

Sizing of a Mobile Sodabi Production Unit

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Abstract

This study focuses on the design of an innovative mobile device for the production of sodabi, a traditional alcoholic beverage from Benin. The design is based on the control of distillation parameters, with an innovative approach aimed at improving production quality and efficiency. The separation of methanol (which is toxic) and the extraction of as much ethanol as possible are based on their different boiling points. Tests were carried out to assess the device's ability to produce high-quality sodabi. The results show that the device designed provides adequate control of the distillation temperature, ensures continuous cooling of the vapours and consumes three times less energy than the traditional device, while achieving a material yield of 20%. What's more, the system is 99% efficient. The tasters were also positive about the quality of the sodabi produced by the device. The prototype, with a maximum production capacity of 1.6 liters of sodabi per hour, costs an estimated FCFA 66,800.

Keywords

Distiller, Sodabi, Quality Improvement, Energy Efficiency

1. Introduction

The oil palm is a rich resource for African agriculture, with many uses, including the production of palm oil, palm nut shells for burning, palm nut fines, toilet soap, brooms and palm [1]. The spirit known as sodabi, meanwhile, is a highly prized product in Africa, particularly in Benin, due to its central role in ceremonies and local consumption [2]. It is obtained by processing palm wine extracted from the oil palm at a mature age using a traditional production device [3]-[5]. However, the extraction of palm wine requires the felling of oil palm trees, resulting in the significant loss of these trees each year, as well as the potential by-products resulting from their growth [6]. On the other hand, many producers, faced with a short-

age of oil palms and driven by the desire to make more profit, resort to fraudulent practices such as using formaldehyde, methanol or industrial ethanol to spice up sodabi [7]-[9]. In addition, a number of studies have shown that traditional devices do not always produce good quality sodabi and result in energy losses [10] [11].

Faced with these challenges, it is imperative to explore innovative approaches to sodabi production, aimed at improving quality while optimizing costs. The major interest of this study lies in controlling the temperature in the distillation tank and cooling the sodabi vapor efficiently, with the aim of reducing losses linked to inadequate sodabi production practices and guaranteeing food safety for consumers.

2. Materials and Methods

In this section, the materials and tools used, the research methodology, the structure of the device and the associated sizing are presented. The main objective is to design an innovative device capable of controlling the essential parameters of the traditional sodabi production process, while making it suitable for industrial use.

2.1. Equipment

The materials and measuring equipment used during the design phase are described below: The stainless steel is used as a distillation tank. It serves as a container for the palm wine to be distilled. Polystyrene is used as thermal insulation to limit heat loss through the walls of the distillation tank. Lever locks are used to secure the lid of the distillation tank.

The immersion heater heats the palm wine in the distillation tank to distillation temperature (Material: Stainless steel; Voltage: 220 V - 50 Hz; Power: 1500 Watts).

SIL-BOND RTV silicone allows instant production of leak-resistant seals. It is used in the food industry and is resistant to temperatures of up to 500 °F (260 °C).

The plastic tank serves as a cooling tank. It will store the cooling water.

The 3/8 copper pipe is used to form the cooling coil.

Arduino Uno is a microcontroller board based on the ATmega328P. Arduino Uno R3 is the third and latest revision of the Arduino Uno. It has 14 digital input/output pins, 6 analogue inputs, a 16 MHz crystal, a USB connection, a power connector, an ICSP connector, a reset button, etc. It contains everything you need to support the microcontroller. It can be powered via a computer with a USB cable, an AC-DC adapter or a battery. It can be programmed with the Arduino IDE.

The Type K0-600 degree thermocouple is a type of temperature sensor commonly used to measure temperatures over a wide range, typically from -200 °C to approximately 1350 °C. Type “K” refers to the specific combination of materials used to make the thermocouple wires. It consists of two metal wires, one made of nickel-chromium (Chromel) and the other of nickel-aluminium (Alumel), welded together at one end, called the hot junction. The other end, called the cold junction, is connected to a measuring device or an electronic circuit.

The SSR 40A allows high current AC loads to be controlled from lower voltage

DC control circuits. Solid state relays have several advantages over mechanical relays. One advantage is that they can be activated by a much lower voltage, and at a much lower current than most mechanical relays. There are also no moving contacts, so solid-state relays can be switched much faster and for much longer without wear and tear (Release current: 7.5 mA/12 V; Control voltage: 24 to 380 VAC; Input voltage: 3 to 32 VDC).

The Ds18sb20 sensor is a waterproof digital temperature probe that accurately measures temperatures in wet environments with a simple 1-wire interface. The DS18B20 provides 9 - 12 bit temperature readings over a 1-wire interface, so only one wire (and ground) needs to be connected from a central microprocessor.

The 12V DC voltage converter is a module that provides a 12 V supply from the mains. It has protection against temperature, excessive currents and short circuits. This is generally the type of module found in wall-mounted power supplies. It accepts an AC input voltage of between 85 and 265 Volts and offers a 12 V DC output voltage (Output voltage: 5 V; Maximum output current: 2 A; Test resistance: 7 ohms (4.9 V) for 5 V; Output indicator: green light; Output protection: overvoltage, overcurrent, overtemperature, overpower, short circuit protection).

The 16×2 LCD is an electronic device used to display data and messages. It is known as a 16×2 LCD screen. As its name suggests, it has 16 columns and 2 rows so that it can display 32 characters ($16 \times 2 = 32$) in total and each character will be made up of 5×8 (40) pixel points. The total number of pixels on this LCD screen can therefore be calculated as follows: 32×40 , or 1280 pixels. The color of the characters is black and the screen has a green background. This also makes it readable in the dark.

A potentiometer is an electrical component used to adjust the electrical resistance in a circuit. It is also sometimes referred to as a “polar” or “variable resistor”. Potentiometers are commonly used to control parameters such as the brightness of a screen, the volume of a loudspeaker, the speed of an electric motor or the tone of an electric guitar.

An electrical resistor is an electronic component that limits the current in a circuit. It is commonly used in electronic circuits to limit the current flowing through LEDs, transistors and other electronic components.

An “On/Off” switch is a type of switch used to activate or deactivate an electrical circuit.

A box contains the components of the control module.

SolidWorks is 3D computer-aided design (CAD) software widely used in the design and engineering industry. It is developed by Dassault Systems and is primarily used for 3D modelling, mechanical part design, component assembly, simulation, technical drawing creation and other design and engineering tasks.

Proteus is an electronic design software package used primarily for the design, simulation and manufacture of electronic circuits. It is developed by Labcenter Electronics Ltd.

The Arduino IDE (Arduino Integrated Development Environment) is an open-

source integrated development environment specially designed for programming Arduino boards and Arduino compatible microcontrollers. The Arduino IDE provides a set of essential tools for writing, uploading and debugging programs on Arduino boards.

2.2. Research Methodology

To achieve our design objectives, we followed a methodical approach based on the following stages:

- ✓ Literature review on traditional Sodabi production, focusing on control parameters, fermentation and DISTILLATION methods and tools used. This step helps to understand existing traditional practices and to identify areas where improvements could be made.
- ✓ Analysis of the key parameters influencing the quality and safety of sodabi. This analysis provided us with a solid basis for the design of our device.
- ✓ Design of the sodabi production system, taking into account the control elements needed to guarantee the quality of the final product and its user-friendliness for industrial use.
- ✓ Modelling and Simulation: modelling software is used to simulate the behavior of the device and assess its effectiveness in producing sodabi. This stage enabled us to virtually test different configurations and refine our design.
- ✓ Prototyping and experimentation: A prototype of the sodabi production system is built based on our design and experiments are carried out to assess its actual performance, using control parameters and real palm sap samples.

2.3. Block Diagram

The synoptic design diagram of the production system is as follows:

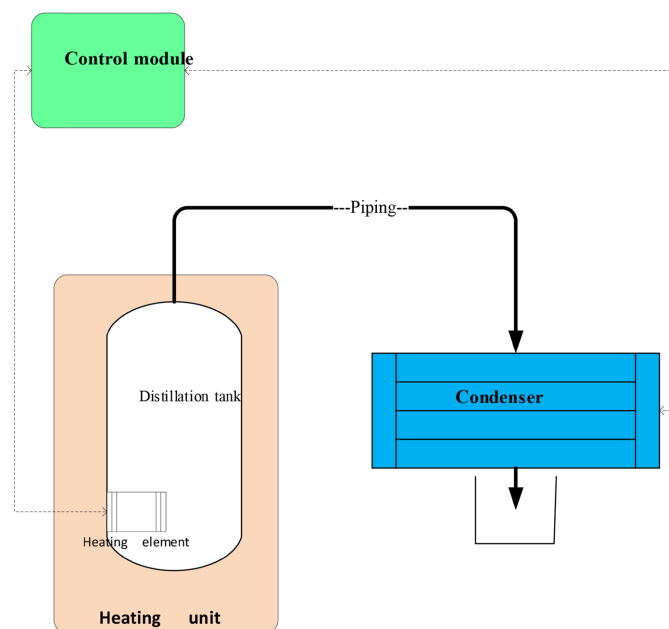


Figure1. Schematic diagram of the system.

The unit consists of the following basic parts: Heating unit (distillation vessel and heating element), condenser (cooling vessel, copper coil), control module and piping as shown in **Figure 1**.

The heating unit is the structure in which the wort to be distilled is heated and vaporised. The palm wine to be distilled is placed in the distillation tank, where it is then heated using a heating element. The heat causes the volatile components, such as alcohol, to evaporate and turn into vapors. These vapors rise in the pipe-work, which directs them to the condenser. The distillation tank is a pressurized vessel. It must be made of a material that is resistant to pressure and temperature. Particular attention is paid to sealing to prevent leaks of alcohol vapor and maximize the efficiency of the process. It includes openings for filling, emptying and cleaning. Safety devices will also be included to prevent accidents related to pressure or overheating.

Thermal insulation will also be incorporated to improve energy efficiency by minimizing heat loss. As alcohol named “sodabi” in Benin is edible, it is not compatible with certain materials. Non-stainless steel, zinc, galvanized steel and aluminum should therefore be avoided as manufacturing materials. Stainless steel is the most recommended because of its quality and price [12]. The heating element is responsible for providing the amount of energy needed to heat the liquid to be distilled to the distillation temperature. For reasons of simplicity, efficiency and economy, in our system the heating will be direct. The heating element will be directly immersed in the liquid. An immersion heater powered at 220 V - 50 Hz will therefore be used to provide the heating. Its operation will be controlled by the control module.

In the condenser, a heat exchange takes place between the coolant and the vapor composed of alcohol and water. The vapor condenses and the coolant heats up. A coil condenser, consisting of a spirally wound copper tube immersed in a container of cold water, condenses the vapor passing through it. It has the advantage of requiring less water.

The control module performs the calculations required for the system to operate correctly, based on the data collected by the sensors. The console shown in **Figure 2** is the interface between the user and the control module. It consists of several elements: A display showing the operating temperatures (setpoint temperature (TC), distillation temperature (TD), cooling water temperature (TR)) and the operating mode (‘Off’ or ‘Running’). A potentiometer to select the set temperature. A push-button to start distillation. An ON/OFF button to power the control module. Palm wine distillation is a process that involves separating the various components of palm wine, including ethanol, methanol and water. Controlling the heating system is essential for this process. It enables stable and precise thermal conditions to be maintained throughout the process, in order to eliminate the toxic methanol and recover as much ethanol as possible. The different components of palm wine are separated on the basis of their boiling point. Methanol boils at 64.7°C, ethanol at 78.3°C and water at 100°C.

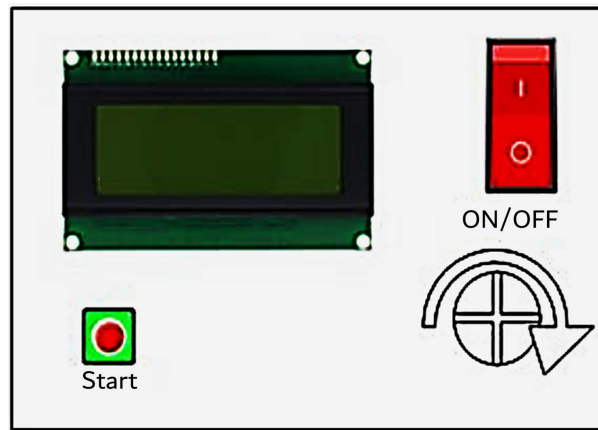


Figure 2. Schematic diagram of the control module.

During the heating process, the temperature of the vapor needs to be stabilized at around 68°C for a while and everything that comes out at this point needs to be collected separately. If there is any methanol, it is in this part of the distillate. Then let the temperature rise slowly. The end of the distillation of good alcohol should be around 94°C.

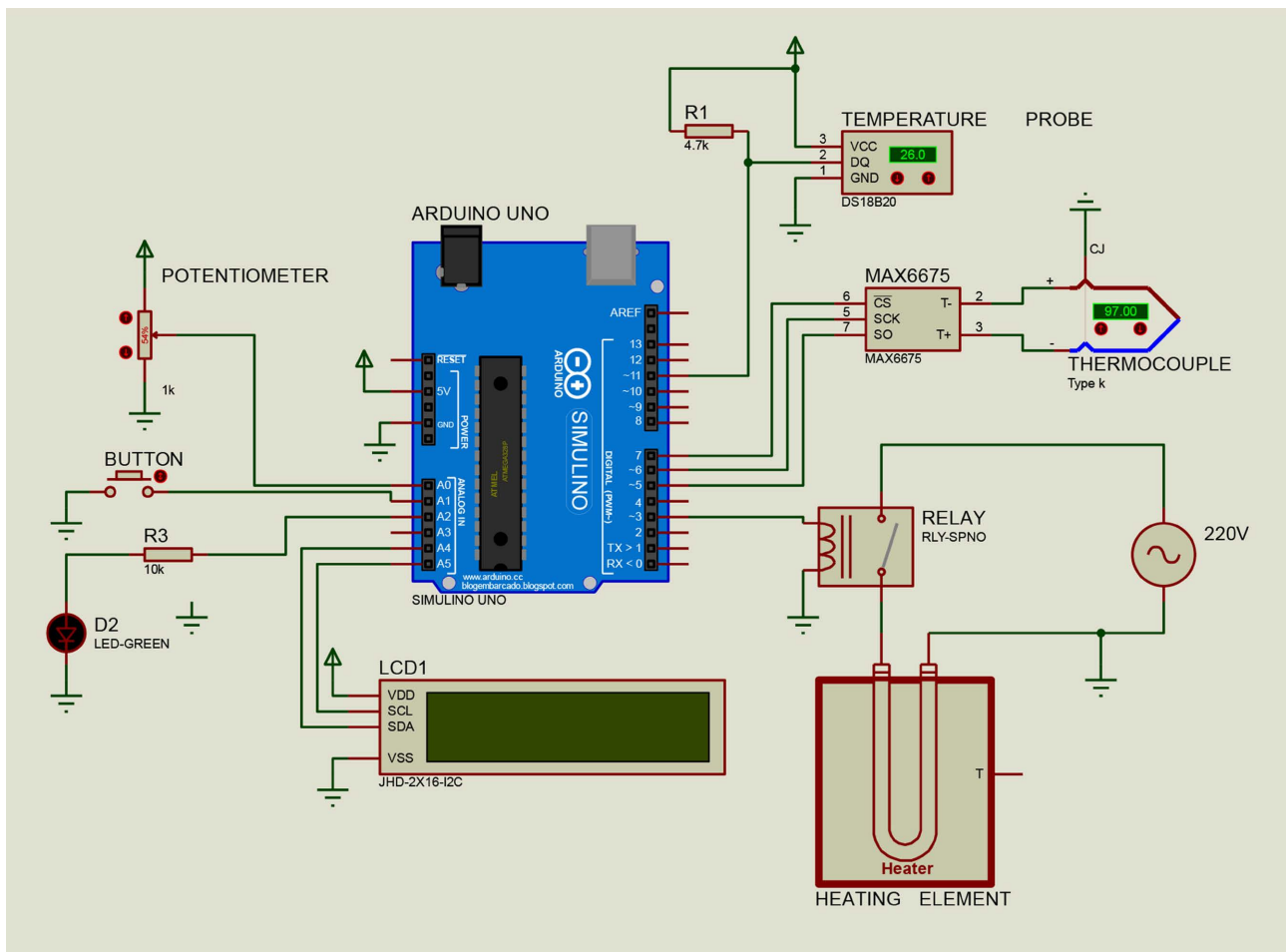


Figure 3. Electronic diagram of the control module.

This is usually regulated by a thermostat. By constantly monitoring the temperature of the wine in the distillation tank, the sensors transmit data to the temperature controller, which activates, deactivates or adjusts the heating element to reach the target temperature. It consists of a sensor to measure the temperature (PT100 type K thermocouple), a controller (Arduino) and an actuator (solid state relay). The set temperature is given to the controller as a reference temperature. The temperature of the wine inside the vat is measured by the PT100. The measured temperature is compared with the reference temperature and, depending on the error generated, the controller transmits the output to the solid state relay, which acts as an actuator for the heating resistor.

The cooling water storage tank will be fitted with a digital thermometer displaying the temperature of the cooling water. It consists of a temperature sensor controlled by the controller (Arduino). In **Figure 3**, we drew up an electronic diagram of the module using Proteus (version 2022). The following diagram shows the various connections between the different components of the module.

The pipework allows the fluids required for each stage of the process to circulate smoothly. 3/8 copper pipes are used.

2.4. Sizing

The basic parameters for sizing the heating unit are taken from the Lokossou study in 2012 [13] and are given in **Table 1** below.

Table 1. Basic parameters.

Parameters	Values	Unit
Temperature of palm wine	27	°C
Maximum steam outlet temperature	94	°C
Alcohol content of palm wine	12.45	%
Title of sodabi	60	%
Time taken to reach distillation temperature	1800	s

Palm wine fermented for three days can contain up to 12.45% alcohol. Sodabi is a Beninese wine brandy obtained from the distillation of palm wine, which under the right conditions of fermentation and heating can contain over 60% alcohol [13].

To simplify dimensioning, sodabi is considered to be a mixture of ethanol and water.

$$V_{sodabi} = V_{ethanol} + V_e \quad (1)$$

$$V_{ethanol} = \%e \times V_e \quad (2)$$

$$V_e = \frac{1-x}{x} V_{ethanol} \quad (3)$$

Where V_{sodabi} is the volume of sodabi to be procuded (L); $V_{ethanol}$ the volume of ethanol in the sodabi (L); V_e the volume of water in the sodabi (L); $\%e$ the

proportion of alcohol in fermented palm wine and x the Sodabi title.

2.4.1. Heat Required for Distillation

The amount of heat needed to heat the palm wine can be calculated using the formula:

$$Q_{\text{useful}} = m_{\text{wine}} \times C_{p_{\text{wine}}} \times \Delta T \quad (4)$$

$$m_{\text{wine}} = \rho V_{\text{wine}} \quad (5)$$

Where Q_{useful} is the quantity of useful heat (Joules); m_{wine} the mass of palm wine (kg); ρ the density of palm wine (kg/m^3); $C_{p_{\text{wine}}}$ the specific heat capacity of wine ($\text{J}/\text{kg} \text{ } ^\circ\text{C}$) and ΔT the temperature difference ($^\circ\text{C}$).

Assuming an energy loss of 5% through the walls of the boiler, the amount of heat required for distillation gives:

$$Q = 1.05 \times Q_{\text{useful}} \quad (6)$$

2.4.2. Power Required for Distillation

The power required for distillation is then calculated using the equation:

$$\Phi = \frac{Q}{t} \quad (7)$$

Where Φ is the power required for distillation (Watts); Q the quantity of heat required (Joules) and t the distillation time (seconds).

2.4.3. Condenser Sizing

The cold fluid is water at a normal temperature of 27°C . This water must not be heated by more than 10°C .

The basic parameters for sizing the condenser are as follows: Water inlet temperature 25°C , Water outlet temperature 37°C , inside diameter of coil 10 mm, outside diameter of coil 12 mm.

1) Determining the amount of heat to be exchanged

The thermal power to be dissipated (Q_{vap}) can be evaluated as follows:

$$Q_{\text{vap}} = Q_{\text{useful}} - Q_{\text{vinas}} \quad (8)$$

$$Q_{\text{vinas}} = m_{\text{wine}} \times C_{p_{\text{wine}}} \times (T_f - T_{\text{wine}}) \quad (9)$$

$$Q_{\text{vinas}} = \rho_{\text{vinas}} (V_{\text{wine}} - V_{\text{sodabi}}) \times C_{p_{\text{vinas}}} \times (T_f - T_{\text{wine}}) \quad (10)$$

Where Q_{vap} is the quantity of heat used for vaporisation (Joules); Q_{vinas} the quantity of heat from the vinasse (Joules); m_{vinas} the mass of vinasse (kg); $C_{p_{\text{vinas}}}$ the heat capacity of vinasse ($\text{J}/\text{kg} \text{ } ^\circ\text{C}$); T_f the final outlet water temperature ($^\circ\text{C}$) and ρ_{vinas} the density of vinasse (kg/m^3).

2) Determining the volume of water needed to condense sodabi

The volume of water to be stored in the condenser tank for distillation is deduced from the formula:

$$M_e = \frac{Q_{\text{vap}}}{C_{p_e} (T_{s_e} - T_{e_e})} \quad (11)$$

The heat flux transferred by the steam in the condenser is evaluated using the following expression:

$$Q = U \times A \times \Delta LT \quad (12)$$

$$A = \frac{Q}{U \times \Delta LT} \quad (13)$$

Where A is the exchange surface (m^2); U the overall heat transfer coefficient ($\text{W}/\text{m}^2 \cdot ^\circ\text{C}$) and ΔLT the logarithmic temperature difference ($^\circ\text{C}$).

The logarithmic mean ΔT takes account of nonlinear temperature variations across the heat exchanger, making it more accurate than simple temperature difference.

$$\Delta LT = \frac{\Delta T_c - \Delta T_f}{\ln\left(\frac{\Delta T_c}{\Delta T_f}\right)} \quad (14)$$

Where ΔT_c is the warm temperature difference ($^\circ\text{C}$) and ΔT_f the cold temperature difference ($^\circ\text{C}$).

The overall transfer coefficient of a heat exchanger is written as:

$$\frac{1}{U_c} = \frac{r_{ex}}{h_e r_i} + \frac{r_{ex} \ln\left(\frac{r_{ex}}{r_i}\right)}{\lambda_{copper}} + \frac{1}{h_{ve}} \quad (15)$$

Where r_i is the inside radius of pipe (m); r_{ex} the outer radius of pipe (m); h_e the convective heat transfer coefficient of the cooling water ($\text{W}/\text{m}^2 \cdot \text{K}$); h_{ve} the convective heat transfer coefficient of the water vapour ($\text{W}/\text{m}^2 \cdot \text{K}$) and λ_{copper} the conduction heat transfer coefficient of copper tube ($\text{W}/\text{m} \cdot \text{K}$).

In the situation where the cooling coil is just placed in a large tank of water (and nothing stirs the water), the order of magnitude is 100 - 200 $\text{W}/\text{m}^2 \cdot \text{K}$ [14]. We will therefore consider the arithmetic mean 150 $\text{W}/\text{m}^2 \cdot \text{K}$ as the overall heat transfer coefficient.

3) Determining the length of the copper tube

The required length of copper tube to be used for cooling is determined as follows:

$$L = \frac{A}{\pi \times D} \quad (16)$$

Where A is the exchange surface (m^2); D the tube diameter (m) and L the tube length (m).

4) Performance evaluation of the system

The palm wine used for the tests was purchased in Abomey and was made from the third week of harvesting of the felled palms.

The performance analysis was designed to assess the efficiency of the innovative device in sodabi production. The tests were designed to evaluate key parameters such as the quantity of sodabi produced, energy consumption, the final temperature of the cooling water and the efficiency of the device. To evaluate the perfor-

mance of our system, we carried out three (03) distillation tests using the following procedure: The palm wine collected is fermented in a vat for 3 days; the fermented palm wine is then distilled using the device designed; the sodabi is collected in 1 litre bottle; production data is recorded, including temperatures and the quantity of sodabi produced.

The experiments were carried out using the following data: Quantity of wine distilled is 5 litres and distillation temperature is 94°C.

The material yield is an indicator of the quantity of raw material that is transformed into the finished product.

$$R_m = \frac{V_{sodabi}}{V_{palm\ wine}} \times 100 \quad (17)$$

Where R_m is the material yield; V_{sodabi} the volume of sodabi and $V_{palm\ wine}$ the volume of fermented palm wine used.

Device performance is the indicator used here to assess the tightness of the device. It provides information on material losses.

$$R_m = \frac{m_{sodabi} + m_{vinasse}}{m_{palm\ wine}} \times 100 \quad (18)$$

Where P is the performance of the system; m_{sodabi} the mass of sodabi produced; $m_{vinasse}$ the mass of vinasse remaining in the distillation tank and $m_{palm\ wine}$ the mass of fermented palm wine used.

3. Results and Discussion

This section presents an analysis of the choice of technology and sizing, as well as an assessment of the performance of the device designed, followed by a sensory analysis and an evaluation of the cost of production.

3.1. Technological Choice and Sizing

The technical data relating to the sizing of the heating unit are summarized in **Table 2** below.

Table 2. Technical data for sizing the heating unit.

Parameters	Value	Unit
Production capacity	7.50	L
Heat for distillation	2323.38	kJ
Power requirements	1.29	kW
Volume of ethanol	0.98	L
Volume of water	0.65	L
Volume of sodabi	1.63	L

The power required to bring 7.5 litres of palm wine up to distillation temperature in 30 minutes is 1.29 kW. We will therefore opt for a standard 1 kW electric

heater sold on the market.

The technical data relating to condenser sizing are summarized in **Table 3** below.

Table 3. Technical data for condenser sizing.

Parameters	Value	Unit
Power	490.83	kJ
Volume of water	11.74	L
Overall exchange coefficient	150.00	W/m ² ·C
Logarithmic temperature difference	29.97	°C
Exchange surface	0.09	m ²
Total length	2.41	m

The volume required for cooling is 11.74 L, which justifies the use of a 15 L tank to store the cooling water. For the cooling coil, a length of 2.4 m is required. For this purpose, we used a 3/8 copper pipe, 3 m long, which we shaped into a suitable coil. **Figure 4** below shows the control module designed to regulate the distillation temperature.



Figure 4. Photograph of the control module.

3.2. Analysis of System Performance

To evaluate the performance of our device, we carried out a series of three distillations, the results of which are summarized in **Table 4**. Before proceeding with any analysis of the results, it is crucial to bear in mind that the data obtained are intrinsically linked to the quality of the palm wine used in the tests. Due to the lack of suitable equipment, we were unable to carry out a detailed study of its properties.

Table 4. Summary of data from performance test 1.

Test	Quantity of palm wine	Distillation temperature (°C)	Final cooling water temperature (°C)	Distillation temperature (°C)	Quantities of sodabi produced (L)
1	5 ± 0.02	94 ± 0.5	35 ± 0.5	60	1 ± 0.02
2	5 ± 0.02	94 ± 0.5	38 ± 0.5	60	1 ± 0.02
3	5 ± 0.02	94 ± 0.5	37 ± 0.5	60	1 ± 0.02

During the tests, we observed adequate regulation of the distillation temperature. However, we noted that the methanol did not exit at 68 degrees Celsius, which can be explained by the length of the cooling pipe. The quantity of methanol produced was not sufficient to cover the entire length of the pipe, so it had to be extracted by suction. The quantity extracted was estimated at 5 ± 0.01 ml using a 10 ± 0.01 ml syringe. It is therefore recommended to remove the equivalent of two 1-litre caps from the first drops to ensure that the methanol does not end up in the final product.

The cooling water outlet temperature remained relatively low, with a deviation of no more than $8^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$. This indicates that our condenser ensured continuous cooling of the vapors. The distillation time turned out to be about one hour for 1 litre of sodabi. It should be noted, however, that we kept the temperature stabilized for five (05) minutes at around 68°C to guarantee methanol recovery.

We obtained a material yield of around 20%, which is well above the 15% found by Lokossou during controlled distillation in the laboratory but slightly less than or equal to the 20% to 23% obtained by Lokossou in 2012 [13], as well as the 21% found by Kouchoewanou in 2021 [15]. However, it is important to take into account the alcohol and sugar content of the palm wine, as these factors can influence the distillation yield. It is likely that this discrepancy is due to a lack of optimal temperature control during production, which could lead to an increase in the water content of the sodabi, thereby reducing the alcohol content of the final product.

Table 5. Summary of data from performance test 2.

Parameters	Value	Unit
Mass of palm wine	5 ± 0.02	kg
Mass of sodabi	0.95 ± 0.02	kg
Mass of vinasse	4 ± 0.02	kg
Performance (%)	99	-

Our device has a performance rating of 99% as shown in **Table 5**. This means that the device is well sealed and that the rate of material loss is negligible. What's more, in terms of energy efficiency, our device stands out favorably. Producing one kilogram of sodabi requires around 1,475 kJ, whereas artisanal producers use 4,317 kJ of energy to produce 1 kg of sodabi, according to data from Lokossou in 2012 [13]. This greater energy efficiency can help to reduce production costs.

In summary, our distillation experiments have shown promising results for our sodabi production system. The material yield, established at around 20%, combined with a performance evaluated at 99%, attests to its production efficiency and its ability to considerably reduce material losses. The tests also demonstrated effective control of the distillation temperature, although manual extraction of the methanol was necessary due to the length of the cooling pipe. It should be noted, however, that this analysis does not rigorously take into account the alcohol con-

tent or the characteristics of the palm wine, which are essential factors to consider in order to better assess the distillation yield. What's more, our system is energy-efficient.

3.3. Sensory Analysis

The statistical results of the triangular test are summarized in the following **Table 6**.

Table 6. Statistical results of the triangular test.

Parameters	Value
Number of responses	10
Number of correct answers	8

Out of ten (10) subjects, eight (08) found the correct answer. According to the binomial table of the triangular test (**Table 7**), there is a noticeable difference between the two sodabi (confidence level 0.9).

Table 7. Binomial table for the triangular test.

Number of responses obtained	Number of responses for a differentiation for the triangular test with a threshold of:		
	95%	99%	99.9%
10	7	8	9
11	7	8	10
12	8	9	10
13	8	9	11
14	9	10	11
15	9	10	12
20	11	13	14
30	15	17	19
40	19	21	24
50	23	26	28
60	27	30	33
70	31	34	37
80	35	38	41
90	38	42	45
100	42	49	49

All the subjects (those who found the right answer or not) indicated "flavour" as a differentiating characteristic. Those who found the right answer also noted that the aroma of palm wine was more pronounced in the sodabi produced by the system. The comments were quite positive for the latter: "It's real sodabi".

Sensory analysis confirms tasters' satisfaction with the sodabi produced by our innovative device. These results reinforce our confidence in the device's ability to

produce a high-quality sodabi that could rival traditional methods. This sensory evaluation adds to the quantitative data previously analysed to validate the effectiveness and quality of our sodabi production device.

3.4. Evaluation of the Cost of the System

The cost of completion is estimated on the basis of the cost of components, materials and labor. **Table 8** below summarizes these cost estimates.

Table 8. Estimated cost of construction.

Equipment	Designation	Features	Quantity	Total cost (FCFA)
Distillation tank	Stainless steel tank	Capacity 10L	1	5000
Cooling tank	Plastic bowl	Capacity 15L	1	1500
Thermal insulation	Polystyrene		3	3000
Heating element	Immersion heater	1 500 Watts	1	1500
Control module	Regulation kit	Arduino board; temperature sensor; K thermocouple; LCD screen; SSR relay; ON/OFF switch	1	15,000
	Case		1	2000
Piping	Copper pipe	3/8	4m	6000
Taps	Compression fitting		2	2800
Support			-	5000
Other (lever lock, seal, glue)			-	5000
Work force			-	20,000
				66,800



Figure 5. Photograph of the whole system.

The prices shown in **Table 8** are based on local market rates. It is important to note that these prices may be subject to fluctuations depending on the supplier or subject to VAT. **Figure 5** below shows the system designed for sodabi production.

The total estimated cost of producing this prototype is FCFA 66,800. However, for the design of a large-scale device, significant price variations will be observed, mainly for the distillation tank, the cooling tank, the copper pipes and the thermal insulation.

The results of our experiments, combined with a favorable sensory evaluation, indicate that this device is promising in terms of yield and quality. However, future investigations are needed to explore other quality parameters such as the alcohol content and the physico-chemical composition of the sodabi obtained.

4. Conclusion

Performance tests have shown that our system has a material yield of around 20%, combined with a performance evaluated at 99% and energy consumption three (03) times lower, while allowing stable control of the distillation parameters. In addition, sensory analysis revealed that the sodabi produced by our system retains the taste and aroma characteristics of real traditional sodabi. Overall, our system offers a modern, efficient approach to producing sodabi, while preserving its authenticity and improving its quality. Future work could focus on the following improvements to the device—Carrying out physicochemical analyses of the sodabi produced by the device—Implementing a quality control system for the sodabi—Exploring the use of solar thermal energy as a source of heat—Developing a viable economic model for marketing the device. These improvements could make the system even more attractive and facilitate its wider use.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Carrere R. (2010) Oil Palm in Africa: Past, Present and Future. WRM Plantation Series, No. 15. World Tropical Forest Movement. https://www.wrm.org.uy/fr/files/2013/01/Palmier_a_huile_en_Afrique.pdf
- [2] Lokossou, C. and Ahouannou, C. (2017) Influence of Fermentation Parameters on Physicochemical Characteristics of *Elaeis Guineensis* Jacq. Wine Used for Spirit Production. *International Journal of Biosciences*, **10**, 43-50.
- [3] Tagba, P., Osseyi, E., Fauconnier, M. and Lamboni, C. (2018) Aromatic Composition of 'Sodabi', a Traditional Liquor of Fermented Oil Palm Wine. *Advance Journal of Food Science and Technology*, **14**, 15-22. <https://doi.org/10.19026/ajfst.14.5421>
- [4] Dissou, M. (1972) Développement et mise en valeur des plantations de palmier à huile au Dahomey. *Cahiers d'études africaines*, **12**, 485-499. <https://doi.org/10.3406/cea.1972.2756>
- [5] Ade, R.H., Bio Bigou, B.L. and Luo, Z.H. (2010) Exploitation of Palms Wine in the Municipality of Ze (Benin): Socio-Economic and Physical Impacts. *Journal of Amer-*

- ican Science*, **6**, 95-102.
- [6] Kouchade, C.A., Kounouhewa, B. and Awokou, S.K. (2017) La récolte de vin de palme: Procédé et effets des conditions environnementales. *OCL*, **24**, D505. <https://doi.org/10.1051/ocl/2017035>
- [7] Ikenna, N.N., Vincent, I.I., Nwabueze, R. and Anyanwu, B.N. (2006) Characterisation of Palm Wine Yeast Isolates for Industrial Utilisation. *African Journal of Biotechnology*, **5**, 1725-1728.
- [8] Mulumeoderhwa, L.R. (2021) Physico-Chemical and Bacteriological Analysis of Oil Palm (*Elaeis guineensis* Jacq) Wine Sold and Consumed in the Town of Beni/RD Congo. *Journal of Business and Management*, **23**, 47-53.
- [9] Nwachukwu, I.N., Ibekwe, V.I. and Anyanwu, B.N. (2006) Investigation of Some Physicochemical and Microbial Succession Parameters of Palm Wine. *Journal of Food Technology*, **4**, 308-312.
- [10] Bokossa, I., Gandeho, J., Tchekessi, C., Banon, J., Adigun, N. and Seni, I.S.R. (2015) Design of a Distillerrectifier for Semi-Industrial Production of the Ethanol. *International Journal of Innovation and Applied Studies*, **11**, 804-815.
- [11] Moritiwon, O., Ogundeko, T.O., Oyeboode, D., Bitrus, J., Edugbe, A.E. and Ramyil, M.S.C. (2021) Spermatotoxic Effects of Selected Traditional Alcoholic Beverages from North-Central Nigeria on Adult Male Albino Rats. *Magna Scientia Advanced Biology and Pharmacy*, **2**, 14-22. <https://doi.org/10.30574/msabp.2021.2.2.0023>
- [12] Ravelomanantsoa, H., Ranaivoson, S.I.O., Razafindrakoto, F.N.R., Letsara, R., Razafindramanga, A.W. and Rakotomanjy, P. (2021) Design and Manufacture of a Mobile Electric Alembic for Naturally Occuring Essential Oils Extraction. *Budapest International Research in Extra Sciences*, **5**, 113-129.
- [13] Lokossou, C. (2012) Analysis of Artisanal Sodabi Production Technology: Definition of Optimal Operating Conditions. Master's Thesis, EPAC/UAC Benin.
- [14] HomeDistiller (2010) Calculation of Condenser Size. https://homedistiller.org/wiki/htm/calcs/calcs_cond_calc.htm
- [15] Kouchoewanou, M. (2021) Design of an Optimal Sodabi Production System. Master's Thesis, ENSGEP/UNSTIM Benin.

Nomenclature

A	Exchange surface, m^2
c_p	Specific heat capacity of fluid at constant pressure, $J \cdot kg^{-1} \cdot ^\circ C^{-1}$
e	Proportion of alcohol in fermented palm wine (%)
h	Convective heat transfer coefficient, $W \cdot m^{-2} \cdot K^{-1}$
m	Mass, kg
P	System performance
Q	Amount of heat, J
r	Pipe radius, m
R	Performance
t	Distillation time, s
T	Temperature, $^\circ C$
U	Overall heat transfer coefficient, $W \cdot m^{-2} \cdot ^\circ C^{-1}$
V	Volume, m^3
x	Title of sodabi

Greek Letters

ΔT	Temperature difference, $^\circ C$
ΔTL	Logarithmic temperature difference, $^\circ C$
Φ	Power required for distillation, W
ρ	Density of the fluid ($kg \cdot m^{-3}$)
λ	Conductive heat transfer coefficient, $W \cdot m^{-1} \cdot K^{-1}$

Subscripts

c	hot
e	water
ex	external
f	cold
i	internal
m	material
vap	vaporization
ve	Water vapor