluation.

Apparatus

The apparatus and material used in carrying out the test were as follows:-

1. Locust Bean 33.75 Kg
2. The machine (boiler) itself
3. 50 litres of water.
4. Time piece
5. Weighing scale.
6. 25litres plastic bucket.
7. Digital Thermometer

Performance test procedure

A digital thermometer was used to determine the temperature changes at 5 minute interval of heated empty cooler filled with 50, 37.5, 25, 12.5, litres of water. The result obtained was tabulated in table 4. Then the boiler was used to cook 33.75kg of locust bean (table 5) and temperature outside the cooker was also determined and tabulated (table 6).

Table 7; Result of performance evaluation.

Time Minutes	Control Experiment Empty Boiler (Ambient Air)°C	50 Litres of Water °C	37.5 Litres of Water °C	25 litres of Water °C	12.5 Litres of water °C
0.0	31.2	32.5	29.6	28.8	30
0.5	45.5				
1	61				34.0
1.5	92				
2	107.5			32.9	38.8
2.5	122		32.3		
3	138.9				46.0
3.5	154				
4	169			40	48.5
4.5	183.9				
5	200.7	43.0	40.0		56.0
5.5					
6				48.0	62.0
6.5					
7					65.3
7.5			47.6		
8				55.0	72.5
8.5					
9					75.0
9.5					
10		53.0	55.5	61.0	78.9
10.5					
11					85.2
11.5					
12				70.7	90
12.5			63		
13					98.5
13.5					
14				76.4	99.6
14.5					
15		65	69.8		
15.5					
16				85.0	
16.5					
17					
17.5			77.1		
18				92.5	
18.5					
19					

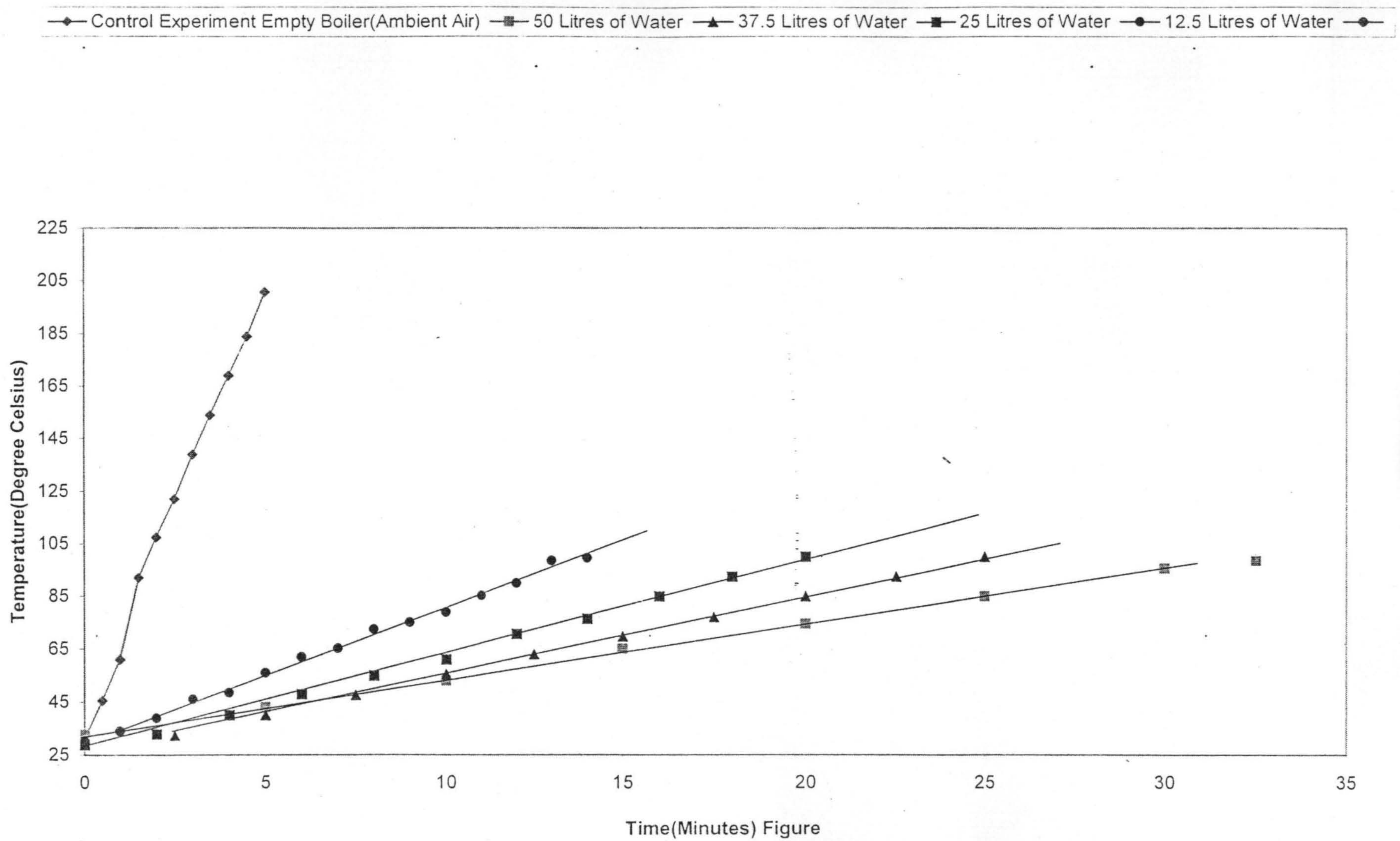
19.5			
20	74.5	85	100.0
20.5			
21			
21.5			
22			
22.5		92.5	
23			
23.5			
24			
24.5			
25	85	100	
25.5			
26			
26.5			
27			
27.5			
28			
28.5			
29			
29.5			
30	95.5		
30.5			
31			
31.5			
32			
32.5	98.5		

Table 8; Performance evaluation of cooking locust bean

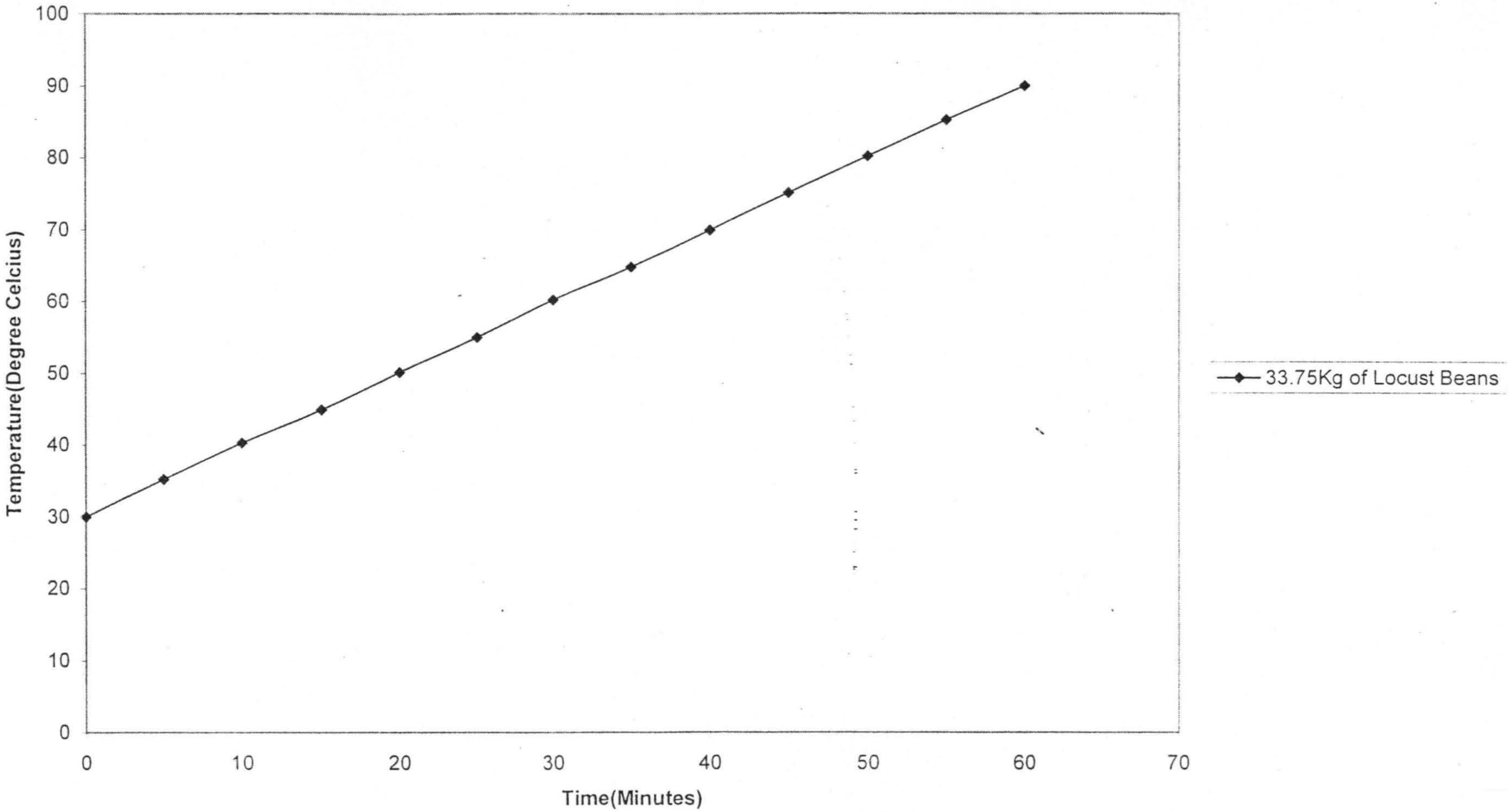
Time Minutes	33.75 Kg of Locust Bean °C
0	30.0
5	35.2
10	40.3
15	44.9
20	50.1
25	55.0
30	60.2
35	64.8
40	69.9
45	75.1
50	80.2
55	85.2
60	90.0

Table 9; Temperatures on outer surface of boiler.

Time taken to conclude experiment (Minutes)	Event	Temperature outside the boiler at the end of the experiment
5	Empty	68.5
25	50 Litres of water	65.2
20	37.5 Litres of water	60.0
15.5	25 Litres of water	50.4
13	12.5 Litres of water	40.5
60	33.75 Kg of Locust Bean	26.15



Control Experiment Empty Boiler(Ambient Air)
50 Litres of Water
37.5 Litres of Water
25 Litres of Water
12.5 Litres of Water
Temperature(Degree Celsius)
225
205
185
165
145
125
105
85
65
45
25
0
5
10
15
20
25
30
35
Time(Minutes) Figure



100
90
80
70
60
50
40
30
20
10
0
Temperature(Degree Celcius)
0
10
20
30
40
50
60
70
Time(Minutes)
33.75Kg of Locust Beans

4.6 Discussion of results

Judging from the results obtained from the tests carried out, it has been observed that the 33.75 Kg of Locust Bean cooked after 62minutes

The relationship between temperature and Time is linear. There was more or less a proportionate increment on both axis.

The machine worked efficiently, it also shows that, the use of the machine is more efficient than the traditional method of Locust Bean boiling. The Boiler drastically reduced the time for cooking and under hygienic conditions.

The boiler was able to attain a temperature of 200.7°C within 5 minutes and it boiled 50 Litres of water within 32.5 minutes. The maximum external temperature recorded in course of the performance evaluation was 68°C, which was rather high and unanticipated.

It can be deduced that as the amount of water in the coiler reducesd, it took a shorter time to boil.

4.7 Machine maintenance

Proper care and maintenance of the Locust Bean boiler enhances efficient production under hygienic condition and increase its service life. Always use clean water in the processes.

Basic maintenance includes; proper cleaning of the boiler shell and dusting of the outer shell. However should a fault develop, ease of disassembly was catered for in design, as the boiler shell and the outer casing was joined by bolts and nuts which could be easily unscrewed. Changing the heating element or wire would thus be trouble-free.

Such that, incase of the need to change products or replace on account of wear or breakage easy access is provided and the necessity of removing other parts to accomplish this is eliminated.

From the commercial value, it is then possible to justify the expenditure of a considerable sum of money. The aim here is to reduce the manufacturing cost to the minimum.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The machine was designed and constructed based on the fact that locust bean is indigenous to the entire West African sub region.

Moreso, considering that the traditional method of producing the condiment especially while cooking is laborious, time wasting and slow, hence yielding little quantity at a time. The machine was also designed considering the low cost involved and can be affordable to rural communities.

Each component of the machine is made from materials readily available in the market. the heating element could be replaced after long use or when the efficiency of cooking dwindles.

The machine was tested and found to be efficient, easy to maintain and replacement of parts can be done with ease. It saved time, energy expended and eliminate drudgery involved in boiling.

Result and discussion

From the result obtained it has been observed that the 33.75Kg of locust bean cooked after 62minutes.

The relationship between the temperature and time is almost linear. There was none or less a proportionate increment on both axes.

The machine worked efficiently, it is also shown that the use of the machine is more efficient than the traditional method of locust bean cooking. The cooker drastically reduced the time for cooking and under hygienic conditions. The cooker was able to attain a temperature of 200.7^{0}C within 5minutes and it boiled 50litres of water within 32.5minutes. The maximum external temperature recorded in course of the performance evaluation was 68^{0}C which was rather high.

It can be deduced that as the amount of water in the cooker reduced, it took a shorter time to boil.

5.2 RECOMMENDATIONS

Owing to technological advancement world over, I suggest that improvement should be made in the following areas:-

(1) For safe reliable operation and efficient, cost-effective operation proper external and internal control should be carried out.

(2) The preparation of feed water for boiler injection should be optimized through the removal of undesirable salts and contaminants. In addition, the removal of oxygen and other non condensable gases should be completed through chemical and mechanical deaeration.

(3) Modification should include the following parts

- Adjustable thermostat 50-160° F
- Built-in manual reset hi-limit safety thermostat set at 205° C heat zone
- Grounded heating element
- Spigot cutout
- Optional non-heated lid
- High-temperature shut off
- Internal controlling thermocouple
- 180° C exposure temperature

• A beeping device.

• The boiler shell should be constructed from stainless steel in an industrial layout.

• There should be another layer of insulation outside the boiler. This would further minimize heat loss.

(4) The machine could be improved upon to be of a continuous flow operation instead of the batch system. This would further enhance speed of processing and hygienic operation.

(5) Operating personnel should initiate a treatment program. The heating element, internal wire connection and insulator should be checked periodically. Any faulty part should be repaired or out-rightly replaced if need be.

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