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Fuzzy modeling applied to a microwave dryer: Cotton weaving fabric drying process

Feyza Akarslan Kodaloğlu *1

[1]Suleyman Demirel University, Engineering Faculty, Textile Engineering Department, 32200, Isparta-Türkiye

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Abstract: Microwave drying stands out because it is faster than traditional drying methods, drying in the product is more uniform and energy efficiency. In this study, fuzzy modeling of a microwave dryer was developed. Microwave dryer is considered as a non-linear dryer. The proposed fuzzy model is used to estimate the drying rate for different electrical powers and different drying times. Different experimental measurements were used to evaluate the reliability of this model. Compared to other modeling techniques, thanks to simulation, the fuzzy model of the dryer provides an immediate estimation of the drying rate. This study will provide drying rates under demanded conditions and help determining machine parameters for a given product providing time and energy saving.The behavior predicted by the fuzzy model confirms the suitability of the defined model.

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Mikrodalga kurutucu için bulanık modelleme: Pamuklu dokuma kumaş kurutma işlemi

Anahtar Kelimeler
Bulanık mantık kontrol
Mikrodalga kurutucu
Pamuklu dokuma kumaş
MATLAB/Simulink

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Öz: Mikrodalga kurutma, geleneksel kurutma yöntemlerine göre daha çabuk olması, ürün içinde kurumanın daha düzgün olması ve enerji verimliliği sebebiyle öne çıkmaktadır. Bu çalışmada, bir mikrodalga kurutucunun bulanık modellemesi geliştirilmiştir. Mikrodalga kurutucu doğrusal olmayan bir kurutucu olarak kabul edilmiştir. Önerilen bulanık model, farklı elektriksel güçlerde ve farklı kuruma süreleri için kurutma hızının tahmin edilmesi için kullanılmıştır. Farklı deneysel ölçümler bu modelin güvenilirliğini değerlendirmek için kullanılmıştır. Diğer modelleme teknikleri ile karşılaştırıldığında simülasyon sayesinde, kurutucunun bulanık modeli, kurutma hızının anında tahmin edilmesini sağlar. Bu çalışma, belirli bir ürün için zaman ve enerji tasarrufu sağlayan makine parametrelerinin belirlenmesine yardımcı olacaktır.Bulanık model ile tahmin edilen davranış, tanımlanan modelin uygunluğunu doğrular niteliktedir.

1. Introduction

Microwave energy is widely used as a heat source due to its ability to heat products quickly. Microwave drying stands out because it is faster than traditional drying methods, drying in the product is more uniform, and energy efficiency [1].

Microwaves are electromagnetic waves that lie between radio waves and infrared rays in terms of wavelengths and frequencies within the electromagnetic spectrum. Microwaves are one of the types of electromagnetic energy with wavelengths ranging from 1 mm to 1 m in the electromagnetic spectrum, with frequencies between 300 Mhz and 300 GHz, and which can be used for drying with radiation. Waves with a frequency of 2450 MHz are used in microwave ovens for drying. Microwaves dryer works with the logic of converting electromagnetic energy into thermal energy by penetrating polar molecules in the

* İlgili yazar/Corresponding author: feyzaakarslan@sdu.edu.tr

product. In this way, while maintaining the quality of the product, low cost and energy values are obtained [2]. Microwave drying systems can be operated at desired powers using control units. They pollute their environment to a minimum. Microwave systems operate faster and are more energy efficient than traditional methods. The obtained product quality is high and they can be operated in combination with other systems.

Microwave is an electromagnetic energy that is formed as a result of the intersection of vertical electrical and magnetic fields. Polar molecules in the material to be exposed to microwaves are normally arranged randomly in the material, but when they are exposed to electricity, they change their positions and line up in parallel. The constantly changing sinusoidal motion of the microwave causes the molecules to change their positions continuously. The energy generated as a result of this movement causes these materials to heat up. Another mechanism that causes heating, but not as effective as dipolar rotation, is ionic polarization. In this mechanism, the ions carrying the electric charge accelerate when they are exposed to the electric field. The kinetic energy received by the electric field is converted into heat when they collide with other ions, causing the material to heat up frequency and wavelength vary inversely [3]. As the wavelength increases, the penetration ability of the microwave increases, but in this case, the energy of the wave decreases. The energy of the microwave is inversely proportional to its penetration ability.

Microwave drying; Although it produces heat both inside and on the surface, other drying methods apply heat only to the surface. In a study conducted to determine the energy consumption of drying methods [4], the energy consumption of hot air drying, infrared drying, microwave drying and vacuum drying methods has been examined. In addition to these drying methods, another experiment was conducted in which microwave drying method was used as a pre-drying method before the hot air drying method. According to the results of the drying studies, it was seen that the highest energy consumption was obtained in the vacuum drying method, and the lowest energy consumption was obtained in the microwave drying method. It has been determined that the drying time and energy consumption in the drying studies in which microwave drying is applied as pre-drying are less than the drying time and energy consumption of the drying studies using only hot air. It is observed that the drying time and total energy consumption decrease with the increase in the temperature used in vacuum drying studies. It has been determined that the increase in air speed used in infrared drying studies increases energy consumption. As a result, considering the energy consumption, it was determined that the best drying method was the hot air drying method with microwave pre-drying.

The nonlinear system is linearized into different operating points. Then, linear models corresponding to every operating point are established. The fuzzy model is described by a family of fuzzy IF-THEN rules where each one represents a linear input-output relation of the system. The global fuzzy model of the studied dryer was achieved by smoothly blending these linear models together through the fuzzy membership functions in order to give the overall nonlinear behavior of the dryer [5-6].

Fuzzy logic control is used to increase the energy efficiency of the washing machine and the cleaning behavior of the washing process. Matlab software was used for simulation. The mass of the material and the pollution level were selected as the input variables, and the engine speed was chosen as the output variable for washing the material. The material and pollution level increased the speed of the engine [7-8]. In a study, the treatment of wastewater obtained from the cotton textile industry was carried out by electrocoagulation (EC) method. Simultaneous control of temperature, conductivity and pH was made using fuzzy control method to increase the efficiency of the treatment. MATLAB/Simulink program was used in control experiments. As a result, it has been revealed that the EC process is an effective method in the treatment of textile industry wastewater and the efficiency increases with the fuzzy control method [9]. There are not many studies on microwave drying in the textile field. This situation reveals the originality of this study. In one study, the usability of microwave energy in the fixation of reactive prints was investigated. It has been found that fixation with microwave energy is possible [10].

Microwaves can instantaneously heat any materials that respond to microwave radiation based on rapid polarization and depolarization of charged groups[11-12]. Due to the deep penetration and relatively rapid and uniform heat distribution, mainly in the wet part of the exposed product, microwave radiation, which has lower energy consumption, accelerates the drying process [13-14].

Recently, modern methods and technologies have found application in the textile industry [15-18]. Expert systems are among the leading techniques [19-21]. With fuzzy logic, which is the basis of expert systems, machines are given the ability to work with the help of mathematical modeling created depending on each rule created by processing people's experiences and data [22-24]. Therefore, its main use is in system control

[25-29]. With these systems, energy consumption is reduced without sacrificing product quality [30].
In this study, fuzzy modeling of a microwave dryer was developed. This method has never been explored for microwave dryers. Microwave dryer is considered as a non-linear dryer. When the studies in the literature were examined, no study was found in which artificial intelligence method was used in the drying process of cotton woven fabrics in microwave dryers. The proposed fuzzy model is used to estimate the drying rate for different electrical powers and different drying times. Different experimental measurements were used to evaluate the reliability of this model. Compared to other modeling techniques, thanks to simulation, the fuzzy model of the dryer provides an immediate estimation of the drying rate. The behavior predicted by the fuzzy model confirms the suitability of the defined model.

2. Material and Method

Fabric products with dimensions of 20 x 20 cm were used as material in the drying process. The properties of 100% cotton woven fabrics used in the scope of the study are given in Table 1.

Table 1. Properties of cotton fabric

Fabric properties	Density	Yarn count (Nm)	Weight (g/m2)	Weaving type
Weft	13	20	230	D 1/3 S
Warp	20	34		

In the experimental studies, a domestic digital microwave oven (Arçelik MD 595) was used as a microwave dryer. The technical specifications of the microwave oven are 50 Hz, 230 V and 2650 W. Five different microwave power outlets were used to dry the fabric samples and three repetitions were performed at each of these power outlets.

Fabric samples were first kept in laboratory conditions for 24 hours (65% humidity, 20±2ºC) for conditioning. The conditioned fabric samples were weighed with a precision balance of 1/1000 sensitivity at ambient humidity (49-50%) measured with a hygrometer, and their weight in ambient humidity was determined. After that, the samples were wetted with distilled water so that the entire surface was moistened equally, and the water was rendered non-drip (pre-drying) and weighed again to determine their total moist weight. Meanwhile, the dryer was brought to the temperature conditions predicted for the experiment and set to the desired regime.

2.1.Fuzzy Logic

Almost all of the events that human beings encounter in the World is complex. This complexity generally arises from uncertainty, certainty, or inability to make a decision. People have the ability to operate with approximate and uncertain data and information. The concept of fuzzy logic is a logic system that overlaps with people's ability to think in imprecise terms. In other words, fuzzy logic compares the sharp world consisting of binary variables such as cold-hot, fast-slow, high-low to the real world with flexible qualifiers such as less cold-less hot, less fast-little slow, less high-little low.

2.2 Membership Functions and Fuzzification

A membership function is created for each selected fuzzy set. The membership function is a typical curve that translates the numeric value of the input in the range 0 to 1. This step is "blurring". Membership function can take various forms such as triangle, trapezoid and Gaussian. The triangle membership function is the simplest.

2.3. Fuzzy Rules

Fuzzy rules provide quantitative reasoning that relates input variables to output variables. A fuzzy rule base consists of a set of fuzzy if-then rules. For example, in the case of a three-input and single-output fuzzy system, the rule can be written as follows.

If A is low and B is medium then C is high

where A, B and C are variables representing two inputs and one output; low, medium and high are the fuzzy sets of A, B and C, respectively.

2.4. Defuzzification

The output of each rule is a fuzzy set. Output fuzzy sets are aggregated into a single fuzzy set. Finally, the resulting set is resolved by 'blurring' to a single exact number. There are various defuzzification methods such as center, center of gravity, average of maximums.

3. Findings

The fuzzy logic tables created in this study were described using the MATLAB program, and the resulting data were examined. With the fuzzy logic module of the MATLAB program, the Mamdani model with two inputs and one output has been established. In this model, the method of obtaining the results with the center of gravity method is based. The fuzzy logic method used in solving the problem is given in Figure 1.

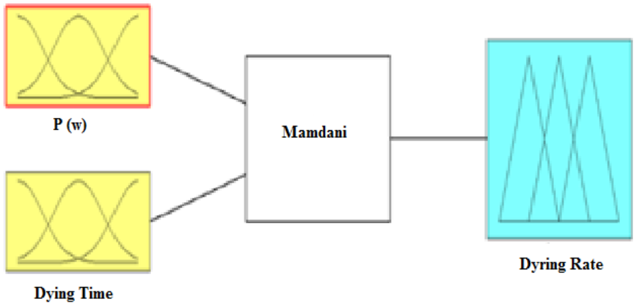

Figure 1. Structure of microwave dryer fuzzy system

Input P(W) to the first of the membership function sets. As seen in Figure 2 below, the values are processed into the fuzzy logic module of the MATLAB program.

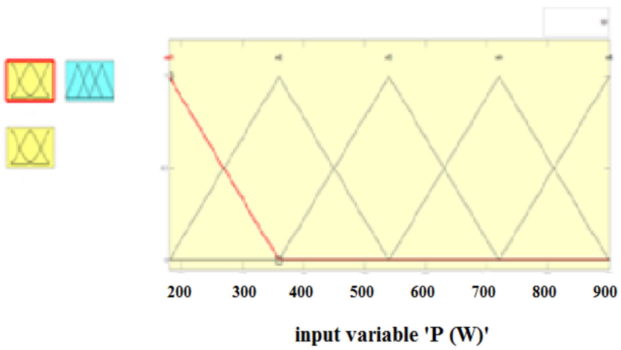

Figure 2. Membership functions of the first input set, P(W).

The second of the Input Membership function sets is drying time. As seen in Figure 3 below, the values are processed into the fuzzy logic module of the MATLAB program.

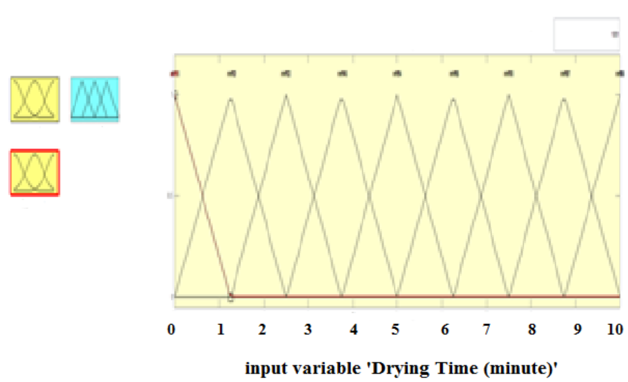

Figure 3. Drying time membership functions, which is the second set of inputs

Output the drying rate is given as a set of membership functions in Figure 4, the values are processed into the MATLAB program fuzzy logic module. Fuzzy rules, which are the heart of the fuzzy expert system, determine the input-output relationship of the model. 90 self-explanatory fuzzy rules are prepared in matrix form.

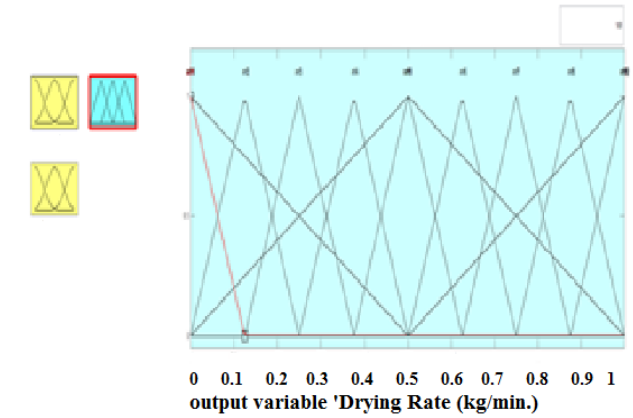

Figure 4. Drying rate membership functions with output set.

Fuzzy rules, which are the heart of the fuzzy expert system, determine the input-output relationship of the model. 90 self-explanatory fuzzy rules are prepared in matrix form. The rule table created between the input and output function sets is given in figure 5. Membership functions are entered in the MATLAB fuzzy logic editor. The values of the membership function are also entered in the rule editor. During the creation of the results, the centroid method was chosen as the blurring.

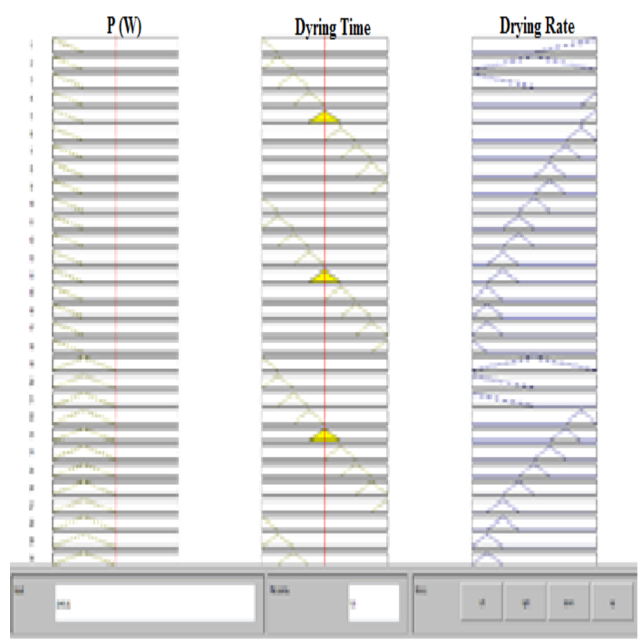

Figure 5. Rule table

In the study, the trimf method was chosen as the membership function type used in the input and output sets. Thus, the geometric shape, the triangle shape, was obtained. In this way, approximate values are obtained within the framework of fuzzy logic rules. A total of ninety fuzzy rules were created and used for the output graphs.

After the membership functions are entered in the MATLAB fuzzy logic editor, the values of the membership function are also entered in the rule editor. After the rule entries were completed, the results were monitored with the rule viewer. During the creation of the results, the center of gravity method was chosen as the defuzzyfication. After processing all the data, the system was described with the MATLAB program.

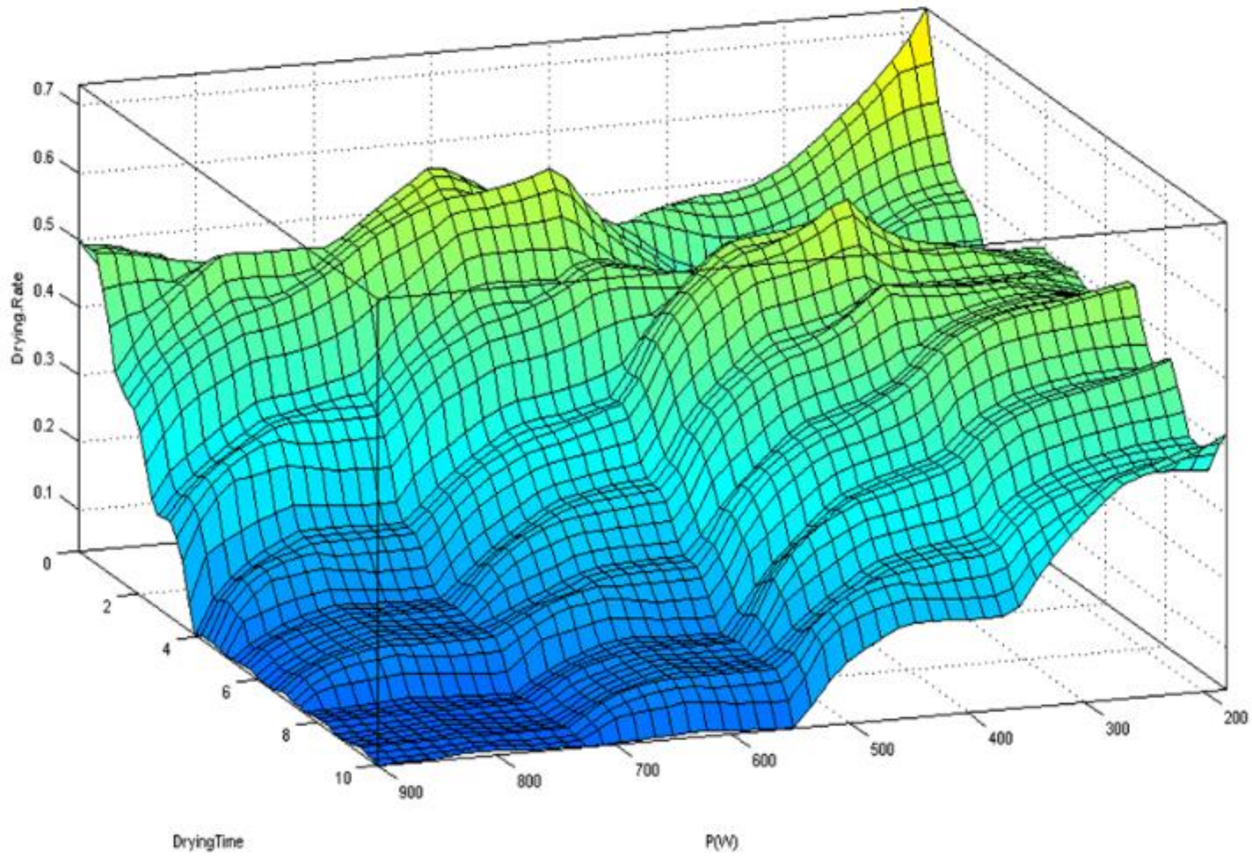

Figure 6. The result function obtained with the MATLAB program

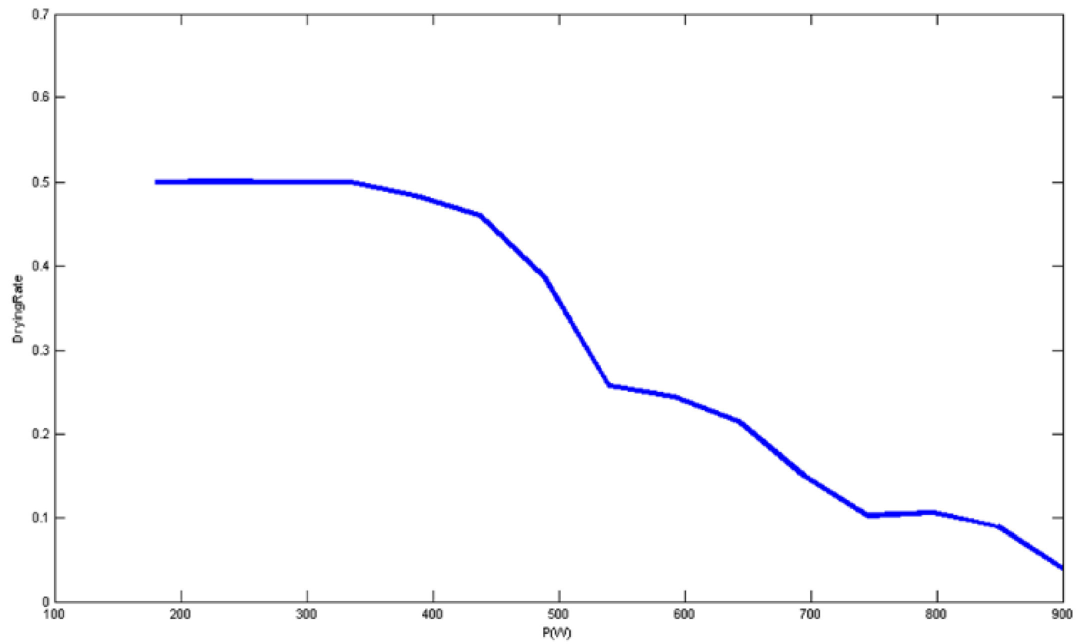

Figure 7. Drying rate- electrical power Graph

As seen in the figure 6, while low electrical power performed faster drying, drying time is longer when electrical power decreases. In the graphic, all intermediate value variaitons are also seen.

As seen in the Figure 7, drying rate is directly related to the electrical power. While the electrical power is at 200 W, the drying speed is 0.5 kg/min, while it does not change much up to 400 W, it quickly drops to 0.3 kg/min after 500 W. At 700 W, it drops to 0.1 kg/min.

In this study using fuzzy logic, while drying rates increases. electrical power and drying time decreases, Also loading electrical increase is found to correlate with decline in drying rate.

This study will provide drying runs under demanded conditions and help determining machine parameters for a given product providing time and energy saving. Thus, observation of behaviours to a given product would serve developing better approaches in product optimization. In this study, all intermediate value variations are also seen.

4. Results and Discussion

In this study, fuzzy logic is applied on microwave dryer system. This method has never been explored for microwave dryers. For the analysis, electrical power and drying time are evaluated as input parameters, whereas moisture variation depend on drying time (drying rates) is being the output parameters. Microwave dryer is considered as a non-linear dryer. When the studies in the literature were examined, no study was found in which artificial intelligence method was used in the drying process of cotton woven fabrics in microwave dryers.

In fuzzy logic analysis, Mamdani expression system is used and the center of gravity method is applied during defuzzyfication. Experimental data in such an analysis, can be processed in a wanted convergence and easily inserted into rule base. Ninety rules were created by using experimental data and the effect of input parameters (electric power and drying time) on output parameter (drying speed) was investigated. While low electrical power performed faster drying, drying time is longer when electrical power decreases. Drying rate is directly related to the electrical power. While the electrical power is at 200 W, the drying speed is 0.5 kg/min, while it does not change much up to 400 W, it quickly drops to 0.3 kg/min after 500 W. At 700 W, it drops to 0.1 kg/min. Accordingly, reduction of moisture with the increase of electrical power and drying time were detected.

In this study using fuzzy logic, while drying rates increases. electrical power and drying time decreases, Also electrical power increase is found to correlate with decline in drying rate. This study will provide drying rates under demanded conditions and help determining machine parameters for a given product providing time and energy saving. Thus, observation of behaviours to a given product would serve developing better approaches in product optimization. Obtained fuzzy logic results and experimental data were found to be very close in comparison. The obtained results would be used as reterence data in future studies. In future studies, neural network or neuro fuzzy system applications can be studied on different fabric types with different dryers.

References

[1] Haghi AK, Amanifard N. Analysis of Heat and Mass Transfer During Microwave Drying of Food Products. *Brazilian Journal of Chemical Engineering*, 25 (3), 491-501, 2008.

[2] Uysal B, Özkal, SG. Limon Kabuklarının Sıcak Hava, Mikrodalga ve Sıcak Hava-Mikrodalga Kombinasyonu ile Kurutulması, *Journal of the Institute of Science and Technology*, 12 (4) , 2223-2236, 2022.

[3] Coruk KS, Baltacıoğlu H. Determination of the Effect of Different Drying Methods on the Physicochemical Properties of Potato Powder Using Multivariate Analysis. *Turkish Journal of Agriculture-Food Science and Technology*, 10(7), 1300-1307, 2022.

[4] Motevali A, Minaei S, Khoshtagaza MH. Evaluation of Energy Consumption in Different Drying Methods, *Energy Conversion and Management*, 1192 – 1199, 2011.

[5] Zoukit A, El Ferouali H, Salhi I, Doubabi S, Abdenouri N. Fuzzy modeling of a hybrid solar dryer: experimental validation. *Journal of Energy Systems*, 3(1), 1-12, 2019.

[6] Zoukit A, El Ferouali H, Salhi I, Doubabi S, Abdenouri N. Takagi Sugeno fuzzy modeling applied to an indirect solar dryer operated in both natural and forced convection. *Renewable Energy*, 133, 849-860, 2019.

[7] Azhari Asyauqi MF, Apriaskar E, Djuniadi D. Simulasi Sistem Pencuci Bahan Tekstil Berbasis Logika Fuzzy, *JTE UNIBA (Jurnal Teknik Elektro Uniba),* 5 (2), 109-113, 2021.

[8] Hosseinpou S, Martynenko A. Application of fuzzy logic in drying: A review. *Drying Technology*, 40(5), 797-826, 2022.

[9] Altınten A, Demirci Y, Pekel LC, Alpbaz M. Elektrokoagülasyon Reaktöründe Bulanık Kontrol Metodu ile Ph, İletkenlik ve Sıcaklığın Eş Zamanlı Kontrolü. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 31 (4), 987-996, 2016.

[10] Özerdem A, Tarakçıoğlu I, Özgüney A. Mikrodalga Enerjisinin Reaktif Baskılı Pamuklu Kumaşların Fiksajında Kullanılabilirliği, *Tekstil ve Konfeksiyon*, 4, 289-296, 2008.

[11] Chen L, Wang L, Wu X, et al. A process-level water conservation and pollution control performance evaluation tool of cleaner production technology in textile industry. *J Cleaner Prod.,* 143, 1137–1143, 2017.

[12] Oktav Bulut M, and Sana NH. Modification of woolen fabric with plasma for a sustainable production. *Fibers Polym.,* 19, 1887–1897, 2018.

[13] Rattanadecho P and Makul N. Microwave-assisted drying: a review of the state-of-the-art. *Drying Technol*., 34, 1–38. 2016.

[14] Katovic D, Vukusic SB, Grgac SF, et al. The effect of microwave drying on warp sizing. *Text. Res. Journal*, 78, 353–360, 2008.

[15] Hosseinpour, S, & Martynenko, A. Application of fuzzy logic in drying: A review. *Drying Technology*, 40(5), 797-826, 2022.

[16] Arief M, Nugroho F, et al. Analysis of Maizena Drying System Using Temperature Control Based Fuzzy Logic Method. *AIP Conference Proceedings; AIP Publishing*, 1941(1), 020005, March 2018.

[17] Heriansyah H, Istiqphara I, Adliani N. Optimization of Herbal Dryer System Based on Smart Fuzzy and Internet of Thing (IOT). *Int. J. Eng. Sci. Appl.,* 6, 104–110, 2019.

[18] Nadian H, Abbaspour-Fard H, Martynenko A, Golzarian R. An Intelligent Integrated Control of Hybrid Hot Air-Infrared Dryer Based on Fuzzy Logic and Computer Vision System. *Comput. Electron. Agric.*,137, 138–149, 2017.

[19] Sourveloudis C, Kiralakis L. Rotary Drying of Olive Stones: Fuzzy Modeling and Control. *WSEASTrans. Syst.*,4, 2361–2368, 2005.

[20] Dayık M, Kodaloğlu M. Kondisyonlama Şartlarının İplik Rutubetine Etkisinin Yapay Zekâ Yardımıyla Tespiti. *Tekstil Teknolojileri Elektronik Dergisi*, 2, 25-32, 2007.

[21] Kodaloğlu M, & Kodaloğlu, F. A. Evaluation of Thermal Comfort in Terms of Occupational Safety in Weavıng Facilities By Fuzzy Logic. International *Journal of 3D Printing Technologies and Digital Industry*, 6(2), 273-279, 2022.

[22] Atthajariyakul S, Leephakpreeda, T. Fluidized Bed Paddy Drying in Optimal Conditions via Adaptive Fuzzy Logic Control. *J. Food Eng*., 75, 104–114, 2006.

[23] Khodabakhsh Aghdam, H, et al. Modeling for Drying Kinetics of Papaya Fruit Using Fuzzy Logic Table Look-up Scheme. *Int. Food Res. J.,* 22, 1234–1239, 2015.

[24] Bagheri N, Nazilla T, Javadikia, H. Developmentand Evaluation of an Adaptive Neuro FuzzyInterface Models to Predict Performance of a Solar Dryer. *Agric. Eng. Int. CIGR J.,* 17, 112–121, 2015.

[25] Jafari M, Ganje M, Dehnad D. Ghanbari, V.Mathematical, Fuzzy Logic and Artificial Neural Network Modeling Techniques to Predict Drying Kinetics of Onion. *J. Food Process*, 40, 329–339. 2016.

[26] Abdenouri N, Zoukit A, Salhi I, Doubabi S. Model identification and fuzzy control of the temperature inside an active hybrid solar indirect dryer. *Solar Energy*, 231, 328-342, 2022.

[27] Kayacan C, Dayık M, Çolak O, Kodaloglu M. Velocity Control of Weft Insertion on Air Jet Looms by Fuzzy Logic, *Fibres & Textiles in Eastern Europe*, Vol.12, No. 3(47), 29-33, 2004.

[28] Bayhan M, Kodaloğlu M, Cengiz Y, Kaplan S. Drum ve Loop Sistemlerinde Atkı Hareketinin Dinamik

Modellenmesi ve Hızın Bulanık Mantıkla Kontrolü, *Tekstil Maraton Dergisi,* 63-69, Mart / Nisan 2002.
[29] Kodaloğlu M, Dayık M, Çolak O, Kaplan S. Hava Jetli Dokumada İplik Tipinin Atkı Hızına Etkisinin Bulanık Mantıkla Tespiti, *Tekstil Maraton Dergisi*, 56-61, Mayıs / Haziran 2002.
[30] Júnior MP, et al. Energy savings in a rotary dryer due to a fuzzy multivariable control application. *Drying Technology*, 40(6), 1196-1209, 2022.