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Research Paper

Studies on combined cooling and drying of agro products using air cooled internal heat recovered vapour absorption system

R. Sivakumar [a,*], A. Elayaperumal [b], R. Saravanan [a]

[a] Refrigeration and Air Conditioning Laboratory, Department of Mechanical Engineering, Anna University, Chennai 25, India
[b] Engineering Design Division, Department of Mechanical Engineering, Anna University, Chennai 25, India

HIGHLIGHTS

- Air cooled ammonia–water absorption heat pump cum cooling system for drying and cold storage is developed and tested.
- Combined cooling and drying mode operation in the system was able to achieve overall COP of 1.4–1.8.
- Discussion of drying characteristics and parameters of nylon sago and simulated cold storage system is presented.

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ABSTRACT

The objective of this study is to develop an energy efficient heat pump combined storage and drying technology for agricultural products, to reduce the net energy consumption compared to conventional storage and drying systems. An experimental study of an improved air cooled condenser and absorber in ammonia–water vapour absorption refrigeration system and using more internal heat recovery by generator absorber heat exchangers is carried out simultaneously using the generated hot air for drying and better storage of the agricultural product. Vertical annulus radial grain bin dryer of 5 kg/h capacity is adopted to suit 10.5 kW for cold storage ammonia absorption refrigeration. The effect of heat sink and evaporator temperatures on the coefficient of performance (COP) of the system and the heat rejected from condenser and absorber for drying applications are studied. The temperature of the air at the outlet of the condenser/absorber is around 43–53 °C for various atmospheric conditions and is used for drying of the selected agro product (nylon sago) in the bin dryer. The drying characteristics of nylon sago, heat pump capacity and combined COP of the system are presented with descriptions. It is found that the combined COP of the system varies from 1.8 to 1.4 when the heat rejection temperature is between 53 °C and 43 °C respectively under actual operating conditions.

1. Introduction

Cooling, heating and power generation systems are the most important energy consumers in the world. To overcome the individual system losses, transmission losses and to minimize the total energy consumption, combined cooling heating and power generation (CCHP) systems are developed with ammonia absorption refrigeration as Kalina cycle. This CCHP system utilizes low form of waste heat from many generation processes and offers higher electrical energy generation efficiency compared to conventional steam cycle systems. This ammonia–water cycle is successful for many waste heat and renewable energy applications [1]. A typical food industry needs heating, cooling and refrigeration facilities for products, with drying facility for raw materials and finished goods. The conventional cooling, heating and power generation systems are based on fossil fuels or electrical energy for their operation. The overall source efficiency of conventional power generation systems is really low, which results in high cost of energy including transmission and carbon losses [2].

Cogeneration is widely recognized as an alternative to conventional cooling, heating and power generation processes. Thermally activated cogeneration systems favour better overall efficiency as compared to individual conventional systems [3,4]. Hence research activities were accelerated on combined cooling, heating and power generation technologies. Among CCHP cycles, vapour absorption systems in cooling or heating modes demand strong attention because these systems accept low and medium energy sources for their operation of combined production of heating and cooling [5]. A laboratory scale CCHP test plant, composed of a natural gas fired internal combustion engine generator whose waste heat drives a double effect absorption heat pump and a liquid desiccant refrigeration unit with heat recovery unit, is reported to offer maximum efficiency of 75–90% in combined cooling or heating with power generation mode [6,7].

* Corresponding author. Tel.: +91 8973589273; fax: 044-2235 3637.
E-mail address: thermalsiva@gmail.com (R. Sivakumar).

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In a similar approach, it is found that production of heat to use for drying agricultural products and at the same time using the cold for separate, effective, long term storage in controlled atmosphere is possible using the vapour absorption system. It will provide considerable saving in overall energy than separate conventional drying and cold storage systems [8–10]. Keeping the moisture content and the storage temperature at low levels is the fundamental concept to increase the lifespan of agricultural products. This is because with higher moisture content at open atmosphere, possibilities for growth of micro-organisms, molds and other degrading bacteria are high, which reduces the lifespan of the products. In general, moisture present in the hygroscopic products is removed (up to safe level) by desorption operation in which hot air blown over the fresh wet products desorbs the water from the product thereby increasing the humidity of outlet air. However, in this drying operation a number of key factors such as temperature, pressure, grain structure, moisture content, air relative humidity and air velocity are involved [11]. On the other hand, some of the dried and fresh commodities should be stored at low temperature (≤10 °C) in order to prevent bacteria/fungus/other micro-organism growth. Cold storage for food preservation also supports the need to maintain the nutritional value, flavour and texture of the food preserved. Several advanced techniques have been developed for cold storage and drying of agricultural products individually to facilitate short drying time and for limiting wastage. But these systems require investment and operational cost analysis to make it suitable for mass production to meet human needs. In some of the advanced drying methods, undesirable chemical reactions were reported for heat sensitive agro products. Similarly, microwave and infrared drying methods may cause uneven heating and tissue damage if not properly operated. The use of such advanced drying methods will be energy efficient only for particular and selective drying needs determined by the physio-chemical properties of a product [12–14].

On the flipside, reports on hybrid systems such as heat pump assisted convective dryer, microwave assisted fluidized bed dryer, chemical heat pump assisted and solar assisted heat pump dryers demonstrated high quality dried products and higher drying rate with energy cost savings with effective utilization of waste heat. Jangam et al. [15] reviewed and highlighted possible strategies for saving energy in drying operations and concluded that hybrid drying or multistage drying reduced the energy consumption by 20–50% compared to conventional drying methods. The amount of energy savings reported in hybrid or multistage drying systems by the previous study is given in Table 1. As discussed earlier, vapour absorption systems are one of the promising techniques that can be adopted for the development of needed heating and cooling applications. But such studies on combining cooling and drying for agricultural applications are limited.

Hence, the present work illustrates the possibility of simultaneous cooling and drying of agro products using modified air cooled NH_3–H_2O vapour absorption system. The chilled water produced by the system is used for cold storage whereas the heat rejected in the form of hot air by the system is utilized for low temperature drying applications.

Table 1
Hybrid energy efficient drying systems.

Hybrid/multi stage drying	Energy savings	Reference
Wood chip drying with an absorption heat pump	10–15% cost saving and 30% higher in energy efficiency compared to conventional dryer	[16]
Combine microwave–convective drying; Combine microwave–vacuum drying; Solar drying with heat pump.	Almost 10% higher thermal efficiency in all the cases and 8–10% higher drying efficiency than conventional systems.	[17]
Heat pump in drying systems with waste heat recovery	Higher thermal efficiency with increased optimum life time and reduced energy cost.	[18]
Heat pump assisted mechanical dryer	Drying time of the material reduced by four times compared to natural drying.	[19]
Longan drying using heat recovery method, wood as fuel, applying thermal insulation and better temperature and humidity control	20% improvement in thermal efficiency and 80% reduction in fuel cost	[20]

2. Experimental setup

The experimental setup consists of a modified generator absorber internal heat recovery air cooled vapour absorption cooling system (AVAR) attached to a bin dryer unit, as shown in Fig. 1a.

The designed cooling capacity of the modified air cooled absorption system is 10.5 kW with ammonia–water as working pair. The weak (ammonia rich) solution from the absorber is pumped to the generator through four heat exchangers, namely high pressure heat exchanger (HPGAX), low pressure heat exchanger (LPGAX), solution heat exchanger I (SX1) and solution heat exchanger II (SX2). Here the weak solution is preheated by refrigerant vapour (in HPGAX), heat of mixing (in LPGAX), strong solution (in SX1) and flue gas (in SX2) respectively. With the concept of high pressure heat exchanger, the refrigerant vapour is cooled and rectified and the need for separate rectification column is eliminated. The refrigerant vapour from the evaporator is partially mixed with the strong solution in the low pressure heat exchanger (LPGAX) where the heat of mixing is used to pre-heat the weak solution and hence the absorber load is reduced. The other heat recovery components such as condensate pre-cooler and solution cooler help to improve the coefficient of performance of the system. The details of each component such as material, type and heat transfer area are given in Table 2.

At the evaporator side, chilled water from the evaporator is circulated to an air cooler placed inside a cold storage room and hence the room is maintained at a desired low temperature by controlling the chilled water flow rate. The pictorial view of the modified air cooled absorption system with bin dryer is shown in Fig. 1b. The positions of the major components indicating the relative temperature, pressure and mass fraction are shown in the Duhring plot (Fig. 2). The weak solution circuit and the strong solution circuits are represented by processes 1–7 and processes 8–13 respectively, whereas processes 14–24 indicate the refrigeration circuit. The strong solution concentration increases in LPGAX by partial mixing of refrigerant vapour as indicated in processes 12–13.

In the heating side, the heat rejected by exothermic reactions at the air cooled condenser–absorber unit (CAU) is utilized for heating air to use in drying applications of bin dryer attached to

Table 2
Heat transfer area of individual components.

S. No.	Component	Material	Configuration	Heat transfer area (m^2)
1	Absorber	Mild steel	Finned tube	0.89
2	Condenser	Mild steel	Finned tube	0.72
3	Evaporator	Mild steel	Shell and coil	5.77
4	Generator	Mild steel	Direct fired	1
5	HPGAX	Mild steel	Shell and tube	2.98
6	LPGAX	Mild steel	Shell and tube	0.54
7	Condensate pre cooler	Mild steel	Shell and tube	4.55
8	Solution heat exchanger I	Mild steel	Tube and tube	0.68
9	Solution heat exchanger II	Mild steel	Tube and tube	0.1
10	Solution cooler	Mild steel	Shell and tube	0.24
11	Bin dryer	Stainless steel	Cross flow circular bin	0.18

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