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Thermal performance analysis on a two composite material honeycomb heat regenerators used for HiTAC burners

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Abstract

Honeycomb heat regenerators do not only reduce the fuel consumption in a high temperature air combustion (HiTAC) burning system but also provide the necessary high temperature of combustion air. A two-dimensional simulation model was developed to numerically determine the dynamic temperature and velocity profiles of gases and solid heat-storing materials in a composite material honeycomb regenerator. Consequently, the energy storage and the pressure drop are calculated and the thermal performance of honeycomb heat regenerator is evaluated at different switching times and loading. The model takes into account the thermal conductivity parallel and perpendicular to flow direction of solid and flowing gases. It considers the variation of all thermal properties of solid material and gases with temperature. Moreover, the radiation from combustion flue gases to the storage materials was considered in the analysis. The results are presented in a non-dimensional form in order to be a design tool as well. These analyses were applied on a regenerator made of two layers of ceramic materials, one is pure alumina and other is cordierite. This regenerator is contained in a 100 kW twin-type regenerative-burning system used for HiTAC. The effectiveness and the energy recovery rate were 88% and 72% respectively at nominal operating range of the regenerator and the pressure drop across the twin regenerator system was 1.16 kPa. The periodic steady state condition is reached after about 11 min and it takes only 2 min of operation until the temperature of combustion air remains above the self-ignition temperature that is required for HiTAC. Furthermore, these mathematical analyses show good agreement with experiments made on the same regenerator. In

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the experiments, the dynamic behavior of the heat regenerator operation was considered in order to compensate measurement readings for this effect.
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1. Introduction

Many researchers have recently realized significant energy savings, NO_x emissions reduction and heat transfer uniformity resulting from high temperature air combustion technology (HiTAC) [1–4]. Normally, regenerative burner systems are used in the application of HiTAC. They operate on the principle of short-term heat storage using a ceramic compact regenerative heat exchanger (regenerator). In the regenerators, flue gases from the furnace and combustion air alternately flow through a chamber filled with ceramic as a heat storage medium, storing heat from flue gas during the regenerative mode and releasing that heat to combustion air. The regenerator used for this application is either a fixed bed with randomly packed ceramic balls or having honeycomb structure with identical cells, matrices. They recover between 65% and 85% of the heat from the furnace waste gases. As a result, the incoming combustion air can be preheated to very high temperatures, ~50 degrees below the furnace operating temperature if efficient regenerators are used. Therefore, the material must resist high temperatures and thermal stresses due to high temperature gradient along the regenerator. In fact, pure alumina is one popular material in such applications of regenerator in spite of its high cost. In order to reduce this cost, the regenerator is made of composite materials in which the hot portion only is made of alumina and the medium and cold portion is made of another cheaper material. Consequently, the thermal performance of the regenerator, which is probably the most important element of the whole HiTAC burning system, is an important factor to achieve the desired temperature of the combustion air. The heat exchange efficiency depends mainly on the regenerator structure, thermal properties of regenerator material, switching time, flue-gas suction rate and others.

The classical books by Hausen [5], Schmidt and Willmott [6] and Kays and London [7] provide excellent background on analytical methods and mathematical models for calculating temperature profiles, effectiveness and other thermal performance parameters of regenerators having different heat transfer geometries and flow patterns. Simple design techniques such as Λ–Π [5,6] and ε–NTU were developed and presented in these books.

The first approximate solution to determine the spatial temperature distribution in solid material at a certain time and at a certain cross-section in a heat regenerator was presented by Heiligenstaedt and Rummel [5]. They assumed time independent fluid flow temperature, the assumption that does not hold well in practice. In order to get away from this assumption Rummel introduced some constants to the heat transfer coefficient that are determined by experiment. Another approximate solution developed by Schack [5] in which he formed an empirical expression that also contains constants that are experimentally determined. These methods were restricted to a brick or plane wall cross-section. In addition, Hausen [5,6] developed a theory, which is free from the above assumptions. He used the zero eigenvalue function, which corresponds to the fundamental temperature oscillation. However, this theory is only valid when

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