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Experimental investigation of pressurized packing saturator for humid air turbine cycle

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HIGHLIGHTS

- The mal-distribution factor of annular gas distributor is at 0.15–0.35.
- Outlet air temperature is a key parameter of weighing the humidifying capacity.
- Outlet air temperature is mainly affected by inlet water temperature and L/G ratio.
- Outlet humid air humidity increases with inlet water temperature and L/G ratio.
- Outlet water temperature is mainly influenced by inlet gas temperature.

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ABSTRACT

Humid air turbine (HAT) cycle is an advanced power generation system, and its efficiency and output power are improved by humidifying the compressed air. This humidification process is completed in the saturator. Therefore, the humidifying performance of saturator has great influence on the performance of HAT cycle. In this work, a new type packing saturator was designed and a series of experiments were carried out to study its humidifying performance. In order to improve the uniformity of the saturator inlet, a twin-tangential annular flow gas distributor was designed. Then it was authorized by China invention patents (ZL201010200778.9). Now, the mal-distribution factor of inlet air is mainly between 0.15 and 0.35 in all experimental conditions. Some key parameters of air and water at the inlet and outlet of saturator were measured at different experimental conditions. These results show the outlet humid air temperature is an important parameter for determining the humidifying amount of the saturator. The humidifying performance of the saturator is mainly affected by the inlet water temperature and the liquid/gas (L/G) ratio. At the same operating pressure, the humidity ratio of outlet humid air increases with inlet water temperature and L/G ratio. At higher inlet water temperature, the L/G ratio has a greater effect on the humidity ratio of outlet humid air. The outlet water temperature is mainly affected by the inlet gas temperature. With the increasing of inlet air temperature, the outlet water temperature increases, and it is close to the wet-bulb temperature of inlet air.

1. Introduction

In WEO-2008 Reference Scenario, which assumes no new government policies, world primary energy demand grows by 1.6% per year on average between 2006 and 2030-an increase of 45% [1]. About 80% of total primary energy nowadays originated from fossil energy sources. But the production of oil and natural gas all over the world will peak in 2010 and 2020, respectively. Coal and nuclear energy cannot fill the gap. Therefore, energy efficiency and energy saving are key elements to minimize disruptions in energy provision and allow for a long-term and sustainable energy supply [2]. In addition, the IEA predicted that the demand for electricity will grow by 2.4% per year. It also predicted that most of new power generating capacity will be nature gas-fired combined cycles, since gas turbine has relatively high efficiency, lows specific investment cost, high power-to-weight ratio and low emissions. The research interests of advanced power cycles based on gas turbines have increased considerably over the past decades. In HAT cycle, steam turbine unit does not need. Therefore, comparing with gas/steam

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turbine combine cycle, the initial investment of HAT cycle can be greatly reduced. In addition, the efficiency and output power of HAT cycle can be improved by humidifying the compressed air.

In 1980s, HAT cycle was proposed by Mori [3] and a research program on the HAT was commenced in the USA. This evaporative cycle was patented by Fluor Daniel [4]. The first commercial demonstration plant in the world was built in Sweden [5], and they run an actual HAT cycle based on the micro-turbine VT600 with a simple cycle power output of 600kw and an efficiency of 22%. In this pilot plant, the compressed air is after-cooled and humidified by heated water in the saturator with structured internal packing. The water is heated in the after-cooler and an exhaust gas economizer, and a recuperator. According to the measurement of the pilot plant, the efficiency of the HAT cycle could be 35%. The second pilot plant, AHAT cycle [6,7], was built in Hitachinaka city, Japan, and the trial operation started in October 2006. In this pilot plant, the water atomization cooling (WAC) system substitute for the intercooler system of HAT cycle, and a humidification tower and water recovery system were designed and built for the pilot plant. Its electrical efficiency is 40.02% with the power output of 3990 kW. In our lab, the third pilot system of HAT cycle was build, and its output power is 100 kW.

The saturator is a key component of HAT cycle. Usually, its design was done according to the design methods of cooling tower. However, because the saturator and the cooling tower differ greatly in pressure, temperature and humidity levels, it is necessary to conduct a detailed study of the humidification performance of saturator. Modeling of humidification towers and different methods for humidification of air were discussed by Dalili [8]. Lindquist et al. [9] proposed the models of packed bed humidification towers, and these models have been used in most evaporative cycle simulations. Pedemonte et al. [10] designed a pressurized humidification tower with structured packing inside, and carried out an experimental study over 162 working points, covering a relatively wide range of possible operating conditions. Westermark et al. [11] investigated an innovative solution for humidifying the compressed air and recovering heat from the exhaust gas in one single device, which consists of a tube with rods on the outer surface.

In our previous works, a counter flow spray saturator without internal packing was built, and it is suitable for measuring the velocity field by the laser measurement [12]. Its humidifying performance was investigated by the experimental measurement and numerical analysis [12,13], and the velocity and diameter of droplets was measured by dual phase Doppler anemometry (DualPDA) [14]. These results show the humidifying performance of counter flow spray saturator and the validity of the saturator height are sensitive to inlet air velocity. In other words, the off-design performance of the counter flow spray saturator without internal packing is not good. According to theoretical analysis, if the internal packing is installed in the saturator, it can effectively reduce the sensitivity of the saturator's humidifying performance to the inlet air velocity. Therefore, in this work, a pressurized saturator with internal packing was designed for the pilot HAT cycle. Its humidifying performance of the pressurized saturator was investigated at different operating conditions. A new structure inlet air distributor was developed, and the uniformity of inlet air was measured by the hot-wire anemometer.

2. Experiment and measurement system

2.1. Experiment system

The experiment system of the pressurized saturator, as shown in Fig. 1, mainly consist of a centrifugal compressor used to generate high pressure air (0.1–0.3 MPa), a packing saturator, a tank used to supply water, a water heater and a water pump used to provide the power for water cycle. The flow rate of air into the saturator is controlled by a discharge valve at the outlet of compressor. The humid air after leaving the saturator enters into the combustion chamber. According to the function, the saturator can be divided into 5 parts. In order to adjust the packing height, the heights of three sections at the middle of the saturator are 400 mm, 400 mm, and 200 mm, respectively. In this experiment system, the random packing was installed, and its parameters were listed in Table 1. It provides the major surface of heat and mass transfer between air and water.

Usually, the efficiency of heat and mass transfer is mainly affected by gas–liquid distribution in the packed bed. Because air is with higher liquidity, it is more difficult to organize the air distribution. The uniformity of air distribution depends on the feeding manner of the saturator. Good initial distribution of air at the inlet

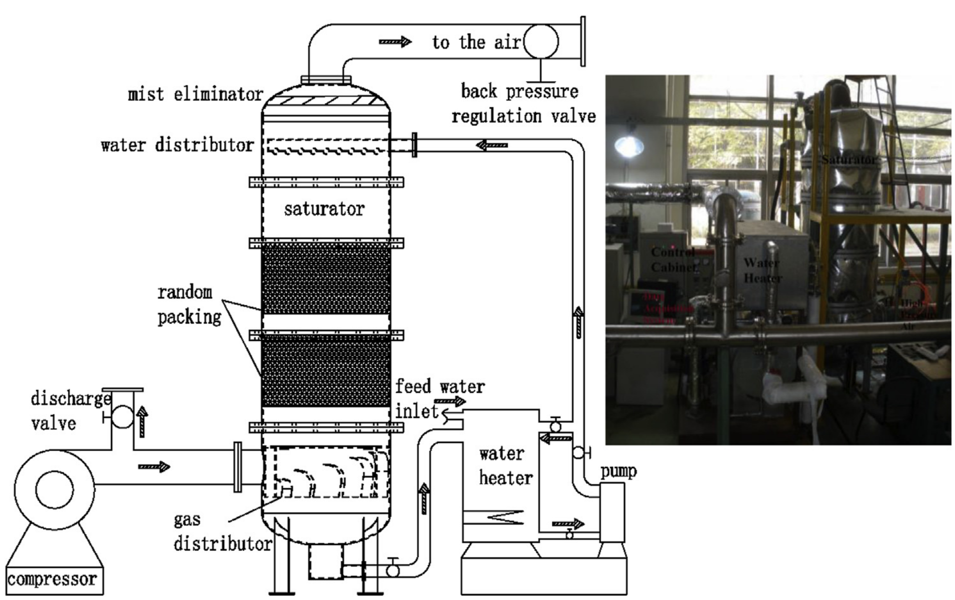

Fig. 1. Saturator experiment system.