Troubleshooting the Deodoriser Unit in a Palm Oil Refinery

Intan Suhairi Salleh
School of Chemical and Energy Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
UTM Skudai 81310 Johor, Malaysia

Nur Syuhada Ali
Malaysia-Japan International Institute of Technology (MJIIT)
Universiti Teknologi Malaysia (UTM)
54100 Kuala Lumpur, Malaysia

Farzad Hourfar
Department of Chemical Engineering, Faculty of Engineering
University of Waterloo
Waterloo, Ontario N2L 3G1, Canada

Khairiyah Mohd-Yusof
Centre for Engineering Education (CEE)
Universiti Teknologi Malaysia
UTM Skudai 81310 Johor, Malaysia

Nurul Sulaiha Sulaiman
School of Chemical and Energy Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
UTM Skudai 81310 Johor, Malaysia

Hishamuddin Jamaluddin
School of Mechanical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
UTM Skudai 81310 Johor, Malaysia

Gholamreza Zahedi
Ozone Solutions Inc.
451 Black Forest Rd, Hull, Iowa 51239, United States

Ali Elkamel
Professor, Department of Chemical Engineering, Faculty of Engineering
University of Waterloo
Waterloo, Ontario N2L 3G1, Canada
aelkamel@uwaterloo.ca

Abstract

This paper discusses the fuzzy expert system for troubleshooting the deodoriser in palm oil refinery plant. Interviews with experienced plant staffs and operators were conducted, and required information regarding the whole process were gathered for identifying the faults, defining the membership functions and providing a sequence of necessary actions. Industrial plant data were used to check the performance of the fuzzy expert system. It was found that the troubleshooting system is capable of predicting the failures and suggesting necessary actions with a similarity value of 80 percent with the system database. In addition, the proposed expert system is useful for operators' guidance and for field training purposes.

Keywords
Palm Oil Refinery, Fuzzy Logic Inference, Plant Troubleshooting, Expert Systems, Process Systems Engineering.

1. Introduction
Plant troubleshooting in the complex systems is a challenging task which is done to diagnose faults in sensors, actuators and key equipment to take necessary actions. The sensors help to identify the deviations in operating conditions. Moreover, any failure in process equipment disrupts yield production and so complex systems need theory-based knowledge to identify the exact faults that intricately link to each other. The deviation of operating conditions in the industrial deodoriser lead to inefficient and quality issues. The high acidity refined palm oil is one of the common quality issue that originates from the deviation of operating condition such as low-temperature, high-pressure, and high amount of stripping steam (Ceriani and Meirelles 2006). The excessive adjustment on the condition setting leads to other problems. For example, the excess amount of stripping steam gives lower acidity of refined oil, but higher neutral oil losses in the side-product (Petrauskaitè et al. 2000). The obtained knowledge collected from experienced plant operators which is used to find the possible faults is puzzling, because of the plant's complexities especially when the problems begin in the vacuum system. The deviation of motive steam and cooling water condition, machinery breakdown, and human error contribute to vacuum system failure (Lieberman 2012) to create low-pressure in the industrial deodoriser. The lower motive steam pressure consumes higher amount of steam and cooling water to condense the exhaust steam from ejector (Landucci et al. 2013). The absence of knowledgeable personnel due to the attrition of experienced operators results in applying appropriate fault diagnostic systems, to help plant workers in overcoming the difficulties in plant troubleshooting.

In general, the fault diagnostic methods need usable data whether numbers, information, or historical data. The quantitative-methods can isolate and classify faults by using numbers but they have trouble to deal with imprecise information and explain the solution. On the other hand, the qualitative-methods can deal with imprecise information to diagnose faults with the use of rich information from various sources. For example, the rule-based expert systems provide solutions while considering data confusion and uncertainty (Venkatasubramanian et al. 2003a). Moreover, the pattern classification techniques extract the features of possible faults based on the history-based knowledge which are collected from experiences workers (Venkatasubramanian et al. 2003b). In addition, the fuzzy logic approach can simplify the required steps in the expert systems through a simple formula of IF-THEN rules (Mohd Ali 2015).

Fuzzy expert system applied in troubleshooting can diagnose faults and provide advice on necessary actions. For example, Zahedi et al. (2011) developed a troubleshooting program for a complex system that eased operators to decide correctly, prevents serious economic losses and major injuries in a desalination plant. The program used a fuzzy system that integrated data of professional operators, plant manual, handbooks, and the literature. Abdul-Wahab et al. (2007) incorporated the fuzzy logic into expert system to offer advice for brine heater problem in desalination plant. Differently, the fuzzy system merged case reasoning could match current cases to the known solution of available cases in the complex system database. As another example, the fuzzy system application in other field could successfully assess the risk level in environment (Liu and Yu 2009) and provided decision-makers with useful data in construction phase (Cheng et al. 2009). These examples show that fuzzy expert systems based on case formula can be applied in industrial deodoriser troubleshooting as a fault detection approach.

This paper propose a troubleshooting tool based on a fuzzy expert system applicable for palm oil deodoriser in a real plant. The fuzzy expert system can diagnose possible faults relating to deodoriser failure and suggests a list of necessary actions. Two plant experts with more than 15 years of working experience validate the fuzzy logic-based expert system. The thematic analysis is used to discover the pattern of the possible faults of deodoriser failure from field observation and interviews. The deodoriser thematic tree shows the expert knowledge synthesis with technical data and the pattern of the possible faults. The fuzzy expert system comprises both the deviation of operating condition and failure in equipment to extend the previous work on the deodoriser troubleshooting (Salleh et al. 2012). The developed tool helps plant operators in troubleshooting activities and provide field training data. The advice on sequence of actions may shorten the response time to make a correct decision, guide inexperienced plant staffs in troubleshooting, and thus prevents serious losses. Clearly, quick action on the deodoriser failure reduces the costs corresponding with the quality-specifications and the environmental impacts. The successful use of the deodoriser troubleshooting system opens the possibility of expanding it to encompass the whole refinery key equipment, as well as the other types of palm oil refineries. The plant expert knowledge incorporated into a troubleshooting tool is useful in the absence of skilled and experienced operators during plant troubleshooting. In other words, this tool can aid inexperienced plant workers to decide quickly, save costs, and increase the safety.

2. Process Description

The deodoriser processes palm oil at temperature between 230ºC and 250ºC, and pressure below 0.4 kPa to remove odour, flavour, and other compounds. The deodoriser takes some actions to remove the odorised compounds, which are: 1) strips of volatile compound, and 2) high temperature to volatile undesired compound, and 3) degrade pigment that creates undesired side chemical reactions (Sime Darby 2011).

Figure 1 shows a typical semi-continuous deodoriser system that runs under vacuum. The deodoriser is a special designed distillation column that is divided into three sections: heating, deodorising, and cooling. The vertical thermo-siphon reboiler connects the heating and cooling trays to provide the oil with slow heating and cooling. The reboiler contains mineralised water circulation that works based on the density difference. High-Pressure steam heats up the oil to a high temperature, while cooling water lowers the oil temperature. During the operation, the High-Pressure Boiler pressure controlled the deodoriser at high-temperature setting, while dry steam at pressure 0 to 2 kPa keeps the stripping (Greyt and Kellens 2005).

The deodoriser distillate circulates in a vapour scrubber, a heat exchanger, and a pump to recover fatty acid and to remove non-condensable substances. The vapour scrubber is a packed distillation column that transfers heat between the distillate liquid and the vapour. The packed column and spray nozzle inside the vapour scrubber provide a medium of contact between the distillate liquid and the vapour, which flows counter-current and collects the condensates in the tank bottom. The distillate circulates through a heat exchanger to lessen the temperature at 55ºC.

The vacuum system consists of a four-stage steam ejector and a cooling tower (Körting-Hannover AG 2015). The four-stage steam ejector units consist of condensers, liquid-ring pump, and steam ejectors, i.e. jet and air ejectors. The four-stage steam ejector is installed without a condenser at the first-stage. Moreover, the liquid-ring pump at the fourth-stage can help to save energy and to reduce motive steam and cooling water consumption (Akteriana 2011). The jet ejector creates vacuum pressure through high-speed motive steam constriction that also removes noncondensable gases. In a condenser, the cooling water condenses the exhaust steam from air ejectors and collected in the hot well. The cooling tower consists of cooling tower fill, spray nozzle, and fan to increase the contact surface area and retention time between cooling water and surrounding air.

3. Methodology

There are four major phases in this research methodology. The first step is qualitative and quantitative data collection. The second phase is deodoriser thematic tree extraction to search for the possible fault patterns, obtained from qualitative data and troubleshooting table which combine the possible faults with the necessary actions. The third phase is troubleshooting tool development, using fuzzy expert system in the Matlab environment. The last phase is tool verification and validation.

The fault propagation is included in the troubleshooting tool which covers several cases in the deodoriser failure. Fuzzy inference system integrates membership functions and the rule formulas. The inference system contains a reasoning platform to perform as a decision-making unit. The membership functions describe vagueness in the possible faults and in the necessary actions. A set of rules provide a mapping connection between the possible fault and the necessary action. The deodoriser-troubleshooting tool contains 27 inputs, 27 outputs and 16 rule-lists. The 27 inputs include the normal range of 27 possible faults gathered from various sources. The sources of data are: a) SOP, b) DCS, c) operation checklist, d) published document vendor, and e) plant expert rule of thumb. The DCS provides setting data and normal condition. The checklist contains standard operating condition when the data is not available in the DCS. The SOP contains information on designed value for the possible faults. The plant expert rule of thumb is applicable to the missing possible faults data.

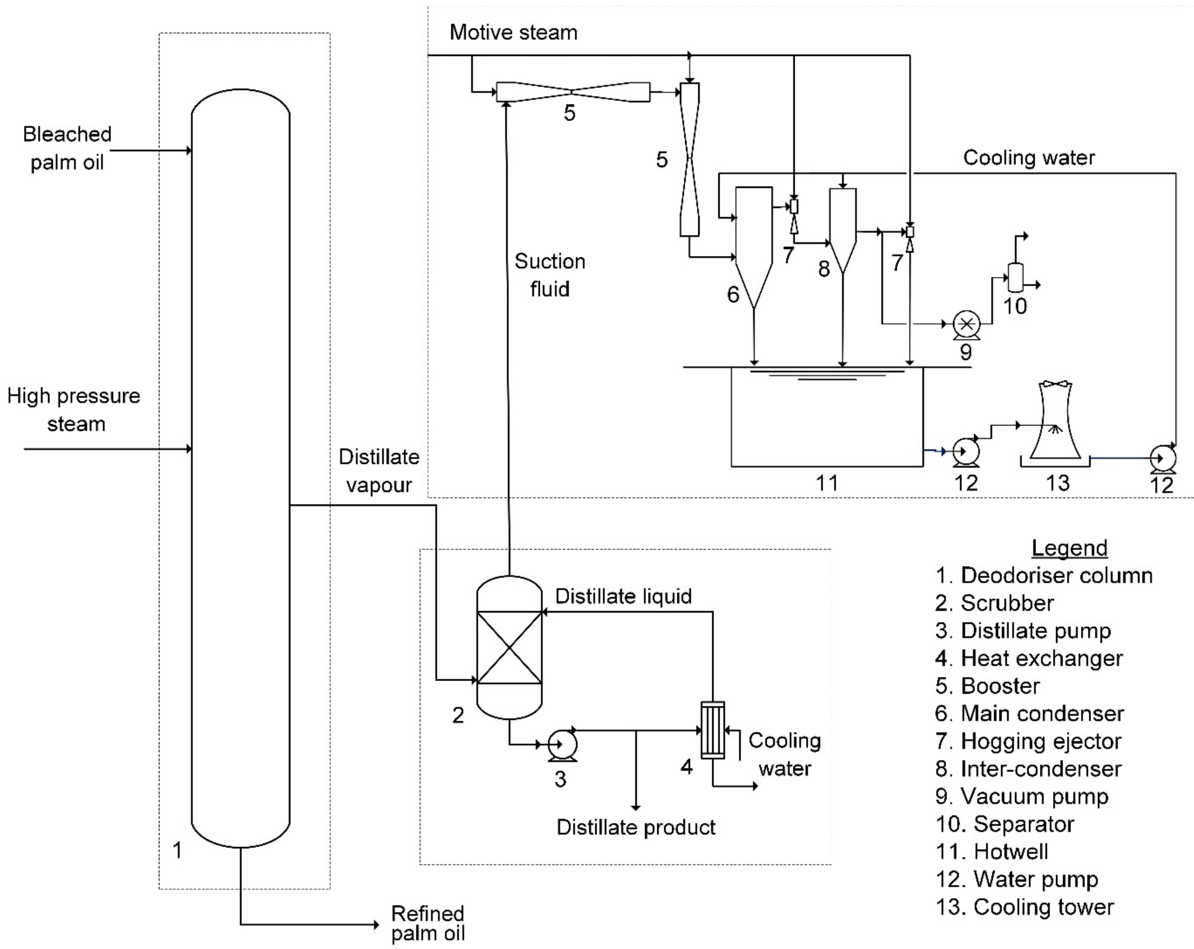

Figure 1. Schematic of semi-continuous deodoriser system

3.1 Qualitative and Quantitative Data Collection

The qualitative data are extracted to grasp the plant personnel experiences in identifying the possible faults of deodoriser failure. Fifteen experienced plant workers and an expert in a Malaysia palm oil refinery have been interviewed to gain the qualitative data. Experienced plant personnel are plant worker with a minimum four years working experience. Plant expert is a manager with an engineering background who has been working in palm oil refining process for more than 30 years. The open-ended questions have been prepared to explore the possible faults of deodoriser failure and the necessary actions.

3.2 Deodoriser Thematic Tree and Troubleshooting Table

The deodoriser thematic tree contains the possible faults of deodoriser failure and its fault propagation. The possible faults are final themes from thematic analysis (Braun and Blarke 2008) that relate to the theory-based knowledge. In fault propagation, the "OR" gate connects the possible faults, where one possible fault is deviated from normal condition and causes failure at the top.

The thematic study analyses the patterns of the possible faults, based on the researchers' theory-based knowledge. The data familiarisation is important to get an overall picture of the deodorisation in industry practice and to identify the possible faults when the deodoriser failure occurs. This step is conducted during the field observation and interview. The themes are a group of code data that consider causative and effects at different levels. During themes revision, the themes are organised as follows: 1) combining the redundant themes, 2) discarding the problematic themes, and 3) adding other important themes by following the plant expert advice. As the developed thematic tree is beyond the field of fuzzy application, it will be explained in another paper.

3.3 Fuzzy Membership Function

The fuzzy membership function maps the terms used in the possible faults and the necessary actions to the conditional data and fuzzy values. The terms in the possible faults or necessary actions, depend on the fuzzy value (0 to 1) and shows the possibility of partial membership to the correspondence data.

The membership functions formula uses both qualitative and quantitative data, while fuzzy rule formula just uses qualitative data. The simple shapes of membership function contain flexible straight-line curves that convert the discrete value of conditional data to a continuous line. These shapes map the variable vagueness to the suitable data and fuzzy value, i.e. degree of condition and urgency. The fuzzy value calculations for triangular and trapezoidal membership functions (Zahedi et al. 2011):

$$f(x; a, b, c) = \max\left(\min\left(\frac{x-a}{-b}, \frac{c-x}{c-b}\right), 0\right)$$

$$f(x; a, b, c, d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right)$$

where f(x,a,b,c) is a fuzzy value for triangular curve while f(x,a,b,c,d) is a fuzzy value for trapezoidal curve. a, b, c and d are the membership function parameters, and x is a conditional data. In this problem, the inputs and outputs contain 2 or 3 membership functions (mf).

3.4 Fuzzy Rules

The rules-list gives simple formulas on the several cases in the deodoriser system. It connects the possible faults to the necessary actions. The fuzzy rules in this study represent sixteen cases from deodoriser thematic tree. Ten rules apply “AND” connective and six rules use “OR” connective. The “AND” connective apply for several cases in normal and faulty condition such as normal motive steam condition, low deodorisation temperature, and low stripping steam pressure. The applied “OR” connective links the possible faults in faulty cases to one another. The “OR” connective in if-part decreases the number of fuzzy rules in a complex system. The “OR” connective based on the theory-based knowledge provides a large coverage of the fired rule. The IF-Then statement of this case study is as follows:

IF “possible fault 1 is abnormal” OR “possible fault 2 is abnormal” OR “possible fault 3 is abnormal” or “possible fault 4 is abnormal” OR “possible fault 5 is abnormal” OR “possible fault 6 is abnormal” OR “possible fault 7 is abnormal” THEN “possible fault 1 (action) is action 1” OR “possible fault 2 (action) is action 2” OR “possible fault 3 (action) is action 3” OR “possible fault 4 (action) is action 4” OR “possible fault 5 (action) is action 5” OR “possible fault 6 (action) is action 6” OR “possible fault 7 (action) is action 7”.

3.5 Fuzzy Inference Systems

The inference system is a platform that contains the fuzzy membership functions and rules. Fuzzy rule is a key tool to map the possible faults into necessary actions and it is translated as "IF-THEN rule" based on input-output connection. The platform infers a list of necessary actions in five-steps: fuzzification, application of the logical connective, implication, aggregation, and defuzzification. The first step is fuzzification to discover the degree of failure for each possible fault, via membership function in the if-part of the fuzzy rule. The logical connectives, i.e. "AND" and "OR" gate combine fuzzified possible faults of each rule. The third step is an implication to calculate the result from the fired rule. The result is presented as a graph truncation of membership function in the THEN-part of fuzzy rule. The weight value of “1” is assigned to each rule. The logical operator of "max" aggregates the truncated graphs from different rules. The last step is defuzzification that converts membership function into a single value.

3.6 Tool Verification and Validation

The final step is troubleshooting tool verification and validation, to diagnose fault and to predict necessary action. The tool verification is the proof of the correct tool prediction, while tool validation is used to approve the tool’s usefulness for industrial deodoriser. The plant experts in the palm oil refinery check the correct tool setting, the possible faults and the sequence of necessary actions for implementation in the industrial practice. In this study, two plant experts have validated the deodoriser-troubleshooting tool and its usefulness with correct results.

The tool verification uses artificial adjustment and plant data to diagnose faults and predict the list of necessary action. The fuzzy inference adopts similarity value from case-based reasoning for the inferred target cases. The similarity value formula is based on source cases, target cases, and weight value (Cheng et al. 2009). The source cases are in the inference system, while the inferred cases are predicted by the inference system. The similarity formula is as follows:

$$S_{PS} = \frac{\sum C_{Pi} W_i}{C_S}$$

where SPS is a similarity value between the necessary action from the predicted cases, CP , and the source cases, CS. Wi is a weight value at the fuzzy rule i.

4. Results and Discussion

The diagnosed possible faults and the predicted list of necessary actions can help young engineer or inexperienced workers in familiarising with the concepts of deodoriser troubleshooting. The troubleshooting tool can facilitate plant workers, where the diagnosed fault and predicted list of action give hint to start the deodoriser troubleshooting. The troubleshooting tool is designed with a translator that uses qualitative data to label the numerical value in input and output variables. The assessment of fuzzy expert system is based on the similarity value between sources and inferred case, while the logic rule is being fired by the tool.

4.1 Training Tool

The troubleshooting tool can be applied as a training tool with correct prediction of necessary action and diagnosed possible faults. Default value is a normal condition that is used for missing data during tool verification. The inserted value into the tool is high motive steam pressure, 1.3 MPa, which is more than 20% of the designing pressure, 0.9 MPa. The use of qualitative data improves troubleshooting tool ability by displaying the diagnosed fault and the list of recommended action in human language that help plant workers to understand the value. Figure 2 shows the diagnosed faults and the list of recommended actions in the Matlab command window.

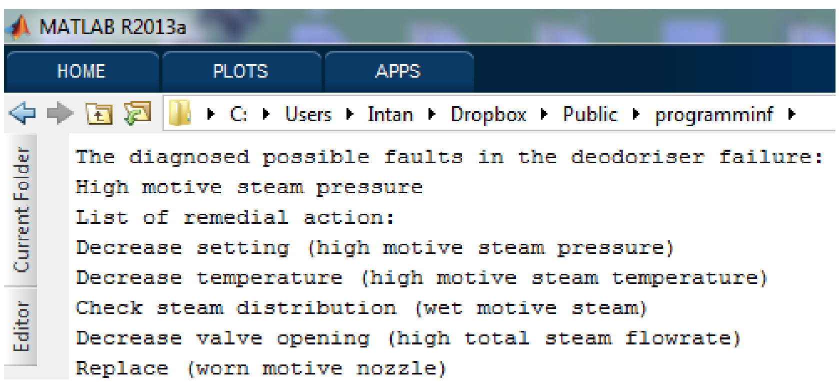

Figure 2. Fault Diagnosis and Recommended Actions

The diagnosed possible fault is "high motive steam pressure", which fires several cases in the deodoriser-troubleshooting tool to infer a list of necessary actions with similarity value of 93%. The fired cases are: 1) excess motive steam, 2) normal condition of deodoriser and scrubber, 3) normal cooling water system, 4) normal liquid ring pump, and 5) normal hot well level. The recommended list of necessary action contains five steps. The first action is to decrease setting to reach the normal limit of 0.9 to 1.1 MPa, when the motive steam pressure is higher than 1.1 MPa. The next action is to decrease setting for the slightly superheated temperature of 150ºC for 0.9 MPa for excessive motive steam temperature. The third action is to check the steam distribution to identify the moisture content in the motive steam pipeline. High pressure or low temperature can produce wet steam. The fourth action is to decrease the valve opening to make the total steam flow rate between 3000 and 4000 kg/hr when the rate is higher than normal range. The last action is to replace the worn motive nozzle.

The troubleshooting tool is tested over 11 sets of testing data. It is capable to diagnose up to 2 possible faults and predicts list of actions with a similarity value of 92.6% to 100%. Each testing data contains a maximum of 2 possible faults with abnormal value but still within the range, while others with default values. Table 1 lists the diagnosed fault, number of action for testing data, fired rules and the similarity values.

Table 1. List of diagnosed faults and the number of action by using tested data

Set	Diagnosed fault	No. of action	Fired Rule No.		S (%)
			Normal	Fault	
1	-	0	1	-	100
2	Low deodorisation temperature	1	7, 9, 12, 14	5	100
3	High distillate temperature, wet stripping steam	10	7, 9, 12, 14	3	92.6
4	High motive steam pressure	5	2, 7, 12, 14	11	96.3
5	Malfunction cooling tower fan	8	2, 9, 12, 14	8	96.3
6	High cooling water temperature	8	2, 9, 12, 14	8	96.3
7	Low motive steam pressure	5	2, 7, 12, 14	10	96.3
8	High hotwell level	1	2, 7, 9, 12	16	100
9	Low hotwell level	1	2, 7, 9, 12	15	92.6
10	High vacuum pump temperature	1	2, 7, 12, 14	13	92.6
11	High deodorisation pressure	27	-	3, 8, 10, 13, 15	100

One set of data has no diagnosed fault, 9 sets have 1 diagnosed fault and 1 set has 2 diagnosed faults. Set 1 has no diagnosed fault where all input value are within the normal range. Meanwhile, set 3 has 2 diagnosed faults where 2 input variables are beyond the normal range, which are distillate temperature, 80oC and stripping steam quality, 90%. The troubleshooting tool lists the diagnosed faults as "high distillate temperature" and "wet stripping steam," and predicts lists of action from rule 3. The rule 3 is a logic that has information on the diagnosed fault of high distillate temperature and its action.

4.2 Data Monitoring Tool

The troubleshooting tool can diagnose fault and predict the list of appropriate actions for missing information or the data that is beyond the range. The troubleshooting tool can monitor the possible fault condition by tracking the status in fault diagnosis and determine the group of rules that should be fired in action prediction. Troubleshooting tool can handle the issue of reduced workforce and improve plant troubleshooting flexibility with the list of actions which are derived based on the expert knowledge to solve the deodoriser failure.

The deodoriser troubleshooting tool is validated using 10 sets of plant data. The diagnosis is designed for 4 possible faults with the corresponding predicted list of actions and with the similarity values of 81.5% to 100%. Each set of plant data consists of 7 possible faults, monitored by the DCS, which indicates the specific critical locations in the deodoriser such as the deodoriser, scrubber, cooling tower and ejector. The possible faults are deodorisation pressure, suction pressure, deodorisation temperature, distillate temperature, distillate level, tailpipe temperature, and total steam flowrate. Table 2 shows the list of diagnosed fault and the number of actions using plant data.

The similarity value above 80% indicates the sufficient information on rules in the troubleshooting tool database. One to 5 rules from cases with failure condition are fired, while number of actions can achieve up to 27. Sets 2 and 5 fire similar rules of 3 and 8 but predict different number of actions because of different possible diagnosed faults. The diagnosed faults, high deodorisation temperature (set 2) and high distillate temperature (set 5) are set in similar rules with different sequence and type of actions. The action suggested for high deodorisation temperature is to decrease setting (step 7), while for high distillate temperature is to check heat exchanger (step 3). Table 3 summarises the list of actions from fired rule 3 for both sets 2 and 5. The action predicted by the troubleshooting tool is indicated with slashes (/) but the unlisted action is indicated with cross (x).

In other cases, sets 2 and 9 have actions with defuzzified value in the membership function overlapping. The troubleshooting tool lists the action with higher fuzzy values. In set 2, the membership function with label "replace" has a higher fuzzy value of 0.75 compared to the label of "do nothing" with a 0.25 fuzzy value. Whereas in set 9, the membership function with label "replace" has a higher fuzzy value of 0.9 than the "do nothing" label with a fuzzy value of 0.1. Figure 3 shows the fuzzy value in membership function overlapping.

Table 2. A list of diagnosed faults and number of actions by using plant data

Set	**Diagnosed Fault**	**No. of action**	**Fired Rule No.**		**S (%)**
			Normal	**Fault**	
1	Low total steam flowrate	5	2, 7, 12, 14	10	96.3
2	Low suction pressure, high deodorisation temperature, high tailpipe temperature	14	9, 12, 14	3, 8	81.5
3	Low suction pressure, high tailpipe temperature, high total steam flowrate	13	7, 12, 14	8, 11	92.6
4	Low suction pressure, high tailpipe temperature	9	2, 9, 12, 14,	8	96.3
5	Low suction pressure, high distillate temperature, high tailpipe temperature	19	9, 12, 14	3, 8	88.9
6	Low suction pressure, high distillate temperature, high tailpipe temperature, low total steam flowrate	20	9, 12, 14	3, 8, 10	81.5
7	High deodorisation pressure, high suction pressure, high distillate temperature, high tailpipe temperature	27	-	3, 8, 10, 13, 15	100.0
8	Low deodorisation temperature, low total steam flowrate	3	7, 12, 14	5, 10	85.2
9	Low suction pressure, high tailpipe temperature, low total steam flowrate	10	2, 12, 14	8, 10	88.9
10	Low suction pressure, high tailpipe temperature, low total steam flowrate	10	2, 12, 14	8, 10	88.9

Table 3. List of actions from fired rule 3 for diagnosed faults in sets 2 and 5

	List of action	**Listed**	
		Set 2	**Set 5**
1	check deodoriser, scrubber and vacuum system (high deodorisation pressure)	×	×
2	check scrubber and vacuum system (high suction pressure)	×	×
3	check heat exchanger (high distillate temperature)	×	/
4	check pump (low distillate pressure)	/	/
5	check valve opening (low distillate flowrate)	/	/
6	increase setting (low distillate level)	×	/
7	decrease setting (high deodorisation temperature)	×	/
8	decrease setting (high stripping steam pressure)	×	/
9	check steam distribution (wet stripping steam)	/	/
10	clean (clogged scrubber spray nozzle)	/	/
11	clean (clogged scrubber packed column)	/	/
12	replace (dirty hotwell water)	/	/

The diagnosed faults and list of actions are useful for plant workers/operators during plant troubleshooting, where the quick problem identification can save money and time. The list of actions can help plant workers to monitor operating condition in the DCS and to be prepared for upcoming actions in reduced workforce and absence of experience workers. The prediction of diagnosed faults can also decrease environmental risks.

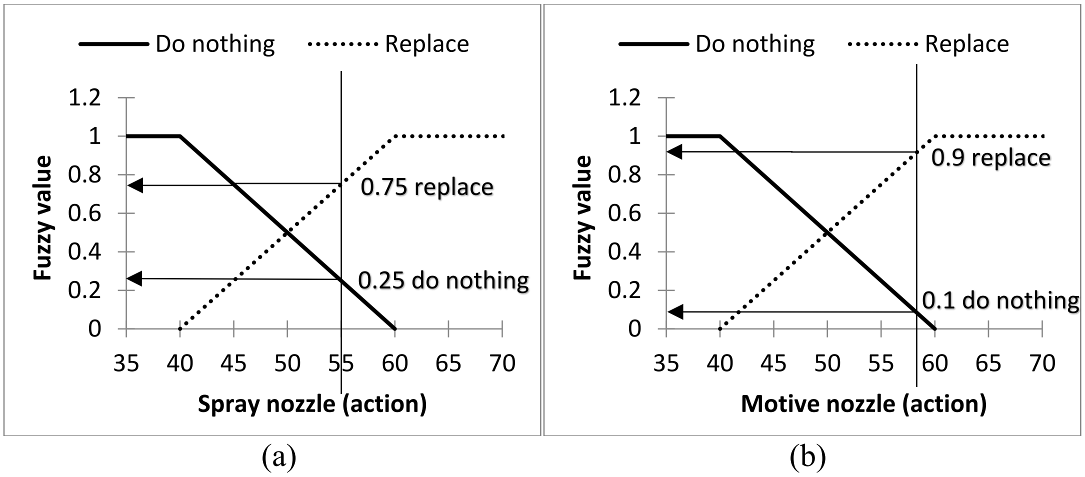

Figure 3. Fuzzy value in membership function overlapping: (a) spray nozzle (action), (b) motive nozzle (action)

5. Conclusion

The proposed troubleshooting tool based on fuzzy expert system can diagnose the possible fault of deodoriser failure and provide recommendations for necessary action. The possible fault is extracted by interviewing experienced plant workers/operators in a palm oil deodoriser unit and analysed based on themes afterwards. The fuzzy logic applied in troubleshooting tool can deal data vagueness and mapping the possible fault to its necessary action(s). The sequence of necessary actions with linguistic phrases help plant workers in troubleshooting as well as in field training purposes. For the future work, the tool considers the different vegetable oil and integrated pre-treatment process in other refineries to generalise deodoriser troubleshooting techniques. In other words, the generalised deodoriser-troubleshooting methodology will be applicable in other types of vegetable oil refineries.

Acknowledgment

The authors would like to thank National Science Fellowship (NSF), Ministry of Science, Technology, and Innovation (MOSTI) of Malaysia for financial support.

References

Abdul-Wahab, S.A., and Elkamel, A., and Al-Weshahi, M.A., and Al-Yahmadi, A.S., "Troubleshooting the brine heater of the MSF plant fuzzy logic-based expert system", *Desalination*, vol. 217, pp. 100-117, 2007.

Akteriana, S., "Improving the energy efficiency of traditional multi-stage steam-jet-ejector vacuum systems for deodorizing edible oils" *Procedia Food Science*. vol. 1, pp. 1785-1791, 2011.

Ali, J.M., and Hussain, M.A., and Tade, M.O., and Zhang, J., "Artificial intelligence techniques applied as estimator in chemical process systems - A literature survey", *Expert Systems with Applications*, vol. 42(14), pp. 5915-5931, 2015.

Braun, V., and Blarke, V.," Using thematic analysis in psychology", *Qualitative Research in. Psychology,* 3(2), pp. 77-101, 2008.

Ceriani, R., Meirelles, A.J.A., Simulation of continuous physical refiners for edible oil deacidification , *Journal of. Food Engineering*, vol. 76(3), pp. 261-271, 2006.

Cheng, M.Y., and Tsai, H.C., and Chiu, Y.H., "Fuzzy case-based reasoning for coping with construction disputes", *Expert Systems with Applications*, vol. 36(2), pp. 4106-4113, 2009.

Greyt, W.D., and Kellens, M., *Deodorization: Bailey's Industrial Oil and Fat Products*, J. Wiley & Sons, Inc, 2005.

Körting-Hannover AG, Vacuum Systems in Edible Oil, accessed on May 25, 2015. http://www.koerting.de/docs/default-source/brochures-multistage/vacuumsystems.pdf?sfvrsn=5

Landucci, G., and Pannocchia, G., and Pelagagge, L., and Nicolella, C., "Analysis and simulation of an industrial vegetable oil refining process", *Journal of. Food Engineering*, vol. 116(4), pp. 840-851, 2013.

Lieberman, N.P., *Troubleshooting Vacuum System*. J. Wiley & Sons, 2012.

Liu, K.F.R., and Yu, C.W., "Integrating case-based and fuzzy reasoning to qualitatively predict risk in an environmental impact assessment review", *Environmental Modelling & Software*, vol. 24(10), pp. 1241-1251, 2009.

Petrauskaitè, V., and De Greyt, W. F. and Kellens, M. J. " Physical refining of coconut oil: Effect of crude oil quality and deodorization conditions on neutral oil loss", *Journal of the American Oil Chemists' Society*, 77(6), 581-586, 2000.

Salleh, I.S., and Yusof, K.M., and Zahedi, G.,"Fuzzy Logic Model of Deodorizer Troubleshooting in Palm Oil Refining," *12th International Conference on Control, Automation and System (ICCAS 2012)*, 2012.

Sime Darby Sdn. Bhd., *Deodorising. Standard Operating Procedure*, 2011.

Venkatasubramanian, V., and Rengaswamy, R., and Kavuri, S.N., and Yin, K., "A review of process fault detection and diagnosis Part III: Process history based methods", *Journal of Computers and Chemical Engineering*, vol. 27, pp. 327-346, 2003a.

Venkatasubramanian, V., and Rengaswamy, R., and Kavuri, S.N., "A review of process fault detection and diagnosis Part II: Qualitative models and search strategies", *Journal of Computers and Chemical Engineering*, vol. 27, pp. 313-326, 2003b.

Zahedi, G., and Saba, S., and Al-Otaibi, M., and Yusof, K.M., "Troubleshooting of crude oil desalination plant using fuzzy expert system", *Desalination*, vol. 266, pp.162-170, 2011.