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Temperature Control of Essential Oil Extraction Process Using Second Generation of Commande Robuste d'Ordre Non Entier (CRONE-2)

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Abstract- Steam distillation is one of the most popular methods used to extract the essential oils. Because of the behavior of aromatic plants that are volatile and fragile to excess heat, steam temperature needs to be regulated within a permissible range. Changes in the dynamics of steam temperature because of several factors such as variation of water level, capacity of loads, error in modelling and others had made the control effort more challenging. In fact, variation of parameters in plant models have interrupted the stability of the system and may jeopardize the quality of essential oils. In this paper, a CRONE controller which means Non-integer order robust controller will be applied to suppress the effect of variability in process parameter changes to the control loop. CRONE controller design pursued in frequency domain approach made it easier to achieve a constant transient within an iso-damping region. The CRONE performance will be compared with Internal Model Control PID with fractional-order Filter (IMCPID-FOF). The comparative study was done in time and frequency domain to reveal the robustness of the two controllers. It was shown that both controllers have good performance in time domain of closed-loop system where the desired percentage overshoot 5% ±3% are followed by system due to parameter of phase margin and gain crossover frequency. However, CRONE-2 has better performance while handling plant uncertainty with approximately 3% and 10% faster than IMC PID-FOF in rise time and settling time, respectively.

Keywords—*Essential oils extraction, Steam temperature, FOPDT model of steam distillation, Fractional Order Controller, second generation CRONE (CRONE-2), Internal Model Control (IMC).*

I. INTRODUCTION

In the past few years, essential oils have become popular because of its benefits to human health and well-being. It was shown that by inhaling certain essential oils such as Lavender scents might have a positive side effect on people who have mild sleep disturbance[1]. Besides that, essential oils had also been used for household products such as repellent of mosquito [2], refreshing up things like cleaning agent or freshener for home [3], natural scents for cosmetics and others.

Essential oils can be obtained from botanical sources such as lavender plant, rosemary, pandan leaves, serai wangi and many others. Hence, the extraction process must be done to extract the oils from the aromatic plants and strictly no other chemical mixture was allowed to produce an authentic essential oil. In essential oil industries, the quality of essential oils becomes one of the significant attributes in attracting customers to buy their products. Most essential oils has volatile chemical compounds with its unique combination and they are too fragile to external parameters such as temperature [4]. According to [5]-[6] , temperature control is crucial especially when handling a sensitive environment because it can react with almost everything and the effect might include the material, pressure, conductivity and others.

Generally, essential oils are extracted using a distillation process. There are various types of distillation processes such as hydro distillation and steam distillation. In this study, the steam distillation process was chosen as a method of extraction where it was able to produce highly concentrated oil. A strict range of temperature is maintained to preserve the essential oil quality. From previous studies conducted on Cymbopogon Nardus extraction, the optimal temperature range was found to be between 70°C to 85°C. According to [7], the higher temperature will change in composition of major chemical compounds and it will not be released if the temperature is too low.

The natural aromatic plant material can be purified or isolated by using steam distillation method where the process was done by injecting the steam into the plant. Thus, the aromatic molecule is released. Indeed, almost 93% have used this extraction method compared to other methods [8]. Furthermore, the steam distillation is good in handling heat sensitive materials and the temperature can be adjusted within the desired range. The system is cheap but good in productivity which leads to industry preference.

This study was focused only on steam temperature control of a steam distillation process. Steam temperature dynamics are not sustainable due to influences from internal and external factors such as quantity of loads, water level, noise, error in

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plant modelling and others had made control effort more challenging. Fractional-order calculus is widely used in various fields especially in engineering such as signal processing, control system and system theory. Fractional-order was also known because of its flexible frequency shape and fulfilling more demanding design requirements [9].The development of fractional order was started by Bode in the 19th century who had proposed a Bode's Ideal transfer function in control system and also Tustin who had implemented a fractional- order in position control of massive objects [10]. Next, Oustaloup has proposed a Commande Robuste d'Orde Non Entier in French is an acronym for CRONE which can be translated as Non-integer order Robust Controller with three generation of control strategies which are First, Second and Third generation of CRONE controller by implementing a frequency domain approach in order to achieve robustness on a stable system [11].

The first Generation of CRONE [12] is a controller with strategy of achieving constant phase around open loop gain crossover frequency, ω_{cg}. Thus, the phase margin only varies from the variation of the plant gain. Within this range, the variety of plants is acquired. However, the high frequencies in this range lead to high levels of control input. Hence, this problem was referred to the next generation of CRONE.

The Second Generation of CRONE [13] uses a constant phase of nominal around open loop gain crossover frequency, ω_{cg}. The focus was in open loop Nichols locus which have a vertical straight-line segment called vertical template around ω_{cg}. The performance on vertical sliding of template was along one contour at different parameter of gain around ω_{cg}, proved the robustness of control. Thus, second generation of CRONE controller will be evaluated in this study.

Recently, many researchers were interested in developing CRONE controllers in different types of plant uncertainty. Hussein et al [14] performed a comparative study on robustness of plants between First generation CRONE and PID controllers on anti-roll system for electric vehicles where the specification value of gain crossover frequency around frequency range was fixed in this plant. The result illustrated that First Generation of CRONE is more robust to plant uncertainty compared to PID controller when the phase margin was constant along the frequency range, ω_{cg}. Other research referred in [15], the CRONE Controller was implemented in Speed Control of Permanent Magnet Direct Current Motors. This study highlighted on the effect of torque on PMDC motor speed control, where the temperature was increase and the frequency are decreases cause the uncertainty on shaft of the motor. From the results, they had proved that second generation of CRONE are good in handling plant uncertainty. Francisco et.al [16] studied on Robust control of a wind turbine using third generation of CRONE. In this study, the controller in the simulation environment was tested on three different types of disturbance such as step, modelled harmonic turbulent wind and white noise. The result was obtained where the performance of plant using CRONE controller shows better performance of ISE compared to uncontrolled plant. This performance also supported by [17] and [18] where both studies on CRONE have proven less sensitive to disturbance and parameter rejection.

The objective of this study is to design a fractional order controller in order to maintain the temperature of steam at its saturated level even though the plant parameters vary. The Second generation of CRONE controller was chosen as a proposed controller to be evaluated and the result was compared with other controllers that have a fractional order property.

An Internal Model Control based PID with Fractional Order Filter (IMC-PID-FOF) was proposed by [19] where it also proved robust and had better control by previous research study. The structure of the controller was a combination of IMC structure based PID controller and cascaded with a fractional order filter. This control technique has only two parameters which belong to fractional order filter that need to be manipulated to have a better control. Thus, an Oustaloup Recursive Approximation method has been used to find the integer order.

An overview of the plant model uncertainty will be described in section II. Next, the design methodology of a fractional-order controller using CRONE-2 and IMC-PID-FOF controller will be discussed in section III. The performance analysis of the controllers will be discussed in section IV. In the last section, summary and conclusion of this study will be drawn with some future recommendations.

II. PLANT MODELLING

The experimental study was conducted by [20] using a pilot-scale steam distillation plant. Figure 1 shows the schematic diagram of a steam distillation plant where it consists of a condenser with mounted steel and stainless-steel column. The operation starts with filling in the water and boiling it in a distillation column to generate the saturated steam. The water was heated up by a 1.5kW coil-type heater. Two TCs (Temperature Control) were installed; TC2 was used for water temperature monitoring, while TC1 was installed approximate of 40 cm from the water level for steam temperature control.

The TC1 has begun to measure the steam temperature during closed-loop operation and a signal converter was used to convert the resistance to voltage. The output signal of the signal converter was set within 1 to 5 Vdc to represent the temperature from 0 °C to 120 °C. An offset of 1 Vdc was set intentionally by researcher to detect any malfunction in the sensor whenever the output becomes zero. In addition, the electrical heater used in this research can be manipulated by a power controller, where the input voltage of controller can influence the output voltage. Thus, the input voltage was set in the range of 0V to 5V. In the result, the temperature of water will change and influence the temperature of the steam.

The process model of this system was adopted in [8]. The researchers proposed a linear transfer function which is First Order Plus Dead Time (FOPDT) model due to specific operating range of steam temperature shows a linear S-shape step response which is between 85°C until 100°C. Hence, FOPDT model of steam distillation was defined by equation (1).

$$G(s) = \frac{k}{\tau s + 1} e^{-\theta s} = \frac{4.5}{280s + 1} e^{-25s} \tag{1}$$

where the value of gain, K is 4.5, time constant, τ is 280 and the dead time, θ is 25 second.

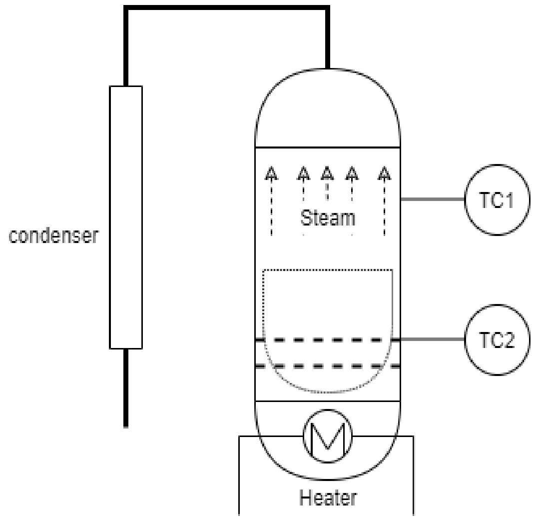

Fig 1. Schematic diagram of steam distillation plant[8]

A. Plant uncertainty

In the previous section, it was mentioned how the steam temperature was generated. One of the factors that influence the dynamic of steam temperature was the water level in the distillation column. The water level for a nominal plant is 10 liters. However, it may decrease over time as the process is running. The variation in water level causes changes in the process time constant. As the process is running, the time constant will become faster as the water level may decrease. Thus, uncertainty in the plant parameters were distinct. In this study, we focused on the variation of time constant with 280 ±10% by maintaining the parameter of gain k=4.5 and time delay, θ=25 second. Table 1 shows three possible plant models with variation of time constant that will be evaluated in this study.

TABLE I
PLANT MODEL WITH TIME CONSTANT VARIATION

Plant model	Plant 1 (nominal)	Plant 2	Plant 3
Time constant	280	252	308

III. Controller Framework

The development of controller was based on transfer function of plant modelling (the system to be controlled) with unity feedback control system diagram such in Fig. 2.

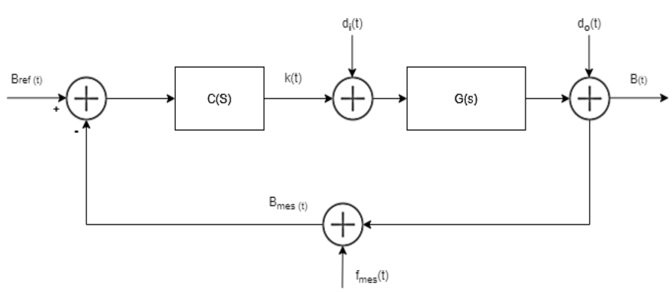

Fig 2. Block diagram of closed loop with unity feedback

$B_{ref}(t)$ is a reference (desired) value of output B(t), C(s) is the linear controller with control effort k(t), *G(s)* is transfer function of its linear model, $d_i(t)$ and $d_o(t)$ is the input and output disturbance for plant, and Fmes(t) is a high frequency measurement noise. In this study, there are two types of controllers with fractional order which are CRONE controller (CRONE-2) using CRONE CSD toolbox and Internal Model Control based PID with FOF controller. The controller design is followed by the specification in the next section.

A. Design Specification

To design a fractional order controller, there are several specifications that need to be considered so that the system can achieve accuracy in plant uncertainty [21]. In this study, stability margin and robust constraint were considered in the design.

1) Phase margin definition:
Phase margin can be obtained by relationship of damping ratio and phase margin for open loop frequency response where it can be written as equation (2).

$$\zeta = \frac{-In\,(\%OS/100)}{\sqrt{\pi^2 + In^2((\%OS/100)}}$$

$$\emptyset_m = \frac{\tan^{-1} 2\zeta}{\sqrt{-2\zeta^2 + \sqrt{4\zeta^4+1}}} \quad (2)$$

According to [22], the damping ratio of system was typically in the range of 0.4 until 0.8 since small value of damping ratio produces severe overshoot and if the value is higher, the rise time increases. Table 2 indicates three of phase margin and overshoot with fixed value of crossover frequency $\omega_{cg} = 0.0075$ where it has been suggested by [23] to be evaluated in this system. Hence, to preserve the essential oil quality, the settling time was set to 400 s which represent by gain crossover frequency of 0.0075 and percentage overshoot of ±10% with phase margin, $\emptyset_m$ of 84°.

TABLE II
LIST OF PHASE MARGIN AND OVERSHOOT

Damping ratio, ζ	Phase margin,$\emptyset_m$	Overshoot,%
0.4	45.25	25
0.5	57.24	15
0.7	84.02	5

2) Gain crossover frequency,ω_{cg} that proposed in [11]

$$|G(j\omega)C(j\omega)| = 1 \quad (3)$$

3) Iso damping properties where the phase curve open loop transfer function is flat within its frequency range that leads to better control against parameter variation in specific range.

B. Second Generation Of CRONE

The transfer function of a Second generation CRONE was obtained through derivation where the transfer function of open loop system for frequency in the range $[\omega_A, \omega_B]$ was defined in equation (4),

$$\beta(s) = \left[\frac{\omega_{cg}}{s}\right]^n \tag{4}$$

where ω_{cg} is gain crossover frequency for which uncertainty does not affected on the phase variation, $n \in R$. Besides that, the control signal and transient response can be obtained by adding an integrator and eliminating equation (4) in frequency. Hence, the new open loop transfer function was defined by equation (5)

$$C_{frac}(s) = \beta_0 \left(\frac{1+\frac{s}{\omega_1}}{\frac{s}{\omega_1}}\right)^{n_1} \left(\frac{1+\frac{s}{\omega_h}}{\frac{s}{\omega_l}}\right)^{n} \left(1+\frac{s}{\omega_h}\right)^{-n_h} \tag{5}$$

where ω_l and ω_h represent the low and high transitional frequencies with $n_l$and n_h as a system behaviour for those frequency, n is the fractional order around the frequency ω_{cg} between 1 and 2, and β_0 is a constant value that assures a crossover frequency ω_{cg}. The controller was strictly proper when low pass filler was added into (5). Thus, it reduced gain of the control sensitivity function .The transfer function was defined based on the requirement in design specifications in section A. Fractional order transfer function was computed using CRONE Toolbox [24]. Thus, the transfer function was given in equation (6).

$$C_{frac} = 12.1286\left(1+\frac{0.082158}{s}\right)^1 \left(\frac{1+s/0.082158}{1+s/0.00068465}\right)^{1.0391} \frac{1}{(0.082158)^3} \tag{6}$$

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C. Internal Model Control (IMC) based PID with FractionalOrder Filter (IMC PID-FOF)

The IMC PID- FOF controller was discussed in detailed based on paper [19], [23], [25] and [26]. The transfer function of controller was defined by equation (7) where the parameter of controller consists of K_p, K_i and K_d for PID controller and two extra parameter which alpha, α and time constant, τ_c for fractional order filter.

$$C_{IMC} = \frac{1}{1+\left({}^{2\tau_c}/_{\theta}\right)s^{\alpha}}\frac{2\tau_p+\theta}{k_p\theta}\left(1+\frac{1}{\frac{2\tau_p+\theta}{2}}s+\frac{\tau_p\theta}{2\tau_p+\theta}s^2\right) \tag{7}$$

The desired specification of IMCPID-FOF controller also based on requirement in section A Thus, the transfer function was determined by equation (8)

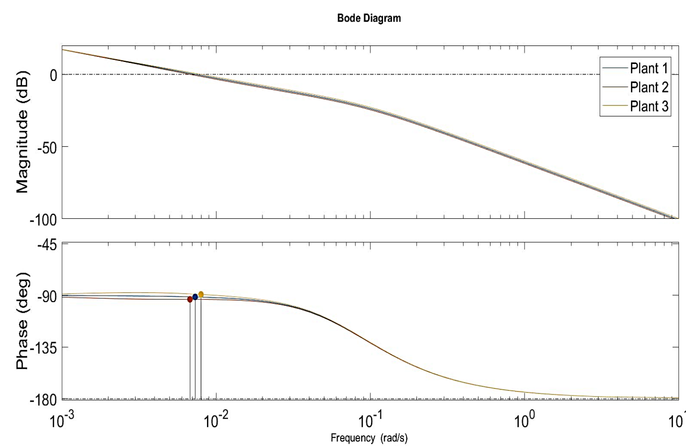
$$C_{IMC} = \frac{1}{1+\left({}^{405.16}/_{25}\right)s^{0.1}}5.2\left(1+\frac{1}{292.5}s+11.97s\right) \tag{8}$$

IV. Results And Discussion

The simulation results using Simulink/MATLAB is presented in this section where the step input is 70°-85°C for 1500 seconds. In addition, the performance analysis of the plant model with time constant variation was discussed in section A for both controllers with feedback control input only in the frequency and time domain. Then, the analysis on step response for closed loop system of steam distillationwas discussed in section B.

A. Performance analysis of plant model with time constant variation

The illustration of the stability degree robustness versus time constant variation can be seen in frequency response properties where Bode and Nichols plot diagram of open loop system for both controllers were presented in Fig. 3 and Fig. 4. For bode plot diagram, the system is proven robust when phase curves are constant around its gain crossover frequency within its frequency range. Thus, this behaviour is presented in IMC PID-FOF controller where the phase margin for all three plants have small differences with 2° - 4° of each other. Besides that, it also can be proved by Nichols plot that represents CRONE-2 behavior where the performance vertical sliding of Nichols template was along the same contour which is -3db for all three plants. All the data have been listed in Table 3.



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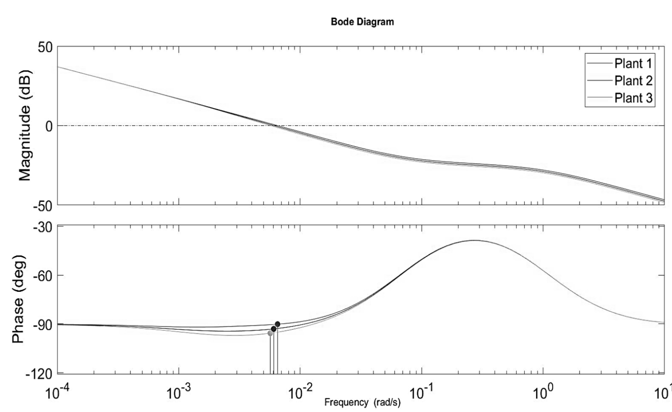

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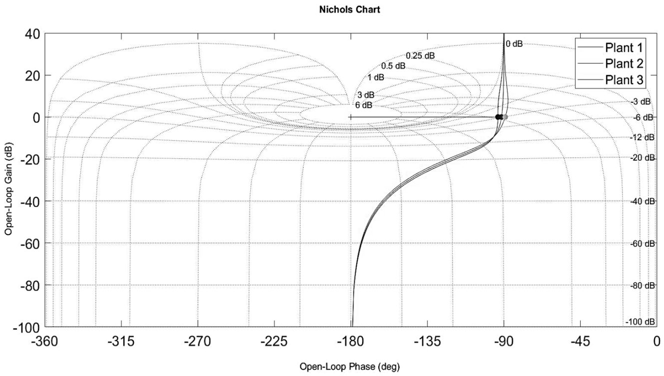
Fig 3. Bode diagram of open loop system (a) CRONE-2

(b) IMC PID with FOF



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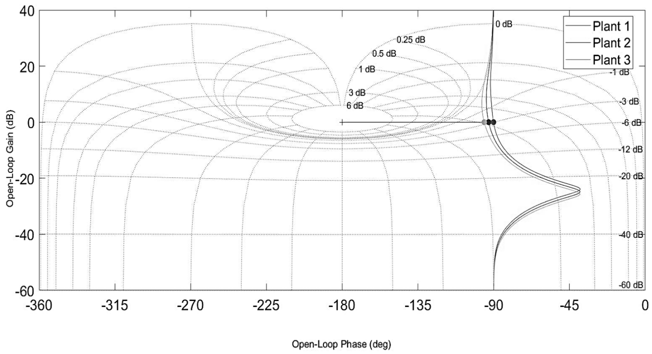


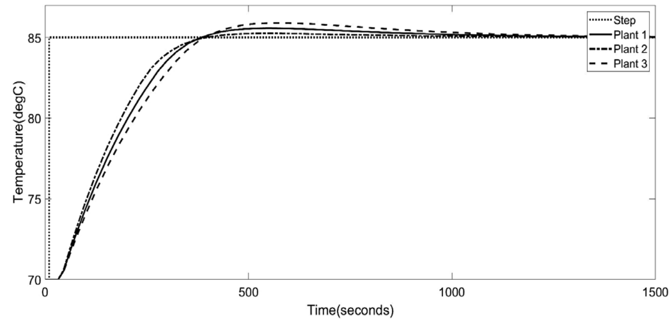
(b)

Fig 4. Nichols plot of open loop system (a) CRONE-2 (b) IMC PID with FOF

TABLE III
PARAMETER OF OPEN LOOP SYSTEM

	CRONE-2		IMC PID FOF	
	Phase margin, Pm	Gain crossover frequency ω_{cg}	Phase margin, Pm	Gain crossover frequency ω_{cg}
Plant 1 (Nominal plant)	88.5	0.0073	87	0.0060
Plant 2	90.7	0.0079	89.8	0.0061
Plant 3	86.5	0.0067	84.3	0.0056

Figure 5 shows the step response of plant variation for both controller and has been listed in Table 4. As for closed loop step response, all of three plant model for both controllers show the same result where the overshoot value are 5% with ±3 or 10% of overshoot are still acceptable. However, the response of IMC PID-FOF controller are oscillate at 641 seconds and settle at 791 seconds for plant 3 while the response of CRONE-2 are smooth. Thus, this behavior proves CRONE-2 controller have better control towards plant uncertainty.



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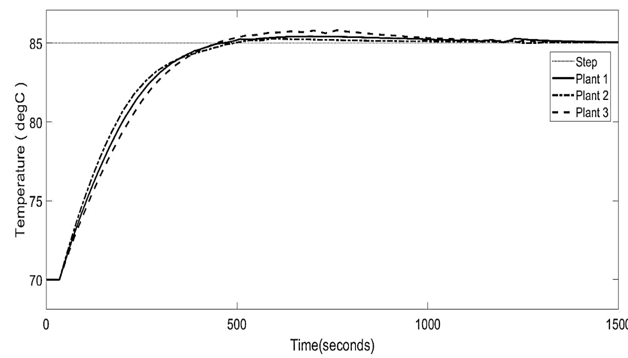


(b)

Fig 5. Step response of closed loop system for plant uncertainty (a) CRONE-2 (b) IMC PID with FOF

TABLE IV
STEP RESPONSE OF CLOSED LOOP SYSTEM

	CRONE-2	IMC PID FOF
	Overshoot, %	Overshoot, %
Plant 1 (Nominal plant)	3.8	2.8
Plant 2	2.0	1.7
Plant 3	6.0	5.3

B. Step response of Closed loop system

The step response of the closed loop system presented in Fig. 6 and the data were tabulated in Table 5. The response of the CRONE-2 controller arises 3 percent faster than IMC PID-FOF at 306.9 seconds. However, the percentage overshoot for IMC PID-FOF are smaller than CRONE-2 controller with 2.8 and 3.8 percent, respectively. Besides that, the settling time of 5 percent of the tolerance band was led by the CRONE-2 controller with 320 seconds which are 10 percent faster than IMC-PID with FOF controller.

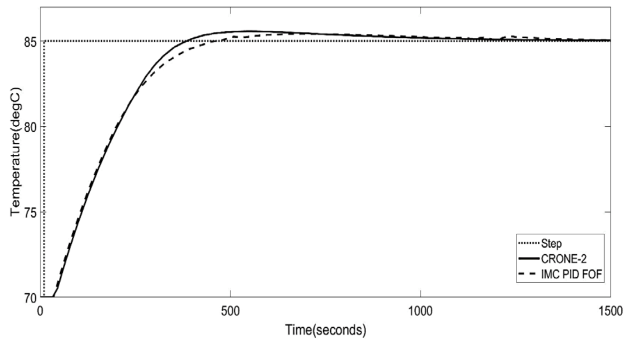


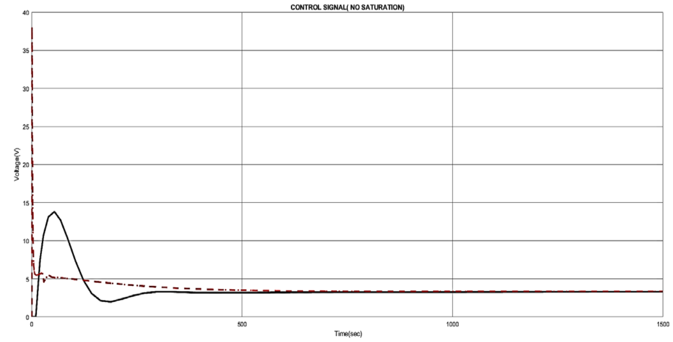
Fig 6. Step response of closed loop system for both controller

TABLE V
PARAMETER OF STEP RESPONSE

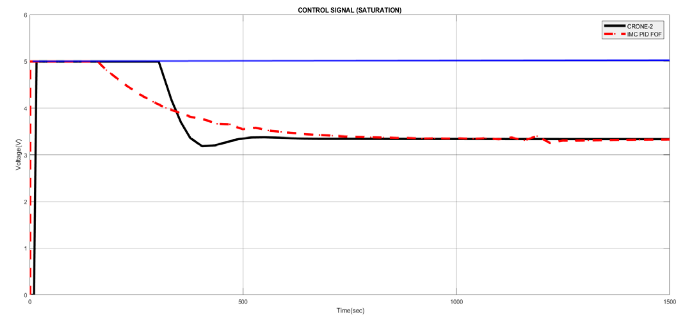
Parameter	CRONE 2	IMC-PID FOF
Rise Time, sec	297.6	306.9
Settling Time, sec	323.7	360
Percent Overshoot, %	3.8	2.8

C. Control signal

The practical implementation of the controller can be validated by control signal requirement. Figure 7(a) shows the controller techniques are out of control signal requirements which exceed 5V. However, saturation block was implemented into the Simulink block to have minimum control with the range of 0 until 5V. It can be seen in Fig. 7(b), where both control signals start from 5V at 0s. Then, the signal drops are slowly begun by IMC PID-FOF controller at 200s and followed by CRONE-2 controllers at 300s. However, the control signals for CRONE-2 are saturated at 500s with output signal 3.33V which is faster than IMC PID-FOF controller at 800s with output signal 3.35V. This can prove that CRONE-2 is a more reliable controller in terms of real time implementation.



(a)



(b)

Fig 7. Performance of control signal (a) without saturation b) with saturation

V. Conclusion

In conclusion, this paper successfully implemented the Second generation CRONE controller (CRONE-2) in the steam distillation system by complying with the design specifications. In addition, a comparative study was conducted by comparing CRONE-2 and IMC PID-FOF controllers where both controllers have fractional order properties. Both controllers were designed with the same criteria, such as phase margin and gain crossover frequency. The CRONE-2 has shown better performance with 3% and 10% faster than IMC PID-FOF in rise time and settling time, respectively. Also, both controllers can follow the desired overshoot value needed by the user. While in CRONE 2, it meets the robustness requirement in handling plant uncertainty of steam distillation. For future recommendation, this controller can be implemented with other controllers in real application.

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References

[1] A. S. Lillehei and L. L. Halcon, “A systematic review of the effect of inhaled essential oils on sleep,” *J. Altern. Complement. Med.*, vol. 20, no. 6, pp. 441–451, 2014.

[2] G. Benelli *et al.*, “Insecticidal and mosquito repellent efficacy of the essential oils from stem bark and wood of Hazomalania voyronii,” *J. Ethnopharmacol.*, vol. 248, p. 112333, 2020.

[3] I. Falcó, M. Verdeguer, R. Aznar, G. Sánchez, and W. Randazzo, “Sanitizing food contact surfaces by the use of essential oils,” *Innov. Food Sci. Emerg.Technol.*, vol. 51, pp. 220–228, 2019.

[4] Z. L. Chen, J. P. Chao, H. L. Cao, W. T. Bi, H. Y. Cui, and M. L. Li, “Research on the extraction of plant volatile oils,” *Procedia Environ. Sci.*, vol. 8, no. November, pp. 426–432, 2011.

[5] A. D. M. Africa, J. A. A. Mercado, and J. K. S. Sim, “Modeling of a temperature controller using heat exchangers,” *Int. J. Emerg. Trends Eng. Res.*, vol. 8, no. 7, pp. 3185–3190, 2020.

[6] A. D. M. Africa, A. M. J. L. Divino, and K. A. B. Hartigan-Go, “Fuzzy logic temperature control: A feedback control system implemented by fuzzy logic,” *Int. J. Emerg. Trends Eng. Res.*, vol. 8, no. 5, pp. 1879–1885, 2020.

[7] E. Cassel, R. M. F. Vargas, N. Martinez, D. Lorenzo, and E. Dellacassa,

"Steam distillation modeling for essential oil extraction process," vol. 9, pp. 171–176, 2008.

[8] M. Tajjudin, M. Hezri Fazalul Rahiman, N. Ishak, H. Ismail, N. Mohd Arshad, and R. Adnan, "Adaptive Steam Temperature Regulation for Essential Oil Extraction Process," *Int. J. Control Sci. Eng.*, vol. 2, no. 5, pp. 111–119, 2012.

[9] C. Flores, J. Muñoz, C. A. Monje, V. Milanés, and X. Y. Lu, "Iso-damping fractional-order control for robust automated car-following," *J. Adv. Res.*, vol. 25, pp. 181–189, 2020.

[10] I. Birs, C. Muresan, I. Nascu, and C. Ionescu, "A Survey of Recent Advances in Fractional Order Control for Time Delay Systems," *IEEE Access*, vol. 7, no. c, pp. 30951–30965, 2019.

[11] A. A. Dastjerdi, B. M. Vinagre, Y. Q. Chen, and S. H. HosseinNia, "Linear fractional order controllers; A survey in the frequency domain," *Annu. Rev. Control*, vol. 47, no. xxxx, pp. 51–70, 2019.

[12] A. Oustaloup and P. Melchior, "The great principles of the CRONE control," in *Proceedings of IEEE Systems Man and Cybernetics Conference-SMC*, 1993, vol. 2, pp. 118–129.

[13] A. Oustaloup, B. Mathieu, and P. Lanusse, "Second generation CRONE control," in *Proceedings of IEEE Systems Man and Cybernetics Conference-SMC*, 1993, vol. 2, pp. 136–142.

[14] H. Termous, X. Moreau, C. Francis, and H. Shraim, "Effect of vertical dynamics on vehicle's lateral stability control system," *IEEE Intell. Veh. Symp. Proc.*, vol. 2019-June, no. Iv, pp. 1993–1998, 2019.

[15] I. Garba, Y. A. Sha'aban, M. B. Mu'azu, and Z. Haruna, "Crone Controller Based Speed Control of Permanent Magnet Direct Current Motor," *2019 2nd Int. Conf. IEEE Niger. Comput. Chapter*, pp. 1–8, 2020.

[16] F. Ravasco, R. Melicio, N. Batista, and D. Valério, "Robust Control of a Wind Turbine Using Third Generation CRONE Control," *Proc. - 2019 IEEE Int. Conf. Environ. Electr. Eng. 2019 IEEE Ind. Commer. Power Syst. Eur. EEEIC/I CPS Eur. 2019*,2019.

[17] Z. Dimitrova, M. Tari, P. Lanusse, F. Aioun, and X. Moreau, "Robust control for an electromagnetic actuator for a camless engine," *Mechatronics*, vol. 57, no. May 2018, pp. 109–128, 2019.

[18] J. L. Bouvin, X. Moreau, A. Benine-Neto, V. Hernette, P. Serrier, and A. Oustaloup, "CRONE body control under driver inputs through heave velocity regulation," *2017 IEEE Veh. Power Propuls. Conf. VPPC 2017 - Proc.*, vol. 2018-Janua, pp. 1–5, 2018.

[19] M. Bettayeb and R. Mansouri, "Fractional IMC-PID-filter controllers design for non integer order systems," *J. Process Control*, 2014.

[20] M. Tajjudin, M. H. F. Rahiman, N. Ishak, R. Adnan, and H. Ismail, "Model evaluation of a steam distillation process for steam temperature regulation," *Proc. - 3rd Int. Conf. Intell. Syst. Model. Simulation, ISMS 2012*, pp. 431–435, 2012.

[21] V. Feliu *et al.*, "PROPOSALS FOR FRACTIONAL PI λ D μ TUNING," *Proceedings of the first IFAC symposium on fractional differentiation and its applications (FDA04), 2004.*

[22] W. Bolton, "System Response," *Instrum. Control Syst.*, pp. 213–239, 2015.

[23] B. Maâmar and M. Rachid, "IMC-PID-fractional-order-filter controllers design for integer order systems," *ISA Trans.*, vol. 53, no. 5, pp. 1620–1628, 2014.

[24] A. Oustaloup, P. Melchior, P. Lanusse, O. Cois and F. Dancla, "The CRONE toolbox for Matlab," *CACSD. Conference Proceedings. IEEE International Symposium on Computer-Aided Control System Design (Cat. No.00TH8537)*, 2000, pp. 190-195.

[25] M. Tajjudin, M. Azfar Abdullah Pani, S. A. Aziz, N. Ishak, and R. Adrian, "A study on IMC-based PID for steam distillation process," *Proc. - 2018 IEEE Int. Conf. Autom. Control Intell. Syst. I2CACIS 2018*, vol. 17, pp. 133–136, 2019.

[26] S. N. H. B. Johari, M. H. F. Rahiman, N. Hambali, R. Adnan, and M. Tajjudin, "Design of imc-pid controller with fractional-order filter for steam distillation essential oil extraction process," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 21, no. 2, pp. 801–810, 2020.