

# THE CIRCULATING BALLS HEAT EXCHANGER (CIBEX)

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## Abstract

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 air stream, 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 section 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
T	Temperature
U	Velocity

## Greek Letters

$\gamma$	Specific Heat Ratio for Gas
$\epsilon$	Volume Fraction of Solids
$\eta$	Loading Factor
$\mu$	Viscosity
$\rho$	Density
$\phi$	Concentration
$\xi$	Dissipation Tensor

## Subscripts

g	Gas
i	Inlet
p	Particle
w	Wall
0	at $x=0$ bottom of heat exchanger
1	at $x=1$ top of heat exchanger

## Superscripts

*	Dimensional Quantity
$\vec{\phantom{x}}$	Vector Quantity
( )	Derivative with respect to x

## Introduction

The 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, for instance, a combustor for a MHD generator<sup>1</sup>, or for enhancing chemical reactions between a flowing gas stream and a solid material in the metallurgical, chemical or petroleum

industries<sup>2,3</sup>. Schematically shown in Figure 1, the solid particles fall through a counter flowing hot gas stream in the gas generator. The gas cools down 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 similarly rated conventional heat exchangers, it provides greater heat recovery, low pressure drop and easy access for cleaning.

## 1. Mathematical Formulation

The two phase counter flow 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<sup>4</sup>. In theory, the gas flows in the open spaces between the particles. As the number density of the