Glycerin Bleaching Process Control Structure

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Abstract— **This paper deals with the possibility of controlling the glycerin bleaching process that would improve the bleached glycerin quality using proportional-integral-derivative (PID) controller. An ideal and alternative PID control structures was analyzed. The controller parameters were adjusted and evaluated based on the available and well-known tuning methods. The results show that the glycerin bleaching process control can be best achieve by using modified PID control structure with integral time absolute error (ITAE) (load) tuning method.**

Index Terms—GLycerin bleaching process, tuning, PID controller

I. INTRODUCTION

GLYCERIN is a by-product of vegetable or animal fats and oils that become more attractive as it has a commercial value for pharmaceutical, food and plastic industries. In Malaysia, the highest potential source for crude glycerin production is from palm oil and fat hydrolysis and transesterification process. Bleaching process is a process of removing the undesirable substances presence in the crude glycerin that contribute undesirable effects to the quality of the end-product such as free-fatty acids (FFA), gummy materials and coloring pigments [1]. Bleaching process is a critical step in purification process and can be carried out using biological, chemical or physical method. In oil industries, the bleaching aspect is best performed by adsorption method in which involving the application of adsorbent or bleaching agent to the process. In general, bleaching process significantly depends very much on the properties of oil to be bleached, the operating temperature, dosage and type of adsorbent used [2]. Mechanically, the process is carried out by adding adsorbent to a vessel containing contaminated oil, stirring the mixture to achieve good contact of adsorbent with the oil and maintaining the temperature for a sufficient time, then letting the adsorbent settle, and drawing off the bleached oil. Amongst the stages, heating process is the crucial stage as the application of heat to fats and oils will creates more formation of hydro-peroxides and secondary oxidation products. The hydrolysis of free-fatty

Acids affects the total chlorophylls, carotenes and alpha-tocopherol contents which clearly decrease the nutrition value as the temperature increases [3-5].

Research conducted by M. Rossi et al. (2001) [6] had shown that the color of the finished palm oil is totally depending on the temperature as compared to the treatment with adsorbent clays and synthetic silica. However, very long heating process and sudden changes in temperature may affect the quality of output product. Therefore the method of heating process and controlling the temperature should be carefully design which can significantly impact on reducing energy consumption and improving product quality. In order to obtain a good quality of bleached glycerin, a good controller for the process is much needed. Better control performance can give better yield of the pure glycerin.

In control system, despite the introduction of many sophisticated control techniques, the majority of industrial processes are still dominated by the implementation of the proportional-integral-derivative (PID) controller with proven success in delivering control solution over six

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decades [7-9]. This is because the wide range of operations carried out in process industries suggests that control strategies and systems will need to be robust enough to be used, yet be simple enough so that they can be implemented and used by non-experts.

This paper presents the possibility study of controlling the glycerin bleaching process to improve the bleached glycerin quality by using different structure of PID controller with appropriate tuning rule.

II. System Description

The control of the specific glycerin bleaching process plant which is installed at the DCS laboratory in UiTM, Shah Alam is a significant application to demonstrate the challenges and difficulties in dealing with a real world delay time process.

The reactor tank is the important part of the process plant as this is where the process variables are measured and controlled. Fig. 1 shows the simplified diagram of the process control system. The percentage of color reduction of the glycerin is directly related to the amount of heat released inside the tank. Therefore, by controlling the temperature in the tank, the percentage of color reduction can be determined.

The temperature of the crude glycerin in the tank has to be kept as low as possible but high enough to yield the desired final product. In this process, the temperature is maintained at 85°C under constant agitation speed of 480rpm. In the existing system, the bleaching took about 2 to 3 hours to complete the process in which will degrade the bleached glycerin.

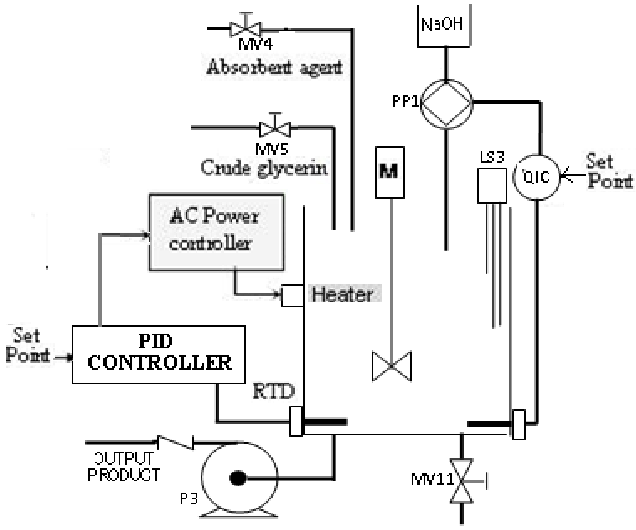

Fig. 1 Glycerin bleaching temperature control system

The temperature detector, Pt100 RTD is inserted into the reactor tank within reasonable thermal distance of the heaters such that it will respond to the changes in the temperature of the glycerin in the reactor. The reactor tank is insulated with a suitable fiber and aluminum foil so that the heat from the heaters accumulates in the reactor and drives the reactor temperature higher.

The motorized agitator, M is installed at the middle of the tank so that the glycerin is completely and homogenously mixed. The purpose of this installation is also to provide sufficient thermal transfer between heaters and the glycerin in the tank. The stirring speed is kept constant at 480rpm so that its turbulence does not adversely affect the measured temperature. The type of heater used for the system is the band heater equipped with ceramic or mineral insulation to reduce heat loss to the environment. The heater is controlled via 4-20mA control signal injected to AC power controller.

III. Process Model

Usually, a model is estimated by the step test data from open loop process and it is used to design the controller. This procedure is widely used in industry [10]. As the model is linear, it can be analyzed through the superposition principle, that is the total response at a given time resulting from two or more signals is the sum of the responses which would have been resulted from each signal individually. For temperature model, a step signal is applied to the input of the system.

The open loop system and its equivalent block diagram are as shown in Fig.2. For the sake of simplicity, the process is handled as a single-input single-output (SISO) system whose input to the process, U(s) is the current signal to drive heating element and the output, Y(s) is the temperature of the process.

In this process, inlet volumetric flows, liquid densities and heat capacities are assumed constant. The mixture in the tank is assumed to be well mixed and the tank is well insulated that is there are negligible heat losses to the surroundings. Finally, the energy input by the stirrer is also assumed negligible.

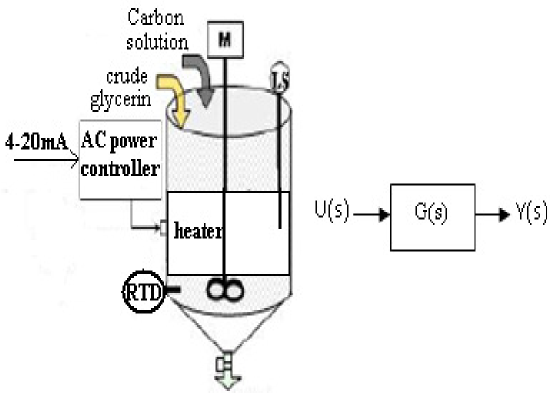

Fig. 2. Open loop system and its equivalent block diagram.

The step test was carried out by applying 15% step input change to the process with the control loop opened. In this experiment, the initial temperature was at 25°C. The dynamic response of the process was recorded and a process model was estimated from the data.

The process model chosen to represent the dynamic of glycerin bleaching process is the first order plus dead time (FOPDT) because this model is widely used for controller tuning and its relative time delay to time constant ratio able to indicate the difficulty level of control [10]. Processes with large time delay to time constant ratio are more difficult to control. The FOPDT model in transfer function form is as shown in Equation (1) in which the process gain (k), dead time (L) and process time constant (T) are estimated through the process dynamic response.

$$G(s) = \frac{k}{Ts+1} e^{-Ls} \tag{1}$$

IV. PID CONTROLLER

The most dominant PID control algorithm used in research [7-9, 12] was the ideal PID controller which calculates the control signal, u based on the error, e as shown in Equation (2).

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int e(t)dt + T_d \frac{de(t)}{dt} \right] \tag{2}$$

Applying the Laplace transform, the transfer function of PID controller becomes

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \tag{3}$$

where K_p is the proportional gain, T_i is the integral time constant and T_d is the derivative time constant. The ideal control structure for PID controller [9] is as shown in Figure 3.

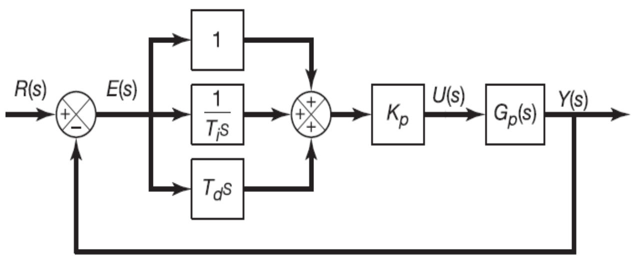

Fig. 3. Ideal PID Controller structure.

The ideal structure of PID controller given in Equation (3) also known as feedback on error system and cannot be implemented because U(s)/E(s) are improper. In this case, a low pass filter or median filter is normally implemented with filtering constant, $\alpha \in [0,1]$ as shown in Equation (4).

In practice, 80% of PID controllers in use have the derivative term switched off. However, proper use of the derivative action can increase stability and help maximize the integral gain for better performance.

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s} + \frac{T_d s + 1}{\alpha T_d s + 1}\right) \quad (4)$$

Figure 4 shows the modified PID control structure in which the derivative term in control loop is relocated. The algorithm is as shown in Equation (5).

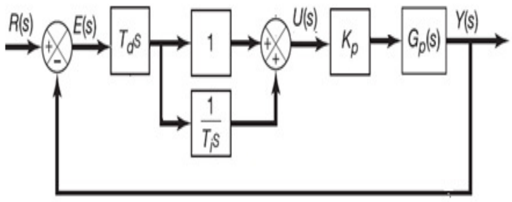

Fig. 4. Modified PID control structure (D-PI Controller)

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p\left(\frac{T_d s + 1}{\alpha T_d s + 1}\right)\left(1 + \frac{1}{T_i s}\right) \quad (5)$$

An alternative of ideal PID control structure is as shown in Figure 5.

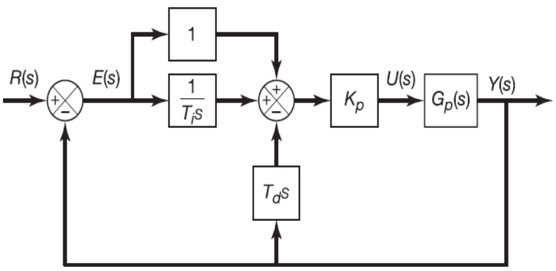

Fig. 5. Alternative PID control structure.

In this control structure, the set point and the process response are treated separately. The derivative parameter is being driven only from process response. The error signal drives the proportional and integral elements. The resulting signals are added together and used to drive the process plant. The appropriate control algorithm is as shown in Equation (6).

$$G_{PID}(s) = \frac{U(s)}{E(s)} = \frac{K_p\left(1+\frac{1}{T_i s}\right)}{1+K_p\left(1+\frac{1}{T_i s}+\frac{T_d s+1}{\alpha T_d s+1}\right)} \quad (6)$$

V. PID TUNING

Controller tuning is referred to the adjustment of the controller parameters so that the control system meet given performance specifications. Good controller tuning is an important component of improved system. Ziegler-Nichols tuning rules are the first and most well-known tuning method widely used in process control industries to determine the parameters of a PID controller [11]. The tuning of the PID controller remain a topic of current control research that contribute to improve the controller performance, and there exits a collection of tuning methods [11-13]. The formulae for optimum PID setting using well-known methods [10, 13] are as shown in Table I.

TABLE I
TUNING METHODS

Tuning Method	K_c	T_i	T_d
Ziegler-Nichols	$\frac{1.2}{k\frac{L}{T}}$	$2L$	$0.5L$
Cohen-Coon	$\frac{T}{kL}\left(1+\frac{L}{3T}\right)$	$\frac{(32T+6L)L}{13T+8L}$	$\frac{4LT}{11T+2L}$
ISE	$\frac{1.49}{k}\left(\frac{L}{T}\right)^{-0.945}$	$\frac{T}{1.101}\left(\frac{L}{T}\right)^{-0.771}$	$0.560T\left(\frac{L}{T}\right)^{-1.006}$
ITAE (Set point Criterion)	$\frac{0.965}{k}\left(\frac{L}{T}\right)^{-0.855}$	$\frac{T}{0.796+(-0.147)\left(\frac{L}{T}\right)}$	$0.308T\left(\frac{L}{T}\right)^{0.9292}$
IAE (Disturbance Criterion)	$\frac{1.435}{k}\left(\frac{L}{T}\right)^{-0.921}$	$\frac{T}{0.878}\left(\frac{L}{T}\right)^{-0.749}$	$0.482T\left(\frac{L}{T}\right)^{-1.137}$
ITAE (Disturbance Criterion)	$\frac{1.357}{k}\left(\frac{L}{T}\right)^{-0.947}$	$\frac{T}{0.842}\left(\frac{L}{T}\right)^{-0.738}$	$0.381T\left(\frac{L}{T}\right)^{-0.995}$
IMC	$\frac{T+\frac{L}{2}}{k\left(\lambda_{IMC}+\frac{L}{2}\right)}$	$\frac{L}{2}+T$	$\frac{TL}{2\left(\frac{L}{2}+T\right)}$
Wang's Tuning Method	$\frac{\left(0.7645+\frac{0.6032T}{L}\right)(T+0.5L)}{k(T+L)}$	$T+0.5L$	$\frac{0.5TL}{T+0.5L}$

The factor that contribute to the increasing interest in proposing further tuning rules is because the available methods do not mean it is always the best for every application in which specific method might be effective for a specific plant model as the most of the methods are derived based on the local dynamic behavior of the particular processes at the time of tuning and therefore apply well only to their own areas.

The rise in the accumulation of tuning rules resulting from the lack of comparative analysis in the performance and robustness of closed loop systems compensated with controllers whose parameters are chosen using available tuning methods. Therefore a critical analysis of available tuning rules relevant for glycerin bleaching process is discussed rather than the proposal for further tuning rules.

In this work, these tuning methods were comparatively analyzed for glycerin bleaching process considering ideal, modified and alternative PID control structures in which the filtering constant was chosen between 0.05 and 0.2.

VI. RESULTS

The response for glycerin bleaching process corresponds to the input signal when performing open loop test is as shown in Fig. 6.

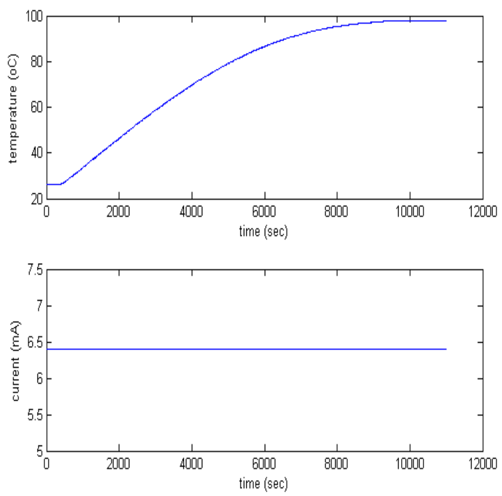

Fig. 6. Open loop test process response.

The plot covers the entire test period from the introduction of the step test until the system reaches a steady state [14]. It is found that process gain, k = 4.8, process time constant, T = 3397 sec and dead time, L = 420 sec. Based on these parameters, the process model was identified and the controller was tuned as shown in Table II.

TABLE II
CONTROLLER PARAMETERS USING DIFFERENT TUNING METHODS

Tuning Methods	Kp	Ti	Td
Ziegler-Nichols	2.0220	840	210
Cohen-Coon	1.7545	983.0197	149.3695
ISE	2.2455	615.6853	232.2685
ITAE(load) Criterion	2.0468	862.5672	161.7013
Wang's Tuning	1.1110	3607	197.7738

The process control performance for different PID control structure was evaluated in term of percent (%) overshoot, settling time and rise time as shown in Table III and Table IV.

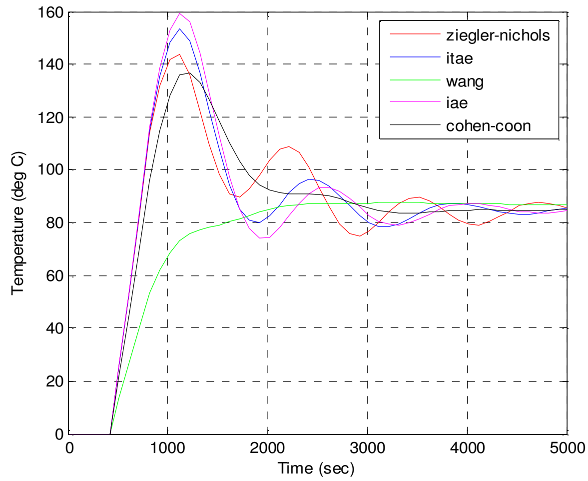

Fig. 7. Step response using ideal PID control structure

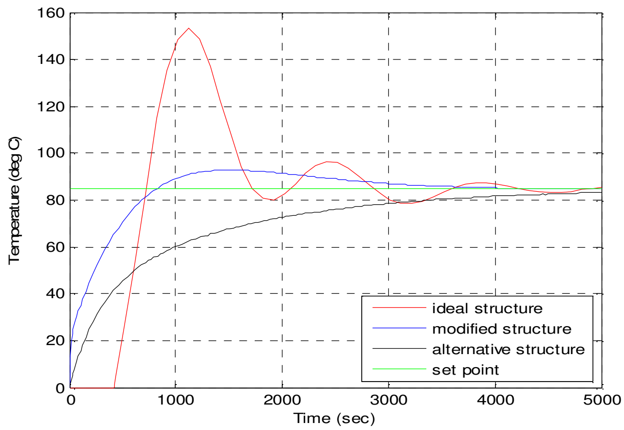

Fig. 8. Step response using ITAE (load) tuning method

Fig. 7 shows the process response for different tuning methods using ideal PID control structure. The results showed that the overshoot appears in the output for all tuning methods. This overshoot appears as expense of achieving a better load disturbance rejection. However, to avoid damage to the content of bleached glycerin, temperatures need to be gradually controlled.

The results also showed that for all tuning methods the percent overshoot was improved when using modified PID control structure except for ISE tuning rules. The settling time when using modified PID control structure also improved except for Ziegler-Nichols and ISE tuning method. Amongst, the ITAE (load) tuning method outperformed the other for all PID control structures.

TABLE III
DYNAMIC PERFORMANCE FOR IDEAL PID CONTROL STRUCTURE USING VARIOUS TUNING METHODS

Tuning Methods	Ideal PID Control Structure			
	Rise Time	Settling Time	Peak Time	% Overshoot
Ziegler-Nichols	263.4533	1106.0	1172.9	61.8288
Cohen-Coon	301.9709	3903.5	1172.9	58.8971
ISE	386.2331	1498.6	1172.9	8.2822
ITAE (load) Criterion	256.0572	8110.6	1172.9	75.5111
Wang's Tuning	882.7018	5565.4	3872.9	3.1108

TABLE IV
DYNAMIC PERFORMANCE FOR MODIFIED PID CONTROL STRUCTURE USING VARIOUS TUNING METHODS

Tuning Methods	Modified PID Control Structure (D-PI)				Alternative PID Control Structure			
	Rise Time	Settling Time	Peak Time	% Overshoot	Rise Time	Settling Time	Peak Time	% Overshoot
Ziegler-Nichols	610.0471	3214.5	1545.3	8.7454	2177.9	3894.1	4948.4	0.0344
Cohen-Coon	690.7340	3489.7	1721.1	8.9527	2498.6	4171.4	5000	0
ISE	504.8146	2703.6	1340.4	9.6220	1582.1	3087.2	4941.1	0.0118
ITAE (load) Criterion	596.0967	3144.8	1505.2	9.1454	2261.8	3958.9	4972.7	0.0621
Wang's Tuning	1690.6	2967.0	5000	0	3236.6	4628.4	5000	0

Fig. 8 shows the process response for all control structures using ITAE (load) tuning method applied in the glycerin bleaching process. The process took longer time to settle albeit using the alternative PID control structure improves the percent overshoot. In this case, it might affect the content of bleached glycerin.

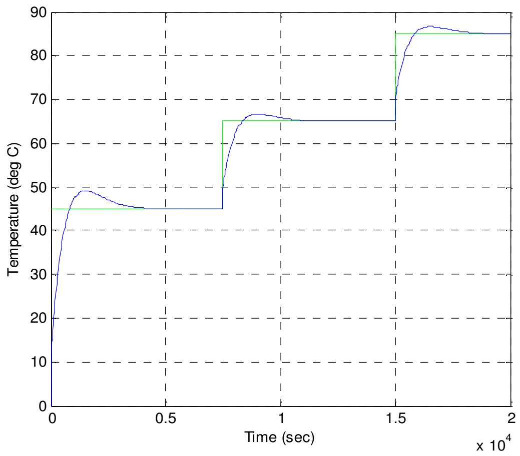

Fig. 9. Response for set-point change test using ITAE (load)

It is observed that the modified PID control structure tuned using ITAE (load) method gives better results among other structures. The settling time is satisfied, the process completed within 1 to 1.5 hour. In order to observe how good the controller able to track a set point, set point-change test was performed to the process plant in a closed loop system using modified PID control structure tuned using ITAE method. The results were plotted as shown in Fig. 9.The results show that the process tracks the set point change smoothly; reaching the new value with minimal overshoot and the settling time is satisfied.

VII. Conclusion

The results demonstrated that PID controller can give good performance for the glycerin bleaching process. The comparison of various tuning methods concluded that ITAE method resulted in the best choice for glycerin bleaching process when using modified PID control structure.

Acknowledgment

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