Jurnal Kejuruteraan 32(2) 2020: 215-220
https://doi.org/10.17576/jkukm-2020-32(2)-05

‘SMART’ Manufacturing Method of Oleochemical Plants by Determining Fatty Acid Composition of C12 of Palm Kernel Stearin using Fuzzy Logic System

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Received 14 December 2018, Received in revised form 18 July 2019
Accepted 29 August 2019, Available online 30 May 2020

ABSTRACT

Industry 4.0 is the name given to the latest evolution in the digitalisation and automation of manufacturing processes. Transitioning to Industry 4.0 is an emerging imperative for chemical processing based manufacturers throughout the world. “Smart” equipments, products and factories are transforming how companies do business, both internally and with suppliers and customers. At the present moment palm oil products particularly, Palm Kernel Oil have become a major feedstock for the oleochemical industries in Malaysia. Since Malaysia accounts for 42% of the global production of palm oil products, it is inevitable that the oleochemical industries has been flourishing and blooming in the last few years. The majority fatty acid found in palm kernel stearin is C12 which can be found in range of 54.8 to 64.0 wt%. But this value is determined by the iodine and saponification value of the palm kernel. The higher the iodine and saponification value, hence the higher the fatty acid composition can be found for higher extraction for oleochemical plant. The iodine value (Wjis) is ranged from 5.8 to 8.1 whereas the saponification value is ranged from 245 to 254 mgKOHg^{-1}oil. Fuzzy Logic system is developed to determine the fatty acid composition for the different range of iodine value and saponification value to ensure kernel with different composition of fatty acid to be separated and produce higher purity of oleochemical substances. This system will ensure ‘SMART’ manufacturing replacing the ‘NON-SMART’ methods where all kernels are grinded randomly and extracting altogether.

Keywords: ‘SMART’ manufacturing , fuzzy logic

INTRODUCTION

Today, Malaysian oleochemical industry is one of world’s, leader in the sector with more than 19 active oleochemical plants capable of producing more than 10 million tonnes in combined capacity and now producing at least 20% of the global production, wherein the annual revenue of these production amounts to about 10 billion MYR (Chin et al.,2013). Edible oils and fats are biological mixtures of plant origin consisting of ester mixtures derived from glycerol with chain of fatty acids (Eqbql et al., 2011). Both the physical and the chemical characteristics of oils and fats are greatly influenced by the kind and proportion of the fatty acids on the triacylglycerol (Senanayake and Shahidi ,2002; St. Angelo,1996). Fatty acids can be classified in classes as saturated, mono-unsaturated (MUFA) and polyunsaturated (PUFA) fatty acids. The basic oleochemical products such as Fatty Acids, Glycerol /Glycerine, Esters are used for the production of numerous products such as pharmaceutical, cosmetics, soaps, detergents, lubricants and anti-freeze. These oleochemical plants involve numerous chemical process such as bleaching, evaporation, distillation, esterification, deodorization and hydrogenation, most of the processes are at present operated through the conventional ‘non-smart manufacturing process’ and hence not operated at the optimal online efficiency of the process. Most of non-SMART is still used in oleo chemical industries due to lack of understanding the concept of SMART manufacturing and high cost for implementing computer programming at the distillation column. SMART used in this paper refer to combination of data from the distillation column and application of fuzzy logic in order to determine PUFAs (polyunsaturated fatty acids). Hence it is highly appropriate to implement the smart manufacturing processes for this oleochemical industry to further enhance it productivity and embrace all the advantageous of introducing the Industrial Revolution (IR) 4.0 concept in the oleochemical process system. This is also new and novel in nature, which will made us pioneer in developing the smart factory for the oleochemical industry.

Standard methods for the determination of fatty acid profile in fats and oils entail: (a) conversion of fat or oil in to mixed methyl esters by methanolysis, and (b) analysis and separation by Gas-Liquid Chromatography, GLC (Sonntag 1979). Sometimes butyl esters are also used. For most general purposes, flame ionization detectors are used for the identification: these detectors can produce sufficiently detailed fatty acid profiles. GLC is combined with mass spectrophotometer where further confirmation is required (Rangana 1986). Other instruments reportedly used for the similar analysis are improved versions of Thin Layer Chromatography (TLC) and Reversed-Phase-Argentation-HPLC. In particular, the latter is the method of choice for analyzing triglyceride composition and geometric isomers of fatty acids (Sleeter 1985).

Because of high cost of the above mentioned instruments, they are seldom used on routine basis. These are the problems that will be solve by using fuzzy logic. Their operation also calls for considerable experience on the part of the analyst. An alternative method included in the American Oil Chemists' Society ,AOCS Methods for the indirect determination of fatty acid profile is the Thiocyanogen Number (Rangana 1986). It was extensively used prior to 1939. With the advent of newer methods, particularly the GLC, this method has become largely obsolete. The main limitations in it were the toxic nature of thiocyanogen and the lack of reliability as confirmed by GLC (Sonntag 1982). For details of Thiocyanogen Number, the reader is referred to AOCS Methods, Vol. 1 (1975). In this paper, the main objective is to prescribe determination of PUFAs (polyunsaturated fatty acids) using Fuzzy logic (Nur Najihah et al., 2018; Ahmad Zuhari et al.2014) as an alternative to Thiocyanogen technique. Fuzzy logic is part of Artifical Intelligence (AI) technique which implemented in IR 4.0.

TABLE 1. Typical fatty acid profile of palm kernel stearin (Yaakob et al,1999)

Composition	**Wt%**
C6	0-0.1
C8	1.5-2.3
C10	2.5-2.9
C12	54.8-58.2
C14	21.1-24.1
C16	7.2-8.6
C18	1.3-2.2
C20	0-0.2

PROBLEM STATEMENT

The continuous challenge of juggling among the above-mentioned constraints necessitate sufficient solutions that can only obtained via an insightful, quantitative knowledge of the process and of relevant process parameters in the fractionation plant. Hence, it is imperative to have adequate measuring systems to monitor these large numbers of variables. Unfortunately, physical measuring devices (hardware sensors) typically found in industries have two key disadvantages: measurement delay which will greatly affect the control systems and cost-ineffective installation and maintenance of the hardware. Monitoring and estimating the product quality variables of C8-C10, C12, C14 and C16-C18+ fatty acids in the five distillation columns via these sensors require lab sample analysis which introduces discontinuity and considerable delays. The conventional method of determining fatty acid composition of C12 could be very expensive for the production of Oleochemical. Typical weight percentage of fatty acid in palm kernel stearin as shows in Table 1. By using Fuzzy Logic system, the cost of the fatty acid determination can be cut aversively. Fuzzy Logic System will give a range of fatty acid composition according to the set iodine and saponification values. Fuzzy logic system is used to simulate fatty acid composition of C12 since most of the previous researchers lack of this method. Compared with other analysis method such as Gas-Liquid Chromatography (GLC) and High Performance Liquid Chromatography (HPLC), fuzzy logic system has ability to process the input information as well as creating the required output (Ahmad Zuhairi et al. 2014; Dernoncourt 2013).

The objectives of this paper are to show a potential fuzzy logic system for determination of fatty acid composition of C12 via simulation.

METHODOLOGY

The methodology for this process starting with process monitoring, sensing and control of the Palm Kernel Oil Fatty Acid distillation units will be carried out by employing data-driven models. These models will be developed and validated using “big data” available from historical plant database and simulation of process using fuzzy logic (FL) via simulation.

Developing Fuzzy Logic

Data for simulation was obtained from Yaakob et al.1999. Some assumptions were made in order to simulate this study are;

1. Chemical process such as bleaching, evaporation, distillation, esterification, deodorization and hydrogenation was not involved in the FL system.
2. Operating conditions of distillation column were assumed to be constant.
3. Process control for distillation column was assumed to be in steady-state.
4. Fractionation process at optimum conditions.
5. Similar operating conditions for Gas-Liquid Chromatography (GLC) and High Performance Liquid Chromatography (HPLC).
6. The oil does not contain saturated fatty acids of carbons numbers greater than 18 and smaller than 16.

A Fuzzy System is a Computer System that uses Fuzzy Sets in either the Antecedent and/or Consequent of Fuzzy IF-THEN Rules

It consists of:

a) The 'base' Fuzzy sets that describe the problem

b) The IF-THEN Rules

c) Rule Composition

d) Defuzzification.

The input for this study are iodine and saponification value. The range of iodine is from 6,6.5,7,7.5 and 8 whereas for saponification value is from 246,248,250,252 and 254. Output for FL is Fatty acid composition within 54.8-58.2 wt%. MATLAB version R13a is used to run the simulation. Fig.1, shows initial method of using MATLAB toolbox of FL in order to run the simulation. The Triangular membership function is choose in this research because it is the most popular representation form. The triangular function is used to represent fuzzy numbers, the apex of the triangle is the unity of a number. Low, Medium & High represent the x co-ordinates of the three vertices of mA(x) in a fuzzy set. There are two main models for Fuzzy Inferencing Systems which are Mamdani and Takagi-Sugeno. Mamdani has been choose as a Fuzzy Inferencing Systems (FIS) as illustrated in Fig.2.

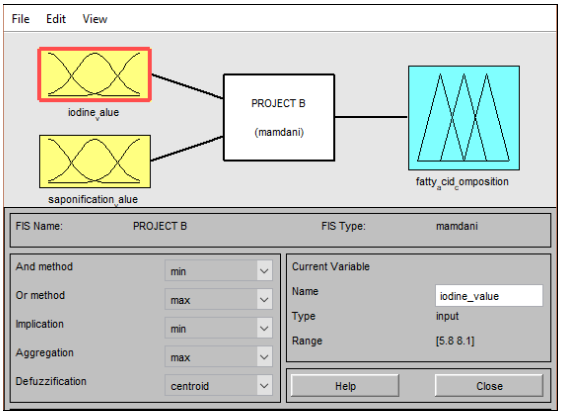
Determination number of rules was another procedure to simulate FL as in Fig.3. Nine rules was proposed in this study based on the type of Mamdani for two rules;

IF x is A1 and y is B1 THEN z is C1

Where x is Iodine value, y is saponification value and z is Fatty acid composition. 9 rules apply in this study are;

1. If Iodine value is low and saponification is low then fatty acid composition is low
2. If Iodine value is medium and saponification is medium then fatty acid composition is medium
3. If Iodine value is high and saponification is high then fatty acid composition is high
4. If Iodine value is not low and saponification is low then fatty acid composition is not low
5. If Iodine value is low and saponification is not low then fatty acid composition is not low
6. If Iodine value is not medium and saponification is medium then fatty acid composition is not medium
7. If Iodine value is medium and saponification is not medium then fatty acid composition is not medium
8. If Iodine value is not high and saponification is high then fatty acid composition is not high
9. If Iodine value is high and saponification is not high then fatty acid composition is not high

Fig. 1. Development FLC using MATLAB



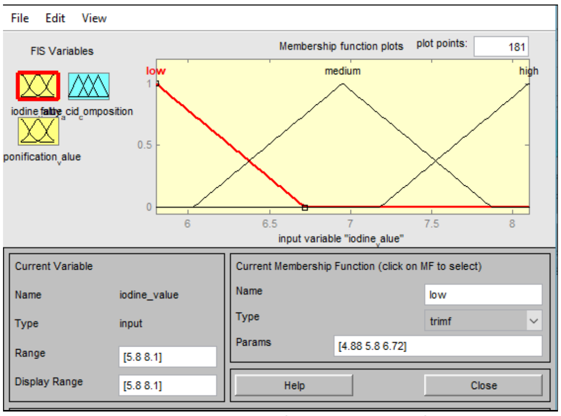


Fig.2. Determination of membership function

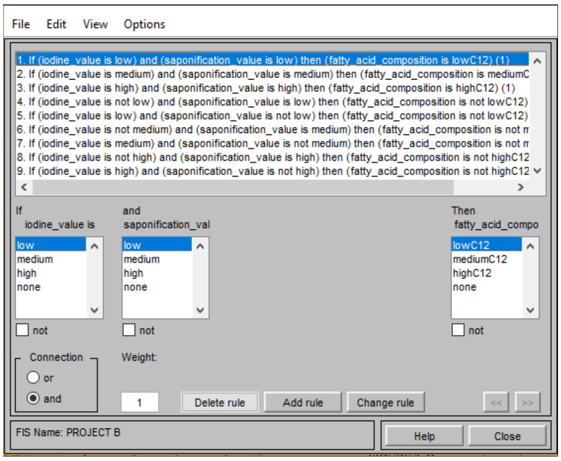


Fig.3. Development of rules for FLC

Final procedure in developing FL is defuzzification. Defuzzification is required to obtain a crisp output from a Fuzzy Inference System as a final output. Centre of Area is one of the various methods for defuzzification and shown by equation below;

$$x_{COA} = \frac{\int x\mu_A(x)\,x\,dx}{\int x\mu_A(x)\,dx}$$

where μA(x) is the aggregated output membership function. Center of Area is the most widely adopted defuzzification strategy.

RESULTS AND DISCUSSION

The composition of fatty acid C12 had been determined using the iodine and saponification value that has been set in the Fuzzy Logic system. Based on the output, it shows a range of different fatty acid composition from 54.8 to 64 wt. % which is quite similar with Yaakob et al., 1999 (54.8-58.2 wt. %) according to the iodine and saponification value. Fatty acid composition directly proportional to the iodine and saponification value. The higher the iodine and saponification value, the higher the fatty acid composition in the palm kernel stearin. The difference results between FL and Yaakob et al., 1999 mainly on the set of rules and the assumption for the FL system.

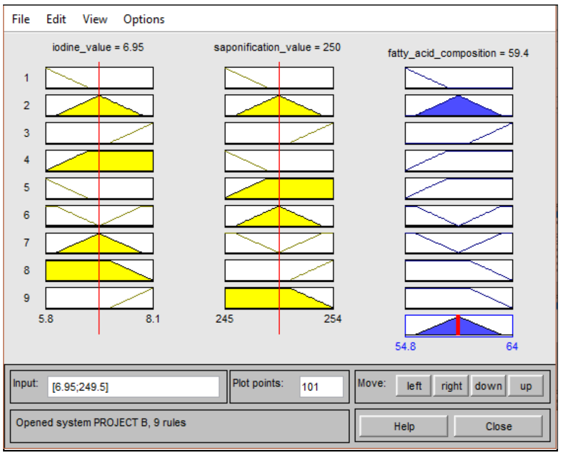
Figure 4 shows the output of fatty acid composition data using rules and surface view based on the Fuzzy Logic system with two inputs which are iodine and saponification value. Optimal value of fatty acid composition is at 59.4 wt. % with iodine value of 6.95 and saponification value of 250. The results proved the FL system ability to determine fatty acid composition which is faster, cost effective and improve in safety aspect since no chemical involved such as acetone/acetonitrile compared to conventional method by Rangana, 1986 and Sleeter, 1985. The findings are quite similar with Sina et al. 2019 which is the higher the iodine and saponification value, the higher the fatty acid composition in the palm kernel stearin but using difference technique for fuzzy logic.

The only disadvantages using FL system is that it depends on quantitate and quality of the data. Therefore sorting of data must be done before it can be apply to the FL system. The results can be improved with using other types of membership function such as linear, sigmoid, and trapezoidal. Improving the rules in this study should be take into consideration in order to improve the findings from this research.

Similar study using FL system but at different process with additional of process control was done by Nur Najihah et al., 2018 and Abdul et al. 2014. This findings provide a new study for using FL system as an alternative for determination of more complex functional groups without using expansive and sophisticated pieces of equipment such as Gas-Liquid Chromatography (GLC) and High Performance Liquid Chromatography (HPLC). However this method does not reflect the thermal profile. Obasa & Adejumo, 2017; Shahid et al, 2016, shows application of fuzzy logic controller for the reactor in a Oleo chemical process but not for the distillation column as in this study.

Nevertheless, one should not forget that, like any other tool, AI methods have their limitations. One major criticism of many AI paradigms (e.g., neural networks), which was previously alluded to in the article by Van Zuylen, 2012, is that they are often regarded as black boxes that merely attempt to map a relationship between output and input variables based on a training data set. This also immediately raises some concerns regarding the ability of the tool to generalize to situations that were not well represented in the data set. In this study, the generalize in terms of fatty acid composition for the output which is saturated and unsaturated fatty acid. One solution that has been proposed to address the black box problem is the combination or integration of multiple AI paradigms into a hybrid solution (e.g., combining neural networks and fuzzy sets into neuro-fuzzy systems) or coupling AI paradigms with more traditional solution techniques (Chowdhury and Sadek, 2012).

The results show an alternative method for analysis of the products which is on line analyser. This is an example of SMART manufacturing that can be implement for the whole plant in oleo –chemical process. It will be integrated through Internet of Things, IoT and cloud computational tools to form a software framework for a smart oleo –chemical process purported to be the factory for the future achieving Industry 4 0 targets.



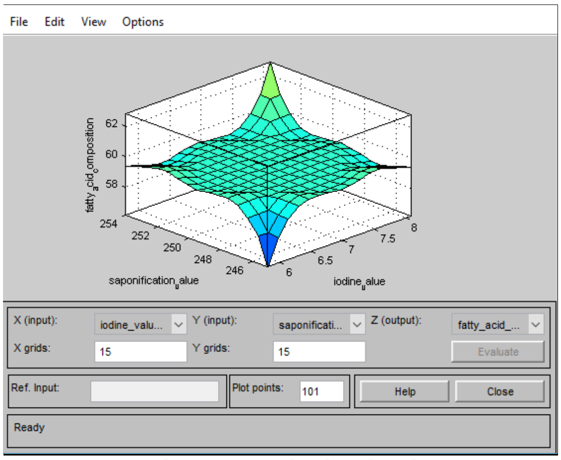


Fig. 4 Fatty acid composition data based on the Fuzzy Logic iodine and saponification value

CONCLUSION

Optimal value of fatty acid composition at 59.4 wt% with iodine value of 6.95 and 250 of saponification value. The higher the iodine value (8.1), the higher the fatty acid composition of C12 in palm kernel stearin (64 wt %). The lower the iodine value (5.8), the lower the fatty acid composition of C12 in palm kernel stearin (54.8). The higher the saponification value (254), the higher the fatty acid composition of C12 (64 wt %). The lower the saponification value, the lower the fatty acid composition of C12. Fuzzy Logic system can be used to evaluate and determine the wide range of fatty acid composition of C12 in palm kernel stearin.

ACKNOWLEDGEMENT

The authors would like to thank the Universiti Kebangsaan Malaysia (UKM) for supporting this research through grants GGP-2017-084 and GUP-2018-009.

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