PAPER PRESENTATION

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Complete Breakup of Liquids into Ultrafine Droplets by Grid Turbulence

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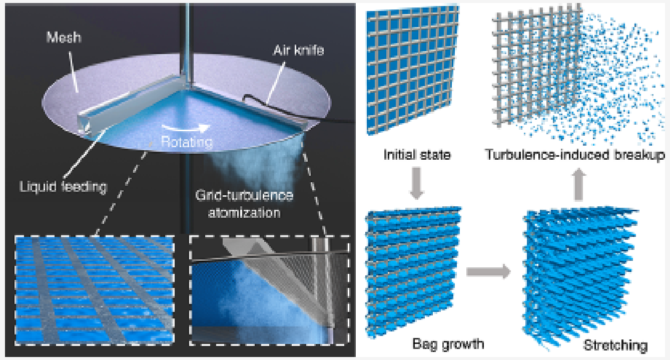
ABSTRACT: Ultrafine droplets are crucial in materials processing and nanotechnology, with applications in nanoparticle preparation, water evaporation, nanodrug delivery, nanocoating, among numerous others. While the potential of turbulent gas flow to enhance liquid breakup is acknowledged, constructing turbulence-driven atomizers for ultrafine droplets remains challenging. Herein, we report the innovation of grid-turbulence atomization (GTA), which employs a rotating mesh to deliver liquid and an air knife to spray ultrafine droplets. The airflow across the mesh transitions from laminar flow to grid turbulence, resulting in complete liquid breakup through three stages: bag formation, stretching, and turbulence-induced breakup. Ultrafine water droplets with a 4.8 μm Sauter mean diameter were achieved through GTA. The GTA system demonstrates versatility in atomizing various liquids and proves effective for ultrafine spray-drying. Our strategic methodology establishes a pivotal link between turbulence characteristics and materials processing, influencing a wide range of applications and sparking further innovation in the field.



KEYWORDS: *Liquid atomization, grid turbulence, ultrafine droplets, breakup mechanism*

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By: ANUBHAV MAHAPATRA

15-02-2025

Introduction

- While the potential of turbulent gas flow to enhance liquid breakup is acknowledged, constructing **turbulence-driven atomizers** for ultrafine droplets remains challenging.
- Liquid atomization is fundamentally important across various scientific and industrial processes particularly pronounced in material processing and nanotechnology.
- Effectively breaking up bulk liquid into **ultrafine droplets** poses a significant scientific challenge requiring innovative solutions.
- Ultrasonic atomization can produce ultrafine droplets but **struggles with high-viscosity** liquids and has low flow rates and high operating costs, hindering industrial adoption.
- GTA does not involve two nozzle fluids atomization and it can be used to atomize wide range of liquids having low to high viscosity.

Different ways of atomization

- Electrospray ionization
- Ultrasonic atomization
- Paper spray ionization
- Nebulization induced atomization
- Grid turbulence atomization

Terminology

- **Liquid Atomization:** The process of breaking a bulk liquid into smaller droplets.
- **Grid Turbulence:** Turbulence generated by passing a fluid through a grid or mesh.
- **Weber Number (We):** The ratio of inertial forces to surface tension forces.
- **Sauter Mean Diameter (SMD):** A measure of the average droplet size in a spray, defined as the diameter of a droplet having the same surface area-to-volume ratio as the entire spray.
- **Tyndall Effect:** The scattering of light by particles in a colloid or fine suspension.
- **Volume of Fluid (VOF) Method:** A numerical technique used to track the interface between two or more immiscible fluids.
- **Vorticity:** A measure of the local rotation of a fluid.
- **Strain Rate:** A measure of how much a fluid is deforming.
- **Q criterion:** Reflects the difference between the magnitudes of the **fluid vorticity and strain rate**.

Why this paper?

- **Turbulence driven atomizers** is a challenge to realize, while so many articles focus on the development of atomization involving turbulent gas flow to break the liquid.
- A new method has been discovered to atomize the wide range of bulk liquids including **low to high viscous** fluids (e.g., Silicone oil) by producing sub 10 μm droplets.
- This paper evolves innovation from the natural process of sneezing in which high speed air flow creates **ultrafine pathogen consisting droplets having mucus as a fluid** provides thinking in terms of nature.
- Mechanism has been established by both CFD (Computational fluid design) and VOF (Volume of liquid) simulation and experimentally.

Background

Article

Stabilization of liquid instabilities with ionized gas jets

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Check for updates

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Impinging gas jets can induce depressions in liquid surfaces, a phenomenon familiar to anyone who has observed the cavity produced by blowing air through a straw directly above a cup of juice. A dimple-like stable cavity on a liquid surface forms owing to the balance of forces among the gas jet impingement, gravity and surface tension[1,2]. With increasing gas jet speed, the cavity becomes unstable and shows oscillatory motion, bubbling (Rayleigh instability) and splashing (Kelvin–Helmholtz instability)[3,4]. However, despite its scientific and practical importance—particularly in regard to reducing cavity instability growth in certain gas-blown systems—little attention has been given to the hydrodynamic stability of a cavity in such gas–liquid systems so far. Here we demonstrate the stabilization of such instabilities by weakly ionized gas for the case of a gas jet impinging on water, based on shadowgraph experiments and computational two-phase fluid and plasma modelling. We focus on the interfacial dynamics relevant to electrohydrodynamic (EHD) gas flow, so-called electric wind, which is induced by the momentum transfer from accelerated charged particles to neutral gas under an electric field. A weakly ionized gas jet consisting of periodic pulsed ionization waves[5], called plasma bullets, exerts more force via electrohydrodynamic flow on the water surface than a neutral gas jet alone, resulting in cavity expansion without destabilization. Furthermore, both the bidirectional electrohydrodynamic gas flow and electric field parallel to the gas–water interface produced by plasma interacting 'in the cavity' render the surface more stable. This case study demonstrates the dynamics of liquids subjected to a plasma-induced force, offering insights into physical processes and revealing an interdependence between weakly ionized gases and deformable dielectric matter, including plasma–liquid systems.

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Twin-fluid atomization of viscous liquids: The effect of atomizer construction on breakup process, spray stability and droplet size

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Comparison of atomizers

ABSTRACT

This study focuses on the low-pressure spraying of viscous liquids (μ = 60, 147 and 308 mPa s) using four types of internal-mixing twin-fluid atomizers. We compare two well-known designs, namely the Y-jet and "outside in gas" (OIG) effervescent atomizers, with our new design (CFT) and an "outside in liquid" (OIL) configuration for the effervescent atomizer. The atomizers were operated by two gas inlet pressures (0.14 and 0.28 MPa) and various gas-to-liquid ratios (GLR = 2.5%, 5%, 10% and 20%). The comparison focused on internal liquid–gas flow, spray stability, primary breakup, and droplet size.

The primary breakup was investigated using a high-speed camera. A near-nozzle spray pattern was related to the ratio of forces, which affects liquid deformation, by dimensionless numbers. The breakup was driven mainly by air resistance in the OIG, OIL, and CFT atomizers and by surface tension in the Y-jet atomizer.

The OIL and Y-jet atomizers provided the most stable spray, regardless of the working regime or atomized liquid. The OIL atomizer produced the smallest droplets at low GLRs, while the droplet sizes for the Y-jet atomizer increased significantly at low GLRs. For the OIG atomizer, spray stability was influenced by the GLR, with the best stability being achieved at a GLR of 10% and 20%. The presence of large droplets at a low GLR caused an increase in droplet size. Switching the inlet ports of the effervescent atomizer (OIG–OIL) affected the internal flow, which differed under the same working regimes for these two configurations. The internal flow pattern of the OIL atomizer was estimated to be annular for all regimes, while for the OIG atomizer, it changed from a plug to slug flow with an increase in the GLR.

Background

Ultrasonic atomization of distilled water

L. Gaete-Garretón,[1] D. Briceño-Gutiérrez,[1] Y. Vargas-Hernández,[1] and C. I. Zanelli[2,a)]
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Experimental data on ultrasonic atomization of distilled water in a frequency range from 5 to 50 kHz are presented. A good agreement was found with the predictions of Rajan and Pandit [Ultrasonics **39**, 235–255 (2001)] for the atomized primary drop size as a function of frequency. The correlation of atomization drop size for different frequencies is useful when producing nano-particles, spray drying of suspensions, and covering of surfaces using different liquid products. Determining the displacement amplitude threshold for atomization at different frequencies is valuable in designing ultrasonic atomization systems. It is essential to measure the displacement amplitude of the atomizing surface rather that power applied to the transducer because the former is absolute while the latter depends on the efficiency of the transducer and other design parameters. As previous predictions for atomization threshold proved inaccurate, an empirical expression is proposed (based on the authors' measurements) to predict the amplitude atomization threshold for the studied frequency range. © *2018 Acoustical Society of America*.
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Special Issue - Prevention and control of COVID-19 transmission in the indoor environment

A model to predict the short-term turbulent indoor dispersion of small droplets and droplet nuclei released from coughs and sneezes

Jordi Pallares and Alexandre Fabregat

Abstract
We propose a simple model to predict the short-term indoor turbulent dispersion of the aerosol cloud produced by violent expiratory events. Once the air injection ceases, the turbulent jet transitions to a thermal puff that progressively decays due to viscous effects. According to recent literature, the expelled liquid droplets of saliva and sputum smaller than 20–30 µm in diameter stay afloat within this decaying turbulent puff. In contrast, droplets larger than 100 µm tend to leave the puff following quasi-ballistic trajectories and landing on the floor at relatively short times after release. The model presented here is capable of providing good estimates for the shape and dimensions of the cloud composed of the lighter fraction of droplets as a function of the intensity and the duration of the flow injection and the density difference between the exhaled and the ambient air. Predictions agree with Direct Numerical Simulations and experiments reported in the literature. This model can be used as an operational tool to determine the short-term spatial range of expelled droplets and provides realistic initial conditions for simulations of long-term dispersion of pathogen-laden clouds in indoor environments with forced and natural ventilation.

Results and Discussion

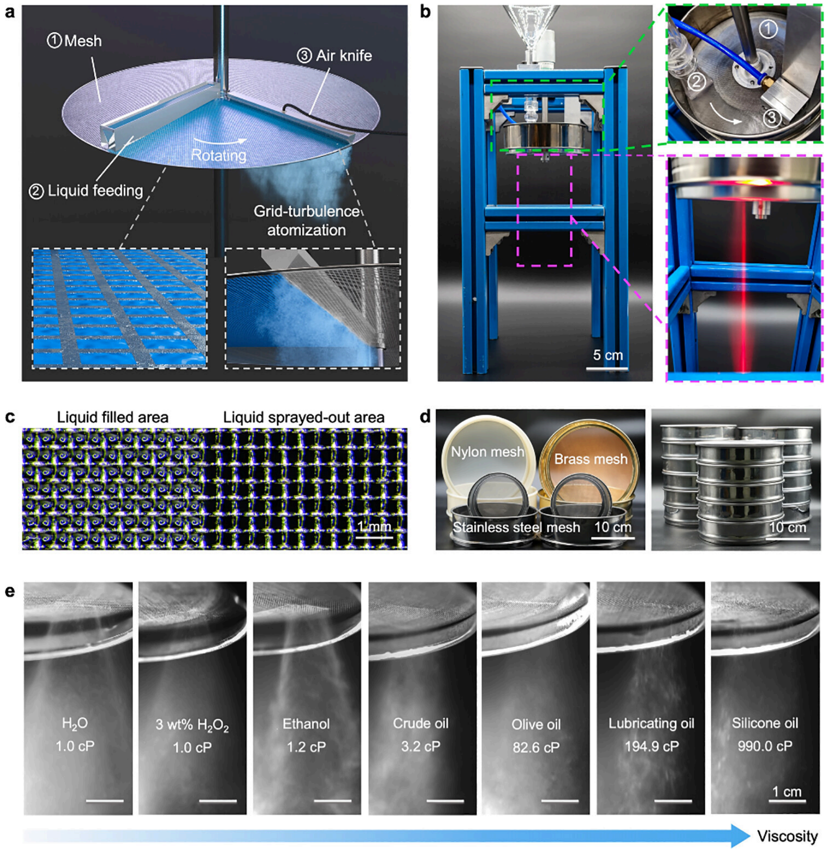


Figure 1. GTA design and construction. **(a)** Illustration of the GTA system. **(b)** Photographs of the GTA equipment. A clear and uniform Tyndall phenomenon was observed. **(c)** Optical microscope image of the mesh during the GTA process. **(d)** Photographs of a collection of meshes with various counts and meshes made with different materials including **nylon, copper and stainless steel**. **(e)** High-speed camera image of the GTA process using different liquids, including water (H_2O), 3 wt % H_2O_2, ethanol, crude oil, olive oil, lubricating oil, and silicone oil, with viscosity values from **1.0 to 990.0 cP**.

Results and Discussion

Supplementary Video 1

Design and principle of GTA

Supplementary Video 2

Water spray by GTA

Results and Discussion

Supplementary Video 4

High-speed video capturing GTA spray of various liquids

Supplementary Video 7

Visualization of grid-turbulence evolution

Results and Discussion

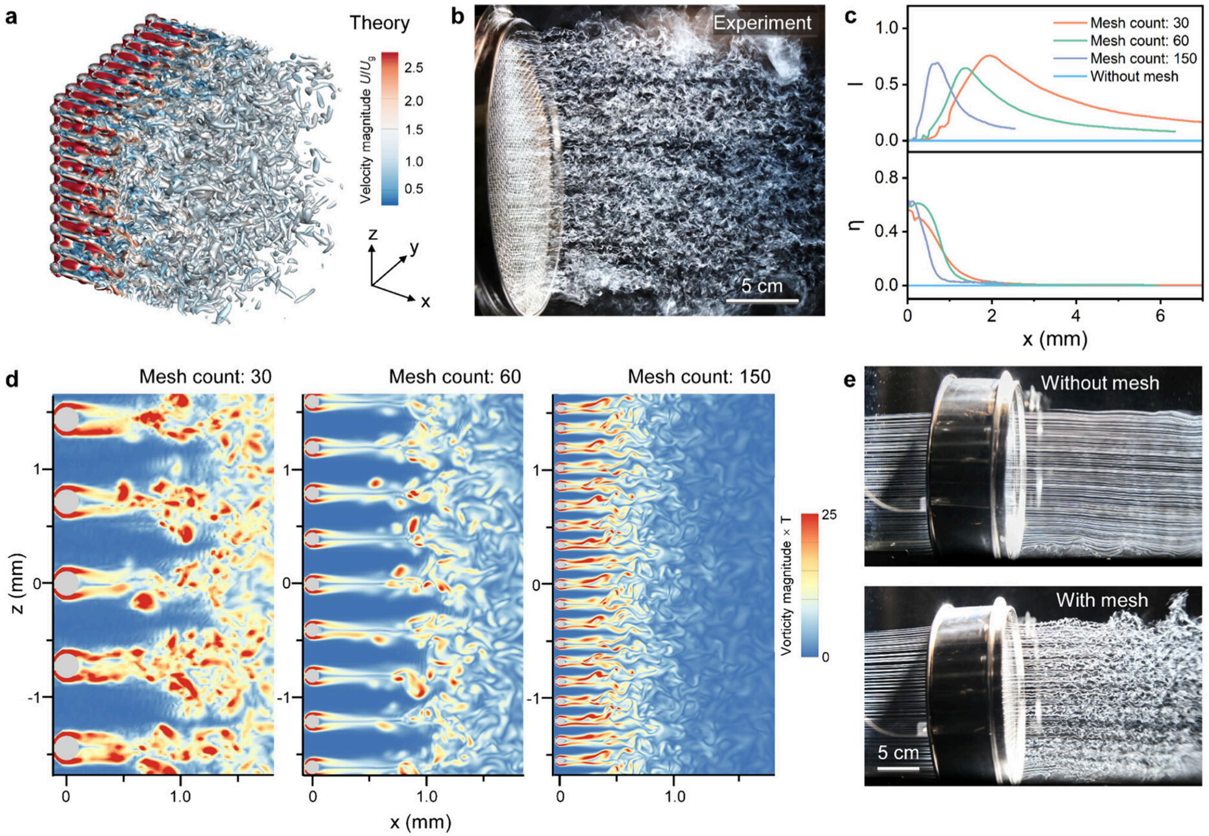


Figure 2. Grid turbulence origins. (a) CFD simulation result depicting the flow structures **(b) Experimental flow** visualization illustrating the airflow dynamics as it passes through a mesh, captured using the **smoke wire technique** to trace the airflow patterns. **(c)** Turbulence intensity I and anisotropy η along the x-axis at y = 0 and z = 0 using meshes with different counts **(d) CFD simulation** result depicting the nondimensionalized vorticity magnitude, **(e)** A comparison of experimental flow visualizations with and without the presence of mesh.

Results and Discussion

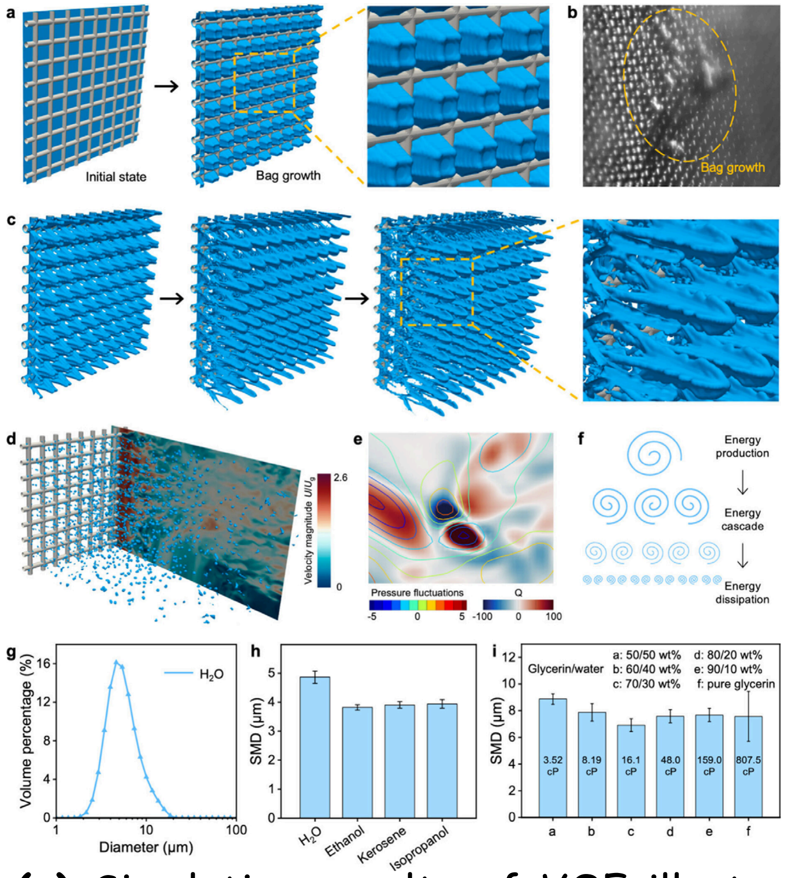


Figure 3. Liquid breakup mechanisms. **(a)** Simulation results of VOF illustrating the bag formation process. **(b)** A high-speed camera image of the GTA process illustrating bag formation. **(c)** Simulation results of VOF illustrating the liquid stretching process. **(d)** Simulation results of VOF illustrating the turbulence-induced liquid breakup process, coupled with airflow velocity field. **(e)** A 2D map of vortices identified by the Q criterion in grid turbulence, **(f)** Schematic illustration of the energy cascade process during the evolution of grid turbulence. **(g)** Size distribution of water droplets generated by GTA. **(h)** Sauter Mean Diameter (SMD) of droplets generated by GTA for different liquids. **(i)** SMD of droplets generated by GTA for glycerin/water mixtures with different ratios and viscosities.

Results and Discussion

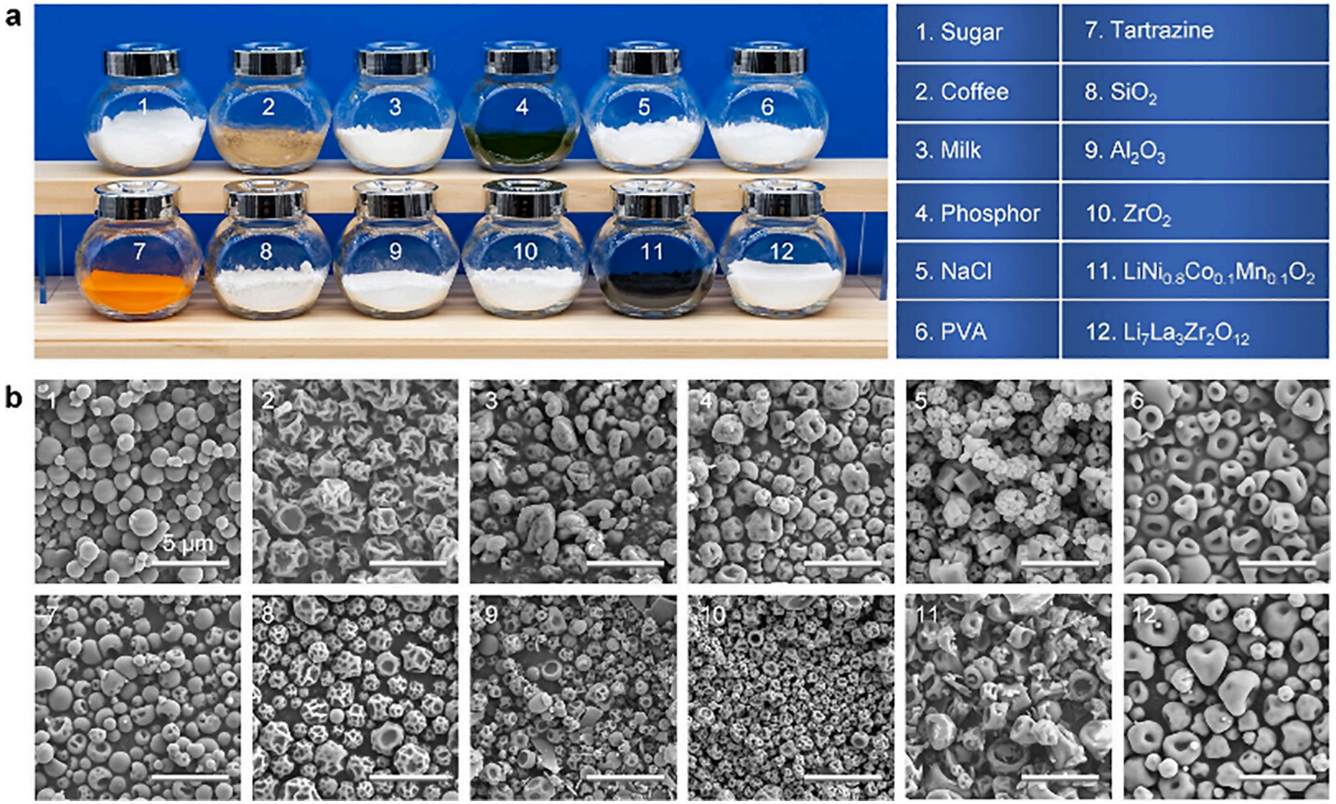
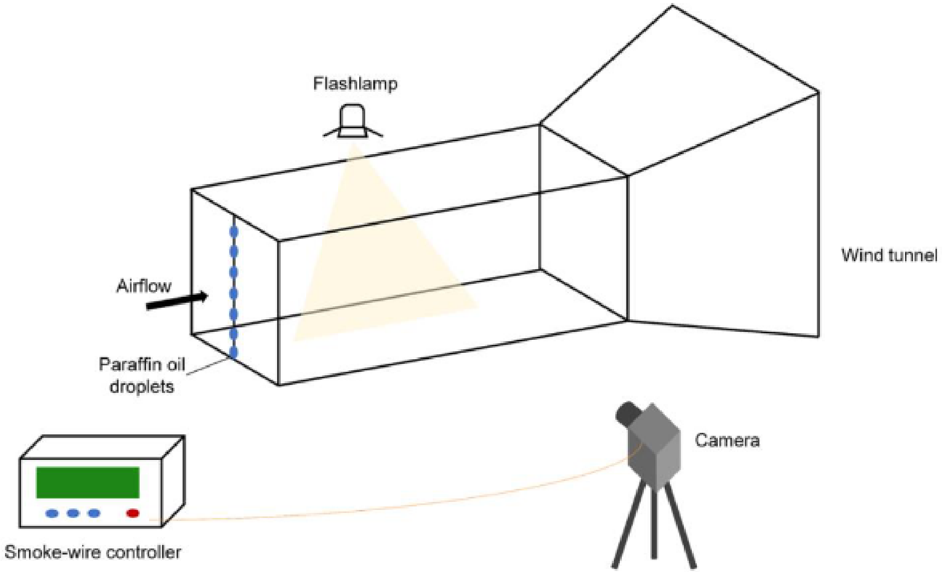


Figure 4. GTA as a generalized strategy to fabricate ultrafine powders. (a) Photographs of a rich variety of powders fabricated by GTA spray-dry. **(b)** Scanning electron microscopy (SEM) images of the corresponding powders (Nos. 1–12).



Smoke-wire system to visualize the flow of fluid.

Table S1. The dynamic viscosity of different liquids and their atomization properties.

Liquid	Viscosity / cP (Tested at 20 °C)	Ultrasonic atomization (1.7 MHz, 30W)	GTA (This work)
Water	0.99	√	√
3 wt% H_2O_2	1.03	√	√
Ethanol	1.24	×	√
Isopropanol	2.39	×	√
Kerosene	2.56	×	√
Crude oil	3.20	×	√
Ethylene glycol	20.80	×	√
Peanut oil	71.68	×	√
Olive oil	82.56	×	√
Lubricating oil	194.88	×	√
Methyl silicone oil #1	343.50	×	√
Methyl silicone oil #2	530.00	×	√
Methyl silicone oil #3	990.00	×	√

Conclusions

- A highly effective grid turbulence atomization (GTA) method for rapid, consistent, and extremely fine dispersion of various liquids, leveraging the principles of grid-induced turbulence.
- The GTA method effectively achieved superior atomization quality through its three-stage breakup mechanism, including bag formation, stretching and turbulence-induced atomization.
- The flexibility of the GTA platform allows it to atomize a wide range of liquids, including those with high viscosity, making it broadly applicable across industries.
- This advanced technique of turbulent gas–liquid interactions paves the way for a host of prospective developments in practical applications, such as improved fuel injection systems, more effective disinfection methods for public spaces, and the atomization of molten metal for ultrafine metal powders.

-THANK YOU