FUZZY GENETIC OPTIMIZATION MODEL OF CRUDE PALM OIL AND PALM KERNEL PRODUCTION

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Abstract

In this paper a fuzzy optimization model of crude palm oil processing is presented. The model is focused on the minimization of oil losses and kernel losses during palm oil processing. The Mamdani fuzzy if then rules models are performed for each processing station in order to describe the relationships between the amount of oil losses and kernel losses with the processing variables which influence those losses. In conjunction with optimization method, genetic algorithm (GA) is applied to solve this problem. Using this method, the result shows that at 12 % of unripe fruits, the optimized sterilizing time is 110 minutes, steam pressure 2.9 kg/cm^2, digesting time 21 minutes, digesting temperature 92.6 ^{o}C, screw press pressure 35 bar, CST and decanter temperature 90 ^{o}C, oil+NOS concentration in decanter feeding 55 %, rotor speed of ripple mill 1950 rpm, air velocity at LTDS I 10 m/s and at LTDS II 14 m/s. At these conditions, the minimum total loss is 1.522 % of the amount of fresh fruit bunch. This consists of oil loss is as 1.107 % and kernel loss is as 0.41 % of the amount of fresh fruit bunch.

Key words: *Crude Palm Oil; Qualitative Model, Optimization, Fuzzy If Then Rules, Genetic Algorithm*

1. Introduction

Crude palm oil (CPO) is yielded from fresh fruit bunch of palm oil that is processed through some stages of processing. After fresh fruit bunch of palm oil is loaded into loading ramp, fresh fruit bunch is sterilized in a sterilizer in order to make fruit separate from the bunch much easier. Then, the sterilized fruit bunch is carried by hoisting crane to the thresher where the fruits are threshed in a stripper drum and separate from the bunch. The fruits are digested in a digester to separate nut from mesocarp for 15-20 minutes at temperature 90-100 ^{o}C. After the fruits are digested, they are carried by feed screw conveyor to the screw press. Crude oil resulted from pressing is flown to the clarification station, while press cake are carried by cake breaker conveyor to kernel station. In the clarification station, crude oil which consists of oil, water and non oil solid (NOS) is separated based on the density difference between oil and water by using centrifugal force and heating treatment at temperature 80-90 ^{o}C. Nuts that separated from mesocarp in the digester are processed to yield palm kernel. The mix of fibre and nuts which flow out from screw press are carried to the kernel station by cake breaker conveyor. After that, fibre and nuts are separated in depericarper and enter nut silo to reduce water content. Nuts are broken in the nut cracker or ripple mil to get kernel. The mix of kernel and shell are separated by using separating coloum and hydrocyclone. Lastly, kernel are dried in the kernel dryer before they are storaged.

Through those processing stages, the objectives would like to be achieved by decision makers are to optimize crude palm oil and kernel production and to minimize oil losses and kernel losses at all of processing stages. Nevertheless, palm oil processing is a complex process with many variables that influence oil losses and kernel losses during the processing. The mathematical models or quantitative models that describe the relationship between oil losses and processing variables that influence those losses are very difficult to be formulated. Due to the lack of quantitative models, an alternative problem solving by using fuzzy logic could be implemented.

Fuzzy logic was developed by Lotfi A. Zadeh in 1965 and since then fuzzy logic has been applied to many fields. Fuzzy logic allows decision making process that involves a vague, imprecise and ambiguous information. Fuzzy logic system may also allows the use of data and information from experts knowledge.

Fuzzy logic provides a methodology to mimics human expert instead of mathematical model. The application of fuzzy logic expert system in the production process control and optimization have been widely used since Mamdani and Assilian (1975) developed fuzzy inference fuzzy logic controller model for a steam engine and is known as Mamdani system. After that, Takagi and Sugeno (1985) also developed Sugeno fuzzy models (also known as TSK fuzzy model). In the TSK model the if parts (antecedents) are fuzzy sets and the then parts (consequences) are a crisp functions, while in the Mamdani fuzzy model the both parts are fuzzy sets. Mamdani fuzzy model consists of three components, which are : fuzzification, an inference engine and defuzzification process (*see Figure 1*).

In this study, the processing parameters that influence the quantity of oil losses and kernel losses at each station are identified. Fuzzy expert models are designed in order to minimize oil losses and kernel losses. The Mamdani fuzzy model is created based on knowledge of decision makers and experts in palm oil processing and case study was taken from a palm oil mill, i.e. PTPN VII, that is located in South Sumatra, Indonesia.

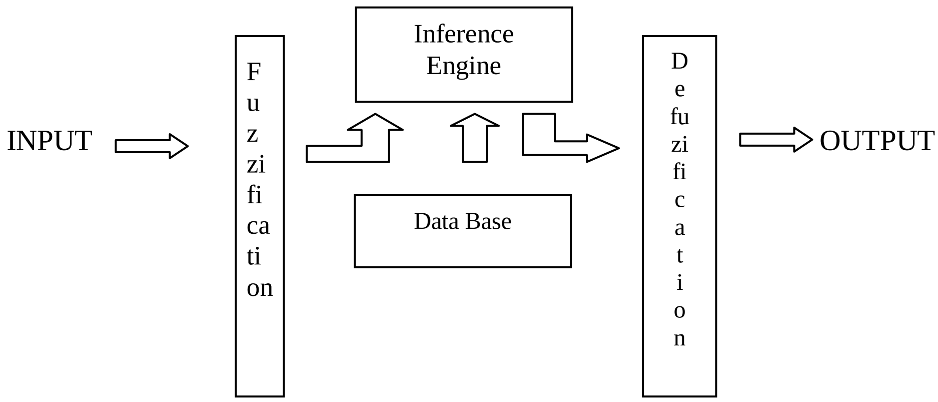


FIGURE 1. Mamdani Fuzzy Inference System

2. Mamdani Fuzzy Model Fuzzification

Palm oil processing pass through some stations, are as follow : loading ramp, sterilizing, threshing, pressing and digesting, clarification and kernel. The oil losses are caused by some processing factors in sterilizing and threshing, digesting and pressing as well as in clarification station.

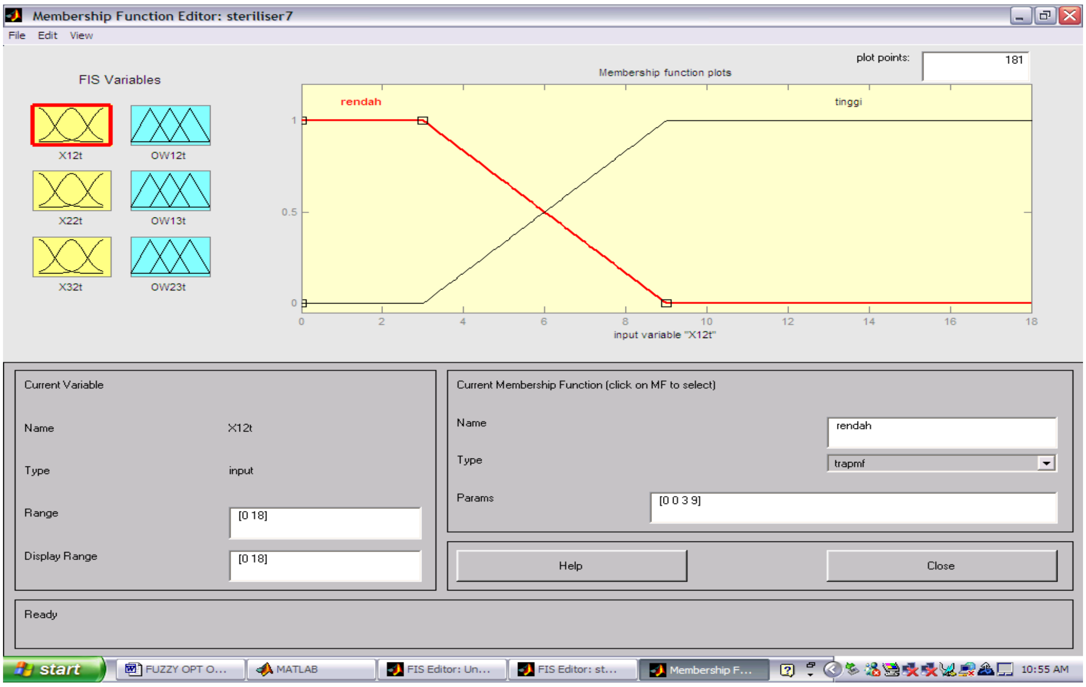
In sterilizing process, wastes are resulted from the process may still contain oil. Oil losses are in such wastes as follow : in condensate water, in empty bunch and in fruits within empty bunch. Oil losses during sterilizing and threshing process are influenced by some parameter processes, such as : sterilizing time, steam pressure and the percentage of unripe fruits in fresh fruit bunches. If sterilizing time and steam pressure increase, the oil losses in condensate water and in empty bunch will increase, but oil loss in fruits decreases. In contrast, if the sterilizing time and steam pressure decrease, the oil loss in condensate water and in empty bunch decrease, unfortunately oil loss in fruits become increase (Naibaho, 1998).

Based on this expert knowledge, fuzzy membership functions of input variables and output variables at sterilizing and threshing stations are formulated as follow :

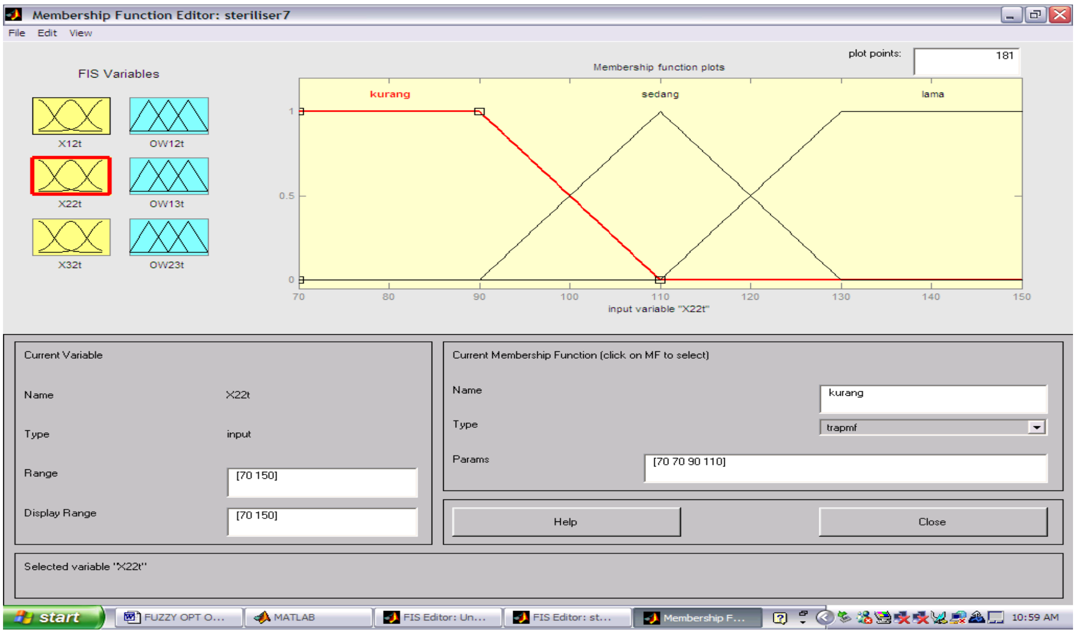
Table 1. Fuzzy variables at sterilizing and threshing station

No.	Fuzzy variables	Lingustic qualifier	Range
1.	*Fuzzy input variables* :		
	a. % unripe fruits (X_{12})	Low	0 – 6 %
		High	3 - 18 %
	b. sterilizing time (X_{22})	Short	70 – 110 min
		Medium	90 – 130 min
		Long	110 – 150 min
	c. steam pressure (X_{32})	Low	2.5 – 2.9 kg/cm^2
		Medium	2.7 – 3.1 kg/cm^2
		High	2.9 – 3.3 kg/cm^2
2.	*Fuzzy output variables* :		
	a. % oil loss in condensate water (OW_{12})	Low	0 – 0.3 %
		Medium	0.2 – 0.4 %
		High	0.3 – 0.6 %
	b. % oil loss in empty bunches (OW_{13})	Low	0 – 2 %
		Medium	1.5 – 2.5 %
		High	2 – 4 %
	c. % oil loss in fruits remaining in empty bunches (OW_{23})	Low	0 - 0.35 %
		Medium	0.2 – 0.5 %
		High	0.35 – 1.3 %

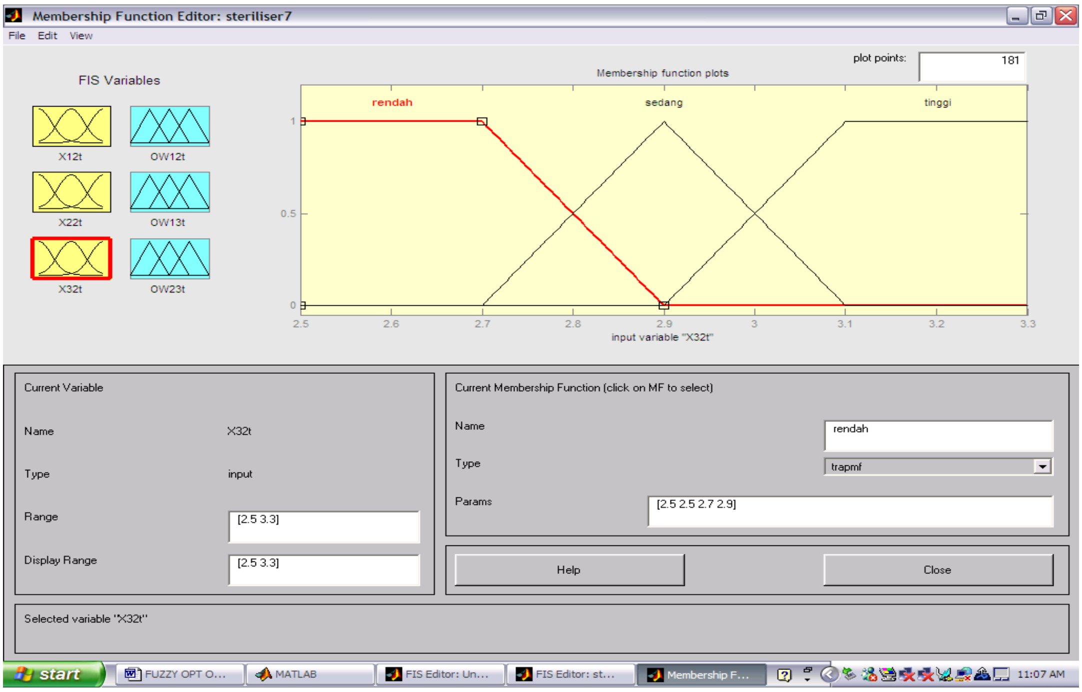
Membership functions of fuzzy input and output variables in sterilizing and threshing stations can be seen at Figure 2 and Figure 3.



(2a). % of unripe fruits

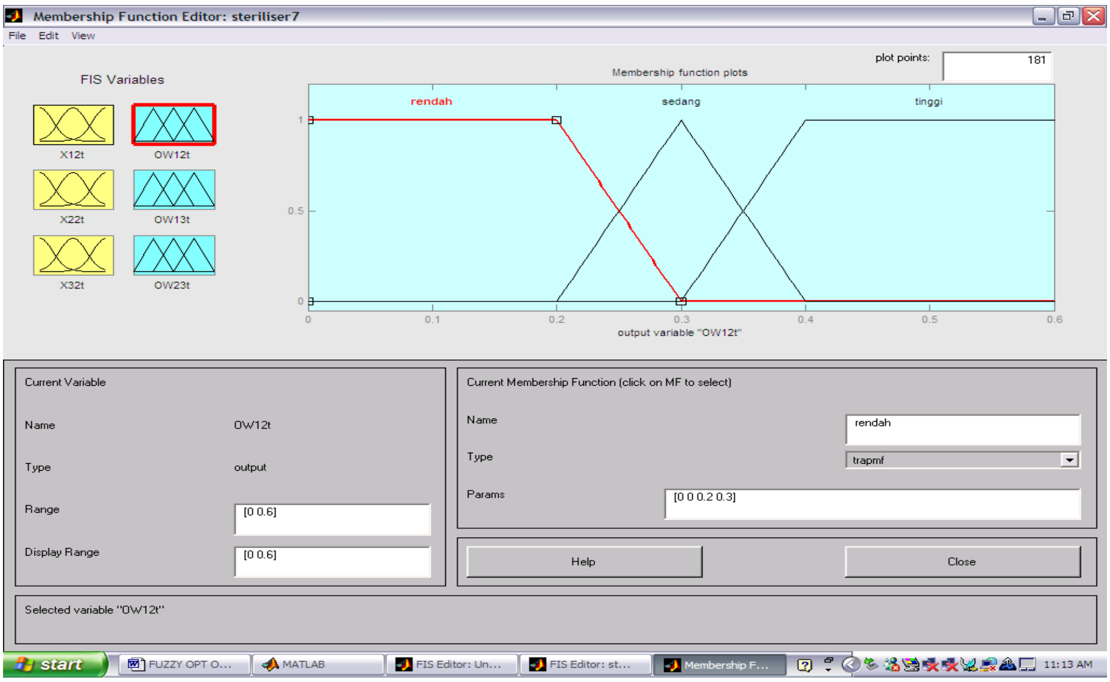


(2b). sterilizing time

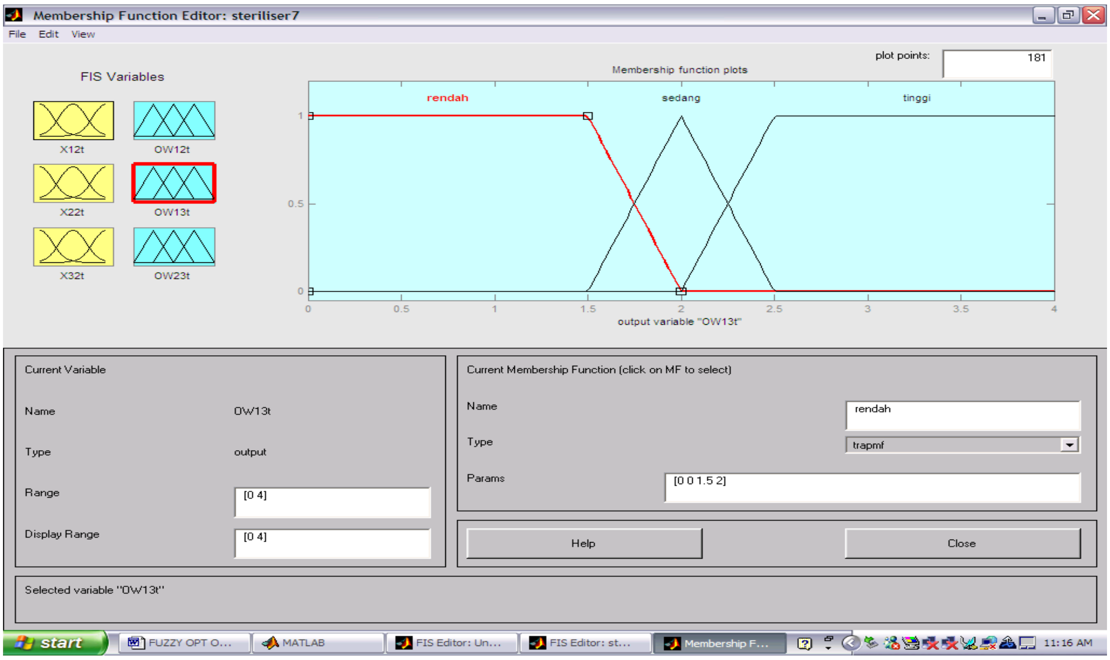


(2c). steam pressure

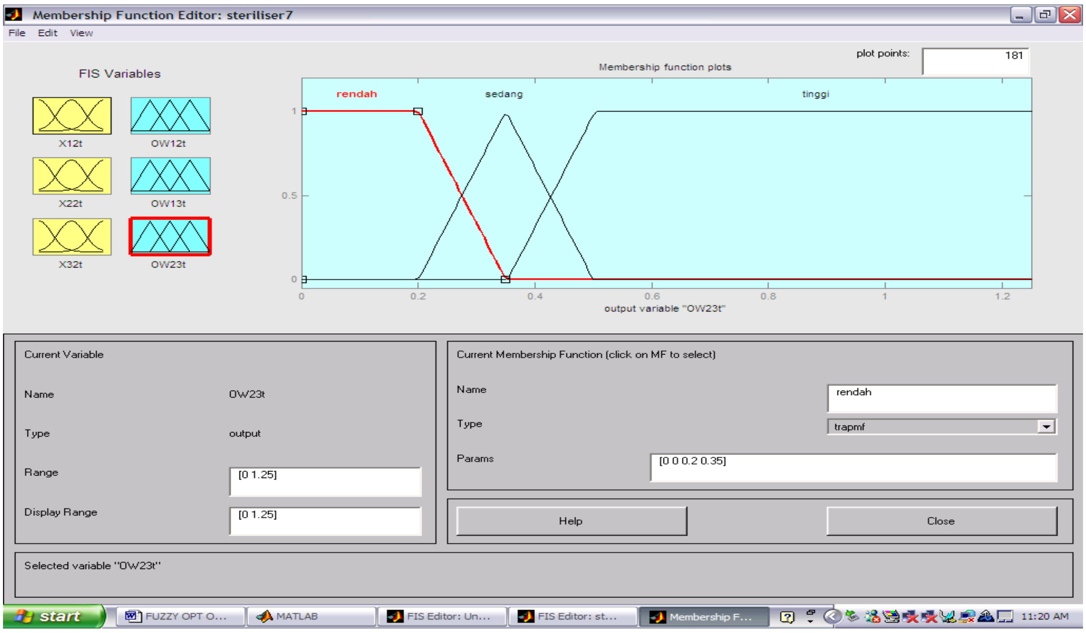
FIGURE 2. Membership function of input variables at sterilizing and threshing stations



(3a). % oil loss in condensate water



(3b). % oil loss in empty bunches



(3c). % oil loss in fruits remaining in empty bunches

FIGURE 3. Membership functions of fuzzy output variables at sterilizing station

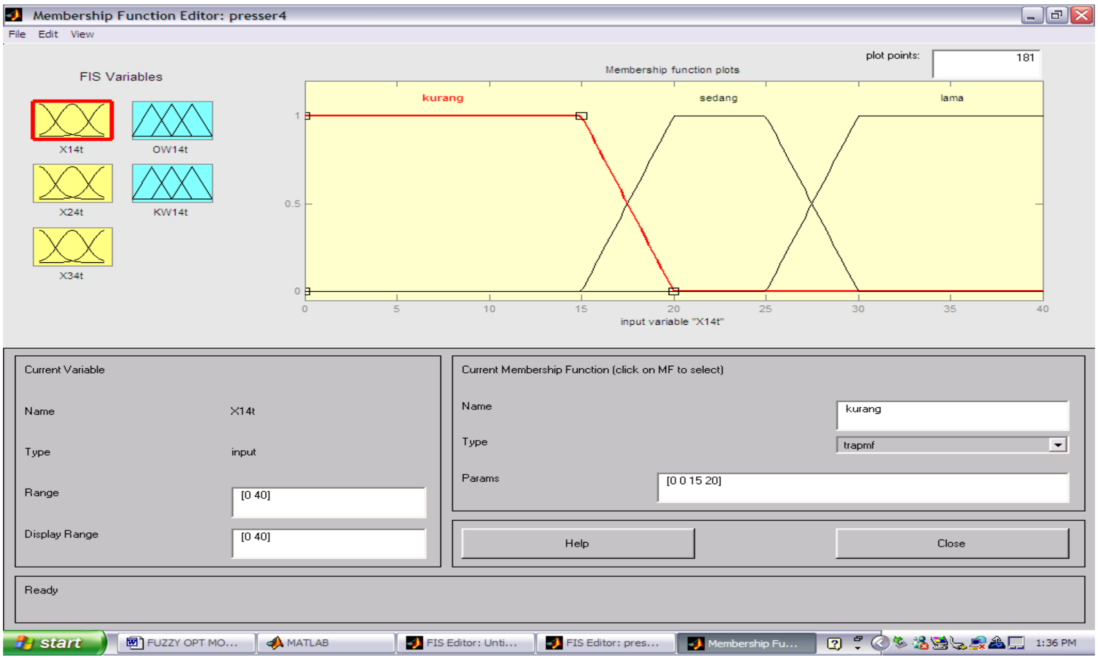
According to expert knowledge, at digesting and pressing station, screw press pressure very influence the amount of crude oil resulted. If the pressure too low, fiber may still contain much oil. However, if the pressure too high, kernel loss will be high. Other factors that influence oil and kernel losses during digesting and pressing are digesting time and digester temperature. Digester temperature have to be kept at 90-100 ^{O}C and digesting time is around 15-20 minutes. If digesting time is too short, mesocarp is not separated from nut perfectly, therefore the oil loss will be high.

Based on this knowledge, the formulation of fuzzy membership functions of input variables and ouput variables at digesting and pressing station can be seen at Table 2.

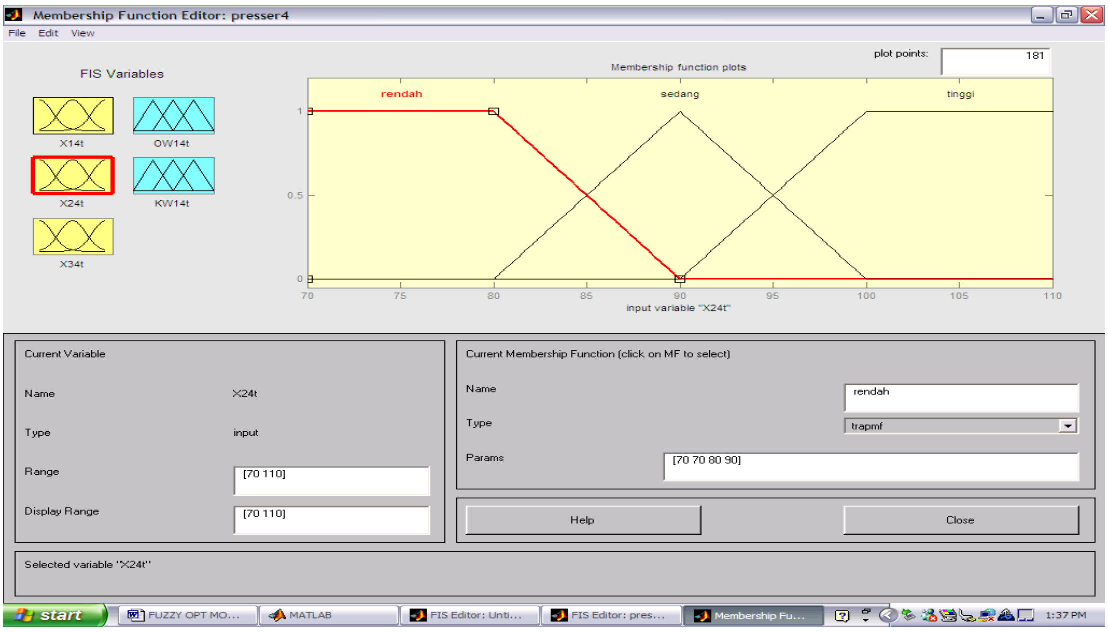
Table 2. Fuzzy variables at digesting and pressing station

No.	Fuzzy variables	Lingustic qualifier	Range
1.	*Fuzzy input variables* :		
	a. Digesting time (X_{14})	Short	0 – 20 min
		Medium	15 – 30 min
		Long	25 – 40 min
	b. Digesting temperature (X_{24})	Low	70 – 90 ^{o}C
		Medium	80 – 100 ^{o}C
		High	90 – 110 ^{o}C
	c. Screw press pressure (X_{34})	Low	20 – 35 bar
		Medium	30 – 45 bar
		High	40 – 60 bar
2.	*Fuzzy output variables* :		
	a. % oil loss in fibre (OW_{14})	Low	0 – 4 %
		Medium	3 – 5 %
		High	4 – 8 %
	b. % kernel loss in fibre (KW_{14})	Low	0 – 2 %
		Medium	1.8 – 2.2 %
		High	2 – 6 %

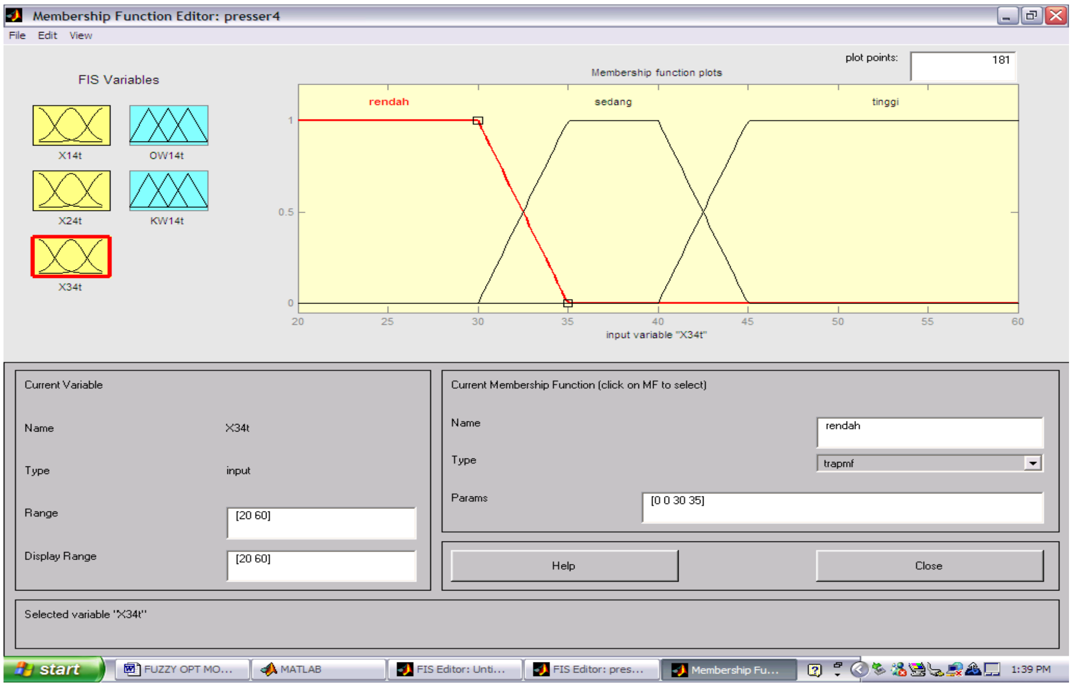
Membership functions of fuzzy input and output variables at digesting and pressing station can be seen at Figure 4 and Figure 5.



(4a). Digesting time

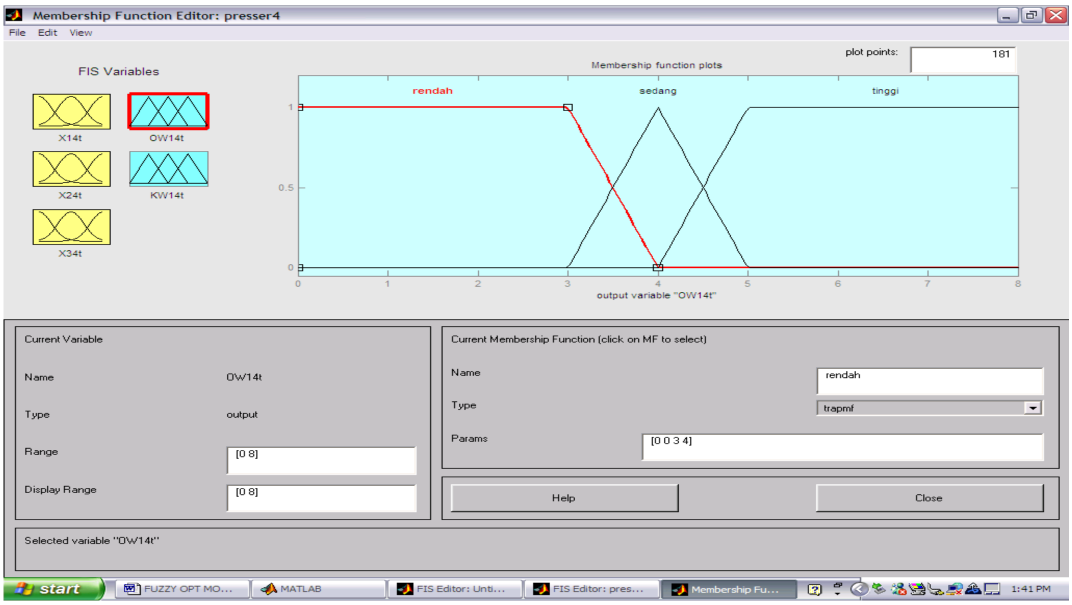


(4b). Digesting temperature

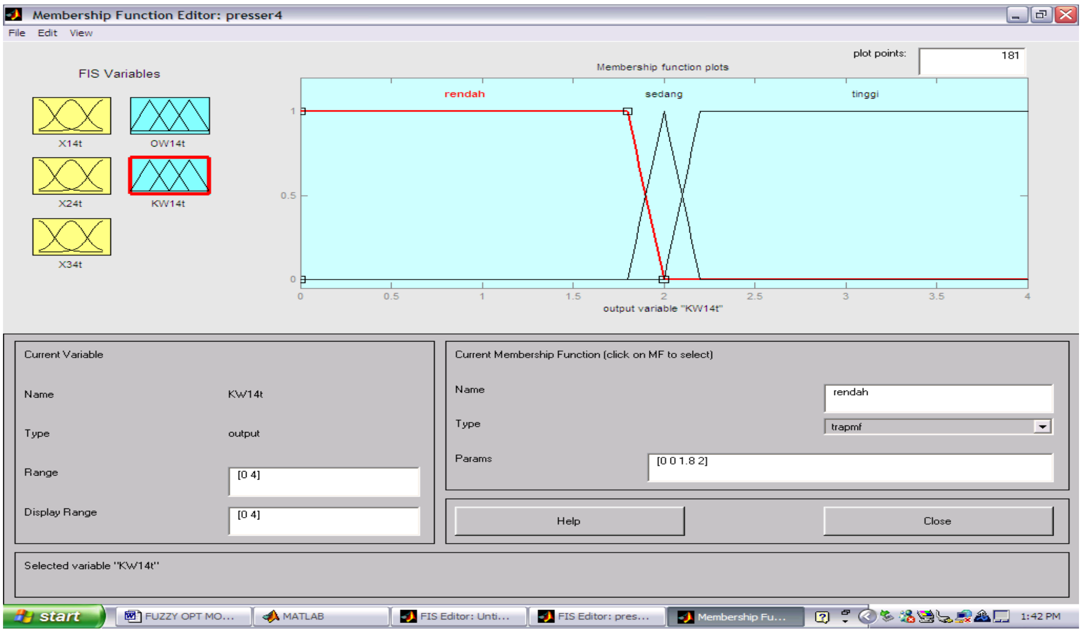


(4c). Screw press pressure

FIGURE 4. Membership functions of input variables at pressing and digesting station



(5a). % Oil loss in fibre



(5b). % Kernel loss in fibre

FIGURE 5. Membership functions of output variables at pressing and digesting station

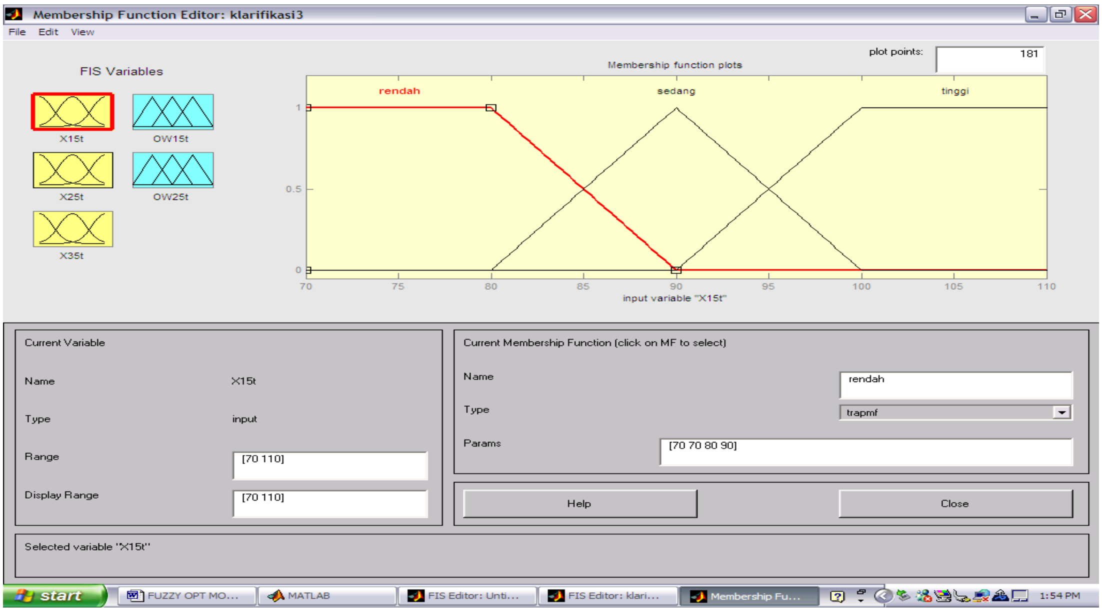
The next process is at clarification station. In this station crude oil is separated from water and non oil solid (NOS) in continuous settling tank and sludge separator/decanter and after that is purified by oil purifier in order to obtain CPO. The oil losses in this station are influenced by some processing parameters, such as : continuous settling tank (CST) temperature, decanter temperature, and oil and NOS concentration in decanter feeding. If these parameters fulfill the requirement of process, the oil loss in water drab and in oil loss in solid decanter will be minimized.

Fuzzy input variables and fuzzy output variables at clarification station are formulated at Table 3.

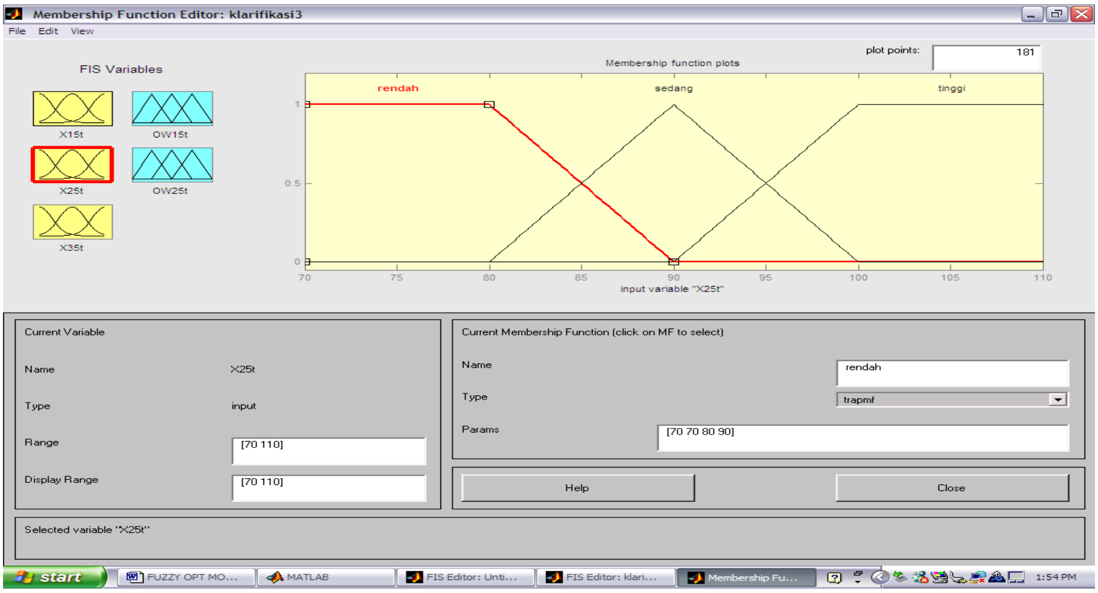
Table 3. Fuzzy variables at clarification station

No.	**Fuzzy variables**	**Lingustic qualifier**	**Range**
1.	*Fuzzy input variables* :		
	a. CST temperature (X_{15})	Low	70 – 90 ^oC
		Medium	80 – 100 ^oC
		High	90 – 110 ^oC
	b. Decanter temperature (X_{25})	Low	70 – 90 ^oC
		Medium	80 – 100 ^oC
		High	90 – 110 ^oC
	c. Oil+NOS concentration in decanter feeding (X_{35})	Low	40 – 55 %
		Medium	49 – 61 %
		High	55 – 90 %
2.	*Fuzzy output variables* :		
	a. % oil loss in drab water (OW_{15})	Low	0 – 0.6 %
		Medium	0.45 – 0.75 %
		High	0.6 – 1 %
	b. % oil loss in solid decanter (OW_{25})	Low	0 – 3.5 %
		Medium	2 – 5 %
		High	3.5 – 6 %

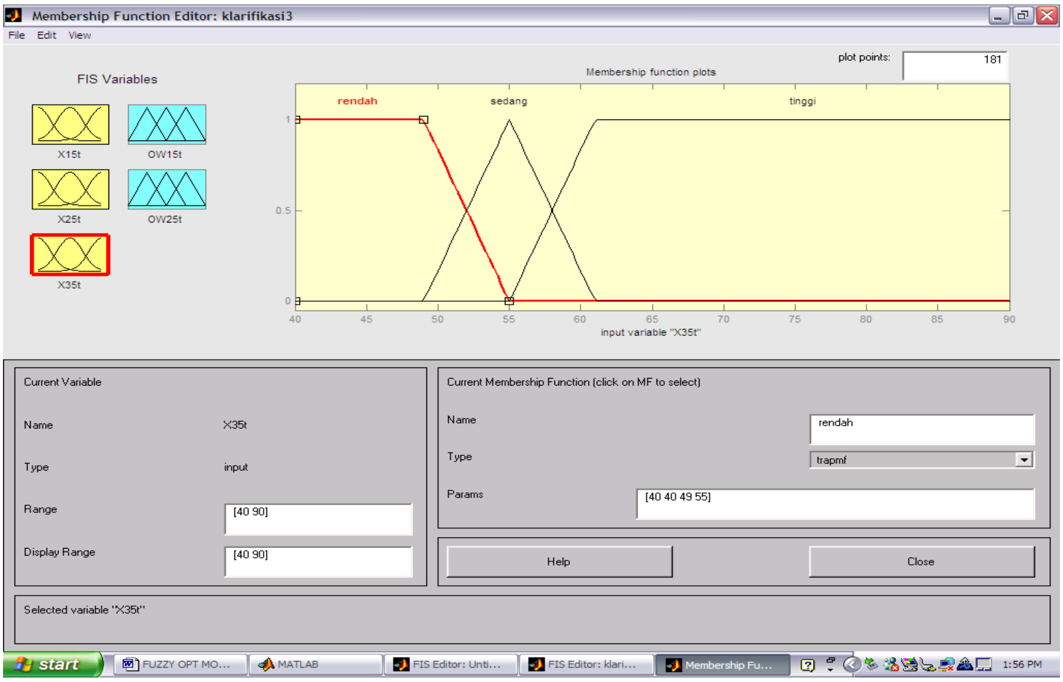
Membership functions of fuzzy input and output variables at clarification station can be seen at Figure 6 and Figure 7.



(6a). Continuous Settling Tank temperature

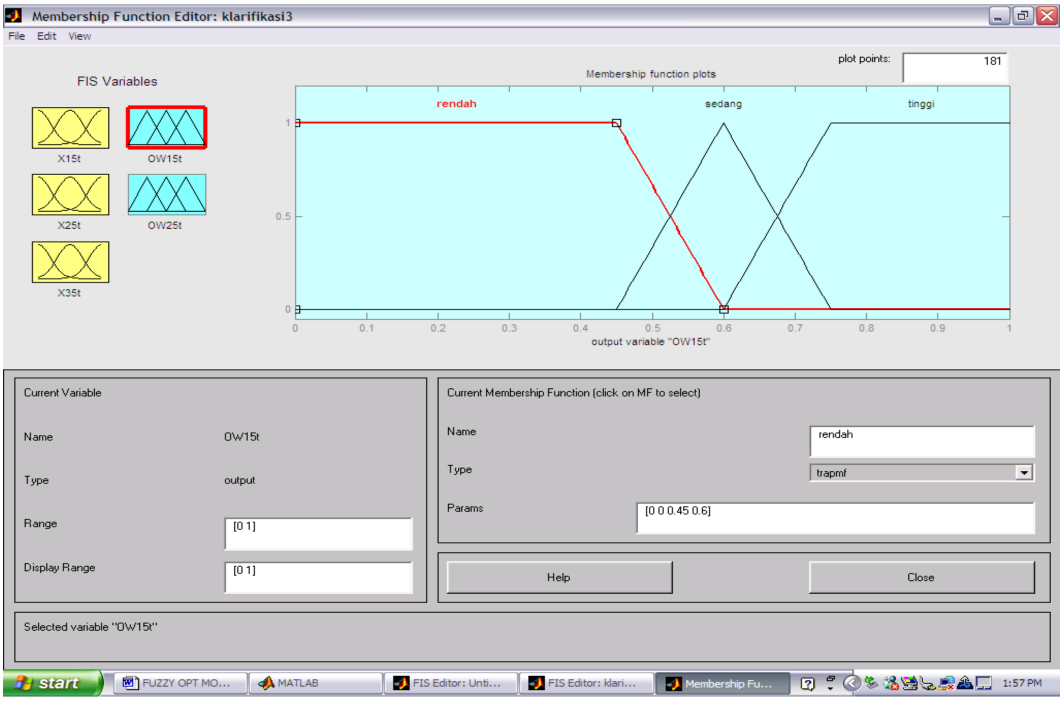


(6b). Decanter temperature

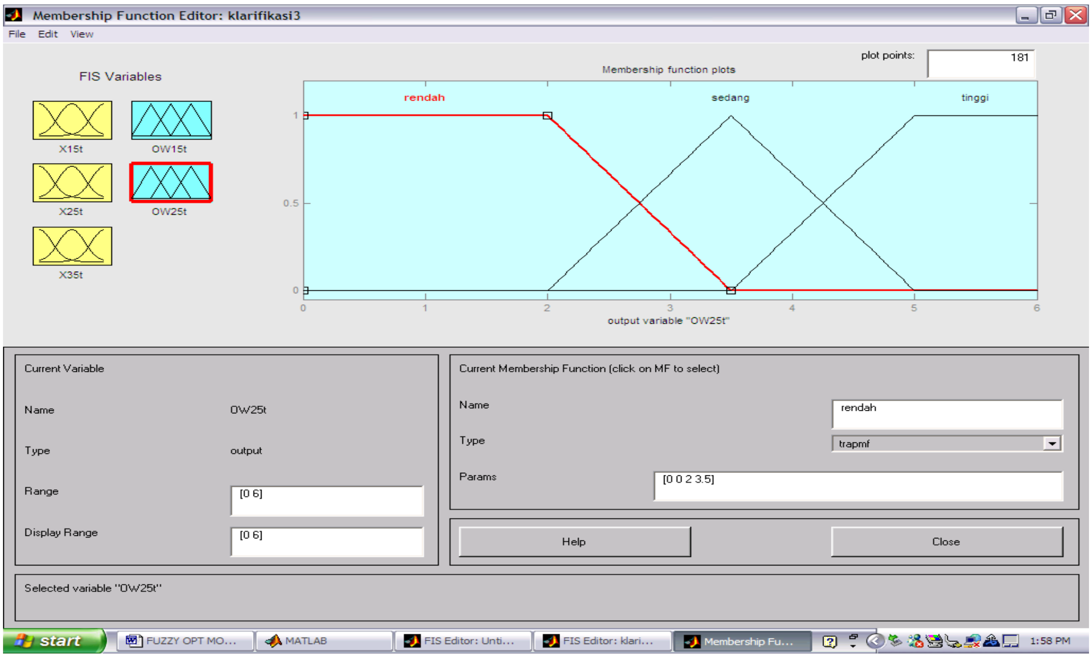


(6c). Oil and NOS's concentration

FIGURE 6. Membership functions of input variables at clarification station



(7a). % Oil loss in drab water



(7b). % Oil loss in solid decanter

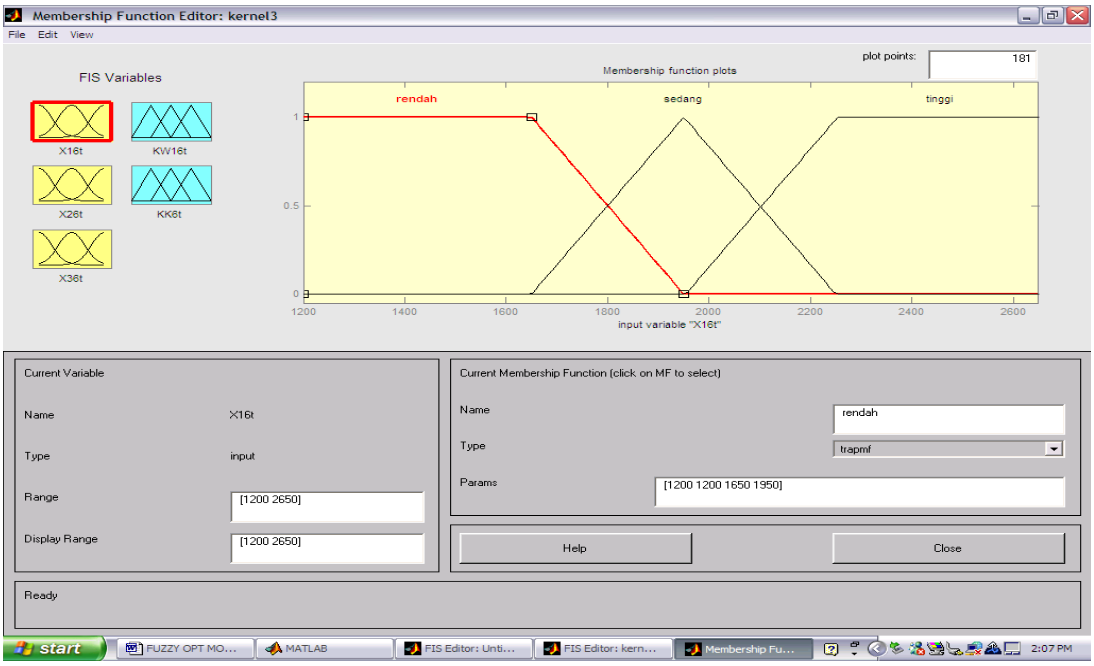
FIGURE 7. Membership functions of output variables at clarification station

Besides at pressing station, kernel loss is also occurred at kernel station. Some processing variables can increase kernel loss at kernel station. According to expert knowledge, the variables which have been identified having major effect to the kernel loss are as follow : rotor speed of ripple mill, air blowing velocity of LTDS I and air blowing velocity of LTDS II. These variables influence kernel loss in LTDS I and LTDS II as well as dirt content in palm kernel. Therefore, fuzzy input variables and fuzzy output variables are formulated as follow :

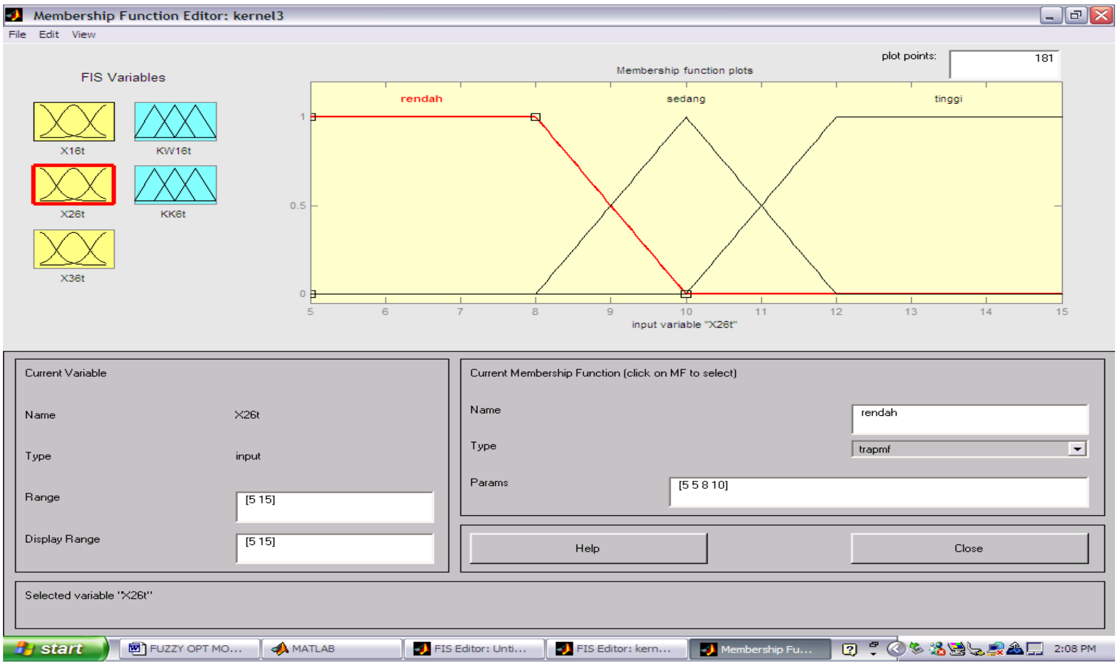
Table 4. Fuzzy variables at kernel station

No.	Fuzzy variables	Lingustic qualifier	Range
1.	*Fuzzy input variables* :		
	a. Rotor speed of ripple mill (X_{16})	Low	1200 -1950 rpm
		Medium	1650 – 2250 rpm
		High	1950 – 2650 rpm
	b. Air blow velocity at LTDS I (X_{26})	Low	5 – 10 m/s
		Medium	8 – 12 m/s
		High	10 – 15 m/s
	c. Air blow velocity at LTDS II (X_{36})	Low	8 – 14 m/s
		Medium	12 – 16 m/s
		High	14 – 20 m/s
2.	*Fuzzy output variables* :		
	a. % kernel loss in LTDS I&II (KW_{16})	Low	0 – 7.5 %
		Medium	5 – 10 %
		High	7.5 – 30 %
	b. % dirt content in palm kernel (KK_6)	Low	0 – 6 %
		Medium	3 – 9 %
		High	6 – 12 %

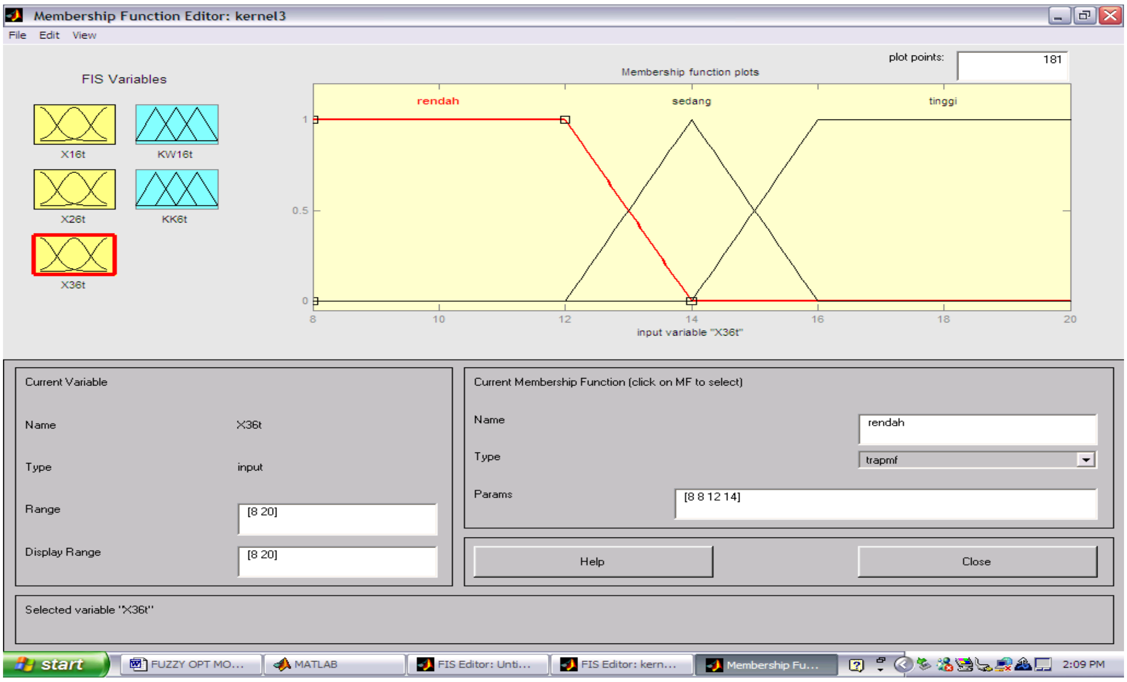
Membership functions of fuzzy input and output variables at kernel station can be seen at Figure 8 and Figure 9.



(8a). Rotor speed of ripple mill

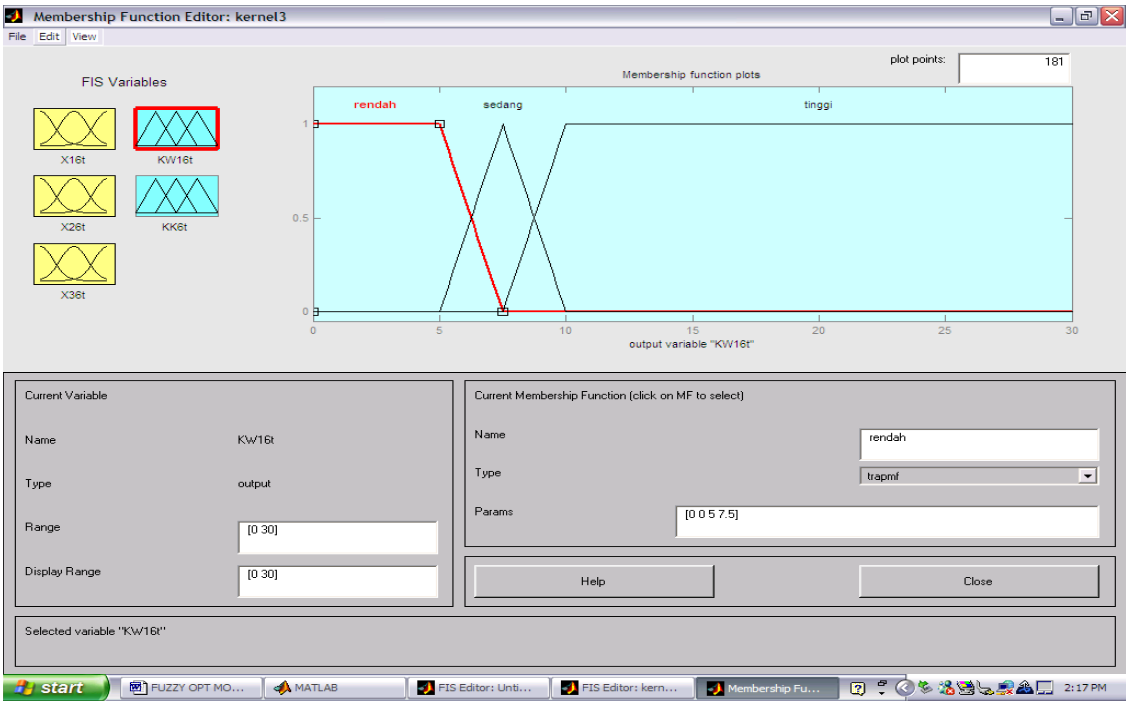


(8b). Air velocity at LTDS I

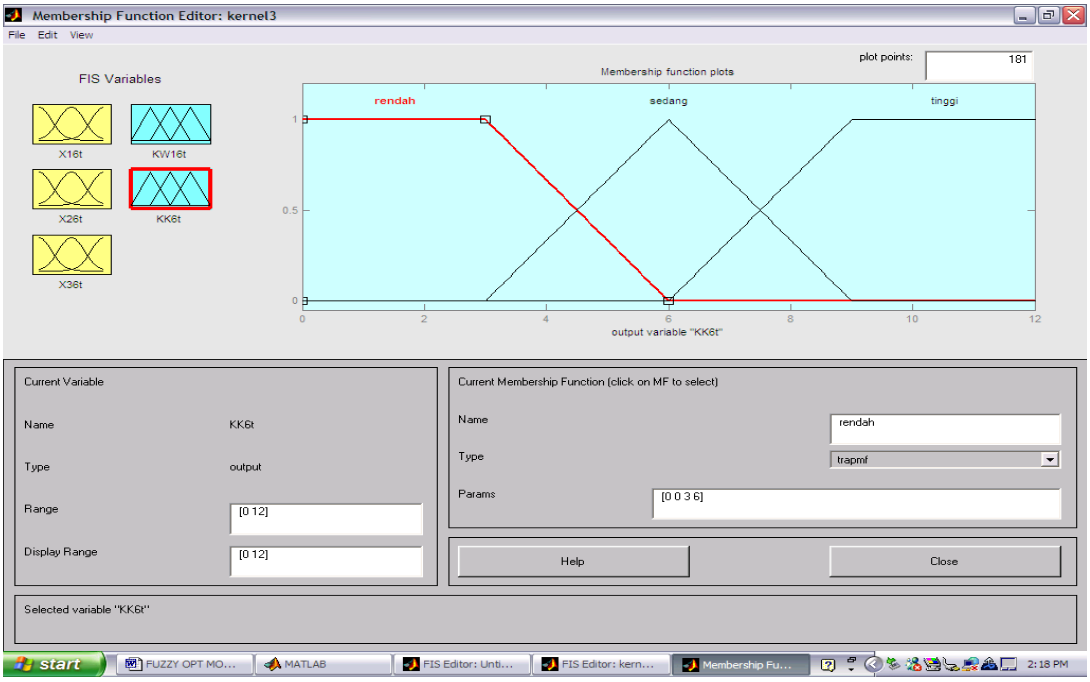


(8c). Air velocity at LTDS II

FIGURE 8. Membership function of input variables at kernel station



(9a). % Kernel loss at LTDS I and II



(9b). % Dirt content in palm kernel

FIGURE 9. Membership function of output variables at kernel station

Inference

Inference process in this fuzzy model use Mamdani fuzzy inference rules. Based on expert knowledge, there are 18 rules that is formulated in describing the relationship between the amount of oil losses with the percentage of unripe fruits, sterilizing time and steam pressure in sterilizing and threshing station. Examples of fuzzy rules are as follow :

- Rule 1 : If X_{12} high and X_{22} long and X_{32} high then OW_{12} high and OW_{13} high and OW_{23} low.
- Rule 2 : If X_{12} high and X_{22} long and X_{32} medium then OW_{12} high and OW_{13t} high and OW_{23} low.
- etc.

There are 27 fuzzy rules in describing the relationship between the amount of oil losses and kernel losses with digesting time, digesting temperature and screw press pressure in digesting and pressing station. Fuzzy if then rules are formulated for example as follow :

- Rule 1 : If X_{14} long and X_{24} high and X_{34} high then OW_{14} low and KW_{14} high
- Rule 2 : If X_{14} long and X_{24} medium and X_{34} high then OW_{14} low and KW_{14} high
- etc.

In clarification station, there are 27 fuzzy if then rules that have been developed, for example :

- Rule 1 : If X_{15} high and X_{25} high and X_{35} high then OW_{15} high and OW_{25} high
- Rule 2 : If X_{15} high and X_{25} high and X_{35} medium then OW_{15} low and OW_{25} low
- etc.

The relationship between the amount of kernel loss with rotor speed of ripple mill, air velocity at LTDS I and LTDS II in kernel station is described in rules for example as follow :

- Rule 1 : If X_{16} high and X_{26} high and X_{36} high then KW_{16} high and KK_6 low
- Rule 2 : If X_{16} high and X_{26} high and X_{36} medium then KW_{16} high and KK_6 low
- etc.

Defuzzification

The center of gravity (COG) defuzzification method will take a membership function possibly modified by linguistic hedges and derive a single representative value :

$$Z_{COA} = \frac{\int_z \mu_A(z)\, z\, dz}{\int_z \mu_A(z)\, dz}$$

3. Fuzzy Optimization Model

In this model, oil and kernel losses are calculated as a percentage of each waste where those losses are incurred. According to the material balance of palm oil, the amount of each waste can be stated as a percentage of the total amount of fresh fruit bunch. Therefore, the amount of oil and kernel losses can be stated as a percentage of the total amount of fresh fruit bunch based on the material balance of palm oil. The percentage of each waste to the total amount of fresh fruit bunch based on material balance of palm oil at palm oil mill PTPN VII can be looked at Table 5.

Table 5. The percentage of palm oil wastes

No.	Palm oil wastes	Percentage
1.	Water condensate	12.80 %
2.	Empty bunch	25.50 %
3.	Fiber	11.12 %
4.	Shell	6.58 %
5.	Cake decanter	2.07 %
6.	Drab water	10.52 %

Source : PTPN VII

Those Mamdani fuzzy if then rules models for each station above are constructed by using Excel spreadsheet. After that, those fuzzy models are optimized by using Genetic Algorithm. The objective function of optimization model is to minimize total oil and kernel losses as a percentage of the amount of fresh fruit bunch. Therefore, the optimization problem is formulated as follow :

Minimization : Z = % total oil loss + % total kernel loss

$$= \Sigma\,\Sigma\, W_{ij}\, OW_{ij} + \Sigma\,\Sigma\, W_{ij}\, KW_{ij}$$

$$= (0.128 * OW_{12} + 0.255*OW_{13} + OW_{23} + 0.112\, OW_{14} + 0.1052\, OW_{15} + 0.0207\, OW_{25}) + (0.112\, KW_{14} + 0.0658\, KW_{16})$$

where as each OW_{ij} and KW_{ij} are generated based on fuzzy if then rules models and subject to other constraints:

$70 \le X_{22} \le 150$ ……………….(1)

$2.5 \le X_{32} \le 3.3$ ……………….(2)

$0 \le X_{14} \le 40$ ………………….(3)

$70 \le X_{24} \le 100$ ……………….(4)

$20 \le X_{34} \le 60$ …………………(5)

$70 \leq X_{15} \leq 100$ ……………….(6)
$70 \leq X_{25} \leq 100$ ……………….(7)
$40 \leq X_{35} \leq 90$ …………………(8)
$1200 \leq X_{16} \leq 2650$ ……………(9)
$5 \leq X_{26} \leq 15$ …………………(10)
$8 \leq X_{36} \leq 20$ …………………(11)
$KK_6 \leq 6$ ………………………(12)

By using genetic algorithm software, the objective function is defined as the fitness function. Genes are as follow : X_{22}, X_{32}, X_{14}, X_{24}, X_{34}, X_{15}, X_{25}, X_{35}, X_{16}, X_{26} and X_{36} with the lowest and the highest value of each gene as it is stated at constraint 1-11. Each OW_{ij} and KW_{ij} value is generated based on fuzzy if then rules models.

The optimization result shows that if the percentage of unripe fruits is known as 12 %, the minimum total loss is 1.522 % of total amount of fresh fruit bunches. This consist of the minimum total oil loss is as 1.107 % and the minimum total kernel loss is as 0.41 % of the amount of fresh fruit bunches. These optimum values are reached after 400 generations (see Figure 10).

FIGURE 10. Fuzzy Palm Oil Optimization with Genetic Algorithm

The optimized value of processing variables can be seen at Table 6. It can be seen that the optimized sterilizing time is 110 minutes and steam presure is at 2.9 kg/cm^2. At digesting and pressing stations, the optimized screw press pressure is 35 bar, digesting time is about 21 minutes, digesting temperature is at 92.6 ^{o}C. At clarification station, the optimized CST and decanter temperature are 90 ^{o}C, while the optimized oil and non oil solid's concentration is 55 %. At kernel station, the optimized speed of ripple mill is about 1950 rpm, air velocity at LTDS I is 10 m/sec and at LTDS II is 14 m/sec.

Table 6. The optimized value of processing variables

No.	Processing variables	Optimized value
1.	Sterilizing time (X_{22}^*)	110 min
2.	Steam pressure (X_{32}^*)	2.90 kg/cm^2
3.	Digesting time (X_{14}^*)	21 min
4.	Digesting temperature (X_{24}^*)	92.6 ^{o}C
5.	Screw press pressure (X_{34}^*)	35 bar
6.	CST temperature (X_{15}^*)	90 ^{o}C
7.	Decanter temperature (X_{25}^*)	90 ^{o}C
8.	Oil+NOS concentration in decanter feeding (X_{35}^*)	55 %
9.	Rotor speed of ripple mill (X_{16}^*)	1950 rpm
10.	Air velocity at LTDS I (X_{26}^*)	10 m/sec
11.	Air velocity at LTDS II (X_{36}^*)	14 m/sec

4. Conclusion

Fuzzy expert system model could be designed to develop the relation ship between the amount of oil losses and kernel losses with the processing variables that influence them in palm oil production. This aims to minimize the amount of oil and kernel losses during the process. The fuzzy model optimization using Genetic Algorithm results in, at 12 % of unripe fruits, the optimized sterilizing time is 110 minutes, steam pressure 2.9 kg/cm^2, digesting time 21 minutes, digesting temperature 92.6 ^{o}C, screw press pressure 35 bar, CST and decanter temperature 90 ^{o}C, oil+NOS concentration in decanter feeding 55 %, rotor speed of ripple mill 1950 rpm, air velocity at LTDS I 10 m/s and at LTDS II 14 m/s. At these conditions, the minimum total loss is 1.522 % of the amount of fresh fruit bunches that consists of the minimum total oil loss is as 1.107 % and the minimum total kernel loss is as 0.41 % of the amount of fresh fruit bunch.

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