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AN IMPROVED ELECTRO-MECHANICAL TECHNIQUE FOR GROUNDNUT OIL EXTRACTION USING EMBEDDED PROCESS AUTOMATION

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ABSTRACT

This work, an improved electro-mechanical technique for groundnut oil extraction using embedded process automation aims at mitigating the poor and irregular heating approach of the traditional system which generally affects the quantity and quality of the extracted oil. Literatures on groundnut oil extraction reveal that the optimum temperature for groundnut oil extraction is 90^0C. This temperature at the preparatory heating chamber was regulated in this work by adopting an automation technique in which Proportional Integral and Derivative (PID) controller was implemented on microcontroller. Mathematical model of preparatory heating chamber, actuator and PID controller were developed. Controller design based on the models was also developed using Simulink. The models were validated through simulation and the Zeigler-Nichol tuning method was adopted as the tuning technique for varying the parameters of the PID controller in order to achieve a desired transient response of the system when subjected to a unit step input. A schematic model of the system was also captured using proteus and animated simulation was carried out to validate the system's performance to varying temperature conditions within the preparatory heating chamber. After several assumptions and simulations, a set of optimal parameters were obtained at the result of the fifth test that exhibited a commendable improvement in the overshoot and peak time, thus improving the robustness and stability of the system.

Keywords: Microcontroller, PID-Controller, Transient response, Temperature stability, Automation, Zeigler-Nichol.

INTRODUCTION

The increase in the population of developing countries is by far greater than increase in food production. The calorie intake of most populace depends on cheap and easily available starch based food, as they cannot afford the expensive animal based meal. Therefore, there is need for a cheap source of nutrients (groundnut) to augment the shortage of protein and oil in the diet of large section of the population for proper growth and development. Hence, to meet the requirement of oil intake as recommended by food and agriculture organization (FAO), as well as meeting the demand of indigenous Agro-allied industries, extraction of oil from oil seeds such as groundnut becomes necessary. About 90% of groundnut seed produced is being utilized for oil extraction [1].

The local roasting of groundnut produces uneven roast due to the unavailability of accurate temperature regulation devices and this tends to affect both the quality and quantity of oil extracted. It is a tedious process involving hand stirring and exposure to heat. Manual groundnut roasters with stirrer have being constructed [2] but a temperature regulatory device is still not inculcated because these roasters are powered by means of wood or charcoal.

The automated groundnut oil extractor system which this paper proposes is aimed at removing drudgery involved at every stage of groundnut oil extraction and also improves both the quantity and quality of groundnut oil extracted. This is achieved by adopting automation technique in which PID controller was implemented in microcontroller to regulate the temperature at the preparatory heating chamber of the system to a desired temperature in the shortest possible time with minimum or no overshoot and thereby improving the robustness and stability of the system.

System Operation

The block diagram of the system is shown in Fig. 1 below.

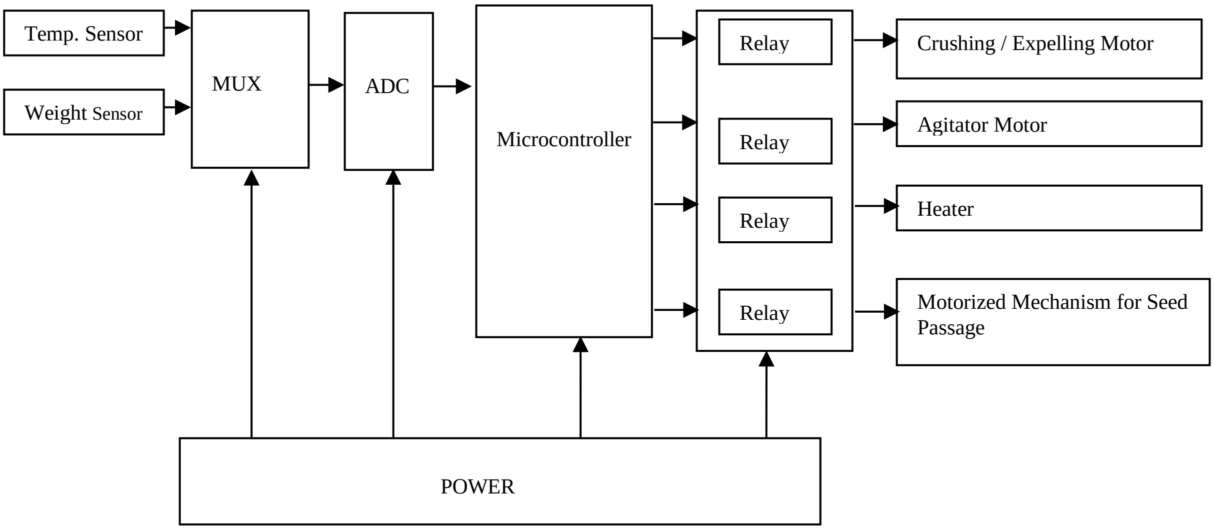


Figure 1: Block diagram of the proposed Groundnut oil Extraction System

According to the proposed system block diagram of figure 1 above, the system is made up of two sensors, they are: Temperature sensor (LM 35) and weight sensor (piezoelectric crystal). The temperature sensor monitors the temperature of the preparatory heating chamber while the weight sensor measures the weight of the groundnut seed in the chamber. The 2- input to 1 output time multiplexer selects the input that goes to the controller via ADC at any given time. The ADC converts the analogue voltage signal from the sensors to an 8-bit binary code which goes to the controller for comparison using embedded algorithm.

Two variables are required by the controller. They are: Actual input i.e. chamber current temperature and desired set- point. The process variable is compared with the set- point of 90^0C, if the actual value does not match with the set-point, the controller generates an output signal which is the difference between the set-point and process variable. The output signal either activates or deactivates the actuator i.e the relay to either ON / OFF the respective elements such as heater, agitator motor, crusher and motorized opening mechanism for seed passage.

System Design

In this section, simplified mathematical models of the overall system will be derived. Figure 2 shows the closed loop structure of a temperature controlled system. The design and fine tuning of the PID controller will be the subject of the analysis. The system will be validated by simulating the controller model with the plant model, sensors and actuators or any combination of these components. The system should track and/or regulate the desired preparatory chamber temperature with minimum peak time, and overshoot.

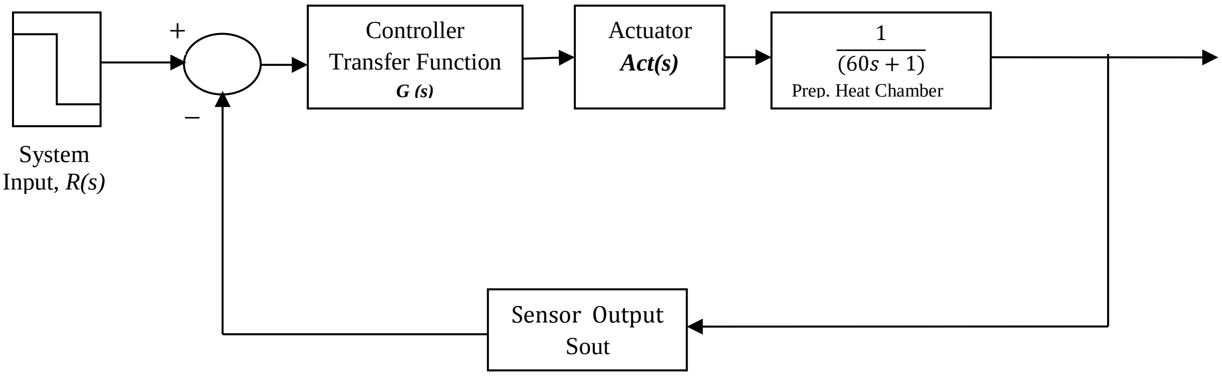


Fig.2: Block Diagram of the Closed Loop Temperature Control System

Temperature Monitor

The temperature sensor is a semiconductor device with a linear voltage-temperature relationship specified as 10mV per degree rise in temperature. That is to say, the LM35 temperature sensor provides an output of 10mV per degree Celsius (^{0}C).

Weight Monitor

The weight sensor monitors the weight of the groundnut seed in the preparatory chamber and the system automatically closes the motorized opening mechanism whenever the groundnut seeds in the chamber finish. In this measurement, it is assumed that weight is proportional to pressure. This is validated as follows:

$$\text{Pressure} = \frac{Force}{Area} \qquad = \frac{Mass\ X\ Acceleration}{Area}$$
(1)

$$\text{Pressure} = \frac{M\ X\ g}{A}$$
(2)

But g, acceleration due to gravity is constant for all weights, and A is constant for the preparatory chamber of known constant cross – sectional area, therefore, pressure is proportional to mass. In measurement of pressure or weight in an industrial process, piezo-electric transducer can be used, in which case the following expressions [3] apply.

Eo = GDP in volts
(3)

Where E_O = output voltage in volt
G = voltage sensitivity (also known as piezo - electric constant) in voltmeter/N
D = thickness of the material (sensor) in meters
P = pressure exerted in Newton per square meter

The piezo- electric crystal is a self-generating transducer, so that, what is needed is circuitry to amplify, shift and scale the analog voltage generated so that it corresponds to a $0V$ and $5V$ signal. For weight measurement in this research work, we have

$$E_o = GDW \quad \text{(volts)} \qquad (4)$$

Where W = weight of groundnut seed processed.
Voltage sensitivity or piezo-electric constant G = 0.050Vm/N,i.e for Quartz
Thickness of the material (Quartz) = 0.5mm.

Mathematical Model of Preparatory Chamber

Let's consider the mass M (kg) of groundnut seed at temperatureθ_1. The mass is placed in an environment (preparatory chamber) at temperature θ_2 and heat q is transferred into the mass causing its temperature to rise. LM35 sensor is used as the sensing device to take the temperature reading of the chamber and we want to know how long it takes for the groundnut seed temperature in the chamber to get to its tolerable limit i.e. its maximum temperature for optimum performance in terms of oil yield and quality of oil obtain. From the law of heat transfers which states: Temperature riseis proportional to heat added [4].

$$dq = cd\theta_1 \qquad (5)$$

c = heat capacity
By dividing both sides by dt

$$\frac{dq}{dt} = \emptyset = \frac{cd\theta_1}{dt} \qquad (6)$$

The rate of heat transfer into the mass is $\emptyset = \frac{cd\theta_1}{dt}$ and the rate is governed by the thermal resistance between the air and the mass of the groundnut seed. This obeys a law similar to ohms law so:$\emptyset = \frac{(\theta_2 - \theta_1)}{R}$ (7)

whereR is the thermal resistance in Kelvin per watt. Equating for $\emptyset$ we have $\frac{cd\theta_1}{dt} = \frac{(\theta_2 - \theta_1)}{R}$

$$\frac{d\theta_1}{dt} = \frac{(\theta_2 - \theta_1)}{RC}$$

$$\frac{d\theta_1}{dt} + \frac{\theta_1}{RC} = \frac{\theta_2}{RC} \qquad (8)$$

In all system, the product of the resistance and capacitance is the time constant τ so we have:

$$\frac{d\theta_1}{dt} + \frac{\theta_1}{\tau} = \frac{\theta_2}{\tau} \qquad (9)$$

Changing from a function of time into a function of *"s"* we have

$$s\theta_1 + \frac{\theta_1}{\tau} = \frac{\theta_2}{\tau} \qquad (10)$$

$$\theta_1(\tau s + 1) = \theta_2$$

$$\frac{\theta_1}{\theta_2}(s) = \frac{1}{(\tau s + 1)} \qquad (11)$$

Where τ = 60 seconds, assumed time it takes to reach maximum temperature
.:

$$\frac{\theta_1}{\theta_2}(s) = \frac{1}{(60s + 1)} \quad (12)$$

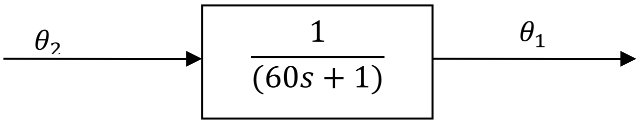


Fig. 3: Modeled Block Diagram of the Preparatory Heating Chamber

The relationship between the applied voltage and the energy generated by an electrical heater is non-linear. In this paper this relationship is linearised by driving the heater and motors from a pulse signal. A pulse signal is generated from the microcontroller.This signal is used to control a Darlington pair transistor which links the system loads and the controller.

Mathematical Model of the Controller

The Ziegler-Nichols tuning rule was applied in the design of the parallel Proportional-Integral-Derivative controller [5].The PID controller was selected since it is probably the most extensively used method in industrial process control applications. The block diagram of the continuous PID controller is shown in figure 5, where, K_p is the proportional gain, T_i is the integral time constant,T_d is the derivative time constant, U(t) the control signal to system and e(t) is the error signal.The transfer function of the standard PID algorithm [4] is:

$$U_{(t)} = K_p e_{(t)} + \frac{Kp}{Ti}\int_0^t e(t)dt + K_p T_d \frac{de(t)}{dt} \quad (12)$$

In the s-domain, the PID controller can be written as:

$$U_{(S)} = K_p[1 + \frac{1}{Ti.s} + T_d.s\ ]\ E_{(s)} \quad (13)$$

The discrete form of the PID controller can be achieved by finding the Z –transform of the equation above.

$$U_{(z)} = E_{(z)} K_p\ [\ 1 + \frac{T}{Ti(1-z^{-1})} + T_d \frac{(1-z^{-1})}{T}\ ] \quad (14)$$

Equation 14 can also be written as:

$$\frac{U(z)}{E(z)} = a + \frac{b}{1-z^{-1}} + c\ (1 - z^{-1}) \quad (15)$$

Where

$$a = K_p\ , b = \frac{K_p T}{T_i},\ c = \frac{K_p T_d}{T}$$

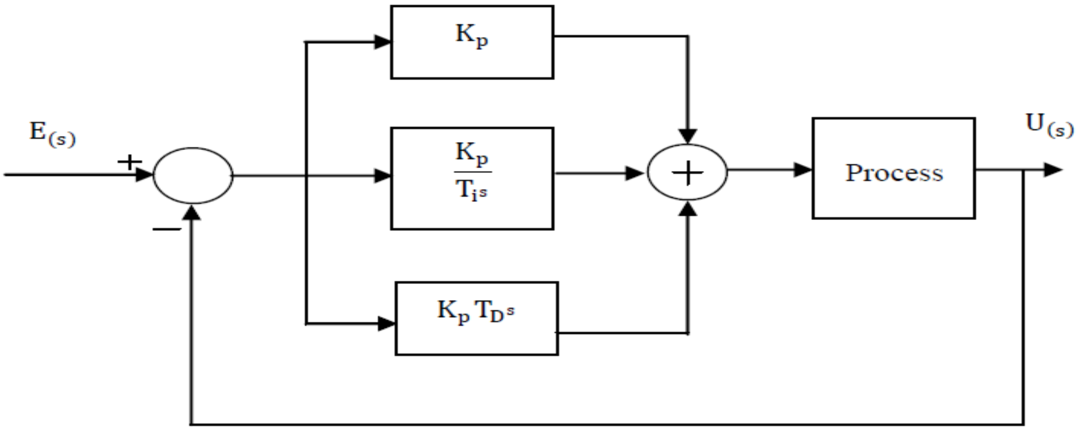


Figure 5: Block Diagram of a Continuous Parallel PID Controller

Control Algorithm for the System

The control algorithm is implemented in the control sub-program and is used by the controller to control the entire system when the temperature (T_{max}) and groundnut seed weight are sensed, converted to volts, digitized and the values sent to the controller for appropriate action to be taken. The following therefore, is a complete PDL for a single batch.

Algorithm-Algorithm for Embedded Chip Based Sequencer for Groundnut Oil Extraction.

```
Input: Weight, Temperature, Process 1, Process 2;
Output: Agitator, Crusher, Heater, motorized opening for seed passage
Begin ( ): Set Gain
C           Batch
C           Process 1, Process 2;
C           Process 1
              Load Groundnut Seed into Preparatory heating Chamber
    Start Heating
              Start Agitator
            Begin Temperature Test Until
            Temperature = 90°C
            Stop Heating
C           Process 2
            Open Motorized Seed Passage
            Start Crusher / Expeller
            Begin Weight Test Until
            Weight = 0kg
            Close Motorized Seed Passage
```

Reference Results

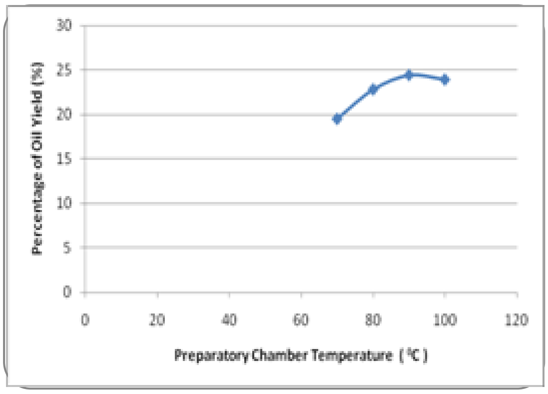
The major aim of this work is to achieve automatic regulation of the optimum temperature for optimum yield in an automated groundnut oil extraction system. In realizing this, we first have to ascertain the optimum temperature at which we will lock the system based on practical results. In [5] the researchers experimentally investigated the effects of heating temperature and heating time on the yield and quality of extracted oil, based on 4Kg/hr capacity of groundnut expelling machine, with the aim of identifying the temperature at which optimum oil in terms quantity and quality was obtained and their result is presented in table 1.

Table 1: Effects of Heating Chamber Temperature on the Oil Yield

Preparatory Chamber Temperature (°C)	Percentage of Oil Yield (%)	Heating Time (minutes)
70	19.50	10
80	22.80	20
90	24.40	25
100	23.90	30

Source **[5]**

The experiment as shown in table 1 above revealed that the oil yield increases with increase in heating temperature but tends to decrease as the temperature increases from 90^{0}C to 100^{0}C as presented in fig. 6. The table also revealed that the oil yield increases with increase in heating time but tends to decrease as the heating time exceeds 25 minutes as shown in fig. 7. Increasing heating temperature to a highest value of 90°C and a heating time of 25 minutes increased the percentage of oil yield to a value of 24.40% which is an equivalent of 92% when compared to 45% oil content of groundnut [6]. The increased heating temperature and time also increased the colour intensity of the oil expelled and this result agrees with the finding on groundnut in previous work by other researchers **[7, 8]**. The expression efficiency is approximately 92% when compared to the 45% oil content of groundnut. The colour of oil extracted was observed to be affected by the heating time and heating temperature as confirmed by **[9].**Thus no substantial increase was observed in the percentage of oil yield beyond 90°C, this is in correlation with the findings of **[7, 8].**



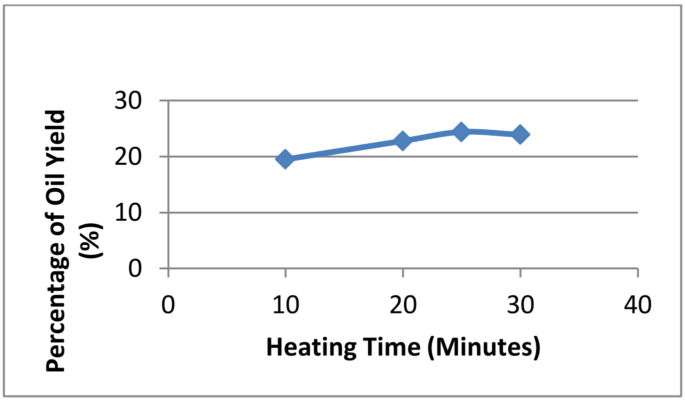


Figure 6: Percentage of Oil Yield against
Chamber Figure 7: Percentage of Oil Yield against heating time. Temperature.

Simulation Results

Having confirmed from the result of the previous work by **[5]** as depicted in table1 and figures 6 and 7, that the optimum oil yields were obtained at 90^{0}C and heating time of 25minutes, our next step was to regulate the preparatory chamber temperature so that the temperature within the chamber is maintained at 90°C. This is achieved by developing a mathematical model of the chamber to stabilize the temperature at 90^{o}C. Based on the models and PID controller, 2013a Matlab/Simulink was used to simulate the system and Ziegler- Nichols tuning method was adopted as the tuning technique for varying the parameters of the PID controller in order to achieve a desirable transient response of the system when subjected to a unit step input. Figure 8 shows the simulink block diagram of the temperature control system.

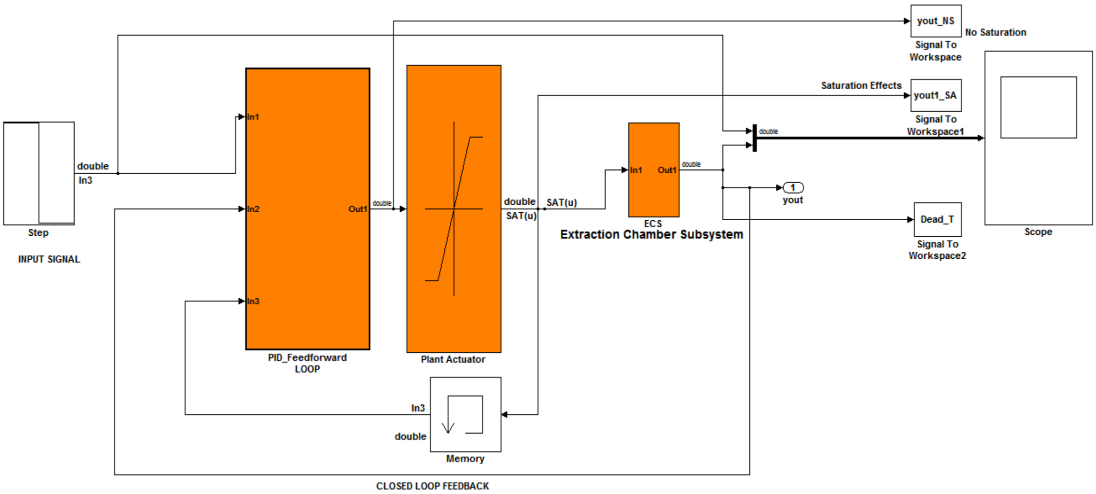


Fig. 8: Simulink Block Diagram of Temperature Control System

Closed loop Stability Analysis

In this section various values of variable temperature control parameters of the PID were used in the simulation with a view to determining the optimum parameter values for achieving the optimum system stability response. A step input signal was applied to the system in a series of tests and output response in each test recorded.

Test 1

Table 2 shows the first set of assumed values of the parameters of the PID controller while figure 9 depicts the response of the system based on these values. The blue line in each response plot of all the tests carried out represents stabilized temperature response while the faint line depicts unstabilised temperature response of the preparatory chamber.

Table 2: First Set of Assumed Values of the Parameters of the PID Controller

Parameters	Tuned	Block
K_p	1.6176	1.00
K_i	0.03565	0.25
K_d	-35.2765	0.00

Table 3: Performance and Robustness Result of Test 1

Parameters	Tuned	Block
Rise Time	48.6 secs	18 secs
Settling Time	149 secs	257 secs
Overshoot	9.62%	49.7%
Peak	1.1	1.5
Gain Margin	44dB @ 1.5rad /s	38.4dB @ 1.41rad /s
Phase Margin	60 deg @ 0.0297rad/s	25.3 deg @ 0.0645rad/s

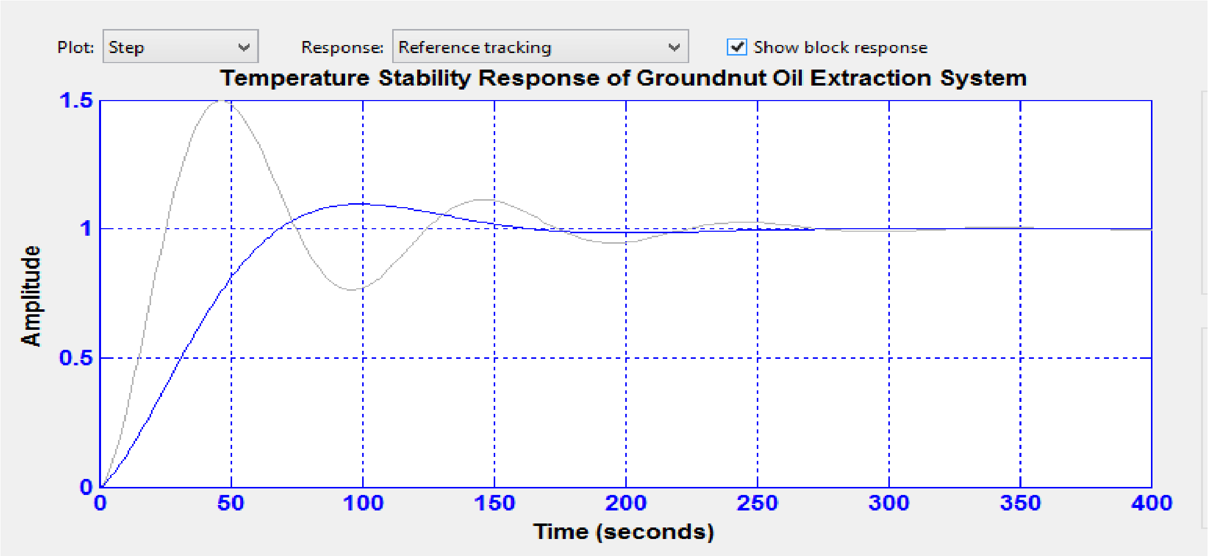


Figure 9: Temperature Stability Response of Preparatory Chamber for test 1

Test 2

Table 4: Second Set of Assumed Values of the Result of Test 2
Parameters of the PID Controller

Parameters	Tuned	Block
K_p	1.6176	1.00
K_i	0.0356	0.125
K_d	-35.2767	0

Table 5: Performance and Robustness

Parameters	Tuned	Block
Rise Time	48.6 sec	27.1 secs
Settling Time	149 secs	233 secs
Overshoot	9.62 %	33.9 %
Peak	1.1	1.34
Gain Margin	44 dB@ 1.47 rad/s	39 dB @ 1.5 rad/s
Phase Margin	60 deg @ 0.047 rad/s	37.5 deg @ 0.0456 rad/s

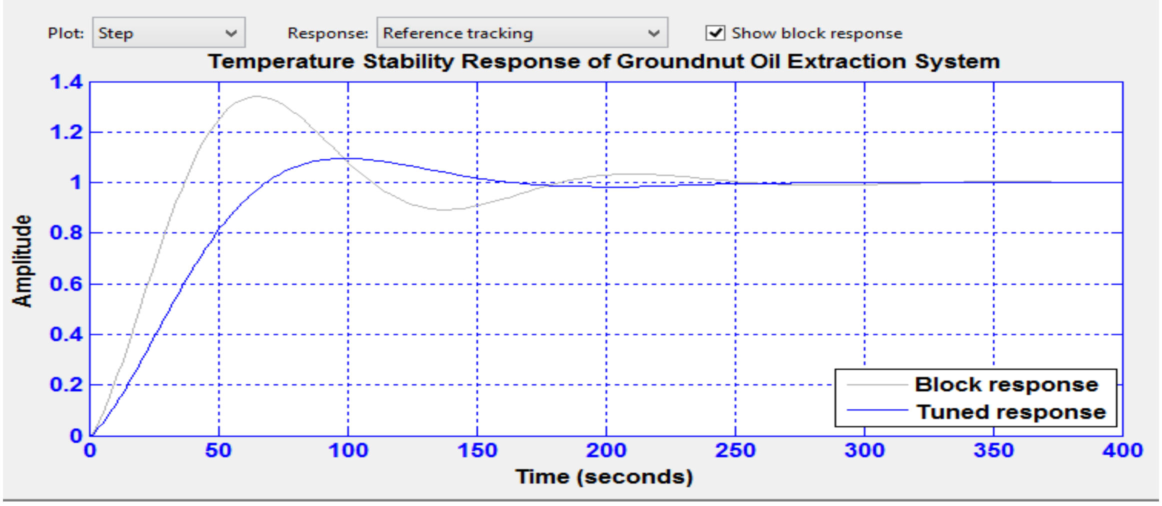


Figure 10: Temperature Stability Response of Preparatory Chamber for Test 2

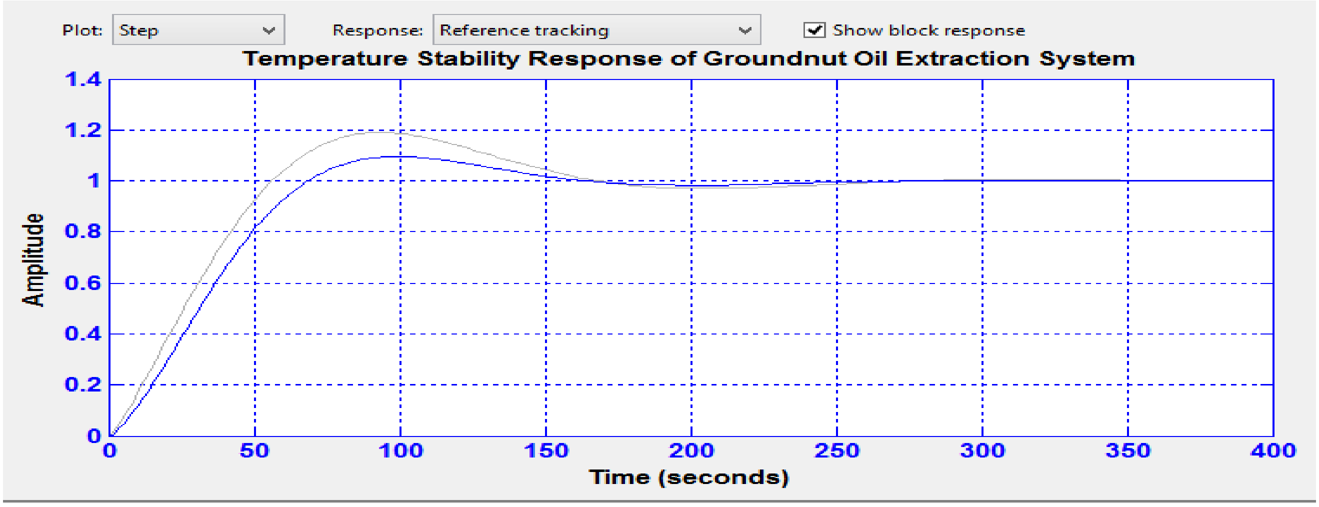
Test 3

Table 6: Third Set of Assumed Values of the Table 7: Performance and Robustness Result of Test 3

Parameters of the PID Controller

Parameters	Tuned	Block
K_p	1.6176	1.00
K_i	0.0356	0.0625
K_d	-35.2767	0.00

Parameters	Tuned	Block
Rise Time	48.6 secs	41.9 sec
Settling Time	149 secs	237 sec
Overshoot	9.62 %	18.9 %
Peak	1.1	1.19
Gain Margin	44dB @1.5 rad/s	39.3dB @ 1.54 rad/sec
Phase Margin	60 deg @ 0.0292 rad/s	60 deg @ 0.0323 rad/sec



Plot: Step
Response: Reference tracking
☑ Show block response

Figure 11: Temperature Stability Response of Preparatory Chamber for Test 3

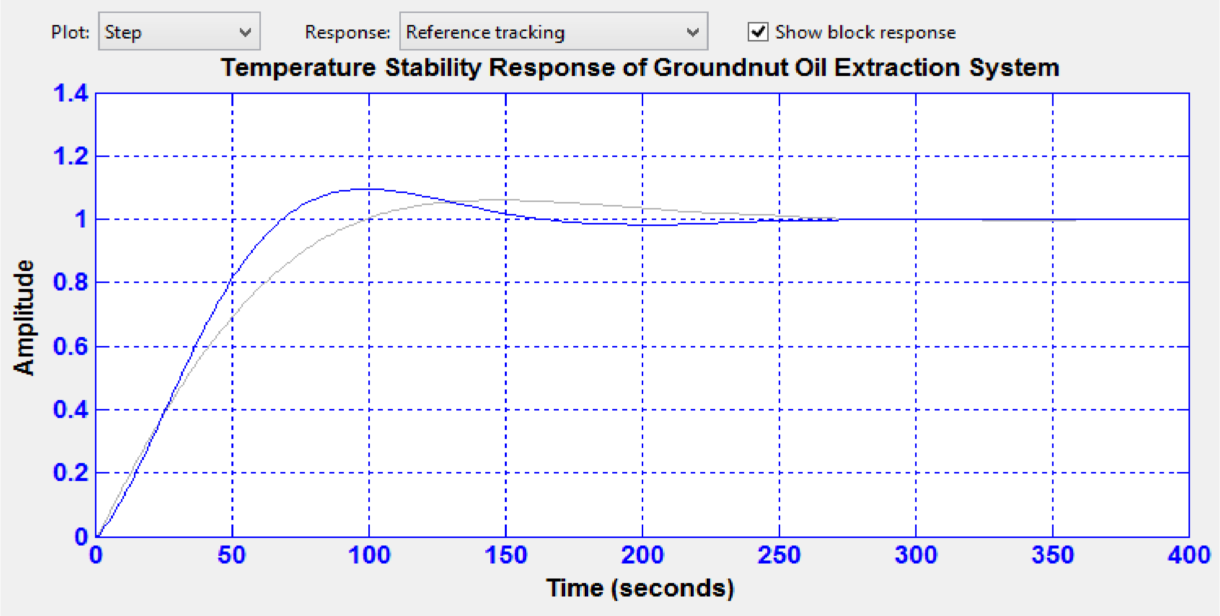
Test 4

Table 8: Fourth Set of Assumed Values of the Table 9: Performance and Robustness Result of Test 4

Parameters of the PID Controller

Parameters	Tuned	Block
K_p	1.6176	1.00
Ki	0.0356	0.0313
K_d	-35.2765	0.0000

Parameters	Tuned	Block
Rise Time	48.6 sec	69.5 sec
Settling Time	149 sec	228 sec
Overshoot	9.62 %	5.95 %
Peak	1.1	1.06
Gain Margin	44 dB @ 1.5 rad/s	39.4 dB @ 1.5 rad/s
Phase Margin	60 deg @ 0.0297 rad/s	71 deg @ 0.0228 rad/s



Plot: Step

Response: Reference tracking

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Figure 12: Temperature Stability Response of Preparatory Chamber for Test 4

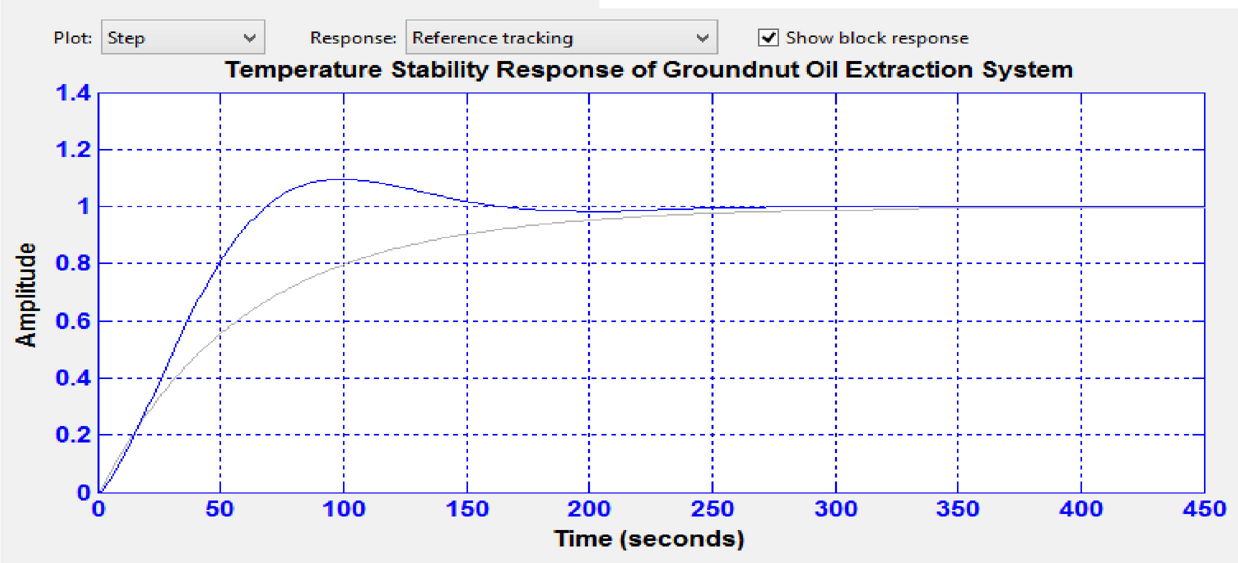
Test 5

Table 10: Fifth Set of Assumed Values of the Parameters of the PID Controller

Parameters	Tuned	Block
K_p	1.6176	1.00
K_i	0.0356	0.0156
K_d	-35.2765	0.0000

Table 11: Performance and Robustness Result of Test 5

Parameters	Tuned	Block
Rise time	48.6 sec	140 sec
Settling time	149 sec	261 sec
Overshoot	9.62 %	0.0788 %
Peak	1.1	1
Gain Margin	44 dB@ 1.5 rad/s	39.5 dB @ 1.57 rad /s
Phase Margin	60 deg @ 0.0297	90.9 deg @ 0.06161 rad/s



Plot: Step

Response: Reference tracking

☑ Show block response

Figure 13: Temperature Stability Response of Preparatory Chamber for Test 5

Result Analysis

Using 2013a Matlab/Simulink toolbox, various parameters were tested and the best parameters were used for PID implementation on the microcontroller. The results showed the system responses to a step input with varying PID controller parameters based on Zeigler-Nichols tuning method. It can be inferred from the results that the optimal set of parameters that gave a more desirable transient response in terms of low overshoot and peak time are gotten from the results of the fifth test where: Proportional gain, K_p= 1, T_i = 0.0156, T_d= 0, as shown in table 10. The overshoot was reduced from 49.7% as shown in the result of test 1 to 0.0788% as in result of the fifth test.

Hence, a PID algorithm implemented on a microcontroller, simulated and fine-tuned using the set of parameters obtained from test 5 will exhibit a better control performance to changing temperature conditions in the groundnut oil extraction preparatory chamber.

CONCLUSION

This research, an improved electro-mechanical technique for groundnut oil extraction as it seeks to mitigate the effect of poor and irregular heating that existed in the traditional system which often leads to low oil quality and quantity will help a long way in maximizing groundnut oil quality and quantity production and also ensuring minimal human involvement as the system is fully automated.

REFERENCES

[1] Ajao, K.R., Ajimotokan, H.A. and Olaomi, J. (2006). Development and performance Evaluation of a Groundnut oil Expelling Machine. *New York Science Journal*, **2**(6):432-459.
[2]Lawal A.O, Yiljep Y.D, Abubakar S.Z. National Agricultural Extension and Research Liaison Services Ahmadu Bello University Zaria. Agric. Engineering Series Extension Bulletin Series No 4, Issue 88. Pp 10
[3] JedolDayou, Man – Sang C, Dalimin M.N and Wang S. (2009) ‘’*Generating Electricity Using Piezoelectric Material’’ Borneo Science* Pp 1-5
[4] K.A Akpado1, C.O Ezeagwu, A. Ejiofor, A.O Nwokeke, (2013) “Design, Modelling and Simulation of a Microcontroller Based Temperature Control in a Ventilation System “International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, *Vol. 2, Issue 7*,2013,Pp. 3470-3479.
[5] Yusuf, K.A, Olaniyan, A.M, Atanda, I.A and Sulieman I.A., (2014) “Effects of heating temperature and seed condition on the yield and quality of mechanically expressed groundnut oil”. International journal of technology enhancements and emerging engineering research, Vol.2, issue 7.
[6] Olatunde, O.B, Ajav, E.A. and Fatukasi, S.O. (2014). “Design and fabrication of groundnut roaster cum expeller”. International journal of science and technology Vol.3 no.3
[7] Adeeko, K.A and Ajibola, O.O (1990). “Processing factors affecting yield and quality of mechanically expressed groundnut oil”.Journal of agricultural engineering research. Vol.45. Pp. 31 – 43.
[8] Ajibola, O.O., Eniyemo, S.E, Fasina, O.O and Adeeko, K.A. (1990). Mechanical Expression of Oil from Melon Seeds.Journal of British Society of Research in Agricultural Engineering.Volume 45, No. 1.Pp. 45- 53.

[9]Makeri M.U, Bala S.M and Kassum A.S., (2011). ‘*’The effects of roasting temperature on the rate of extraction and quality of locally – processed oil from two Nigerian peanut (Arachis hypogeal L)*’’. “African Journal of food Science vol.5 (4) Pp. 194 – 199, 2011.Available online www. Academicjournals.org