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Research paper

Hydrodynamic and heat and mass transfer performances of novel ceramic foam packing to humidification tower

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HIGHLIGHTS

- A novel Sic ceramic form corrugated packing is used in humidification tower.
- Relative low pressure loss is promising for gas turbine cycle.
- Excellent heat and mass transfer is favorable for compact humidification tower.

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ABSTRACT

The humidification tower is the key unit of a humid air turbine cycle. The compactness problem of a humidification tower is crucial to the flexibility and safe operation of the cycles. This research focuses on the potential application of the novel ceramic foam corrugated packing in humidification. The hydrodynamics and heat and mass transfer performances of this packing (type FSC-1) are investigated and compared with those of the traditional structured packing (type TJH-250). The experimental results show that the specific surface area obviously increases with a competitive voidage of 93% for ceramic foam corrugated packing. In comparison with THJ-250, FSC-1 exhibits about 60% pressure drop per mass transfer unit, 50% flooding gas velocity, and no more than 37% height of gas-phase mass transfer unit. Although the ceramic foam packing has relatively low air flux, it is also promising for the compact humidification tower due to its excellent heat and mass transfer performance and low pressure loss.

1. Introduction

Over a long period of time, power generation technologies based on gas-fired gas turbines have been paid more attention for its compactness, flexibility, few accessory equipments and low emissions. In order to improve the efficiency of simple-cycle, various advanced gas turbine cycles are proposed and studied. The most successful technology is combined cycle, but this cycle requires a complicated and expensive steam turbine system, which makes it not suitable for small or mid-size power plants. On the other hand, gas turbines using air–water mixtures as the working fluid, such as steam-injected gas turbine (STIG) cycle and Humid Air Turbine (HAT) cycle, may be a solution for this problem [1].

After initially patented by Rao [2] in 1989, HAT attracts increasing research interests for its eminent performance of low grade heat recovery. Different cycle configurations are presented in open literature, such as cascade HAT [3], externally fired HAT [4], part flow HAT [5], Advanced HAT (AHAT) [6] and micro HAT (mHAT) [7]. More recent theoretical investigations are presented in Refs. [8–10]. In contrast, the demonstration and test investigations for cycle layout are still absent so far. The first demonstration of HAT cycle based on a prototype of gas turbine VT600 with 22% efficiency in simple-cycle was performed in Lund University and achieved the efficiency up to 35% [11]. Hitachi built an AHAT pilot plant which substitutes the intercooler between high- and low-pressure compressors in HAT cycle by water atomizing inlet air cooling. The test results indicated an electrical efficiency of 40% when the power output was 3990 kW [12]. Recently, a mHAT cycle facility based on a micro-turbine TG80 has been built in China. At the output power of

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80 KW, the HAT cycle achieves an electrical efficiency of 30.88% which is remarkable higher than that of the recuperated cycle (about 26%) [13]. Another Chinese research group develops a small-sized two-shaft HAT test rig without aftercooler and recuperator. First off-design experiment results are reported in Ref. [14]. More recently, an additional mHAT cycle test rig is built in Belgium, as reported in Ref. [15]. In such system, a Turbec T100 mGT is turned into mHAT using a novel spray saturator with no internal packing. The first preliminary experiment has been carried out to evaluate its characteristics.

HAT is distinguished by introduction of water into the compressed air with a humidification tower at temperatures below the boiling point. In the literature, the governing equations for the simultaneous mass and heat transfer process occurring in a countercurrent humidification tower have been presented by many researchers such as Mickley [16], Enick [17], and Parente et al. [18]. In practice, several different types of humidification tower are proposed. Dalili and Westermark [19] investigated a tubular humidification tower which could humidify compressed air and recovery heat from flue gas at the same time. In our previous work, a no-packing tower using nozzles to inject water in the compressed air [20] was investigated. In this device, contact area between water and air was provided by water droplets and the pressure drop could be decreased. Lindquist [21] and Pedemonte [22] investigated humidification tower with structured internal packing. Hidefumi [23] studied the humidification tower with random packing of modified Raschig ring. Due to uniform contact area all over the volume and mature design method, packed tower seems most likely to be available in commercial HAT package. Therefore, this type of humidification towers had been demonstrated in the existing HAT pilot plants [21,23].

Both pressure drop and compactness are important for humidification tower. The former has a severe negative effect on the cycle performance and low compactness will lead to more thermal and volume inertia which is a threat to the flexibility and safe operation of HAT cycle. On the other hand, it is obvious that faster air velocity in compact design means increasing pressure drop. The goal of this paper is to improve compactness of humidification tower by utilizing novel packing. A ceramic foam corrugated packing is developed and two important parameters for packing (the specific surface area and the voidage) are tested. An experimental facility for packing humidification tower is built. The hydrodynamics and heat and mass transfer performances of this packing are investigated at elevated pressure and compared with those of traditional structured packing. These data may be employed for design of commercial humidification tower with ceramic foam packing in future work.

2. Ceramic foam corrugated packing structure

Ceramic foam studied in this work is in the form of Silicon Carbide (SiC). Due to the advantageous properties such as low density, high specific area and high heat conductivity, SiC ceramic foam has been recognized as a promising material for packing and been used for catalyst support [24] or distillation [25,26]. The material preparation method was developed by the Institute of Metal Research, Chinese Academy of Sciences. Fig. 1 shows the appearance of the typical packing structure and SiC-foam material. The packing is constructed by a group of SiC ceramic foam corrugated sheets and formed as cylindrical module so that the packing height in the tower can be varied in steps. The ceramic foam corrugated packing has similar geometric shape and flow channel with traditional perforated corrugated packing (showed in Fig. 2). However, it has better mass transfer performance because the imbibition effect (leading to transverse flow) of interconnect network shape structure allows better fluid dispersion ability and more effective air–water contact area [27]. In order to further improve the liquid hold-up and wettability, microporouses are added to the framework of SiC-foam by surface treating. Table 1 shows the parameters of experimental SiC ceramic foam corrugated sheets and packing module. Correspondingly, the parameters of traditional perforated corrugated packing are also listed. For humidification tower, the more compact design may be benefit from decreasing packing volume and simplifying fluid distributors.

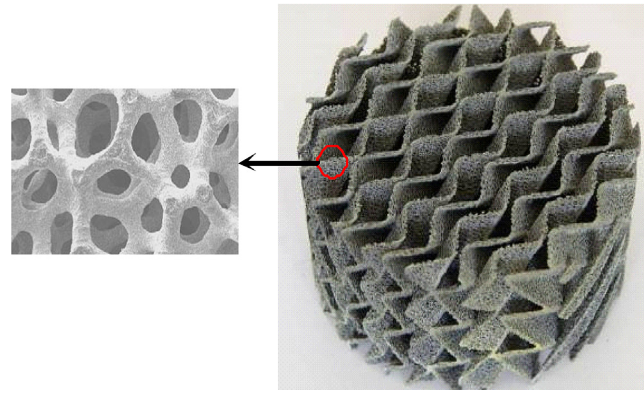

Fig. 1. SiC ceramic foam corrugated packing.

Fig. 2. Traditional perforated corrugated packing.

Table 1
Parameters of ceramic foam packing.

Parameters	Ceramic foam packing	Traditional packing
Type	FSC-1	TJH-250
Material	SiC	Stainless steel
Interconnect pore size	1.5 mm	/
Perforated size	/	4 mm
Thickness of sheet	2 mm	0.3 mm
Corrugation base width	25 mm	25 mm
Corrugation height	9 mm	11 mm
Corrugation inclination angle	45°	45°
Packing module diameter	123 mm	123 mm
Packing module height	80 mm	210 mm