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Numerical modeling of interaction between surface radiation and natural convection of atmospheric aerosol in presence of transverse magnetic field

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ABSTRACT

After the era of industrialization, technology is developing daily since the last century. Urbanization, communication, and transportation have grown rapidly and simultaneously deforestation and volcanic eruptions take place on a large scale. As result every moment tons of foreign particles like soot, dust, ash, and bio-fuel contaminants are released into the atmosphere. These contaminants mix with air and various green house gases, form a blanket structure in atmosphere. This mixture of ultrafine particle suspension with atmospheric air is known as aerosol. In the present study, numerical simulations of hydrodynamic single cell buoyant convection of atmospheric aerosol sample enclosed within a gray enclosure in the presence of a transverse magnetic field and surface radiation is addressed. Flow of the aerosol over deserts and industrial belts is a practical example of such a condition, where the thermal radiation emanating from the surface, affects the flow mechanism of the aerosol transport. The emphasis of the present study is only on carbon-black solid particles of a size in the nanometer range present in atmospheric air. The aerosol is treated as nanofluid for the numerical simulation. A comprehensive study on the controlling parameters that affect the flow and heat transfer characteristics are delineated. The governing equations are solved using modified MAC method and SIMPLER algorithm has been used to solve pressure velocity coupling employing relaxation technique. The transport equation for surface radiation is solved using the net radiation method. The cross string method is used to evaluate the view factor. The most striking result is that the heat transfer rate increases with increase in the volume fraction of the carbon-black particles, which has an adverse effect on both the climate and living creatures. The results are presented in tabular and graphical form. The heat transfer and flow characteristics are depicted in the form of isotherms and streamlines revealing the physics of this complex phenomenon.

1. Introduction

Air pollution is accelerated with the development and growth of civilization. Due to the rapid growth of industrialization, urbanization, transportation, deforestation and volcanic eruptions a large scale of foreign particles like soot, carbon dust emission and other pollutants are released into the atmosphere in the form of ultrafine dust particles, which are suspended in the atmosphere and are called aerosols. Large size particles in aerosols play an important role as cloud condensing nuclei

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Nomenclature

B_0	applied magnetic field [Wb m^{-2}]
C_p	specific heat capacity [J kg^{-1} K^{-1}]
E_b^*	dimensional emissive power [W m^{-2}]
E_b	dimensionless emissive power
F_{i-j}	view factor between segment i and j
g	acceleration due to gravity [m s^{-2}]
G	irradiation [W m^{-2}]
Gr	Grashof number $\mathrm{Gr} = g\beta_f(T_H - T_C)L^3/\nu_f^2$
Ha	Hartmann number $Ha^2 = B_0^2 L^2 \sigma_{ef}/\mu_f$
j	dimensionless radiosity
J	dimensional radiosity [W m^{-2}]
k	thermal conductivity [W m^{-1} K^{-1}]
L	length of the cavity [m]
Nu	Nusselt number
N_{CR}	conduction–radiation number $N_{CR} = \sigma T_H^4 L/k_f(T_H - T_C)$
p	dimensional pressure [N m^{-2}]
P	dimensionless pressure
Pr	Prandtl number ν_f/α_f
q_r	dimensional net radiative heat flux [W m^{-2}]
Q_r	dimensionless net radiative heat flux
r	positional vector
Ra	Rayleigh number $Ra = g\beta_f(T_H - T_C)L^3/\nu_f\alpha_f$
T	temperature in absolute scale [K]
u,v	dimensional velocity component [m s^{-1}]
U,V	dimensionless velocity component
x,y	dimensional coordinates [m]
X,Y	dimensionless coordinate

Greek Symbols

α	thermal diffusivity [m^2 s^{-1}]
α'	absorptivity of the wall
β	coefficient of thermal expansion [K^{-1}]
ε	emissivity
μ	dynamic viscosity [kg m^{-1} s^{-1}]
ν	kinematic viscosity [m^2 s^{-1}]
θ	dimensionless temperature
ρ	density [kg m^{-3}]
ϕ	volume fraction of particle concentration
σ_e	electrical conductivity of the medium [Ω^{-1} m^{-1}]
σ	Stefan–Boltzmann constant [W m^{-2} K^{-4}]

Subscripts

C	Cold
H	Hot
c	convective
r	radiative
f	base fluid
s	suspended solid particles
nf	nanofluid
tot	total

(CCN) favoring formation of rain. While small size particles in aerosols have adverse effects on health when inhaled and on the climate. The brownian movement of aerosols due to kinetic coagulation in the presence of external forces like gravitational, magnetic and electric fields leads to the formation of tiny particles in the range of nano scale. These aerosol particles act like a sun shield and affect the earth's energy balance. Scientists are keen to study the increase of these atmospheric pollutants, because of their adverse effect on health and climate. In this regard, researchers like Dockery et al. [1–3] and Stieb et al. [4] have investigated the adverse effects of aerosol.

Soot is a vital part of atmospheric aerosols, which are formed by the process of incomplete combustion of fossil fuel and biomass. Materials with size in the nano meter range possess unique physical and chemical properties, hence the study of