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Research paper

Feasibility and economic analysis of solid desiccant wheel used for dehumidification and preheating in blast furnace: A case study of steel plant, Nanjing, China

Yipeng Guan [a, b], Yufeng Zhang [a, b], Ying Sheng [a, *], Xiangrui Kong [c], Song Du [a]

[a] School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China
[b] Collaborative Innovation Center of Chemical Science and Engineering, Tianjin 300072, China
[c] School of Architecture, Tianjin University, Tianjin 300072, China

HIGHLIGHTS

- A novel two-stage desiccant wheel dehumidification system for blast furnace is proposed.
- Average moisture removal of 8.7 g/kg is achieved and dehumidification efficiency is 47%.
- Outlet humidity ratio is less than 10 g/kg that satisfies the requirement of blast air.
- Waste heat in slag flushing water is utilized and 61.4 million kJ is saved annually.
- The investment and operating cost is 37% and 57% of former dehumidification system.

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ABSTRACT

To overcome the shortcomings of huge energy consumption from conventional dehumidification using lithium bromide adsorption refrigerating (LBARD) system, a novel desiccant wheel dehumidification and preheating (DWDP) system using two-stage desiccant wheel for blast furnace is brought forward. The DWDP system was designed for dehumidification and preheating in blast furnace of steel plant. It takes waste heat in the slag flushing water as desiccant regeneration and preheating energy. To validate the feasibility of the new DWDP system, experimental studies were conducted based on a steel plant in Nanjing, China. The experiment was designed to use DWDP system in humid outdoor climates e.g. summer seasons. The experimental results indicate that the moisture removal capacity of DWDP system can reach 8.7 g/kg which will lead to the improvement of steel production by 0.9% and the coal is saved of about 2100 tons per year. With the DWDP system, the energy consumed by cooling tower of slag flushing water can decrease 7.3%. All of these energy saved equates to 10.3 million CNY annually. A comparison of initial investment and operating cost between DWDP system and LBRAD system was then carried out. The results show that the initial investment and operating cost of DWDP system is 37% and 57% of present LBARD system, and the payback period is shortened 66%.

1. Introduction

Dehumidification for blast-furnace is originated in 1940s. It attracted more attentions since 1970s with the advent of world-wide energy crisis in 1970s. Many studies showed that the moisture in the air could cause endothermic reaction and grabbed an amount of energy which was originally designed to be used for steel making. This is more serious in summer seasons which have more humid outdoor climates [1,2]. Therefore removing the moisture in the air delivered to the blast furnace is helpful to reduce the energy consumption and boost the steel output [3].

Nowadays, there are mainly three dehumidification methods applied in the blast furnace including liquid desiccant dehumidification, solid desiccant dehumidification and condensation dehumidification [4]. The solid and liquid desiccant dehumidification is based on the principle of sorption that the moisture in the process air is removed when the air passes through the surface of the desiccant. Lithium bromide crystal and its aqueous solution are normally used as desiccant in liquid dehumidification system to

* Corresponding author. Tel.: +86 186 2200 7007
E-mail address: ysheng@tju.edu.cn (Y. Sheng).

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absorb the moisture. But due to the corrosion of lithium bromide, liquid desiccant dehumidification using lithium bromide is limited in the steel industry since the requirement of protection for fans and air pipes. Condensation dehumidification has been widely used for the dehumidification of blast-furnace air. The principle is to cool the air below the dew point, and then the moisture is condensed out. However a large amount of thermal energy is consumed for overcooling and reheating since the air should be reheated before it is delivered to the blast furnace. Meanwhile, the refrigerants used for condensation dehumidification such as R134a, R744 are either unfriendly to environment or technical immaturely [5,6]. Another application of condensation dehumidification is the lithium bromide absorption refrigerating dehumidification (LBARD) system which uses high temperature steam as driving power. This kind of systems widely used in large steel plants of China such as Chongqing steel plant, Hangzhou steel plant, Maanshan steel plant and Qinhuangdao steel plant [7–10]. With the LBARD system, the humidity of blast-furnace air can be highly decreased. However, the energy consumption of LBARD system is huge due to the utilization of high temperature steam.

Solid desiccant wheel has been widely employed in the industrial dehumidification and indoor humidity control due to its energy efficiency and environmental friendliness. Air-conditioning system based on desiccant wheel dehumidification can attain low dew point dry air and has been utilized in many public buildings such as shops, restaurants and theatres [11,12]. The applications in the supermarket were studied by Burns et al. and Mazzei et al., and positive effects were achieved [13,14]. Solid rotary wheel can also be applied in some special occasions. For example, the desiccant wheel was applied in the indoor skating rink to remove the moisture floating on the ice [15]. Solid desiccant wheel dehumidification can also be used in the industrial sites for providing acceptable indoor air quality to achieve a productive indoor environment. The theoretical analysis of the feasibility of the desiccant wheel used in the medical workshop was investigated by Ding and Zhao [16]. Moreover, desiccant wheel dehumidification also existed in the occasions of seed drying and vegetable preservation in agriculture, paper or ammunition storage where high dryness was required [17,18].

Desiccant wheel is the main component in the dehumidification system. Great efforts including theoretical, numerical and experimental studies have been taken on analyzing the desiccant wheel performance. Ge et al. [19,20], compared the performance of two-stage rotary desiccant cooling system with one-stage system. Low regeneration temperature and high thermal COP were obtained in the two-stage system. Angrisani et al. [21] focused on the influence of rotational speed on the performance of the wheel. Chung et al. [22] studied the effectiveness of wheel speed and regeneration area ratio on dehumidification under a wide range of regeneration temperatures. Optimization of these parameters was conducted based on the wheel performance evaluated by means of its moisture removal capacity. Another important aspect of the desiccant wheel is the available models to simulate its dehumidification performance. In the study of Ref. [23], detailed and simplified models were formulated respectively to enable the numerical prediction of the heat and mass transfer occurring in a two-dimensional channel configuration of parallel plane wall. A comparison of the performance between the two models was conducted. Ge et al. [24] established an optimal mathematical model by taking the both the gas side and solid side resistances into consideration for predicting the performance of silica gel haloid compound desiccant wheel. Furthermore, the main parameters which influence the performance of desiccant wheel were investigated and rotation speed was optimized by utilizing the model. Ruivo and Angrisani [25] investigated the validity of the simplified effectiveness method in predicting the behavior of a desiccant wheel by using different pair of effectiveness parameters based on the experimental data.

The energy required to regenerate the desiccant wheel is the main drawback. When the desiccant material is regenerated by “free” energy, energy saving potential is significant. Sheng et al. [26] made full use of waste heat from high temperature heat pump to regenerate the wheel. Solar energy was used for regenerating desiccant wheel in the study of Mavroudaki et al. [27], and unremitting efforts have been taken on the studying of performance of desiccant wheel driven by solar heat [28]. The waste heat of marine diesel engine can also be used as regeneration heat source [29]. The new regeneration method using electro-osmosis was put forward by Li et al. [30]. Therefore the waste heat utilized for desiccant wheel regeneration could be an energy efficient way for desiccant wheel dehumidification.

However, the exhaust heat especially large amount of low temperature waste heat in steel industry is not utilized reasonably and comprehensively in China. According to the survey [31], 11.2 tons of slag flushing water was released when 1.0 ton of furnace slag was dealt with. In 2013, the production of pig iron was 782 million tons and about 240 million tons of furnace slag were produced, thus nearly 2688 million tons of slag flushing water were generated in steel company of China [32]. The temperature of slag flushing water was up to 80–90 °C after scouring the slag [33]. In order to recycle the slag flushing water, the water was commonly sent to the cooling tower to reduce the temperature to 50 °C. This process not only wasted the heat of slag flushing water but also increased the energy consumption and the investment of cooling tower.

According to the dehumidification requirement and slag flushing water waste heat phenomenon in steel company, a novel solid desiccant wheel dehumidification and preheating system is put forward for providing the dry blast-furnace air and utilizing the waste heat of slag flushing water in this paper. The feasibility of new desiccant wheel dehumidification and preheating (DWDP) system was investigated by the experimental study based on a steel plant in Nanjing, China. The energy saving and economic benefit is analyzed by comparing with the presented lithium bromide absorption-type refrigerating dehumidification (LBARD) system.

2. Design of DWDP system

2.1. System description

The desiccant wheel dehumidification and preheating (DWDP) system is designed for a steel plant in Nanjing, China. The design volume of the blast furnace is 500 m^3 and the volumetric airflow rate is about 75,000–90,000 m^3/h. The flow of cooling water for flushing the slag is 600,000 kg/h with the temperature of 85–90 °C. In the existing system, the flushing water is reused after being cooled to 55 °C by cooling tower. During the cooling, the thermal heat in slag flushing water is wasted, and the heat loss can reach 21 kW when the temperature difference is 30 °C.

DWDP system is designed to use the heat which is lost during the cooling process in cooling tower. The DWDP system is comprised of three subsystems: (1) dehumidification unit; (2) accessorial unit; and (3) preheating unit. The schematic diagram of DWDP system is shown in Fig. 1.

The function of each subsystem is as follows:

(1) Dehumidification unit: one air-to-water heat exchanger and two-stage desiccant wheel dehumidifier are the main components of the subsystem. The desiccant wheel adsorbs the moisture in the process air to realize dehumidification. Heat exchanger keeps the subsystem running continuously by