Applied Thermal Engineering 90 (2015) 478–488

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

Thermal deformation prediction based on the temperature distribution of the rotor in rotary air-preheater

Limin Wang [a], Lei Deng [a], Chunli Tang [a], Qiang Fan [a], Changxia Wang [b], Defu Che [a, *]

[a] State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China
[b] Harbin Boiler Preheater Co., Ltd., Harbin Electric Corporation, Harbin 150046, PR China

HIGHLIGHTS

- The temperature distribution of the matrix in air-preheater was calculated.
- The thermal deformation was calculated based on the temperature distribution.
- The effects of operation and geometry parameters of rotor were studied.
- Good agreement between the numerical results and the measurements was achieved.
- A formula was fitted to evaluate the thermal deformation.

ARTICLE INFO

Article history:
Received 1 March 2015
Accepted 3 July 2015
Available online 22 July 2015

Keywords:
Finite element method
Rotary air-preheater
Temperature distribution
Thermal deformation

ABSTRACT

Thermal deformation of the rotor in the operating rotary air-preheater dramatically decreases the efficiency of air-preheating system. The investigation on the thermal deformation characteristics is of great significance. In this paper, the temperature distribution of the matrix in air-preheater was calculated by using finite difference method, and then the thermal stress induced deformation was calculated by employing finite element method based on the temperature distribution obtained. The effects of operation parameter, inlet gas temperature, and geometry parameters including radius and height of rotor were studied. Good agreement between the numerical results and the measurements was achieved. With the decrease in the axial coordinate, the influence of inlet gas temperature on the temperature distribution decreased, whereas the influence of outlet gas temperature increased gradually. At both hot and cold ends, the droopy deformation increased gradually along the length coordinate. The maximal droopy deformation increased with the inlet gas temperature. The deformation increased with the decrease in height of plate at both hot and cold ends. According to the data obtained, a formula was fitted to evaluate the thermal stress induced deformation, which would provide a reference for the seal system application.

1. Introduction

Energy saving is of great importance. The efficiency improvement of the energy-conversion device including large fossil-fuel-fired boiler has been challenging scientists and engineers. Air-preheater, also called air-regenerator, has made considerable contribution to improving the overall efficiency of the fossil-fuel-fired boiler. Due to its compactness and superior performance, rotary regenerator has been employed widely in waste heat recovery applications. Its main task is to recover considerable amount of waste heat from flue gas. Much work has been conducted regarding how to improve the thermal hydraulic performance of the heat transfer elements in the rotary regenerators [1–3]. Recently, the reliability and the safety of the operating air-preheater have drawn much more attention.

Fig. 1 shows the internal parts of a rotary regenerator, including beams, gas channels, end sector seals, rotator and segmental plates. The rotor consists of large scale of heat transfer plates known as matrix. The heat is transferred from the flue gas to the air, as they flow through the matrix alternately. The hot end of the rotary air-preheater usually operates at a high temperature ranging from 200 to 400 C. In addition, there is a large temperature difference

* Corresponding author. Tel.: +86 029 82665185; fax: +86 029 82668703.
E-mail addresses: dfche.xjtu@gmail.com, dfche@mail.xjtu.edu.cn (D. Che).

http://dx.doi.org/10.1016/j.applthermaleng.2015.07.021
1359-4311/

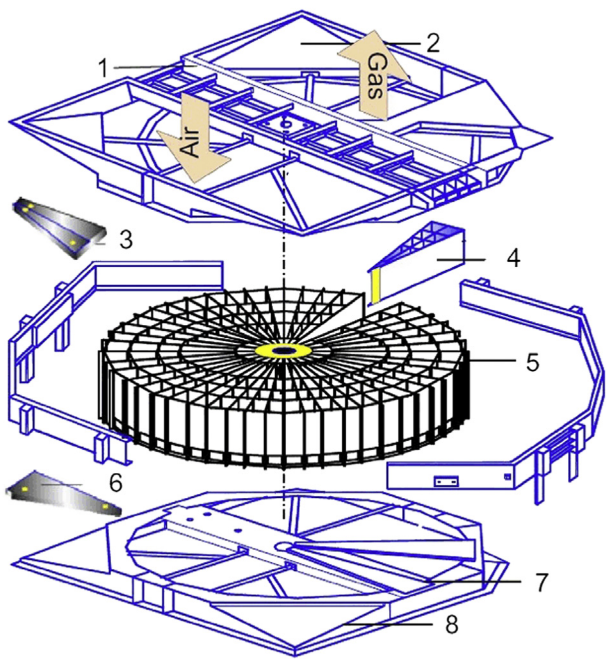

Fig. 1. The internal parts of a rotary regenerator [4] 1. Upper beam; 2. Upper gas channels; 3. Hot end sector seals; 4. Segmental plate; 5. Rotor; 6. Cold end sector seals; 7. Bottom beam; 8. Bottom gas channels.

between its hot and cold ends, as the counter-flow is commonly used. Thus, the thermal expansion at the hot end is significantly larger than that at the cold end, which results in a dramatic mushroom droopy deformation of the rotor in the running air-preheater. A noticeable weakness of the rotary regenerator is the unavoidable leakages between streams caused by the pressure difference near the clearance and by the carriage of the rotor. The mushroom deformation would not only aggravate the leakage problem but also increase the mechanical friction, which seriously affects the thermal efficiency and security of the system [5–7]. Therefore the compulsory reserved clearance would be larger in the application in order to ensure the reliability and safety, thus leading to a more serious leakage problem. Drobnic et al. [6] proposed a method for online monitoring of the tightness of the radial seals. A great deal of investigations have been conducted by Skiepko et al. [7–9]. They proposed a method to calculate the mass flows of gas through the seals [8], and presented an adjusting method to reduce the seal clearances [9], and analyzed the influence of leakage on the performance of a rotary air-preheater [7]. They indicated that both total leakage and the distribution of the leakages within the rotary regenerator have an important influence on the efficiency. Therefore, an efficient sealing system to decrease the leakages is indispensable for the high performance of an air-preheater and, consequently, the high efficiency of the boiler. So it is of great necessity to investigate the droopy deformation of the rotor to improve the performance of seal system.

The thermal deformation is considered to be directly related to the temperature difference of the rotor, so the temperature distribution of the rotor matrix should be obtained before the calculation of the thermal stress deformation. A number of investigations have been conducted to study the method of evaluating the temperature of rotary regenerators. It is difficult to measure temperature distribution directly in the air-preheater due to its complexity. Analytical methods and numerical methods have been employed widely by a number of investigators to evaluate the temperature distribution in the air-preheater [4,10–12]. Bahnke et al. [13] employed a numerical finite-difference method to determine the regenerator heat transfer effectiveness considering the longitudinal conduction effect. Razelos et al. [14] evaluated the temperature distribution of the matrix in regenerator by solving the discretized space continuous time differential equations analytically. Skiepko et al. [15,16] derived an analytical solution for the rotary regenerator problem taking account of the longitudinal conduction effect in the matrix wall. Li et al. [17] proposed a numerical finite difference method to calculate the fluid and metal temperature distribution for the rotary regenerator, also accounting for the effect of heat conduction in the wall in the direction of fluid flow. These investigators mentioned above have demonstrated that both analytical method and numerical finite difference method can be utilized to calculate the heat-transfer of air-preheater accurately.

Although a number of studies have been performed on the heat transfer calculation of rotary regenerator, less research has been done on its thermal stress deformation. Only an analytical study was performed by Wang et al. [4]. Many simplifications had to be made in the process of solving the equations analytically, which may lead to some deviation. Moreover, the analytical method can be used only for the computation of the air preheater with one layer of heat transfer matrix. In fact, there are several layers of matrix in the rotor and there are big gaps between the matrix layers. It is difficult to deal with these cases by using analytical method.

In this study, a combination of finite difference method (FDM) and finite element method (FEM) was used to investigate the effects of geometry parameters and operational parameters on the temperature distribution and the thermal deformation of the rotor in the air preheater. The temperature distributions were calculated by using FDM, and then the thermal deformations were computed by using FEM based on the temperature distribution obtained. This method can deal with more complex geometries, compared with analytical methods.

2. Cases investigated

A specific type of tri-section air-preheater commonly used was investigated in this study. As shown in Fig. 2, this kind of regenerator consists of three sections in rotational direction and three layers of matrixes in axial direction. The sections include a gas section of 180°, a secondary air section of 130° and a primary air section of 50°, sequentially. The three layers consist of a hot end layer, a middle layer and a cold end layer respectively, which have the same heat-transfer matrix. In this study, the effect of the type of heat-transfer element on the temperature profile of rotor was neglected, compared to other factors.

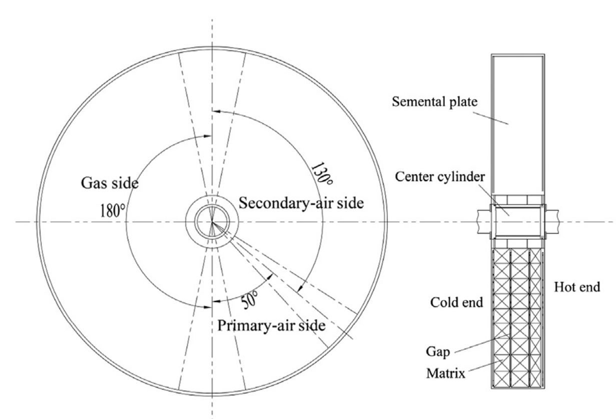

Fig. 2. Rotor schematic of a specific air-preheater.