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A New Design and Control System Development of a Combined Heat-Boiling Tank Applied for Natural Dyes Process

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Abstract

Nowadays, the people are mostly prefer to use the natural products. These things focus on the everyday human needs such as foods and clothes. People recognizes that the natural products have great advantages as environment friendly, non-toxic, not cause the allergy for human being, etc. Based on this requirements, this paper introduces about one steps in the whole process of natural dyeing process. This process is used to dye textile products from the natural colors such as leaves, bark, root and agriculture by-products, etc. This extracting and dyeing process includes these main following procedures as: crushing, heating-boiling, filtering, and finally dyeing. In this whole process, the heating-boiling procedures is the most important steps. In this step, we need to control the suitable temperature and suitable pressure to get the complete extracting matter from the natural ingredients. We also need to choose the appropriate steering speed to get the good quality of the matter. Therefore, this paper concentrates on the most important step of the whole process which is the heating-boiling procedure. The mechanical design of the heating-boiling tank (fermenting and extracting module) will be introduced at the beginning. Then, the system identification method and controller design for temperature will be carried out. These parameters have great influence to the quality of the dyeing matter. The simulations and also the experimental results will be considered to check the agreement of our design.

Keywords: natural dyeing, leaves, by-product, temperature, pressure, speed, controller, heating-boiling

1. Introduction

Synthetic dyes is the greatest procedure for textile dyeing used in recent years. However, this method does not sustainable for a long period of time. Industrial textile is facing extremely contaminated environment, which is considerably as insurmountable problems. Therefore, natural dyes not only counteracting effect on environment but also claim to be non-toxic to human. Along with socioeconomic developments, remarkable improvements have taken place in the new trend to use the natural based products.

Thus, natural dyeing technology is proliferating in many countries in the world. Many countries have the great development of textile industry such as Turkey, Thailand and some European ones. They began to manufacture semi-automatic or automatic system in application of natural dye to improve their product quality and productivity.

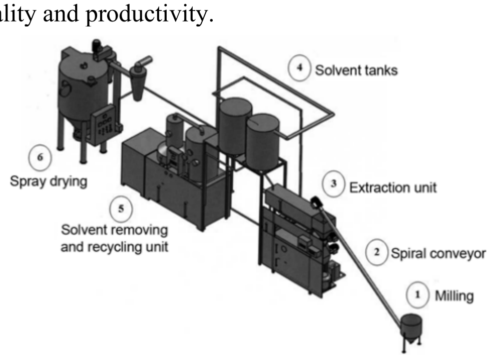

Fig. 1 Natural dye extraction machine [1]

Turkish red pine bark was used as dye-stuff source. The dye-stuff was extracted in the natural dye-stuff extraction machine. The machinery is shown Fig 1. The extraction of dye-stuff from Turkish red pine bark was carried out step by step. Before putting the barks into the extractor, they were vacuum-dried and the vacuumed plant fluid was then retained for use instead of fresh water in further processing. The barks were fragmented into 1mm^3 particles to increase the particle-solvent interaction by a milling machine. After that, particles were moved by a spiral conveyor to the extraction unit. Bark particles were processed with ethanol and stocked plant fluid after recovered from the vacuuming process by extraction unit. Barks were steeped subsequently in this stage for 24 hours to carry out the osmosis process. The residue was then eliminated while the dye-stuff extract was transported to the solvent removing and recycling. This step make ethanol and water be removed from the extract and separated from each other for reuse process. The solvent removing and recycling module was operated on the distillation principle. Recycling of solvent materials is significant in protecting the environment. The dye-stuff was spray-dried (Fig. 1) during the last step of the process in order to obtain the final product which is the powder dye-stuff [1].

Vietnam is a tropical country that has much by-product from natural material such as leaves, flowers, fruits, roots, barks… [2]. However, the natural dyeing process is mostly done manually, which is difficult to improve productivity and process control. Dyes system of the same species but from different sources may contain different amounts of same dye-stuff ingredient depending on its origin. This can create diverse colors of the product from natural dyeing material. [1]

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Based on manual process from the leaves and barks, we develop and build the conjugate extracting and dyeing system applied for natural dyeing materials. The proposed dyeing system includes four main modules as: Module 1: grinding; module 2: fermenting and extracting; module 3: filtering and module 4: heating and dyeing. Each module can operate as a separate machine.

These four modules make the whole process for the integrated natural extracting and dyeing system. However, this paper concentrates on modeling and controlling temperature for fermenting and extracting module (module 2). In order to find the mathematical model of this module, we apply the system identification method which is based on the experimental measurement process. Base on this mathematical model, we can design and choose different controllers to operate the system effectively.

A good model can be used in off-line controller design and implementation of new advanced control schemes. In some special cases, the system modeling is very difficult for complex machines such as experimental apparatus, industrial machine… by conventional methods as Lagrange, D'alembert, etc. So using the experimental based identification method is vitally necessary in this cases. For example, modelling and system identification of a laboratory test apparatus that has been constructed to experimentally validate the concepts of anomaly detection in complex mechanical systems [3]. In other applications, the experimental based identification method is also used effectively such as in an industrial sewing machine [4].

2. Mechanical design

2.1 Operation process

Developed from manual natural dye process, the semi-automation system was built up and applied into dyeing system which includes four main modules as introduced in Fig. 2.

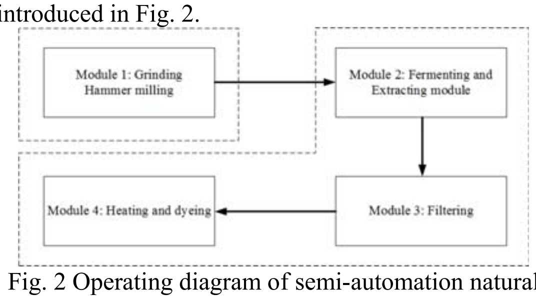

Fig. 2 Operating diagram of semi-automation natural based dye system

There are a number of previous researches which were carried out for the optimal extracting and dyeing process from dried barks and leaves. In this research, we choose "dry breadfruit leaves process" which is the typical tested process/material for our proposed system. The dry breadfruit leaves process is introduced in Fig. 3 below. In this process, the raw material or the input material must be dried up before putting into the grinder module. The ration between the material and the water must be consider with the suitable value to get the good fermentation process. Then, during the extracting and dying process, the temperature should be controlled quite precisely to get the best color of the dye process.

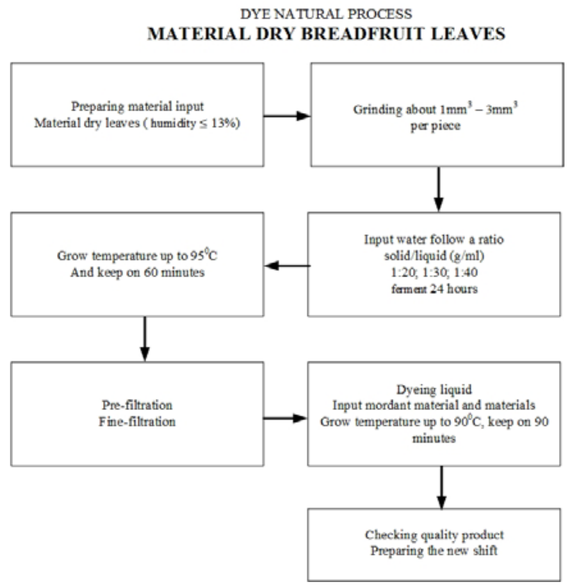

Fig. 3 Breadfruit leaves dye natural process [5]

2.2 Mechanical design

The whole conjugate extracting and dyeing system is a semi-automation system. All of the mechanical systems and control systems are designed to meet the requirement of the industrial standards. The whole system is introduced in Fig. 4.

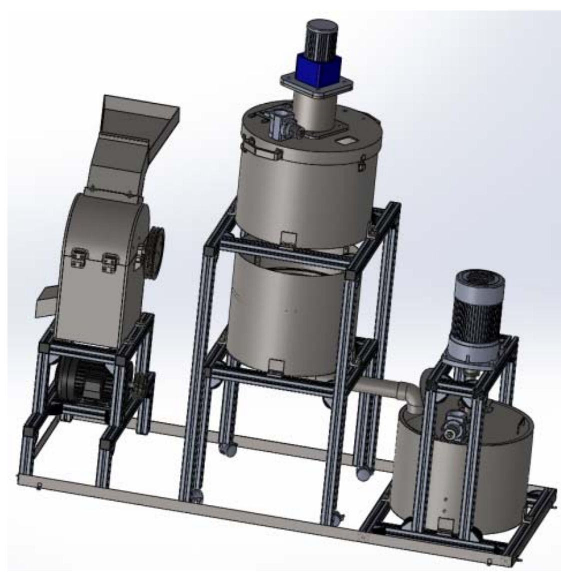

Fig. 4 Natural dye system 3D

In this module 2, the grinded materials is mixed with water with the suitable ratio, then it is fermented at about 24 hours, stirred and heated, following the technical parameters requirement of process. This module was completely automated from fermentation step to dye-stuff material liquid. Temperature control is one of the most important steps controller in this module.

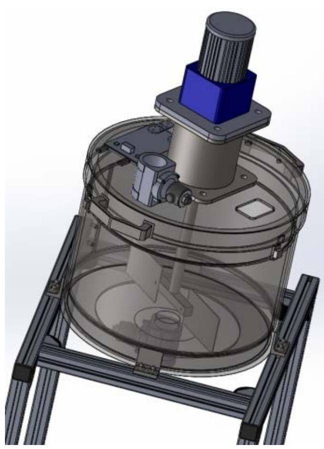

Fig. 5 Module 2 – Fermenting and extracting module

Table. 1 Parameters specification

Actual volume (liter)	78.54
Volume requirement (liter)	60
Heating power (kWh)	11.5
Type of paddle	Turbine
Heating temperature requirement (^{0}C)	95
Tolerance of temperature (^{0}C)	±2

3. System modeling

3.1 Transfer function identification

There are severe issues, which can not find the transfer function in this module by conventional method because this practical system depends on many practical parameters such as: input material, heating element, temperature, pressure, stirred velocity…

In this research, we use the system identification methods which is based on the practical measure values of the input and output signals. These signal are the input voltage (V) and the output temperature (^{0}C).

In our system, the voltage is limited from 0V to 220V because this system has small power. Thus, power of heating electric element is limited maximum at 12 kWh so response time of module is also limited. Similarly, the heating temperature requirement is 95^{0}C, which do not reach the boiling point of water. Therefore, output temperature is measured at atmospheric pressure. The temperature is measure by the Pt100 sensor and also calibrate by the other measurement tool as the thermometer as introduced in Fig. 6..

Fig. 6 Measuring output temperature tool

Fig. 7 Measuring input voltage tool

In this experiment, the grinded materials is mixed with water that ratio is 1:10 (g/ml). Measuring output temperature tool is Pt100 and laser temperature gun – Fluke. The tolerance of temperature is ± 1^{0}C. Measuring input voltage tool is digital Multimeters. The maximum tolerance of voltage is ± 2.2V. The sample time is a minute.

Table. 2 Measuring parameters: voltage – temperature

No.	u(V)	T(^{0}C)	No.	u(V)	T(^{0}C)
1	0	31.2	19	160	60
2	0	31.2	20	167	63.2
3	75	32.4	11	173	66.7
4	82	33.2	22	175	68
5	85	34.6	23	180	69.4
6	90	35.2	24	185	72.2
7	104	36	25	190	74.2
8	109	36.8	26	194	76.5
9	113	38.4	27	197	79.2
10	115	40.2	28	203	81.6
11	121	42.6	29	207	83.9
12	127	45.8	30	210	85.3
13	133	48.1	31	215	87.6
14	137	50.2	32	217	88.9
15	140	51.2	33	220	89.6
16	145	52.8	34	220	91.2
17	148	55.3	35	220	92
18	153	57.6			

Based on this experimental results, we use the ARX Models of System Identification Toolbox with the single-input/single-output system (SISO).
The ARX model structure is [5]:

$$y(t)+a_1y(t-1)+...+a_{na}y(t-n_a)= \\ b_1u(t-n_k)+...+b_{nb}u(t-n_k-n_b+1)+e(t) \quad (1)$$

Where,
$y(t)$: signal output at time (t)
$u(t-n_k)$: signal input at time ($t - n_k$)
$e(t)$: white-noise disturbance at time (t)

By using trial and error method in choosing all of the coefficients of ARX model such as: n_a, n_b, n_c, n_k and adjusting coefficients of transfer function within tolerance of ARX model.

With $n_a = 2$; $n_b = 2$; $n_c = 1$; $n_k = 1$. The mathematical model of the system is introduced as in Eq. (2).

$$A(z)y(t) = Bu(t) + C(z)e(t) \quad (2)$$

Where,
$A(z) = 1 - 1.609(\pm 0.1609)z^{-1} + 0.7217(\pm 0.1141)z^{-2}$
$B(z) = 0.02095(\pm 0.05075)z^{-1} + 0.01802(\pm 0.03028)z^{-2}$
$C(z) = 1 - 1(\pm 0.3145)z^{-1}$

This Eq. (2) described the system in discrete domain. The, the expression of this system in continuous domain which is adjusted the coefficients within tolerance of ARX model as introduced in Eq. (3).
The transfer function follow time (t):

$$y(t) = 0.006u(t-1) + 1.706y(t-1) \\ -0.706y(t-2) \quad (3)$$

3.2 Transfer function calibration

In order to calibrate or to check the system transfer function by using system identification methods, we compare the real experimental result with the value generated by the transfer function. We can see that these two value are matched together quite well. This is mean that, the transfer function of the system is the correct one. The calibration process is introduced in Fig. 8.

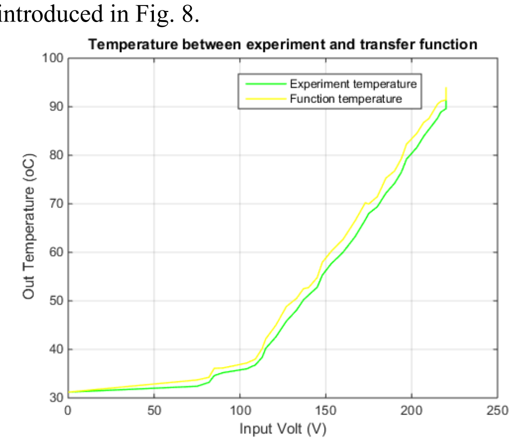

Fig. 8 Temperature between experiment and transfer function

In Fig. 9, the different temperature error between experiment and transfer function is sometimes quite high. The maximum range is around 3.5^0C and minimum range is 0^0C. However, the accuracy of the measurement data depends on several factors such as tolerance of measuring tools, environmental factors, human being, etc. However, based on the calibration process as introduced in Fig. 8, the two experimental data and the transfer function output data is nearly identical. So, the transfer function can be used as the mathematical model of this system.
Because of this transfer function is linear function and SISO system, so the PD controller is designed to control temperature of module.

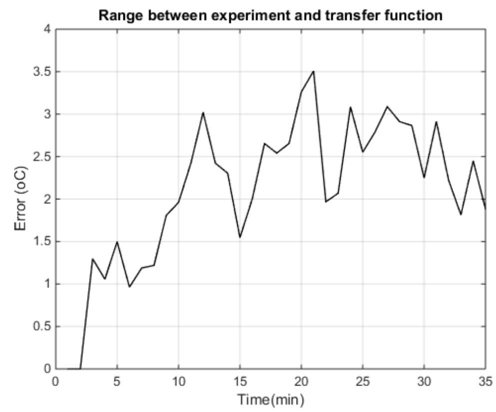

Fig. 9 Error of temperature difference between experiment and transfer function

4. Controller design

The PD controller, which is the PID based controller, is widely used in many processes of different industries. Controlling temperature is a typical application in industry.

The PD parameters are evaluated the result of step response simulations to produce a response with minimal settling time and overshot following to process requirement. All of the result from this simulation is applied in module.
The chosen PID function [6]:

$$u_{PD}(t) = K_p e(t) + K_i \frac{de}{dt} \quad (4)$$

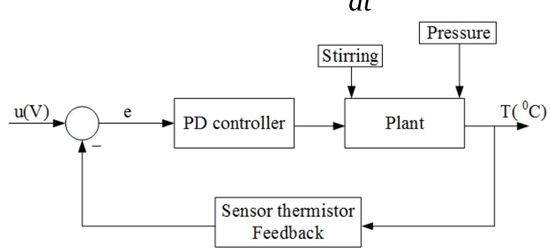

Fig. 10 Closed-loop PD diagram

In this part (Fig. 10), we use PD controller to control the temperature of the system (V). The temperature of liquid material is adjusted by heating electric element. Adding another factors are stirring and pressure. After that, the thermistor sensor is used to feedback the responsible temperature of the system.

The response of the system temperature using the PD controller is introduced in Fig. 11. In this Fig, the control value of temperature is matched quite well to the desired value. And, we also see that the error of the system has the trend to reach to zero. This is mean that the proposed controller is suitable for the system.

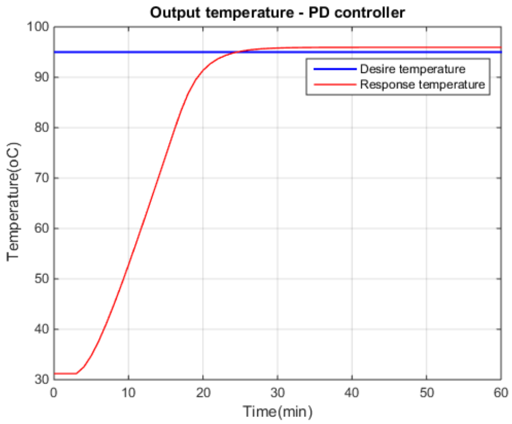

Fig. 11 Responsible temperature

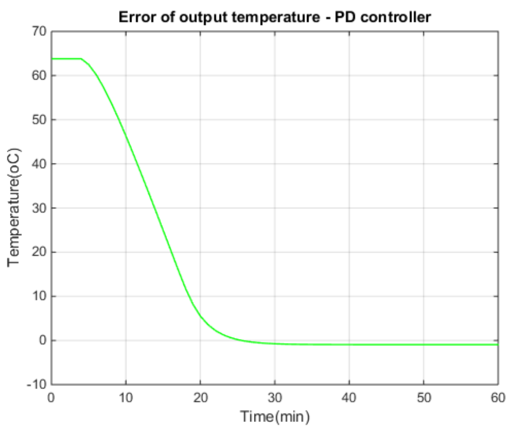

Fig. 12 Error temperature

From the result of simulation in Fig. 11 and Fig. 12. Response time is 22 minutes with minimum responsible temperature is 93.67^{0}C. Maximum responsible temperature is 95.94^{0}C at the 39 minutes. After that, this temperature is kept unchanged until the 60th minute. This is also meet the requirement of the process control theory.

5. Conclusions

In this paper, the design of the module 2 (Fermenting and extracting module) of the whole of process of integrated natural dye system is introduced. Because of the quite complex mechanical system and also other objective parameters, we proposed the system identification method by using ARX model. The comparison between simulation results and the practical values of the real experiment show that the transfer function of the system is the quite correct function.

Then, the PD controller is design to control the temperature of the module 2 with good response. In the near future, the whole system is now carrying to be manufacture to put them to server for the practical needs of the dying industry.

6. Acknowledgement

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7. References

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