WOOL DRYING PROCESS IN HEAT-PUMP-ASSISTED DRYER BY FUZZY LOGIC MODELLING

by

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The drying process in the textile industry is an expensive and laborious process that requires a lot of energy. The main purpose of the drying process is to provide maximum energy saving and energy efficiency at minimum time and cost without compromising the quality and structural properties of the material used. Since heat pumps are devices that can produce more heat compared to the work they consume, energy consumption substantially reduce is important. In drying processes, which are widely used in agriculture and textile industry in our country. It is important to use a heat pump in terms of energy saving. In this study, wool drying process in a heat-pump-assisted dryer was investigated with fuzzy logic metods. The test material used was wet wool, which is a fibrous material. The air velocities at the inlet of the dryer were varied from 0.8 m/s to 1.5 m/s, while the material loading ratio (material/dryer volume) ranged from 0.5 to 2.5. The temperature at the inlet of the dryer were varied from 40 °C to 90 °C. In this study, a fuzzy model was created to determine the effect of time, temperature, loading ratio and air velocity on the drying rate by using the fuzzy logic method, which is one of the artificial intelligence methods.

Key words: *wool fibres, drying, fuzzy logic, heat-pump-assisted dryer*

Introduction

Drying is used to describe a process that involves removing the desired amount of moisture from any material. Removal of moisture from the material is done in different ways and methods. Factors such as the type of the product, its structure, ambient conditions, the quality and speed of the air are effective in the drying technique [1].

Numerous theoretical and experimental studies have been conducted on the drying mechanism. During the drying process, the product must be continuously heated. Depending on the heat transfer method, the following classification can be made in drying with heat energy. These are convection drying, heat conduction drying, and irradiation drying. Convection drying method is the most used one for drying textile products [2, 3].

Convection drying is done in a stream of hot air. The hot air used must be dry in order to absorb moisture. The temperature of the dry air can be increased depending on the type

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of dryer and the rate of passage in the dryer (like 60-100 °C). The main thing in all drying methods is to take the moisture in the material to be dried and bring it to the desired level.

During drying, the phenomenon of *heat transfer* from the hot gas to the evaporating liquid from the solid body and from the inner parts of the solid to the outer surface, as liquid or vapor. On the other hand, from the outer surface into the hot gas, only the *mass transfer* processes take place as steam [4]. The conditions that determine these processes are also the conditions that determine the drying process. These can be examined in two parts formed during the coming of the liquid in the solid to the solid surface: internal conditions such as internal diffusion, capillarity and hot gas used as a desiccant, and external conditions such as flow rate, temperature, and humidity [5].

Humidity rate is a matter directly related to the drying event. Although it is usually possible to carry out the complete dehumidification or drying process, that is, the removal of moisture from a substance, sometimes the dried substance may be damaged at the end of this process [6-10]. All hygroscopic materials, which are exposed to the effect of the atmosphere, continue to absorb moisture depending on the relative humidity of the atmosphere in which they are in contact with the substance. Conversely, wet or moist substances exposed to the atmosphere for a long enough time dry out and lose their moisture.

The amount of moisture present in a substance can be expressed either on the basis of wet weight or on the basis of dry weight. Humidity, M_{wb}, on a wet basis, is the amount of moisture present per unit weight of moist matter.

$$M_{\mathrm{wb}} = \frac{W_o - W_k}{W_o} \tag{1}$$

Humidity on a dry basis, M_{db}, is the amount of moisture present per unit weight of dry matter:

$$M_{\mathrm{db}} = \frac{W_o - W_k}{W_k} \tag{2}$$

where W_o is the weight of moist substance and W_k – the dry weight of the substance.

In the literature studies on drying of fibers, when an external force is applied to the fibers, moisture can be reduced more easily as a result of the growth that occurs in the case of compression in the fibers. Moisture in the trapped fibers moves from this trapped state in the direction where they encounter the least resistance, namely the roots. The fibers, which begin to knot under the influence of the moisture in the roots, begin to feel felt because they cannot return to their former state. For this reason, it has been determined that the drying method of the fibers is of great importance in preventing the felting of the product [11].

There are regions where the fibers in the textile product are mixed, as well as regions where they are less dense. When conditioning process is applied to the product, the fibers between the dense regions in the direction of the flake layers approach each other and felting occurs by connecting them with the bonds between them. As a result of a study, he stated the importance of moisture balance between the fibers in the drying of the fibers [12].

The heat pump drying system generally consists of two parts, the heat pump unit and the dryer unit. Heat pump and dryer models developed separately are combined. Figure 1 shows the heat pump dryer model [13, 14]. The conditions of the dryer outlet air are considered as the conditions of the air entering the heat pump. The outlet conditions of the heat pump unit are considered as the conditions of the inlet air of the dryer. This provides the possibility to change dryer or heat pump models without changing the main design. In the model, all conditions of air and refrigerant. It can be found from the mass and energy balances depending on the fresh air intake [15, 16]. In the study conducted by Storslett [17], experimental analysis of R134a and R290 refrigerants in heat pump tumble dryers was made. A heat pump product containing 220 g R134a refrigerant was chosen as the reference product. Cooling COP, specific dehumidification rate (SMER), and dehumidification rates (MER), were compared with the reference. The effects of different refrigerant types and refrigerant amounts on COP, SMER, and MER values were investigated.

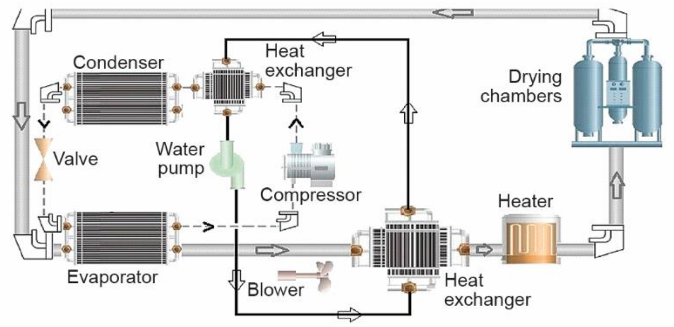

Figure 1. Schematic view of heat pump dryer

Wool fibers are the type of fiber that absorbs the most moisture. Wool fibers can absorb moisture up to half their own weight. In this respect, the amount of moisture that the wool will contain commercially has been determined as percentage. This rate is between 16-18%. By penetrating the intermicelle regions of wool fibers, water molecules lead to an increase of 25%, especially in the cross-sections of the fibers. Since water breaks various bonds between macromolecules, especially at high temperatures, wool fibers that are treated with water vapor at temperatures above 100 °C under pressure for a long time can be damaged [18]. Therefore, special attention should be paid to the drying process of woolen products. Because, in animal fiber materials such as wool, if the crystallized water contained in the fiber is lost through the drying process, the properties of the fiber deteriorate and problems such as felting occur.

In the textile sector, besides the classical drying studies, modern methods have recently started to be applied. Chief among these are expert systems. In the literature studies, the Taguchi optimization method was used, the experimental and theoretical results were matched with the simulation program and the results were shown to be compatible [19-21]. Fuzzy logic is the basis of expert systems. The most important feature of fuzzy logic is that it allows mathematical modeling of systems in which people reason based on common sense or systems that benefit from expert knowledge. It is mostly used in system control applications. In addition, it is a more practical method than the use of experimental methods in terms of time and energy savings.

The most important function in the drying process is the control of the parameters affecting the drying (moisture change). From this point of view, the most suitable intelligent method for the control of the drying process of textile products is the fuzzy logic method.

Fuzzy logic has recently found widespread use in many branches to show confusion and uncertainties. The increase in research in this field in recent years is due to the fact that fuzzy logic is much stronger than standard logic in certain subjects. Fuzzy logic, very different from standard logic, is used in situations where the problem cannot be fully described, information about the problem is insufficient or unclear, and it gives very successful results. In addition, fuzzy logic is used in the modeling of systems that are difficult to model in any way. What is meant here as system modeling is rather the modeling of nonlinear complex systems.

In this study, the variation of the moisture amount, W, calculated according to the dry mass of the fibers, depending on drying time, t, air velocity, V, loading ratio, P, and temperature, T, using the results obtained by experimental drying of the wool fiber, was investigated using fuzzy logic.

Fuzzy logic

After the fuzzy logic theory was introduced with the classic article published by Zadeh [22]. Instead of Aristotelian logic, which has only two possibilities, fuzzy logic and its related applications have started to take their place in the literature.

The real world is complex. This complexity generally arises from uncertainty, definite thinking and inability to make decisions. In this case, a real event is interpreted approximately in the human thought system and mind. Unlike the Aristotelian logic used by computers. Humans have the ability to operate with data and information containing approximation and uncertainty. The concept of fuzzy logic is imprecise approximate criteria rather than random variables. Zadeh [22] intensified his studies on fuzzy logic, observing that the key elements in human thought are not numbers but the levels of fuzzy sets. Although it was not very popular in the first years, fuzzy-based applications have become quite common in recent years. So much so that it is possible to find an application example in almost every field from social sciences to engineering applications. The area where fuzzy logic finds the most application is seen as control systems. The reason for this was that Mamdani *et al.* [23] designed and implemented a fuzzy logic-based controller in the early 1970's.

Controllers controlled by fuzzy logic work just like a human being using that machine by observing the working conditions at the machine. Therefore, they adjust the system input by looking at the system output, just like a master operator. Here, temperature, air velocity, amount of substance and time are sent to the fuzzy controller as input signals [24, 25].

A fuzzy logic-based controller generally consists of three parts. These are respectively, fuzzifier, rule assignment table, and defuzzifier. Two input signals (time, air velocity, fill rate, and temperature) sent to the fuzzy controller and having real values are converted into fuzzy numbers by the fuzzifier in the first step. Then, these fuzzy numbers are used by the rule assignment table to determine the fuzzy number representing the change in the control signal, and a number is obtained as a result of the fuzzy decision making process. In the last step, the fuzzy number representing the change in the control sign is converted to a real number by the defuzzifier, and a new control sign is determined by adding it to the previous value of the control sign [26, 27].

During the clarification and application of the rules, fuzzy variables were represented verbally by using many fuzzy sets in each fuzzy number group. These verbal variables were defined between very little and very much. Fuzzy rules are the basic elements of the unit where fuzzy operations are made and fuzzy decisions are made. These fuzzy rules enable to reach new fuzzy results from the fuzzy data at hand. The actual values of time, air velocity, filling rate, temperature and humidity obtained at any sampling time are converted into fuzzy numbers depending on their membership degrees in fuzzy sets. The conversion is done by the blurrier. Air velocity, time filling rate, temperature are expressed in verbal terms represented by the cluster or clusters in which fuzzy set has a membership degree other than zero.

Rules are expressed verbally in the form of:

IF Temperature ≡ Mf1 and Air Velocity ≡ Mf1 AND Loading Ratio ≡
≡ Mf1 and Dring time ≡ Mf1 THEN Moisture ≡ Mf13

This is just a rule. If there is more than one rule, they are connected to each other with ELSE or ELSE IF terms. As can be understood from the verbal expressions above, each rule defines the fuzzy relationship between the fuzzy set intersections representing temperature, air velocity, amount of matter and time, and the fuzzy set representing humidity change [28].

Detection of drying parameters with fuzzy logic

During time, *t*, air velocity, *V*, loading ratio, *M*, temperature, *T*, input variables and moisture, *W*, are selected as output parameters, which play an important role in solving the relationship between drying parameters with fuzzy logic. The fuzzy logic model created in the solution of the problem is given in fig. 2.

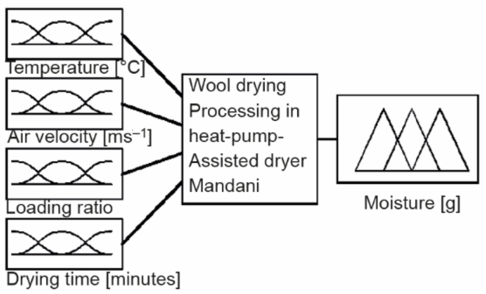

Figure 2. Constructed fuzzy logic model

The membership function numbers and foot widths of the temperature, air velocity, substance amount, time and humidity variables, which are effective in determining the drying rate, were determined by using the data obtained from the experimental studies and the opinions of the experts. Here, the input membership functions, which act as the input parameter to the problem, are selected in intervals of twenty feet, air velocity five, matter quantity five, and temperature five feet. The amount of moisture, which is our output function, is determined in the range of thirty feet. Two thousand five hundred rules were created in order to understand the effect of the relationship between the determined membership functions on the result. The 3-D graphics of the results obtained according to the created rule base are shown below.

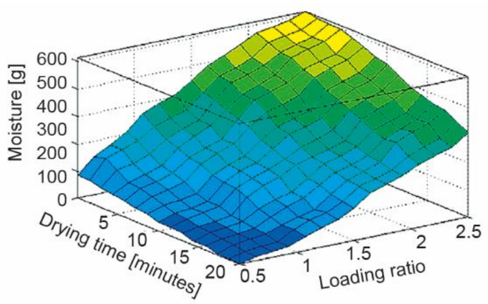

Figure 3. With drying time and mass variation of result function

In determination of drying rates (removal of moisture depend on drying time), active parameters which are temperature, air velocity, loading ratio, membership functions of time and moisture variables, and foot ranges are set using expert data and experimental data. They had chosen the air velocity as membership functions five intervals, loading ratio as membership functions five intervals, the variation of temperature as membership functions five intervals and also a last function the drying time as membership functions twenty intervals and the removal of moisture are examined at thirty intervals. As a result 2500 rule bases has been occurred in order to understand their effects by determining the relations between the membership functions as shown at 3-D graphics (Mamdani methods) in fig. 3.

As seen from fig. 3, while low loading ratio performed faster drying, time period is longer when mass increases. In the graphic, all intermediate value variaitons are also seen. In fig. 3, it is seen that as the air velocity increases, the humidity in the material decreases rapidly after a certain fixed period and decreases with the increase in air temperature. Moisture changes in all intermediate values can be easily seen from this graph. Moisture-drying time graph for load ratio for different temperatures (40 ºC, 60 ºC, and 90 ºC) is given in figs. 4-6.

Figures 4-6, which moisture variation as a function of drying time, is directly related to the loading ratios, where e = experimental modelling, f = fuzzy modelling. Investigating these figures, shows that experimetal results and fuzzy results were found to be compatible.

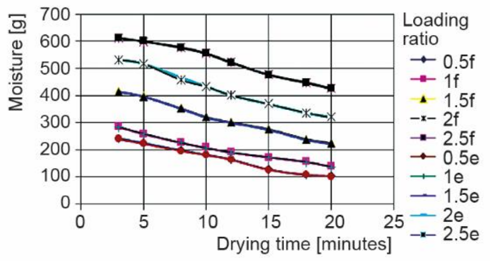

Figure 4. Moisture-drying time graph depend on loading ratio (e = experimental modelling, f = fuzzy modelling) (for air velocity *V* = 1.2 m/s, drying temperature *T* = 40 °C)

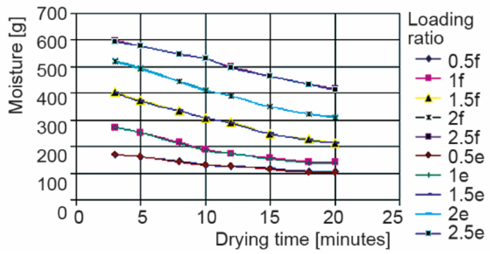

Figure 5. Moisture-drying time graph depend on loading ratio (e = experimental modelling, f = fuzzy modelling) (for air velocity *V* = 1.2 m/s, drying temperature *T* = 60 °C) drying temperature

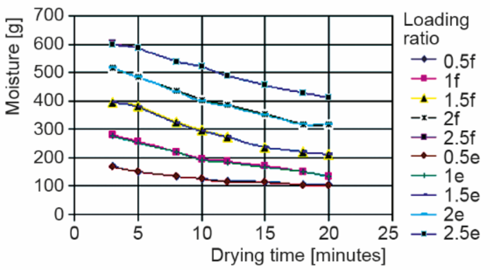

Figure 6. Moisture-drying time graph depend on loading ratio (e = experimental modelling, f = fuzzy modelling) (for air velocity *V* = 1.2 m/s, drying temperature *T* = 90 °C)

In this study using fuzzy logic, decreasing in air velocity, temperature, and drying time, moisture is determined, while drying rates increases. Also loading ratio increase is found to correlate with decline in drying velocity. Resolved data available for experimental studies were provided.

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 behaviors to a given product would serve developing better approaches in product optimization. In this study, all intermediate value variations are also seen.

Conclusions

In this study, fuzzy logic is applied on wool drying process in a heat pump assisted dryer system. For the analysis, temperature, air velocity, loading ratio and drying time are evaluated as input parameters, whereas moisture variation depend on drying time (drying rates) is being the output parameters.

In fuzzy logic analysis, Mamdani expression system is used and sentroid method is applied during defuzzyfication. Experimental data in such an analysis, can be processed in a wanted convergence and easily inserted into rule base. Experimental data obtained from the literature, 2500 rules were formed and effects of input parameters (temperature, air velocity, loading ratio and drying time) to output parameters (moisture variation or drying rates) are investigated. Accordingly, reduction of moisture with the increase of air velocity, temperature and drying time, also the increase of drying rates with reduction of the loading ratio were detected. In this study using fuzzy logic, decreasing in air velocity, temperature, and drying time, moisture is determined, while drying rates increases. Also loading ratio increase is found to correlate with decline in drying velocity. Resolved data available for experimental studies were provided. 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 behaviors to a given product would serve developing better approaches in product optimization. In this study, all intermediate value variations are also seen. Obtained fuzzy logic results and experimental data were found to be very close in comparison. Experimental and theoretical results were matched with the simulation program and the results were found to be compatible. The obtained results would be used as reterence data in future studies.

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