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Development of Optimisation Model based on Genetic Algorithms for Palm Oil Refining Industry

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In palm oil refining industry, the major concern is on the end quality of refined oil and one of the factors affecting this quality is the amount of raw chemicals used during refining process. In current practice, the amount of chemicals used are fixed within a certain range. There is no system that can estimate the right amount of chemicals to be added in accordance to the required quality of the refined palm oil. The optimisation model of palm oil refining is developed. The process of optimisation of palm oil refining industry involves an objective function that consist of palm oil refining production raw chemicals cost and its dosage. For this type of problem, Genetic Algorithms (GAs) optimisation is demonstrated to be an effective tool to solve it. In this paper, optimisation model development based on GAs is presented to improve the industrial production of refined palm oil. The model must optimise an objective function consists of dosage of bleaching earth and citric acid subjected to the constraint of the process which is the quality of the refined oil. The optimum value of bleaching earth and citric acid dosage given by the model are 0.9 and 0.03. This model is crucial in maintaining the good quality of the refined palm oil as well as increasing the process profitability.

1. Introduction

World's palm oil production is increasing from year to year compared to other vegetable oils, where the production increased from 52.58 to 61.46 million metric tons from 2011 to 2014. As stated in 2015 report from Foreign Agricultural Service, United States Department of Agriculture, in 2014, Malaysia produced 19,800 thousand metric tons of palm oils which is 32% of palm oil world production last year. Malaysia is the second largest palm oils producer after Indonesia. This accelerative production of palm oil is due to the increase of palm oil's demand. The major reason for this increase is the wide application of palm oil in various industries. Palm oil food products exported are not only limited to bulk oils but also specialty fats products such as shortening, margarine, cereal, chocolate, sweets and confectionery fats. For non-food purposes, there are varieties of products such as soaps, washing powders, cosmetics, plastics, steel, textile, animal feedstuffs and biofuels (Chutchai and Morrakot, 2013). Palm oil is being used increasingly for biofuel production therefore the demand is growing (Figueroa-Jimenez et al., 2015). The unique components in palm oil make this variation of palm oil's end product.

Palm oil is rich in palmitic and monounsaturated fatty acid where the free fatty acids (FFA) need to be removed in the refining process. FFA content in the palm oil at level of 4.8 % to 7.2 % can be lowered to minimum 0.005 % (Ceriani and Meirelles, 2006). There are several minor constituents in palm oil such as carotenes, tocols, phytosterols and squalene. The carotenes level in palm oil varies between 500 - 700 ppm. The major carotenes include α- and β-carotenes that constitute to ~90 % of the total carotenes. Crude palm oil with high carotenes components will results in deep red colour while light-coloured crude palm oil shows a low carotenes content in the oil. Carotenes components determined the colour of the palm oil. However, most of carotenoids in palm oil are destroyed during refining process (Basiron, 2005).

Refining process is needed in order to remove these undesired components. This process will also remove other impurities like sand and husk in the palm oil. The end product of refining process should have

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characteristic like light colour, bland taste, good oxidative stability and also a low FFA content. Refining process is crucial in ensuring the refined oil is safe to be used by the consumers.

There are two types of refining process which are physical and chemical refining however physical refining is more favoured compared to chemical refining and been widely used in Malaysia's palm oil refining industry. The difference in these two types of refining process is the method used in order to remove the unwanted components in the oil. The chemical refining used sodium hydroxide in neutralization which didn't include in physical refining. This is the reason why physical refining is more favoured compared to chemical refining because of it is more suitable in producing edible oil. Degumming, bleaching and deodorisation process are three major process in palm oil refining industry (Gibon, 2007). Degumming process is done in order to remove gums like phospholipid and protein in the oil by using citric or phosphorics acid while bleaching process used bleaching earth and activated carbon as bleaching agent for removal of colour pigments like carotene and chlorophyll. The final stage is deodorisation process under vacuum pressure and high temperature where it removed FFA content in the oil (Basiron, 2005).

In 2014, China as world's second-largest palm oil importer had tighten the specification on quality of imported edible oil which include refined palm oil. The specification needs to be accurately followed or else the edible oil will be said as off-spec product and thus rejected (Adnan, 2013). It is scared that Malaysia's palm oil refining industry may encounter big losses if this rejection happens due to the fact that Malaysia is second world's largest palm oil supplier after Indonesia. About 31 % of the total world palm oil production is contributed by Malaysia in 2015 (USDA-FAS, 2015). This quality restriction by China may hurt Malaysia's palm oil industry because this tougher requirement is believed could slow down the refined oil's demand as well as weaker the price of crude palm oil. To circumvent this problem and rejection from importers, Malaysia's palm oil industry needs to pay more attention to their final quality of the refined palm oil.

In order to achieve high quality of refined oil products while maintaining the production cost, palm oil refinery plant needs to be run at optimum process conditions. Factors such as quality of the crude oil, amount of chemicals used and operating parameters may cause the increase in operating cost or vice versa (Sulaiman and Mohd-Yusof, 2015). In the current practice in Malaysia's palm oil refinery plant, the amount of chemical used during bleaching and degumming process is usually fixed within a certain range. There is no system that can estimate the right amount of chemicals to be added in accordance to the final required quality of palm oil. Using fixed amount of dosage regardless of the required quality will cause losses in production profit. In order to maintain excellent quality of refined palm oil while increasing process profitability, an optimum dosage of chemicals like bleaching earth, activated carbon and citric acid should be used in the refining process. Optimisation of the refining process of palm oil is needed.

The process of optimisation of palm oil refining industry involves an objective function that minimises the production costs by minimising the dosage of chemicals used throughout the refining process. For this type of problem, GAs optimisation has demonstrated to be an effective tool to solve it. GA is based on the analogy of improving a population of solutions through modifying their gene pool. It mimics the natural evolutionary process by introducing the principles of 'survival of the fittest' and genetics theory in finding the optimum results (Goldberg, 1989).

The uses of GAs for different industrial applications are available in the literature. Some of these works include thermally coupled distillation system optimisation (Gutérrez-Antonio et al., 2011), membrane bioreactors optimisation (Silvia et al., 2013), multi-product lignocellulosic biorefineries optimisation (Aryan et al., 2013) and optimisation of high vacuum distillation system (Astrid et al., 2015). GAs has been widely use in chemical process optimisation problem.

The main objective in this study is to develop an optimisation model to improve industrial production of refined palm oil. To minimise production cost of refined palm oil, optimum dosage of bleaching earth and citric acid need to be found. The optimisation model is useful in maintaining the good quality of refined palm oil and thus increasing the process profitability.

The remainder of this paper is organized as follow. Section 2 provides a description on Malaysia's palm oil refining process. Section 3 provides an introduction to the method used in this paper and applies the method to optimization of palm oil refining process. Section 4 discusses the result from the optimization model, and finally, a conclusion is given in section 4.

2. Process Description of Industrial Palm Oil Refining

Quality of refined palm oil is depending on the composition of its components and theoretically, composition of phospholipids, proteins and carbohydrates, gums and fatty acids as well as colour pigments. These components give negative influence to the quality of oil. They are considered as undesirable components in refining and need to be removed to certain accepted level (Gibon, 2007).

The overall palm oil refining process is shown in Figure 1. Crude palm oil undergoes three major process in physical palm oil refining which are degumming, bleaching and deodorisation. When crude palm oil entering bleacher unit, the citric acid is dosed and degumming process takes place for about 10 to 15 minutes. This process removed impurities such as phosphatides, chlorophyll, carotenoid, trace metal ions and oxidative product. The added citric acid coagulates these impurities to separate the impurities from the oil. However, the amount of acid used is a critical issue because under- or over-dosage of concentrated acid may lead to darkening of the oil during deodorisation process later on (Gibon, 2007).

After a short retention time, bleaching earth and activated carbon as bleaching agent are dosed to the oil. Bleaching earth absorbed the coagulated impurities and other impurities like soaps, trace metals, oxidation products and polyaromatics. The bleaching process retention time is about 30 min. Degumming and bleaching process is in vacuum pressure and at temperature 80 - 120 °C. Kaynak et al. (2004) proved that bleaching earth dosage affected the colour reduction and chlorophyll removal. The increase in bleaching earth dosage resulting in increasing of chlorophyll adsorption by the bleaching earth. The bleached palm oil is then undergo filtration process where it removed the spent bleaching earth from the oil.

The last step in palm oil refining process is deodorisation process. This process is where all volatile components such as FFA and odoriferous pigments are distilled and removed as Palm Fatty Acid Distillate (PFAD). This process is also known as distillation process (temperature range: 245 – 265 °C, vacuum pressure). The final product coming out from deodoriser is called Refined Bleached and Deodorised Palm Oil (RBDPO).

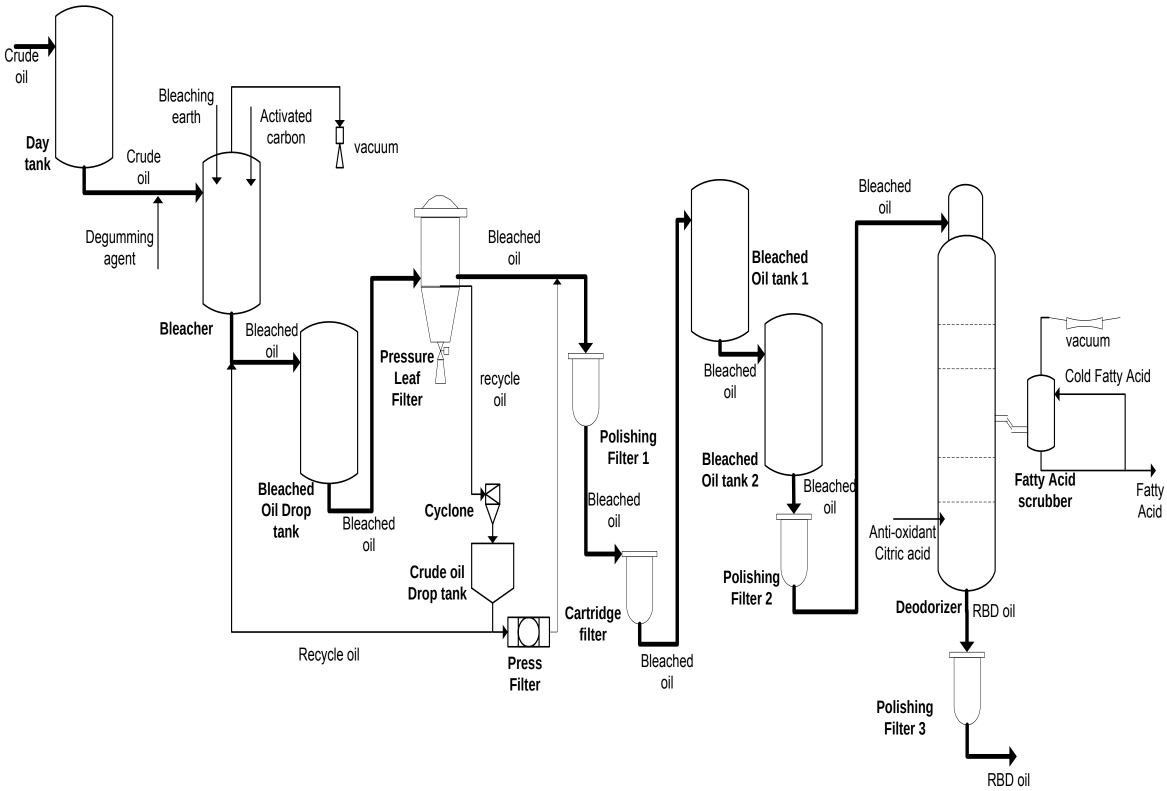

Figure 1: Overall industrial palm oil refining process

3. GA Optimisation Methodology

3.1 Overview of Genetic Algorithms

GAs solves optimisation problems by mimicking the principle of biological evolution, repeatedly modifying a population of individual using crossover and mutation operators on gene combination in biological reproduction. Its random nature improves the chances of finding global solution. The whole process of GAs optimisation can be summarised as follows (Goldberg, 1989):

1. Initialisation - generate meaningful populations and set the maximum evolution algebra.
2. Individual evaluation - calculate the corresponding fitness of the individual in the population.

3. Select operation - select the individual with high fitness to inherit to the next generation.
4. Crossover operation - generate new individuals according to a certain crossover probability.
5. Mutation operation - Change certain characteristic value of the individual in the population according to a certain probability.
6. Termination - optimising process stop when GA reaches the pre-set maximum evolution. The individual with the highest fitness during the evolution is taken as an optimal output.

3.2 GA Optimising of Palm Oil Refining

To keep the plant running at optimum throughput constantly, the process condition must be at its optimum value. There are a few parameters that can be considered in optimising palm oil refining process; bleaching earth dosage, citric acid dosage, activated carbon dosage, steam consumption and others. This paper only focused on optimising the citric acid and bleaching earth dosage in degumming and bleaching process. To compose the objective function, dosage amount of citric acid and bleaching earth is selected as decision variable. The objective function is as below:

$$f(x1, x2) = -C1 \text{ x } (\text{round } \frac{m1 \text{ x } \left(\frac{x(1)}{100}\right)}{m2} \text{ x } m2 - C2 \text{ x } (\frac{\pi \text{ x } 42.5 \text{ x } 42.5 \text{ x } \left(\frac{x(2)}{100}\right) \text{ x } m1}{7.99})$$

$$f(x1, x2) = -C1 * (round \frac{m1 * (x(1)/100)}{m2}) * m2 - C2 * (\frac{\Pi * 42.5 * 42.5 * (x(2)/100) * m1}{7.99} \quad (1)$$

Objective function in this study composed by cost and dosage amount of both citric acid and bleaching earth per batch of refining process. The cost objective function of the model is shown in Eq(1). The cost of bleaching earth that been used in Malaysia's palm oil denoted as C1 while C2 is the cost of citric acid. Decision variables is denoted as x1 and x2 which is the dosage amount of bleaching earth and citric acid per batch of refining process. m1 refers to mass of crude oil per batch and m2 is the mass of bleaching earth per batch.
As mentioned before, this cost function is restricted to few constraints such as the final required quality of the refined oil and the boundary constraint of both bleaching earth and citric acid. Thus this objective function will have a significant value if and only if the decision variables are in the range that bounded by the constraints. Eq(2) represents the final required quality constraints while Eq(3) and Eq(4) are boundary constraints for bleaching earth and citric acid.

$$0.3x(1) + 0.033x(2) - 0.5 \leq 0 \quad (2)$$

$$0.3 \leq x(1) \leq 2 \quad (3)$$

$$0.033 \leq x(2) \leq 0.6 \quad (4)$$

3.3 Data Description

The input parameters used in this model are obtained from one palm oil refinery plant in Malaysia. The mass of crude oil per batch is 12,000 t per batch. Bleaching earth prices are assumed to be RM 973/t. Citric acid prices are assumed to be RM 2,840/t.

4. Results and Discussion

The GAs optimisation of palm oil refining process for this paper is run in MATLAB R2014b by using GA optimisation toolbox. The optimisation is run for one of the major palm oil product in palm oil refining industry which is Crude Palm Kernel Oil (CPKO). It is due to the fact that CPKO is use in manufacturing of variety of edible palm oil product such as margarine, shortening and others. This wide range of product type makes it one of the major palm oil refining product beside Crude Palm Oil.
Table 1 lists the comparison between normal dosage of bleaching earth and citric acid used in palm oil refinery plant with the optimum dosage produced by the GAs model. The normal dosage depends on the type of oil. This study focused on CPKO because it is one of the major palm oil refining product. CPKO is one of the most produced in palm oil refinery industry due to the fact that it use in manufacturing of variety of edible oil product. As shown in the table, the GAs model is able to give an optimum value of the dosage. With this optimum dosage, one refining plant can save the production cost and thus increase its profitability.

Table 1: Current dosage of bleaching earth and citric acid vs optimum dosage generated by GA model and its cost saving

Type of Palm Oil	Normal Bleaching Earth Dosage (%)	Optimum Bleaching Earth Dosage by GA Model (%)	Normal Citric Acid Dosage (%)	Optimum Citric Acid Dosage by GA Model (%)	Cost Saving (RM)
Crude Palm Kernel Oil	1.0	0.9	0.042	0.03	194,113.65

Figure 2 is the result from MATLAB optimisation. The result presents the best fitness value for the objective function which is RM 194,113.65. The optimisation is terminated at this fitness value because final at this point, each individual that bounded to the constraints give an smallest value of the fitness function. The individual given by the model which are 0.9 and 0.03 is the optimum value for bleaching earth and citric acid. Different type of oil will be bounded by different constraints, therefore the optimum dosage of both bleaching earth and citric acid will be different. The iteration of the model is at 51 iteration. This shows that GA takes quite some time to generate a good optimum individuals.

The validation of the model is done by calculating the MSE of the normal dosage and optimise dosage by the model. For bleaching earth dosage, the MSE is about 90 % while for citric acid is about 71.43 %. These results show that the model give a good optimum value of both bleaching earth and citric acid dosage.

However, this study only focused on degumming and bleaching process. For further work, it is recommended that overall optimisation of palm oil refining process should be considered. Other parameters such as steam consumption should be considered. This overall optimisation of palm oil refining industry will bring huge help to Malaysia's palm oil refinery industry in reducing their production cost and thus maximising their profit.

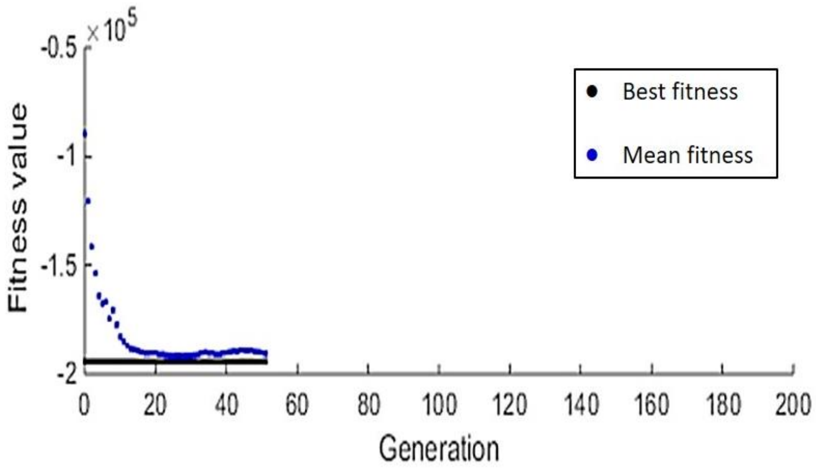

Figure 2: Best objective function values and its corresponding best individual

5. Conclusions

The model is able optimise the objective function of the model which is the cost function of palm oil refining process. The model is able to give an optimum dosage value of the raw chemicals which are bleaching earth and citric acid. The optimum individuals given by the model are 0.9 and 0.03. For these optimum individuals, the best fitness value is at RM 194,113.65. This model is crucial in improving the quality of the refined oil as well as increasing the process profitability.

On the other note, the optimisation of palm oil should be extended to deodorisation process and taking steam consumption into consideration. By taking the deodorisation process into the optimisation model, overall palm oil refining process optimisation can be achieved. For further work, it is suggested that overall palm oil refining process optimisation should be considered for a better optimisation result.

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