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Regulatory performance of two different tuning methods for milk cooling control system

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Abstract. Temperature is one of the essential factors for bacterial growth in milk. The higher the temperature, the faster the growth of bacteria. It is empirically proven that the bacteria will stop growing at the temperature of about 4˚C. In this research, continuous milk cooling process was simulated and then controlled by using Proportional - Integral (PI) feedback control system. The regulatory performance of the two different tuning methods were then analyzed (i.e Tyreus - Luybean and Hagglund – Astorm). Their SSE (sum squared of errors) were compared. It was found that Tyreus – Luyben method gave better regulatory performance than Hagglund – Astorm.

1. Introduction

Milk is collected, transported and delivered to milk cooling centres in a number of ways, as shown in Figure 1.

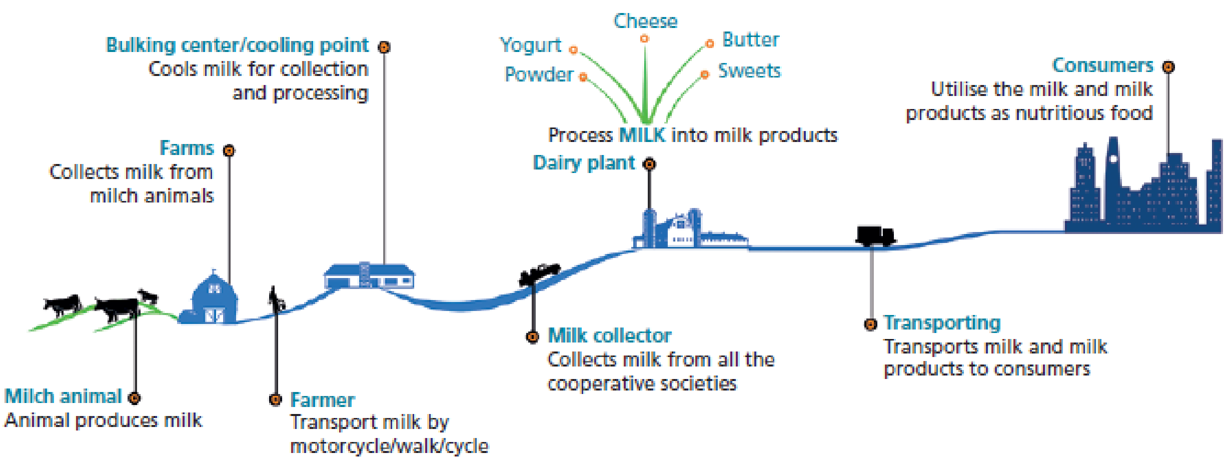

Figure1. Rural dairy collection [1]

Warm fresh milk should be cooled immediately after milking to preserve the quality and prevent spoilage. Cooling to 4˚C within 3 to 4 hours is essential, but more rapid cooling is much preferred [1].

Normally, milk arrives at the milk cooling centres in the morning and late in the afternoon / early evening. Therefore, batch milk cooling is performed as such in cooperatives (i.e Koperasi Unit Desa SAE in Pujon, KUD Batu and elsewhere). However, in this study continuous milk cooling process was simulated as it was more applicable for larger capacity and it gave more rapid cooling.

Proportional Integral (PI) controllers were the most commonly used form of Proportional Integral Derivative (PID) controllers, accounting for over 90% of industrial PID applications. Tuning a PI controller involved setting the controller gain (k_c) and the reset time (τ_I) [7]. There was a strong evidence that PI and PID controllers remained poorly understood and, in particular, poorly tuned in many applications [9].

The aim of this research was to compare regulatory performance of two different tuning methods (i.e Tyreus - Luyben and Hagglund – Astorm) for controller parameter determination while servo performance for this application had been published elsewhere [2].

2. Simulation

The system being studied was the milk cooling system at Koperasi Unit Desa SAE Pujon [2] as shown Figure 2 and 3.

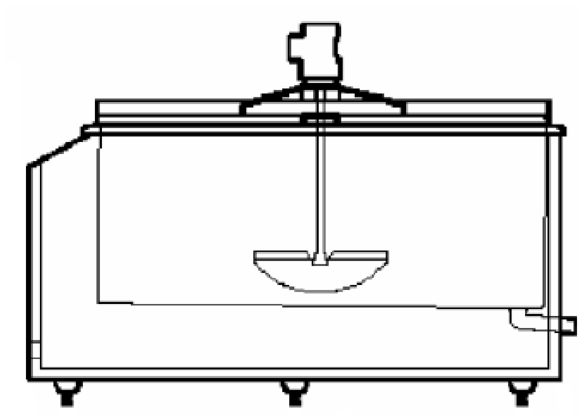

Figure 2. Milk cooling system seen from side

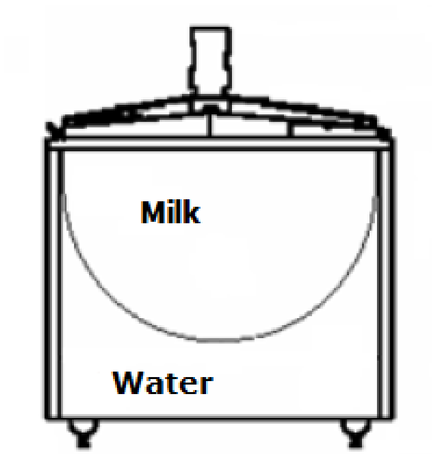

Figure 3. Milk cooling system seen from the front

For continuous system with Proportional – Integral (PI) controller installed as shown in Figure 4, its mathematical model can be derived based on energy balance. The final model in Laplace Transform is shown below [2]:

$$T_0(s) = \frac{T_i(s)}{\left(\frac{m}{w_s}s+1\right)} - \frac{\frac{Q(s)}{w_s C_p}}{\left(\frac{m}{w_s}s+1\right)} - \frac{\frac{(T_{0,s}-T_{i,s})W_s}{w_s}}{\left(\frac{m}{w_s}s+1\right)} \quad (1)$$

Where:

$W_s =$ milk flowrate (kg/min)

$T_{0,s} =$ steady state temperature of inlet milk (˚C)

$T_{i,s} =$ steady state temperature of outlet milk (˚C)

$m =$ mass of inlet milk(kg)

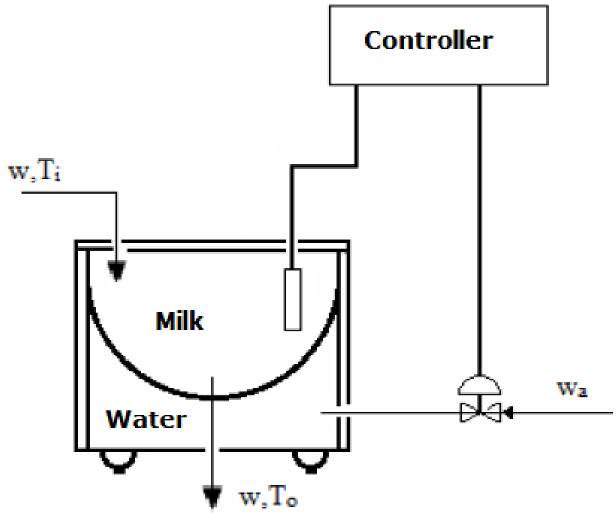

Figure 4. Continuous milk cooling system

The data for milk is as follows:

$$C_p = \text{heat capacity of milk} = 3.93 \ \frac{kJ}{kg.K} \quad (2)$$

$$\rho = \text{density of milk} = 1027 \ \frac{kg}{m^3} \quad (3)$$

Table 1 shows data at steady state.

Table 1. Steady state data

Parameter	Value	Unit
V_{milk}	2500	L
T_i	36	˚C
T_0	4	˚C
T_1	-13	˚C
T_2	0	˚C

Tyreus – Luybean Tuning Method

PI or PID parameters can be determined by using equation as shown in Table 2 [3-4], where:

k_{cu} = ultimate gain

P_u = ultimate period

P_u and k_{cu} are similar to those in Ziegler – Nichol method and detail can be read elsewhere [5-7].

Table 2. Tyreus – Luyben settings [3,4]

Controller	k_c	τ_I	τ_D
PI	$\frac{k_{cu}}{3.2}$	$2.2P_u$	-
PID	$\frac{k_{cu}}{2.2}$	$2.2P_u$	$\frac{P_u}{6.3}$

Hagglund – Astorm Tuning Method
Setting PI controller for Hagglund – Astorm is using equation below [8]:

$$k_c = \frac{1}{K}\left(0.14 + 0.28\frac{\tau}{\theta}\right) \quad (4)$$

$$\tau_I = \theta\left(0.33 + \frac{6.8\tau}{10\theta + \tau}\right) \quad (5)$$

Where:
K = process gain
θ = process time delay
τ = process time constant

3. Results and Discussion

Tyreus-Luyben is quite similar to Ziegler Nichols method. There are two methods in obtaining k_{cu} (ultimate gain) and P_u (ultimate periode). For simplicity, we chose plotting Bode diagram of open loop system (which depends on parameters of the process) [5]. Therefore, both Tyreus-Luyben and Hagglund-Astorm were basically model based control methods. The values for time delay were assumed ranging from 1 to 5 min so that both tuning methods could be applied. Table 3 shows the values for controller parameters obtained.

Table 3. Controller parameters

Time Delay	Controller Parameters	Tyreus - Luyben	Hagglund - Astorm
1	k_c	-10209	-2834
	τ_I [min]	4.2	5.4
2	k_c	-6200	-1441
	τ_I [min]	6.9	8.7
3	k_c	-4894	-977
	τ_I [min]	8.8	10.9
4	k_c	-3674	-745
	τ_I [min]	11.7	12.6
5	k_c	-2954	-606
	τ_I [min]	5.5	14.0

Most commercial PID controllers use a controller gain, k_c (or proportional band, PB) that is expressed as a standard dimensionless %/%. But k_c actually has units of (% of CO signal)/(% of PV signal). In a precise mathematical world, these units do not cancel [10]. However, as most process control paper do [5,6,11], we also did not show the unit.

In this research, direct acting controller was applied, but as we can see from its transfer function: $\frac{T_o}{Q}$ was negative, therefore the controller gain should be negative. Tuning parameter was based on servo problem but tested for regulatory problem. Hence the process model : $\frac{T_o}{Q}$ was still used.

At certain times, the temperature of inlet milk (T_i) was disturbed in the form of step function of -2˚C (form its steady state value) at t = 35 min and at 3˚C at t = 60 minutes. When interference was given, the output would move away from its setpoint but would be back immediately. These disturbances may affect the output milk temperature and the amount of heat released (Q).

Figure 5 shows profile of output milk temperature (T_0) and its setpoint when such disturbances of inlet milk temperature (T_i) occurred. Profile of heat released (Q) was also shown. This figure was for one min time delay assumption and using Tyreus-Luyben. Profile for T_0 and Q under similar disturbances are shown in Figure 6 for Hagglund–Astorm tuning method. Again, one minute time delay assumption was applied. Simulations were then continued for other time delay values (i.e time delay = 2 to 5 minutes). The figures similar to figure 5 and 6 could also be generated. The sum squared of errors (SSE) values for both method and all time delay assumptions are listed in Table 4. Both methods were successful in term of disturbance rejection, but Tyreus – Luyben gave smaller values of SSE.

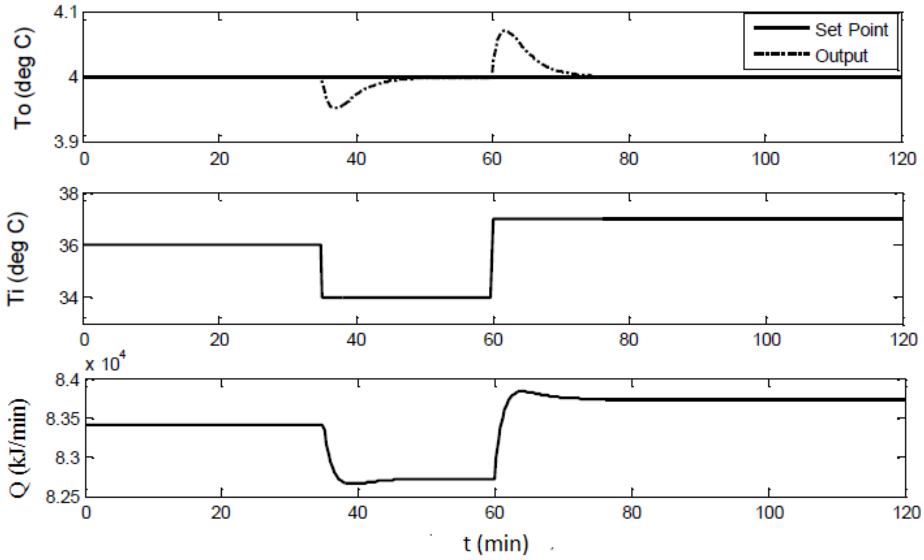

Figure 5. Profile of outlet milk temperature (T_0) and heat released (Q) for 1 min time delay assumption using Tyreus - Luyben tuning method

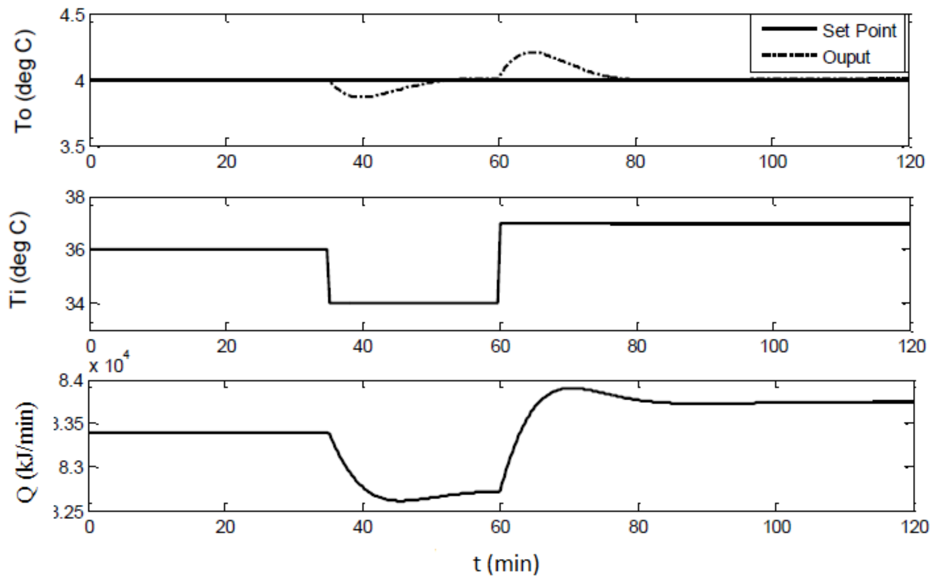

Figure 6. Profile of outlet milk temperature (T_0) and heat released (Q) for 1 min time delay assumption using Hagglund – Astorm tuning method

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Table 4 also shows that small value of time delay assumption were preferred since the higher the value, the higher their SSE values (other error definitions for comparing the performance of different tuning methods such as IAE, ITAE, ISE could also be applied [6]). Looking at the controller parameters between the two methods in Table 3, it seems Tyreus – Luyben has higher values of k_c and lower values of τ_I compared with one of Hagglund - Astorm. Therefore PI controller based on Tyreus - Luyben should be better than that of Hagglund - Astorm.

Table 4. SSE (sum squared of errors) values of outlet milk temperature

Time Delay	SSE	
(min)	Tyreus - Luyben	Hagglund - Astorm
1	0.0953	1.4872
2	0.4117	8.1972
3	0.8057	17.5491
4	1.7406	27.2457
5	3.0064	36.5148

4. Conclusions

Feedback control system using PI controller has been applied for continuous milk cooling process. Two methods of tuning have been investigated (i.e. Tyreus – Luyben and Hagglund – Astorm) and both gave satisfactory results for regulatory performance. However, it seems that Tyreus- Luyben was slightly better because it gave smaller SSE values than Hagglund Astorm. It is also recommended that small time delay assumption is used instead of higher values.

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