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International Journal of Heat and Mass Transfer 49 (2006) 5001–5009
International Journal of HEAT and MASS TRANSFER
www.elsevier.com/locate/ijhmt

A numerical model for the analyses of heat transfer and leakages in a rotary air preheater

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Received 5 October 2005
Available online 22 August 2006

Abstract

Air preheaters make a considerable contribution to the improved overall efficiency of fossil-fuel-fired power plants. In this study we used a combination of fluid dynamics and a newly developed three-dimensional numerical model for heat transfer as the basis for a theoretical analysis of a rotary air preheater. The model enables studies of the flue-gas flow through the preheater and the adjoining channels as well as the regenerative heat transfer and the resulting temperature distribution in the matrix of the preheater. Special attention was focused on the influences of leakages on the flue-gas parameters in the preheater. The numerical analysis and the experimental results showed an obvious dependence of the flue-gas parameters on various seal settings. Based on the results a method for online monitoring of the tightness of the radial seals is proposed.

Keywords: Regenerative heat transfer; Rotary air preheaters; Sealing; Leakages; Numerical simulation; CFD

1. Introduction

High efficiency is the key feature in the operation of any energy-conversion device, and this includes large fossil-fuel-fired steam boilers. It is therefore very important to recover as much energy as possible from that available in the fuel. Air preheaters have proved to have an important influence on the efficiency of the entire steam boiler. Their primary task is to return considerable amounts of waste heat, carried by the flue gas, back to the combustion process. Due to their compactness and high performance, rotary regenerative air preheaters are very common in fossil-fuel-fired steam boilers. Rotary preheaters have a specific operating principle where the heat is transferred from the flue gas to the air by means of a rotating matrix. A significant weakness of this type of heat exchanger is the unavoidable leakages between both streams caused by the pressure difference between the streams and by the rotation of the matrix. At the same time there is a need for the constant monitoring of the seals' settings in order to ensure their optimum operation under various working conditions.

An efficient sealing system is therefore a prerequisite for the high performance of an air heater and, consequently, the high efficiency of the steam boiler. The main side effect of the leakage is the need for larger flow rates of air entering the heater and, consequently, larger flow rates of flue gas exiting the heater. The increased flow rates also require more ventilation power.

This article presents a method that makes possible the online monitoring of the air preheater's seal tightness. The method is based on the results of numerical simulations. A numerical method was developed that makes it possible to simulate the operation of the rotary air preheater, including the influences of various seal settings on the properties of the flue gas after the preheater. The numerical results were confirmed by measurements.

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doi:10.1016/j.ijheatmasstransfer.2006.05.027

Nomenclature

c	specific heat, J/kg K
i	index in radial direction
j	index in tangential direction
k	index in axial direction
N	number of grid divisions
r	radial coordinate, m
T	temperature, °C
w	velocity, m/s
z	axial coordinate, m
Greek symbols	
α	convective heat-transfer coefficient, W/m^2 K
β	heat-transfer surface in unit volume of matrix, m^2/m^3
θ	tangential coordinate, rad
λ	thermal conductivity, W/m K
ρ	density, kg/m^3
σ	solid fraction of matrix volume, m^3/m^3
φ	solid fraction of matrix cross-section, m^2/m^2
ω	rotational speed, rad/s
Subscripts	
amb	ambient
g	gas
m	matrix
p	constant pressure

2. Leakages in rotary heat exchangers

The basic element of a rotary heat exchanger's operation is a rotating matrix in a compact casing that transfers the heat from the hot flue gas to the cold combustion air. The rotation of the matrix requires an appropriate sealing system to prevent mixing of the flue gas and the air, commonly referred to as leakage. The importance of sealing and leakage and its influence on air-preheater performance was studied by several authors. MacDuff and Clark, for example, present an overview of radial sealing systems [1]. A lot of research was carried out by Skiepko, who studied the influence of leakage on a heat exchanger's performance [2]. He also presented methods for calculating the mass flows of gas through the seals [3], a method of measuring and adjusting the seal clearances in radial seals [4–6], and the irreversibilities caused by leakage [7]. The general conclusion is that the sealing system is an important part of a rotary heat exchanger. Although the leakages in the air preheater do not significantly affect the boiler's overall thermal efficiency [8], excessive leakages can reduce the effectiveness of the air preheater itself by over 10% [2]. At the same time, leakages require more air to be transported to the preheater and more flue gas to be transferred from the preheater, and larger quantities of gases require more power for the air and flue-gas fans. These fans typically use up to 1.5% of all the power produced. An increased amount of power required for the fan results directly in a noticeable drop in the power plant's overall efficiency. It is therefore important to pay special attention to the adjustment of the seals and to monitor their tightness.

Fig. 1 schematically shows a typical arrangement of seals around the rotor of a rotary heat exchanger. The three types of seals in Fig. 1 prevent leakage due to pressure differences between certain locations in the heat exchanger.

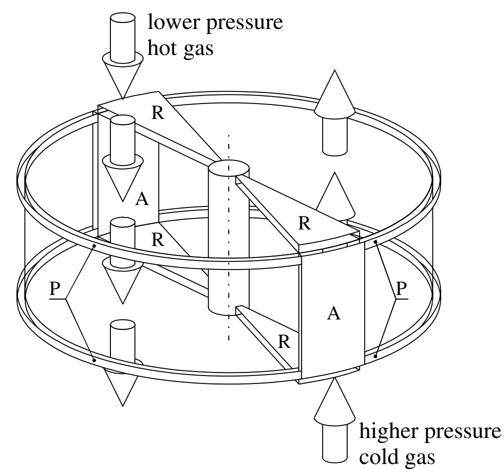

Fig. 1. Typical arrangement of the seals in a rotary heat exchanger (A – axial seals, P – peripheral seals, R – radial seals).

Radial and axial seals reduce the amount of air that is leaking into the flue-gas channel. Typically, the pressure on the air side is considerably higher than the pressure of the flue gas: the difference can reach several thousand Pa. Peripheral seals, on the other hand, prevent the bypass flow of air or flue gas around the matrix. This flow does not contribute to the heat exchange and should also be reduced.

Mass flow rates through the peripheral seals are relatively small since the pressure gradients in the axial direction are much smaller than the pressure difference between the hot and cold gas streams. The axial seals are usually several times shorter than the radial seals, so the majority of the gas is expected to pass through the radial seals.

Both the radial and axial seals are adjustable. During start-up or after changing the boiler's load the rotor is deformed due to temperature differences at the hot and cold ends of the rotor. The seals need to be adjusted after any change in the temperature conditions in the exchanger.