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Automation and Optimization of Industrial Scale Essential Oil Extraction from Citrus Peel Using a Neutrosophic Control System Model

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Abstract. The extraction of essential oils in the world is widely used to combat various diseases, and also helps for giving a good taste to food (flavoring condiments) and cosmetics that do not pollute the environment or generate chemicals. Peru is in the top 10 countries with the greatest biological diversity in the world, having an approximate 10% of world flora and endless endemic species, also valuing the citrus fruits having productive of orange, lime, grapefruit, tangerine, and tangelo. Therefore, processes are analyzed and a model for the extraction of essential oil from citrus fruits is developed, through the design of an industrial-scale steam extractor, which establishes the automation of the filling and emptying of the distiller to obtain better results and also automates a closed-loop control for refrigeration, to help the operator to control and supervise the process of refrigeration and water filling using a control panel. The distillation process was analyzed where an average of 1% to 5% of essential oil of citrus fruits was obtained and the development of a control for the supervision of the filling and emptying of the water was analyzed. In this paper we introduce a Neutrosophic (Indeterminate) Control System model based on the well-known Fuzzy Control Systems models, especially Mamdani's. It is applied in the process of automating the extraction of essential oil from citrus fruits. An Indeterminate Control System, like its similar Fuzzy Control System, makes it possible to control the oil production process with the help of natural language. The advantage of the Indeterminate Control System is that it explicitly considers indeterminacy due to the non-homogeneity of the parameters within the system, thus it is more accurate.

Keywords: Steam Traction, Essential oils, Automation, Essential oil distillation machine, Programmable Logic Control (PLC), Indeterminate Control System, Mamdani`s Control System, Neutrosophic Number.

1 Introduction

Essential oils were first used in the home over 1000 years ago in the civilizations of India, Greece, Rome, and Mesopotamia. Essential oils contain a homogeneous mixture of organic compounds. All compounds have the effect of producing aromas that the human olfactory can smell, they are complex alloys of volatile organic compounds with a pleasant aroma and can be found in different families of plants, fruits, stems, etc. Naturally, they are substances that provide a characteristic odour and are present in different parts of the plant, such as valerian root, leaves (mint, eucalyptus), fruits (fennel, cumin), flowers (chamomile, roses) or the skin of fruits (orange, mandarin, grapefruit, and tangelo).

Generally, to obtain oil, plants must contain an average of 0.5% - 5% oil about the mass of the plant. A brief exploration of essential oils tells us that the consistency groups are low molecular weight aliphatic compounds consisting of phenylpropanoids, terpenes, monoterpenes, sesquiterpenes, etc. Industrial-scale extraction methods for essential oils are based on steam extraction [1]. There are different extraction methods such as pressing, supercritical, enfleurage, expression, microwave liquid extraction, volatile solvent extraction, and vapour extraction, which have excellent product quality, but in most cases are extremely expensive to implement and operate. Steam entrainment distillation is based on the fact that the aroma of the plants can be entrained by the steam generated from the water, then cooled, and finally separated. The vapour produced from the water will be cooled, causing it to condense and form two immiscible states, the mother liquor (hydrolyzed) and the essential oil. This type of distillation focuses on equal amounts of immiscible liquids used to separate organic substances that are insoluble in water.

In this work an approximate amount of essential oil is extracted from the peel of mandarin, tangelo, grapefruit, and orange, the citrus fruit will be extracted to use the peel. The essential oil of citrus fruits is used in the pharmaceutical industry as a flavouring agent to mask unpleasant odours in medicines, as well as in perfumes, cleaning products, and citrus fruit essential oil is in high commercial demand. An essential oil extraction pilot plant allows us to see the productivity that can be achieved with an extraction machine, and then having a pilot extraction plant allows us to evaluate the performance that can be achieved and learn from practice. An industrial-scale essential oil extractor was designed focusing on the control of the machine, automation through a Programmable Logic Control (PLC), looking for the correct operation of the extraction plant in case of possible failures, having a result of automation in the part of filling and emptying of the tanks, it will also help to cool in an average of 8 to 13°C. The automation has a PLC, which is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices; a Human Machine Interface (HMI) screen (it can be programmed to display important status and control information to the operator), which seeks to automate industrial plants to regulate process parameters through automatic control systems, taking into account steam, temperature and pressure. This system will allow us to program and monitor the essential oil extractor. The extractor will have a manual control that can be operated from the plant through a control panel, allowing better management of the extractor machine, which will increase productivity and reduce operation time, which will benefit the user and operator.

However, this automation process can be considered ambitious in the sense that different types of citrus peels are distilled, which means that the results will not always have the same quality when processing two different types of citrus. It is known that some of them perform more efficiently than others. Also, part of the process depends on manual work, which can lead to human errors, while other components depend on code, which can sometimes fail. That is, there are several factors in which automation can fail.

Traditional automation methods try to minimize errors as much as possible, including staff training. The way to understand this problem by the authors of this article is that within the same system, we deal with elements of natural language and with IF-THEN rules that allow operators and software the most appropriate treatment of the processes that they proposed [2].

There is a similar theory of Fuzzy Inference Systems (FIS) models such as the Sugeno's, Mamdani's, and Tsukamoto's models, which are the most popular, where the characteristics of Fuzzy Sets are combined with Artificial Neural Networks [2]. There are also Fuzzy Control Systems (FCS) that are applied in the control of industrial processes that require automation with certain characteristics of approximate reasoning [2-9-18-19]. For their part, Neutrosophic Systems, coined by F. Smarandache, have a distant relationship with what we are dealing with in this article since Smarandache uses a definition more in line with Systems Theory and Dynamic Systems [10]. On the other hand, there are approaches to define Neutrosophic Control Systems that respond to linear control models used in electrical circuits, for example [11], and others like in [12, 13, 17].

The article is divided into sections, the first of which is Materials and Methods, where the fundamental concepts of Fuzzy Systems are explained, as well as the basic notions of citrus oil extraction. In the Results section, we expose the designed model and its application in the essential oil extraction plant of citrus fruits. Conclusions are given at the end of the paper.

2. Materials and Methods

2.1 The Essential Oil Extraction from Citrus Peel

The use of the VDI 2221 methodology will help us to show detailed known levels, and the evaluation of components and types of materials in the calculation memory for its adequate final design, the purpose of this method is to find the appropriate solution among multiple proposed alternatives, as shown in Figure 1.

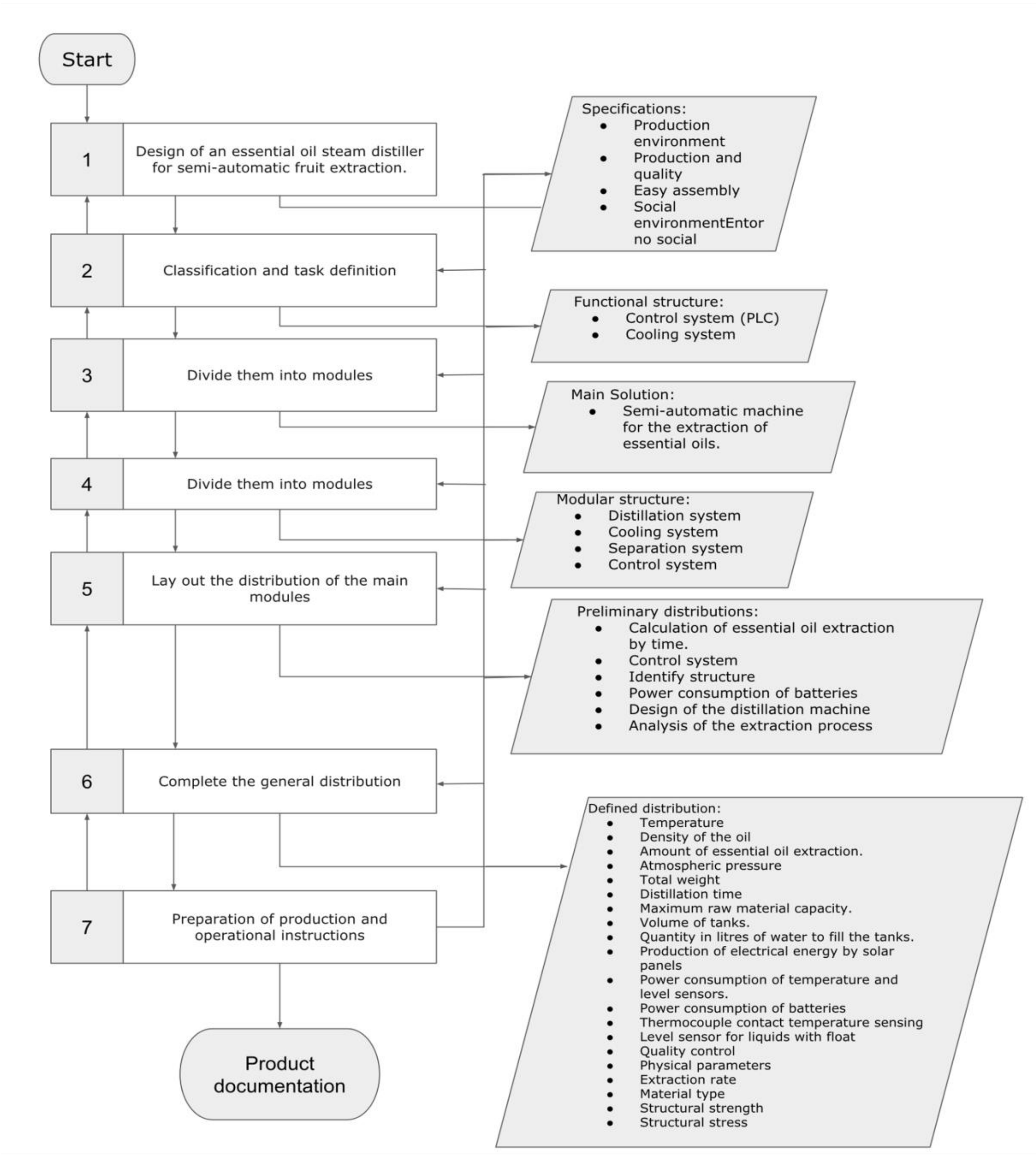
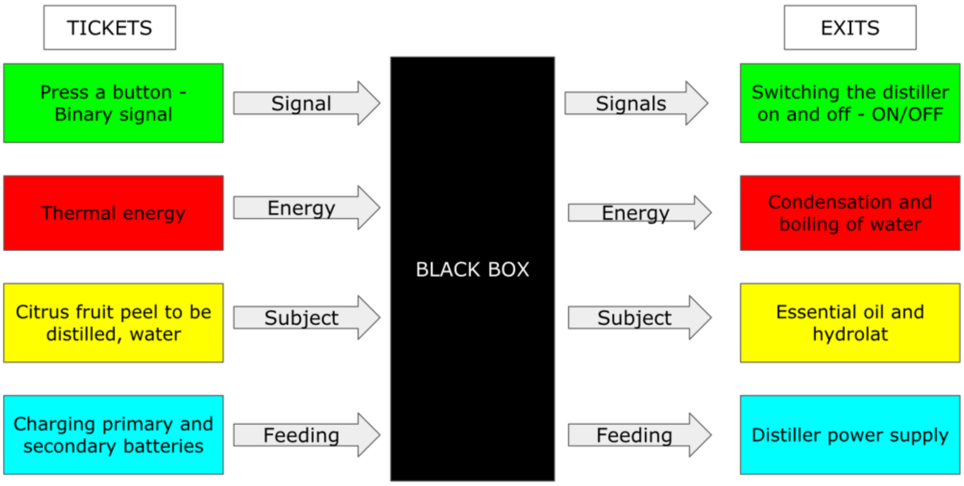


Figure 1: Mechanical Design Standard VDI 2221.

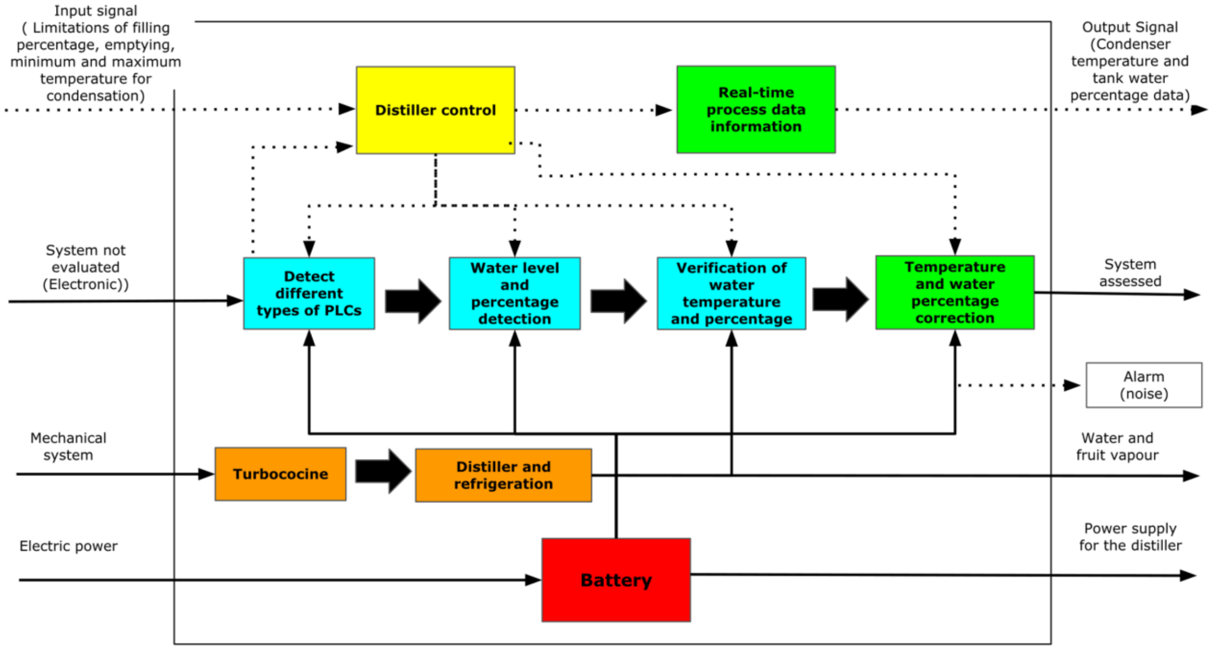
During the analysis, we will seek to determine the functions that must be satisfied to achieve the project objective. Starting with the elaboration of the black box to find the inputs and outputs of the essential oil distiller as shown in Figure 2.

Figure 2: Scheme of the Black Box.



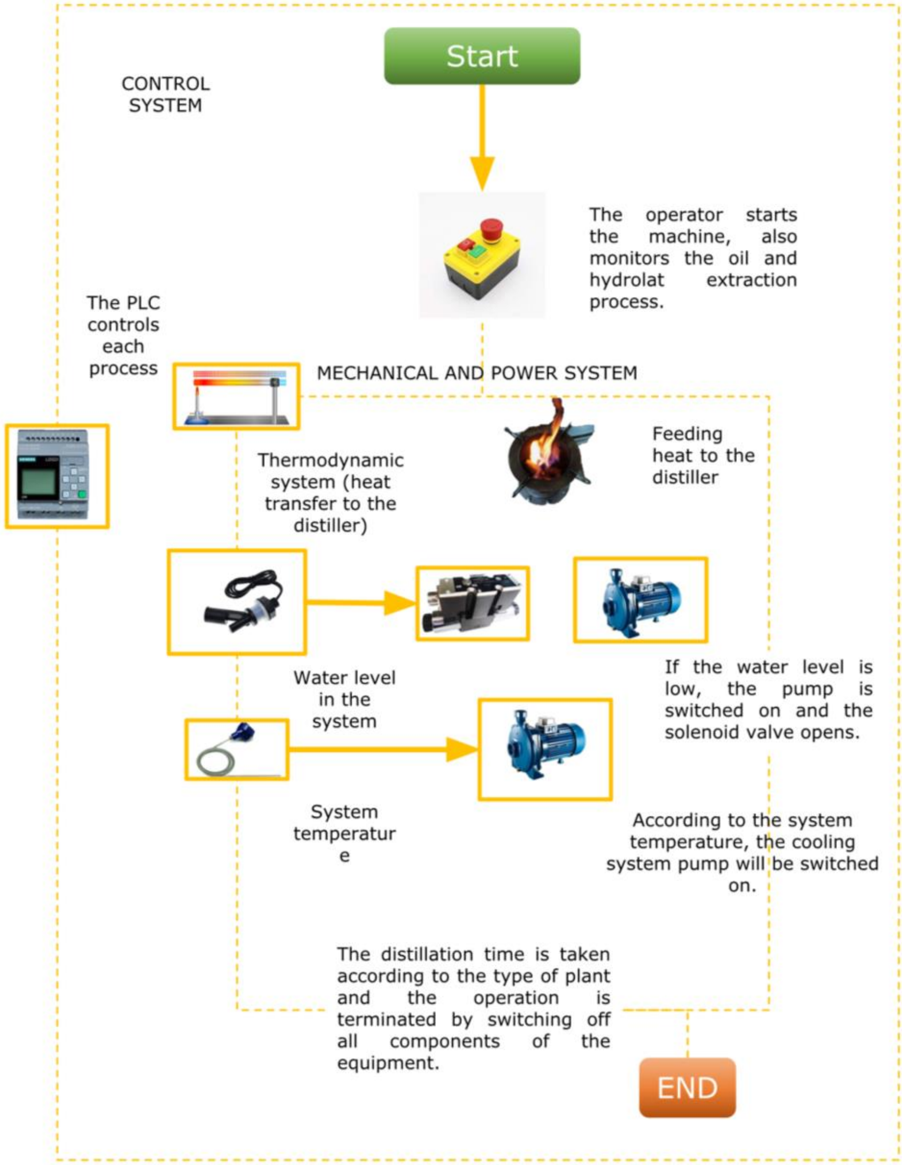
The next step was to define the functions to be performed based on the processes to be fulfilled by the system, in addition to other factors related to the distiller. To do so, a sequence of functions was made to better detail the idea of this section, as shown in Figure 3.

Figure 3: Function structure.



The figure shows the operating diagram of the mechatronic system for the distillation of essential oils according to the type of material, thus automatically shutting down for optimal operation of the machine, as shown in Figure 4.

Figure 4: Mechatronic system diagram.



2.2 Fuzzy Control System

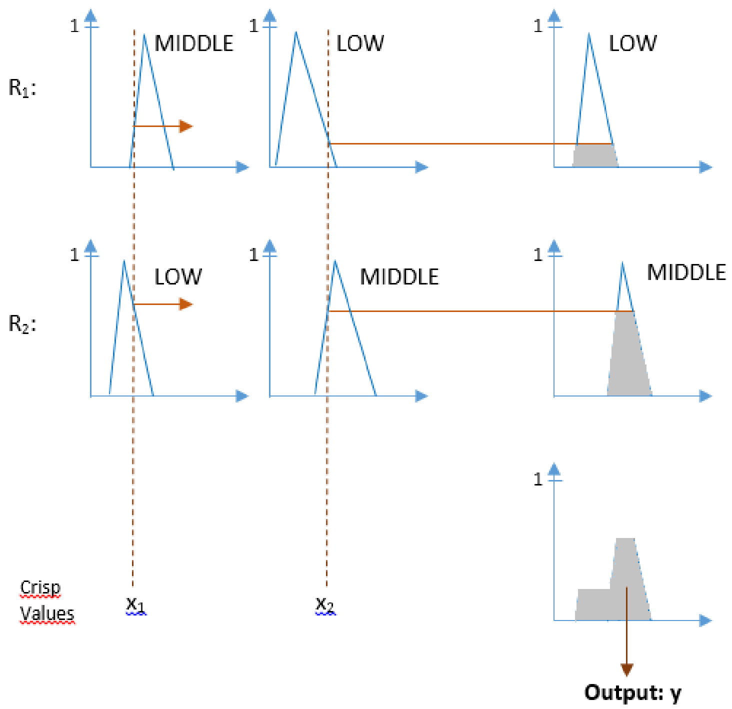
A Fuzzy Control System is a control system where some fuzzy IF-THEN rules are defined by experts [6]. Thus, the system responds to these rules dynamically. When the system is referred to as multi-input-multi-output (MIMO), there are two or more rules in the following form:

R_1: IF x is A_1 AND y is B_1 THEN z is C_1,
R_2: IF x is A_2 AND y is B_2 THEN z is C_2,
$\vdots$
R_n: IF x is A_n AND y is B_n THEN z is C_n.

An example of a Fuzzy Controller is Mamdani's model, see Figure 5, where the represented rules in the figure are the following:

R_1: IF x_1 is MIDDLE AND x_2 is LOW THEN y is LOW,
R_2: IF x_1 is LOW AND x_2 is MIDDLE THEN y is MIDDLE.

Figure 5: Scheme of a Mamdani's fuzzy control.



3 Results

In this section, we describe the Neutrosophic Model we designed and the results. First, we recall the following definition in Neutrosophic Theory [14-16]:

A Neutrosophic Number can be represented in the form of $N = a + bI$, where $a, b \in \mathbb{R}$, and I is a constant such that $I^2 = I$, $0 \cdot I = 0$, $\underbrace{I + I + \cdots + I}_{n\ times} = nI$. a is called the *determinate part* and b is the *indeterminate part*.

Given $N_1 = a_1 + b_1 I$ and $N_2 = a_2 + b_2 I$ two neutrosophic numbers, some operations between them are defined as follows:

$N_1 + N_2 = a_1 + a_2 + (b_1 + b_2)I$ (Addition),

$N_1 - N_2 = a_1 - a_2 + (b_1 - b_2)I$ (Difference),

$N_1 \times N_2 = a_1 a_2 + (a_1 b_2 + b_1 a_2 + b_1 b_2)I$ (Product),

$\frac{N_1}{N_2} = \frac{a_1 + b_1 I}{a_2 + b_2 I} = \frac{a_1}{a_2} + \frac{a_2 b_1 - a_1 b_2}{a_2(a_2 + b_2)} I$ (Division).

Undoubtedly, the temperature, pressure, and other parameters are not constant in time or space. So, we want to take into account the indeterminacy of them in the space during a certain time. Thus, we use neutrosophic numbers in the form of $N = a + bI$ to model the value measured for this parameter by the sensor and also the estimation of other values not directly captured by the sensor. E.g., when the sensor takes temperature is 20ºC, maybe at a farther point we have 18º, then $N = 20 + 2I = [18, 22]$ when $I = [-1, 1]$.

In this model it is necessary to control mainly two variables, *Distillation Temperature* (*T*) and *Water Level* used in cooling (*W*). The rules are simple but effective:

R_1: IF T is $High$ AND W is Low THEN S is Hot,

R_2: IF T is Low AND W is $High$ THEN S is $Cold$.

Here, S is the variable *Temperature of the System*. If S is *Hot*, the pump is operated, while if S is *Cold*, the temperature T is increased and the solenoid valve is closed.

The solenoid valve is one of the most important actuators for our distiller as they will be in charge of transporting the water to the highest points of the machine. This actuator will allow us to control the water flow to the condenser and distiller as well as the filling of the water storage tanks.

At the same time, these rules must be adapted to the species of citrus to distill.

Figure 6 is the depiction of the membership functions used to model the variable High Temperature (in red lines), Low Temperature (in blue lines), and Normal Temperature (in cyan lines).

Figure 6: Membership functions of the linguistic values of T. High is represented in red line, Low is in blue line, and Normal is in cyan lines.

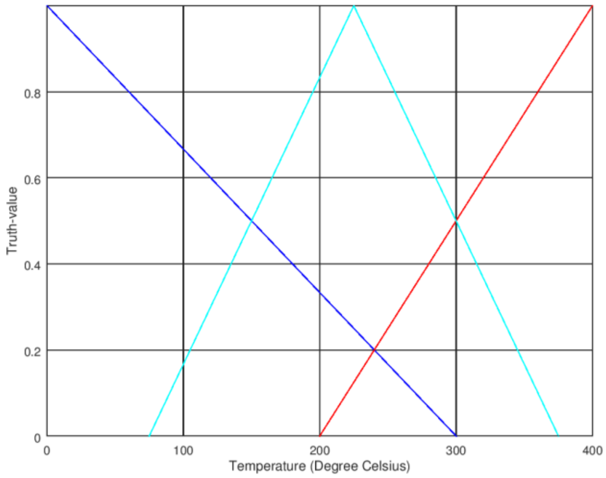
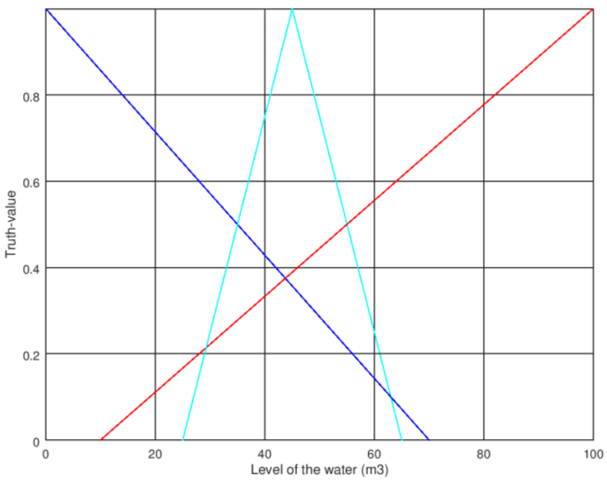


Figure 7 contains the plots of the membership functions for Low Levels of Water (in blue lines), High Levels of Water (in red lines), and Normal Levels of Water (in cyan lines).

Figure 7: Membership functions of the linguistic values of W. High is represented in red line, Low in blue line, and Normal is in cyan lines.



For modeling the Temperature of the System we use again the membership functions of Figure 6, with the labels "Cold" for "Low Temperature", "Hot" for "High Temperature" and "Adequate" for "Normal Temperature".

The indeterminacy constant is $I_T = [-5, 5]$ºC for T and S; whereas, $I_W = [-5, 5]\ m^3$ for W.

For processing the input data in the form of $N_T = T_d + T_i I_T$, $N_W = W_d + W_i I_W$, and $N_S = S_d + S_i I_S$ we use the Indeterminate Mamdani's Fuzzy Control which we introduce in this paper. See Figure 8:

Figure 8: Scheme of the Indeterminate Mamdani's Control System.

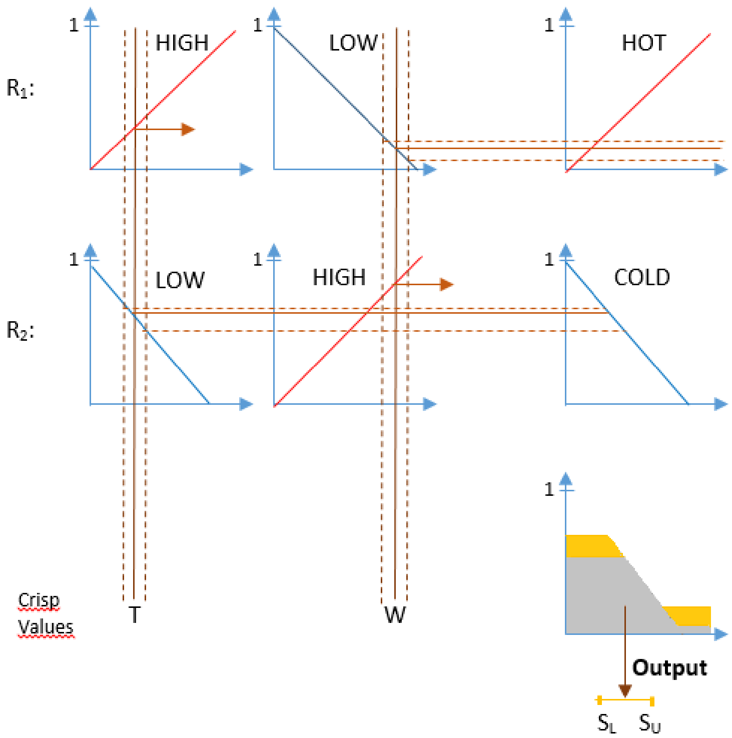
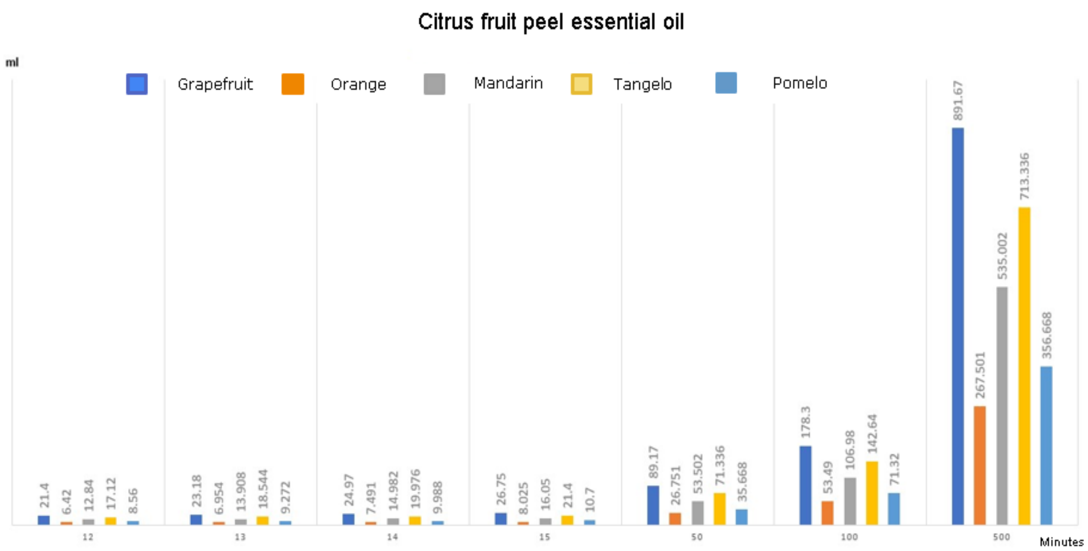


Figure 8 represents graphically the Indeterminate Mandani's Control System used in this problem. Here, instead of inputting crisp values, we input neutrosophic numbers. In the defuzzification process, we defuzzify the region in grey, and also the region colored (including the zones in yellow). So, we obtain an interval as the output of the temperature of the system $S = [S_L, S_U]$.

When, $S_L < 150\ ^oC$ the system has to be heated, while if $S_U > 300\ ^oC$ the system has to be cooled.

The results obtained were that within 8 hours approximately 40 to 50 liters of hydrolase and essential oil would be obtained, of which only 1.338% is citrus fruit essential oil. We also obtained the fixed and manipulable parameters of the distiller, as shown in Figure 9.

Figure 9: Hydrolat and essential oils obtained during 8 hours.



Conclusion

The steam distiller designed to obtain essential oils from citrus fruits contains a semi-automatic control system, which allows the extraction of essential oils with a percentage between 1% and 5% of the total. The results obtained show that, on average, 2.3% of essential oils were extracted from every 10,000 kilograms of citrus fruit used in the process. In addition, an average density of 96.7 kg/l was determined for the oils of the five types of citrus fruit used. Through experimental and theoretical calculations, a quantity of approximately 2.3 liters of essential oil per 10,000 kilograms of citrus fruit was obtained, which represents an error of 3.2999% concerning the theoretical value. The distiller's control system includes a closed loop that automates the filling and emptying of the storage tanks, as well as temperature control during cooling. Also, maybe for the first time, a Plant uses an Indeterminate Control System. The advantage is that the non-homogeneity in the distribution of heat and water for cooling is included in the modeling, having adequate results.

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