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Breakup morphology of annular liquid sheet with an inner round air stream

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HIGHLIGHTS

- Annular liquid sheet breakup can be divided into shell, cellular and fiber regime.
- Dimensionless cellular size is proportional to $We^{-0.5}$.
- Breakup regime of annular liquid sheet has been made in h/D_2–We map.

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ABSTRACT

Experiments were performed on the deformation and breakup of annular liquid sheet of nine coaxial twin-fluid air-blast atomizers with water–air systems by using a high speed camera. Due to the morphological difference, the annular sheet breakup could be classified into three regimes, which were bubble (shell) breakup, Christmas tree (cellular) breakup and fiber breakup. The roles of atomizer size and Rayleigh–Taylor instability in the annular sheet breakup were studied. The correlations on the instability wavelength and the size of cellular structure were deduced. The results showed that the dimensionless cellular size was proportional to $We^{-0.5}$, which were in good agreement with the experimental results. In order to have an overview of the different breakup mechanisms taking place over the wide range, we suggested categorizing these breakup regimes in a Weber number and dimensionless sheet thickness map.

1. Introduction

The transformation of liquid into spray is of importance in agriculture, meteorology and many industrial processes. Liquid atomization is also a fundamental research topic in multiphase flow, which has been studied extensively both theoretically and experimentally (Wang et al., 2014; Kulkarni and Sojka, 2014; Kekesi et al., 2014; Prakash et al., 2014; Xiao et al., 2014). As a common type of atomization, coaxial jets are utilized in a number of devices, including as burners in industrial furnaces and gasifiers, propellant injectors in rockets, and the exhaust of modern large bypass turbofan engines (Schumaker and Driscoll, 2012). In these applications, the complex near-field structure plays a critical role in determining how well the system performs (Lasheras and Hopfinger, 2000; Villermaux, 2007; Gorokhovski and Herrmann, 2008; Dumouchel, 2008; Theofanous, 2011).

There are two basic types on coaxial gas–liquid jets: (I) a cylindrical liquid jet surrounded by an annular gaseous stream and (II) an annular liquid sheet with an inner round gaseous stream. The properties of above two basic types are the foundation of three or multi-channels coaxial jets (Carvalho and Heitor, 1998; Wahono et al., 2008; Duke et al., 2010, 2012; Liu et al., 2006; Leboucher et al., 2010, 2012, 2014), which are also helpful in the research of monodisperse microbubbling by capillary flow focusing (Gañán-Calvo and Gordillo , 2001; Gañán-Calvo, 2004, Gañán-Calvo et al., 2006).

In this paper, we focus on the latter type (II). Annular liquid sheets are typically generated with circular slit nozzles or by diverging nozzle configurations which are common in many applications. So the distortion and disintegration of annular liquid sheets are of both fundamental and practical interest. The theoretical analysis on the instability of an annular liquid jet has been studied by Meyer and Weihs (1987), Oguz and Prosperetti (1993), Shen and Li (1996), Mehring and Sirignano (2000a, 2000b), Sevilla

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Table 1
The ranges of experimental parameters in coaxial jets, type (II).

	Gas velocity (m/s)	Liquid velocity (m/s)	Dimensionless sheet thickness (h/D_2), where h is the width of the annulus, D_2 is the outside diameter of annulus exit.
Kendall (1986)	1.5–13.7	0.5–4.75	0.19
Lee and Chen (1991)	5.5–32.0	0.96	0.21
Martínez-Bazán et al. (1999a, 1999b)	1.07, 4.48, 8.88, 9.84	17	0.30, 0.40, 0.43
Adzic et al. (2001)	0–40	0.86	0.11
Li and Shen (2001)	3.85–45	1.73–3.47	0.024
Choi and Lee (2005)	136–283	1.6–21.5	0.04–0.13
Sevilla et al. (2005a, 2005b)	2.7–58.5	1.85–9.65	0.36, 0.39, 0.42
Leboucher et al. (2010, 2012, 2014)	25–155	2	0.125
This study	4.4–154.7	0.17–3.03	0.06–0.37

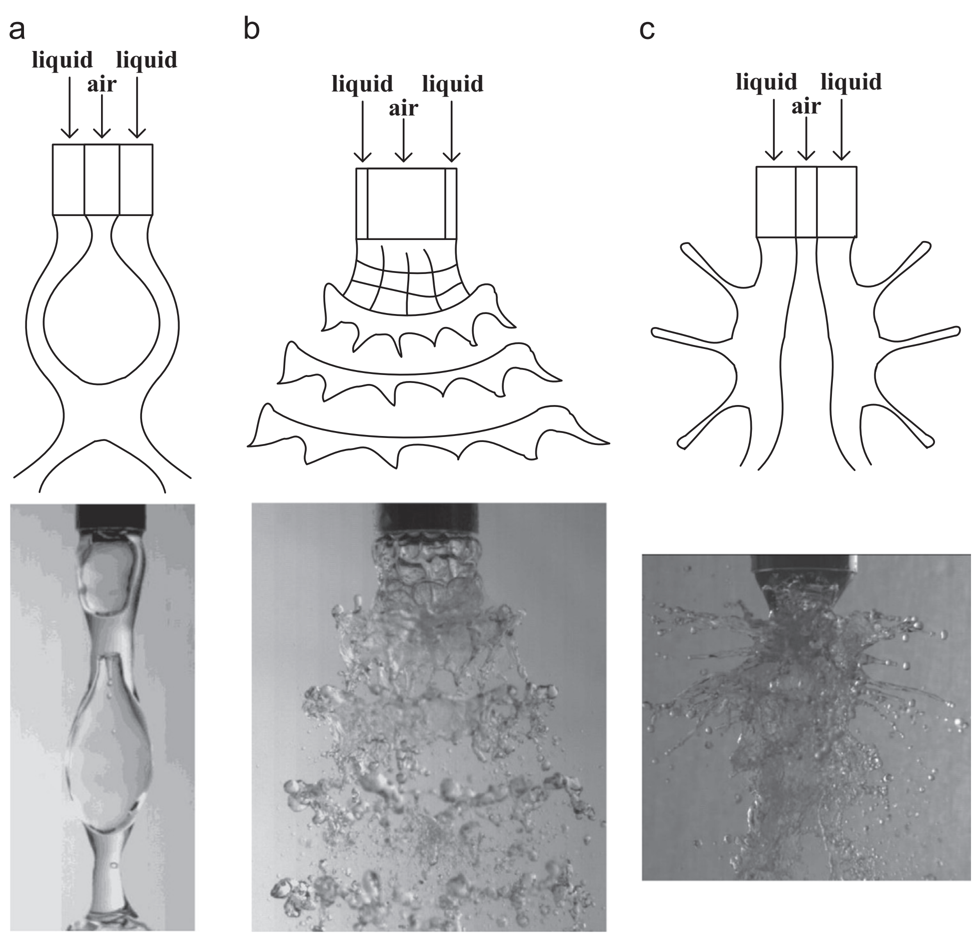

Fig. 1. Simple schematic diagrams illustrating the shape of the different regimes. (a) bubble breakup (shell breakup) (b) Christmas tree breakup (cellular breakup) (c) fiber breakup.

et al. (2002), Chen et al. (2003) etc. The experimental characteristics of annular sheet distortion and disintegration have also been investigated, whose atomizer sizes are as shown in Table 1. These data show various breakup morphologies and properties of coaxial jets, which are very interesting and useful. Kendall (1986) observed the bubble (shell) regime at low air velocity and studied the formation of liquid shells firstly. The breakup morphologies of annular sheet were also observed by Lee and Chen (1991), Martínez-Bazán et al. (1999a, 1999b), Adzic et al. (2001), Li and Shen (2001), Choi and Lee (2005), Sevilla et al. (2005a, 2005b) and Leboucher et al. (2010, 2012, 2014). A series of simple schematic diagrams illustrating the shape of the different regimes are shown in Fig. 1.

There are some high-quality papers on the atomization of liquid annulus around a central gas core. However, some papers only focus on the single breakup regime; other papers only focus on the single nozzle. The influence of atomizer sizes on breakup morphology and transition of different regimes is also absent. There are some correlations on the ranges of the breakup regimes in the literature. Unfortunately, these correlations are purely empirical or apply to the single nozzle. To overcome this, a theoretical model is needed which is based on the underlying physics.

Here in order to have an overview of the different breakup mechanisms taking place over the wide ranges, this paper focuses on the ranges of different breakup regimes which can apply to