Impact of adsorbent finishing and absorbent filming on energy exchange efficiency of an air-to-air cellulose fibre heat & mass exchanger

Liu, S. , Riffat, S. , Zhao, X. and Yuan, Y.

* Manuscript

Impact of Adsorbent Finishing and Absorbent Filming on Energy Exchange Efficiency of an Air-to-Air Cellulose Fibre Heat & Mass Exchanger

S. Liu[a,*], S. Riffat[a] , X. Zhao[a] and Y. Yuan[b]

[a] School of the Built Environment, University of Nottingham, Nottingham NG7 2RD, UK

[b] Hangzhou ISAW technolgy Corporation , 310018, CHINA

* Corresponding author, Tel.: +44 115 846 7261; fax: +44 115 951 3159.

E-mail address: laxsl1@nottingham.ac.uk (S. Liu).

Abstract

This paper aimed to investigate the impact of two coating methods, namely solid adsorbent ($CaCl_2$) finishing and liquid absorbent (LiCl) filming, on energy (enthalpy) exchange efficiency of a cellulose fibre air-to-air heat & mass exchanger, through both theoretical analyses and experimental testing. Heat and mass transfer through three types of membrane, i.e., clear fibre and the fibre with adsorbent finishing and absorbent filming, were analysed. This led to the conclusion that the coating on the membrane would help improve energy exchange efficiency of the exchanger. Experimental testing was carried out for the exchangers with the two coatings, and the testing results were compared with the existing data of a clear fibre exchanger. It was found that absorbent (LiCl) filming had larger impact towards the energy exchange than the solid $CaCl_2$ powder did, and the level of efficiency increase for the two coatings are 25.6% and 15.9%, respectively. However, the inherent problems existing in liquid absorbent system, i.e., complexity of the desiccant cycle and potential air contamination by desiccant solution, limited its wide application in practical engineering, and therefore, the adsorbent finishing is a suitable option for this purpose.

Key words: fibre cellulose, hydrophilic membrane, efficiency, adsorbent finishing, liquid desiccant filming

Nomenclature

c	Specific heat capacity	J/kg K
D	Equivalent diameter of the exchanger tunnel	m
h	Enthalpy of air	kJ/kg
k^{heat}	Convective heat transfer coefficient	W/m^2 K
$k^{moisture}$	Convective mass transfer coefficient	m/s
k	Thermal conductivity	W/m K
k_{mass}	Moisture infiltration coefficient through exchanger membrane	m^2/s
L	Length of the exchanger tunnel	m
m	Mass quantity of materials	kg
p	Vapour Pressure	Pa
T	Absolute temperature	K
t	Temperature	℃
u	Air flow speed	m/s

α	Thermal diffusivity of air	m^2/s
δ	Thickness of the heat/mass transfer membrane	m
ν	Kinematic viscosity	m^2/s
μ	Dynamic viscosity	Ns/m^2
ρ	Density	kg/m^3
ϑ	Porosity of materials	%

Subscript Term

in	Intake air from the ambient
out	Outgoing air from the room space
b	Bulk temperature of the fluid within the exchanger tunnel
dry	Dry air stream
s	Supply air to the room space
w	Temperature of the exchanger tunnel wall
wet	Wet air stream

Superscript Term

heat	Sensible heat energy
moisture	Condensed/evaporated moisture (mass)
enthalpy	Total energy including both sensible and latent energy

1.0 Introduction

In building ventilation and air conditioning engineering, air-to-air heat & mass exchangers are often employed to carry out energy recovery between the outgoing and intake air. This type of exchanger is known as the energy (enthalpy) exchanger and made as the plate-stack or rotary wheel. In recent years, a low-cost air-to-air heat & mass exchanger made of fibre membrane has been developed. The device exchanges heat and moisture between two air streams through adjacent fibre membranes. The membranes are separated by guides that run the length of each sheet. This allows the development of a large number of energy exchange microenvironments between the two air streams, and its energy (enthalpy) exchange efficiency is as high as 50~55% [1].

This paper investigated two coating methods, i.e., solid adsorbent ($CaCl_2$) finishing and liquid absorbent (LiCl) filming, onto the fibre membrane and its potential to further increase the energy exchange efficiency of the exchanger. Mechanism of the coatings for increasing heat and mass transfer was analysed theoretically. Furthermore, experiment was carried out to determine the level of increase in terms of energy (enthalpy) exchange efficiency, and heat and moisture transfer efficiency. This would generate some useful conclusions related to coating effectiveness to energy recovery.

2.0 Theoretical analyses of heat and mass transfer within the clear and coated fibre membranes

Three types of fibre membranes, i.e., clear fibre, fibre with adsorbent finishing, and fibre with absorbent filming, were investigated. Two airstreams were forced to cross the adjacent channels separated by the fibre membranes. The heat and mass transfer through the three membranes are shown schematically in Figure1 (a), (b) and (c) respectively.

2.1 Description of three fibre configurations

Clear fibres

A clear fibre membrane is composed of hundred thousands of long cellulose fibres which are squeezed into a thin layer of 0.1 to 0.5mm, as shown in Figure 1(a) [2]. The fibres themselves act as the conductors allowing heat to be transferred from hot to cold airstreams separated at the two sides of the membrane, thus contributing to recovery of sensible heat [3]. The voids among the fibres allow transfer of moisture between the two airstreams, but prevent diffusion of air molecules across the membrane, which could be made through adjusting the sizes of the voids (pores) [4, 5, 6]. The wet airstream contains higher amount of moisture which builds up a higher water vapour (divisional) pressure; whereas the dry airstream contains lower amount of moisture and therefore has a lower vapour (divisional) pressure. This pressure difference forms a driving force to the moisture transfer. In operation, the fibres absorb moistures from the wet airstream, owing to their strong water affinity characteristics. This is accompanied by a condensation process of water vapour, which releases the heat amount to the latent heat of the water vapour condensed. This part of heat will be directed to the cold airstreams due to the temperature difference existing between the two airstreams. The moistures penetrate through the voids of the fibre membrane and enter its other side, where they evaporate into vapour by absorbing the heat from the hot airstream. The vaporised moisture is merged into the dry airstream and flows away with the airstream.

In this process, heat follows the route from the hot to cold airstreams, while moisture makes its way from wet to dry airstreams. If the intake air is hot and humid, and outgoing air is cold and dry, the heat and moisture would be transferred at the same direction. Otherwise, heat and moisture would be transferred in different ways. Transfer of heat and moisture would lead to change of enthalpy of passing airstreams. As the result, part of energy (either cooling or heating) will be recovered from the outgoing air, which will be added to the intake air.

Fibre membrane with solid adsorbent ($CaCl_2$) finishing

As the $CaCl_2$ solid powder is an adsorbent with very strong water affinity, it can attract much more moisture than the fibres do under the same water vapour pressure of the passing airstream. Finishing the $CaCl_2$ powder onto the wet side of the fibre membrane would increase the adsorption capability of the surface, and allow more moisture to be removed from the passing wet airstreams. The moisture deposited on the wet surface would be forced to cross the voids within the membrane and enter the other side of the membrane, under the influence of the vapour pressure difference between the two sides of the membrane. If the dry side of the membrane were also finished with the same type of adsorbent, an additional 'drag' force would be generated to pull the moisture off the wet side and into the dry side. The moisture established on the dry side would develop a vapour pressure difference between the coating and passing dry airstream, which would pull the moisture off the dry side coating and into the dry airstreams. On the other word, finishing an adsorbent powder onto the dry surface of the membrane would increase the desorption capability of the surface. Similar to the clear fibre, the process is accompanied by condensation of vapour and evaporation of the water, which would lead to additional heat flow added to the sensible transfer [7]. As some amount of adsorbent fills the voids inside the membrane, the thermal conductivity of the membrane would be higher, which would lead sensible heat transfer increasing.

In summary, finishing an adsorbent powder onto the membrane surfaces increases moisture/sensible-heat transfer and therefore, increases heat and energy (enthalpy) exchange efficiency between the two airstreams. The rate of increase would be experimentally investigated in the following sections.

Fibre membrane with liquid absorbent (LiCl) filming

Liquid absorbents have much higher moisture absorption capacity than the solid adsorbents. For instance, the LiCl solution can hold about 10 times more water than the same weight of $CaCl_2$ powder does [7]. This would create much higher water absorption and desorption capacities.

Liquid absorption process can best be illustrated by comparison to the operation of an air washer. When air passes through an air washer, its dew point approaches the temperature of the water supplied to the machine. Air that is more humid is dehumidified and air that is less humid is humidified. In a similar manner, a liquid absorption device brings air into contact with a liquid desiccant solution. The absorbent has a vapour pressure lower than water at the same temperature, and the air passing over the solution approaches this reduced vapour pressure; it is dehumidified. Otherwise, it is humidified [8].

If the membrane is bathed by a liquid desiccant film, i.e., LiCl solution, the dehumidification would occur at the wet air channels where moisture would be absorbed by the liquid absorbent over the surface. This is caused by the vapour pressure difference between the airstream and the absorbent film. Under the same vapour pressure difference condition, the absorbent can absorb more moisture than solid adsorbent due to its stronger water affinity characteristic [8].

The moisture deposited on the wet membrane would be forced to cross the voids of the membrane and enter the dry side film, which is driven by the concentration difference between the two desiccant films. This part of moisture would be then dispersed to the dry airstream due to the vapour pressure difference in between. In this process, the desiccant solution acts as the moisture conveyor, which results in moisture removal from the wet airstream and moisture addition to the dry airstream. The sensible heat transfer across the membrane is a also bit higher than the solid adsorbent finishing and clean fibre owing to its higher moisture transfer ability.

As the liquid absorbent fills the void space of the membrane, the thermal conductivity of the membrane would be higher than that of the clear fibre. This will lead to increased sensible heat transfer across the membrane.

In principal, the fibres membrane with liquid absorbent filming has the highest moisture transfer capacity, and therefore, can achieve the highest energy (enthalpy) exchange efficiency between the two airstreams. This efficiency will also be experimentally investigated in the following sections.

2.2 Mathematical description of the heat/mass transfer with the fibre membranes

The heat transfer within three types of membranes has the same mathematical indication, which is shown as follows:

$$q = (t_{in} - t_{out})/(\frac{1}{k_{in}^{heat}} + \frac{\delta}{k} + \frac{1}{k_{out}^{heat}}) \tag{1}$$

k^{heat} is the convective heat–transfer coefficient, which can be calculated using the following equations [6]:

$$k^{heat} = 1.86(\frac{uD}{v_b} \cdot \frac{\mu_b c_b}{k_b^{air}} \cdot \frac{D}{L})^{1/3} (\frac{\mu_b}{\mu_w})^{0.14} \frac{k_b^{air}}{D} \tag{2}$$

The thickness of the wall δ is in the range 0.1 to 0.5mm, while its thermal conductivity, k, takes the average of the k values of the materials and the filling water, owing to its porous structure. In that case, k value can be written as [9]:

$$k = \vartheta k_{moisture} + (1-\vartheta) k_{materials} \tag{3}$$

The mass transfer across the membrane could be written as follows:

$$m = \frac{(p_w - p_d)/RT}{(\frac{1}{k_{wet}^{moisture}} + \frac{\delta}{k_{mass}} + \frac{1}{k_{dry}^{moisture}})} \quad (4)$$

Whilst the mass-infiltration coefficient, $k^{moisture}$, could be calculated using the following equation:

$$k^{moisture} = k^{heat}(\rho_b c_b)^{-1}(\frac{\alpha_b}{D_{AB}})^{-2/3} \quad (5)$$

The mass diffusion coefficient, D_{AB} is a function of air temperature and pressure, and can be calculated using the following equation [10]:

$$D_{AB} = D_0 \frac{P_0}{P}(\frac{t_b + 273.15}{T_0})^{3/2} \quad (6)$$

For an air-to-air exchanger in buildings, its operation is usually at the atmospheric pressure. In this case, $P_0 / P = 1$, $T_0 = 273.15K$. This will yield a value of 2.2×10^{-5} m^2/s for D_0.

Moisture infiltration coefficient, k_{mass}, is another factor that affects moisture transfer, and largely dependent upon the porosity and pore sizes of the fibre membrane. Adequate porosity rate of the membrane are necessary in order to accommodate the condensed moisture. Also the pores of the membrane should have reasonable sizes that would allow the penetration of the condensed liquid but resist the cross flow (diffusion) of the two adjacent airstreams. Calculation made by the authors [5] indicates that the diameter of pores within the membrane would be in the range 2.75×10^{-10} to 3.2×10^{-7}m.

If a solid adsorbent or a liquid absorbent is applied, filling ratio of these materials to the voids within the fibre membranes should be taken into consideration. Comparing the thermal conductivity of the air (2.6×10^{-2}W/m K), solid adsorbent ($CaCl_2$: 7~9W/m K) and liquid absorbent (LiCl: 0.5W/m K), the adsorbent finishing and absorbent filming membranes should have higher conductive transfer ability than clean fibre [11].

Applying solid adsorbent finishing or liquid absorbent filming onto the membrane surfaces will increase the thermal conductivities of the fibre membrane, and thus increase sensible heat transfer across the membrane. It will largely increase the moisture transfer owing to change made on convective mass transfer coefficient, $k^{moisture}$, and moisture infiltration coefficient, k_{mass}. These changes are too subtle to find the solution through theoretical method. Instead, experiment was arranged to investigate the impact of adsorbent or absorbent onto the sensible heat and moisture transfer and subsequently, energy exchange efficiency. To facilitate the analyses, the mathematical expressions of heat, mass and energy (enthalpy) exchange efficiency are given as below [12].

$$\varepsilon^{heat} = m_{in}c_{in}(t_{in} - t_s) / C_{\min}(t_{in} - t_{out}) \tag{7}$$

$$\varepsilon^{moisture} = m_{in}h_{in}(d_{in} - d_s) / m_{\min}h_{in}(d_{in} - d_{out}) \tag{8}$$

$$\varepsilon^{enthalpy} = m_{in}(h_{in} - h_s) / m_{\min}(h_{in} - h_{out}) \tag{9}$$

$C_{\min} = \min\{\rho_{in}V_{in}c_{in}, \rho_{out}V_{out}c_{out}\}$; $m_{\min} = \min\{\rho_{in}V_{in}, \rho_{out}V_{out}\}$

3.0 Experimental investigation of the impact of adsorbent finishing and absorbent filming to energy exchange efficiency

3.1 Prototype fibre membrane exchanger

Experiment was based on a counter-flow fibre membrane exchanger as shown in the Figure 2. Testing of the clear fibre was carried out by the exchanger manufacturer, i.e., ISAW in China, and the results of the testing were presented in Figure 3. The authors made a follow-up experiment on the solid adsorbent ($CaCl_2$) and liquid absorbent (LiCl). The data obtained from experiment were compared with those from the manufacturer to examine the difference between the clear fibre and the fibres with solid adsorbent finishing and liquid absorbent filming.

The prototype fibre exchanger presented in Figure 2 (a) , consists of two exchanging stacks; each contains 100 layers of fibre membrane separated by triangle-shaped air guides, which forms numerous air-flow channels allowing air to pass through as shown in Figure 2 (b). The intake air was forced to cross the two separate stacks from the middle entry and flew downward along the channels within the two layers of membrane; while the outgoing air was brought into the stacks from lower part of stack (outside edge), and flew upward along the channels adjacent to the intake air tunnels, which are within the next two membrane layers. At the inlet and outlet of the stack, the triangle-shaped air introducing and discharge stacks are positioned to allow the air enter the main exchanger stack.

The first set of testing used an exchanger with the exactly same geometrical sizes as above. However, the membrane surfaces were finished with an adsorbent ($CaCl_2$) powder. This will be followed by the second set of testing where the membrane was bathed by a liquid absorbent (LiCl) film. The absorbent filming was carried out by a periodically operated desiccant cycle system consisting of a collection tank, a pump, a desiccant distributor and the piping. The schematic of the desiccant bathed exchanger is shown in Figure 4. The pump delivered the absorbent to the distributor on the top of the exchanger, where the absorbent was sprayed over the membrane surfaces to keep the whole area of the surfaces wet. Some absorbent droplets fell down to the collector at the bottom of the exchanger. At the air passages, the shelves were installed to prevent the desiccant to be carried away by the passing air flow.

3.2 Test rig for the heat & mass exchanger

A test rig was constructed at ELU (Energy Learning Unit) of the University of Nottingham to carry out the associated experiment. The image of the rig incorporating with the exchanger stack is shown in Figure 5. The stacks were trapped into two dedicated wooden boxes able to separate intake and outgoing air from inside sealing stuff. Both air were delivered by the controllable fans to the exchanger stacks using the black flexible air ducts, which were suitably insulated from outside to remain its temperature. On the inlet and outlet duct of the intake and outgoing air, instruments including thermocouple probes, humidity sensors and anemometers, were installed to allow measurement of temperature, humidity and volume flow rate. The specifications of the measurement instruments are shown in Table1. All instruments were pre-calibrated and then connected with a DT500 data-taker/computer, which allow data acquired from the measurement points to be transferred to the computer.

The experiment was carried out from the March to July in 2007 in Nottingham. The intake and outgoing air control system was constructed to provide the steady inlet air conditions as required, which are shown in Figure 6. Room air is forced to cross the electrical heater (a combination of two 2kW electrical heaters) using a 2kW centrifugal fan, which is controlled by the voltage adjustor to allow the airflow rate to vary from 0 to1000m^3/h. This raised air temperature to the level of the UK summer condition. The heated air entered the humidifier unit, where it gained the moisture and achieved the required humidity. Control of humidification process was made by adjusting water supply rate using a valve. The air ducts were insulated to prevent loss of heat and moisture gained and kept the air condition steady prior to entering the exchanger. This ensured both the intake and outgoing air remain at a steady temperature, humidity, and flow rate.

The intake air temperature and relative humidity varied from 29 to 35^{o}C and 30% to 70% respectively; the outgoing air temperature was controlled at about 24~26^{o}C and the relative humidity was around 50%. Both the airstreams had the same volume flow rate, i.e., 500m^3/h. The adjustment was made 30 minutes prior the testing to allow a steady air states to be achieved. Testing was then started and the results were instantly recorded and transferred into the computer, with the time interval of 1 minute. The average value of the each measure parameter was used for analyses of the results.

3.3 Testing results and discussion

Figures 7 presents the data of clear fibre, testing results of adsorbent finishing and absorbent film, which allows an easy comparison of the three types of membrane. It has indicated that the adsorbent finishing achieved energy efficiency 15.9% higher than the clear fibre did, and the absorbent filming further increased its energy efficiency by 25.6%. This efficiency increased slightly with the intake (fresh) air temperature increasing.

The adsorbent finished and absorbent filmed membrane have similar sensible heat exchange efficiency, which is 9.0% and 5.9% higher than the clear membrane respectively, as shown in Figure 8. This is due to increased thermal conductivity of the membrane caused by the coatings. However, their moisture exchange efficiencies are much different. The absorbent filming achieved the highest level of moisture exchange, and its efficiency was as high as 84.5%, 28.1% higher the adsorbent finishing and 38.7% higher than clear fibre (Figure 9).

However, due to complexity of absorbent filming system and its associated carry over problem, absorbent filming seemed difficult to be applied in practical engineering. Although the adsorbent finishing has lower efficiency, its simplicity and easy operation would compensate its drawbacks and would be an idea option for practical engineering application.

4. Conclusion

Impact of adsorbent finishing and absorbent filming onto the energy exchange efficiency of an air-to-air energy (enthalpy) exchanger were investigated, including theoretical analyses and experimental testing. It has indicated that both methods have potential improving energy (enthalpy) exchange efficiency, particularly moisture transfer efficiency of the exchanger. This is because that the methods increased the values of moisture infiltration coefficients of the membrane, and also the levels of convective mass transfer coefficients on both sides of the membrane. However, theoretical analyses can’t evaluate the level of efficiency increase due to large number of undetermined factors involved.

Experiment is the way evaluating the effectiveness of solid adsorbent finishing and liquid absorbent filming on energy exchange efficiency of the exchanger. For the given exchanger geometries and operation conditions, the absorbent filming has the most significant impact to exchanger efficiency and its enthalpy efficiency was about 15.9% higher than the adsorbent finishing, and 25.6% higher than the clear fibre. These two methods significantly affect its moisture exchange efficiency. The absorbent filming can achieve 84.5% of moisture exchange efficiency, which is 38.7 % and 28.1 % higher than those of clear fibre and adsorbent finishing. With the adsorbent finishing and absorbent filming, the sensible heat transfer efficiency was increased by 5.9% and 9.0% respectively, due to the increased thermal conductivity of the membrane caused by the coatings.

However, absorbent filming has its inherent problems in practical application. The major difficulty is the complexity of the liquid desiccant cycle system and more critically, the liquid desiccant may be carried away by the passing airstreams, which may cause adverse impact to occupant health and air quality. Therefore, the adsorbent finishing is a more suitable option for improving energy exchanging of the exchanger, although its efficiency is a bitter lower than that of the absorbent filming.

Reference

[1] Catalogue data of the fibre heat and mass exchanger, manual, Hangzhou ISAW Technology Corporation, 310018, CHINA, 2005.

[2] Michael Piggott, Load Bearing Fibre Composites, 2ed Edition, KLUWER ACADEMIC PUBLISHERS, 2002

[3] L.Tadrist, M. Miscevic, O. Rahli, F. Topin, About the use of fibrous materials in compact heat exchangers, Experimental Thermal and Fluid Science, Vol. 28 (2004) 193-199

[4] Ana Espert, Francisco Vilaplana, Sigbritt Karlsson, Comparison of water absorption in natural cellulosic fibres from wood and one-year crops in polypropylene composites and its influence on their mechanical properties, Composites: Part A , Vol. 35 (2004) 1267–1276

[5] S. Liu, X. Zhao, S. Riffat and Y. Yuan, Comparative Study of the Hydrophilic Materials for Air-to-Air Heat/Mass Transfer, in press

[6] S.Liu, A novel heat recovery/desiccant cooling system, PhD Degree Thesis, Nottingham University, 2008

[7] ASHRAE Handbook, Fundamentals, SI Edition, 2001, Chapter 22 – Sorbents and Desiccants, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 22.1 - 22.3

[8] ASHRAE Handbook, Fundamentals, SI Edition, 2001, Chapter 22 – Sorbents and Desiccants, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 22.3 – 22.5.

[9] J.E. Parrott and Audrey D.Stuckes, Thermal conductivity of solids, Pion Limited, 1975, p 92,123,144

[10] Welty J. R., Wicks C. E., Robert E.Wilson, Gregory L.Rorrer, Fundamentals of Momentum, Heat, and Mass Transfer, John Wiley & Sons, Inc (2001) 723–724.

[11] K. Wang, J.Y. Wu, R.Z. Wang, L.W. Wang, Effective thermal conductivity of expanded graphite–CaCl2composite adsorbent for chemical adsorption chillers, Energy Conversion and Management 47 (2006) 1902–1912

[12] ASHRAE Handbook—HVAC Systems and Equipments Chapter 44, 2004

Figure

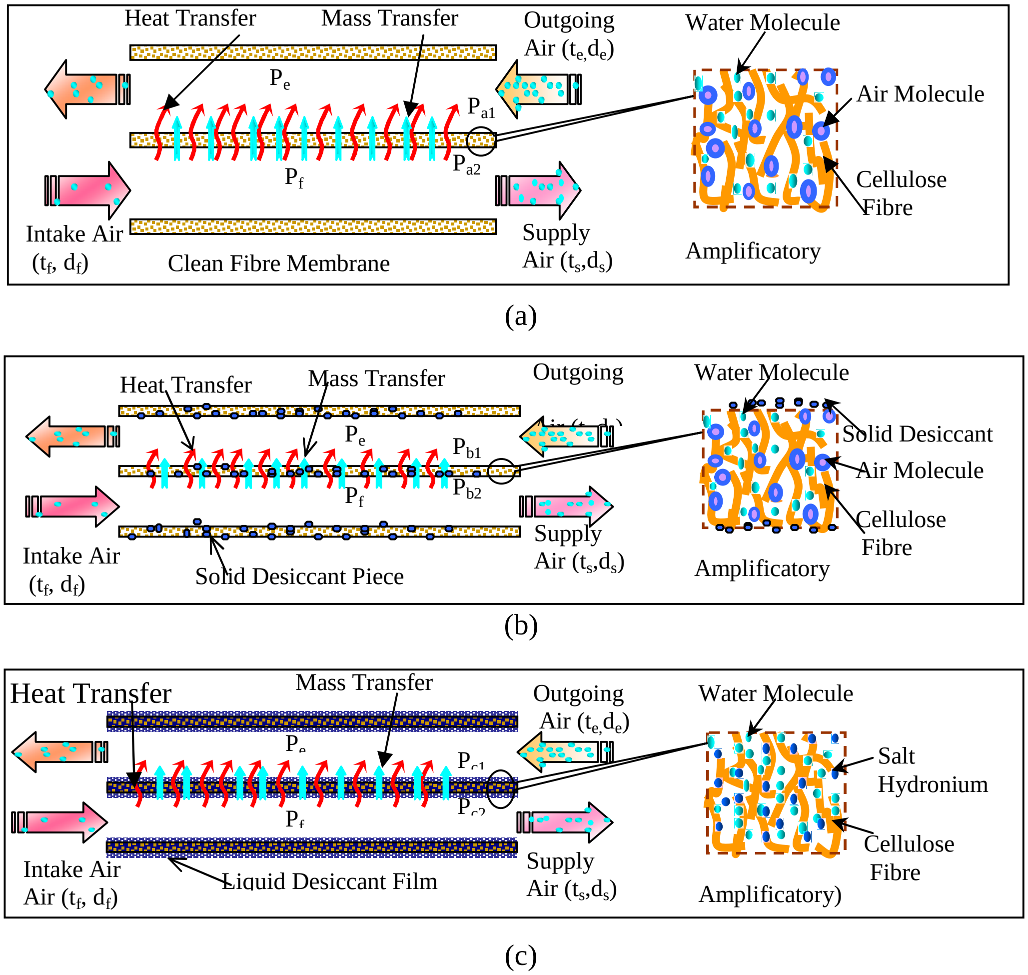


Fig.1. Schematic diagram of three types of cellulose fibre membranes (a) Clean fibre membrane (b) Solid desiccant-coated fibre membrane (c) Liquid desiccant-soaking fibre membrane

Figure

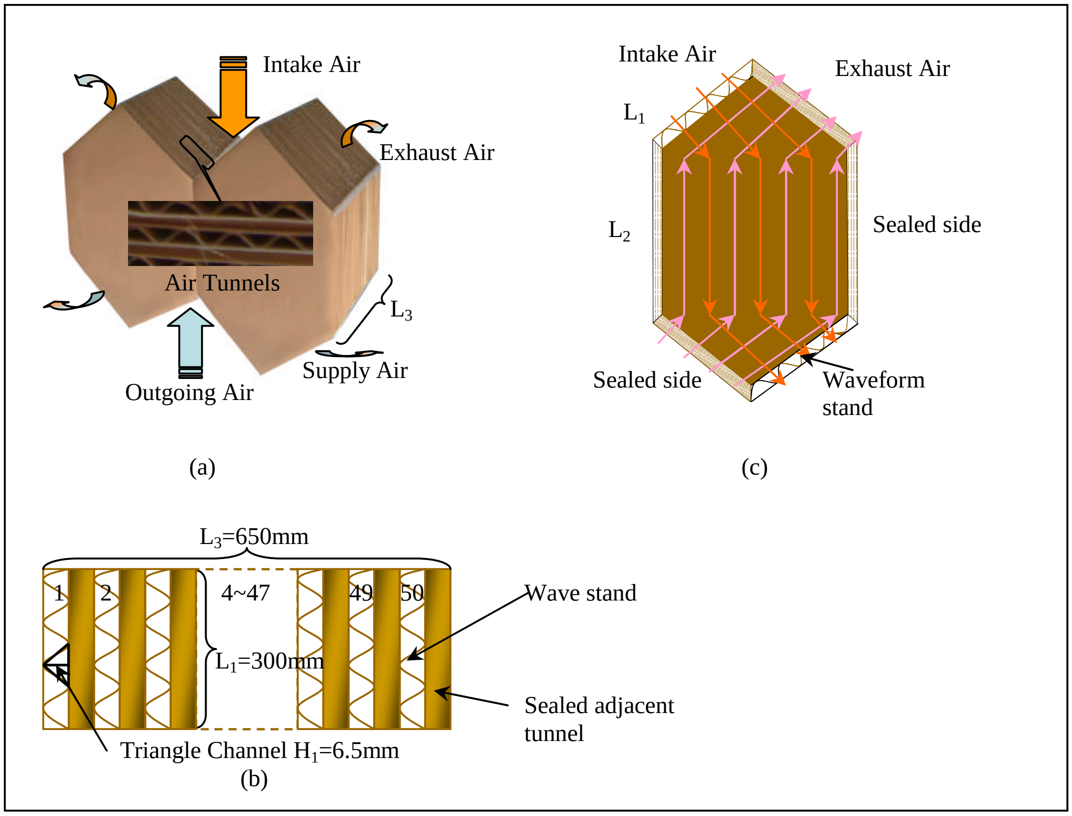


Fig.2. (a) Prototype of cellulose fibre exchanger (b) Schematic diagram of one layer of the fresh air tunnel (c) Schematic diagram of C side

Figure

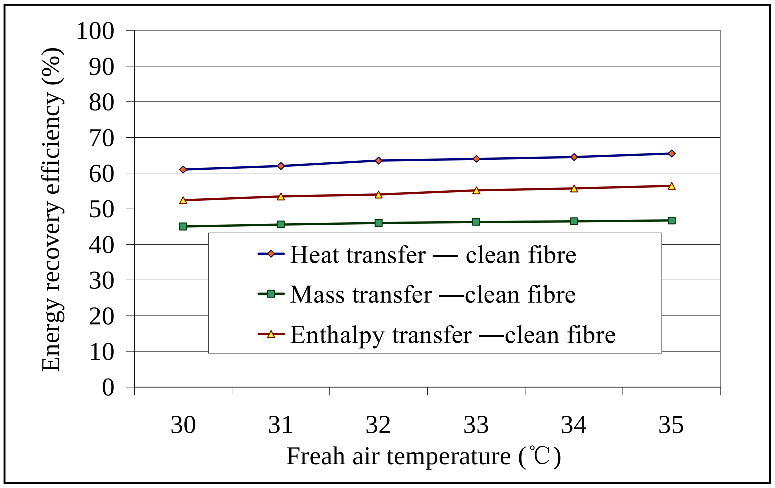


Fig.3. Heat & mass recovery efficiency of the clean fibre exchanger vs. fresh air temperature

Figure

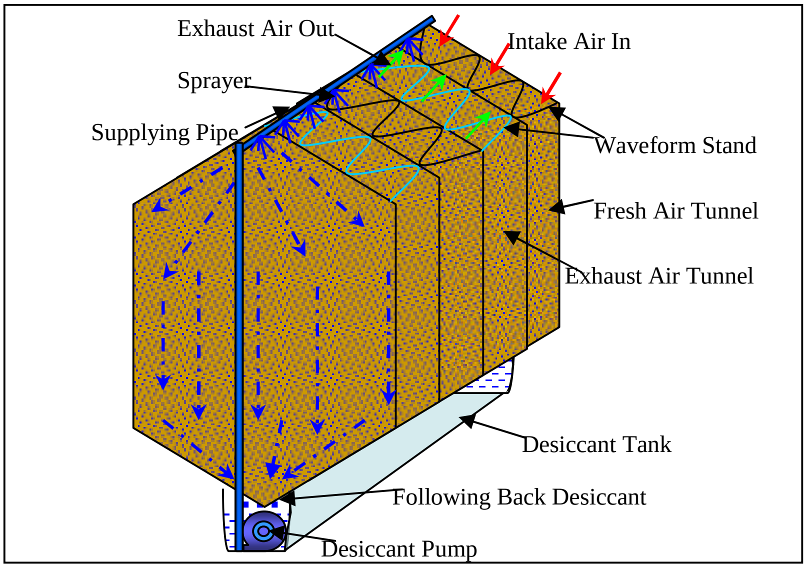


Fig.4. Schematic diagram of cellulose fibre stack exchanger

Figure

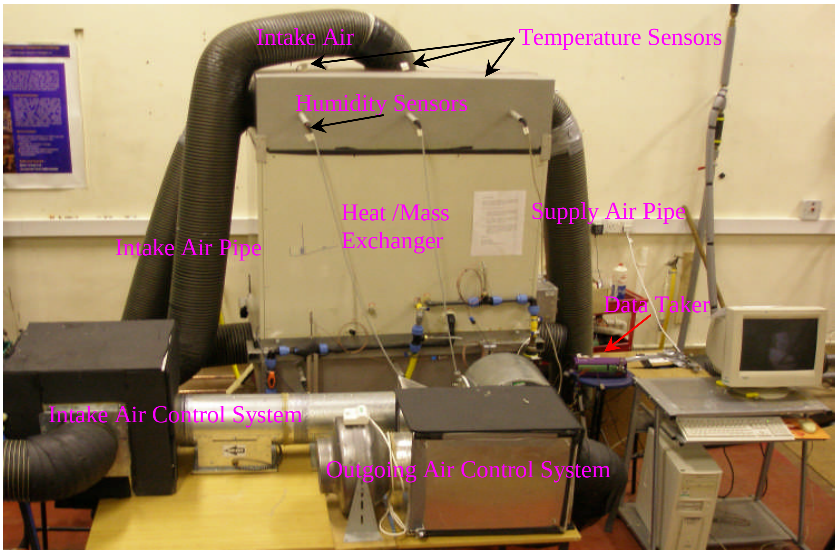


Fig.5. Heat/mass exchanger testing rig

Figure

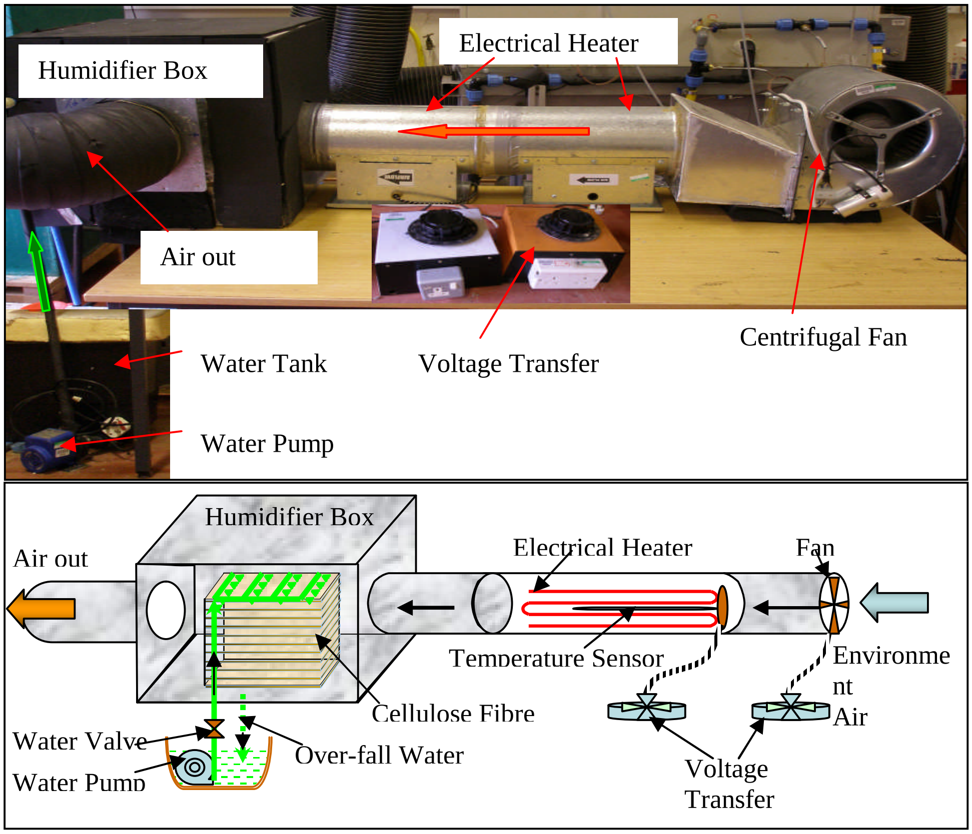


Fig.6. Prototype and schematic diagram of the airflow control system

Figure

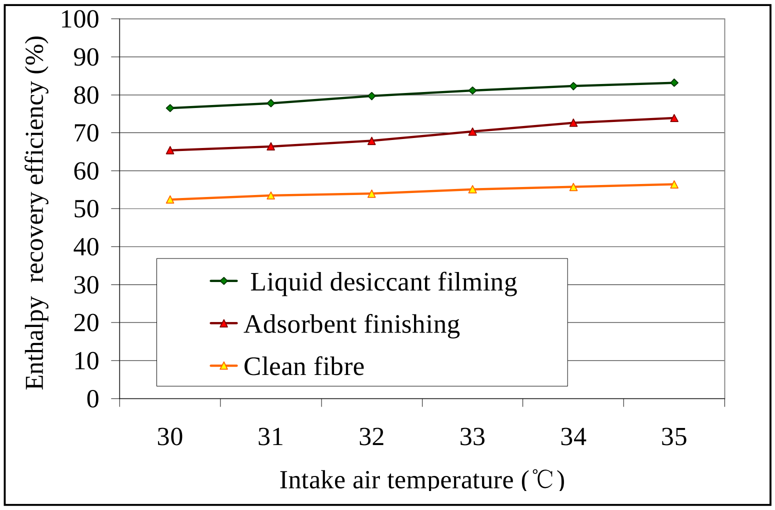


Fig.7. Enthalpy recovery efficiency of three fibre exchangers vs. intake air temperature

Figure

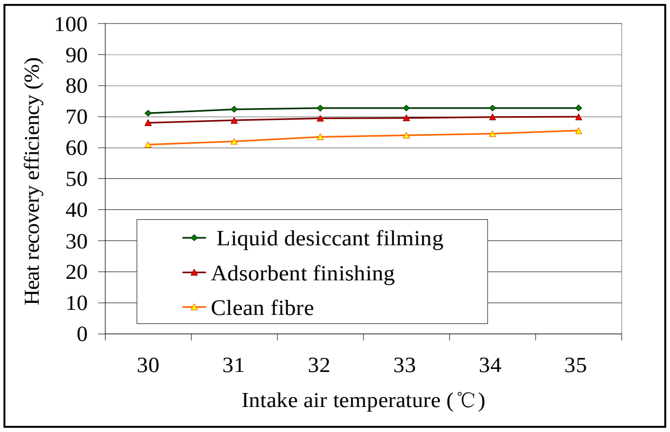


Fig.8. Heat recovery efficiency of three fibre exchangers vs. intake air temperature

Figure

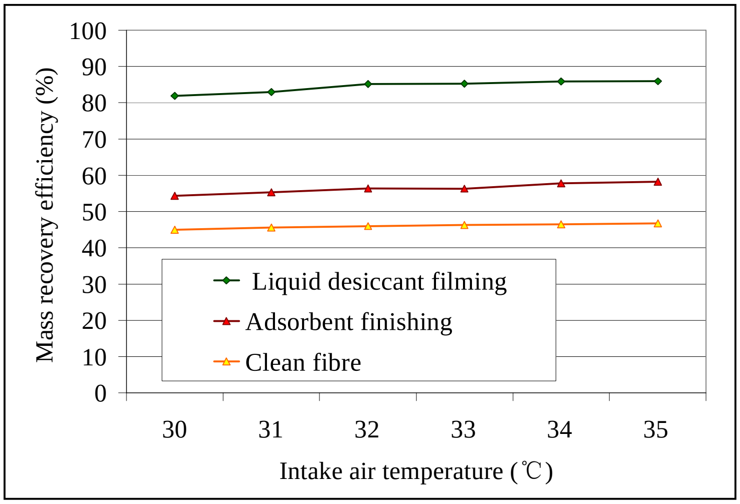
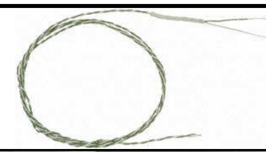
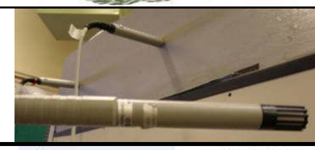


Fig.9. Mass recovery efficiency of three fibre exchangers vs. intake air temperature

Table

Table 1 Experimental measuring equipment

Equipment	Type	Measurement range (%)	Measuring Accuracy	Image
Thermocouples	T 219-4696	-50~200℃	±1℃	
Humidity sensor	HMP45A	0.8~100%RH	±2%RH (0~90%RH) ±2%RH (0~90%RH)	
Thermal anemometer	TA 45	Velocity range: 0.25~30m/sec; Volume flow range: 0~270m^3/sec	At 20℃: ±3%