Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Energy 30 (2005) 359–371
ENERGY
www.elsevier.com/locate/energy

Development of a high efficiency radiation converter using a spiral heat exchanger

S. Maruyama [a,*], T. Aoki [a], K. Igarashi [b], S. Sakai [a]

[a] *Institute of Fluid Science, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai 980-8577, Japan*
[b] *Azuma Machine Works Co., Ltd., 13-10, Motomachi, Rokuchounome, Wakabayashi-ku, Sendai 984-0014, Japan*

Abstract

Heating by radiation is widely used for materials processing. Electrical radiant heaters are the most commonly used heaters. Electricity is expensive and the combustion of fossils fuels for electricity production emits CO_2. In order to convert the energy from the fuel to radiation energy directly and efficiently, our group has developed a compact, high efficiency, radiation converter using a spiral heat exchanger to recover the energy from high-temperature exhaust gas. The spiral heat exchanger has a weld-free construction to prevent cyclic thermal stress, and is constructed from inexpensive ferrite steel plates. The combustion chamber, equipped with a swirler to mix the gas fuel and air, can achieve stable combustion. The distribution of the surface temperature on the radiant tube was measured by a radiation thermometer, called a thermo viewer, and then the radiant energy emitted from the radiant tube was estimated. The efficiency of the spiral heat exchanger was measured from the temperature of the inlet air and exhaust gas. The heat exchanger achieved a high effectiveness, and heat loss from the exhaust gas was minimized. Consequently, a highly efficient radiation converter was produced to convert the fuel energy to radiation energy.

1. Introduction

Heating by radiation is widely used for materials processing and as the operating principle for radiant heaters, because uniform heating and high heat flux are achievable. Furthermore, the heat transfer does not depend on the medium. Many radiant heaters are powered by electricity. This electricity is mainly generated by the combustion of fossil fuels distributed via a grid network to the required location, and finally converted to radiant energy by an electric heater. Therefore, radiation energy is expensive and CO_2 is emitted as a byproduct of this process.

* Corresponding author. Tel./fax: +81-22-217-5243.
E-mail address: maruyama@ifs.tohoku.ac.jp (S. Maruyama).

0360-5442/$ - see front matter
doi:10.1016/j.energy.2004.04.021

Nomenclature

c	specific heat [kJ/(kg K)]
c_{pg}	specific heat [kJ/(N l K)]
D_e	the equivalent diameter of flow passages [m]
$E_{b,\lambda}(T)$	spectral black body emissive power [W m^{-2} μm^{-1}]
E_{con}	energy loss of convection and conduction [W]
E_f	fuel gas energy [W]
E_{ext}	energy loss of exhaust gas [W]
E_{rad}	radiation energy [W]
f	Fanning friction factor [–]
G	mass velocity [kg/s]
L	fluid flow length on one side of an exchanger [m]
N	the number of tube rows in the flow direction [–]
$\dot{m}$	mass flow rate [kg/s]
ΔP	pressure drop [Pa]
$\dot{Q}$	exchanged heat [W]
q_{ext}	exhaust gas flow rate [N l/min]
S	radiation converter surface area [m^2]
T_0	ambient air [K]
T_{c1}	inlet temperature of cold flow [K]
T_{c2}	outlet temperature of cold flow [K]
T_{h1}	inlet temperature of hot flow [K]
T_{h2}	outlet temperature of hot flow [K]
T_{ext}	exhaust gas temperature [K]
ε	heat exchanger effectiveness [–]
ε_λ	normal spectral emissivity [–]
ρ	fluid density [kg/m^3]
ρ_o	fluid density of outlet [kg/m^3]
ρ_i	fluid density of inlet [kg/m^3]

However, if direct conversion from the combustion of fossil fuel to radiation energy is efficiently achieved, energy costs and emission of CO_2 to the atmosphere can be expected to decrease.

Preheating of air is an effective method to obtain radiation energy efficiently by combustion. In the case of combustion with preheated air, we can get higher flame temperatures compared with ordinary combustion without preheating. Air preheating aids combustion stability, and helps expand the combustible region to the rarefaction region [1]. A Swiss-roll burner is one of the heat-recirculating burners [2], and a radiant tube burner using a regenerative heat exchanger has been presented [3,4]. There are many examples of heat exchangers as heat recovery devices, and the spiral heat exchanger [5–7] is one such device. The advantages of the spiral heat exchanger include high thermal effectiveness and compact design, and hence it is widely utilized