Chemical Engineering Science 107 (2014) 149–157

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

# Influence of spinning cup and disk atomizer configurations on droplet size and velocity characteristics

Mahmoud Ahmed *, M.S. Youssef

*Mechanical Engineering Department, Assiut University, Assiut 71516, Egypt*

## HIGHLIGHTS

- Transition from ligament to sheet occurs in spinning cups before spinning disks.
- Correlation for $d_{32}$ of flat disks predicts those of the cup and disk atomizers.
- Drop velocities of cup and disk atomizers are within 95% confidence of a flat disk.
- The virtual slip ratio ranges between 18% and 41% for disk and cup atomizers.
- Aerodynamic drag is approximately the same for disk and cup atomizers

## ARTICLE INFO

*Article history:*
Received 11 May 2013
Received in revised form
22 November 2013
Accepted 3 December 2013
Available online 17 December 2013

*Keywords:*
Rotary disk and cup atomizers
Phase Doppler Particle Analyzer
Sauter mean diameter
Droplet velocity

## ABSTRACT

The influence of spinning cup and disk atomizer configurations on droplet size and ejection velocity characteristics has been experimentally investigated. The Phase Doppler Particle Analyzer (PDPA) was used to measure spray characteristics in the downstream tangential distance along the spray trajectory. Four groups of both rotating disks and cups with different configurations have been experimentally studied. The first group comprises spinning disks serrated with different numbers of teeth ranging from 0 to 240. The second group includes spinning disks with different upper and lower edge angles in the range of 15° to 60°. The third set consists of spinning conical cups with different half cone angles ranging from 15° to 60° and different base diameters in the range of 0.002 to 0.06 m (2–60 mm). The last set includes spinning cylindrical cups with different heights in the range of 0.005 to 0.045 m (5–45 mm). The outer diameter of all cups and disks in all sets is 0.07 m. All experimental tests have been performed at a rotating speed of 1257 rad/s (12,000 rpm), and supply water flow rate of $2.22\times10^{-6}$ $m^3/s$ (8 L/h). Measurements of Sauter mean diameter and average droplet velocity for droplets produced by studied cups and disks are compared with those of droplets produced by a regular flat disk atomizer. Comparisons indicate that all values of Sauter mean diameters and average droplet velocities for different configurations are statistically within 95% confidence level intervals around the mean of those produced by a regular flat disk. Numerically, the mean of Sauter mean diameters produced by different configurations of spinning disk and cup atomizers varied between −8% and 12% around the mean of Sauter mean diameter produced by a regular flat disk. In addition, the virtual slip ratio ranged between 18% and 41% for all atomizer configurations, while for a regular flat disk, it was 33%. The developed correlation predicting Sauter mean diameter produced by spinning regular flat disks can be satisfactorily used to predict those produced by rotating cup and disk atomizers with different configurations. In addition, the values of drag coefficient and drag force for droplets of a regular flat disk are slightly different from those calculated for investigated disk and cup atomizers.



## 1. Introduction

Atomization of liquids into an ambient gas promotes intimate contact between the two phases. In this process heat, mass, and momentum transfer between the two phases are often accomplished in a very short time. The atomization process is the key to successful design and operation of equipment that is used in various chemical engineering processes, and many other gas-contact applications. Spinning atomizers are particularly suited to slurries, and high viscous fluids. The selection of various operating parameters and geometrical configurations are known to be dependent on physico-chemical properties of the fluid or

* Corresponding author. Tel.: +20 1008370279.
*E-mail address:* aminism@aun.edu.eg (M. Ahmed).

0009-2509/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ces.2013.12.004

slurry. Despite the wide applicability of spinning atomizers, the available data that can be used for selection or design of the proper type, shape and size of such atomizers are still limited. In addition, the quantitative information, which shows the effect that geometrical configurations might have on spray characteristics, is either not available or not yet fully understood.

As reported in Ashgriz (2011) and Masters (1988), inverted bowls, cups and plates are classified as vaneless disk atomizers. The mechanism of atomization for such atomizers depends on the disk geometrical configuration, rotational speed, supply flow rate and liquid properties (density, surface tension, and viscosity). As indicated in Ashgriz (2011), at low supply flow rates, and low rotational speeds the atomization takes place by direct droplet formation mode. This mechanism changes with the increase of supply flow rate to ligament formation mode in which spray droplets are formed by ligament breakup. Further increase of supply flow rate tends to merge the ligaments and consequently, a sheet is shaped around the complete disk periphery. This is defined as a sheet formation mode, in which spray droplets are produced by breakup of the created sheet. Similar results were obtained by Hinze and Milborn, (1950) using a rotating cup atomizer. They observed the same atomization modes for droplet formation as reported in Ashgriz (2011) and Masters, (1988). They concluded that transition from direct drop formation mode to ligament mode, and/or from ligament mode to sheet formation mode were produced by increasing flow rate, angular speed, liquid density, and viscosity, or by decreasing cup diameter, and liquid surface tension. Their results of droplet size measurements revealed that rotating cup atomizers were producing much more uniform droplets than that achieved with pressure atomizers (Hinze and Milborn, 1950). Most recently, Liu et al. (2012) studied the atomization mechanism of rotary cups using a high-speed camera. In their experiments, two different glycerol/water mixtures and three different cups with outer diameters of 0.090, 0.11, and 0.128 m were used. They reported that three modes of disintegration mechanism were observed. In addition, their experiments showed similar effects of operating variables and liquid properties on the transition between breakup regimes as those reported by Hinze and Milborn (1950).

The effect of spinning disk design on droplet sizes was investigated by Adler and Marshall (1951a, 1951b). They mentioned that comparisons of the droplet size distribution produced by seven different disk designs operated at supply flow rate of 660 L/h, and peripheral speed of 63.5 m/s showed that the disk design had a negligible influence on the droplet size distribution. The investigated design parameters were the number of vanes built in the rotating disk surface and their configurations. In their articles, there are no details regarding the atomization mechanism.

The effect of edge profiles of rotating disks on spray characteristics was studied by Walton and Prewett (1949). In their experiments, spinning disks having different edge profiles such as sharp edge, right angle edge, 45° inclined edge, and round edge with different radius were considered. They reported that changing edge profiles leads to insignificant differences in droplet sizes. However, Lefebvre (1989) concluded that serrating the edge of the cup or disk delays the transition from ligament mode to sheet mode and improves the atomization quality. No further details were reported by Lefebvre (1989).

Tanasawa et al. (1978) investigated the effect of rotating disk and cup atomizer configurations on the critical flow rates for the transition between different breakup regimes, and on the droplet sizes. They concluded that for the serrated disks, the number of teeth affects the droplet sizes, and for the rotary cups, the cone angle has no effect on the critical flow rate at which the transition between different breakup modes takes place.

The above survey of literatures indicated that there are noticeable discrepancies among the reported effects of disk and cup configurations on spray characteristics. These discrepancies are most likely due to several reasons. First of all, the operating variables are not the same for each test case. The disk diameter ranges from 0.1 to 0.15 m in Tanasawa et al. (1978) test, and from 0.02 m to 0.08 m for Walton and Prewett (1949), while no details were available for Lefebvre (1989), and Adler and Marshall (1951a, 1951b) tests. Similarly, a wide range of rotational speed was reported where it varies from 50 to 10,000 rad/s for Walton and Prewett's (1949) test, and from 400 to 7000 rpm for Tanasawa et al.'s (1978) test. These wide ranges of variables resulted in different breakup regimes. This means that the breakup regime is not the same for all tests; it is varied from direct drop formation to sheet formation mode. Walton and Prewett (1949) reported that droplet formation occurred at a direct drop, ligament, and sheet formation mode. Tanasawa et al.'s (1978), and Lefebvre (1989) reported that the ligament formation mode has been observed. Furthermore, in Adler and Marshall (1951a, 1951b) only the sheet formation mode has been observed. These multiple formation modes resulted in wide ranges of droplet sizes.

Finally, measuring methodology, sampling location and the total number of measured droplets are not the same for all tests. Walton and Prewett (1949) estimated the droplet size by impaction of the droplets on magnesium oxide coated slides and measurement of the crater diameters. Adler and Marshall (1951a, 1951b) reported that spray droplets were caught in an oil bath and then photographed, measured, and counted. Tanasawa et al. (1978) directly photographed the spray droplets and measured the droplet photos. While there are no details regarding the accuracy of each method, the expected accuracy is low due to accumulating errors in photographing, sizing, and counting of droplets. In addition, the number of measured droplets is expected to be limited. Consequently, the accuracy of the calculated mean droplet size is mainly dependent on the total number of the measured droplets. The more the number of droplets measured, the higher, the accuracy achieved. Furthermore, there is no information regarding the sample locations. Since the droplet size changes with downstream tangential distance, it is essential that the sample locations be reasonably selected along the whole sprayed area. This will greatly help to estimate an accurate mean droplet size representing the whole spray. All the above mentioned factors significantly affect the accuracy of calculation of the mean droplet size and accordingly the final conclusion. Therefore, the objective of the present work is to investigate the effect of various and alternative atomizer configurations on spray characteristics that include mode of droplet formation, mean droplets size and velocity. This study is carried out at the same operating variables, and consequently the same breakup regime. In addition, in the present work, PDPA has been applied to measure droplet size with high level of accuracy as explained in the next section. Moreover, the optimal configuration of rotating disks and cups atomizers that can produce minimum size of spray droplets will be specified.

## 2. Experimental setup and procedure

The experimental setup for measuring the size and velocity of droplets produced by disk and cup atomizers of different configurations is shown in Fig. 1. Major parts include rotating atomizers, a pressure tank, a three-dimensional traversing mechanism, a flow meter (rotameter), and a pressure gage along with proper piping and valves. A variable-speed AC commutator motor with a built-in tacho-generator whose maximum no-load speed equal to 1885 rad/s (18,000 rpm) has been used. Tacho-generator calibration was performed by measuring the rotational speed and the corresponding output voltage. A digital velocity meter has been used to measure the motor's rotational speed. Speed measurement, which was controlled