CFD Calculations of Reverse Vortex Reactive Flows

Igor Matveev
Applied Plasma Technologies, McLean, USA

Serhiy Serbin and Anna Mostipanenko
National University of Shipbuilding, Nikolaev, Ukraine

The development of a new generation of combustion chambers with plasma torch and spatial arc should be based on better understanding of the physical and chemical processes of turbulent combustion in highly swirled flows and the modeling of such combustors taking into account the complexity of their 3D geometry and variety of operation modes.

Theoretical investigations of the operating processes in triple vortex (or "Tornado") combustors [1] with highly turbulent flows of air, fuel, and products of their reactions are not simple [2]. Due to intensive development and achieved progress in numerical solutions of the fluid dynamics and chemical kinetics equations it is now possible to model the main physical and chemical processes inside combustors that are difficult to study experimentally. This can dramatically reduce costs for research and development of prospective devices.

For modeling of physical and chemical processes inside a triple vortex combustor with plasma torch and spatial arc a generalized method based on numerical solution of the combined conservation and transport equations for a multi-component chemically reactive turbulent system was employed [3, 4]. This method provides a procedure for the sequential numerical integration of the differential equations, which describe reacting viscous gas flows. A 3D model of stationary and non-stationary reacting flows has been utilized which permits prediction of the plasma-chemical influence and optimization of parameters of the combustors taking into consideration mixing, turbulence, radiation and combustion.

Turbulent flows in a triple vortex combustor are characterized by eddies with a wide range of length and time scales. The largest eddies are typically comparable in size to the characteristic length of the mean flow. The smallest scales are responsible for the dissipation of the kinetic energy of turbulence. Therefore, in some cases, for the definition of instantaneous velocities inside the combustor the large eddy simulation (LES) model has been used [5].

CFD methods have been used for modeling of the following processes:

- swirl flows in a "Tornado" combustor under cold, non-reacting, isothermal conditions;
- reactive flows inside reverse vortex combustor with internal diameters (ID) of 145 and 73 mm;
- gaseous fuel burning inside a triple vortex combustor with spatial arc and ID of 73 mm;
- coal burning and gasification processes in a 1 MW hybrid plasma torch;
- liquid fuel gasification processes in a hybrid plasma reformer with ID of 73 mm.

Contours of static temperature in a reverse vortex combustor with ID 145 mm working on gaseous propane are shown in Fig. 1. Operation conditions are: air mass flow rate through tangential swirler 15.53 g/s, air inlet temperature 318.5 K, air mass flow rate through the plasma torch 0.666 g/s, temperature of plasma feedstock air 294.1 K, propane mass flow rate through the plasma torch 0.155 g/s, propane inlet temperature 294.1 K. In calculations a RNG k-ε turbulence

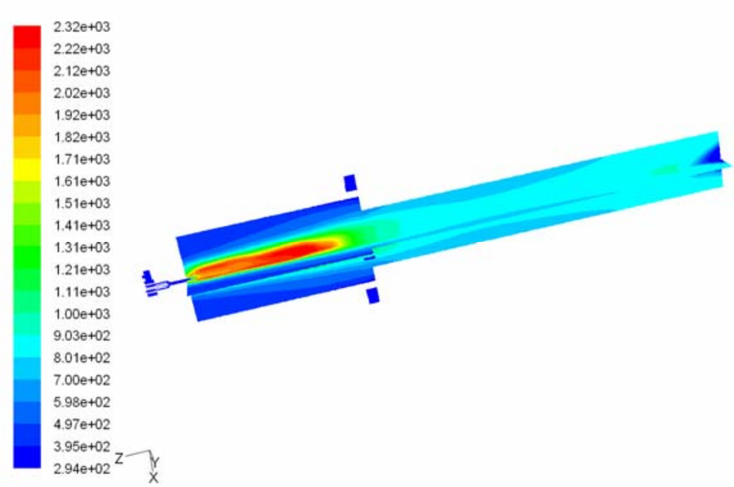

Fig. 1. Contours of temperature

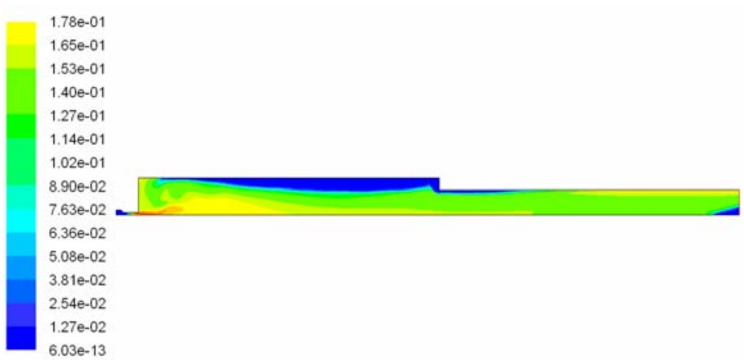

Fig. 2. Contours of H_2 mole fraction

model with swirl dominated flow, 3D pressure based solver, steady formulation, SIMPLE pressure-velocity coupling, eddy-dissipation combustion model of propane (C_3H_8) are used. Note, that a special exhaust tube with 600 mm length has been added to the exit combustor nozzle to avoid air injection from the atmosphere and combustion products dilution.

Contours of H_2 mole fraction in hybrid plasma reformer working on liquid diesel fuel $C_{10}H_{22}$ are shown in Fig. 2. Operation conditions are: air mass flow rate through tangential swirler 5 g/s, air mass flow rate through the plasma torch 0.6 g/s, temperature of plasma air 1000 K, water steam mass flow rate through the plasma torch 0.1 g/s, liquid fuel mass flow rate through the plasma torch 1.4 g/s, fuel inlet temperature 300 K. Rosin-Rammler diameter distribution for injection of fuel drops is assumed.: Minimum, maximum, and mean diameters 10, 30, and 70 micrometers correspondingly, spread parameter 3.5, injection velocity 5 m/s. For turbulent dispersion the discrete random walk model with number of tries 10 has been utilized.

For calculations RNG *k*-ε turbulence model with swirl dominated flow, 2D axi-symmetric pressure based solver, steady formulation, SIMPLE pressure-velocity coupling, Eddy Dissipation Concept (EDC) combustion model of $C_{10}H_{22}$ which combine turbulence-chemistry interaction with simple chemical mechanism (5 main reactions) are used. On the exit reformer cross-section calculated values of main mixture components mole fractions are the following: CO = 0.1409, H_2 = 0.1501, $C_{10}H_{22}$ = 0.019, CO_2 = 0.0468, H_2O = 0.0782, O_2 = 0.0037.

The performed theoretical investigations have demonstrated the modeling capability for the complex aerodynamic flows with chemical reactions inside reverse and triple vortex combustors and plasma reformers using coal and liquid organic materials. This work revealed deficiencies of the existing turbulence and combustion models for the prediction of parameters and have indicated major directions for the improvement of computational models.

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Igor B. Matveev was born on February 11, 1954 in Russia. He received his Master of Science degree in mechanical engineering from the Nikolaev Shipbuilding Institute in 1977 and earned his Ph.D. degree in 1984. The Ph.D. theses were entitled "Development and Implementation of The Plasma Ignition Systems for Naval Gas Turbines". From 1977 to 1990 he was a researcher, teacher and associate professor of the Nikolaev Shipbuilding Institute. In 1990 established a privately owned company Plasmatechnika (Ukraine) for development and mass production of the plasma systems. From 2003 is with Applied Plasma Technologies (USA) as President & CEO. Over 1,200 plasma ignition and flame control systems, developed under his supervision are in operation worldwide.

In 1989 has organized the first in the former Soviet Union conference on Plasma Ignition and Flame Control. From 2006 organizes annual International Workshop and Exhibition on Plasma Assisted Combustion. He is a guest editor for the IEEE Special Issue on Plasma Assisted Combustion from 2004.

Serhiy I. Serbin was born on April 29, 1958, in Mykolayiv, Ukraine. He received the MS. (DipI. Mech. Eng.) and Ph.D. (Cand. Sc. Tech.) degrees in mechanical engineering from the Mykolayiv Shipbuilding Institute, Ukraine, in 1981 and 1985, respectively, and the Dipi. D. Sc. Tech. and DipI. Prof. degrees from the National University of Shipbuilding, Ukraine, in 1999 and 2002, respectively.

Since 1984, he has been working with the Ukrainian State Maritime Technical University as an Assistant Professor, Senior Lecturer, Associate Professor. Since 1999, he has been working with the National University of Shipbuilding as a Professor of Turbine Units Department. His research interests are plasma-chemical combustion, the techniques of intensifying the processes of hydrocarbon-fuels ignition and combustion in power engineering, combustion and plasma processes modeling.

Dr. Serbin is the real member (Academician) of Academy of Shipbuilding Sciences of Ukraine and International Academy of Maritime Sciences, Technologies and Innovations.