Instrumentation of NCAM developed coffee roasting machine

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Abstract. The increase in demand of coffee in the world as well as high cost of imported coffee roasting machines has made many local fabricators to develop coffee roaster. Unfortunately, the roasted coffee from the machines is not too different from the locally roasted coffee in terms of qualities revealed during sensory and organoleptic tests. This paper presents the development of coffee roaster operational sequence which has a temperature controller, stirring and cooling mechanism embedded into it, which mitigate the effect of poor and irregular heating pattern of most traditional roasting methods. Optimum Coffee roasting temperature is 200°C. However, the roaster can attain a temperature of 400°C. The evaluation of the coffee roaster revealed that the machine attained a steady temperature of 200°C, 250°C and 300°C at 6, 7 and 10 minutes respectively. It was observed that uniform and even roasting was achieved by proper stirring of the coffee bean inside the roaster at the desired temperature which reduced the drudgery, operators’ interference and contamination of the roasted coffee.

1. Introduction

Coffee which is grown worldwide as a recreational beverage is harvested from coffee strubs that belong to the family Rubiaceae and genus coffee. The coffee trees grow up to 10 meters in height and are usually characterised by their deep green long oval leaves which is glossy in colour with a wavy edge. It flowers in clusters of two or three. The coffee tree fruits from the ovaries of the flowers into berries which develop under three weeks and change from a deep green colour to bright red when ripe. The fruits are picked and passed through a series of processes in order to bring out the main part of the berry which is the coffee bean. This is roasted to become the popularly known coffee drink which is savoured around the world for its excellent aroma [1].

Obtaining perfect coffee brew is majorly dependent on the method of roasting and time taken to roast. Different Coffee roasters have been produced and developed to suit personal taste and flavour. The use of manual and local coffee roasting methods produces low quality coffee which is not appealing to buyers both locally and internationally due to unsteady temperature of roasting as well as inconsistent stirring during roasting. The process, which is majorly manual in Nigeria is labourious. Many of the coffee
roasters with stirrer being constructed in Nigeria still lack temperature controller and effective stirring mechanisms [2].

However, the few with temperature controller use a non Proportional Integral Derivative (PID) temperature controller. This type of temperature controller has characteristics of causing temperature overshoot due to non-precise temperature regulating technique. The development of the operational sequence controller is aimed at reducing drudgery, reducing the stress involved in coffee roasting and improving the quality of the roasted coffee is imperative. To achieve these, a PID based temperature controller was used to control the temperature, to prevent temperature overshoot that might burn the beans while maintaining and attaining the desired temperature within shortest time possible [3]. A motorized stirring mechanism was also incorporated to stir the coffee beans in a back and forth movement along the longitudinal plain of the roasting chamber.

In Africa, Ethiopia is the highest Arabica coffee producer which is developed in highland area of Ethiopia. Coffee is a leading export crop commodity in Ethiopia and more than 60% of the annual foreign exchange earning of the country comes from the production and sale of coffee [4]. The structure of a coffee bean is very porous containing several organic compounds, such as; cellulose, arabinogalactans, lignin, essential oils etc. There are biological cells which contain water, aromatic compounds and gas within this porous structure. The art of roasting the coffee bean under proper stipulated temperature and time works to release these compounds as the roasting process is carried out [5].

The coffee bean releases it well renowned aroma from the combination of several chemical compounds that are discharged while roasting. The combination of time and temperature should be sufficient for chemical reactions without burning the beans and compromising the flavour of the beans [6]. During roasting, some physical changes occur to the coffee bean. The weight of the bean reduces due to the loss of moisture, decomposition of some chemical compounds, the volume of the bean increases, the density of the bean reduces due to swelling and the brittleness of the bean also increases [5].

[7]. It was reported that coffee roasting process is the increase in temperature of coffee from room temperature to a range between 190°C and 250°C. This process is similar to pyrolysis as chemicals, moisture and oils are released from the bean. This process is performed for a minimum of twenty minutes in order to get the perfect quality of coffee that allows for easy preparation. In this state, the coffee bean becomes more elastic and more brittle with colour changing from green to brown through caramelizing of sugar and some carbohydrates. The formation of certain pigmented substances also occurs with the chemical reaction known as Strecker’s reactions. The higher the temperature, the darker the coffee.

Lots of effort has gone into the development of new coffee roasting technologies all over the world. But here in Nigeria, there has been lots of challenges in this aspect, which has hindered the advancement of similar technologies locally. One of the recurring challenges which this project has tackled is the development of an automated temperature controller to increase and maintain the roasting machines charge temperature as required.

Charge temperature is the temperature of the roasting drum before introducing the coffee into the chamber, there are several factors to consider while selecting the charge temperature such as the size of the drum, even distribution of heat to the coffee bean, density, moisture content of the bean, location of the temperature probes, local climate, coffee variety among others, The charge temperature is an imperative parameter and should be adjustable to suit the desired condition [2]. Coffee roasting machine is a specially made oven that transfers heat to the coffee beans in a stream of hot gas with continued stirring of the beans to ensure even roasting of the beans [8].

This project incorporates an automated temperature controller, stirrer and cooling chamber into a developed coffee roaster and synchronizes its roasting operations. As a result of the recurring challenges faced in coffee production in Nigeria. From the early fifties, Nigeria has been a major producer of coffee up until the 60’s, however due to poor handling during processing, the Nigerian coffee was rejected in the international market. In a bid to end this ban and stigma, more effort has been geared towards local development of processing machine for coffee roasting, thus the need to work on the developed roasting machine to meet the international standard. The average cost of a commercial moderately sized imported roaster is €15,000.00 which translates to about ₦6,000,000.00 (conversion at ₦404.09 to €1) which is
beyond the reach of an average Nigerian. Developing and instrumenting a locally produced coffee roaster would not only conserve foreign earnings but also make the machine available at a cheaper cost relative to the imported coffee roaster. Moreover, it would increase the rate of post harvesting processing operation and value added to the coffee bean. The spare parts of the machine will also be readily available because the machine is locally fabricated and the maintenance of the machine will be easier.

2. Methodology

2.1 Development of operation and sequence controller for coffee roaster

The developed coffee roaster is electrically powered. It has a total power consumption of nine (9) kilowatt and powered by a three phase (415V) power supply. The entire operational sequence is coordinated by a control panel as shown in figure 1.

2.2 Panel description

**RYB Indicator**: indicates the presence of power in the respective phase in the sequence of Red, Yellow and Blue.

**Temperature Controller**: controls and allows for pre-setting the roasting temperature. It displays the present value (PV) as well as set value (SV).

**Clockwise Rotation Indicator**: glows when the motor is rotating in clockwise direction.

**Clockwise ON/OFF Switch**: manually runs the motor in the clockwise direction while the green button is start, red is stop.

**Anticlockwise Rotation Indicator**: glows when the motor is rotating in anticlockwise direction.

**Anticlockwise ON/OFF Switch**: manually runs the motor in anticlockwise direction while the green button is start, red is stop.

**Manual/Automatic Selector**: selects either Manual or Auto operation. When in Auto, the manual clockwise and anticlockwise ON/OFF switches are inactive.

**Fan Blower ON/OFF Switch**: to power ON/OFF the blower for cooling of coffee beans.

**Standby ON Switch**: To put the motor operation on standby for a command from the temperature controller. When pressed its corresponding indicator glows while the motor awaits the run signal.

**Standby ON Indicator**: glows when the motor is on standby mode.

**Standby OFF Switch**: puts the motor off standby mode. The motor will not start automatically in this mode.

The control panel, apart from coordinating the sequence of operation, also provides protection to electrical components of the machine as well as the coffee bean. The roaster does its roasting through conduction, convection and radiation of heat energy. A total of four (4) 2000W heating elements are attached to the base of the roasting cylinder to provide the required heat energy for roasting operation.

A 0.75kW electric geared motor was used to stir and agitate the coffee bean in the roaster and runs at a speed of 58 rpm in both clockwise and anticlockwise operation as the coffee bean is being stirred and conveyed longitudinally along the plain. These two operations however needed to be controlled, coordinated and synchronized. Hence, the need for an operational sequence controller. The controller was constructed with discrete electronic and electromechanical components which were interconnected to realize and implement the block diagram in figure 2.
2.3 Functional description of block diagram

The machine is protected by a 3pole thirty Ampere (30Amps) circuit breaker which had the characteristic of shutting down the system when there is an overload. This component supplies power to other parts of the panel. It supplies the motor starters with 3phase supply for the electric motor while the temperature controller and other components are powered with single phase.

The temperature controller compares the roasting chamber temperature through an attached thermocouple with the desired pre-set temperature to give either a high output when temperature is below set temperature and a low when set temperature is attained. The temperature controller used was a PID based temperature controller because of its precession and anti-overshoot characteristics. The temperature controller sends a control signal (High or Low) to the solid-state relays which in turn supply or cut-off supply to and from the element. It also sends the same signal to the priority latch. The priority latch gives priority to the temperature controller to lock the motor starting components to prevent the motor from starting at the instance of switching-on until the set temperature is reached through the recycling timers.

The recycling timers for clockwise and anticlockwise motor operation are pre-settable timers. The timers are set for one (1) minute run operation and four seconds stop operation for each. These timers are interlocked such that when one is in cycle, the other is locked down. These timers also control the direct-on-line (DOL) motor starters. The direct-on-line motor starters are motor controller which power and protect the motor against overload or other mechanical failure that might make the electric motor in operative. The roaster is incorporated with an electrically operated centrifugal fan which cools the roasted beans after roasting.

2.4 Operational sequence

At instance of switch on, the desired temperature is pre-set on the temperature controller and the standby switch is pressed indicating that the standby mode is active. When the set temperature is attained, the motor starts automatically and the coffee bean is introduced into the roasting chamber. The motor starts with a
rotation in a direction for one minute and stays off for 4 seconds then it triggers the second timer to rotate the motor in opposite direction for one minute and off again for another 4 second. This process goes on until the desired degree of roasting is achieved.

2.5 Design considerations

Selection of Solid-State Relay (SSR):
Current drawn by each element is calculated from

\[ P_e = I_e V_e \]

Source: Mathew (1965)

Where,

- \( P_e \) is power rating of each element
- \( I_e \) is current flowing in each element
- \( V_e \) is voltage applied across the element

But \( V = 220 \) Volts

SSR of 40Amps was chosen due to market variable. From the table of standard wire gauges and sizes, a 2.5mm\(^2\) cable will conveniently support the current drawn by each element.

2.6 Selection of motor starter

The motor starter powers the 0.75 kW electric motor. The required current to start the electric gear reduction motor is calculated below

\[
\text{Power (} P_m = I_m V_m \text{)}
\]

\( P_m \) is power rating by motor

\( I_m \) is current in drawn by motor

\( V_m \) is voltage in the circuit

\[
\therefore I_m = \frac{P_m}{V_m} = \frac{750}{415}
\]

\[ I_m = 1.8 \text{Amps} \]

A presentable Direct on line (DOL) starter having a range from 1 – 5Amps was used. From the table of standard wire gauges, a 1.5 mm\(^2\) 4 core cable was used to power the electric motor.

3. Conclusion

An electrically controlled coffee roasting machine was designed and fabricated. It was established that the machine can attain a maximum temperature of 400°C but attained a temperature of 200°C, 250°C and 300°C within 6, 7 and 10 minutes respectively. The roasting temperature was kept constant throughout the roasting operation at the pre-set temperature because of the PID based temperature controller. The stirring operation was synchronized with the electrical geared reduction motor thus providing smooth stirring at 58 rpm. The coffee was evenly roasted to light brown, brown and dark brown depending on desired roasting time without coffee bean splitting and crushing.

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