Renewable and Sustainable Energy Reviews 59 (2016) 73–83

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Solid desiccant dehumidification and regeneration methods—A review

Kishor S. Rambhad *, Pramod V. Walke, D.J. Tidke

G. H. Raisoni College of Engineering, Nagpur 440016, India

ARTICLE INFO

Article history:
Received 8 December 2014
Received in revised form
10 November 2015
Accepted 27 December 2015

Keywords:
Dehumidifier
Regeneration
Solar concentrator
Solid desiccant

ABSTRACT

Desiccant dehumidification system is an alternate option against conventional dehumidification system in hot and humid climates. Conventional dehumidification systems have many drawbacks that include high power consumption and increase the chlorofluorocarbon (CFC) level in the environment and major contribute to depletion of ozone layer. This paper discuss the functioning of dehumidification, cooling and air-conditioning systems using various solid desiccant with focus on the use of solar energy for dehumidification of humid air and regeneration of solid desiccant wheel. A comparative study of various dehumidification, cooling and air-conditioning systems show that solid desiccant has low operating and maintenance cost and is environment friendly.

Contents

* Corresponding author.
E-mail addresses: kishorsrambhad@gmail.com (K.S. Rambhad), pramod.walke@raisoni.net (P.V. Walke), d.tidke@raisoni.net (D.J. Tidke).

http://dx.doi.org/10.1016/j.rser.2015.12.264
1364-0321/

1. Introduction

In tropical countries, increasing demand for active air-conditioning has lead to a large consumption of electric power (as compared to the energy demand for the sensible cooling of air). The high humidity in the tropics results in a significantly high air dehumidification load. Separate handling of the dehumidification load and sensible cooling load can significantly reduce the requirement of power for air-conditioning [1] if the dehumidification is done by solar thermal or waste heat recovery instead of using electricity. Desiccant cooling and air-conditioning systems that use solid or liquid desiccant are an interesting substitute [2–10] to an electrically driven vapor compression cooling system [2–10]. Heat requirement can be satisfied by supplying thermal waste [11] and solar energy [7,12] which are low grade energy system. Development of conventional desiccant [13–17], natural desiccant [18], bio-desiccant [19–23] and composite desiccant like silica gel and lithium chloride [24–39] have been the area of investigation relates to general aspects of solid desiccants and their areas.

Mathematical modeling, thermal analysis and experimental investigations have been performed over the past several by many researchers have focused on various aspects of the desiccant dehumidification [40]. These includes the desiccant material studies [41–44], rotary desiccant dehumidification and air conditioning processes [45–52] and performance modeling of desiccant wheels [53–57].

Air dehumidification is crucial aspect for increasing durability of products because dry air is used for improving the process, product or conditions in large industries such as food production, pharmaceutical production, industrial chemicals production etc. It is also required in goods storage, packaging equipment rooms, organic plant, inorganic products and hygroscopic raw materials storage [58].

Researchers have been used variety of dehumidification techniques only a few out of these have been listed in this paper. Conventional dehumidification based on vapor compression refrigeration system suffers from the disadvantage that the system has low efficiency. In this system evaporative temperature is lowered below dew point temperature. It leads to the growth of mold on the heat exchanger tubes surface or air ducts, which is also a serious problem for the depletion of ozone layer and human health. Other typical method of creating dry air is compression based dehumidification. When air gets compressed, the dew point temperature of moist air is increased till the moisture condensed from the air at a comparatively higher temperature. However, the quantity of cooling water needed for after cooling makes it unrealistic for large volume of air. It is very tough to handle the high range of pressure required with proper safety [59].

Desiccant dehumidification and air-conditioning system have received much attention in recent times as an substitute to the conventional dehumidification system. Humid air can be dehumidified without water condensation using desiccant dehumidification as there is direct contact between humid air and dry desiccant. The regeneration/reactivation of desiccant can be done using low grade regeneration heat source such as the solar energy and the waste heat from a cogeneration of other source [60,61]. Many researchers have tried to reduce the regeneration temperature by implementing high efficiency cooling sources and by utilizing high-efficiency and renewable heating sources such as solar heating [62–71].

Rotary desiccant wheel is widely applied for solid desiccant cooling and dehumidification system for removing latent load also for direct evaporative cooling by taking up sensible heat. Researchers have also developed different cycles to achieve high system performance or optimal configuration or method [72–75]. Some researchers integrated desiccant system with vapor compression cycle [76–79].

2. Desiccant dehumidification and cooling: Principle

Fig. 1 shows desiccant dehumidification and cooling system. In desiccant dehumidification and cooling system, moist air stream is allows to flow through desiccant material and then dry air comes out of the desiccant material. If the adsorption process is continued, ability to adsorb moisture of desiccant material decreases. Therefore, to keep system working constantly, the water vapor adsorbed must be removed. This is done by heating the desiccant material to its temperature of regeneration depending on the type of desiccant material used. Desiccant material can be generated by low grade heat source like solar energy, waste heat, natural gas etc.

When solid desiccant is employed, the desiccant dehumidification system consist of slowly rotating desiccant wheel of adsorbent bed. In liquid desiccant based dehumidification liquid desiccant is brought in contact with the moist air stream [80].

3. Rotary desiccant wheel

In rotary desiccant wheel, an air to air heat and mass transfer takes place, at low rotation speed. Wheel consists of a frame with thin layer of desiccant material. The channels of desiccant wheel frame are fabricated in various structures like honeycomb, triangular, sinusoidal etc. [81].

Fig. 2 illustrates the basic operating principle of rotary desiccant dehumidifier schematically. The cross section of wheel is divided into moist (process) air side and regeneration air side. When the wheel constantly rotates through two separate sections, the process air is dehumidified by the desiccant due to the adsorption effects of the desiccant material. At the same time, the regeneration air is humidified after being heated by a heater and desorbing the water from the wheel [82].

3.1. Effectiveness of desiccant wheel

Different definitions of desiccant wheel's thermal effectiveness have been introduced by different researchers. The first expression of desiccant wheel efficiency is given by Eq. (1) [83,84].

Thermal effectiveness

$$\varepsilon_{DW,1} = \frac{T_{po} - T_{pi}}{T_{ri} - T_{pi}} \tag{1}$$

T_{pi}, T_{po} and T_{ri} are inlet and outlet temperature of process air and inlet temperatures of regeneration air respectively. Another expression of regeneration effectiveness of desiccant wheel is given by Eq. (2) [83,84].