Performance of low cost sensor temperature logger in double jacket reactor vacuum distillation

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Article Info

Article history:

Received Sep 15, 2023
Revised Jan 4, 2024
Accepted Jan 11, 2024

Keywords:

Arduino mega
Data logger
Heat transfer
Reactor
Temperature
Thermocouple

ABSTRACT

Heat transfer occurs due to the difference in temperature between the system and its surroundings. The effect of temperature can affect various aspects of the refining process, including efficiency, selectivity, reaction kinetics, and the quality of the final product. This study aims to analyze heat transfer in a double-jacket reactor by measuring temperature data taken using a temperature data logger system. Prototype low cost-effective temperature monitoring for double jacket reactor vacuum is this system integrates an Arduino Mega 2560, a type K thermocouple, amplifier MAX 6675 module, and an SD card data logger to measure and record reactor temperature for 30 minutes. The temperature data obtained is used to calculate the heat transfer and analyze the heat transfer characteristics of the reactor. Heat transfer analysis based on measured temperature data is able to provide insight into the characteristics of heat transfer in the observed system and can identify hot spots and heat transfer energy in the system. Thus, the temperature data logger used in the double jacket reactor in the vacuum distillation system can produce accurate data and information, and this system has broad application potential in temperature monitoring in various fields.

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1. INTRODUCTION

Bioethanol (C_2H_5OH) is an environmentally friendly alternative fuel resulting from the glucose fermentation process followed by a purification process [1], [2]. The bioethanol purification process is one of the important steps that must be passed because the fermented ethanol only has a purity of less than 10%. In the process of purifying bioethanol, it can be done if all the components to be separated are equally volatile. Manipulation of the phases that play a role in the purification process will increase the purity of the components to be separated by distillation [3]. However, the distillation stage requires concrete and renewable innovation. This is because the bioethanol products that have been produced at this time are still average and have a low alcohol content. One way that can be done is by using a vacuum distillation system [4]. Vacuum distillation has the advantage of being able to separate two or more fluid components based on differences in their boiling points. The vacuum distillation process cannot be separated from the heat transfer scheme [5]. Heat transfer in the reactor will determine the resulting bioethanol product. Heat transfer is a form of energy transfer that moves from a system to the environment or to the surrounding system [6]. So heat can move across the boundary of one system to another [7].

Heat transfer occurs due to the difference in temperature between the system and its surroundings [8]. Temperature is one of the key factors in the bioethanol purification process in the reactor. The effect of temperature can affect various aspects of the refining process, including efficiency, selectivity, reaction kinetics, and the quality of the final product. So a control and monitoring system is needed in the bioethanol purification reactor medium to monitor the conduction and convection heat transfer temperatures in the reactor and maintain the stability of the fluid temperature in the reactor. To read the heat transfer temperature and store the results in data form, a device called a temperature data logger is required [9]. The advantage of this tool is that it can store large amounts of data for a long time.

This tool is no stranger to researchers or industry, because with the help of this tool, data analysis is easier to do simply by transferring data from the storage media to the analysis device used [10]. This tool is widely available and compatible, but the price is not cheap, to overcome this can be done by designing your own using components that are already on the market. This temperature data logger consists of 3 units, the first is a temperature reader, data processor, and data store [11]. The results can be seen directly on the computer monitor screen and can also be obtained by importing data stored on the SD card. This equipment consists of a thermocouple as a temperature sensor, an Arduino ATmega microcontroller as a data processor, and a data logger as a data store [12]. The temperature sensor will detect changes in the temperature of the object to be measured [13], then converted into an electrical signal and sent to the microcontroller to be processed into the desired data form, the results are displayed on the monitor screen and stored in the data storage media.

2. PROCEDURE SPECIFICALLY DESIGNED

The bioethanol purification process requires special design procedures because bioethanol produced from fermentation or chemical synthesis processes usually contains various impurities that need to be removed to meet established quality standards. Temperature measurement also allows better control of process conditions. Changes in temperature can affect the reaction rate and purification efficiency. The right temperature can ensure that bioethanol is processed under optimal conditions to produce a product with the desired level of purity. Thus, this research uses specially designed procedures, including the design of a double-jacket vacuum distillation reactor and the design of a temperature data logger.

2.1. Double jacket vacuum distillation reactor design

The design of the bioethanol purification process tool in this study is one of the most important parts [14]. Success in testing is highly dependent on how the initial design is planned for the tool to be made [15]. A double jacket is a tank covered by a heating chamber. This jacket functions as a room to distribute heating material to heat the fluid contained in the tank [16]. The use of a jacket is to maintain an even heat circulation around the tank and reduce heat transfer from inside the tank directly to the environment because the temperature around the jacket is kept above the fluid temperature in the tank so that the fluid in the tank absorbs heat from the jacket [17].

Vacuum distillation with a double jacket reactor as shown in Figure 1, when the reaction requires heating, the heating liquid is pumped into the inner layer of the jacket. This heating fluid will be heated through a heater with a modified liquefied petroleum gas (LPG) fuel stove. Heat from the heating fluid will be transferred through the jacket wall and forwarded into the reactor. This allows the reaction to take place at the desired temperature. A reactor system with a double jacket allows for more accurate temperature control during reaction. The heating or cooling liquid flow settings can be adjusted to achieve the desired reaction temperature. This is important because the reaction temperature can affect the speed and yield of a chemical reaction [18]. The steam formed from the vaporized components is directed to the vacuum condenser. In the condenser [19], the vapor is cooled and condensed back into liquid [20].

2.2. Temperature data logger design

The equipment required in designing a temperature data logger consists of a thermocouple as a temperature sensor, an Arduino ATmega microcontroller as a data processor, and a data logger as a data store [21], [22]. The temperature sensor in Figure 2 uses a K-type thermocouple with a working voltage specification of 3-5 V, a temperature measuring range of 0-800 °C, and a temperature accuracy of 0.25 °C. This sensor can detect differences in heat in two different materials and convert them into a voltage, or electricity. To carry out temperature data acquisition with a K-type thermocouple using the Max 6675 module shown in Figure 3, with a working voltage specification of DC 5 V, operating 50 mA, a measuring temperature range of 200–1,200 °C, a temperature measurement accuracy of 1.5 °C, a resolution temperature of 0.25 °C, and a storage temperature of 50–150 °C.

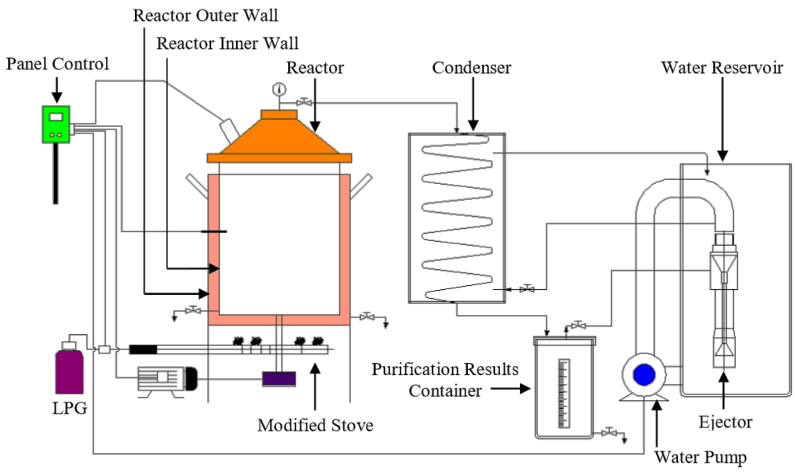

Figure 1. Double jacket reactor design

Figure 2. Thermocouple type-K Figure 3. Modul Max 6675

Whereas the tool used to install a micro SD card or micro memory so that it becomes like an SD card or mini SD uses an SD card adapter module see Figure 4. The Arduino microcontroller atmega as a data processor uses an atmega 2560-based microcontroller board shown in Figure 5, which has 54 digital input and output pins, where 15 pins can be used as pulse width modulation (PWM) outputs, 16 pins as analog inputs, and 4 pins as UART (hardware serial port), a 16 MHz crystal oscillator, a universal serial bus (USB) connection, a power jack, an in circuit serial programming (ICSP) header, and a reset button. The Arduino Mega 2560 specifications used are input voltage recommendations of 7-12 VDC, input voltage limits of 6-20 VDC, DC current for each I/O pin is 20 mA, DC current for the 3.3 V pin is 50 mA, flash memory is 256 KB, SRAM is 8 KB, EEPROM is 4 KB, and clock speed is 16 MHz.

Figure 4. SD card adapter module

Figure 5. Arduino Mega 2560

Figure 6 depicts the designed circuit scheme, serving as the foundation for the physical assembly of temperature data loggers showcased in Figure 7. The physical circuit is constructed by connecting various components, and the SPI connection between the Arduino Mega 2560, the MAX 6675 module, the Type-K thermocouple, and the SD card data logger is established to ensure stable and accurate communication. The control program, developed in the Arduino programming language, is responsible for reading temperature data from the Type-K thermocouple and storing it on the SD card.

Arduino Figure 8 software can be obtained freely because it is open source, can be installed on a computer, and can be made into a program. In general, the program listing consists of several stages. Starting with initializing the objects, constants, and variables needed in the program execution process, the program will detect whether the SD card has been inserted in the socket; this is needed to ensure that the SD card is ready, as well as create a new file on the SD card for data storage. Next, it will process the data sent by the thermocouple to be converted to temperature, and the data will go to the SD card.

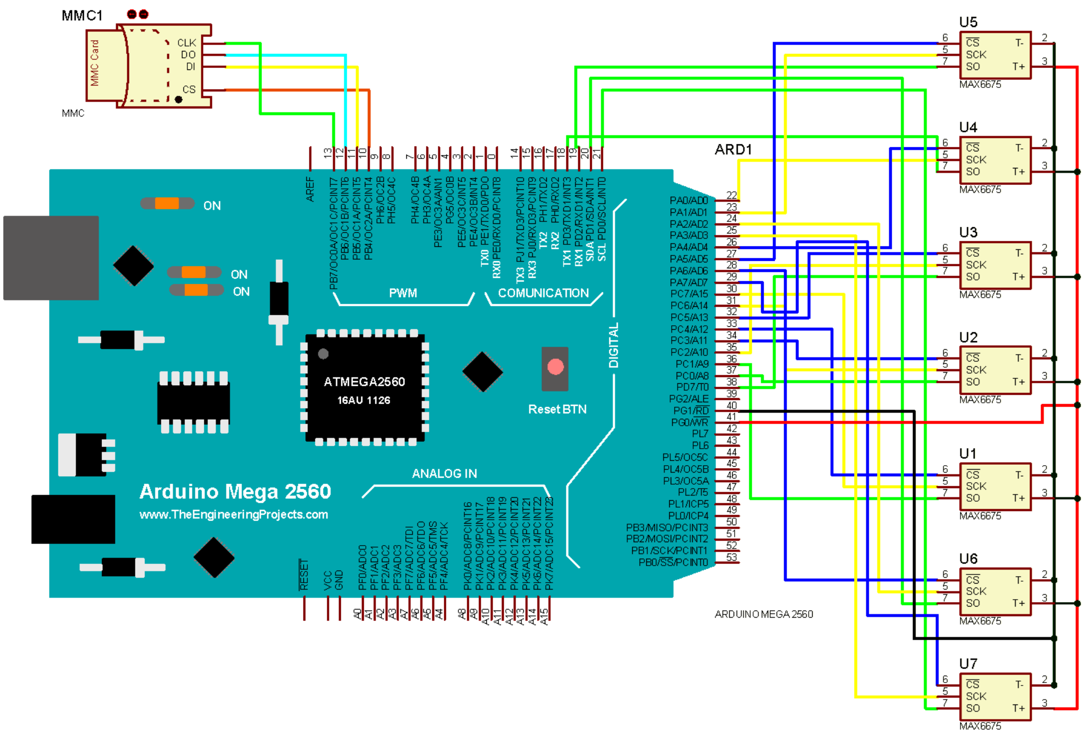

Figure 6. Wiring design

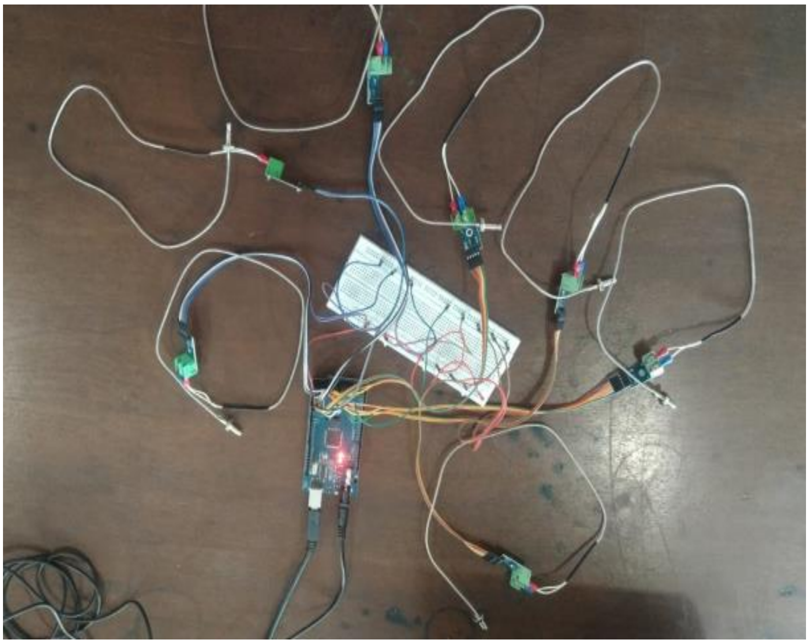

Figure 7. Temperature data logger circuit

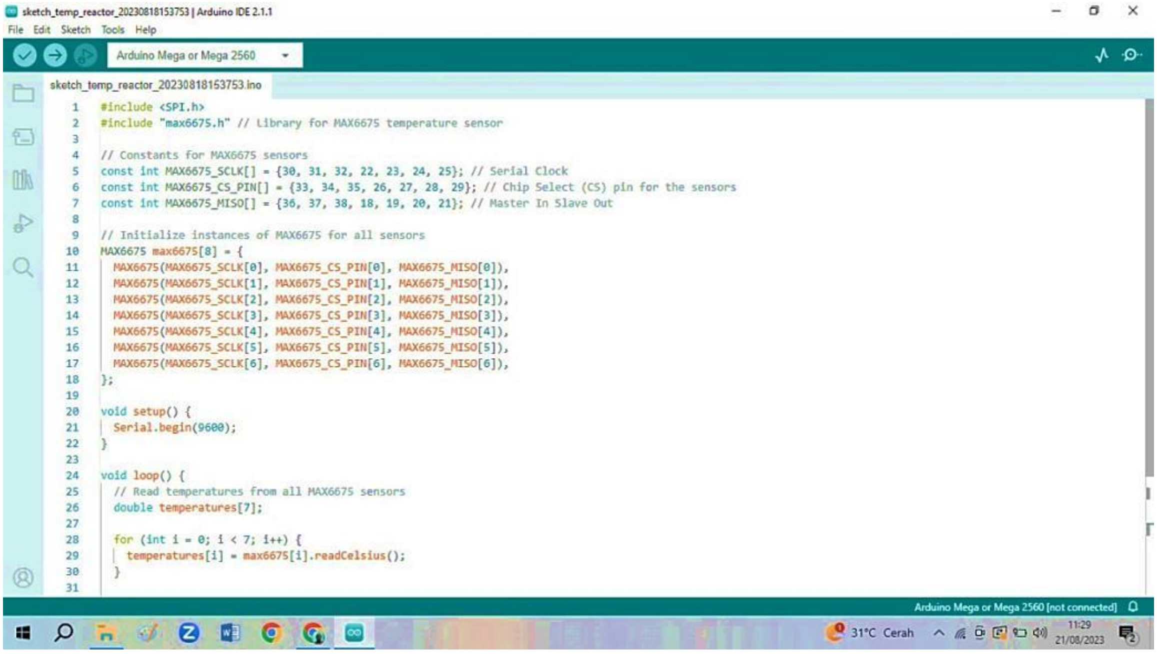

Figure 8. Software display

3. METHOD

The method used in this study is an experimental method based on analyzing heat transfer energy in a vacuum distillation double jacket reactor and temperature data taken by implementing and analyzing data loggers. In this study, the double jacket reactor was designed using AISI 304 stainless steel walls. The outer wall (water jacket) has a diameter and height of ∅395×415 mm, and the inner wall (reactor tank) has a diameter and height of ∅335×423.5 mm, with a thickness of 2 mm. To heat the reactor chamber, in this study, a modified stove with LPG fuel was used. The modified stove is installed under the reactor wall so that the heating temperature can be evenly distributed.

3.1. Prototype of low cost-effective temperature monitoring

The performance of the prototype temperature monitoring system in a double jacket reactor with a vacuum distillation system shows that the analysis of heat energy transfer and distribution is equivalent to the heat energy transfer and distribution formula [23].

$$Q = \frac{(T_2 - T_1)}{R} \tag{1}$$

Where: Q = Conduction heat transfer (J)
T_1 = Outer wall temperature (°C)
T_2 = Inner wall temperature (°C)
R = Thermal wall resistance

$$R = \frac{ln\left(\frac{r_o}{r_i}\right)}{2\pi kl} \tag{2}$$

Where: r_o = Outer diameter (m)
r_i = Inner diameter (m)
k = Thermal conductivity (W/(m. °C)
l = Wall height (m)

The performance of heat energy transfer and distribution can be seen in Table 1. A prototype of low-cost-effective temperature monitoring is implemented to obtain the reactor outlet temperature, which includes the outer walls of the reactor on the outside. (T_1) and the inside (T_2), the walls of the reactor on the outside (T_3) and the inside (T_4), the reactor inner lining on the outside (T_5) and inside (T_6), and the fluid in the reactor tank (T_7), as shown in Figure 9.

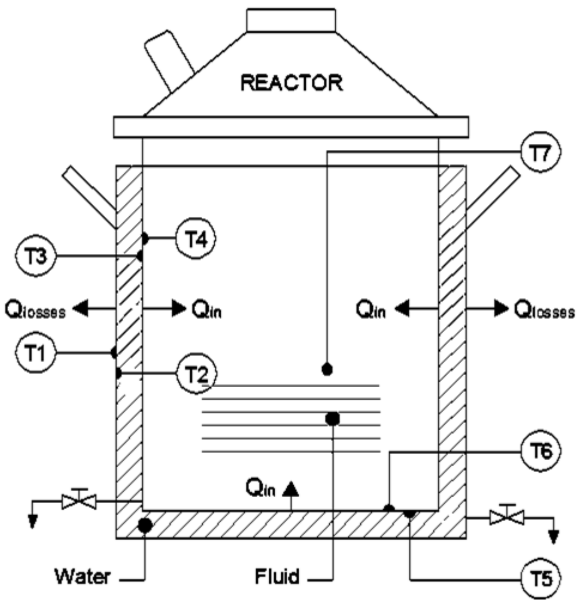

Figure 9. Position of the thermocouple on the reactor

In this study using vacuum distillation with a pressure of (-55) mmHg, the temperature of the fluid in the reactor was 71 °C, and the test material used was bioethanol from sorghum stems with an ethanol content of 30%. As much as 20 liters were tested for 15 minutes. Temperature data is taken every 50 seconds, and the data obtained from the data logger is used to analyze the heat transfer energy that occurs in the vacuum distillation double jacket reactor. Conduction heat transfer energy analysis occurs on the outer wall, inner wall, and reactor base, while convection heat transfer can occur on the inner reactor bed with fluid. The flow of this research is shown in Figure 10.

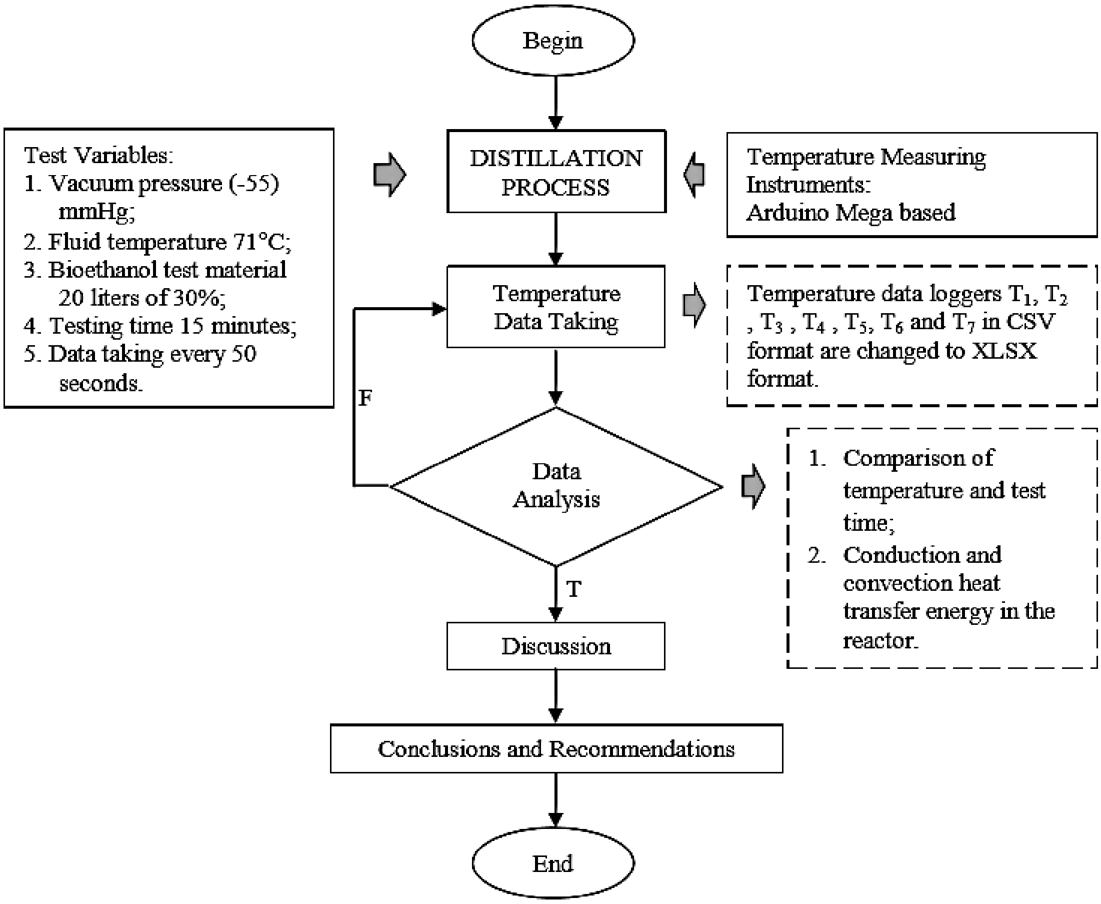

Figure 10. Research flowchart

4. RESULTS AND DISCUSSION

4.1. Test result temperature data

Testing of 7 temperature sensors (thermocouples) in a vacuum distillation apparatus placed in a double jacket reactor was carried out by attaching a thermocouple (T_1–T_6) to the reactor wall plate and a T_7 thermocouple placed in the reactor by immersing the thermocouple in the fluid (30% bioethanol content) as a raw material for the distillation process. Furthermore, the reactor was heated slowly, with the temperature of the fluid in the reactor controlled at 71 °C for 30 minutes. The test results are presented in Table 1, and a graph of the relationship between temperature and time is shown in Figures 11 to 14.

Figure 11 shows the change in temperature on the outer wall of the reactor on the outside and inside. The temperature on the outside (T_1) is quite high; this is due to the direct heating process from the LPG-fired stove. This shows that the thermocouple mounted on the wall is functioning properly. At the thermocouple (T_2), the temperature has decreased from T_1. This is due to the process of conduction heat transfer between T_1 and T_2 and the presence of water fluid contained in the jacket, which absorbs heat from the outer wall of the inner reactor. The temperature change on the inner wall of the reactor shown in Figure 12 between T_3 and T_4 occurs almost linearly. This is due to the thickness of the inner reactor wall of 2 mm, so the conduction heat transfer that occurs is quite small. Likewise, the temperature change that occurs at the bottom of the reactor in Figure 13 changes almost linearly.

Figure 14 shows that the temperature change in the reactor fluid has increased. The temperature rise can occur due to convection heat transfer from the fluid to the reactor wall. The higher the temperature of the fluid and the higher the temperature difference between the fluid and the wall [24], the greater the rate of convection heat transfer that occurs. Based on the tests that have been carried out, it shows that all temperature reading test results designed using thermocouples 1 to 7 have the same pattern, even though there is a slight difference in the values.

Table 1. Temperature data on the double jacket reactor

Time (second)	Reactor outer wall temperature (°C)		Reactor inner wall temperature (°C)		Reactor base temperature (°C)		Fluid temperature (°C)
	Outer side T_1	Inner side T_2	Outer side T_3	Inner side T_4	Outer side T_5	Inner side T_6	T_7
0	29.75	29.75	33.75	33.75	36.47	36.47	35.22
50	35.75	30.50	35.50	35.31	38.19	37.22	36.03
100	37.75	31.00	36.50	36.27	38.73	37.72	36.49
150	38.25	31.50	37.25	36.95	40.05	38.97	37.67
200	40.75	32.00	38.50	38.30	40.45	39.47	38.27
250	41.75	32.25	39.00	38.75	41.5	40.47	39.22
300	46.75	32.75	40.00	39.81	41.94	40.97	39.78
350	47.00	33.50	41.25	41.06	42.69	41.72	40.53
400	46.75	34.00	42.25	42.00	43.50	42.47	41.22
450	48.75	34.50	43.25	42.95	44.55	43.47	42.17
500	50.50	35.25	43.75	43.56	45.19	44.22	43.03
550	49.25	35.25	44.50	44.25	46.00	44.97	43.72
600	49.50	36.50	46.25	46.00	46.25	45.22	43.97
650	51.50	37.00	46.50	46.3	47.20	46.22	45.02
700	51.75	37.50	47.50	47.29	47.71	46.72	45.51
750	52.00	38.25	48.00	47.71	49.04	47.97	46.68
800	50.75	38.75	48.75	48.45	49.30	48.22	46.92
850	51.50	40.00	49.50	49.25	49.75	48.72	47.47
900	52.75	40.00	49.75	49.5	50.50	49.47	48.22
950	54.00	40.75	50.75	50.45	50.80	49.72	48.42
1,000	53.50	41.25	51.25	51.04	51.96	50.97	49.76
1,050	53.75	41.50	52.25	52.00	52.50	51.47	50.22
1,100	51.75	42.75	53.00	52.70	52.80	51.72	50.42
1,150	52.50	43.00	53.75	53.45	53.30	52.22	50.92
1,200	53.75	43.25	54.75	54.46	54.79	53.72	52.43
1,250	55.25	44.50	55.75	55.5	55.50	54.47	53.22
1,300	55.25	45.25	55.75	55.55	56.20	55.22	54.02
1,350	56.75	45.50	57.00	56.79	55.96	54.97	53.76
1,400	59.00	46.00	58.25	57.96	58.54	57.47	56.18
1,450	57.25	46.75	58.75	58.45	59.30	58.22	56.92
1,500	57.00	47.50	59.75	59.54	59.71	58.72	57.51
1,550	58.75	48.50	61.00	60.75	60.75	59.72	58.47
1,600	57.75	49.00	61.50	61.2	61.55	60.47	59.17
1,650	57.50	49.75	62.00	61.79	61.96	60.97	59.76
1,700	57.25	50.75	63.00	62.79	62.46	61.47	60.26
1,750	58.00	50.25	64.25	64.05	63.70	62.72	61.52
1,800	59.00	52.50	65.00	64.80	64.45	63.47	62.27

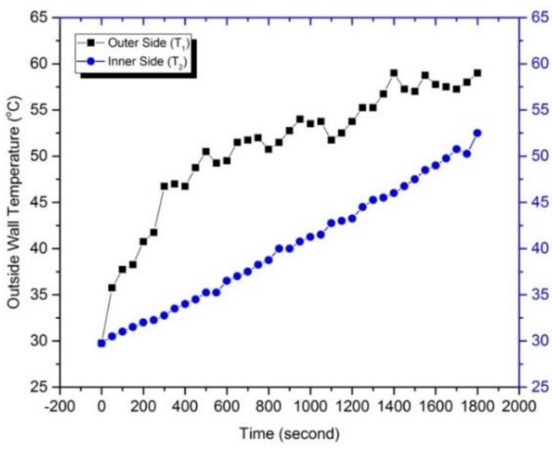

Figure 11. Temperature changes on the reactor outer walls

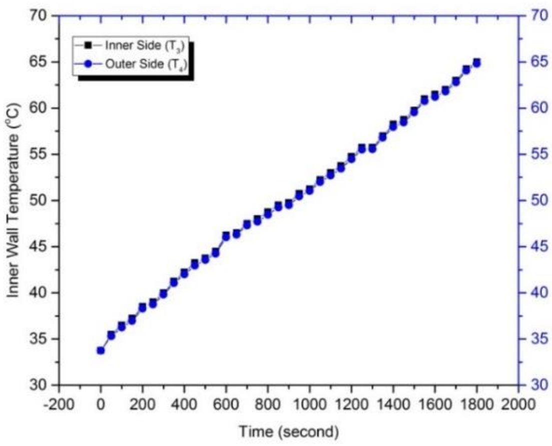

Figure 12. Temperature changes on the reactor inner walls

4.2. Heat transfer analysis

The temperature data recorded on the SD card by the data logger system is used to build a temperature profile over time [25]. By using the temperature difference between the two points that occur in the reactor, the energy of conduction and convection heat transfer through the material between the two points can be calculated. In addition, temperature data can also be used to analyze the phenomenon of thermal convection that occurs in a double-jacket reactor.

In the 30-minute test, heat transfer energy was produced in the reactor as shown in Figure 15, where the results can be seen: (a) conduction heat transfer on the outer walls; (b) conduction heat transfer on the inner walls; (c) conduction heat transfer on the reactor base inner wall; and (d) convection heat transfer in reactor fluid. On heat transfer to the outer wall (water jacket) Figure 15(a) an energy value is obtained with a negative value, it means that there is energy loss or energy loss during the heat transfer process (energy losses). The causes of negative energy can involve several factors including heat radiation, unwanted thermal conduction and inefficient convection [26]. While the energy generated on the inner wall Figure 15(b) and bottom Figure 15(c) of the double jacket reactor from the calculation process has increased and decreased energy. The increase in energy is caused by a temperature difference between two objects that are interconnected. If there is an increase in one of the objects, heat energy will flow from the object with a higher temperature to the object with a lower temperature, causing an increase in energy for the cooler object. Furthermore, if the energy decreases, this is due to a shrinking temperature difference. The temperature difference between these objects is smaller, so the transfer of heat energy by conduction will be slower, so that the energy transferred will be reduced [27].

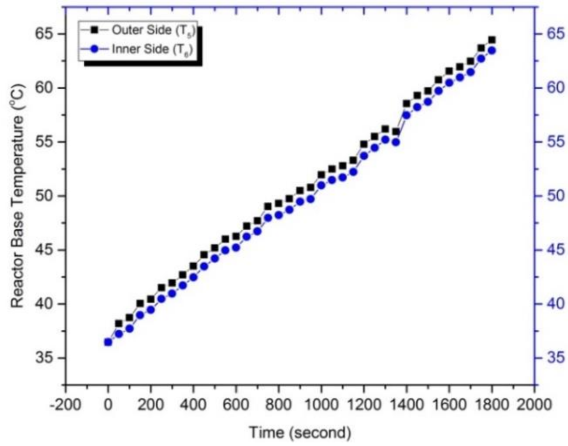

Figure 13. Temperature changes on the reactor base wall

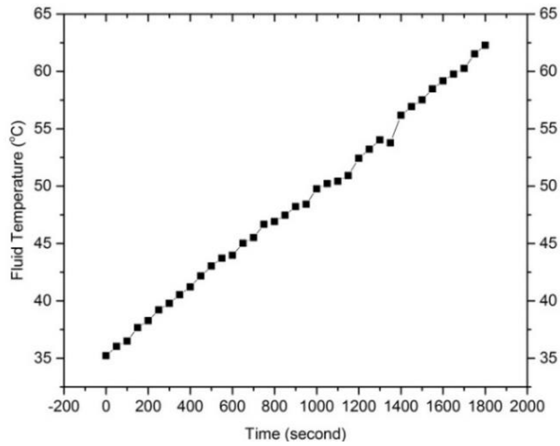

Figure 14. Temperature changes in the reactor fluid

Furthermore, from the results of the calculation of the convection heat transfer energy Figure 15(d) between the inner wall of the reactor tank and the bioethanol fluid, it can be seen that the energy increases and decreases. The increase in energy can be affected by temperature differences [28]. The energy reduction in convection heat transfer can be caused by changes in fluid properties [29]. Fluid properties such as viscosity, thermal conductivity, or density can change with changes in temperature, pressure, or composition. This change can affect the efficiency of convection heat transfer, so that the energy transferred by convection can be reduced [30].

Heat transfer analysis based on measured temperature data is able to provide insight into the heat transfer characteristics of the observed system. By analyzing temperature data at various points, hot spots, the direction of heat flow, and the energy of heat transfer in the system can be identified. Thus, the temperature data logger used in the double jacket reactor in the vacuum distillation system can produce data and information that is accurate and efficient and can be developed for other distillation systems.

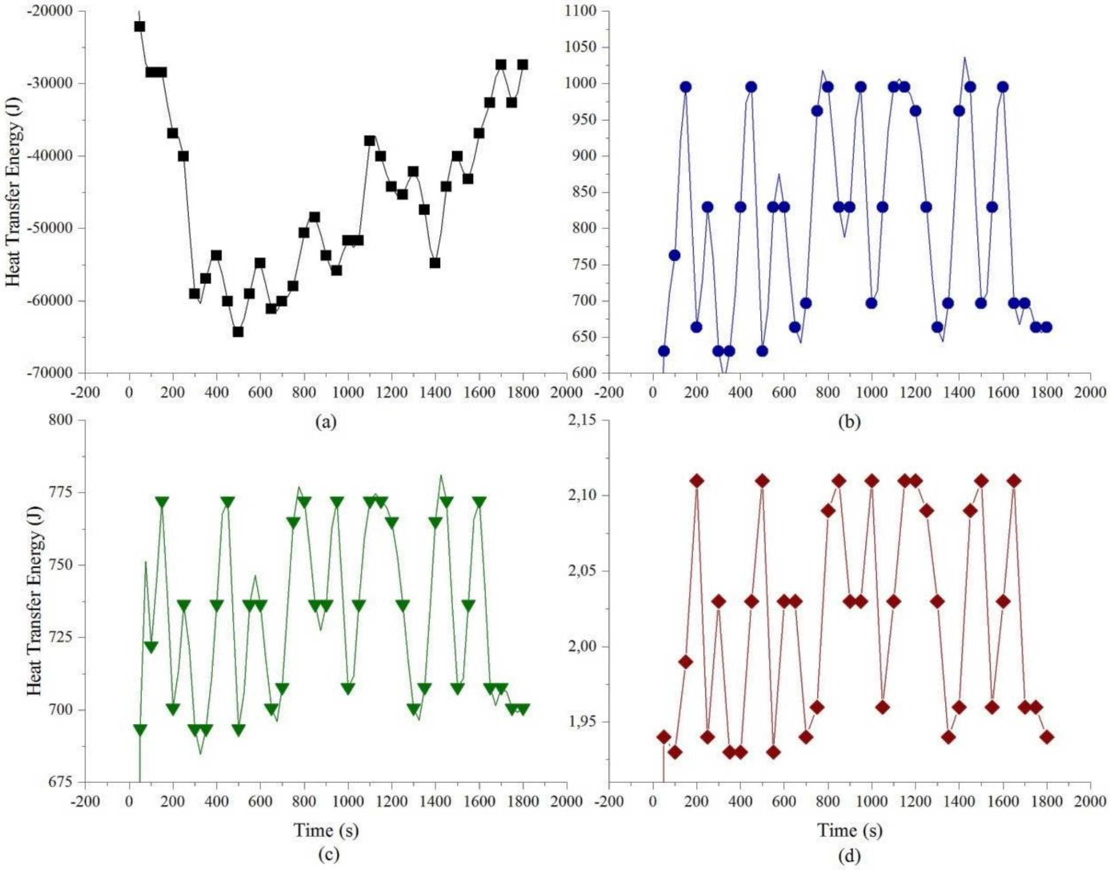

Figure 15. Heat transfer energy in the reactor; (a) conduction heat transfer in the outer wall, (b) conduction heat transfer in the inner wall, (c) conduction heat transfer in the reactor base, and (d) convection heat transfer in the reactor fluid

5. CONCLUSION

In this study, it has been shown that a temperature data logger can be used as an effective tool for analyzing heat transfer in a double-jacket reactor with a vacuum distillation system. Heat transfer analysis based on temperature data provides a further understanding of the distribution of thermal energy in the system and assists in making decisions regarding system design and optimization. Through planning and implementing this temperature data logger system, we managed to illustrate how to integrate the Arduino Mega 2560, MAX 6675 module, type-K thermocouple, and SD card data logger to create a tool capable of recording reactor temperature accurately. This system has wide application potential for temperature monitoring in various fields.

ACKNOWLEDGEMENTS

The authors would like to thank those who have contributed and supported them throughout their journey of completing the study.

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