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Process control of milk pasteurization using Geothermal brine under Geothermal brine temperature and flow rate disturbance

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Abstract. Geothermal brine can be used as a heating liquid for pasteurization unit either by directly use the brine to heat up the raw milk, or by heating secondary fresh water. The geothermal brine can be obtained directly from geothermal well or from geothermal power plant separator. Unlike conventional pasteurization, the flow rate and temperature of geothermal brine might fluctuate due to many factors such as rain, well decline, and well shut down. Inherently the geothermal reservoir tends to decline in pressure and temperature. If the geothermal brine is obtained from geothermal power plant, then the flow rate and temperature of geothermal brine itself is susceptible to many changes in plant's operation. A control system is needed for such utilization of geothermal brine. Simulation has been carried out to study the effect of PID feedback controller under geothermal brine temperature and flow rate disturbance. The result shows that PID controller could be used to compensate such disturbance. The PID controller controls milk inlet flow rate to balance the effect of both disturbances.

1. Introduction

Pasteurization can be accomplished by a combination of time and temperature, such as (i) heating the milk to a relatively lower temperature and maintaining it for a relatively long period of time, or (ii) heating milk to a high temperature and holding it for a short time only [1]. Industrial pasteurization process usually use a reliable source of heating, such as natural gas, therefore guaranteeing the stability of heating medium temperature. Waste geothermal brine has a potential to be used as heating source for pasteurization process. Using waste geothermal brine, heating cost could be reduced significantly.

One problem of heating with geothermal brine is that the temperature or the flow rate itself is not regulated. Temperature or flow rate could changes arbitrarily depending on the operation of the geothermal field itself. Heating of domestic water using geothermal brine is easier to do since it's not required a precise heating temperature and duration. In the other hand, pasteurization process requires precise control of temperature and heating duration as it affect processed milk quality. This raise challenge on how to exploit the heating potential of geothermal brine to be used in pasteurization process. This study aims to simulate the effect of temperature and flow rate changes (disturbance) of geothermal brine on milk pasteurization process and develop a process control scheme to maintain pasteurization process's required temperature and heating duration.

2. Milk Pasteurization Process Dynamics Simulation

In previous study [2], transient response simulation using SCILAB's XCOS has been conducted to simulate transient response of pasteurization process in a shell and tube heat exchanger under geothermal brine temperature disturbance only. The pasteurization process, operating condition, and heat exchanger parameter was based on HTST pasteurization process proposed by Jubaedah et al. [3] to be applied in milk factory at Pangalengan, Indonesia (Figure 1). This process does not directly utilize the geothermal brine as the heating fluid in pasteurizer, but rather use secondary water to be heat up by the geothermal brine and then in turn, used as the heating fluid in pasteurization process. Typical operating temperature for HTST pasteurization is 72°C for 15 seconds with temperature tolerance ±0.5°C [4].

The use of proportional controller has also been studied in previous study. The proportional controller acts as milk flow rate regulator to maintain the milk outlet temperature in acceptable range in response to geothermal brine temperature reduction (Figure 2). The result for control scheme simulation with 10 seconds time delay could be seen in Figure 3. Since the controller action was delayed, the milk outlet temperature decreased below acceptable range in the first 10 seconds after disturbance happen. After 10 seconds delay, the proportional controller start to react due to temperature deviation detected by temperature sensor. The milk outlet temperature then slowly climb and reach acceptable range value 60 seconds after disturbance occurred.

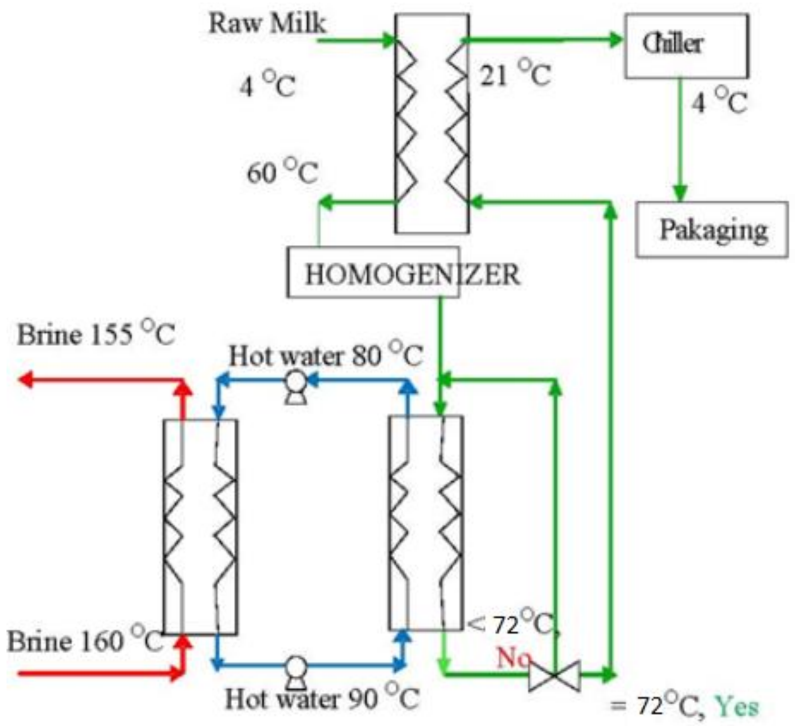

Figure 1. Milk pasteurization process proposed by Jubaedah et al. [2]

The current work aims to study the response of pasteurization process using geothermal brine when both temperature and flow rate of geothermal brine are considered to be disturbance. The equation used in this simulation remains the same as previous work as described by equation (1) to (8). These equation was based on Bunce and Kandlikar (1995) works [5]. Equation (1) and (2) describe the temperature transient response of heat exchanger. Equation (3) and (4) describe the initial condition of hot and cold stream temperature. Equation (5) to (8) describe the left and right boundary condition for both stream.

$$\bar{C}_h \frac{\partial T_h}{\partial t} + C_h \frac{\partial T_h}{\partial \varepsilon} + (\eta_h hA)_h (T_h - T_c) = 0 \tag{1}$$

$$\bar{C}_c \frac{\partial T_c}{\partial t} - C_c \frac{\partial T_c}{\partial \varepsilon} - (\eta_c hA)_c (T_h - T_c) = 0 \tag{2}$$

$$T_h(\varepsilon, 0) = T_{h,in} \tag{3}$$

$$T_c(\varepsilon, 0) = T_{c,in} \tag{4}$$

$$T_h(0, t) = T_{h,in} \tag{5}$$

$$T_c(1, t) = T_{c,in} \tag{6}$$

$$W_h C_{p,h} \left(\frac{\partial T_h}{\partial \varepsilon}\right)_{(\varepsilon=0,t=t)} = W_c C_{p,c} \left(\frac{\partial T_c}{\partial \varepsilon}\right)_{(\varepsilon=0,t=t)} \tag{7}$$

$$W_h C_{p,h} \left(\frac{\partial T_h}{\partial \varepsilon}\right)_{(\varepsilon=1,t=t)} = W_c C_{p,c} \left(\frac{\partial T_c}{\partial \varepsilon}\right)_{(\varepsilon=1,t=t)} \tag{8}$$

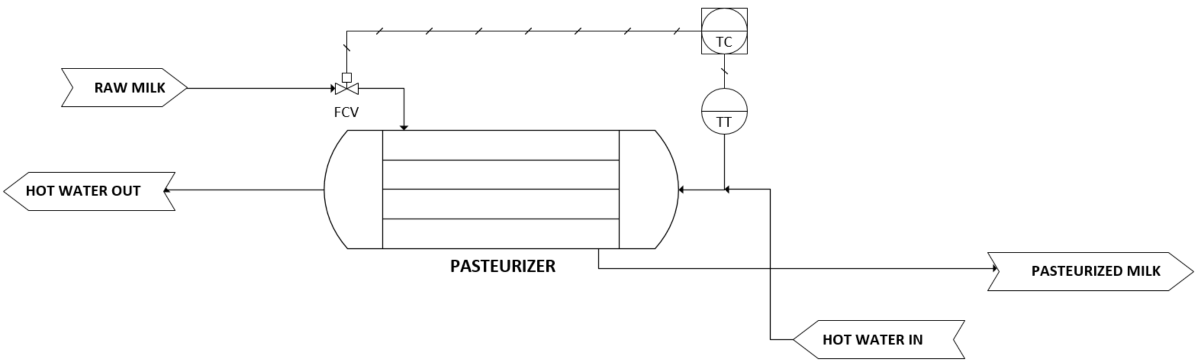

Figure 2. Process control scheme using proportional controller used in previous work [1]

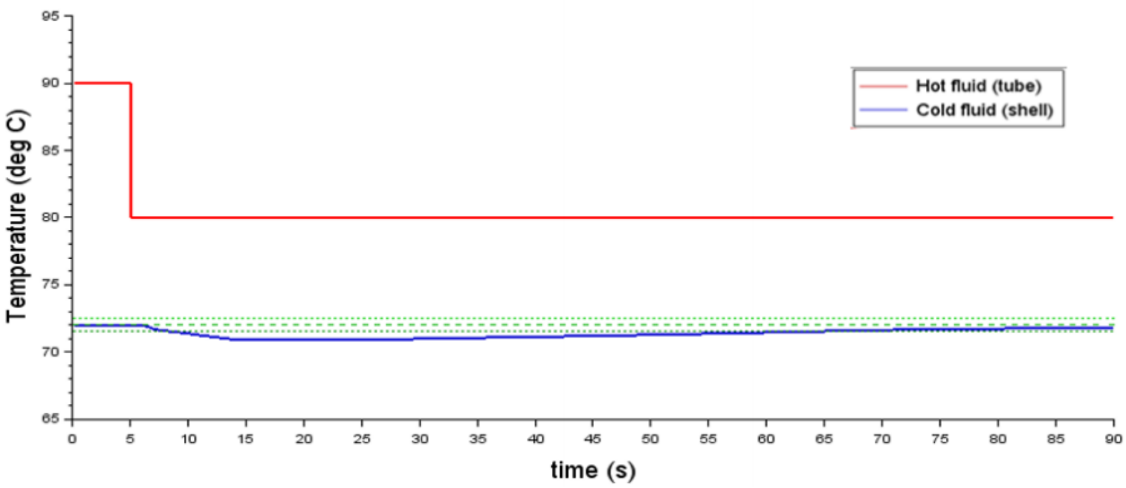

Figure 3. Result of control scheme simulation in previous work with 10 seconds time delay [1]

3. Transient Response with Disturbance

3.1. Geothermal brine temperature disturbance

The purpose of disturbance simulation was to simulate the transient response of heat exchanger when there is a change (disturbance) in geothermal brine (tube side) inlet temperature and flow rate. The simulation uses steady state temperature distribution obtained from start-up simulation as initial condition. Initially, the geothermal brine inlet temperature ($T_{h.in}$) was 90°C. After 5 seconds, $T_{h.in}$ was dropped to a certain temperature. For this simulation, the maximum geothermal brine temperature drop was assumed to be 10°C (90 °C to 80 °C) while the flow rate remains constant. A step change block was used to simulate such disturbance as shown in Figure 4. The response of milk outlet temperature ($T_{c,in}$) was then plotted against time. Figure 5 shows the milk outlet temperature response for two hot water inlet temperature decrease. A 10°C decrease (from 90 °C to 80 °C) of hot water inlet temperature will leads to 4°C decrease of milk outlet temperature.

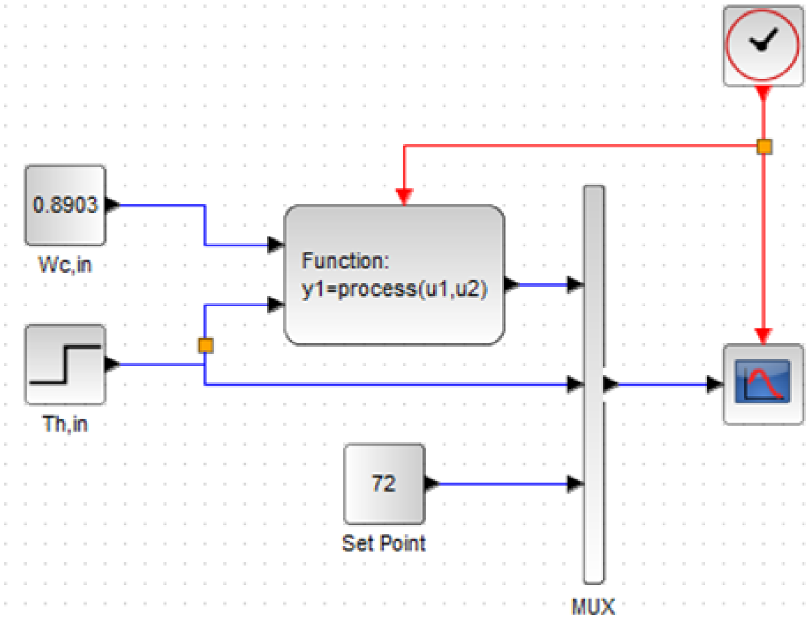

Figure 4. XCOS diagram for disturbance simulation

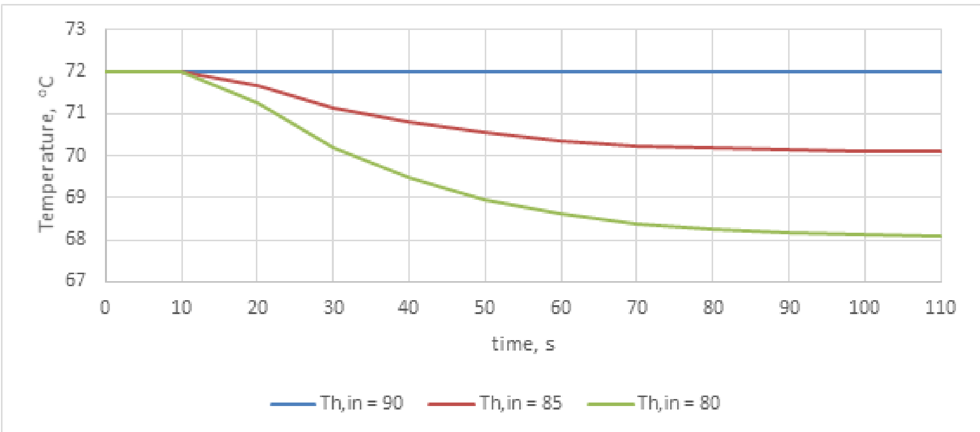

Figure 5. Simulated milk outlet temperature ($T_{c,out}$) response under geothermal brine inlet temperature ($T_{h,in}$) disturbance

3.2. Geothermal brine flow rate disturbance

Similar to geothermal brine inlet temperature disturbance simulation, the geothermal brine flow rate disturbance simulation was conducted by assuming flow rate reduction from 1 kg/s to 0.5 kg/s while the inlet temperature remains constant. The response of milk outlet temperature could be seen in Figure 6. The simulation result shows that 50 seconds after the disturbance happened, the milk outlet temperature reduced to 70°C which is below the ±0.5°C temperature tolerance as indicated by dashed green line.

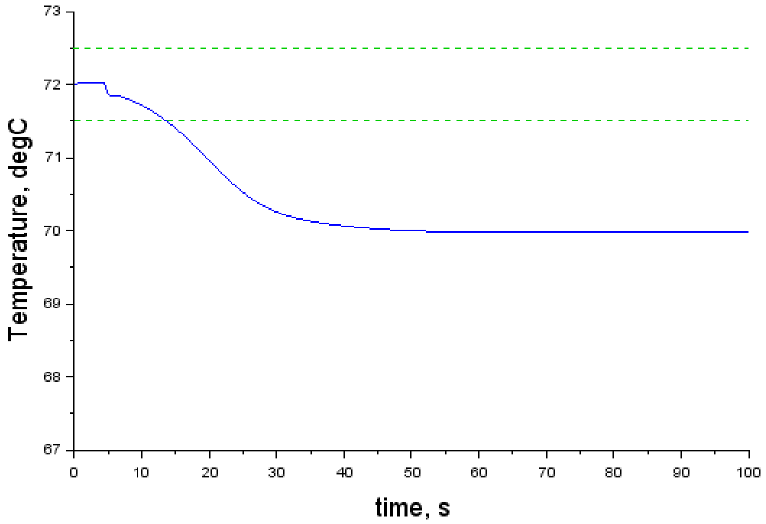

Figure 6. Simulated Milk outlet temperature response under geothermal brine flow rate reduction from 1 kg/s to 0.5 kg/s

3.3. Geothermal brine temperature and flow rate disturbance simulation

The simulation under both disturbance was conducted by simultaneously reducing geothermal brine inlet temperature from 90°C to 80°C and flow rate from 1 kg/s to 0.5 kg/s. Figure 7 shows that under such disturbance the milk outlet temperature dropped to 66.7°C in 60 seconds after both disturbance occurred.

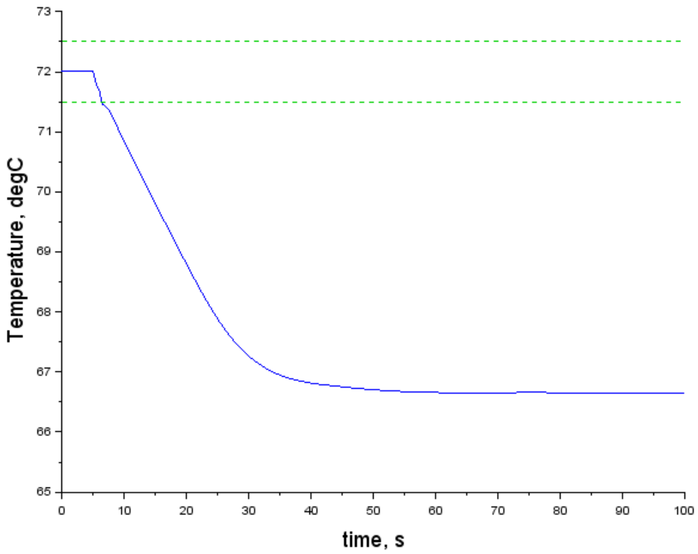

Figure 7. Simulated Milk outlet temperature response under geothermal brine temperature and flow rate disturbance

4. Control Scheme Simulation

There are many control scheme which could be applied on milk pasteurization process under such disturbance. Many controller ranging from ratio controller to fuzzy logic controller available in the market. In this case, we will utilize a simple feedback control scheme using PID controller. In Figure 8, the outlet milk stream from the heat exchanger is constantly being measured by a temperature sensor. The value of measured temperature is then transmitted digitally to temperature controller (PID controller) which also constantly adjusting a flow control valve (FCV) opening to maintain milk outlet temperature in a tolerable temperature range by regulating the milk inlet flow rate.

The PID controller reacts based on the error value, which is the difference between measured temperature and a temperature set point (in this case 72°C). When the error value is zero, no adjustment is done to the FCV by the PID controller. When the error value is not zero (may be plus or minus), the PID controller adjust the FCV opening based on the magnitude of error value until the error value reach zero. The PID controller itself has three parameter which can be adjusted to determine how will the PID controller reacts to the error value, these parameters are called Proportional, Integral, and Derivative term (hence the name PID controller).

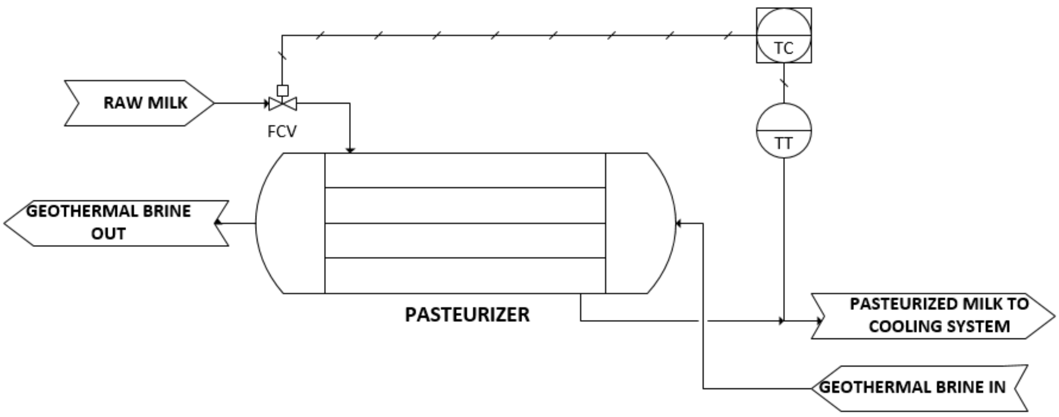

Figure 8. Feedback Control scheme using PID controller

The control scheme simulation include disturbance in both geothermal brine temperature and flow rate. The geothermal brine temperature was reduced from 90°C to 80°C while the flow rate was reduced from 1 kg/s to 0.75 kg/s simultaneously at t = 5s. Milk inlet flow rate was also restricted to an assumed minimum value of 0.445 kg/s (or 50%). Figure 9 shows the XCOS diagram to simulate such process dynamics. For this case, the Proportional, Integral, and Derivative term has been set to 1, 1, and 0 respectively.

The results of this simulation is shown in Figure 10 and Figure 11. Figure 10 shows how the milk outlet temperature reacts to both disturbance. At t = 5s, the disturbance occurred. The milk outlet temperature also dropped to 71.5°C after the disturbance. Since this drop of temperature triggers a non-zero value of error, the PID reacts by reducing the milk inlet flow rate as can be seen in Figure 11. The PID controller response is somewhat fluctuate since the PID controller tries to suppress the error value back to zero as soon as possible. At t = 150s (145 seconds after disturbance), the milk outlet temperature reach a constant value of 72°C. Also, the PID controller manage to maintain the milk outlet temperature inside the $\pm$0.5°C acceptable temperature range.

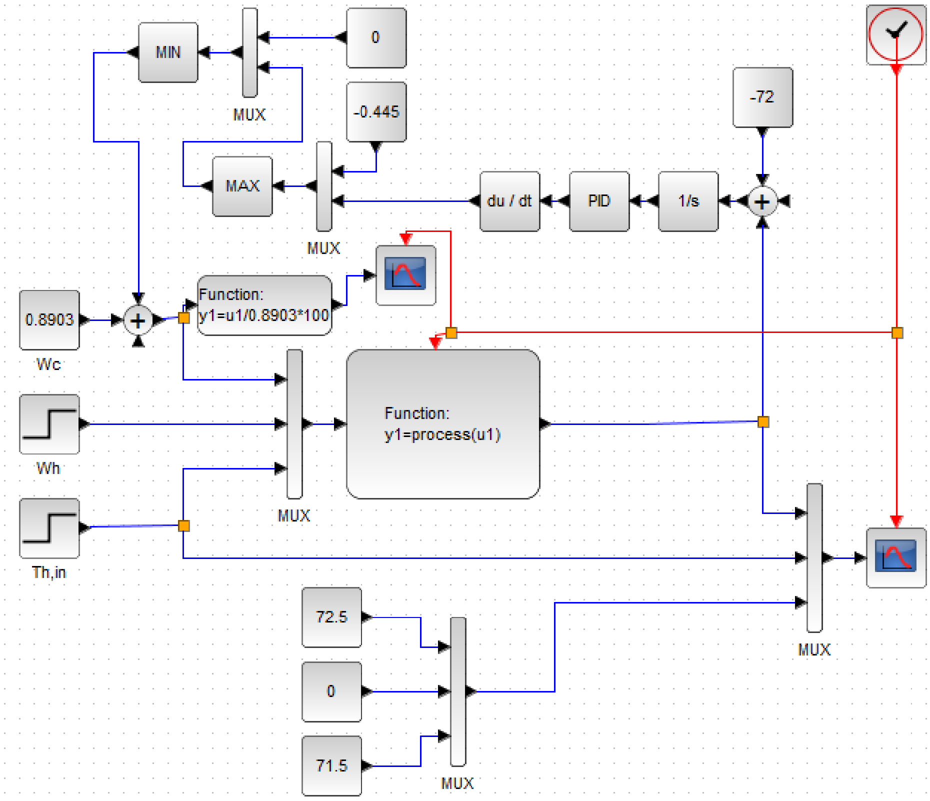

Figure 9. XCOS representative diagram for feedback control scheme using PID controller

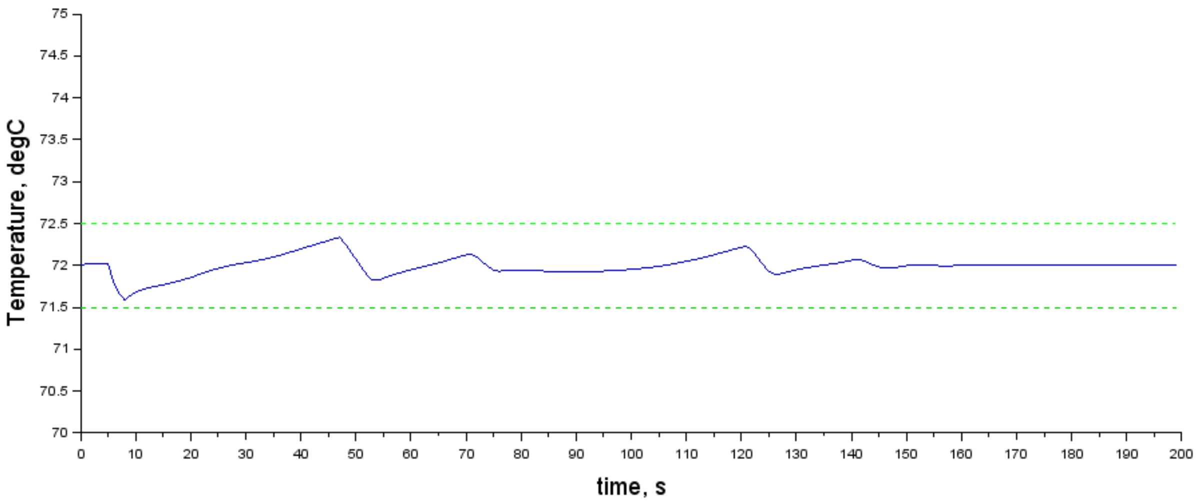

Figure 10. Simulation result of regulated milk outlet temperature response under geothermal brine temperature and flow rate disturbance

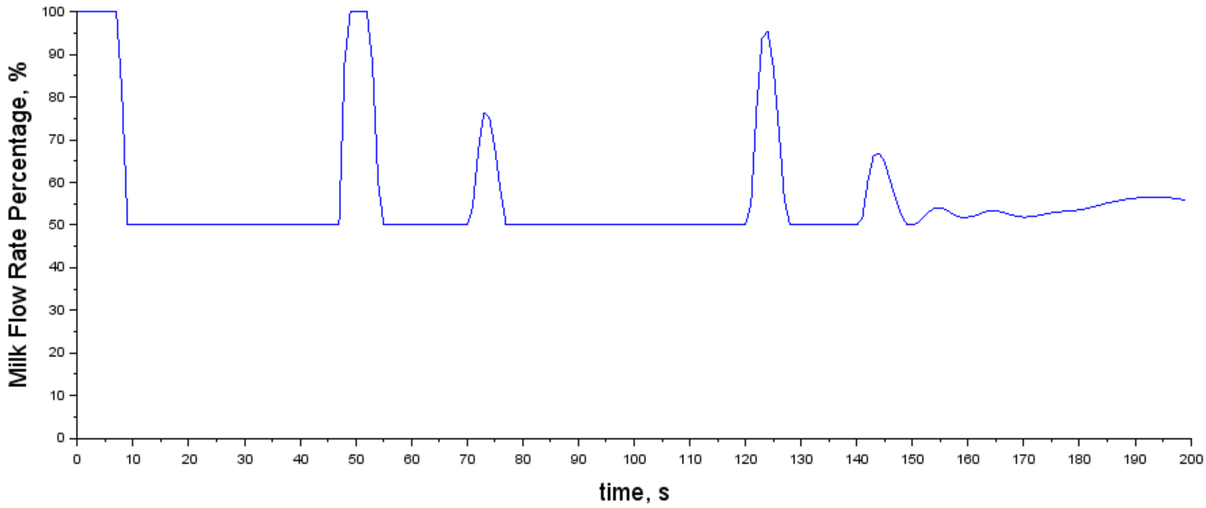

Figure 11. Simulation result of controlled milk inlet flow rate

5. Conclusion

The result shows that feedback control using PID controller is adequate for milk pasteurization process control using geothermal brine with shell and tube heat exchanger. This automatic control may aid and provide ease of operation for milk pasteurization using geothermal brine if the brine supply is not secure. This control system is not meant to be used alone since it only compensates the reduction of geothermal brine inlet temperature and flow rate. This control system might be used with FDV control system to control the quality of pasteurization process. A more thorough mathematical model also needed for a better simulation accuracy. For example, heat transfer through tube wall should be taken into account to obtain a more accurate result. Note that the simulation was conducted without any time delay of measured variable. In reality, the PID controller will receive the measured temperature signal after a fraction of seconds, or even more if the measurement device itself is not in a perfect condition. The time delay will usually cause the PID controller to give a lag and more fluctuating response.

6. Nomenclature

W	Mass flow rate
C_p	Heat capacity
M	Mass of fluid or wall material in heat exchanger
$\bar{C}$	Heat capacitance = MC_p
C	Heat capacity rate = WC_p
T	Temperature
t	Time
L	Length
x	Distance
h	Heat transfer coefficient
A	Heat transfer area
η	Fin efficiency
Kc	Proportional controller coefficient

Subscript

h	Hot fluid
c	Cold fluid
w	Heat exchanger wall
in	inlet

References

[1] Ramesh M N 2007 *Pasteurization and Food Preservation in Handbook of Food Preservation 2nd edition* (Boca Raton: CRC Press) pp 571-579
[2] Widiatmo J S and Hendrasakti J 2018 *Process Control of Milk Pasteurization using Geothermal Brine with Proportional Controller* (Stanford: Proceeding Stanford Geothermal Workshop 2018) pp 1 - 9
[3] Jubaedah E, Bambang T P, Abdurrachim 2015 *Study of Geothermal Utilization for Milk Pasteurization in Pangalengan, Indonesia* (Melbourne: Proceeding World Geothermal Congress 2015) p 5
[4] Smith P T 2011 *Introduction to Food Process Engineering 2nd edition* (Springer)
[5] Bunce D J and Kandlikar 1995 *Transient Response of Heat Exchangers* (New York: Rochester Institute of Technology) pp 1-2