The Circulating Balls Heat Exchanger (CIBEX)

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The **CIBEX** heat exchanger consists of a gas cooling section (gas generator) and an air heating section (air preheater) coupled with a stream of solid particles. The stream of particles falls through a hot gas stream, picking up heat and cooling the gas, then through the airstream, heating the latter. The cooled particles are then returned to the top of the device and the heating/cooling cycle repeated. The paper describes the two-phase equations of motion for the flow of the spherical particles through the fluid. The solid phase is treated as a pseudo-gas by using concentrations instead of density. The equations are then non-dimensionalized and solved by numerical integration. The solution gives temperature and velocity profiles for the two phases for parametric variations in the solid loading and the fluid flux rate. The solution is applied for the design of a heat exchanger for a hypothetical 2500 tons/day coal gasification plant. The dimensions of the **CIBEX** heat exchanger are much smaller than those of a comparable conventional heat exchanger.

Nomenclature

A	= flow cross-sectional area
A,B,C,D,E,F	= variables, defined in Table 5
C_D	= drag coefficient
C_{pg}	= specific heat of gas
C_{pp}	= specific heat of particle
d_p	= particle diameter
g	= gravitational acceleration
h	= heat-transfer coefficient (combined convective and radiative effects)
H	= enthalpy
k_g	= gas thermal conductivity
k_p	= particle thermal conductivity
L	= heat exchanger length
$\dot{m}_g$	= gas flow rate
$\dot{m}_p$	= particle flow rate
n_p	= particle number density
p	= pressure
Q_w	= heat loss to wall
R	= gas constant
S	= quantity defined in Table 3
T	= temperature
U	= velocity
x	= longitudinal coordinate
α	= $0<\alpha<1$ defines the fraction of sensible heat loss to the wall
Δ	= defined in Eq. (26), Table 6
γ	= specific heat ratio for gas
ϵ	= volume fraction of solids
η	= loading factor
μ	= viscosity
ρ	= density
σ	= concentration
$\bar{\bar{\tau}}$	= dissipation tensor

Superscripts

$(\ )^*$	= dimensional quantity
$(\vec{\ })$	= vector quantity
$(\ )'$	= derivative with respect to X

Subscripts

g	= gas
i	= inlet
m	= mean
p	= particle
w	= wall
0	= at $x=0$ bottom of heat exchanger
1	= at $x=1$ top of heat exchanger

Introduction

THIS paper describes a concept of a direct-contact heat exchanger/regenerator in which one medium (gas) flows through a moving bed of a second medium (solid particles) and exchanges heat with it. The concept may be utilized for regenerative heat transfer between the high-temperature combustion gas stream and the cold combustion air of a combustor for a magnetohydrodynamic (MHD) generator[1] or for enhancing chemical reactions between a flowing gas stream and a solid material in the metallurgical, chemical, or petroleum industries.[2,3] Schematically shown in Fig. 1, the solid particles fall through a counterflowing hot gas stream in the gas generator. The gas cools by heat transfer to the particles. The particles then fall through the air preheater in which they give off heat to the combustion air. The particles are then recirculated back into the gas generator via a pneumatic or mechanical lift. The concept is of interest because of its high potential to provide relatively maintenance-free heat exchange in a compact package and is particularly suitable for a stream of dirty combustion products such as in coal combustors and gasifiers. In addition, such a heat exchanger is smaller in size than similarily rated conventional heat exchangers and provides greater heat recovery, low-pressure drop, and easy access for cleaning.

Mathematical Formulation

The two-phase counterflow in the heat exchanger can be described by writing the conservation equations (mass, momentum, and energy) for each phase separately, including the terms for interaction between the phases.[4] In theory, the gas flows in the open spaces between the particles. As the number density of the particles changes, so does the available

Received April 14, 1986; presented as Paper 86-1304 at the AIAA/ASME 4th Thermophysics and Heat Transfer Conference, Boston, MA, June 2-4, 1986; revision received Aug. 8, 1986.

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