Global Advanced Research Journal of Engineering, Technology and Innovation Vol. 1(1) pp. 008-015, April, 2012
Available online http://garj.org/garjeti/index.htm

Full Length Research Paper

Analysis of tea withering process through fuzzy logic approach

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Accepted 30 March 2012

Determination of the completion of withering process at the right instant bears great significance in black tea manufacturing in so far as the quality of the finished product and cost of production are concerned. Daily harvest of plucked tea leaf whether under or over withered, is undesirable for producing quality tea. At present, this is based on the subjective experience and judgement of the tea professionals in charge of the withering section and hence imprecise in nature. The reasons being the combined effects of a number of factors on withering and inherent complicated physics involved in the process. In this paper an attempt has been made to simulate the tea withering process to predict the standard of withering with a desired degree of wither, required for a harvest of green leaf to plan the schedule of tea processing for the achievement of maximum quality utilising minimum energy. This is done by using fuzzy nonlinear simulation methods. For this, withering standard (WS) have been considered as a function of five non-interactive inputs which for a tea industry were identified as moisture content (MC), standard of plucking (SP), thickness of spread (TS), period of withering (PW) and drying capacity (DC) of withering air. A set of fuzzy rules based on expert human judgement were formulated to correlate different fuzzy inputs and output. Fuzzy set operations were used to calculate withering standard of a tea industry. With the application of the developed model in Rosekandi tea estate factory, Silchar, Assam, India, it was possible to predict the withering standard which belonged to the fuzzy category of "good" with a crisp value 70.55.

Keywords: Vagueness, Fuzziness, Degree of wither, Fuzzy set.

INTRODUCTION

Black tea processing as a whole consists of drying processes and a number of mechanical operations combined with or alternated by chemical and enzymatic reactions. Various stages are withering, leaf distortion, fermentation, drying and sorting (Figure 1). Withering of the fresh leaf is the first and indispensable stage in black tea processing. The main objective of withering is to bring the mixed leaf material into the best leaf distortion condition enabling the best possible tea to be made from the basic material that suits the best possible market. Determination of the termination of withering of the tea leaves after the attainment of a desired degree of wither, primarily depends on the experience of the tea professionals and so the leaves can be under or over withered. The reason behind this is that, the process of withering is very complicated and the standard of withering attained by the leaves depends on a combination of controlling factors such as type of leaf, leaf size, age, fineness and coarseness, thickness of spread in the withering trough, drying capacity of withering air, standard of plucking, condition of leaf, period of wither, condition of withering room, temperature of leaf, texture etc in a properly designed trough that excludes the possibility of thermal and velocity variation of withering air longitudinally. The decision to terminate the withering process at the right instant has a direct relation with the colour and quality attributes of made tea as well as the overall energy consumption in tea processing. Presently, the decision about the completion

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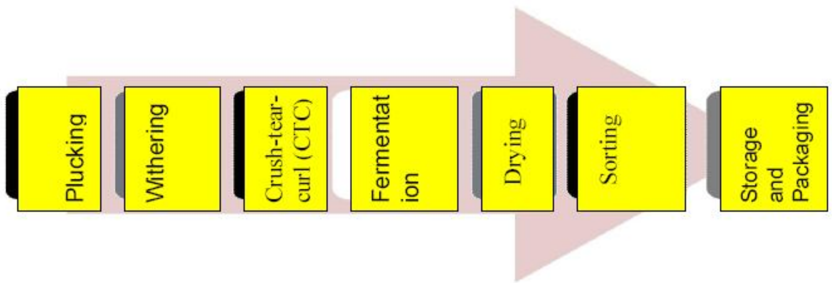

Figure 1. Flow chart for CTC tea manufacturing process

of withering of the fresh leaves depends on the subjective judgement of the professional supervising the withering process and hence can be dealt with approximate reasoning. The physical characteristics of the leaves change with the progress of the withering process and allow an experienced professional to make decision on the state of withering using linguistic variables. Since, withering is an important stage in tea processing and much of the quality attributes and liquor characteristics of the made tea are dependent on the attainment of a desired degree of wither, simulation of the withering process is of immense significance to predict the standard of withering with a desired degree of wither. Further, the underlying physics of the process of withering being very complex, fuzzy nonlinear simulation method can suitably used for the proposed modeling. The advantage of the fuzzy approach is that it enables processing of vaguely defined variables, and variables whose relationships cannot be defined by mathematical relationships. Fuzzy logic can incorporate expert human judgement to define those variable and their relationships. The model can be closer to reality and site specific than that by other methods (Mahant, 2004). Extensive literature survey reveals that, no attempt has been made so far to model the withering process of tea manufacturing.

BRIEF LITERATURE REVIEW

(Panchariya et al., 2002) developed an experimental dryer for determining the kinetics of black tea drying. Drying characteristics of tea were examined using heated ambient air for the temperature range 80–120_C and air flow velocity range 0.25–0.65 m/s. The results illustrate that in spite of high initial moisture content, the drying of tea particles takes place only in the falling rate period. This single-layer drying equation can be used for the simulation of deep-bed drying of black tea. (Wanyo et al., 2009) applied far-infrared radiation and hot-air (FIR-HA) convection drying to improve physical quality and antioxidant properties of mulberry tea. The study demonstrated that the intensity of FIR effected not only on total phenoloic and flavanoid contents but also on individual phenoloc compounds. (Jaya, 2002) investigated various energy options in terms of their potential and quality of energy that can be produced by each of these resources to in order to reduce the fuel wood consumption in tea manufacturing of Sri Lanka. Hafezi et al. (Hafezi et al ., 2006) investigated the optimum fermentation times of black tea manufactured by two systems of manufacture, namely orthodox and CTC by measuring quality parameters of black tea. (Tomling and Mashingaidze, 1997) reviewed the literature on the influence of withering on maceration, fermentation, drying and on black tea quality. (Emaldi et al., 2009) used central composite design technique, a response surface methodology to study the effect of the withering time and the fermentation conditions of the tea leaves on the black tea quality parameters. Fuzzy set approaches always seem to be most appropriate when the modeling of human knowledge is necessary (Evans et al., 1989). (Karwowski and Mital, 1986)] discussed potential applications of fuzzy set theory to risk analysis in the area of industrial safety engineering. Vagueness and imprecision in mathematical quantification of risk were equated with fuzziness rather than randomness. The concept of risk evaluation, using linguistic representation of the likelihood of the occurrence of a hazardous event, exposure, and possible consequences of that event, was proposed. The approximate reasoning technique based on fuzzy logic is used to derive fuzzy values of risk. Similar works are found in (Karwowski and Mital, 1986), (Karwowski, 1992)] and (Grobelny et al., 1995).

It can be observed from above that no attempt has been made for the modeling of tea withering process. Based on the literature survey, the objectives set for the present work are a) identification of various factors of withering and b) development of a fuzzy withering model that incorporates functional relationship between standard of withering (output) and various inputs.

Need for modelling of tea withering process

Withering is the foundation stage which directly influences the quality and cup characteristics of the made tea. Further, smooth operation of the subsequent processes such as leaf distortion, fermentation, drying greatly depends on the standard of withering. Hassle free operation of various stages of tea making contributes to the reduction of energy consumption. Therefore, knowledge of the standard of withering can be used to predict the quality of the finished product and cost of production. In the backdrop of highly competitive market, a modeling of withering is of great significance for proper production planning, energy saving and environment conservation.

Withering process fundamentals

During withering, the first stage of tea processing freshly plucked tea shoots, containing about 70 to 83% water are partially dehydrated to a moisture content ranging from 65% to 70% water. Besides physical changes, chemical changes in the leaf take place. Withering fresh leaf is the first and indispensable stage in tea manufacturing. Withering is carried out to condition the leaf physically for the next step of tea processing namely leaf distortion which is carried out in CTC machine in case unorthodox tea processing or in conventional rollers in case of orthodox processing. At the same time the leaf is to be conditioned for good fermentation. The leaf has to attain a certain degree of withering before it is suitable to roll well or to take a twist.

Withering percentage:

Withering percentage is defined as the weight of 100 kg fresh leaf at the end of withering process. The state of withered leaf is expressed in withering percentage.

Modern withering techniques:

Modernisation of withering with the objective of saving cost and space as well as replacing inadequate installation has resulted in the development of a new withering systems, such as

1. Drum withering.
2. Tunnel withering.
3. Trough withering.
4. Tocklai continuous withering machine.
5. Russian withering machine.
6. Automatic continuously operating installations.

Amongst these the withering troughs are most extensively used in the tea factories of Assam for the withering of green leaves.

Fuzziness and fuzzy logic

Fuzziness describes the ambiguity of an event. Logic for humans is a way quantitatively to develop a reasoning process that can be replicated and manipulated with mathematical precepts. The interest in logic is the study of truth in logical propositions. In classical predicate logic this truth is binary - a proposition is either true or false. From this perspective, fuzzy logic is a method to formalize the human capacity of imprecise reasoning or approximate reasoning. Such reasoning represents the human ability to reason approximately and judge under uncertainty. In fuzzy logic all truths are partial or approximate. In this sense this reasoning has also been termed interpolative reasoning, where the process of interpolating between the binary extremes true and false is represented by the ability of fuzzy logic to encapsulate partial truths. The subjectivity that exists in fuzzy modeling is a blessing. The vagueness present in the definition of terms is consistent with the information contained in the conditional rules developed by the engineer when observing some complex process. Even though the set of linguistic variables and their meanings are compatible and consistent with the set of conditional rules used, the overall outcome of the qualitative process is translated into objective and quantified results. Fuzzy mathematical tools and the calculus of fuzzy IF – THEN rules provide a most useful paradigm for the automation and implementation of extensive body of human knowledge, which is not embodied in the quantitative modeling process. These mathematical tools provide a means of sharing, communicating and transferring this human subjective knowledge of systems and processes. The justifications of the use of fuzzy logic are due to

- It is tolerant of imprecisely defined data.
- It can model non – linear systems or processes of high degree of complexity.
- It is able to build on the human expertise.

Fuzzy union and intersection of two fuzzy sets are given by equations (1) and (2) respectively.

$$\mu_{A \cup B}(x) = \max[\mu_A(x), \mu_B(x)]$$ -------------------------(1)

$$\mu_{A \cap B}(x) = \min[\mu_A(x), \mu_B(x)]$$ -------------------------(2)

Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number. Several methods for defuzzification are used in practice, including the centroid, maximum, mean of maxima, height, and modified height defuzzifier. The most popular defuzzification method is the centroid method, which calculates and returns the center of gravity of the aggregated fuzzy set.

Fuzzy associative memories (FAMs):

There exixts a compact form of representing a fuzzy rule

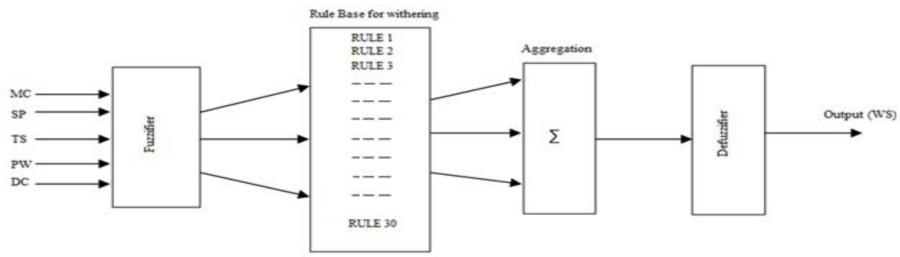

Figure 2. Building a fuzzy tea withering model

based system. This compact graphical form is called fuzzy associative table, or FAM table.

Principles involved in the fuzzy model

The fuzzy withering model is based on the following principles:

i) The leaf is surface dry as harvested in a normal sunny day.

ii) The process of withering is a non-linear fuzzy mapping from five non-interactive inputs to single output (Withering standard).

iii) The knowledge about the withering process is fuzzy i.e. the input-output functional relationship is based on the subjective judgement of the observer.

Development of a fuzzy model for tea withering process

Steps involved in the development of fuzzy withering model:

The following steps are involved

i) Identification of various inputs and outputs.

ii) Fuzzification of various inputs and output into fuzzy sets.

iii) Development of the rule base (IF-THEN statements) for the fuzzy withering process based on intuition, human experience and subjective judgement on the process.

iv) Mamdani inference methodology is used to combine inputs and outputs.

v) Defuzzification of the fuzzy output set to arrive at a scalar value.

Figure 2 illustrates the schematic diagram of the fuzzy inference system for fuzzy simulation of tea withering process.

Fuzzification of the input and output spaces:

Study of the withering process and close discussion with the management experts in tea industries revealed that, the withering process can be modeled as a nonlinear mapping between five non-interactive inputs and one output. The five non-interactive inputs were identified as i) Moisture content of leaf (MC) ii) Standard of plucking (SP) iii) Thickness of spread (TS) iv) Period of withering (PW) and v) Drying capacity of air (DC). The output may be designated as withering standard (WS). The fuzzy partitioning of the input variables was done as follows. A close consultation with the people having a long experience in monitoring the withering process was held and fuzzification was performed on the basis of their expertise in the field.

i) Fuzzification of Moisture content of leaf (MC):

The moisture content of fresh tea leaf varies from around 75% to 78% in case of surface dry leaf. The low moisture content is desirable because it yields higher volume of finished product (made tea) due to higher solid matter content. Moisture content is divided into three fuzzy sets such as Low (around 75%), Average (around 76.5%) and High (around 78%). Moisture content depends on the type of leaf (genetic origin). Figure 3 depicts the fuzzy partitioning of the variable Moisture content (MC).

ii) Fuzzification of standard of plucking (SP):

Standard of plucking involves leaf size, softness of leaf, relative quantity of productive and non-productive (banjhi) leaves and so many. The ideal material to process to produce quality tea is two leaves and a bud. Sometimes, three leaves and a bud or even four leaves and a bud are allowed to process but then the quality of tea would deteriorate. If the leaf size is smaller, it is easier and quicker to remove moisture during withering. Also the leaf is softer if the leaf size is small. The longer leaf generally becomes harder and it takes more time to remove moisture to achieve a particular degree of wither. Leaf size varies from 1 inch to 4 inches. Standard of plucking are categorized in the tea factories by the percentage share of small and soft leaf in a random sample of fresh leaf. A good standard of plucking is indicated by a percentage share of small and soft leaf of around 80% or more and may be designated by a linguistic term “Fine leaf”. An Average standard of plucking contains around 60% of soft and small leaf and may be categorized with

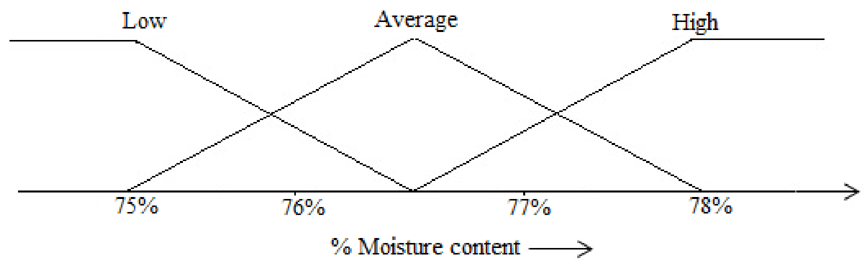

Figure 3. Fuzzy partitioning of moisture content of tea leaf (MC).

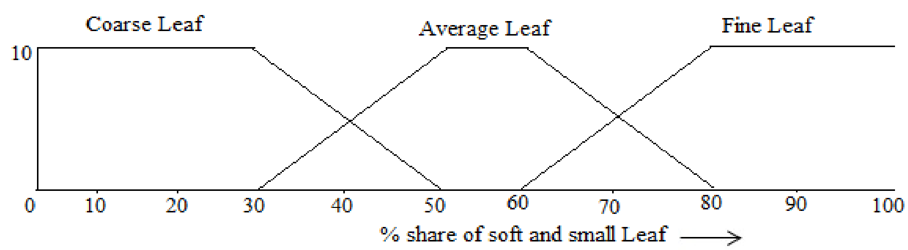

Figure 4. Fuzzy partitioning of standard of plucking (SP).

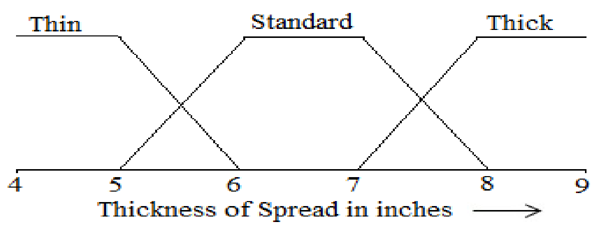

Figure 5. Fuzzy partitioning of thickness of spread (TS).

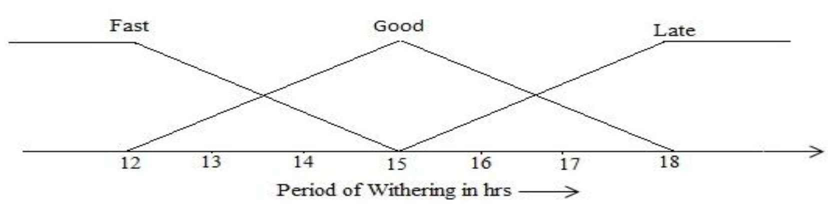

Figure 6. Fuzzy partitioning of period of withering (PW).

linguistic term “Average leaf”. A poor standard of plucking is indicated by a percentage share of small and soft leaf of around 30% or less and categorized with the linguistic term “Coarse leaf”. The fuzzy partitioning of standard of plucking (SP) is shown in Figure 4.

iii) Thickness of spread (TS):

Freshly plucked tea leaves is spread into the withering troughs in a layer of thickness that varies from approximately 5 inches to about 8 inches or more. If the leaf is spread with a higher thickness, withering will be uneven across the thickness of the leaf layer with leaves near the inlet of drying air would wither more than the leaves near the upper layer for downward flow of drying air through the trough. The leaf thickness is partitioned into three fuzzy sets as “Thin”, “Standard” and “Thick”. Fuzzy set Thin represents leaf layer thickness of around 5 inches or less, fuzzy set Standard represents thickness in the vicinity of 6 to 7 inches and fuzzy set Thick represents a leaf layer thickness of around 8 inches or more. Figure 5 shows the fuzzy partitions of the variable TS.

iv) Period of withering (PW):

It is the time interval taken by the fresh leaf to attain a withering percentage of about 70% from the instant of loading into withering trough. Period of withering has been divided three fuzzy partitions as “Fast”, “Good” and “Late”. The most representative value or the prototype value of the fuzzy set “Fast” been taken as 12 hrs, that of fuzzy set “Good” as 15 hrs and of fuzzy set “Late” as 18 hrs. the fuzzified variable PW is illustrated in Figure 6.

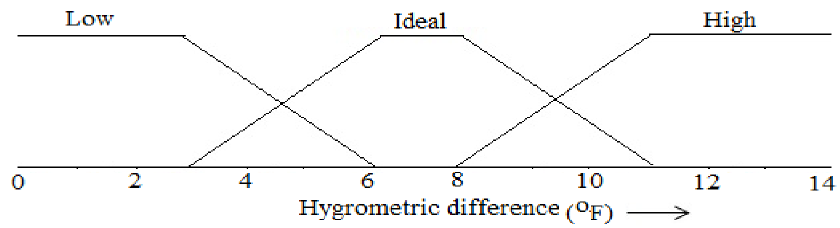

Figure 7. Fuzzy partitioning of drying capacity of air (DC).

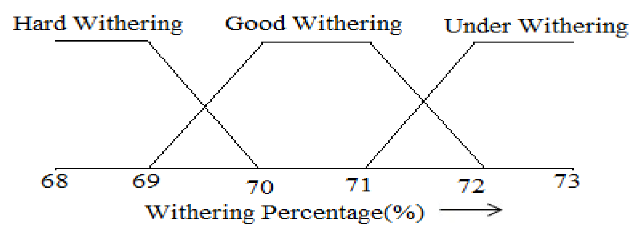

Figure 8. Fuzzy partitioning of moisture withering standard (WS).

v) Drying capacity of air (DC):

It is the capacity of withering air to remove moisture from the tea leaves and is measured by the difference of dry bulb temperature (DBT) and wet bulb temperature (WBT) of the withering air or in other words the hygrometric difference. Drying capacity (DC) of withering air is divided into three fuzzy partitions of "Low", "Ideal" and "High". The prototype values are 3^0F, the interval 6-8^0F and 11^0F. The fuzzified variable DC is shown in Figure 7.

vi) Withering standard (WS):

This is taken as output of the withering process and is expressed as withering percentage. After close discussion with the managements of tea processing units, it was found that a withering percentage of 70-72% is very good for tea processing which results in good quality tea. Measurement of withering percentage is more or less based on the experience of the withering house executive. In another method, baskets each filled with 1 kg of fresh leaf are kept in several places of the withering trough. After withering, the withered leaves in the baskets are weighed to ascertain the withering percentage. The withering standard is partitioned into three triangular fuzzy sets as "Under withering", "Good withering" and "Hard withering". The prototype values being 72%, 70-71% and 69% respectively. The fuzzified variable WS is depicted in Figure 8.

Fuzzy associative memories (FAM) table for withering:

Table 1 represents FAMs for the rule base consisting of 30 rules. Each row of the table corresponds to a rule. The rules are based on intuition, human expertise and subjective judgement on the process of tea withering.

Case study

The fuzzy withering model was used to simulate the withering process at Rosekandi tea estate factory, Assam, India, as case study. Trough withering is carried out in the factory. Crisp values of various inputs of the withering process were found to be i) MC = 75.5% ii) SP = 85% iii) TS = 7.5 inches iv) PW = 14 hrs and v) DC = 7^0F. A simplified explanation of the case study is illustrated in figure 9 showing the application of Rule 1 and Rule 6. AND combination implies an intersection of fuzzy sets and gives the fuzzy output sets of withering standard (WS) on the right side of the figure. A union of the two output sets gives the aggregated output set, shown in the bottom right of the figure. Centroid method of defuzzification yields scalar value of WS as 70.55, the value of withering standard, which falls category defined as Good.

CONCLUSION

The process of tea withering is based on imprecisely defined inputs. Withering being the first and most important phase of tea processing, controlling the quality attributes and liquor characteristics of the finished product with a bearing on cost of production, the current approach of ascertaining the state of withering based on human experience seems to be outdated and needs refinement. Moreover, a simulation of withering process

Table 1. Fuzzy associative memory table (FAM) for withering process.

Sl. No.	Inputs					Output (WS)
	MC	SP	TS	PW	DC	
1	Low	Fine	Standard	Good	Ideal	Good
2	High	Coarse	Thick	Fast	Low	Under
3	Average	Average	Standard	Late	Ideal	Good
4	Average	Coarse	Thin	Fast	Ideal	Under
5	Average	Fine	Thick	Fast	Ideal	Good
6	Average	Fine	Standard	Fast	Ideal	Under
7	Average	Fine	Thick	Good	Low	Under
8	High	Fine	Thick	Late	Ideal	Good
9	High	Fine	Standard	Late	Low	Under
10	High	Average	Standard	Good	Ideal	Good
11	High	Average	Thick	Late	Ideal	Good
12	Low	Average	Standard	Late	Ideal	Good
13	Low	Coarse	Thick	Late	Ideal	Under
14	Low	Average	Thin	Fast	Ideal	Good
15	Low	Fine	Thin	Good	Ideal	Hard
16	Average	Fine	Thick	Late	Ideal	Good
17	Average	Fine	Standard	Good	Low	Under
18	Average	Coarse	Standard	Late	Ideal	Good
19	Average	Average	Standard	Good	High	Good
20	Average	Average	Thick	Good	Low	Under
21	Average	Average	Thin	Good	Ideal	Good
22	Average	Fine	Standard	Good	Ideal	Good
23	Average	Fine	Standard	Late	Ideal	Hard
24	Low	Average	Standard	Late	Ideal	Good
25	Low	Coarse	Standard	Late	Ideal	Good
26	High	Coarse	Standard	Late	Ideal	Good
27	High	Coarse	Standard	Good	Ideal	Under
28	High	Fine	Thick	Good	High	Good
29	High	Fine	Thin	Good	Ideal	Good
30	Low	Fine	Thin	Good	Low	Good

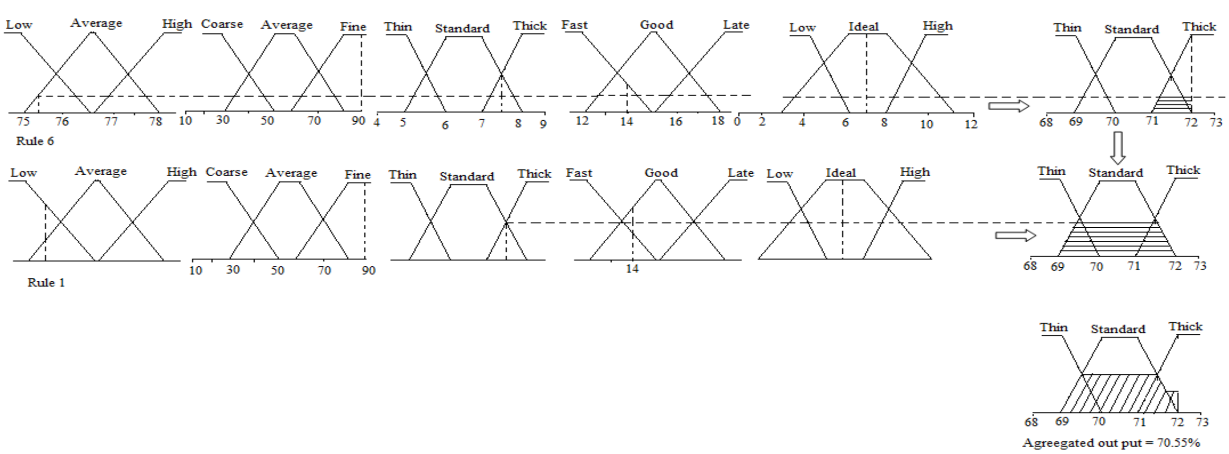

Figure 9. Mamdani method of computing output (WS).

could be helpful in scheduling the subsequent processes in a more scientific manner resulting in the judicious use of energy. The fuzzy withering model presented here is the first of its kind. The model can be made more user friendly with aid of a suitable computer programme.

Since, process of withering and its controlling parameters are do not vary over a tea producing region in case of trough withering, the model so developed is applicable to all tea processing industries of a tea producing region producing black (CTC) tea.

Acknowledgement

The authors acknowledge their sincere thanks to the Rosekandi tea estate management for the help rendered by them in collecting various inputs for this research.

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