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Technical Notes

Heat Transfer Phenomena in a Vortex Engine

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Nomenclature

A = heat transfer area, m^2
b = nozzle radius, m
c_p = specific thermal capacity, $\mathrm{J/kg \cdot K}$
D = outer diameter of chamber, m
e_r = radial unit vector component
e_z = axial unit vector component
e_θ = tangential unit vector component
F = fuel mass flow rate, kg/s
h = height of steal segments, m
k = conductivity, $\mathrm{W/m \cdot K}$
L = length of chamber, m
mo = oxidizer (air + pure O2) mass flow rate, kg/s
p = static pressure, Pa
Q = volumetric flow rate, m^3/s
$\dot{Q}$ = rate of heat transfer, W
q'' = heat flux, $\mathrm{W/m}^2$
R = inner radius of chamber, m
r = radial coordinate
T = temperature, K
t = time, s
U = velocity of tangentially injected oxidizer, m/s
u_z = axial velocity, m/s
z = axial coordinate
ρ = density, $\mathrm{kg/m}^3$

Subscripts

a = actual
C = convective cooling
f = fuel
in = inner side
o = oxidizer
out = outer side
r = radial coordinate
R = radiation heat transfer
s = stoichiometric
T = total heat transfer
z = axial coordinate
θ = tangential coordinate

I. Introduction

CYCLONIC flows are characterized by a bidirectional coaxial swirl motion that is not caused by vortex breakdown or instability. Because of the flow reversal in the conical section of a cyclone, the primary flow is forced to turn around as the core is approached. Many researchers have worked on the hydrodynamics of cyclonic flows. The theory beyond cyclonic flows was modeled basically by Bloor and Ingham [1]. They used a simple analytical method to derive the governing relation of tangential velocity in a cyclone. Neglecting viscosity, they developed a complementary analytic solution to fluid dynamic problem of cyclones [2], by assuming a power law to find streamlines. Having the assumptions of steady, axisymmetric, incompressible and inviscid flow, they found fairly good relations which are still in use.

Cyclone combustion chambers have been developed in many forms, but they have usually been used for the combustion and processing of materials that are normally considered difficult to burn or process efficiently such as vegetable refuse, high ash content coals, anthracite, high sulfur oils, low calorific value waste gas, certain mineral ores, and as part of magnetohydrodynamic combustors [3]. Recently cyclonic flows are used to achieve lower wall temperature rather than axial common burners. In this method (Fig. 1), oxidizer issues tangentially at the partially open end of the chamber and consequently, a cool vortex flows toward the closed head, being mixed with fuel. A secondary vortex of combustible reactants swirls coaxial with the first vortex to the nozzle exit. The first prototype engine is due to the work of Chiaverini et al. [4], called the cold-wall bidirectional vortex combustion chamber. In this chamber a full reverse bidirectional swirl flow is implemented. Vyas et al. [5,6] worked on the fluid dynamic problem of the bidirectional swirl combustor analytically. Having used the assumptions of steady, incompressible, inviscid and axisymmetric, they found a complete formulation of velocity field and pressure distribution along all directions of the cylindrical coordinate. Their solution deteriorates near the centerline due to the inviscid flow assumption; therefore they modified the obtained solution by extending the viscosity effects in the interior core region [7].

Chiaverini et al. [8] developed some experiments on two types of vortex combustion cold-wall thrust chambers to determine the effects of the combustion chamber, nozzle geometry, and injection parameters on specific impulse performance and chamber thermal behavior. They used semi-empirical correlations to estimate the relative magnitude of thermal radiation and convection on the chamber sidewalls and finally concluded that chamber sidewall heating rates did not display a significant dependence on chamber pressure, apparently due to the similar effects of elevated pressure on both

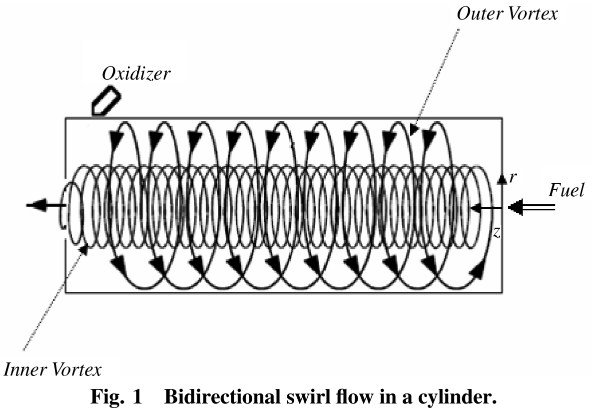

Fig. 1 Bidirectional swirl flow in a cylinder.

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