DIRECT NUMERICAL SIMULATION OF FULLY RESOLVED DROPLETS IN A TURBULENT FLOW

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EXECUTIVE SUMMARY

The objective of our numerical study is to enhance the understanding of liquid droplet vaporization and mixing processes in a turbulent flow. The study employs direct numerical simulations (DNS) to examine the two-way interactions between freely-moving vaporizing droplets and isotropic turbulence. The droplets are fully resolved in 3D space and time (i.e., not treated as point particles), and all the scales of the turbulent motion are resolved down to the smallest relevant length- and time-scales (the Kolmogorov scales). Emphasis is placed on the two-way exchange of mass, momentum and energy between the vaporizing droplets and the surrounding turbulent gas. We simulated the motion of 1000 liquid droplets in isotropic turbulent flow to study their dispersion and compare it to the dispersion of solid particles. The goal is to understand the effect of the surface tension of the droplets on their dispersion.

INTRODUCTION

All liquid fuel combustion devices, mobile or stationary, use atomizers to produce sprays of fine droplets. The fuel droplets must first vaporize before they mix with the surrounding air. This mixing is followed by a chemical reaction between the fuel vapor and air, which converts the chemical bonding energy into thermal energy resulting in the volumetric expansion of the gas mixture. This volumetric expansion produces the desired mechanical energy for rotary or reciprocating engines.

Understanding the physical details of the droplet vaporization and mixing processes in a turbulent flow is an essential prerequisite to understanding the chemical reaction process and the eventual control/optimization of the energy conversion process. The results of the proposed study will have a significant impact on the efficient utilization of energy. This impact stems from the fact that the vaporization rate is the main controlling mechanism of fuel droplet combustion and that liquid fuels are the primary source of energy for all modes of transportation and will remain as such for the foreseeable future.

METHODS & RESULTS

Our numerical procedure solves the discretized incompressible Navier-Stokes and continuity equations in the liquid and gas phases with appropriate jump conditions at the interface between the two phases. To implicitly capture the interface between the two phases, we employ the accurate conservative level set method. The numerical solution of the discretized equations uses the conjugate gradient method preconditioned by a V-cycle geometric multigrid (GMG) solver. To understand the effects of surface tension on the droplets' motion, we compared the dispersion characteristics of finite size liquid droplets and finite size solid particles in isotropic turbulence at moderate values of Reynolds numbers, in zero gravity. The droplets and particles have equal diameters (larger than the Kolmogorov length scale) and equal ratios of particle (droplet) density to the carrier fluid density. The level set method is used for DNS of the droplets where a variable-density projection method is used to impose the incompressibility constraint. The immersed boundary method is used for DNS of the solid particles. Our results show that in isotropic turbulence, the dispersion of liquid droplets in a given direction is larger than that of solid particles due to the reduced decay rate of turbulence kinetic energy via the four-way coupling effects of the droplets.

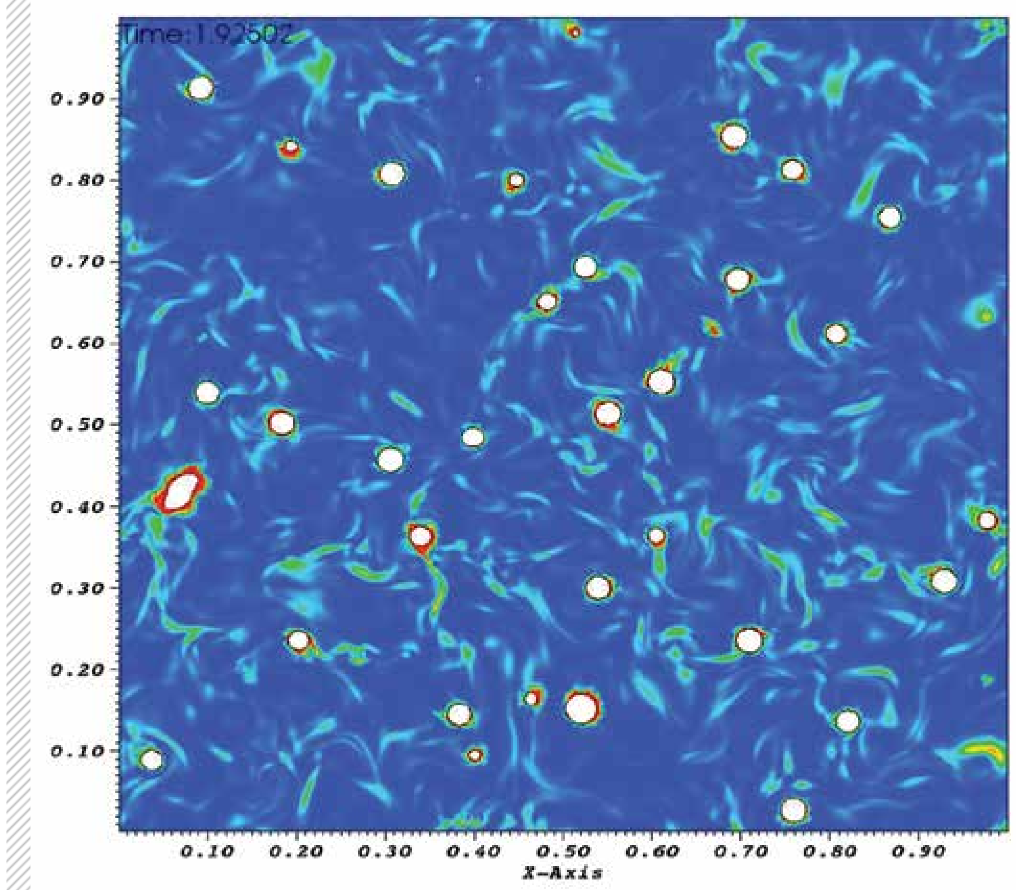

FIGURE 1: Contours of the dissipation rate of turbulence kinetic energy around non-vaporizing droplets in isotropic turbulence. Red and blue contours indicate maximum and minimum dissipation rates, respectively.

WHY BLUE WATERS

Blue Waters is indispensable for the DNS of a droplet-laden turbulent flow since the carrier flow is time-dependent, three-dimensional and contains a wide spectrum of length- and timescales. Furthermore, the interface between the liquid and gas phases must be resolved in time and space as the droplets move, including their shape change and possible droplet-droplet collision and merging. The Blue Waters staff is essential for the success of our study. Their continuous and prompt assistance is greatly appreciated.

NEXT GENERATION WORK

Our next generation work will emphasize the two-way exchange of mass, momentum, and energy between the vaporizing droplets and the surrounding turbulent gas. We plan to study droplet-laden turbulent shear flows after understanding droplet-laden isotropic turbulence.

PUBLICATIONS AND DATA SETS

Rosso, M., H. Wang, and S. Elghobashi, Dispersion of finite size droplets and solid particles in isotropic turbulence. *ICMF-2016 – 9th International Conference on Multiphase Flow*, May 22nd – 27th 2016, Firenze, Italy.