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Exergy analysis of porous cotton fabric drying process during the domestic air vented dryer

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This study reveals energy and exergy efficiencies of the fabric drying processes during air vented dryer. Exergy models of the drying processes have been formed and each stage is examined in terms of exergetic parameters. Additionally, parametric studies, including the exergy destruction rates, exergy efficiencies, and exergy loss ratios of the system and its components, have been investigated under various operating conditions. The results indicate that the exergy efficiency increases with the increase in drying rate. Heater of dryer is the highest exergy destruction component of the whole dryer and its power significantly affects exergy destruction of whole drying process; while fan and motor of driving drum are lower exergy destruction component of dryer. Use of staged heating model of adjusting heater power based on drying period is found to be an effective method to reduce the exergy destruction rate of dryer and fabric damage caused by over-drying. Specifically, exergy efficiency of dryer can be improved by increasing the heater power during the warm up and the constant rate period, or by decreasing the drying-power during the falling rate and the blow-air period. The findings are found to be useful to system design and performance optimization of domestic dryer in term of reducing irreversibility of the drying system.

Keywords: Cotton textile, Domestic dryer, Drying heater power, Exergy analysis, Moisture content, Textile drying

1 Introduction

Exergy refers to the maximum amount of useful work that can be obtained when the thermal system is brought to thermodynamic equilibrium with the specified environment[1-4]. Unlike energy, exergy is an efficient method to reflect the performance of thermal systems by considering the destruction directly caused by the property of an actual system and its specified environment as well as by the mass and energy balances[5]. Therefore, the exergy analysis can directly detect the inefficiencies and the work potential of a system, and the outputs of the analysis can be suitable for the location, cause and true magnitude of the sources destroyed, and the design and optimization of systems by decreasing the irreversibility[6,7].

Although the exergy analysis of various industrial processes of specific systems such as direct gas-heated (DGHS) & hot oil-heated (HOHS) stenters[8,9], food drying[10,11], reactive & pigment printing processes[12], conventional textile washing process[13], dyeing processes[14], and heat pump dryer[15-18] and the sector specific analyses of a whole country have been widely studied respectively, the studies on woven fabric drying process have not been reported due to lack of consideration on fabric deformation and an appropriate platform or system for effective experiment which can get useful data for analysis and to evaluate its exergy destruction rates, exergy efficiencies, exergy loss ratios of different periods, entire drying system and each component of dryer.

In fact, fabric drying is a continuous process, causing change in temperature and moisture of fabric and drying air with fabric deformation[19-22]. The whole drying process is divided into four stages based on the moisture removal rate. At the beginning of drying process (the warm-up period), the temperature rapidly increases towards the wet bulb temperature of air, while moisture content of textile remains constant. As the fabric is heated, the constant rate period starts. Air temperature remains at constant values, while moisture content of fabric experiences a rapid reduction. The moisture removal rate reaches a peak value in this period and evaporation only takes place at the surface of the fabric. In the next period, the moisture content of the material reduces to a level known as the critical moisture content, where the high rate of evaporation cannot be maintained. This suggests the beginning of the falling rate period. During the falling rate period, the moisture flow

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towards the surface is insufficient to maintain saturation at the surface. The surface of the fabric dries out, the surface temperature rises, and the moisture transport takes place only by diffusion. Thus, the moisture removal rate decreases in the falling rate period. Afterwards, the drying process enters the last period. Temperature of fabric decreases by stopping heating and blowing fresh air, while moisture content remains basically unchanged. In the light of the foregoing, it is clear that the moisture removal rate, energy consumption, temperature & humidity of drying air, and real-time weight of wet fabric differ in each stage of the drying process. Thus, in this study a detailed exergetic analysis of textile drying process has been investigated considering the variation of moisture removal rate, energy consumption, temperature & humidity of drying air, and real-time weight of wet fabric at each stage.

Also, textile drying is one of the most energy intensive unit operations, and any error in drying will result in great waste of energy as well as quality problems[23,24]. Therefore, in this study, exergy destruction and exergy efficiency of the entire drying system and its components (electric heating wire, fan and motor) have been investigated. Additionally, the impacts of the heater power, the relative humidity of exhaust air and the final moisture content of fabric on the exergy destructions and respective exergy efficiencies are evaluated by using actual operational data.

2 System Descriptions and Exergy Analysis

2.1 System Description

For a detailed exergetic analysis of the air vented dryers, the main components for the air vented dryers and the status of drying air and porous fabric during the whole drying process are presented in Fig. 1. As shown in Fig. 1 (a), the main components of the drying system are the electric heating wire, the circulating fans and the drying drum. Figure 1 (b) shows that the enthalpy-humidity variation of the

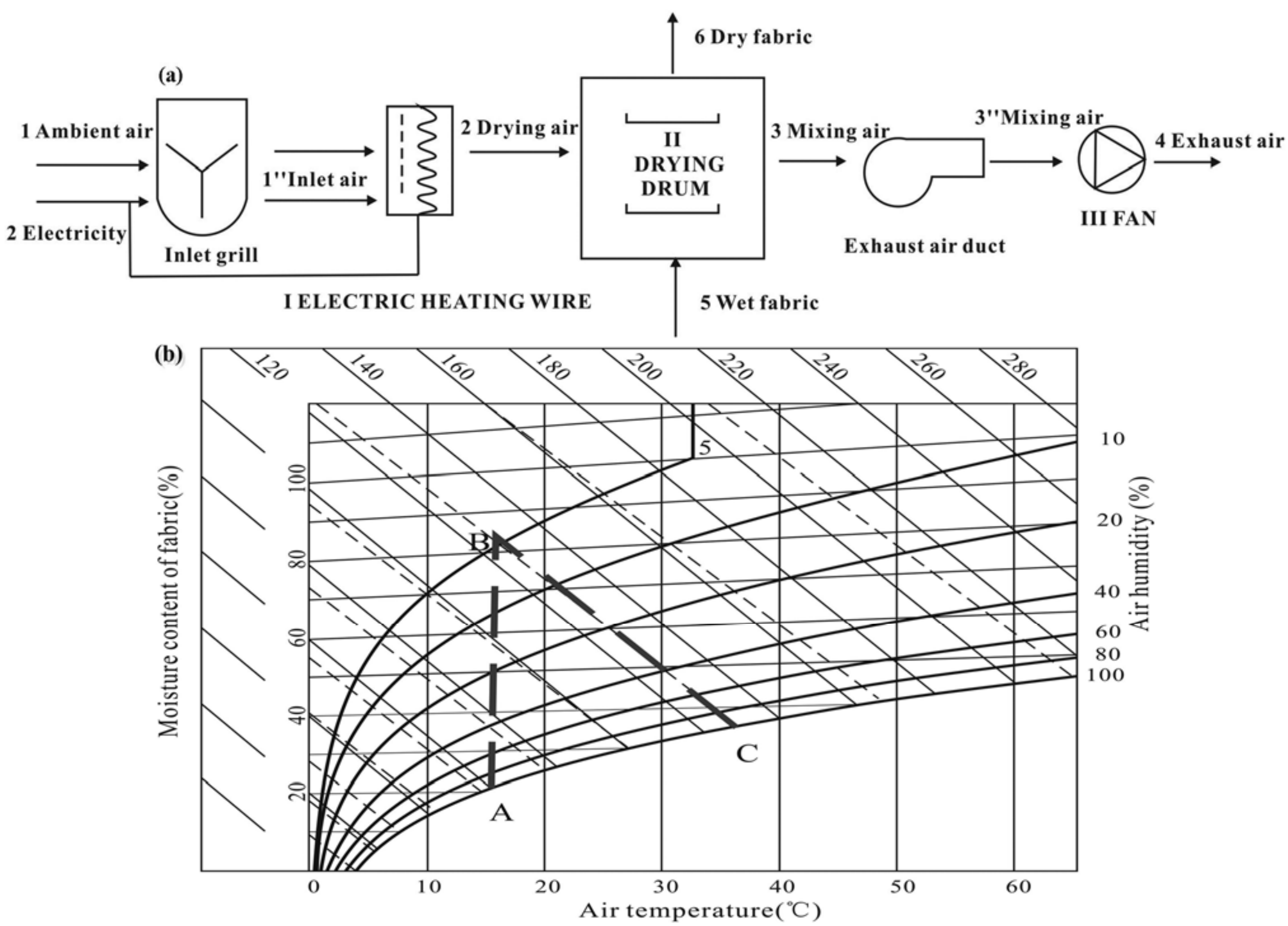

Fig. 1 — Analysis of fabric drying process (a) control volume for the air vented dryer and (b) the enthalpy humidity chart of ideal air path for the air vented dryer [A- inlet air, B- drying air and C- exhaust air]

ideal drying process can be separated into three main categories, viz the inlet air (A) with low temperature and humidity; the air enters by inlet grill of dryer and then is heated by the electric heating wire. The heating of the inlet air (A) is turned into the heated drying air (B) that has a higher temperature and the same constant specific humidity. The heated drying air (B) encounters the wet material in drying drum where it is humidified and cooled (ideally isenthalpic) to point C (exhaust air); its temperature remains close to the wet bulb temperature and the relative humidity close to ~100% for an ideal process. There is no connection between C and A as the air vented dryer is the open cycle dryer. In the light of foregoing, temperature, enthalpy, and specific & relative humidity of whole drying process is a continuous change process. Exergetic evaluations of the dryer are carried out based on the input and output data of each component. Therefore, a detailed exergetic analysis of textile drying process should be investigated considering the variation in each stage of the entire drying process and each component.

2.2 Exergy Analysis

As previously stated, throughout drying, the temperature & humidity of drying air, temperature & moisture content of porous fabric and moisture removal rate of drying process differ, depending on the drying period; the aforementioned factors are also the main factors of influencing exergy efficiency. Hence, the exergy analysis has to be performed for each drying period of the dryer individually using the control volume models. The following assumptions were made during this analysis:

(i) The test pure cotton is macroscopically homogeneous.
(ii) All processes are steady-state having steady flow with negligible kinetic and potential energy effects.
(iii) Heat transfer to the system and work transfer from the system are positive.
(iv) The ideal gas principles are applied to air and exhaust gases.
(v) There is no chemical reaction during the drying process.
(vi) The temperature, relative humidity (RH), and pressure of reference (dead) state are taken as the actual ambient conditions (20°± 2 °C, 55% RH, and 101.325 kPa).

In accordance with mass, energy, exergy conservation and the above assumptions, the following mass, energy and exergy balances equations for drying system can be obtained:

$$\sum \dot{M}_i = \sum \dot{M}_o \qquad \ldots (1)$$

$$\sum \dot{E}_i = \sum \dot{E}_o \qquad \ldots (2)$$

$$\sum \dot{E}_{xi} = \sum \dot{E}_{xo} + \dot{E}_D \qquad \ldots (3)$$

where $\dot{M}$, $\dot{E}_X$ and $\dot{E}$ are the corresponding mass flow rate, energy flow rate and exergy rates with heat and work respectively. The subscripts i, o and D refer to quantities at inlet, outlet and destruction through the process boundary respectively. The specific flow exergy (ex) is evaluated as:

$$\mathrm{ex} = (h - h_0) - T_0(s - s_0) \qquad \ldots (4)$$

where h is the specific enthalpy; s, the specific entropy; and T, the temperature. The subscript zero indicates properties at the reference (dead) state. The exergy rate is expressed as:

$$\dot{\mathrm{E}}\mathrm{x} = \dot{m} \cdot \mathrm{ex} \qquad \ldots (5)$$

where $\dot{m}$ is the mass flow rate; and ex, the specific exergy.

Considering dry air and water vapour as an ideal gas[22], and combining it with the thermodynamic theory, we developed the following relation for the specific physical exergy of the moisture air in steady-state conditions:

$$\mathrm{ex}_{\text{moisture air}} = (C_{Pa} + \omega C_{Pw})\left(T - T_0 - T_0 \ln \frac{T}{T_0}\right) + (1+\tilde{\omega})R_a T_0 \ln \frac{P}{P_0} + R_a T_0 \left[(1+\tilde{\omega}) \ln \frac{1+\tilde{\omega}_0}{1+\tilde{\omega}} + \omega \ln \omega\omega 0 \qquad \ldots (6)$$

$$\tilde{\omega} = 1.608\omega \qquad \ldots (6a)$$

$$\tilde{\omega}_0 = 1.608\omega_0 \qquad \ldots (6b)$$

$$\omega = \frac{\dot{m}_v}{\dot{m}_a} \qquad \ldots (6c)$$

where ω is the relative humidity ratio of air (%); $\tilde{\omega}$, the molar of the relative humidity ratio of air (%); and C_P, the specific heat under constant pressure (kJ/kgk). The subscripts a and w refer to dry air and water respectively; and the subscript zero indicates properties at the reference (dead) state.

The net exergy transfer by heat at temperature T is given by

$$\dot{\mathrm{E}}\mathrm{x}_q = \left(1 - \frac{T_0}{T}\right)\dot{Q}_c \qquad \ldots (7)$$

where T is the temperature at which the heat transfer takes place; and $\dot{Q}_c$, the heat transferred by convection and conduction. $\dot{E}x_q$ is the exergy rates of heat transferred by convection and conduction. The specific exergy destruction is determined as:

$$Ex = \frac{\dot{E}x_d}{\dot{m}_{ev}} \quad \dots (8)$$

where $\dot{E}_{xd}$ and $\dot{m}_{ev}$ refer exergy destruction of the overall drying system (dryer) and the mass flow rate of the water evaporated respectively.

By the modification of Dincer and Sahin's exergy efficiency model[5], the following relations for the exergy efficiency of drying drum (ε_{drum}) and total drying system efficiency (ε_{dryer}) were obtained:

$$\varepsilon_{drum} = \frac{\dot{m}_{ev} ex_{ev}}{\dot{E}x_{da}} \quad \dots (9)$$

$$\varepsilon_{dryer} = \frac{\dot{m}_{ev} ex_{ev}}{\dot{E}x_E} \quad \dots (10)$$

where $\dot{m}_{ev}$ is the mass flow rate of the water evaporated; ex_{ev}, the specific exergy of the water evaporated; $\dot{E}x_{da}$, the exergy rate of the drying air; and $\dot{E}x_E$, the exergy rate of the electricity.

The exergy efficiencies for each component including the electric heating wire (I), motor (II), and fans (III) of the domestic air vented dryer were calculated using the following equations respectively:

$$\varepsilon_{I,hp} = \frac{\dot{E}x_2 - \dot{E}x_1}{\dot{W}_{hp}} \quad \dots (11)$$

$$\varepsilon_{II,motor} = \frac{W_{hp}(\dot{E}x_3 + \dot{E}x_1) - 2W_{hp}\dot{E}x_2 + W_m Ex_1}{\dot{W}_{hp}(\dot{W}_{hp} + \dot{W}_m)} \quad \dots (12)$$

$$\varepsilon_{III,fan} = \frac{\dot{E}x_4 - \dot{E}x_3}{\dot{W}_{fan}} \quad \dots (13)$$

The exergy efficiencies of each period during the air vented dryers can be expressed as:

$$\varepsilon_{k=1,2,3,4} = \frac{\dot{m}_{evk} ex_{ev}}{\dot{E}x_{da} - \dot{E}x_{eak}} \quad \dots (14)$$

where 1, 2, 3, 4 refer to the status of drying air during drying process including ambient air drying air, mixing air and exhaust air respectively; $\dot{m}_{evk}$, the mass flow rate of the water evaporated in k drying process(k = 1,2,3,4); ex_{evk}, the specific exergy of the water evaporated in k drying process (k = 1,2,3,4); $\dot{E}x_{dak}$, the exergy rate of the drying air; and $\dot{E}x_E$, the exergy rate of the electricity in k drying process (k = 1,2,3,4).

A parametric study was also conducted in domestic tumbler dryer using actual operational data. As a drying material, woven cotton fabric was used. The effects of the drying process parameters, such as heater power, exhaust air humidity rate and the final moisture content of fabric on exergy efficiency and destruction rates are studied by the application of the aforementioned models. Tables 1 and 2 show the drying process parameters used in this study.

Additionally, the differential equations in the above section were numerically solved based on the input and output data of each component. The computational procedure was as follows: Firstly, power of heater, power of motor for driving drum, power of fan, air relative humidity(RH), temperature, weight of fabric in drying drum was recorded by relative sensors or calculated using the above formulas to predict the whole drying process. Secondly, relative calculation was completed by the computer.

3 Materials and Methods

3.1 Materials

100% cotton woven fabric (38×38cm^2), having the specifications: woven, 138.2(±0.03)g/m^2 fabric weight, 0.77(±0.03)mm thickness, 78.7% relative porosity, and 1224(±140) kj/kg·k specific heat capacity, was used throughout the analyses. Additionally, prior to each laboratory prewashing treatment and drying experiment, all samples were placed at the constant temperature and humidity for 48 h to fully equilibrate (temperature 20°C ± 2°C, humidity 65% ± 2%). Moreover, a prewashed operation was performed in a standard household automatic drum washing machine (MD80-1407LIDG, little Swan) to ensure average initial moisture content of experimental fabric at 70.0% ± 5% (IEC standards), and then the standard testing fabric was placed into the drying experimental system for dehumidification under the set drying conditions

3.2 Experimental Setup

In order to achieve the purpose of conducting exergy analyses of the drying process and for understanding the impact of different drying conditions on exergy efficiency and exergy destruction, an experimental system for fabric drying was established by modifying the current traditional electric heating clothes dryer (Fig. 2).

Electric heating wire was modified to be integrated with a programmable digital voltage regulator (TDGC2-5000W with an accuracy of ±10W for power) to adjust heater power based on our design of experiment (DOE). In addition, the various temperature and relative humidity sensors (Eyc,

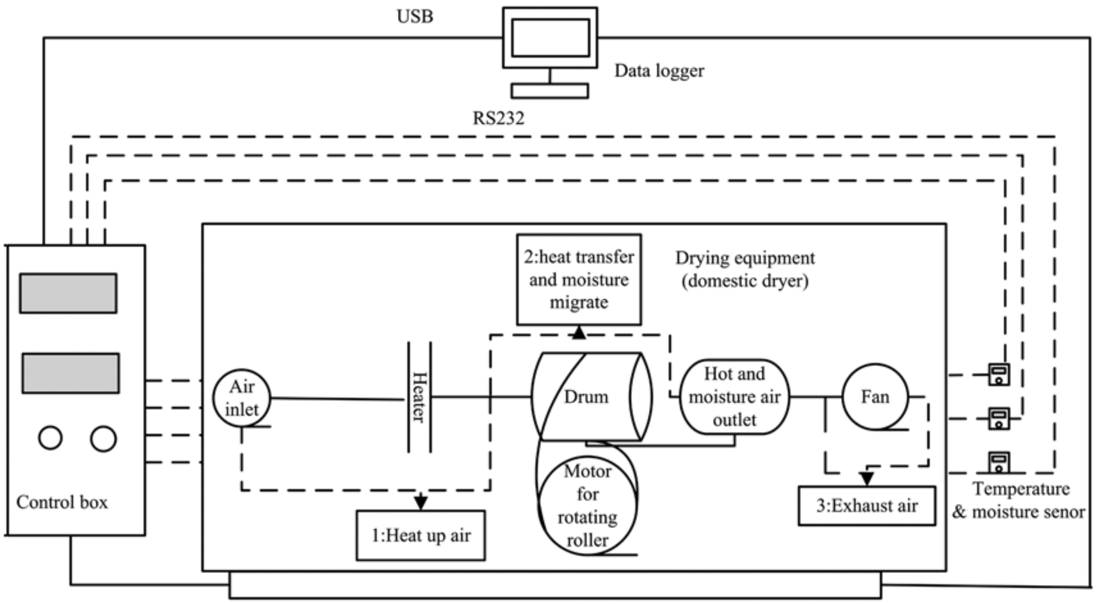

Fig. 2 — Experimental setup

FTS64-2011-MD, Taiwan with an accuracy of ± 0.5˚C for temperature, ± 3.0% for humidity) were installed at different positions of drying system. An electronic scale (Global Weighing Technologies, TCS-XC-A, Shanghai, China) with 232 digital transmitter and 1s response time was installed in order to measure sample's loss of moisture in the dryer. Its capacity was 0-50 kg and its accuracy was ± 5g. Meanwhile, the connection of sensors with data recorder (JY-DAM-PT12 and JY-DAM1012) can display and record actual experimental data on the computer in real time for the calculation and analysis of exergy efficiency.

3.3 Experimental Produces

As aforementioned, throughout drying, the unit mass of water evaporated per unit time and the temperature of the fabric differ depending on the drying period. Thus, the exergy analysis was performed for each drying period of fabric drying individually using the control volume models. Drying experiments were carried out at different treatment combinations (Tables 1 and 2). Three sets of drying experiments were initially performed to demonstrate the effect of different levels of heater power, exhaust relative humidity and final moisture content of fabric on exergy efficiencies and energy efficiencies under the same air velocity (8m/s) and rotating speed of drying drum (45-50rpm). Additionally, the drying process is divided into 4 stages based on the humidity of the exhaust air. Based on multi-objective optimization methods MOPSO (particle swarm optimization) with the targets of minimum energy consumption and our pre-experiments, three demarcation points to determine duration of each stage are found 85%, 70% and 38% respectively. All drying experiments were replicated at least twice in order to guarantee accuracy of experiment. Each drying experiment load was maintained at 2.5 kg ± 10g.

Table 1 — Summary of experiment drying conditions—Heater power evaluation
[Initial moisture of fabric 70% and final moisture of fabric 3%]

Test number	Drying conditions–Each period of heater power (w)			
	First	Second	Third	fourth
1	3000	3000	3000	3000
2	4500	4500	4500	4500
3	3500	4500	3000	1500

Table 2 — Summary of experiment drying conditions—Final moisture of fabric evaluation
[Initial moisture of fabric 70% and Drying heater power 3000w]

Test number	Final moisture of fabric, %	Test indexes of each drying period
1	3	Fabric temperature (˚C)
2	13	Air temperature at drum outlet (˚C)
		Final fabric moisture (%)
		Air moisture at drum outlet (%)
		Air moisture at duct outlet (%)
		Exhaust air humidity (%)
		Drying rate (g/min)
		Mass of wet fabric (g)

After the experiment, analyze all the data including the data regarding energy consumption and drying time, standard fabric weight, design wind volume to furthermore calculate exergy efficiency, exergy destruction rates, and exergy loss ratios of various component and the whole drying system.

4 Results and Discussion

4.1 Exergy Analysis of Whole Drying System

As shown in Fig. 3 (a), moisture removal rate and exergy efficiency show a similar changing trend with drying time. In the heated up period, moisture removal rate and exergy efficiency both experience a gradual upward trend with the increase in drying time. This is because during the drying process temperature gradient difference increases in the drying chamber with drying period[25]. The moisture removal ability increases with the increase in the temperature of drying air. Exergy efficiency is the maximum amount of useful work for which energy is consumed for removing water. Therefore, the exergy efficiency increases with the increase in moisture removal rate during the fabric drying period. In the constant moisture removal rate period, exergy efficiency reaches the maximum value because of the evaporation of water attaining the maximum rate. In the falling evaporation of water period, there is a decreasing change in the moisture removal rate and exergy efficiency. This is due to the increase in friction resistance of capillaries and decrease in moisture content of fabric along continuous drying. In the last drying period, moisture removal rate and exergy efficiency further decline because of the lower degree of water evaporation. Hence, Fig. 3 (a) also illustrates the fact that the changing law of drying rate can reflect exergy efficiency to a certain extent.

As shown in Fig. 3 (b), in the constant evaporation period, specific energy consumption is lower

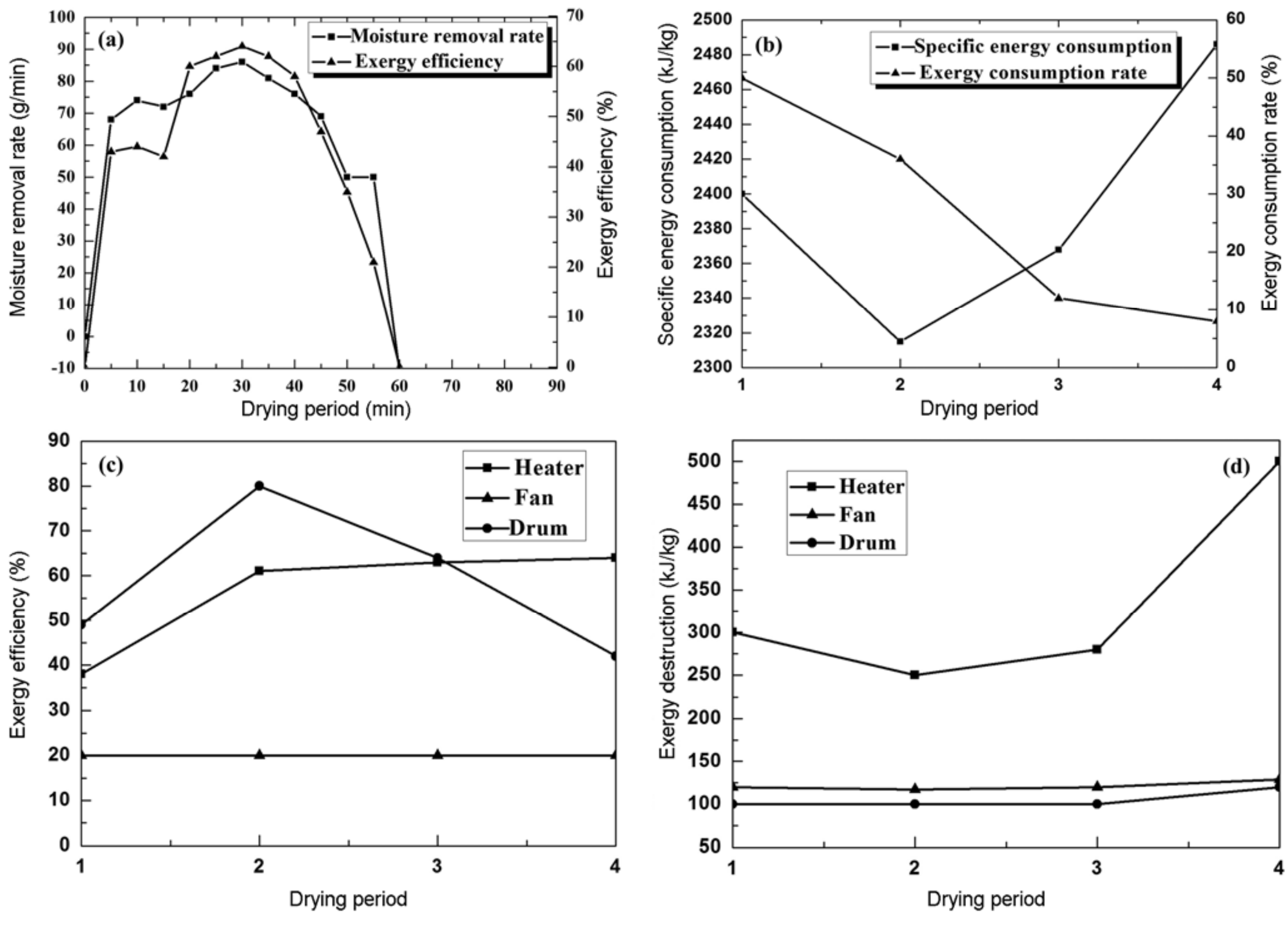

Fig. 3 — Changes in exergy and energy during drying (a) comparison of moisture removal rate and exergy efficiency, (b) comparison of specific energy consumption and exergy consumption rate for each period of fabric drying process, (c) exergy efficiency of each component depending on the drying period and (d) exergy destruction of each component depending on the drying period

compared to other three periods because of the higher moisture removal rate. This is because the fabric is mainly free from water in this period, which shows lower binding energy. In addition, it is clearly seen that the specific energy consumption of pure water reduces with the increase in temperature in term of water evaporation theory. The activity of the water molecules increases due to the increased temperature, and then the water molecules more easily escape from fabric. However, the decrease in the residual moisture content of fabric leads to lower evaporation capacity. In the early drying stage, the fabric has lost a lot of water, and hence the moisture content of the fabric remains very little in the later stage, thereby decreasing the water loss rate. When the decrease in evaporation ability and increase in specific energy consumption are able to offset, the energy consumption rate remains unchanged. When the two is not offset, the change in energy consumption rate depends on the larger one of the two. In this study, we discover the law that the energy consumption rate continuous decline during the drying process. However, the magnitude of decline becomes gradually slow during the whole drying process, as discussed in Fig. 3(b).

As illustrated in Fig. 3 (c), exergy efficiency of each component of the air vented dryer during the four drying period, exergy efficiency of heater and exergy efficiency almost remain unchanged in 60% and 20% respectively. The exergy efficiency of drying drum experiences a first increase to a maximum value and subsequently decrease toward the end of dying. This is because the drying drum is only place of conducting exchange of heat and moisture removal. Furthermore, it means that all changes of system mainly take place in this part. Therefore, the exergy efficiency of each component remains steady except the drying drum. The relation between the exergy destruction of each component and the four drying period is given in Fig. 3 (d). The exergy destruction of fan and drying drum are not affected by the drying time, the exergy destruction of fan and drying drum are calculated to be 120kJ/kg and 100kJ/kg respectively. The exergy destruction of heater has a significant increase in the last drying period due to the decrease in drying rate. From Fig. 4 (a), it is clearly seen that the heater causes the highest exergy destruction of the whole system. In other words, the heating process is an important source of irreversibility. This is due to the two reasons, namely (i) the heater is the largest power component of dryer; and (ii) the work environment of the heater is relatively unclosed environment with the distance of air inlet and heater. As a result, some part of energy of the heater is lost by convection and conduction, where convection causes the difference in temperature of air outlet and air near heater, and the conduction is due to the fact that the dryer enclosure is made of metal , while the thermal conductivity of metal material is very high and it becomes very easy to conduct out the heat. Therefore, reducing the exergy loss of heater is the main method of reducing the whole energy consumption of the air vented dryer.

4.2 Effects of Heater Power

It is clearly seen that the exergy efficiency of each component using single heater power of the whole drying process (Case1 and Case2) is lower than that of combined heater power (Case3), as shown in Fig. 4 (a). This is because more energy is provided by using

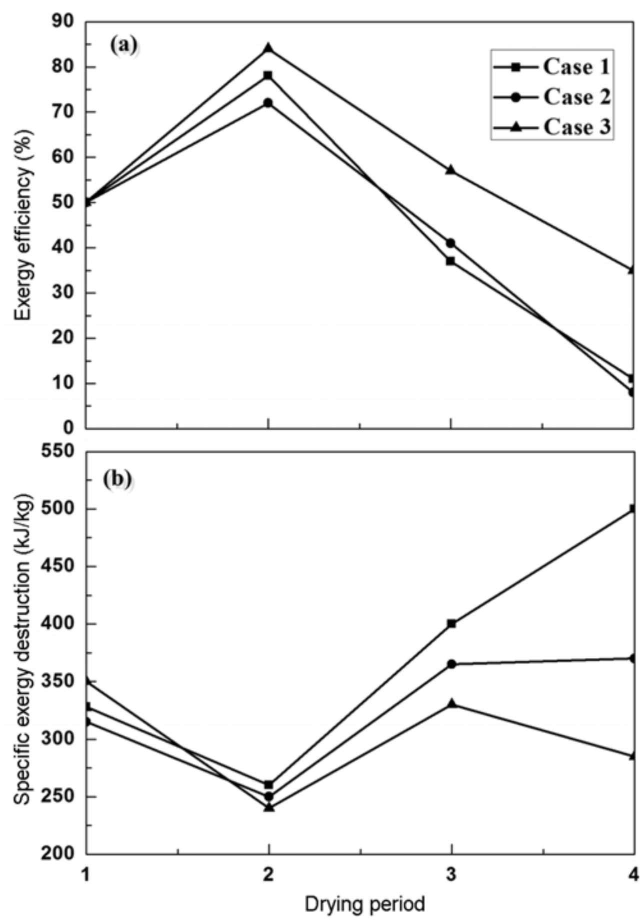

Fig. 4 — Effect of heater power on (a) exergy efficiency of each component during the main four drying process and (b) specific exergy destruction of each component during the main four drying process

higher heater power, whereas energy needed for evaporation is constant due to evaporation of the same amount of water[10]. The use of single excess higher heater power (Case2) results in increase in temperature of fabric instead of reducing the fabric moisture content, even damaging clothings especially heat-sensitive clothing because of over-dry. Over-drying results in the higher irreversibility due to the increase in energy consumption. On the contrary, use of single excess lower heater power (Case1) extends the drying time and even can't dry to the drying degree of the relative drying standards due to the lack of energy as shown in Table 3. The combined drying procedure (Case3) dries the same amount of fabric using less energy as compared to other two cases with single heater power. Additionally, as shown in Table 3, appearance smoothness has a positive linear relationship with the final moisture content of fabric. Therefore, from the perspective of energy consumption, drying time, fabric damage and drying degree of fabric, the combined heater power of drying process based on drying stage is found to be the best way to dry fabric (Case3).

Figure 4(b) shows the relationship of specific exergy destruction with heater power. It can be seen that specific exergy destruction in the constant moisture removal period is found minimum during the whole drying process. This is because water in fabric is easy to evaporate as the evaporation takes place mainly at the surface, and due to the high moisture content of the porous material and smaller binding force of water and fibre. That means all supplied energy is used in evaporation of water, instead of increasing temperature. Additionally, the drying rate of this period is determined by external conditions such as heater power and flow rate of the drying medium. Therefore, the higher power should be adopted in the early two drying periods to improve drying efficiency. However, as the time goes on, the drying rate reduces till the end of drying process, and then the exergy destruction also continuously increases with the drying time. Besides, in the last drying period, the effect of power on exergy destruction is more significant than in other drying periods because the energy of drying air is consumed for the further heating of textile material rather than in evaporation of residual moisture available inside the fabric, and the excess higher power only leads to wasting of energy and over-drying of fabric, then damaging the fabric. The lower power should be used in the last two drying periods. Hence, the combined power method based on drying stage is found an ideal approach to achieve the goal of using less energy for the removal of ideal final moisture content of fabric.

Table 3 — Experimental results

Number	Energy consumption kW·h	Drying time, min	Final moisture content, %	SA.
Case 1	3.68	85	4.17	1.9
Case 2	4.02	60	-2.64	1.4
Case 3	3.51	65	2.14	2.1

SA—Appearance smoothness of fabric after drying.

4.3 Effects of Relative Humidity of Exhaust Air

The experimental data of the process are listed in Table 2. The dependences of exergy destruction rate and exergy efficiency of each component of the air vented dryer with exhaust air relative humidity as shown in Fig. 5. It is clearly seen that the exergy efficiency of each component of air vented dryer significantly increases with the increase in relative humidity of exhaust air, especially at the last drying

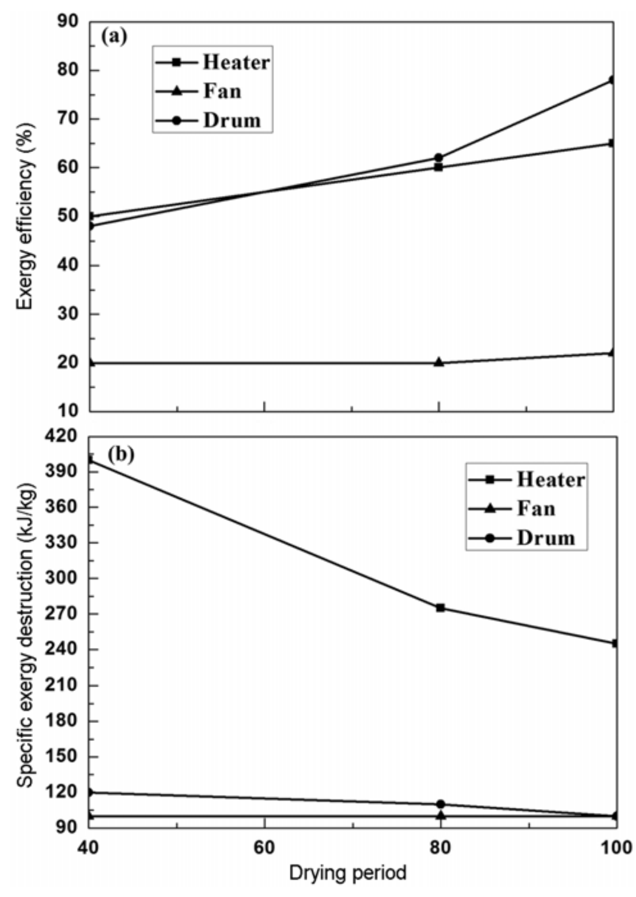

Fig. 5 — Effects of relative humidity of exhaust air on (a) exergy efficiency and (b) exergy destruction of different components

period. This is because the increase in relative humidity of exhaust air causes the increase in exchange degree of heat and moisture; the heat generated by heater is fully used for the evaporation of water when the relative humidity of exhaust air remains 100%. As we know, <100% relative humidity of exhaust air has certain water absorption capacity till the relative humidity reaches to 100%. In addition, Fig. 5 (a) concludes that the exergy efficiency of heater and drying drum is higher than that of fan, and the fan has always the lowest value among the three main component of the system.

Figure 5 (b) presents the exergy destruction of heater as a function of relative humidity of exhaust air. The exergy destruction of fan and drying drum are found almost constant regardless of relative humidity of exhaust air, and is far lower than the exergy loss of heater. Therefore, the fact that heater is main source of irreversibility in the air vented dryer is again proved. Optimization of heater power is an important need to reduce the whole exergy loss of the drying system.

4.4 Effect of Final Moisture Content of Fabric

The final moisture content of fabric significantly affects the exergy destruction rate and exergy efficiency of each component of the air vented dryer (Fig. 6). As shown in Fig. 6 (a), it is quite clear that the final moisture content of fabric directly affects the exergy destruction and exergy efficiency in the falling drying period, specially the last one; the exergy efficiency is increased by increasing final moisture content. This is because the amount of bound water removal is reduced with the increase in final moisture content of fabric and the water inside very fine capillaries is difficult to be replaced by air. Additionally, it is meaningless to achieve lower final water content of fabric. When lowest final water content of fabric is obtained by incresing drying time or by increasing drying power, the fabric reabsorbs moisture from the environment. Lower final moisture content of fabric also causes fabric damage, such as reduction in appearance smoothness. This is because the absorption capacity of cotton leads to maintain the equilibrium moisture content (5% and 8%) under the daily wearing condition and the atmospheric condition respectively. Besides, the 13% moisture content of fabric is usually maintained for fabric ironing. As shown in Table 3, the appearance smoothness has a positive linear relationship with the final moisture content of fabric. Therefore, reducing the final moisture content of fabric not only decreases the exergy destruction rate to achieve the purpose of saving energy, but also improves the appearance smoothness of fabric.

Figure 6 (b) shows that the final moisture content of fabric directly affects exergy efficiency of each component in the drying period specially the last one. This is because less moisture content and larger friction of capillary at the last drying period result in significant increase in the specific energy consumption per mass of water evaporation. Meanwhile, it is known that the constant drying period determines drying rate and the drying time, but the drying rate period determines the final drying degree of fabric[5]. Therefore, it is very important to ensure a suitable drying final moisture content of fabric in order to reduce energy consumption and avoid fabric damage. However, figure 6 also presents the fact that reducing the final moisture content of fabric can reduce the exergy destruction in practical drying systems but the effect

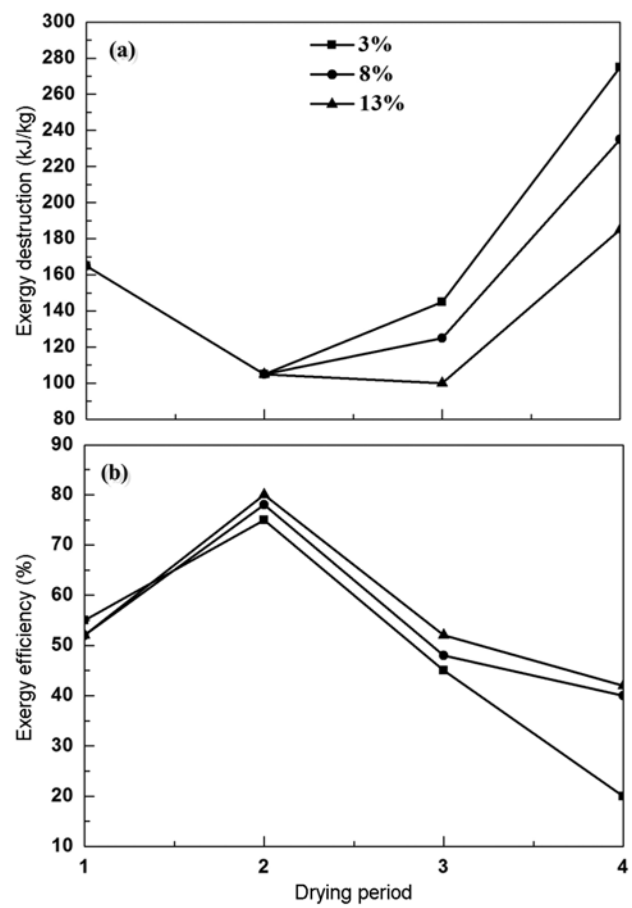

Fig. 6 — Effect of final moisture content of fabric on (a) exergy destruction and (b) exergy efficiency of different components during the four drying periods

is not as significant as that of the heater power. Therefore, a small part of the exergy destruction in practical drying systems can be reduced by increasing the final moisture content of fabric.

5 Conclusion

It is found that the electric heater has higher exergy destruction rates compared to fan and drying drum and also it is an important source of irreversibility for the air vented dryer, because of the heat leakage in the internal system. Its power has a significant effect on the exergy destruction of the drying system as well as whole drying process. The relative humidity of exhaust air and the final moisture content mainly affect the exergy destruction in the last drying period of whole drying process and have a negative linear relationship with the exergy destruction of heater. The effect of relative humidity of exhaust air on the exergy destruction of fan and drying drum are not found comparable with the heater.

Additionally, exergy efficiency gradually declines as the fabric drying process is carried out, but up to a certain extent, exergy efficiency of a dryer can be reflected by its moisture removal rate. It is found that the combined power of adjusting heater power based on the drying period exhibits higher exergy efficiency and lower exergy destruction rate than the single heater power of drying process that is kept constant. Specifically, in the first two periods of the drying process, the higher power for drying fabric should be applied; in the last two stages of the drying process, lower power for drying fabric should be used to achieve the goal of using less energy removing as possible move moisture and ensuring the desired final moisture content. Additionally, by this way, we can reduce exergy destruction of system, and improve smoothness of fabric.

Hence, exergy analysis of the air vented dryer is useful for the optimization of parameter and for product upgrades in industry of dryer, and to accurately locate and characterize the exergy loss among the component of dryer.

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