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Research paper

Three years experimental comparative analysis of a desiccant based air conditioning system for a flower greenhouse: Assessment of different desiccants

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HIGHLIGHTS

- This paper presents a three years experimental comparative analysis.
- Three different desiccants were tested: H_2O/LiCl, H_2O/KCOOH, H_2O/LiBr.
- The desiccant-based system exhibits a primary energy saving from 9.6% to 15.1%.
- H_2O/KCOOH seems to be very promising as "desiccant of the future".

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ABSTRACT

This paper presents three years experimental comparative analysis of a desiccant-based and a traditional air conditioning system for a flower greenhouse in the winter season. Two identical neighbouring flower greenhouses were equipped with a traditional and an innovative air conditioning system respectively. The innovative air conditioning system is based on the Ventilated Latent Heat Converter (VLHC) AGAM 1020 that consists of a dehumidification and a regeneration unit. Heat recovery is performed on the desiccant regeneration process to warm up the dehumidified air coming back into the greenhouse.

Comparative analysis was carried out for three years using three different desiccants in the VLHC: H_2O/LiCl in 2010, H_2O/KCOOH in 2011 and H_2O/LiBr in 2012. The greenhouse equipped with a sorption unit exhibits an energy saving of 9.6% in 2010, 11.7% in 2011, and 15.1% energy saving in 2012. The comparative analysis gives the opportunity for the assessment of the hygroscopic salt solutions currently used as desiccants. Although H_2O/LiBr desiccant exhibits the best performance, the solution H_2O/KCOOH seems to be very promising as "*desiccant of the future*".

1. Introduction

The control of humidity ratio and temperature levels in flower greenhouses is of great importance both under an energetic and economic point of view. In fact, non-optimal humidity and temperature values might produce the condensation of moisture on plants with the proliferation of diseases such as botrytis, which compromises the production of the greenhouse. Moreover, improper thermo-hygrometric conditions inside the greenhouse might increase the heat losses through the envelope enhancing the energy consumption.

A new possibility of controlling the thermo-hygrometric conditions inside the greenhouse is offered by the desiccant technology which allows a reduction of the humidity in the greenhouse together with a decrease in energy required for heating the greenhouse thanks to the heat recovery on desiccant regeneration. The desiccants might have also a direct sanitising effect removing the microbial content of the air [1].

Recently, in 2013, Mohammad et al. [2] have applied Artificial Neural Network approach to investigate the technical feasibility of a solar hybrid liquid desiccant air conditioning system based on H_2O/LiCl solution for greenhouse application in Malaysia.

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Nomenclature

C_p	specific heat capacity (kJ kg^{-1} K^{-1})
E	energy (kWh)
G	hourly consumption (l h^{-1})
k	coverage factor
NCV	net calorific value (kJ l^{-1})
p	partial vapour pressure (Pa)
RH	relative humidity (%)
T	temperature (°C or K)
V	volume flow rate (m^3 h^{-1})
X	humidity ratio (g kg$^{-1}_{dryair}$)
ε	efficiency
ρ	density (kg m^{-3})
λ	thermal conductivity (W m^{-1} K^{-1})
μ	dynamic viscosity (cP)
τ	time (h)
ξ	concentration (kg$_{salt}$ kg$^{-1}_{solution}$)

In 2010, the authors of present paper carried out the experimental comparative analysis between a traditional and an innovative air conditioning system based on the traditional desiccant H_2O/LiCl in the winter season [3]. The experimental results were compared against a simulation model of the whole greenhouse to evaluate and optimise the potential savings and the control strategy of the innovative system. The simulation model of the greenhouse includes a detailed analysis of the heat and mass transfer processes in the traditional and the innovative systems.

Experimental comparative analysis was continued in 2011 and 2012 winter seasons by using the desiccant H_2O/KCOOH and H_2O/LiBr. H_2O/LiBr was selected as it is recognised in the literature to provide better performance, in many respects, and H_2O/KCOOH was selected because of the highly interesting features of being non corrosive, non toxic and less expensive. This paper reports the results of the whole three years comparative analysis and carries out the assessment of the hygroscopic salt solutions currently used as desiccants.

2. System description and measurement

Two identical neighbouring flower greenhouses working in northern Italy were equipped with a traditional and a desiccant-based air conditioning system respectively. Each greenhouse is equipped with the canalised unit heaters for temperature control and relies on natural ventilation by controlled roof opening for humidity control.

The desiccant-based air conditioning system consists of the Ventilated Latent Heat Converter (VLHC) AGAM 1020 basically working with the hygroscopic salt solution H_2O/LiCl [4]. The VLHC system dehumidifies the humid air coming from the greenhouse by the cold strong hygroscopic salt solution, and the heat of absorption warms up both the dehumidified air and the solution. The diluted solution, after the dehumidification process, is further heated up by hot water coming from a gas oil boiler and regenerated by scavenger air evolving in a closed loop. Heat recovery is performed on the desiccant regeneration process by condensing part of the humidity content of the scavenger air at the outlet of the regeneration unit and using the relative latent heat to warm up the dehumidified air coming back into the greenhouse. In this way a part of the latent content of the humid air of the greenhouse is converted into sensible heat of the dehumidified air (latent to sensible heat conversion). Fig. 1 shows a real and a schematic view of the AGAM VLHC 1020 system. The VLHC unit is directly controlled by a hygrometer inside the greenhouse.

In the traditional system the thermo-hygrometric control is carried out by ventilation with outside air (latent load) and a radiator driven by hot water (sensible load).

The heat flow rate supplied to the VLHC unit was recorded by monitoring the working time $\Delta\tau_{boiler}$ of the dedicated gas oil boiler and multiplying it by the hourly fuel consumption of the boiler G_{fuel}, the Net Calorific Value of the fuel NCV, the efficiency of the boiler ε_{boiler} and the efficiency of the distribution line ε_{boiler}:

$$\Delta E_{t.VLHC} = \Delta\tau_{boiler} G_{fuel} NCV_{fuel} \varepsilon_{boiler} \varepsilon_{distr} \quad (1)$$

$$G_{fuel} = 5.6\, l/h \quad NCV_{fuel} = 35200\ kJ/l \quad \varepsilon_{boiler} = 0.85 \quad \varepsilon_{distr} = 0.95$$

The heat flow rate supplied to the radiators both in the innovative and traditional greenhouse was monitored by a calorimeter Caleffi mod. 7554 [5] which measures the hot water volume flow rate V_{water} and its temperature variation ΔT_{water} through the radiator. The relative heat flow rate was calculated by the following correlation:

$$\Delta E_{t.radiator} = \rho_{water} V_{water} C_{p_{water}} \Delta T_{water} \quad (2)$$

The total energy demand of the innovative greenhouse includes the heat flow rates supplied to the VLHC system and to the auxiliary

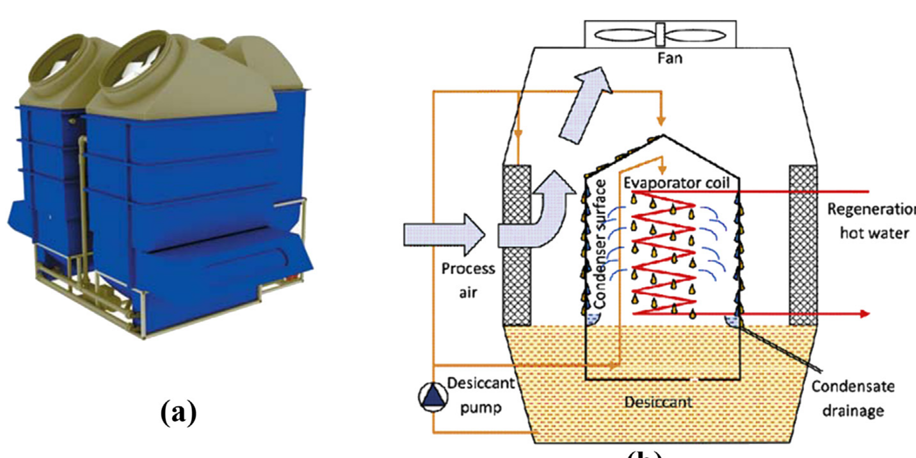

Fig. 1. Ventilated Latent Heat Converter (VLHC) AGAM 1020: a) real view, b) schematic view.