Automatic Yoghurt Making Using Digital PI for Fermentation Temperature Control

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***Abstract*- It is hard to observe yoghurt making manually in long time period and in a large scale production. Thus, it is crucial to develop a controlling instrumentation that can give a continous yoghurt making process temperature and pH without any human existence as observer. The aim of this project was to build and develop a yoghurt making machine using digital PI to control the fermentation temperature. The system with PIC18F4550 as the main controller will monitor and control yoghurt making process and fermentation temperature 42°C. An experiment is conducted to compare system performance between on-off control and PI control in fermentation process. The system has already set up and develop for yoghurt making process requirement. The PI algorithm to control fermentation temperature at 42°C give better system performance compare to on-off controller. But, noise signal is occured randomly. The pH circuit also has not functioned properly. So, the end process indicator is not develop using pH value as an indicator but using estimated 8 hours time to finish.**

Keyword: yoghurt, fermentation temperature, Digital PID, phase angle control, PIC18F4550

I. INTRODUCTION

Yoghurt is a fermented milk product in which milk is inoculated with a starter culture normally used are *Lactobacillus bulgaricus* and *Streptococcus thermophillus*. Yoghurt is known all over the world not only for the specific taste, but also the beneficial for the human health. Research has shown that each bacteria has their own optimum condition to grow. *Lactobacillus bulgaricus* and *Streptococcus thermophillus*. has optimum growth temperature around 42°C. Yet, temperature is one of the critical condition to define how long it takes to make yoghurt until the pH reach pH commercial value 4.6[4]

Yoghurt making process can be done manually though several processes. It is consist of heating milk and cool it down, mix it with yoghurt culture and finally keeping the temperature around its optimum growth by keeping surrounded by warm water or put it in the temperature room. By using PIC18F4550, it is possible to integrate all the yoghurt making process to run automatically while giving a continuous temperature and pH information. Meanwhile, digital PI method will be used to maintain the process temperature at a proper value from the beginning of the process until the end of the process in order to produce good yoghurt.

The objectives of this project are to design and develop automatic yoghurt making using PIC18F4550 as the main controller and digital PI as algorithm to control fermentation temperature of yoghurt. The scope of the project is to build an automatic yoghurt making with PIC 18F4550 as the main controller and PI algorithm as the method to control temperature.

II. LITERATURE REVIEW

2.1 Yoghurt

Generally, yoghurt making process is divided into several steps. First, heating milk in term of pasteurization. Then, coolng down the milk and starter addition. Last step is fermentation process, waiting for bacteria growth until it reach consumed pH. The general process in yoghurt making is shown in figure 1.

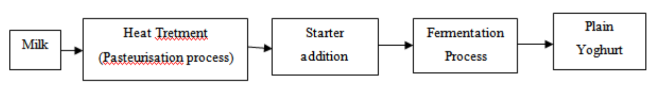

Figure 1 General Process In Yoghurt Making

The heat treatment objective is to pasteurize the milk and creating good texture for the final yoghurt. In this project, this process will control heat treatment temperature 85°C for 30 minutes. Then, the temperature will be cooling down up to 42°C to add the starter. Temperature fermentation process will be kept 42°C until the pH reach 4.6.

2.2 Patents Review

Most of the reviewed patents are automatic on off controller of yoghurt making machine Specification comparison from Table 1 is used as a knowledge base to apply hardware plant design for automatic yoghurt making machine.

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Table 1 Specification Comparison of Patents Review

No.	Patent's Source	Controller Type	Heating Medium	Heater Type	Temperature Indicator/ Sensor
1.	"Yogurt-Making Machine", US Patent 4009368	Automatic On-Off Controller	Melted Paraffin Wax	Resistor via Insulating Element U-Shape	Temperature Limiting Element
2.	"Yogurt Machine", US Patent 3685153	Automatic On-Off Controller	Boiling Water	Water Heater	Thermostat
3.	"Home Yoghurt/Cheese Making Machine", US Patent 6213007	Automatic On-Off Controller	Direct Heating	Embedded Heater	Thermostat

2.3 PID

2.3.1 Concept

A Proportional Integral Derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems[9]. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly. The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. The *Proportional* value determines the reaction to the current error, the *Integral* value determines the reaction based on the sum of recent errors, and the *Derivative* value determines the reaction based on the rate at which the error has been changing. The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = K_p\, e(t) + Ki \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt} \qquad \text{........(1)}$$

2.3.2 PID Tuning

Tuning a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response[9]. The optimum behavior on a process change varies depending on the application. Some processes must not allow an overshoot of the process variable beyond the setpoint and other processes must minimize the energy expanded in reaching a new setpoint.

Most modern industrial facilities no longer tune loops using the manual calculation methods [9]. Instead, PID tuning and loop optimization software are used to ensure consistent results. These software packages will gather the data, develop process models, and suggest optimal tuning. Some software packages can even develop tuning by gathering data from reference changes. SISO Design Tools in MATLAB can be used to analyze the transfer function from SISO (single input single output) system. This project only focuses on designing the digital controller as compensator for the yoghurt making plant. The proportional gain (KP) and integral gain (KI) can be obtained by PID automated tuning in SISO tools.

III. METHODOLOGY

The system architecture part shows the whole project in graphically view. Figure 2 show system control design. Controller, with PID algorithm embedded receive input signal from temperature, pH sensor and start button. All inputs will be processed based on the program, include temperature controlling. Finally, microcontroller will give signal control to heater, motor, and LCD. Process parameters in yoghurt plant could be changed based on the control signal from microcontroller to actuators. The parameters such as temperature and pH will be monitored by sensors and they would be processed by microcontroller.

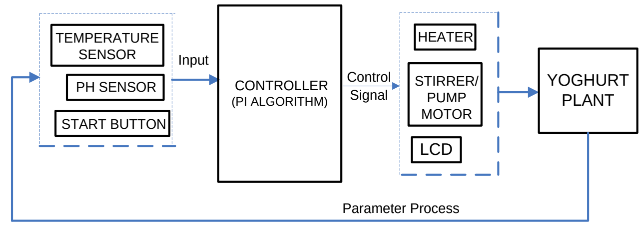

Figure 2 Yoghurt Making Machine Architecture

This project is mainly divided into two parts, hardware and software. The hardware part consists of plant and electrical circuits. The yoghurt plant consists of stainless steel boiler, heater, thermocouple temperature sensor, pH electrode, DC motor for stirrer, plastic can, and motor pump to ………………(2.4) move the culture to the big boiler. The electrical circuits consist of PIC minimum system and interfacing main board, AC driver, interrupt signal generator, thermocouple signal conditioning, pH signal conditioning, and reference source.

3.1 HARDWARE DEVELOPMENT

The hardware development consists of automatic yoghurt plant development and electronic circuits development.

3.1.1 Automatic Yoghurt Making Plant

There are two tanks used in this project. Main tank is made of stainless steel. Stirrer motor, thermocouple sensor, pH sensor, heater, and manual valve is placed in the tank. The size is chosen to hold 5-6 litres of milk. The other one tank is made of plastic. The starter is put in the tank before it is pumped to main tank by pump motor.

Figure 3Automatic Yoghurt Making Plant

3.1.2 Electronic Circuits

The schematic and PCB layout are designed in Eagle 4.11 software.

3.1.2.1 Main Board

The main board consist of PIC18F4550 as the main controller and input/output connectors to other boards or devices. The schematic of main board is shown in figure 4.

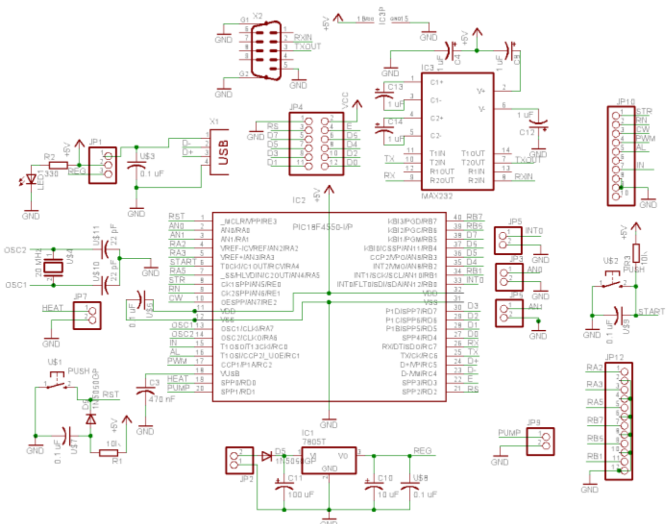

Figure 4 Schematic of Main Board

3.1.2.2 AC Driver

The circuit is one phase full wave rectified AC voltage controller. The main component in this circuit is BT-139. TRIAC is connected directly to the heater wich is also connected directly to AC voltage 240V.

Power given to the heater can be controlled by regulating triac triggering delay time from zero crossing point. The power controlling method known as phase angle control method. The waveform of phase angle control is shown in figure 5.

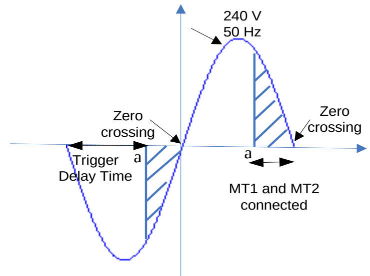

Figure 5 Waveform of Phase Angle Control

Control signal for triac triggering is coming from microcontroller which has low level voltage. Optoisolator MOC 3021 is used to isolate lower level voltage, in this case microcontroller, from high level voltage coming from AC source.

MOC 3021consists of two main parts, LED and photodiac. LED has function to convert electric energy to light energy. LED will beam light coming from square pulse high and low microcontroller. Photodiac has function as a light acceptor from LED and then convert it into electric energy which will control the triac. The AC driver schematic project is shown in figure 6

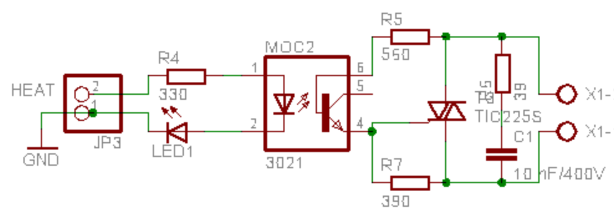

Figure 6 AC Driver Schematic

3.1.2.3 Interrupt Signal Generator

In order to define the correct delay time to gain accurate heater power regulating, microcontroller has to gather zero crossing point information. Zero crossing detector is used to detect sinus wave during passing zero voltage point. It detects transistion from positive to negative signal as well as transistion from positive to negative signal. The zero crossing point is a sign for microcontroller to give delay for triac triggering. The schematic circuit of zero crossing detector is given in figure 7

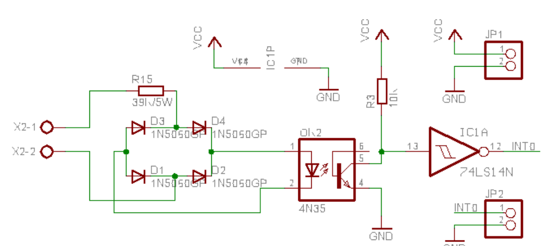

Figure 7 Zero Crossing Detector Circuit

AC 240 V is rectified using bridge diode and the current is limited by resistor 39K. IC optoisolator will active when input current exceed 10 mA. When optoisolator input current exceed 10 mA, led will on and the circuit output is in high level voltage. We signal is in zero crossing point, led optoisolator is off and the circuit output is low level voltage. The signal transition from high to low use as a interrupt input for microcontroller to give certain delay to trigger the TRIAC. Thus, the zero crossing detector circuit at the end has a function as interrupt signal generator for microcontroller.

3.1.2.4 Thermocouple Signal Conditioning

Thermocouple used in the system is K-type thermocouple. The signal conditioning is mostly done by a complete AD595 IC. Thermocouple cold junction and amplifier is integrated inside the IC. The IC output is linier, 10 mV/^{o}C. The AD594/AD595 includes a thermocouple failure alarm that indicates if one or both thermocouple leads become open. In this project, if the thermocouple lead is open or unconnected, the led will on. Schematic for thermocouple signal conditioning using AD595 is given in figure 8

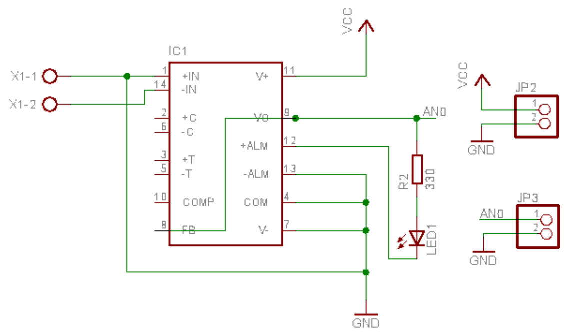

Figure 8 Thermocouple Signal Conditoning

3.1.2.5 pH Signal Conditioning

The source impedance of a pH electrode is very high because the thin glass bulb has a large resistance which is typically in the range of 10 MΩ to 1000 MΩ. This means that the electrode can only be monitored by a high-impedance measuring device. The important sensor characteristics described need to be accounted for in order to design a circuit which will condition the sensor signal so that it can be faithfully utilized by other components (such as an ADC, microcontroller, etc.) along the signal path. First, because the pH electrode produces a bipolar signal and most applications operate on a single supply, the signal will have to be level shifted. Second, due to the high impedance of the electrode, a high-input impedance buffer will be required. Finally, the temperature of the measured solution must be known in order to compensate for the electrode's sensitivity variation over temperature.

3.1.2.6 LCD

LCD is used in this project to monitor temperature value of the system. It is the JHD 162A which has ability to display 16 character data in two lines. Eight bit mode is used to operate the LCD. Since the LCD only use to write data from microcontroller, the R/W will always be low. In this design, the R/W pin is connected to VDD microcontroller.

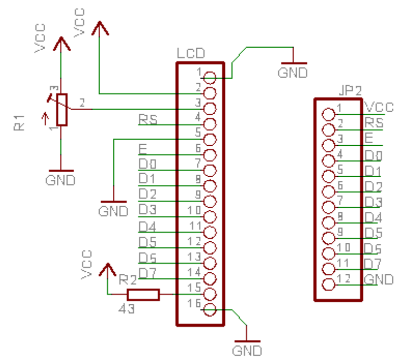

Figure 9 LCD Driver Schematic Design

3.1.2.7 Vexta Driver

A stirrer is used in this system in order to mix the milk and yoghurt starter as well as gaining an isoterm liquid condition. The stirrer speed and movement will be driven by Vexta™ Brushless DC Motor model AXHMO15K-10. It is provided motor speed up to 3000 rpm. In this design, Vexta™ motor movement will be controlled by microcontroller signal using several pins of vexta driver. Those pins are START/STOP, RUN/BRAKE, CW/CCW, and INT VR/ EXT Input. Vexta™ driver board is given in figure 10

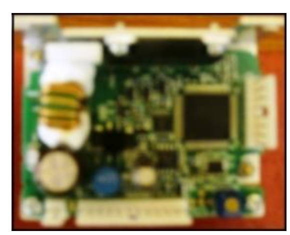

Figure 10 Vexta™ Motor Driver

Fix speed is gathered using internal potentiometer to define required speed by giving low level voltage to INT VR. while giving high level voltage will enable external input to use, such as PWM. If the low level voltage is given to CW/CCW, motor will rotates clockwise. The vexta need 24V source voltage.

Table 2 Motor Action by Giving Varies Logic for START/RUN and RUN/BRAKE pin

No.	START/ STOP	RUN/ BRAKE	Action
1.	0	0	Motor rotates
2.	0	1	Motor stops instantaneously
3.	1	0	Motor stops naturally

The whole circuits of this project is given in figure 11

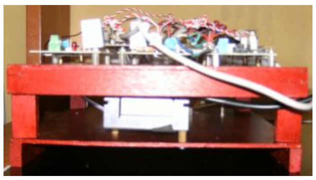

Figure 11 Electronic Circuits of The Project

3.2 SOFTWARE DEVELOPMENT

Digital PID is embedded inside the microcontroller. Software codes is written in C languange using MPLAB IDE 8.0 and MCC18 Compiler by Microchip.

3.2.1 Mathematical Model of the System

In order to implement PID constants, some analysis to define mathematical model of the system before finally gain the PID constants.

The right P, I and D constants determine the system response to reach the set point. In this project, mathematical model of system is analised and thus it is used in PID tuning to get PID constants. The system plant is given in figure 12

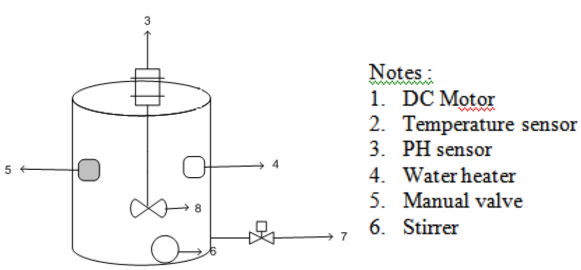

Figure 12 Automatic Yoghurt Making Plant

Heat-balance equation for the tank:

$$\textit{heat input to the system} = \textit{heat increase in the system} + \textit{heat losses}$$

Ignoring the heat loss through manual valve and the heat capacities of the heater element and the mixer, we can write the following equations:

Heat increase in the tank = $(m_1c_1 + m_2c_2)\frac{dT}{t}$ .... (2)

Heat loss from the tank = $hA (T_s - T_a)$ …………… (3)

Where,
m_l = mass of the milk inside the tank (Kg)
m_2 = mass of the stainless steel tank (Kg)
c_l = specific heat capacity of the milk ($JKg^{-1}K^{-1}$)
c_2 = specific heat capacity of the stainless steel tank($JKg^{-1}K^{-1}$)
h = convection heat transfer coefficient ($Wm^{-2}K$)
A = tank surface area (m^2)
T_s = tank surface temperature (K)
T_a = ambient temperature (K)
$\frac{dT}{t}$ = temperature increase in the tank (Ks^{-1})

Thus,

$$E = (m_1c_1 + m_2c_2)\frac{dT}{t} + hA (T_s - T_a) \quad ………(4)$$

If we assume that temperature inside the tank equals to tank surface temperature and ambient temperature is constant, let

$$T_q = T - T_a \quad ….......(5)$$

we can write equation 4 as:

$$E = (m_lc_1 + m_2c_2)\frac{dT_q}{t} + hA (T_q) \quad ....….(6)$$

letting $k_l = m_lc_l + m_2c_2$ and k_2 = hA, and taking the Laplace transforms,

$$\frac{T_q(s)}{E(s)} = \frac{1}{sk_1 + k_2} \quad ...…….(7)$$

Equation (7) describes a first-order system with time constant k_l / k_2. Temperature control systems always exhibit a transportation delay since it takes a finite time for the temperature of the medium to rise.

Based on each value of parameter equation,

$$\frac{T_q(s)}{E(s)} = \frac{1}{306.0155s+0.1465} \quad ....(8)$$

3.2.2 Flowchart

Yoghurt process begins with microcontroller initialisation for input and output port or bits. TRIS command is used to define whether port or bit in a port is an input or output. PID constants also define in this section. The machine will start working when the start button is pressed. There are two temperature close loop control in this system: temperature control for milk heat treatment which control milk temperature 85°C for 30 minutes and mix (yoghurt and starter) fermentation control which control temperature around 42°C. The process will finish after eight hours. The system process description will be broken into several software part. The flowchart of the system is given in figure 13

………. (2)

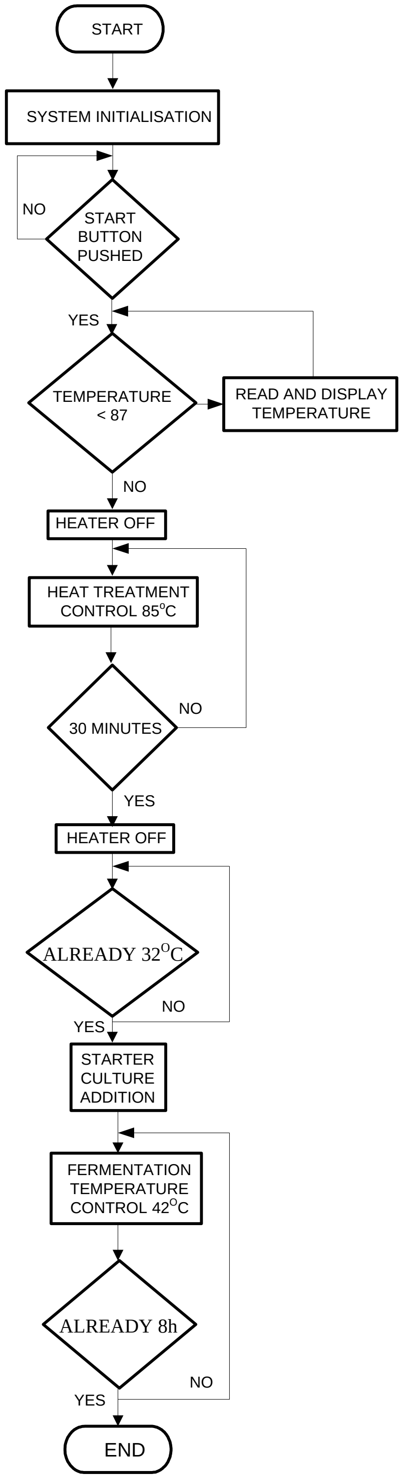

Figure 13Yoghurt Making Process Flowchart

IV. RESULT, ANALYSIS AND DISCUSSION

4.1 Component Testing

4.1.1 Thermocouple and Signal Conditioning

Thermocouple type K sensor to monitor temperature of the plant liquid. The output from thermocouple is connected to signal conditioning circuit to produce sensitivity 10 mV/^{o}C. The data is measured using digital multimeter HELES UX-30. Then, the reading is converted into Celcius. The testing is conducted between the circuit output in V with the output in ^{o}C of "Eutech Instruments pH/mV/^{o}C Meter 300".

Table 3 Temperature Data Comparison Result between Thermocouple Circuit and Eutech Instruments pH/mV/^{o}C Meter 300

No.	Thermocouple Circuit (V - ^{o}C)	Eutech Instrument (^{o}C)	Error
1.	0.3 – 30	30.2	0.2
2.	0.34 – 34	34.0	0
3.	0.38 – 38	38.5	0.5
4.	0.42 – 42	42.3	0.3
5.	0.46 – 46	46.2	0.2
6.	0.52 – 52	52.8	0.8
7.	0.56 – 56	56.6	0.6
8.	0.60 – 60	60.4	0.4
9.	0.64 – 64	64.5	0.5
10.	0.70 – 70	70.1	0.1
Mean error			0.36

4.1.2 Interrupt Signal Generator

The interrupt signal from the interrupt signal generator is given in figure 14

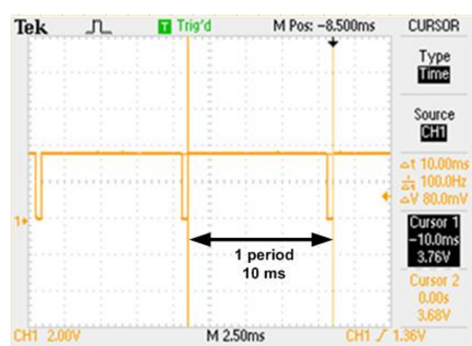

Figure 14 Interrupt Signal, periode=10 ms

Figure 14 show that the interrupt signal has 10 ms period. the transistion from high to low or low to high occured every half cycle period of AC signal. It is because the zero crossing point exist for every half cycle also. Basically, the period of the interrupt signal can be calculated.

fAC = 50 Hz

TAC = $\frac{1}{50}$ = 0.02 s or TAC = 20 ms

For every half cycle the period = 10 ms

Figure 10 shows the interrupt signal high level voltage of 3.68 V. Although it is not the same with microcontroller Vdd which is around 4.9-5 V in the experiment, but the microcontroller still consider this high level voltage as logic 1 since it is still in the range of logic 1 of TTL.

4.1.3 ADC

Temperature data is monitoring by using 10 bit ADC internal in PIC18F4550. AN1 is used as input analog from thermocouple circuit. The testing is conducted in room temperature. ADC setting are right justified and external vref 2.55 V. ADRESH is diplayed to RD3 and RD2, upper bit of ADRESL is displayed to RB5-RB2 while lower bit ADRESL is displayed to RD7-RD4. The result shown that RB2 and RB4 displayed logic 1 (4.96V = vdd) while the other display pin are logic 0 (0V = vss). The thermocouple show 200 mV reading. The result is given in table 4.

Table 4 ADC Result for Room Temperature

ADRESH		ADRESL							
PORTD		PORTB				PORTD			
3	2	5	4	3	2	7	6	5	4
0	0	0	1	0	1	0	0	0	0

The ADC output in voltage can be calculated through formulas:

Step size = $\frac{vref}{ADC\ resolution}$

From table 4 given:

ADC output (V) = ADC bit output

$= \frac{ADC\ bit\ output}{step\ size}$

$= \frac{80}{1024}\ x\ 2.55\ V$

= 0.199 V

Thermocouple output is 200 mV

% error = $\left|\frac{199-200}{200}\right|$ x 100%

= 0.5 %

The ADC output still can be tolerate in measurement because the % error is relative small.

4.1.4 LCD Reading

Temperature value is displayed to LCD to monitor the temperature system process. The LCD is two lines and 16 columns. To display a data in LCD, the data need to be converted to ASCII format. Convertion from char to ASCII can be done by adding '30h' to the char data that will be displayed. An experiment is conducted to compare between LCD reading and thermocouple output measured by digital multimeter 'Heles UX-30' in order to check and develope system design. $|\%\ error|$ then calculated based on the result. Calculation example for a result:

% error = $\left|\frac{Thermocouple\ output - LCD\ reading}{Thermocouple\ output}\right|$ x 100%

= $\left|\frac{30.2-30}{30.2}\right|$ x 100%

= 0.66%

The comparison of gathered data is given in table 5

Table 5 Comparison Between LCD Reading and Thermocouple Output

No	Output (mV)	Output (°C)	LCD (°C)	Error
1	302	30.2	30	0.66
2	321	32.1	32	0.31
3	337	33.7	34	0.89
4	359	35.9	36	0.28
5	379	37.9	38	0.26
6	398	39.8	40	0.67
7	421	42.1	42	0.24
8	435	43.5	44	1.15
9	457	45.7	46	0.66
10	478	47.8	48	0.42
Mean error				0.55

From table 5, it is shown that the mean error for LCD reading compare to thermocouple output is 0.55%. This mean error value is still in tolerate mean error value for a measurement.

4.1.5 SISO Tool Matlab

After defining mathematical model of the system, automated tuning in SISO Tool is used to determine PID constants of the mathematical model of the system given. The mathematical model given is:

$$\frac{T_q(s)}{E\ (s)} = \frac{1}{306.0155s+0.1465}$$

PI compensator equation for the mathematical model given in automated tuning SISO Tool :

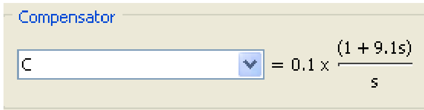

Figure 15 PID Compensator Equation for Given Mathematical Model

PI Compensator equation from figure 15 can be derived:

$$C = \frac{0.1+0.91s}{s}$$

$$= 0.91 + \frac{0.1}{s}$$

Where

$$C = K_p + \frac{K_i}{s}$$

So,

$K_{p=}$ 0.91, K_i = 0.1

4.2 System Testing

4.2.1 On-Off Temperature

In experiment, as the microcontroller execute on-off temperature control function, the heater will on from 30°C until the temperature nearly reach 43°C. Then, heater will off until the temperature reach less than 42°C before it turns on again. The process is repeatable. The temperature respons is given in figure 16

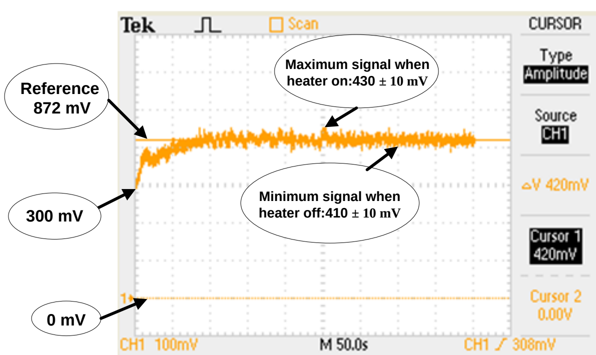

Figure 16 On-Off Control Temperature Response, CH1 100 mV/div, 50s/div

From figure 16, the temperature will rise from 300 mV or 30°C to 420 mV or 42°C in 80 s. Then, the heater will off and temperature will fall down to less than 42 °C. The process will occured repeatably, due to the temperature system value. After a few moment from the starting point, the on-off period will be stable at 70 s. The signal has maximum value 440 mV, 20 mV over from setting point 420 mV or 42°C.

4.2.2 PI Temperature Control

Some experiments to find the right value of PI constants has been conducted around initial setting Kp = 0.9 and Ki = 0.1. Among all experiments, the proper temperature response is gathered from PI constants Kp = 1.1 and 0.3. The temperature will raise from initial temperature 30°C up to setting point 42 °C. The temperature response after 'pi_42' subfunction execution is given in figure 17. The temperature response in steady state is given in figure 18.

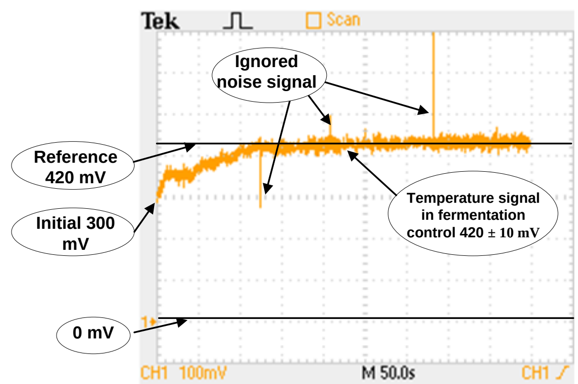

Figure 17 PI Control Temperature Response, CH1 100 mV/div, 50s/div

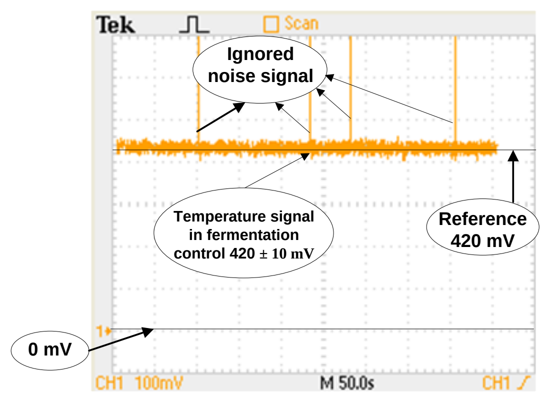

Figure 18 Temperature Response at Steady State

From figure 17, temperature will raise from initial 300 mV or 30°C to setting value 420 mV or 42°C for about 190 s. The vertical signal that comes randomly with a huge differences with most signal is a noise. It is occured because of a fast on-off transition of control signal.

The signal control given to the heater is varies based on error value. Control signal given at initial 30°C is different to control signal given at 42 °C for example. The control signal uk is represented percentage value given to the heater. The bigger uk value, the bigger power given to the heater. For uk =

100, the power given to the heater is 100% while for uk = 40, the power given to the heater is 40%.

In this project, uk signal value has up limit and bottom limit. The upper limit ia 100 while the bottom limit is 0. The heater as an actuator has limitation voltage input. From figure 18, the signal graph show a quite smooth reading. It is steady in value around setting value 42^{o}C. The reading is taken after 470 s. The signal has maximum value 430 or 10 mV over from set point 420 mV.

4.2.3 Comparison Between On-Off and PI

After some experiment has been conducted to both On-Off and PI method to control fermentation temperature, there are some conclusion can be gathered. The comparison is given in table 6

Table 6: Comparison Between On-Off and PI for Fermentation Temperature Control

Parameter	On-Off	PI
Rise Time	64 s	152 s
Settling Time	-	470 s
Noise signal	-	Randomly occured
Overshoot	20 mV (4.76%)	10 mV (2.38%)
Oscillation	Periodically occured every 70s	Oscillate at the beginning of the process before steady

From table 6, fermentation control of on-off control give rise time 64 s while the PI control give 152 s. The difference result is occured since on-off use a maximum control signal 100% connected to the heater while the PI is using pulse width modulation (PWM) that derived from PI calculation based on the error signal value. In term of settling time, on-off control will never reach its settling time since the temperature will swing between 41-43^{o}C. The PI control will maintain temperature around steady state value after 470 s temperature reading from initial temperature.

In term of signal waveform, there is no noise signal produce from on-off temperature control while PI control has noise signal. It is because a fast on-off control signal is interfere with high voltage AC source. The on-off control will have more overshoot compare to PI control since the on-off control implement full heater power to reach the setting temperature while PI control implement varying heater power value based on signal error. In term of oscillation, temperature signal of on-off control will always goes up and down periodically every 70 s while temperature signal of PI control only oscillate at the beginning of the process before finally steady around setting point value 42^{o}C.

Overall, it can be concluded that the PI control give a better system performance compare to on-off control in fermentation temperature control. Noise signal that randomly occured in PI temperature signal can be ignored since it has unsignificance effect on averall system perfomance.

V. CONCLUSION

The system was set up and developed for yoghurt making process requirement. The process already works from the beginning of the process until fermentation control process. The PI algorithm to control fermentation temperature at 42^{o}C give better system performance compare to on-off controller. But, noise signal is occured randomly because of interference AC voltage caused by fast transition on-off control signal. The pH circuit also has not functioned properly. So, the end process indicator is not develop using pH value as an indicator but using estimated 8 hours time to finish.

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Mahasiswi yang satu ini mengambil konsentrasi kontrol di UNDIP tercinta dengan harapan bisa lebih mendalami bidang robotika. Meskipun harapannya belum tercapai tapi dia menemukan keasyikan tersendiri di konsentrasi ini. Motto hidupnya : 'You'll Never Know Till U Have Tried'

Mengetahui,

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