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Fuzzy Logic Model for Degumming and Bleaching Troubleshooting in Palm Oil Refining

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Abstract: Failures at degumming and bleaching process in palm oil refining affect plant performance, production delay, and loss to the company. In current practice, troubleshooting in these process relies on human knowledge and trial and error method which can caused other failures and time consuming. In this study, fuzzy logic model was developed for troubleshooting degumming and bleaching process using Mamdani approached. Operating conditions at bleacher vessel, ejector, condenser, hotwell and cooling tower system were selected as input and output variables in the fuzzy logic model development. Qualitative and numerical data were collected in this study by interviewing plant workers, observing distributed control system (DCS), reviewing standard operating procedure (SOP), operation checklist and plant manuals. The relationship between input and output variables were described by fuzzy membership function and fuzzy rules. Centre of gravity method (COG) method was used for defuzzification. The proposed model was tested with real plant data and the model was shown successfully perform troubleshooting task and suggest necessary action. Therefore, this model has the potential to employed by operator and inexperience workers in palm oil industry.

Keywords: Fuzzy logic, Degumming, Bleaching, Troubleshooting, Palm Oil Refining

1. INTRODUCTION

Palm oil refining is a complex chemical process since it is operated under vacuum at high temperature. The quality of the refined oil is largely dependent on the operating condition of the process. Deviation of the operating condition can cause failure to the overall performance of the plant, production delay, and reduced company's profit. All these may occur due to machinery failures, deviation of operating condition and human error[1]. Incorrect actions taken to overcome the failures can lead to another fault and thus required more time to troubleshoot. This is not surprising because the refining processes are complex with multiple interacting input and output variables, making it complicated to determine the exact root cause of the failure. Therefore, a systematic troubleshooting system is required to suggest actions when any malfunction occurs to reduce human errors and increase time efficient.

Currently, fuzzy logic expert system has been widely used for troubleshooting in many chemical industries due to its the ability to incorporate human knowledge and experience, linguistic data and numerical data. Zahedi et al.[2], has implemented fuzzy logic for troubleshooting crude oil desalination plant. Morgan et al. [3], utilized signal and information interpretation and recommendation in maximizing the milling operations. Meanwhile Wahab et al.[4], applied fuzzy logic to troubleshoot the brine heater in the multi stage flash (MSF) plant.

A previous study was conducted to troubleshoot failure at the deodorizer in palm oil refining using fuzzy logic model [5]. As a continuation, the objectives of this study are to identify the ability of fuzzy logic model to predict failures and suggest action for failures at degumming and bleaching process. The model was tested using 27 inputs representing possible faults in the process. The performance of the model was identified based on similarity values between predicted and actual. The difficulty in developing the system comes from the data collection, which had to be obtained from several sources, including from the plant experts, and analyzing the qualitative data to ensure validity. The model was developed based on knowledge and experience of plant expert's, technical documents, operation checklist and plant manuals which have been analyzed systematically using thematic analysis, a well-known qualitative data analysis technique. The relationship of processing variables that can influence the process efficiency and caused failures were expressed by fuzzy if-then rule.

2. PROCESS DESCRIPTION

Palm oil needs to go through three main processes which are degumming, bleaching, and deodorization process in order to produce light yellow refined oil. The objectives of refining is to eliminate or cleanse the crude oils from unfavorable constituents such as undesirable color and flavor yet at the same time preserve the beneficial compounds such as vitamins, provitamins and antioxidants [6].

Degumming is the initial stage of refining used to separate gums, pigments, and trace metals from the crude oil by mixing the crude palm oil with concentrated phosphoric acid in order to avoid brown discoloration of oil after heating during deodorization[6]. Then, the degummed oil is fed to the more crucial process called bleaching. Throughout the bleaching process, pigments, oxidation products, trace metal and soaps are removed by treating the degummed oil with powdered substances called bleaching clay [6], [7] under vacuum pressure at 80 to 120°C for 15 to 30 minutes. Lastly, the oil is sent to the final part of refining which is the deodorization process to get rid of both free fatty acid contents and malodorous compound to obtain fully refined oil.

Previously, many studies have been done on degumming and bleaching process especially on the effect of clay type on color quality[8], [9], estimation on chemical dosage to degumming and bleaching process [10], and effect of degumming and bleaching process towards unwanted compound in crude palm oil[11]. This study will concentrate on efficiencies of degumming and bleaching process because deviation of operating condition can affect the quality of bleached oil, reduced plant performance and at the same time effect later process. Wrong decision making can worsen the situation, increased operators stress and time consuming. Therefore, a correct decision is important to diagnosed faults in efficient time.

A batch bleaching process was chosen as a case study as illustrated in Figure 1. Throughout the process, unwanted components were removed by several process variables. The efficiency to eliminate undesired constituents is influenced by condition of vacuum condition, bleaching temperature, retention time, agitation, acid and earth dosing [12]. Deviation of these process variables can reduced the bleaching efficiency.

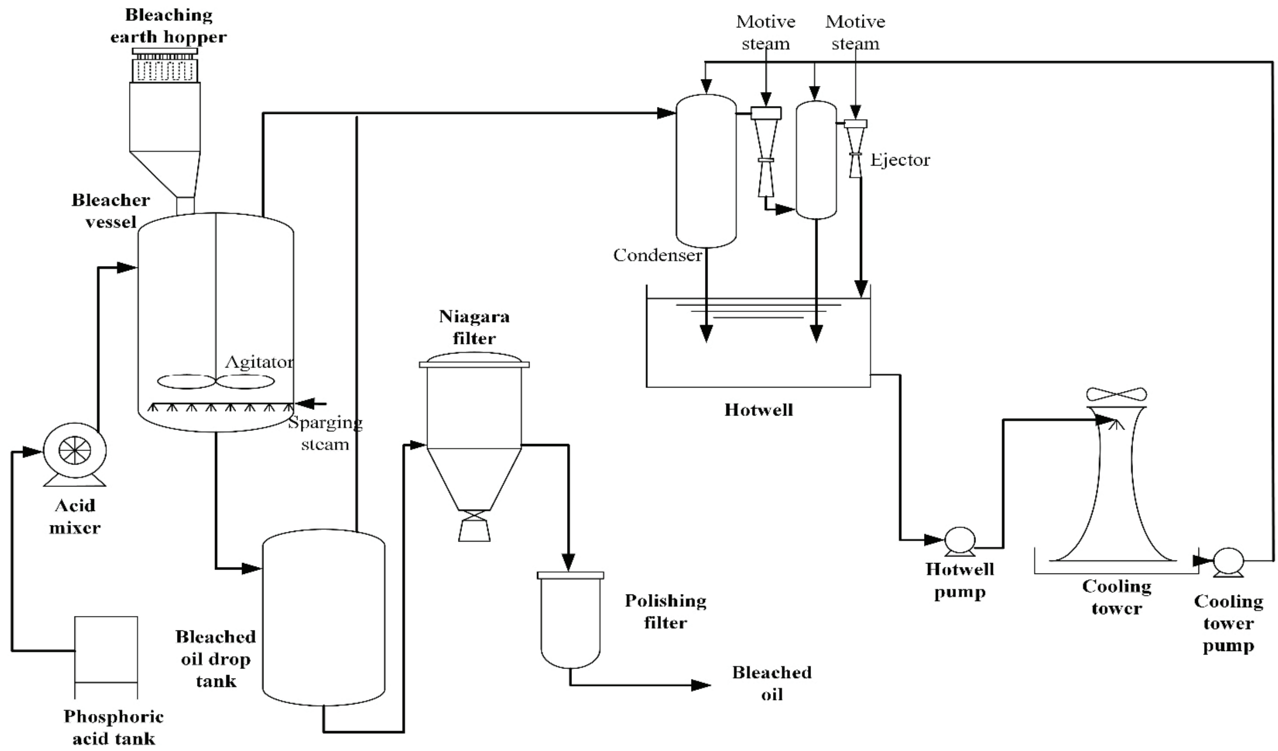

Fig. 1 Bleaching process

3. MODEL DEVELOPMENT

3.1 Fuzzy Logic Model

Fuzzy logic model is developed from three stages which are fuzzification, fuzzy inference system (FIS) engine and defuzzification. In fuzzification, crisp input was fuzzified to fuzzy values using linguistic data and membership functions. Next, the fuzzy values were applied to fuzzy rules stored as inference engine. In this study, Mamdani inference system was selected for its simplicity min-max structure. The final crisp outputs were then defuzzified using Centre of Gravity (COG) method and outcome from the inference engine is deduced. COG method is widely used for defuzzification process due to its capability to produce accurate results[13]. The equation is defined as below:

$$Z_{COG} = \frac{\int_a^b \mu_A(x)xdx}{\int_a^b \mu_A(x)dx} \ , \qquad (1)$$

where $\mu_{A(x)}$ is the aggregated membership function and Z_{COG} is the output variables. Lastly, the model was verified by testing with plant data in order to know its troubleshooting performance using similarity value[14]. This formula evaluates the action predicted based on source of list action, target list of action, and weight value. The formula is shown as below:

$$S_{PS} = \frac{\sum C_{P_i} W_i}{C_S} x\ 100. \qquad (2)$$

where S_{PS} is a similarity value, C_P is the predicted list of action, C_S source of list of actions, and Wi is the weight value at fuzzy rule. 27 input data were fed to the model.

3.2 Data Gathering

Qualitative and numerical data are two types of data collected from a refinery industry located at Pasir Gudang, Johor Malaysia. Qualitative data were obtained from interviews with plant workers, technical documents and operation checklist. The data were analyzed using thematic analysis in order to develop fuzzy membership functions and fuzzy if-then rules. Thematic analysis was done to capture the possible faults that may occur at degumming and bleaching processes. Thematic analysis consists of five steps which are data familiarization, generating initial codes, searching for themes, reviewing themes and defining themes [15]. Lastly, a troubleshooting tree was developed based on themes obtained from the analysis.

Quantitative data were obtained from Distributed Control System (DCS), standard operating procedure (SOP), operation checklist and plant manuals. These data were used to develop range for rules development. The fuzzy output represents actions to be taken for each possible faults. The suggested actions were gathered from expert's knowledge and experience.

In this study, twenty-seven input were recognized as factors affecting degumming and bleaching process efficiency. Failures at degumming and bleaching process were grouped into five categories which are bleacher vessel, ejector, hotwell, condenser and cooling tower system. The details of the input variables used are in Table 1.

Table 1 Input variables effecting degumming and bleaching process

	Input variables
1	Vacuum pressure
2	Suction pressure
3	Bleaching temperature
4	Bleaching earth dosage
5	Citric acid dosage
6	Retention time
7	Agitator speed
8	Sparging steam pressure
9	Sparging steam quality
10	Bleaching level
11	Feed flow rate
12	Tailpipe temperature
13	Cooling water temperature
14	Cooling water pressure
15	Cooling water flow rate
16	Condenser spray nozzle
17	Hotwell level
18	Cooling tower fan
19	Cooling tower fill
20	Cooling tower spray nozzle
21	Hotwell quality
22	Motive steam pressure
23	Motive steam temperature
24	Motive steam quality
25	Total steam flow rate
26	Ejector nozzle
27	Vacuum pump temperature

3.3 Fuzzy Membership Function and Fuzzy Rules

3.3.1 Fuzzy Membership Function

Figures 2 and 3 show the fuzzy membership function for input and output variables for vacuum pressure at degumming and bleaching process. All membership functions for fuzzy input and output variables are in trapezoidal form. Trapezoidal membership function was selected due to its simplicity and easy to calculate at the fuzzy input and fuzzy output variables in degumming and bleaching process.

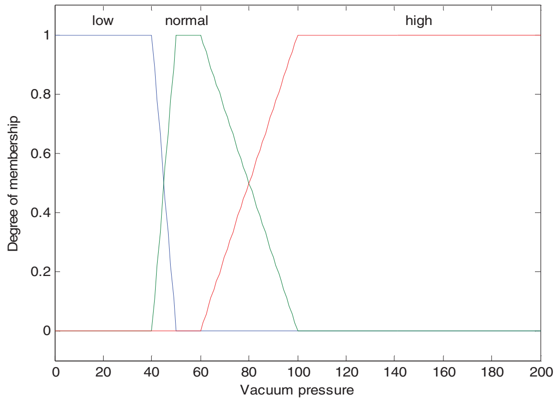

Fig. 2 Fuzzy input membership function
Low range: 0 to 50 torr
Normal range: 40 to 100 torr
High range: 60 to 200 torr

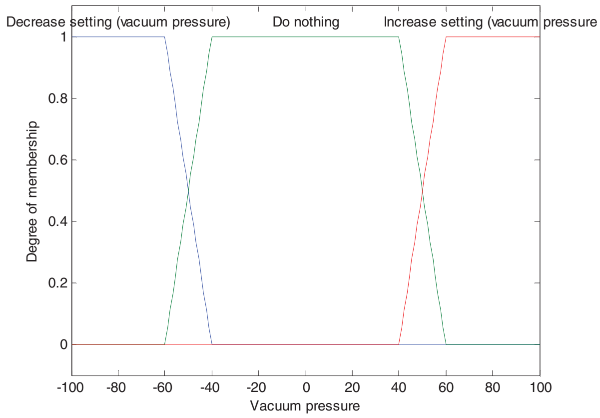

Fig. 3 Fuzzy output membership function
Decrease setting: -100 to -40
Do nothing: -40 to 40
Increase setting: 40 to 100

The action value was scaled from -100 to 100 which was divided into three; decrease setting, do nothing and increase setting. "Do nothing" refer to action for input variables at normal condition. "Increase setting" is an action required when the input variables at low condition. While "decrease setting" is an action suggested for high condition. As can be seen in Figure 3, "decrease setting (vacuum pressure)" was action suggested when vacuum pressure is high. High vacuum pressure indicate inefficient degumming and bleaching process thus affecting bleaching reaction. Meanwhile check motive steam condition is suggested action when vacuum pressure is low.

3.3.2 Fuzzy Rules

The next step for fuzzy logic model development is developing fuzzy rules. Rules were created to represent cases in degumming and bleaching process as listed in Table 2. These rules express the relationship between input and output variables affecting degumming and bleaching process. Input are variables that can influenced the process efficiency. Whilst outputs are suggested action to overcome failure when any malfunction of the input occurs. In this study, "AND" fuzzy operator was used for normal condition and "OR" fuzzy operator was used for abnormal condition. All rules applied value of one as weight factor.

Table 2 Fuzzy rules

Fuzzy rule for vacuum pressure 1. If (vacuum pressure is low) then (action is increase setting) 2. If (vacuum pressure is normal) then (action is do nothing) 3. If (vacuum pressure is high) then action is (decrease setting)
Fuzzy rule for suction pressure 1. If (suction pressure is low) then (action is increase setting) 2. If (suction pressure is normal) then (action is do nothing) 3. If (suction pressure is high) then (action is decrease setting)
Fuzzy rule for bleaching temperature 1. If (bleaching temperature is low) then (action is increase setting) 2. If (bleaching temperature is normal) then (action is do nothing) 3. If (bleaching temperature is high) then (action is decrease setting)
Fuzzy rule for bleaching earth dosage 1. If (bleaching earth dosage is low) then (action is increase setting) 2. If (bleaching earth dosage is normal) then (action is do nothing)
Fuzzy rule for citric acid dosage 1. If (citric acid dosage is low) then (action is increase setting) 2. If (citric acid dosage is normal) then (action is do nothing)
Fuzzy rule for retention time 1. If (retention time is low) then (action is increase setting) 2. If (retention time is normal) then (action is do nothing) 3. If (retention time is high) then (action is decrease setting)
Fuzzy rule for agitator speed 1. If (agitator speed is low) then (action is increase setting) 2. If (agitator speed is normal) then (action is do nothing) 3. If (agitator speed is high) then (action is decrease setting)
Fuzzy rule for sparging steam pressure 1. If (sparging steam pressure is low) then (action is increase setting) 2. If (sparging steam pressure is normal) then (action is do nothing) 3. If (sparging steam pressure is high) then (action is decrease setting)
Fuzzy rule for sparging steam quality 1. If (sparging steam quality is wet) then (action is increase setting) 2. If (sparging steam quality is dry) then (action is do nothing)
Fuzzy rule for tailpipe temperature 1. If (tailpipe temperature is normal) then (action is do nothing) 2. If (tailpipe temperature is high) then (action is decrease setting)
Fuzzy rule for cooling water temperature 1. If (cooling water temperature is normal) then (action is do nothing) 2. If (cooling water temperature is high) then (action is decrease setting)
Fuzzy rule for cooling water pressure 1. If (cooling water pressure is low) then (action is increase setting) 2. If (cooling water pressure is normal) then (action is do nothing)
Fuzzy rule for cooling water flow rate 1. If (cooling water flow rate is low) then (action is increase setting) 2. If (cooling water flow rate is normal) then (action is do nothing)
Fuzzy rule for condenser spray nozzle 1. If (condenser spray nozzle is normal) then (action is do nothing) 2. If (condenser spray nozzle is clogged) then (action is decrease setting)
Fuzzy rule for hotwell level 1. If (hotwell level is low) then (action is increase setting) 2. If (hotwell level is normal) then (action is do nothing) 3. If (hotwell level is high) then (action is decrease setting)
Fuzzy rule for cooling tower fan 1. If (cooling tower fan is normal) then (action is do nothing) 2. If (cooling tower fan is stop) then (action is decrease setting)
Fuzzy rule for cooling tower fill 1. If (cooling tower fill is normal) then (action is do nothing) 2. If (cooling tower fill is clogged) then (action is decrease setting)
Fuzzy rule for cooling tower spray nozzle 1. If (cooling tower spray nozzle is normal) then (action is do nothing) 2. If (cooling tower spray nozzle is clogged) then (action is decrease setting)
Fuzzy rule for hotwell quality

1. If (hotwell quality is dirty) then (action is check bleaching level, replace dirty water) 2. If (hotwell quality is clean) then (action is do nothing)
Fuzzy rule for motive steam pressure 1. If (motive steam pressure is low) then (action is increase setting) 2. If (motive steam pressure is normal) then (action is do nothing) 3. If (motive steam pressure is high) then (action is decrease setting)
Fuzzy rule for motive steam temperature 1. If (motive steam temperature is low) then (action is increase setting) 2. If (motive steam temperature is normal) then (action is do nothing) 3. If (motive steam temperature is high) then (action is decrease setting)
Fuzzy rule for motive steam quality 1. If (motive steam quality is wet) then (action is increase setting) 2. If (motive steam quality is dry) then (action is do nothing)
Fuzzy rule for total steam flow rate 1. If (total steam flow rate is low) then (action is increase setting) 2. If (total steam flow rate is normal) then (action is do nothing) 3. If (total steam flow rate is high) then (action is decrease setting)
Fuzzy rule for ejector nozzle 1. If (ejector nozzle is normal) then (action is do nothing) 2. If (ejector nozzle is clogged) then (action is decrease setting)
Fuzzy rule for vacuum pump temperature 1. If (vacuum pump temperature is normal) then (action is do nothing) 2. If (vacuum pump temperature is high) then (action is decrease setting)

As can be seen in the tables, each input variables has its own membership function. Taking vacuum pressure as an example, it can be seen that vacuum pressure consists of three membership function which are "low", "normal" and "high". For each input membership function, it has output actions such as "decrease setting", "do nothing" or "increase setting".

4. RESULTS AND DISCUSSION

The fuzzy logic model was tested using several set of plant data representing conditions at degumming and bleaching process in order to compare conclusion by the model and human judgment. The process was repeated until the results from fuzzy logic were acceptable. In this study, the model was tested with input variables representing condition of degumming and bleaching process. The model is required to suggest actions when vacuum pressure is high and bleaching earth dosage is low. The value of the inserted input is "180.5" and "0.4". Rule represent "high" and "low" condition at vacuum pressure and bleaching earth dosage is fired in the fuzzy inference system. The defuzzified outputs given by fuzzy inference system is "-75" and "75" which suggest to "decrease setting" and "increase setting" for both failures. In this rule, high vacuum pressure and low bleaching earth dosage indicates poor degumming and bleaching process and may cause product quality failed. Thus, all input variables influenced the process efficiency. 27 actions were suggested by the model as can be seen in Figure 4. The model shows 100% similarity value for action predicted. This indicates that the model is able to relate the influence of input variables towards degumming and bleaching process performance.

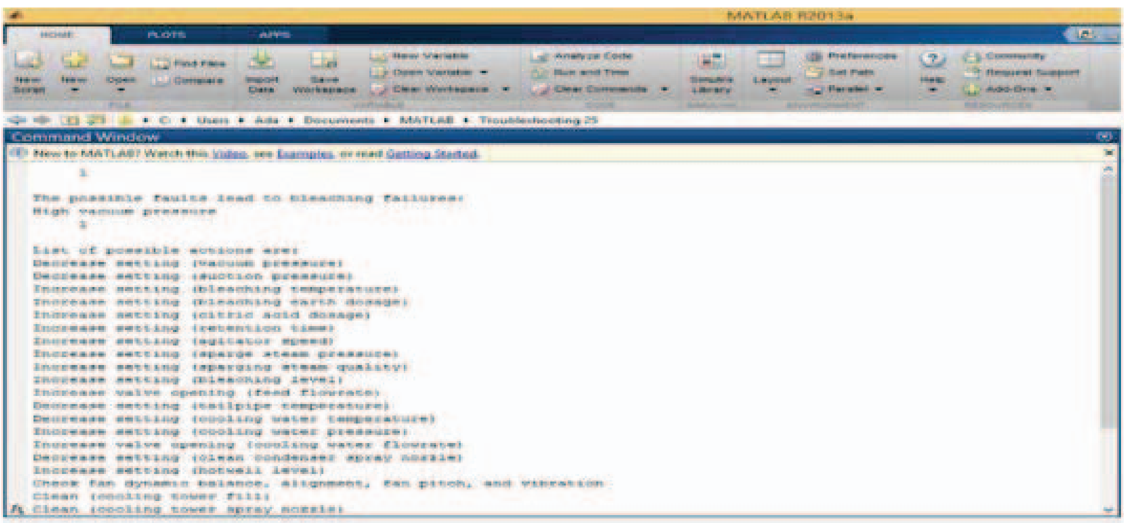

Fig. 4 Output from the model

5. CONCLUSION

A fuzzy logic model was developed for troubleshooting degumming and bleaching process in palm oil refining using linguistic and numerical data. Fuzzy membership function and fuzzy rule was developed to describe the relationship between input and output variables. The model was tested with condition at vacuum pressure and bleaching earth dosage. The predicted results were seen to be satisfactory with 100% similarity value. Thus, the model is able to improve process efficiency and assist operator and inexperience worker in palm oil industry.

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