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MONITORING OF WOODEN MATERIAL COMBUSTION PERFORMANCE WITH FUZZY LOGIC

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Abstract

In this study, monitoring of wooden material combustion performance with fuzzy logic has been realized. Many studies have been made on the combustion properties of wooden material with different combustion mechanisms. Today, wooden material combustion mechanisms do not meet the needs of developing technology and increasing demands. Computer-aided combustion mechanism is designed and monitoring combustion performance with developed user interface software is provided. The most accurate monitoring of measurements obtained by the combustion and combustion process has been realized in real time on the computer. Manual measurement related errors are minimized in wooden material combustion mechanisms. Operations on parameters that obtained from the result of combustion can be made faster with this system. Test performance is determined with fuzzy logic by using data obtained during the combustion process and errors are reported to the user with user interface software. Unexpected situations that experts could not notice can be determined easily by this system during the combustion. It has been observed that the designed computer-aided combustion system prevents the data-loss and gives better results with sensitive measurements. Since repetition of the experiment is reduced, especially time, work and energy savings are provided. This system with these features can be used easily in wooden material combustion R&D centers, academic studies on this issue and companies in this area.

Key Words: Real time control, fuzzy logic, combustion, combustion mechanism.

1. Introduction

Wooden material is the oldest one in various building materials used by people. Brought technical innovations of our age and despite of competing with the large number of new material, it keeps its importance in many fields because of its superior properties today [1]. One of the most negative features of the wooden material is combustible. In order to eliminate this negative property of wooden material, many chemicals are used in to prevent or retard. Many studies have been done with different combustion mechanisms on the combustion properties of wooden material. Fire tube mechanism is the most commonly used among the combustion mechanisms. This mechanism is widely used and well-known in many countries [2]. However, lots of changes have been made on the experiment mechanism thinking that this mechanism is ordinary and it cannot make exact measurements. Measurement of weight loss caused by burning wooden material has been made analytical. For this purpose, the scale sensitivity of which is 0.01 g has been used for precise measurement. The gas analyzer Testo 350-XL probe was placed on the top of pipe. Temperature change caused by combustion of the material and released gases as a product of combustion were measured [3]. When the importance of the combustion properties of wooden material is taken into consideration in literature, combustion mechanism cannot meet the needs of current developing technology. Computer-aided combustion mechanism is needed to minimize the manual measurement and human-induced errors and to increase the sensitivity of the parameters obtained by the combustion.

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In this study, computer-aided wooden material combustion mechanism is prepared and combustion performance is monitored with fuzzy logic. In this way, manual measurement and human-induced errors are minimized. Monitoring of parameters obtained as a result of combustion and combustion process is realized. The measurements are recorded to computer in a real time during combustion. Real time performance of experiment is evaluated by applying the fuzzy inference on the values measured during the combustion and the combustion process is kept under control. Processing of data obtained as a result of combustion process and analysis are realized in computer environment. Then, the data obtained are presented by tables and graphics. Storing of all data recorded as a result of measurement for further usage is provided. In this way, the accuracy of future studies can be controlled through experimental experiences.

Today, studies of the combustion are in the form of reading and recording data observations without the aid of a computer. This case causes not only humanly errors but also measurement errors. Detecting errors beforehand provides manpower and especially time saving. This mechanism can be used in the field of wooden material protection technology and in determining the combustion properties of wooden material. It shed lights on the works about the protection of historical buildings against fire. Protection of wooden which is a combustible organic material against fire and maintenance of our historical culture will be provided for the protection of historical wooden houses in case of a fire. It will contribute to the sustainability of our culture by protecting the wooden material against the combustion danger.

2. Material and Method

2.1.Design of Wooden Material Combustion Mechanism

Wooden material combustion mechanism is planned and designed in the light of technological developments. Materials used in the preparation of the combustion mechanism are selected in accordance with the best monitoring. The mechanism design that allows the monitoring of wooden material combustion performance with fuzzy logic is given in Figure 1. In existing mechanisms chimney temperature, the weight ratio of burning piece, the amount of burning piece of ash and chimney gas (O2 (oxygen), CO (carbon monoxide), NO (nitrogen monoxide), NO2 (nitrogen dioxide)) analysis are done. In addition to these measurements, temperature at the top of the combustion wooden material, temperature at the middle section and humidity measurement in the combustion cabin are also provided in the cabin.

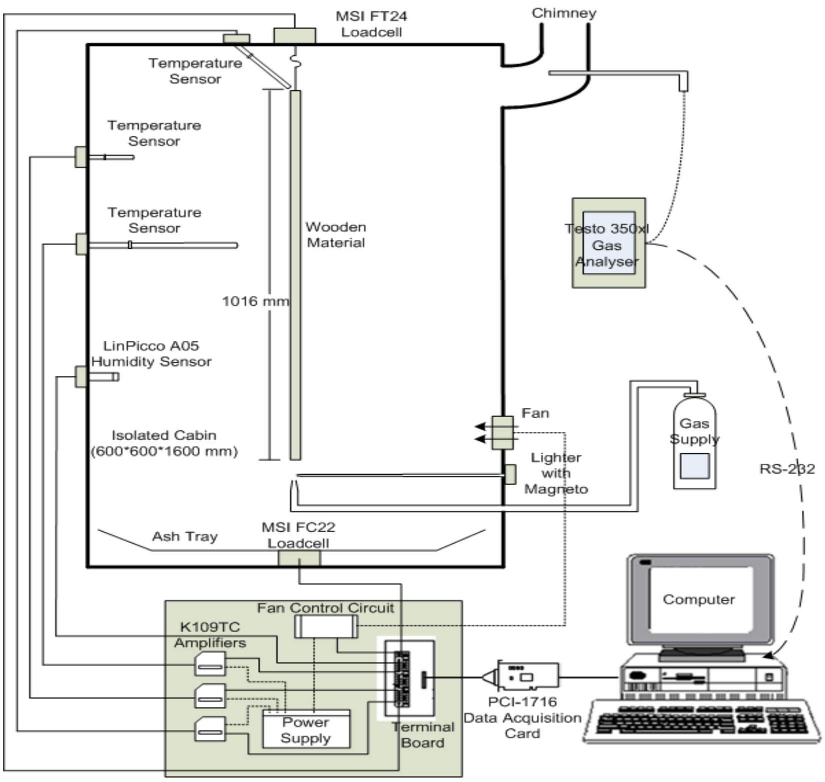

Figure 1. Wooden material combustion mechanism design

Temperatures are measured with temperature sensors that are placed in three different points in the combustion cabin and transferred to a computer in real-time. Temperature sensor placed on the upper side of the cabin measures the temperature change at the top of the burning wooden material. Temperature sensor placed on the side of the cabin measures the temperature change in the middle of the burning wooden material. Temperature sensor placed on the side of the cabin is used to measure interior temperature of the cabin. After passing through the converters, measurement values are transferred to the terminal board. The weight ratio of burning wooden material is measured as a percentage with tension type loadcell. Weight of the ash is measured by compression type load cell. Resulting from the combustion of gases has been measured with gas analyzer equipment placed on mechanism. Humidity sensor is used to measure the amount of humidity in the cabin. Measured values are transferred to a computer via the data acquisition card for being processed and stored.

Used data acquisition card provides real-time data transmission. Fan placed in the air entrance of the mechanism is controlled according to the measurement value of humidity sensors. In this way, the air stream is provided within the mechanism. Measurement data are recorded and stored for evaluation in future studies at the end of the experimental work. In this way, the accuracy of future studies can be controlled through experimental experiences. During the combustion experiment real-time performance is evaluated and errors are detected with fuzzy inference method applied on the chosen measured values. In this study, minimizing of errors and monitoring of the combustion process are effectively realized. Detecting errors beforehand provides manpower and especially time saving. This mechanism can be used in the field of wooden material protection technology and in determining the combustion properties of wooden material.

2.2. Monitoring the Combustion Performance with Fuzzy Logic

Combustion model has been developed primarily in Matlab Simulink environment for monitoring the performance of combustion with fuzzy logic. With this model the mechanism of transferring data to a computer in real-time provided the desired sampling time. Then, real-time processing of the data and its storage has been realized with prepared user interface software design. Data can be received from the sensors at desired sampling time and presented to users with graphic screens thanks to prepared software. Used fuzzy logic method for fuzzy inference system and the reasons for choosing this method are explained. After receiving the data, fuzzy inference system was created according to the input and output variables with Matlab fuzzy inference system editor. Besides the designed system in Matlab environment, fuzzy inference system is modeled with user interface software design written in visual programming. In this system, the experts can determine the input and output variables membership functions, can prepare the rule base according to the demands and can perform fuzzy inference process according to desired methods in real-time.

Many studies have been done on the process control systems. The cases of sintering plant using fuzzy logic in process control systems were investigated [4]. In one study, thermal comfort care application was studied with fuzzy logic process control in measurement laboratories [5]. In another study, experimental investigations were made for fuzzy logic process control [6]. Design, implementation and real-time operation of advanced process monitoring techniques for wastewater treatment plants were presented with studies [7]. Distributed real-time process control was designed for heating and power plant [8].

2.2.1. Getting the Data in Matlab Environment in Real-Time

Matlab is a computing environment that combines numeric computation, advanced graphics and high-level programming language. Building a model of a system and real-time controlling are possible in Matlab. This process is implemented in two ways. The first one is formed in the model or Matlab environment and model is tested with data and/or control inputs. In second type of real-time studies, the actual system is controlled and/or tested in Matlab environment. These transactions are made using XPC Target and RTWT (Real Time Windows Target) tools. Many studies are done by using two libraries of Matlab such as processing data and real-time control. RTWT transmits the data to the Matlab processing environment in real-time. It is very difficult to get the experiment data in real-time on windows operating system. Matlab disables or suspends interruptions and operations of windows operating system. In this way, real-time data acquisition up to 100 kHz and control process are accomplished through the Windows operating system [9].

Matlab Simulink model has been developed for receiving and processing of the data in real-time. Simulink software provides complex systems modeling, simulation and analysis. Computer simulations are largely used in the design of systems and whenever possible design stages of the test is done with the help of computers. This also reduces the need for prototypes and provides a large proportion of costs falling. Simulink simulation of dynamic systems is realized in two steps. First, the graphical model of the system to be simulated is created. This model shows time dependent mathematical relationship between inputs, state variables and outputs. Then system behavior is simulated using Simulink in a certain period of time. Simulink model of the combustion mechanism is given in Figure 2.

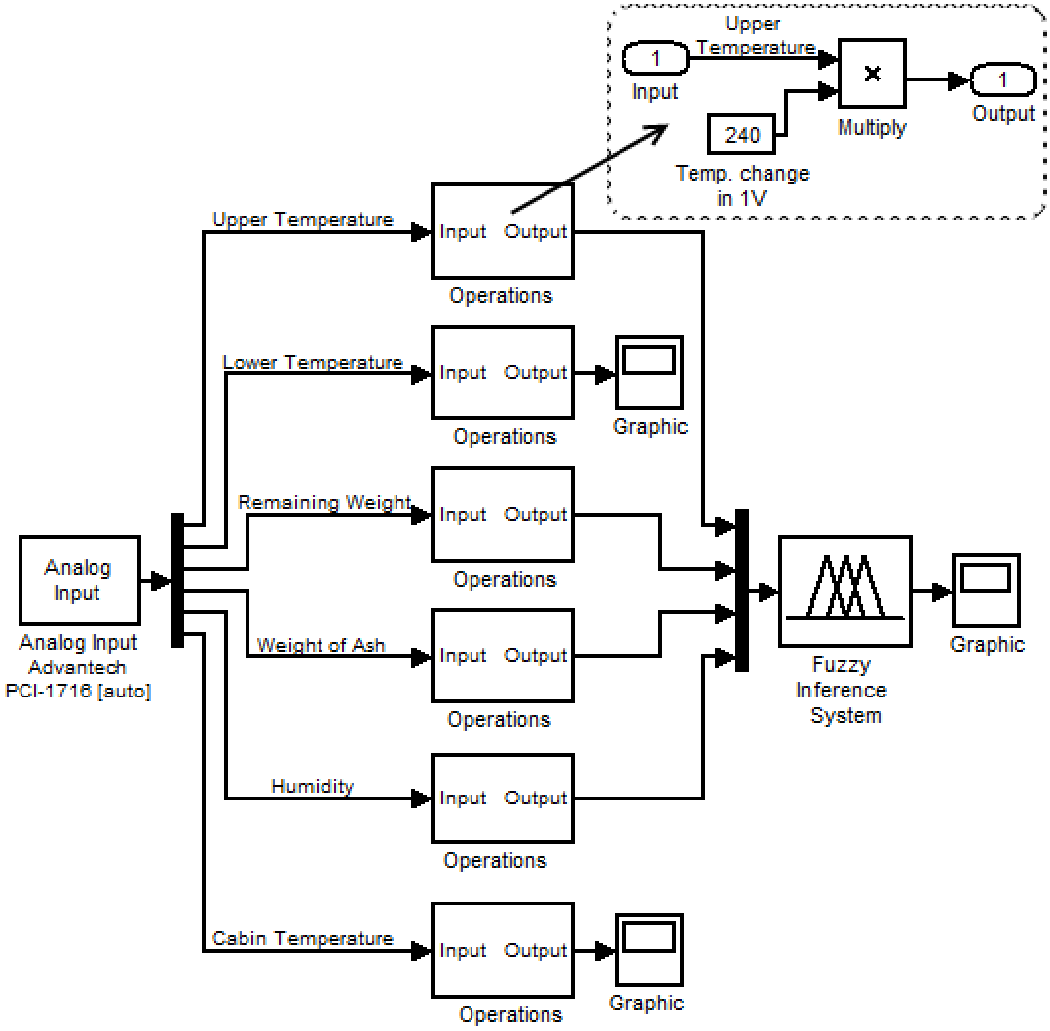

Figure 2. Simulink model of combustion mechanism

2.2.2. User Interface Software Design for Getting Data in Real-Time

User interface software was realized in Visual C # programming language for monitoring the performance of combustion with fuzzy logic. In software design data transmission infrastructure is primarily developed to provide communication with data acquisition card. Data acquisition card driver was installed and tested. After providing real-time data transmission infrastructure, interface and graphic displays that provides the display of received data to the user are designed and the codes are written. Interface screens have been prepared on which the experimental data is entered, experimental features are determined. Besides, scaling of the data and settings of the measurement conducted has also been prepared. The required codes were performed for real-time processing and storage of data. Database infrastructure is built to record obtained measurement results for further uses. Measurement values from mechanism can be obtained from the data acquisition card on desired sampling time with the help of the analog input module. The obtained data are presented to the user by the time of sampling as given in Figure 3. Studied card number and name are given in data display screen. Each channel sampling time can be adjusted on channel window group separately. Opportunity to choose 0-1000 ms has been presented for general sampling time. Measurement data are both showed from the labels and presented graphically to the user. Single data graphic representation on the screen can be provided with show graphic button. All data graphic representation on the screen can be provided with show all graphic button.

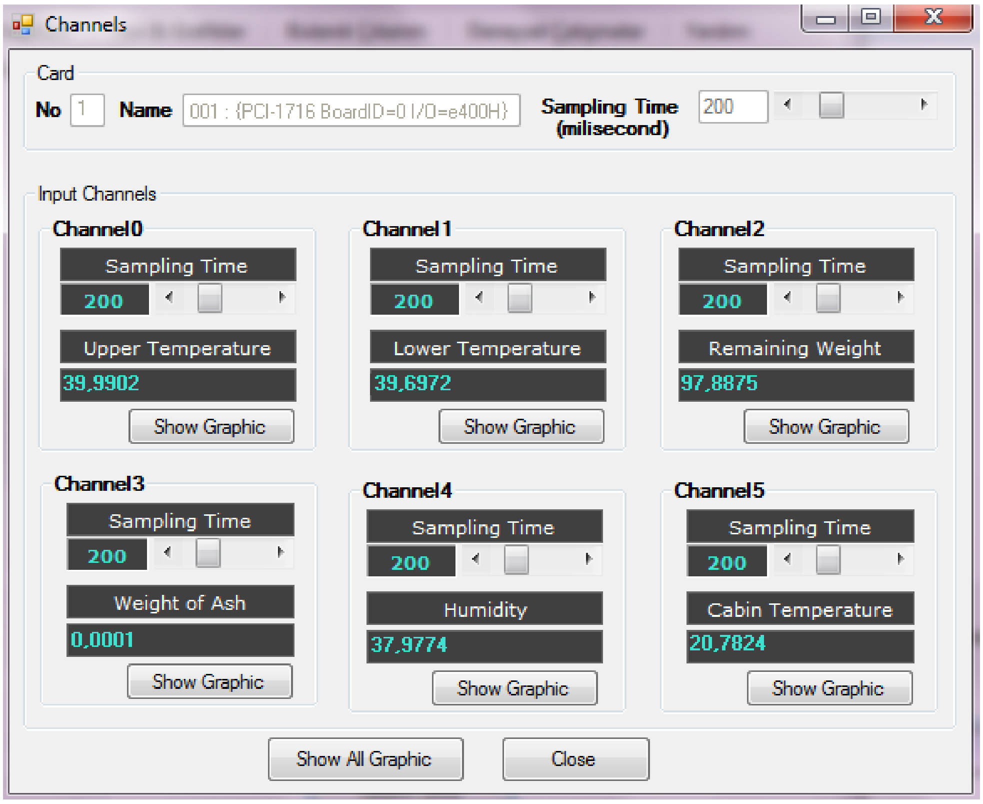

Figure 3. Real-time data reading screen

2.2.3. Fuzzy Logic

One of the methods used to control the combustion process is the artificial intelligence. Artificial intelligence techniques are widely used in monitoring, controlling and modeling the combustion process. The way how the artificial intelligence is provided on combustion process and understanding of it practically are studied [10]. Fuzzy logic is one of the most widely used methods on artificial intelligence applications. Fuzzy logic is a principle of creating an artificial intelligence application and the aim is to reach conclusion. The only disadvantage of fuzzy logic is that it does not give exact results. This is due to the natural structure of fuzzy logic [11]. Fuzzy logic is used in every parts of our life from electric household appliances to car electricity, from electric business machines to industrial technology and from industrial technology to automation. Fuzzy logic controller makes sense converting the linguistic control strategy. General method and performance value that composed fuzzy logic controller is defined. Attention is especially drawn to the strategy of fuzzification and defuzzification, the source of database and fuzzy control rules, the definition of fuzzy inference and the mechanism of fuzzy thinking analysis [12]. Fuzzy sets allow for partial membership of the cluster members. Membership values of fuzzy set elements are between (0-1) values. Therefore, a set of fuzzy is a generalized state of sharp cluster that grades each element membership. B fuzzy set membership function is characterized by μB (x) in universal set U [13-14].

Fuzzy logic is successfully used in results analysis studies and detection of errors. Experts have been consulted in monitoring of the experiments on fuzzy logic combustion studies and detecting the errors on combustion mechanism. Fuzzy logic enables expert's knowledge of combustion to be used in the form of linguistic expressions. This feature provides great flexibility in fuzzy logic. Thus, it can be used effectively on the determination of combustion performance, monitoring and debugging errors. A model based on fuzzy logic classifier was created in order to determine the values of modulus of elasticity and modulus of rupture of flakeboards. Using these values, input and output values and rule base of fuzzy logic classifier were created. With the fuzzy logic classifier model prepared in Matlab Simulink, modulus of elasticity and rupture values for flakes mixture ratios were predicted [15]. Real time control of DC-DC buck converter with fuzzy logic controller was designed. DC-DC converter circuit and real time Matlab/Simulink model that works with this circuit was prepared. For real time control, it was benefited from Real Time Windows Target library. Data acquisition card was used for data transfer between Simulink model and designed circuit. Fuzzy inference system prepared with FIS editor was embedded to fuzzy logic controller used in this model [16]. Alternator faults have been identified in real time using fuzzy logic and artificial neural network. Current, battery voltage, alternator voltage and alternator speed were measured to detect faults. Alternator faults detection categories were applied according to these measured values by creating an intelligent inference system [17].

2.2.4. Matlab Fuzzy Inference Model for Monitoring of Combustion Performance with Fuzzy Logic

According to expert opinions, four inputs and one output variable were determined for fuzzy inference system given in Figure 4. Membership functions of 5 pieces are defined for input and output variables. Some of the abbreviations are used in describing membership function names and the rule base. Membership function CA refers to very low expression, membership function AZ refers to low expression, membership function OR refers to average expression, membership function FZ refers to much expression and membership function CF refers to far much expression. Just upper temperature, remaining weight ratio, amount of ash and humidity ratio data are used in measurement for fuzzy inference system. Minimum-maximum method is used as a fuzzification method and weighted average method is used as a defuzzification method in fuzzy inference system.

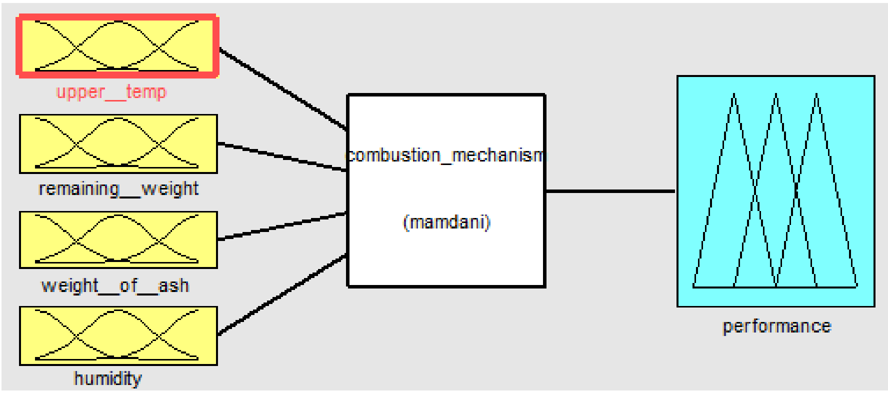

Figure 4. Fuzzy inference system model

Input variables and membership functions are determined in accordance with opinions of the experts and results of test measurement. That CF membership function in a wider range is a special case that experts wanted. Temperature input variable has five membership functions. The membership ranges from 0-120 °C for CA triangular membership function, 60-220 °C for AZ triangular membership function, 140-330 °C for OR triangular membership function, 250-420 °C for FZ triangular membership function, 335-1000 °C for CF triangular membership function. Remaining weight ratio input variable has five membership functions. The membership ranges from % 0-20 for CA triangular membership function, % 10-40 for AZ triangular membership function, % 25-60 for OR triangular membership function, % 45-80 for FZ triangular membership function, % 60-100 for CF triangular membership function. Amount of ash input variable has five membership functions. The membership ranges from 0-6 g for CA triangular membership function, 4-12 g for AZ triangular membership function, 9-18 g for OR triangular membership function, 14-24 g for FZ triangular membership function, 19-50 g for CF triangular membership function. Humidity ratio input variable has five membership functions. The membership ranges from % 0-12 for CA triangular membership function, % 6-25 for AZ triangular membership function, % 15-35 for OR triangular membership function, % 25-45 for FZ triangular membership function, % 35-70 for CF triangular membership function. Performance output variable has five membership functions. These membership functions are also determined in accordance with the opinions of experts and test measurements. The membership ranges from % 0-20 for CA triangular membership function, % 20-40 for AZ triangular membership function, % 40-60 for OR triangular membership function, % 60-80 for FZ triangular membership function, % 80-100 for CF triangular membership function. In case of intersection of the performance output variable membership functions, fuzzy logic monitoring system can produce multiple outputs at the same time. As the results occurring in this case will be difficult for experts to understand, membership functions of the studies were not intersected.

2.2.5. User Interface Software Design for Monitoring of Combustion Performance with Fuzzy Logic

Fuzzy inference system is a part that makes real-time inference according to the measurement results coming from data acquisition card. Firstly, start recording data button must be pressed in fuzzy inference screen shown in Figure 5. After three seconds from this process, the start fuzzy inference button is activated. Real time fuzzy inference system is activated by pressing this button. Input variables can be seen under the inputs group and output variable can be seen under the outputs group. Rule base can be seen under the rule base group. By clicking the pictures in these groups, shifting can be done on the related variable features screen. Click on the triggered rules link to see the triggered rules during real time inference and click on the results link to see the instant results of fuzzy inference.

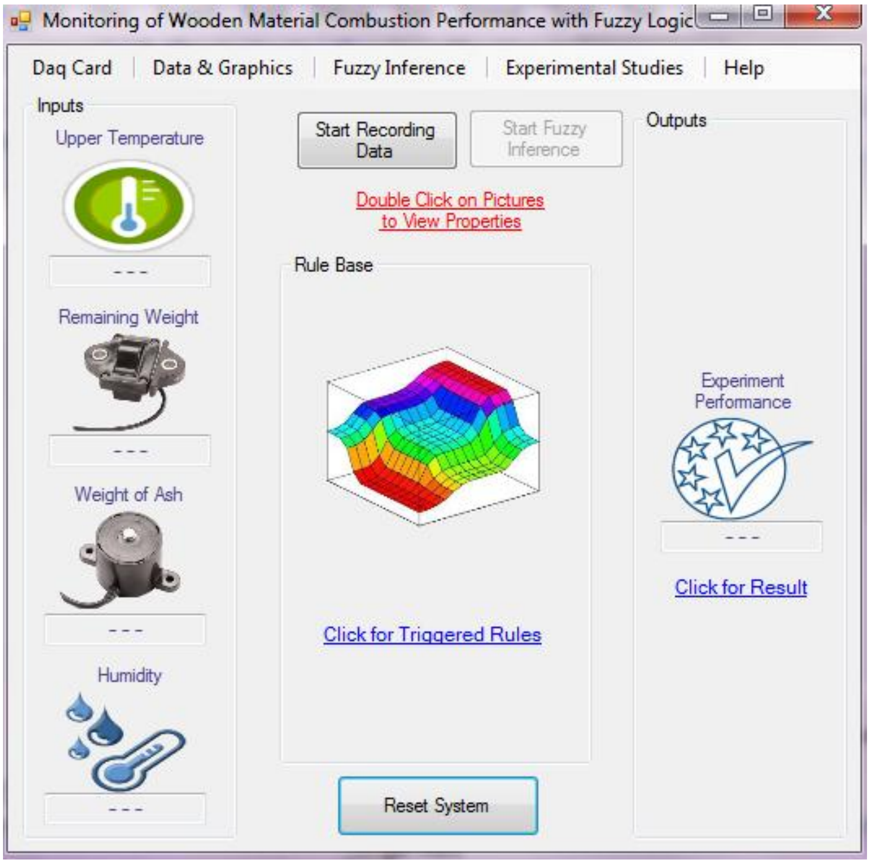

Figure 5. Data recording screen

It is necessary to press set input output option to screen for set input and output variables in fuzzy inference menu. Here, the number of variables to be used in inference system as input and output are selected. According to the selected operation, variables on input, rule base and output groups are created and variable definitions are made. Necessary procedures are performed to use four inputs and one output variable in further studies. Input or output variable properties are shown under the input output group. Input or output variable name, number of membership function and minimum and maximum value ranges are determined in this section. After setting the variable structure of these features taking into account the characteristics of the same group, the save operation is performed by pressing the save button. After this process the necessary properties are assigned to the relevant variables. Properties of membership functions are stated for variables to be added under the membership functions group. Graphical representation of the membership functions is given under the group of membership functions graph.

3. Result and Discussion

Simulation studies were performed primarily in Matlab Simulink environment for monitoring the performance of combustion with fuzzy logic. The data were taken quickly to a computer on studies performed in the Matlab environment. The data from the Simulink model are sent to the fuzzy inference model by pre-processing. Experiment performance is evaluated with fuzzy inference results. Following the successful results obtained from simulation studies, experimental studies are ongoing on the user interface software design. Designed combustion mechanism tests are provided by using two different wooden materials on combustion experiment works.

Before experimental studies data sub-structure is controlled. Then selection of wooden materials used in studies was performed. Initial experiment measurements are realized by running the user interface program. After this is done wooden material is placed on mechanism and combustion cabin door is closed. The gas source is opened in order to start the process of combustion gas supply and igniter is provided with magneto ignition lighter. Experiment is begun after ignition operation by pressing the button on user interface program. In this way, data recording and fuzzy inference operations are started on the system. However, testo device that performs chimney gas analysis is activated to begin acquisition data on the environment. The flame from the combustion process is carried out during three minutes. At the end of this period, the combustion process is continued by closing gas supply. The end of the experimental period of ten minutes, the program automatically terminates the data recording and inference process. Data acquisition with testo device process is ended. All the data obtained during the combustion process and the results of fuzzy inference are presented to users with the program's interface.

Experiment result of fuzzy inference performance graphic obtained from result of combustion of oriental beech wooden material is given in Figure 6. Experiment performance starts with a level of 60% and continues during 1,5 minutes to this value. Test performance decreases to level of 50% rate in the second minute. Then it shows a certain increases to reach level of 61% until fourth minute. Performance begins to decrease again in the fourth minute and decreases the level of 48% at the beginning of the fifth minute. From the fifth minute, it shows a sudden increase and reaches level of 90%. Performance decreases at level of 80% within the seventh minute, and remains at this level until the end of the ninth minute. It decreases at the level of 70% in the tenth minute and experiment is completed at this rate.

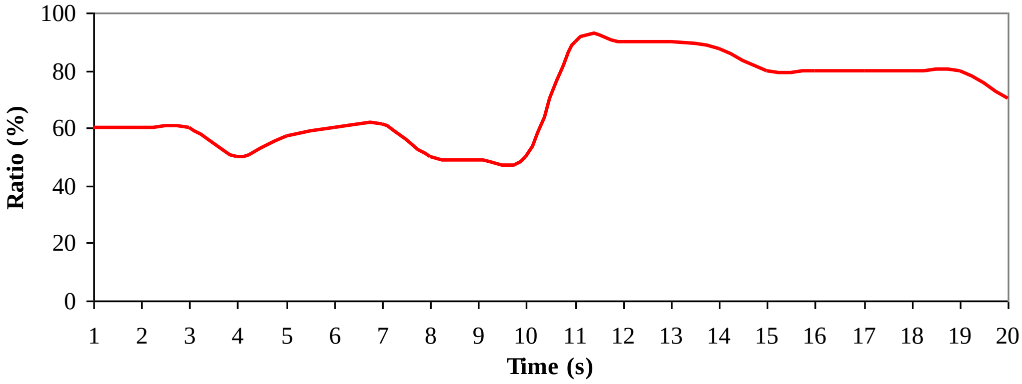

Figure 6. Fuzzy inference performance of combustion experiment of oriental beech wooden material

The performance of fuzzy inference obtained with result of combustion of oriental beech wooden material was compared with experts' opinions. Obtained chart as a result of this comparison is given in Figure 7. The average performance results and expected performance by the experts are presented with graphic in every 30 seconds. It has been observed that, an effective success was achieved as a result of fuzzy inference obtained from the combustion studies.

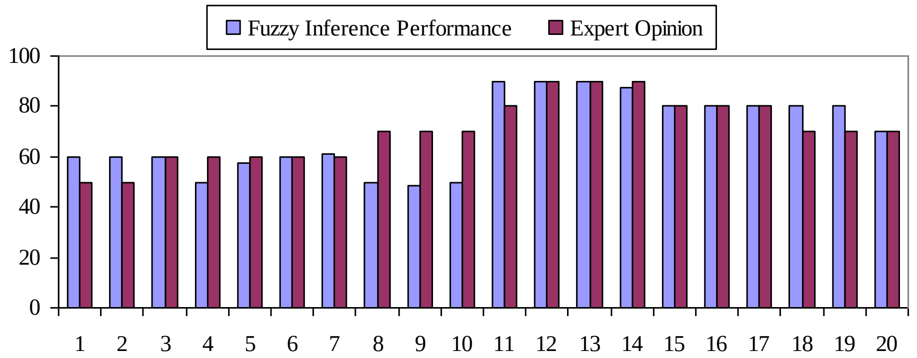

Figure 7. Oriental beech experimental performance and expert assessment

Experiment results of fuzzy inference performance graphic obtained from result of combustion of beech wooden material are given in Figure 8. Test performance starts with level of 60% and decreases to level of 50% in one and a half minutes. From that moment it increases and reaches level of 63% at the end of two and a half minutes. Then, a certain decrease is showed in the fourth minute. It starts to increase again after the fourth minute and reaches level of 90% at the end of the fifth minute. In the sixth minute it decreases again and takes value level of 70%. At the beginning of eighth minute the performance reaches level of 80% with an increase and decreases again level of 70% at the beginning of the ninth minute. It decreases at the level of 61% in the tenth minute and experiment is completed at this rate.

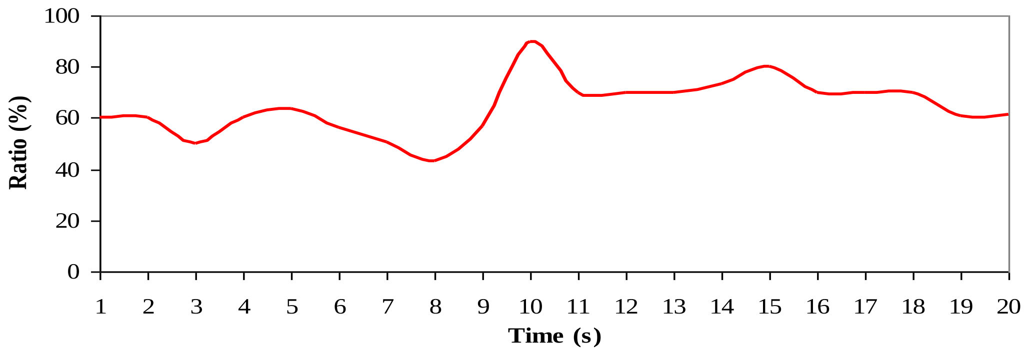

Figure 8. Fuzzy inference performance of combustion experiment of scotch pine wooden material

The performance of fuzzy inference obtained with result of combustion of scotch pine wooden material was compared with experts' opinions. Obtained chart as a result of this comparison is given in Figure 9. The average performance results and expected performance by the experts are presented with graphic in every 30 seconds. It has been observed that, an effective success was achieved as a result of fuzzy inference obtained from the combustion studies.

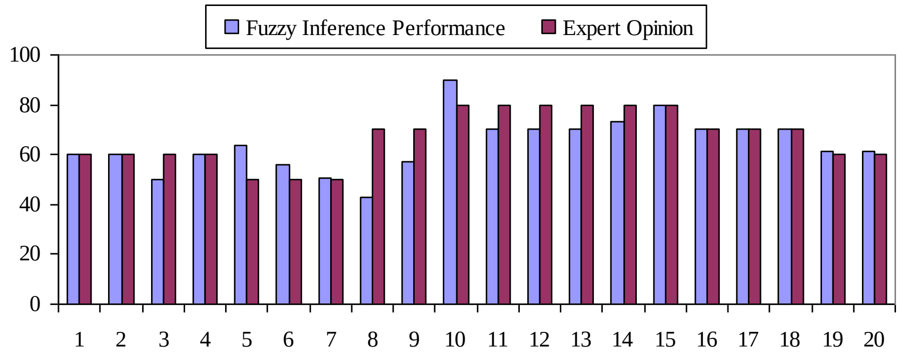

Figure 9. Scotch pine experimental performance and expert assessment

During data measurements of the studies of combustion, unexpected situations have been identified and these cases have been reported to the user. The result of fuzzy inference experiment which came into existence in an unexpected situation that occurred during the combustion of beech wooden material is given in Figure 10.

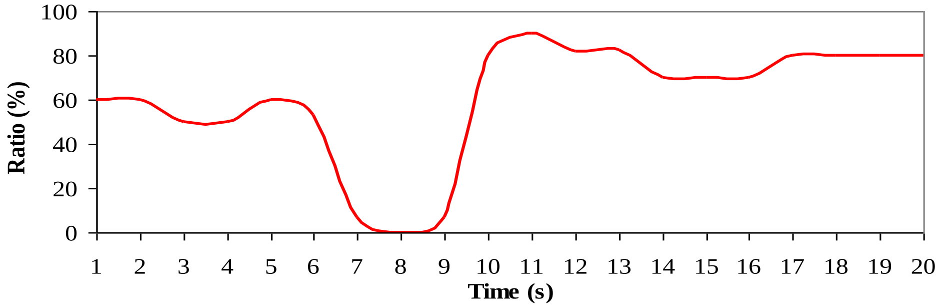

Figure 10. Faulty combustion experiment of oriental beech wooden material

As shown in the graphic, an unexpected situation occurring in the fourth seconds reduces the performance of the test. These are conditions that experts could not identify. Fuzzy inference system indicates us the unexpected conditions. Experimental work continues correctly except for this error condition. On the request of the people who conducted the experiment, the test can be finished immediately and can be passed on new experiment works. In addition, they can continue to experimental work with noting the faulty situations until the end of experiment time.

4. Conclusion

Monitoring of wooden material combustion performance with fuzzy logic has been realized. Computer-aided combustion mechanism has been designed and combustion studies were carried out using this mechanism. As a result of successful simulation studies carried out in Matlab Simulink environment, user interface software design was realized. The most accurate monitoring of measurements obtained by the combustion and combustion process have been realized in real-time on the computer. Minimizing the manual measurement and human-induced errors, increase parameters obtained by the combustion and faster transactions on these parameters are provided. Real-time performance of experiment is evaluated by applying the fuzzy inference on the values measured during the combustion and the combustion process is kept under control. Misconceptions the experts suppose and the unexpected situations they cannot detect can be recognized. It has been observed that, an effective success was achieved in evaluation of fuzzy inference results.

After combustion studies it has been observed that the designed system prevents the data-loss and gives better results with sensitive measurements. Especially time, work and energy savings are provided. Data loss prevention provides the reduction of similar experiments. Thus, this mechanism can be used on the fields of the protection technology of wooden material and determining the combustion properties of wooden material. Protection of historical wooden buildings against fire is provided thanks to these studies. It will contribute to the sustainability of our culture by protecting the wooden material against the combustion danger.

Measurement results can be evaluated and controlled with artificial neural networks on later studies conducted on this field. Monitoring of combustion experiments on the internet and its control can be provided. This mechanism developed as prototype can be used in related departments at universities and at R&D centers.

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