REVIEW OF SCIENTIFIC INSTRUMENTS **87**, 035119 (2016)

TURBOGEN: Computer-controlled vertically oscillating grid system for small-scale turbulence studies on plankton

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(Received 19 July 2015; accepted 14 March 2016; published online 25 March 2016)

In recent years, there has been a renewed interest in the impact of turbulence on aquatic organisms. In response to this interest, a novel instrument has been constructed, TURBOGEN, that generates turbulence in water volumes up to 13 l. TURBOGEN is fully computer controlled, thus, allowing for a high level of reproducibility and for variations of the intensity and characteristics of turbulence during the experiment. The calibration tests, carried out by particle image velocimetry, showed TURBOGEN to be successful in generating isotropic turbulence at the typical relatively low levels of the marine environment. TURBOGEN and its sizing have been devised with the long-term scope of analyzing in detail the molecular responses of plankton to different mixing regimes, which is of great importance in both environmental and biotechnological processes. © *2016 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4944813]

I. INTRODUCTION

Turbulence is present in many fluid media and plays an important role in several natural and industrial processes. Devices to generate turbulence within a controlled, predictable, and reproducible intensity range are therefore useful for laboratory experimentation and process studies. In aquatic ecosystems, turbulence strongly affects planktonic organisms over a wide range of scales,[1] and its impact may substantially affect their function and the related biogeochemical processes.

Peters and Redondo[2] provided the first exhaustive review of the different devices and experimental setups to generate a turbulent regime suited for plankton studies in laboratory conditions. They stressed that a "good" setup should ensure that the results depend on the variable of choice (e.g., turbulence variation) and not on other drivers (e.g., temperature, nutrients/food availability, or light). In addition, three more requirements were highlighted: i—homogeneous and stationary conditions must be present within the microcosms or mesocosms; ii—turbulence must be isotropic, i.e., invariant with direction; iii—dissipation rates must be as close as possible to the micro-turbulence occurring in the real environment, i.e., in the order of $10^{-9} - 10^{-6}$ m^2 s^{-3} with a value of 10^{-7} m^2 s^{-3} in the core of the mixed layer.[3]

Proper characterizations of micro-turbulent fields in nature, especially under high energy conditions, are scanty and mainly restricted to coastal systems,[4–7] given the difficulty to carry out direct or indirect measurements.[8] It follows that the main requirements underlined by Peters and Redondo[2] prioritize the robustness of the experiment vs. the analysis of the effects of a variable turbulent forcing.

Recent field and laboratory observations suggest that turbulence can be inhomogeneous and intermittent also on small spatial and temporal scales, respectively, and even anisotropic in weakly mixed oceanic layers.[8] The problem of exploring additional solutions for its generation in laboratory devices, suitable to perform experiments in variable and reproducible conditions, is clearly related to that issue.

Traditionally, turbulence is generated mostly by shakers and oscillating grids,[2] while a completely alternative approach, based on membranes vibrating at high frequency, was proposed a few years ago by Webster and co-workers.[9] In a comparative analysis, Guadayol and co-workers[10] showed that the two former methods, if properly used, may fulfill the main characteristics for experimental studies in microcosms or mesocosms, e.g.: stationarity, homogeneity, isotropy, and turbulence intensities close to nature.

Vertically or axis-symmetrically oscillating grids have been prevalently used for biological experiments because they are quite customizable by changing the grid mesh, the diameter of the rods, the size and the shape of the grid and of the container, the frequency and the length of the stroke. All of these parameters can be measured independently and the turbulence level derived and fixed *a priori*, while requiring a calibration for each grid type. Guadayol and co-workers[10] carried out a wide set of measurements with different grids and produced standard turbulence levels for a wide array of experimental setups.

Following a similar approach, we designed a device to produce grid generated turbulence with a computer-driven

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