Applied Energy 179 (2016) 99–109

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A novel design of a desiccant rotary wheel for passive ventilation applications

Dominic O'Connor *, John Kaiser Calautit, Ben Richard Hughes

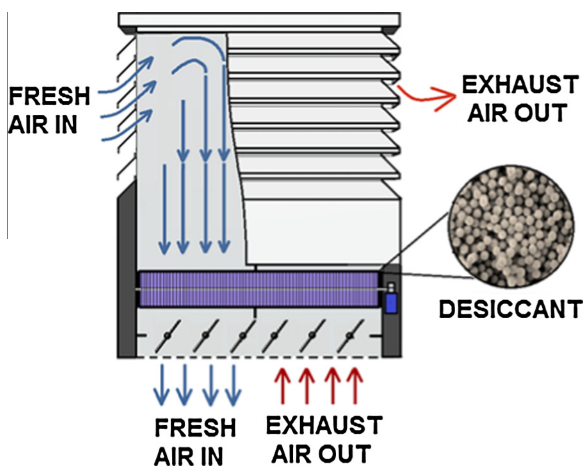
Department of Mechanical Engineering, University of Sheffield, Sheffield S10 2TN, UK

HIGHLIGHTS

- A novel design of a desiccant rotary wheel has been conceptualised.
- The novel design has been tested using Computational Fluid Dynamics and prototype testing.
- Results show that dehumidification of an airstream up to 55% is achieved.
- The regeneration temperature has been lowered to 48.5 °C, significantly lower than previous results.
- The pressure drop across the new design was measured as 2 Pa, significantly lower than previous results.

GRAPHICAL ABSTRACT

Wind tower with desiccant rotary wheel integration concept.



ARTICLE INFO

Article history:
Received 4 April 2016
Received in revised form 3 June 2016
Accepted 11 June 2016

Keywords:
Rotary desiccant wheel
Passive ventilation
Computational Fluid Dynamics
Dehumidification
Rapid prototyping
Wind tunnel

ABSTRACT

Rotary desiccant wheels are used to regulate the relative humidity of airstreams. These are commonly integrated into Heating, Ventilation and Air-Conditioning units to reduce the relative humidity of incoming ventilation air. To maximise the surface area, desiccant materials are arranged in a honeycomb matrix structure which results in a high pressure drop across the device requiring fans and blowers to provide adequate ventilation. This restricts the use of rotary desiccant wheels to mechanical ventilation systems. Passive ventilation systems are able to deliver adequate ventilation air but cannot control the humidity of the incoming air. To overcome this, the traditional honeycomb matrix structure of rotary desiccant wheels was redesigned to maintain a pressure drop value below 2 Pa, which is required for passive ventilation purposes. In addition to this, the temperature of the regeneration air for desorption was lowered. Radial blades extending out from the centre of a wheel to the circumference were coated in silica gel particles to form a rotary desiccant wheel. Computational Fluid Dynamics (CFD) modelling of the design was validated using experimental data. Reduction in relative humidity up to 55% was seen from the system whilst maintaining a low pressure drop across the new design. As an outcome of the work presented in this paper, a UK patent GB1506768.9 has been accepted.

* Corresponding author.
E-mail address: dboconnor1@sheffield.ac.uk (D. O'Connor).

http://dx.doi.org/10.1016/j.apenergy.2016.06.029
0306-2619/

1. Introduction

Up to 80% of a person's time is now spent indoors in a closed environment [1]. This means that the indoor conditions to which occupants are subject to must conform to occupant demands, and should be managed by systems capable of delivering these demands. Thermal comfort, good air quality to maintain health, reliability and control of the system are all key to delivering satisfactory internal conditions for occupants [2]. At present, this role is primarily fulfilled by mechanical Heating, Ventilation and Air-Conditioning (HVAC) systems. Whilst mechanical HVAC systems are capable of delivering the necessary conditions to occupants of comfortable indoor conditions, high energy consumption of such systems contributes a significant amount of greenhouse gas emissions to the climate. The construction, operation and maintenance of buildings accounts for 40% of the total global energy consumption [3]. Within this sector, HVAC systems account up to 40% of the total consumption [4]. Reducing the energy consumption of HVAC systems would substantially reduce the energy consumption of buildings and lead to a reduction in greenhouse gas emissions [5].

The relative humidity of incoming supply air can have a significant impact on the energy consumption of HVAC systems [6]. High relative humidity levels coupled with moderate-to-high air temperature leads to discomfort to occupants, this is caused by high moisture levels in the air preventing evaporation of sweat from the skin's surface [7]. As sweat cannot evaporate, the body's natural cooling mechanism cannot operate effectively and so body temperature rises, increasing the thermal discomfort felt by the occupant. By reducing the level of relative humidity in the air, occupant comfort would increase. High moisture content of indoor air can also have serious health implications for occupants. The presence of high moisture content and warm indoor air temperatures can result in the growth of bacteria and mould [8]. The spores emitted from these growths can affect occupant health, primarily relating to respiratory and skin problems [9]. Reducing the relative humidity of indoor air and maintaining continuous ventilations prevents bacteria and mould build-up.

Rotary desiccant wheels are energy recovery heat exchangers that operate with regard to relative humidity reduction and are often utilised in mechanical air-conditioning systems. The walls of the rotary wheel are commonly fabricated in a honeycomb or sinusoidal shape to form a matrix structure to maximise the surface area, this can be seen in Fig. 1.

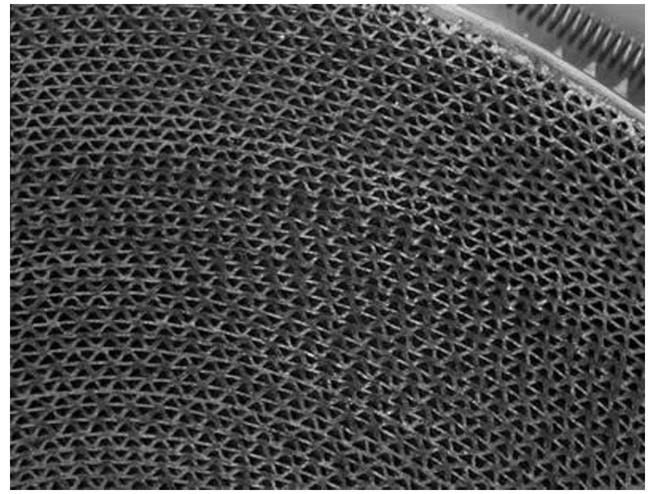


Fig. 1. Section of the matrix of a desiccant wheel for mechanical HVAC.

In this application, desiccant materials are used to transfer moisture from one airstream to another through the process of adsorption and desorption [10]. The mechanisms of adsorption and desorption in desiccant materials have been thoroughly explored in literature [11] along with the various desiccant materials which can be used in rotary desiccant wheel systems [12,13]. Desiccant materials have moisture adsorptive properties; the adhesion of gas, liquid or dissolved solids molecules to the surface of a solid. Adsorption is a weak interaction and can be reversed. In the case of desiccant rotary wheels used for ventilation, silica gel (hydrated silicon dioxide) is the most common desiccant material used for a wide range of applications [14].

There are a number of factors which restrict the widespread uptake of these recovery devices. A high pressure drop in the air flow is experienced across devices, typically up to 100 Pa depending on the system type and configuration [15]. This can be overcome in mechanical systems with fans and blowers. Furthermore, the temperature required for desorption of the water from the surface of the desiccant is generally within the range of 80–120 °C which incurs high energy costs from the regeneration airstream. For desiccant rotary wheels to become a more commonly integrated device in ventilation systems, modifications to the systems are required which can alter the incoming air to maximise comfort to occupants, exhibit low pressure drop on the air flow and operate continually and successfully with a lower regeneration temperature.

Rotary desiccant wheels operate by continuously rotating between two or more airstreams at a low angular velocity. The airstreams have varying conditions; for example in a temperate climate such as the UK, the inlet airstream is cooler with high relative humidity whereas the exhaust/regeneration airstream is drier with a higher air temperature. The section of the wheel which is rotating through an airstream with high relative humidity adsorbs moisture onto the desiccant. The process of adsorption results in a temperature increase of the humid airstream, in certain climates this requires the air to be cooled for thermal comfort. This two-step approach can incur significant additional cost if systems are inappropriately designed. The continued rotation of the wheel results in the section of the wheel which is saturated moving into the drier, hotter airstream. Here, desorption takes place where the moisture on the surface of the desiccant is released into the airstream due to the high temperature and low relative humidity, where the silica gel returns to its original state before adsorption.

A new, and previously untested, structure for rotary desiccant wheels was conceptualised, designed and tested to achieve these aims. By replacing the traditional honeycomb/sinusoidal wave matrix structure of the desiccant wheel with blades which extend out from the centre of the wheel, it was envisioned that a high levels of moisture adsorption could be achieved. Further aims of the redesigned desiccant wheel were to lower the regeneration temperature and pressure drop across the wheel due to the large openings between the blades, when compared to existing devices. The new design of the rotary desiccant wheel, termed as the "radial blade design", was analysed using experimental testing to validate Computational Fluid Dynamics (CFD) models for the same geometry. 3D prototyping was carried out to build the desiccant rotary wheel used to validate the CFD models. No previous work has been conducted redesigning the structure of the desiccant wheel matrix to reduce relative humidity levels and limit the pressure drop, enabling integration into a wind tower or other passive ventilation system.

2. Previous related work

The rate at which the desiccant material adsorbs/desorbs moisture can be controlled by building operators and so can regulate