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THERMODYNAMIC LIMITATION ON BORON ENERGY REALIZATION IN RAMJET PROPULSION

Abstract

Boron exhibits a remarkable theoretical energetic performance when burning with air. The theoretical heat of combustion of boron exceeds that of hydrocarbon (HC) fuels by about 40% on a gravimetric basis (about 58 vs. 42 kJ/g, respectively) and by some 200% on a volumetric basis (about 136 vs. 40 kJ/cm3, respectively – the highest value of all elements). In ramjet systems operating at given conditions (flight speed, altitude, thrust level), the specific impulse is approximately related to the heat of combustion per unit mass of the fuel, whereas the overall impulse delivered from a given volume of fuel is approximately proportional to the heat of combustion per unit volume. In addition, the theoretical specific thrust of boron is also much higher than that of HC fuels. Hence, boron has been a very attractive fuel candidate for ramjets (particularly for volume limited systems), such as solid fuel ramjet (SFRJ) and ducted rocket, where it is added as fine particles into a polymeric matrix, or when added to gel fueled systems. In contrast to the remarkable energetic potential, the realization of the boron energy in practical ramjet systems is difficult, often resulting in poor performance. This study focuses on investigating a specific boron combustion aspect, revealing that thermodynamic conditions associated with highly boron-loaded ramjet combustors, may lead to blockage of the reaction between boron and air, causing termination of the combustion process. During heating in an oxidizing atmosphere, a low-melting-temperature (723 K) liquid boron oxide layer B2O3(l) is formed, covering the entire boron particle surface and avoiding fast reaction with the surrounding air. Ignition and sustained combustion of boron can take place only upon the evaporation of the oxide layer (at about 2300 K) to form B2O3(g). However, this investigation demonstrates, that unlike the combustion of individual boron particles in air, when dealing with ramjet combustors, the concentration of boron oxide gas (vapors) produced may reach the equilibrium vapor pressure. As a result boron oxide gas will condense back on the particle surface, blocking further reaction with air and resulting in incomplete combustion and a loss of energy. The full paper will show the limitation of boron combustion and energy release due to this thermodynamic effect over a range of boron fractions and chamber pressures.