Automated Temperature Control with Adjusting Outlet Valve of Fuel in the Process of Cooking Palm Sugar

by Nurul Hiron

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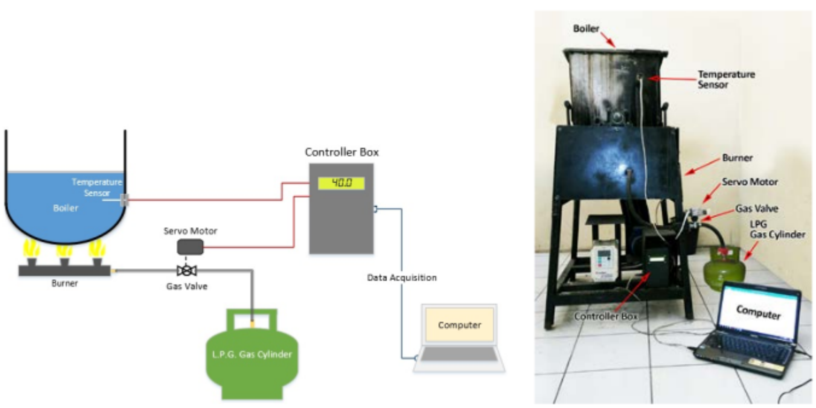
Abstract. In this paper, a real-time temperature control system for coconut sugar cooking is presented. It is based on a thermocouple temperature sensor. The temperature in the closed evaporator is used as a control variable of the DC servo control system for opening and closing of a valve embedded in a gas burner. The output power level, which is necessary in order to reach the target temperature is controlled by the microcontroller ATMega328P. A circuit module for control of the valve and temperature sensors as well as software for data acquisition have been implemented. The test results show that the system properly stabilizes the temperature in the closed evaporator for coconut sugar cooking in the range from room temperature to 110°C. A set point can be reached and held with an accuracy of ±0.75°C at a temperature of 110°C for 60 minutes.

1. Introduction

Coconut sugar is produced from the sap of the coconut palm. Nowadays, most of its production is based on the following traditional method. The sap is poured in a large wok and heated on a wood-fired stove [1]. At the beginning of cooking, the fire must be intensive in order to accelerate the evaporation of water from the sap. The sap is then boiled at a temperature of over 100°C for a few hours until its concentration increases and sugar syrup is obtained. Afterwards, this substance is stirred manually using large wooden spoon until it becomes viscous. The producer then determines the final product quality assessing the intensity of its brown colour, thickness and viscosity of the liquid during the on-going process. The traditional method is laborious and requires a long time to evaporate water until the final product of coconut sugar is produced. In order to reduce the thermal degradation during the evaporation, it is necessary to minimize the heating temperature and the processing time. Efforts have been made to overcome the problem by using the method of vacuum evaporator [2-3]. Palm sap of 15 litres was concentrated by using a vacuum evaporator at 70 and 80°C until its total soluble solids reached 70°Brix to obtain palm sugar syrup. The TSS of finished palm sugar syrup should be not less than 65°Brix according to the Thai industrial standards institute of the ministry of industry. However, these studies have demonstrated that the cooking time estimation cannot be controlled properly. It should be underlined that the sufficiency of heating during the process is a very important factor because it affects such quality factors of the produced sugar as the moisture content, total sugar content, reducing sugar, colour and texture. During the heating process, various chemical and physical changes occur. During a long heating process, a sugar with hard texture and dark brown colour is produced while a short heating provides a soft and easily melted product. Therefore, it is necessary to control the heating temperature and the time during the cooking process.

Ho *et al.*, (2008) [4] have developed a method to monitor the properties of the palm sugar syrup during the heating process by open skillet with a controlled temperature. In this process, the cooking temperature of coconut sugar is measured using an infrared thermometer. The measurement results show that after 30 minutes, the cooking temperature is 78.5°C and rises to 147.6°C at the cooking end. The water content was reduced from 84.66% to 12.11%. The advantage of the cooking temperature control using an infrared thermometer is that the measurement is contactless and the exposure is less specific to the temperature of the measured object. Furthermore, Hasan *et al.,* (2015) [5] have studied a new method for palm sugar cooking and compared it with the traditional method. The palm sap is placed in the cooking pot and heated by using an electrical heater. The temperature is maintained by using a controller in order to produce a more uniform process. In our study, the coconut sugar syrup is produced by evaporating coconut sap in the closed evaporator and heating is performed using a gas burner. The gas output from the LPG gas cylinder is regulated by an output valve installed between the gas burner and the gas cylinder. Prior to this, only manual operated valve was used to open and close the gas flow to the gas burner, such that it is difficult to adjust the desired speed. The speed of opening and closing of the valve affects the size of the fire, especially when the sap is concentrated. At such conditions, a stable temperature is necessary for producing the best quality of sugar in colour and texture. Therefore, an automatic control valve with high accuracy opening valve area is needed to get an appropriate speed and to maintain the gas flow before its entering the gas burner. In the present work, we have developed an automatic control valve by using a servo motor at the inlet of the gas burner that has an adjustable opening area in order to get the appropriate flow rate while raising and lowering the heating of the sap in a closed evaporator as necessary. The aim of this paper is to describe the main features of the developed temperature control system based on a thermocouple temperature sensor as well as to provide the experimental verification validating the performance of this cost-effective solution.



(a) (b)

Figure 1. (a) Schematic of the coconut sugar cooking system and (b) photograph of the test setup.

2. Experimental Procedures

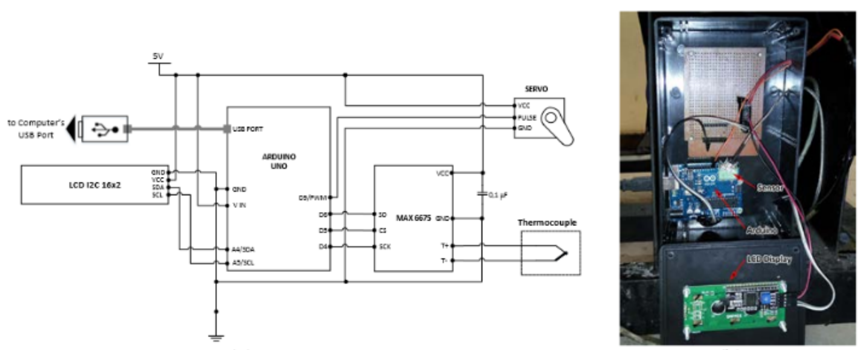
2.1. The coconut sugar cooking system

Figure 1 shows schematic of the coconut sugar cooking system. The main components of the system are: (i) closed evaporator (boiler); (ii) thermocouple as a sensor to read the temperature; (iii) gas burner; (iv) LPG gas cylinder; (v) servo motor; (vi) controller box; and (vii) a computer. The burner module is a self-made gas stove. It consists of three stainless steel pipes with diameter of 2 in and mounted lengthwise under the evaporator. The diameter of the hole for the gas output on the pipe is 3 mm and the number of holes in each pipe is 20. The gas from the cylinder flows through the hose and generates a flame on the gas burner. The gas that flows into the burner is controlled using a gas valve. In fact, the valve regulates the size of the gas flow, which ultimately regulates the size of the flame. The size of the gas flow is controlled by a valve rotation driven automatically by the servo motor. The similar methods have also been used in the previous studies for producing charcoal from coconut shell waste [6].

2.2. Temperature Control System

2.2.1 Temperature Sensor. Figure 2 shows the circuit of the temperature control system in the coconut sugar cooking system set on the controller box on Fig. 1. The temperature sensor uses a thermocouple of the K type module MAX6675 as a temperature gauge. The output of MAX 6675 has a resolution of 0.25°C and has a temperature reading range between 0°C and 1024°C. It has the ability to reduce the noise error in the thermocouple conductor. A noise can arise from the power supply source of MAX 6675. In order to minimize it, a ceramic capacitors is installed between these two components. The thermocouple detects the temperature in the closed evaporator and sends a voltage signal to the IC MAX 6675. The received voltage signal is converted into a digital signal form by MAX 6675 and then it is sent to the microcontroller ATMega328P based Arduino UNO.

2.2.2 Microcontroller Circuit. Arduino UNO is a microcontroller board system based on the microcontroller ATMega328P. It can read data from MAX 6675 by sending a low bit-rate signal to CS pin of MAX 6675, a clock signal to SCK and retrieve data from pin SO MAX 6675. The temperature is displayed by Arduino in real-time using 16x2 LCD. The latter uses I2C communication to save pin I / O Arduino. The temperature data is processed by the Arduino and is compared with the user defined set point (SP).



(a) (b)

Figure 2. (a) Temperature control system circuit of the coconut sugar cooking system and (b) photograph of control system circuit.

2.2.3 Servo motor circuit. This circuit is an automatic switch that regulates the opening and the closing of the gas valve, in accordance with the commands provided by ATMega328P microcontroller through the program installed in it. In this system, the servo is connected to the gas valve to regulate the heat generated by the flame in the gas burner. Rotations from 90° to 0° and from 0° to 90° are used to open and close the gas valve, respectively [7]. The work procedure of the servo motor circuit is as follows. As the temperature rises above the set point, the program sends an appropriate control signal to the Arduino and the servo rotates from 90° to 0° to close the gas valve. On the contrary, when the temperature falls below this point, the program sends another control signal through Arduino making the servo to rotate in the opposite direction from 0° to 90°, i.e. to open the gas valve.

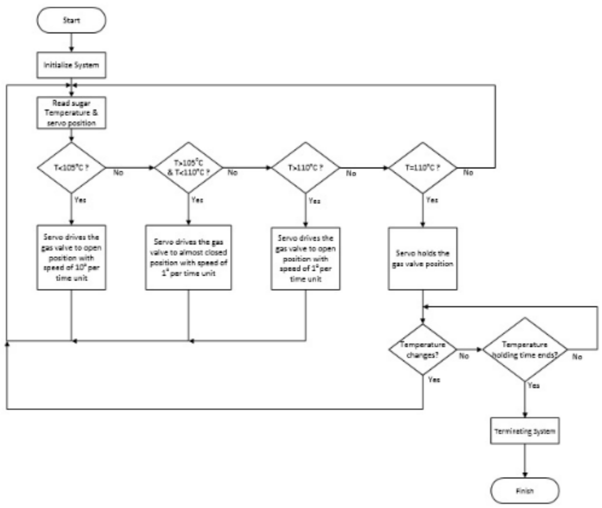


Figure 3. Flowchart of the processes involved in the temperature control.

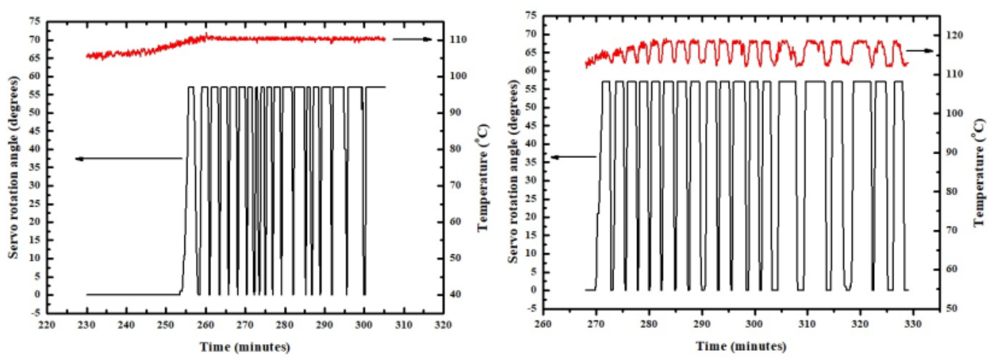
Table 1. Precision of the thermocouple K type sensor module IC MAX6675 for measuring the temperature of cooking of coconut sugar in the temperature range from 30 to 110°C.

No	Time (min)	Detected temperature (°C)	Actual temperature (°C)
1	1	34.50	35.50
2	5	41.00	42.00
3	10	52.75	54.50
4	15	64.75	66.50
5	20	77.00	78.00
6	25	87.25	88.50
7	30	96.75	98.00
8	35	104.00	105.00
9	90	104.75	105.50
10	250	108.25	109.00
11	255	109.50	110.00
12	256	110.00	111.00

3. Results and Discussion

Table 1 shows a comparison between the temperature measured by the thermocouple K type sensor module IC MAX6675 and the actual temperature registered by the thermocouple Mastech MS6514. The measured temperature is the temperature of the coconut sap from first minute to 90th minute and the temperature of sugar syrup from 250th minute to 256th minute. The temperature was measured at the closed evaporator centre. The maximum error deviation of the temperature is less than 2°C. If the test results meet the corresponding standard requirements, it means that the overall performance of the system meets the imposed requirements.

Figure 4a and 4b show open and close cycles of the gas valve controlled by servo rotation and the changes in the temperature around the set-point temperature of 110°C and 115°C as a function of the cooking time, respectively. The working principles for the test results shown in Figure 4a and 4b follow the flowchart presented in Fig. 3. The 0° angle is for the position of completely open valve. At this condition, the cooking evaporator is heated to a set-point temperature of 110°C. As the temperature rises above 110°C, the servo rotates from 0° to 57° at a speed of 60° per milliseconds to partially close the gas valve so that there is still a flame on the gas burner. As the temperature falls below 110°C, the servo rotates from 57° to 0° to open the gas valve, so that the flame is enlarged. This cycle continues until the sugar becomes concentrated. For the case of the set-point temperature of 115°C shown in Figure 4b, it is the same as for 110°C, but the speed of the rotation is 10° per milliseconds. Furthermore, we compare the temperature response around 110°C and 115°C in Fig. 4 and 5, respectively. It can be seen that the temperature fluctuations are ±0.75°C and ±3.0°C for the set-point temperatures of 110°C and 115°C, respectively. The fluctuation around 110°C is much lower than that at 115°C. This behaviour can be related to the speeds of the servo rotation to open and to close the gas valve.



(a) (b)

Figure 4. Open and close cycles of gas valve by servo rotation and changes in temperature around the set-point temperature of (a) 110°C and (b) 115°C as a function of the cooking time.

4. Conclusion

In this work, a temperature control system for cooking of coconut sugar was developed using a DC servo control. The experimental tests have confirmed its efficiency and operational performance. The results have demonstrated that the temperature sensor works with an accuracy better than 2°C to stabilize the temperature in the range from room temperature to 110°C. A significant effect of the servo rotation on the detected temperature in the closed evaporator is clearly observed at higher speeds of the servo rotation. At this condition, the temperature can be held at 110°C with an accuracy of ±0.75°C for 60 minutes. Such accurate temperature control in a closed evaporator for cooking of coconut sugar has been realized for the first time.

Acknowledgments

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