ILASS–Europe 2022, 31th Conference on Liquid Atomization and Spray Systems, 6-8 September 2022, Virtual, Israel

Nanobubble suspension jets break-up by doublet impingement

Vivek K*[1], Aditya Saurabh[2], Lipika Kabiraj[1]
[1]Mechanical Engineering, Indian Institute of Technology Ropar, PB 140001, India
[2]Mechanical Engineering, Indian Institute of Technology Kanpur, UP 208016, India

*Corresponding author: 2018mez0025@iitrpr.ac.in

Abstract
Atomization experiments on a like-on-like impinging jet configuration conducted on suspensions of water containing bulk oxygen nano-bubbles. Effects of the presence and concentration of nanobubbles on liquid sheet formation, its break-up, and formation of droplets are investigated.

Keywords
Atomization, nanobubbles, impinging jets

Introduction

The requirement for enhanced combustion and emission characteristics has led researchers to explore the processes preceding and succeeding combustion in detail. In the liquid fuel systems break-up, atomization and mixing with oxidizer are essential stages that directly affect the combustion quality in rocket prolusion systems, gas turbines, IC engines, and furnaces. In the field of rocket propulsion, the effervescent atomization technique employs gas bubbles of size micro and milli meter inside liquid [1]. These bubbles assist in atomization and produce smaller droplets. The bubbles of such sizes are primarily unstable, and a continuous gas supply during atomization is essential.

In recent years, studies on small-size bulk gas bubbles termed nanobubbles in liquids have drawn considerable interest. The possibility of generating nanobubbles in liquids, especially fuels, is an opportunity to manipulate their physical and chemical properties. More importantly, it shows that such nanobubble suspensions are relatively stable [2-3].

Impinging jet atomization is a conventional injection method to atomize liquid rocket propellants. The process of liquid break-up is mainly influenced by the injector geometry, ambient conditions, and physical properties of the liquid fuel. A doublet impingement configuration is a widely used configuration and has been used to study both Newtonian and non-Newtonian propellants with and without additives. The liquid sheet break-up length generally reduces for increasing Weber number[5-6]. In the present study, we investigate impinging jets atomization of water—oxygen nanobubble suspensions.

Material and Methods

Oxygen nanobubbles are generated in pure water by hydrodynamic cavitation in a Venturi tube. Pure water circulates through the throat of a Venturi tube and passes through a nanomembrane where it is exposed to pressurized oxygen gas. The nanobubble suspension is formed via continuous circulation of water through the setup for 1 hour. Characterization of nanobubble liquid samples thus produced is performed in Nano sight NS300 Nanoparticle Tracking Analyzer (NTA). This measurement provides the nanobubbles size and their concentration. Surface tension measurement of oxygen nanobubbles suspension in water and pure water is measured by Wilhelmy Plate method.

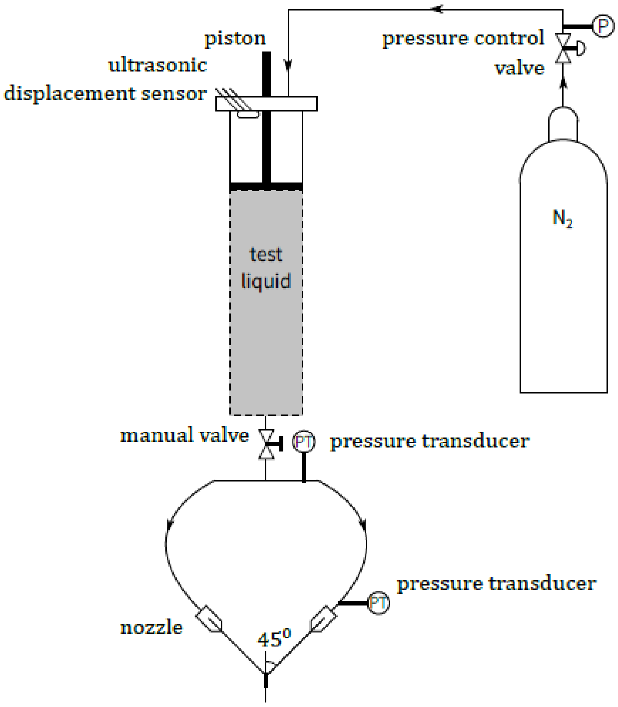

Figure 1. Doublet like-on-like impinging jets atomization set up schematic

Pure water and Oxygen nanobubbles water are atomized in a doublet like-on-like impinging jets atomization configuration and at impingement angle of 90°. We used two identical nozzle of orifice diameter 0.41 mm. The test liquids are stored in a chamber connected to high pressure Nitrogen supply as shown in Figure [1]. The liquid jet emerges from the two orifices according to the pressure applied by the piston. An ultrasonic sensor tracks the position of the piston. Pressure transducers mounted near the inlet to the nozzles measure nozzle inlet pressure. A similar configuration was used in our previous study on the atomization of Carbopol gels

High-speed shadowgraph images of the liquid impingement plane are captured using a high-speed camera and a 20 W LED backlight. At a frame rate of 4000 fps and a shutter speed of 5 microseconds, clear images of sheet breakup are captured. The frame included the tip of the nozzle, impingement point, liquid sheet, and droplet formation with a spatial resolution of 40 micrometers per pixel.

Results and Discussion

NTA measures nanobubbles concentration per milliliter of a sample of water-oxygen. The mean size of nanobubbles is found to be 147.3 nm with a standard deviation of 67.5 nm. The concentration of nanobubble per milliliter of the sample measured is 2.16 x 10^8. The surface tension of nanobubble water suspension by Wilhelmy Plate method gave a value of 0.0692

mNm^{-1}. This small reduction in surface tension of 0.072 mNm-1 is explained by the presence of bulk nanobubbles.

$$We = \frac{\rho u^2 d_0}{\sigma} \quad (1)$$

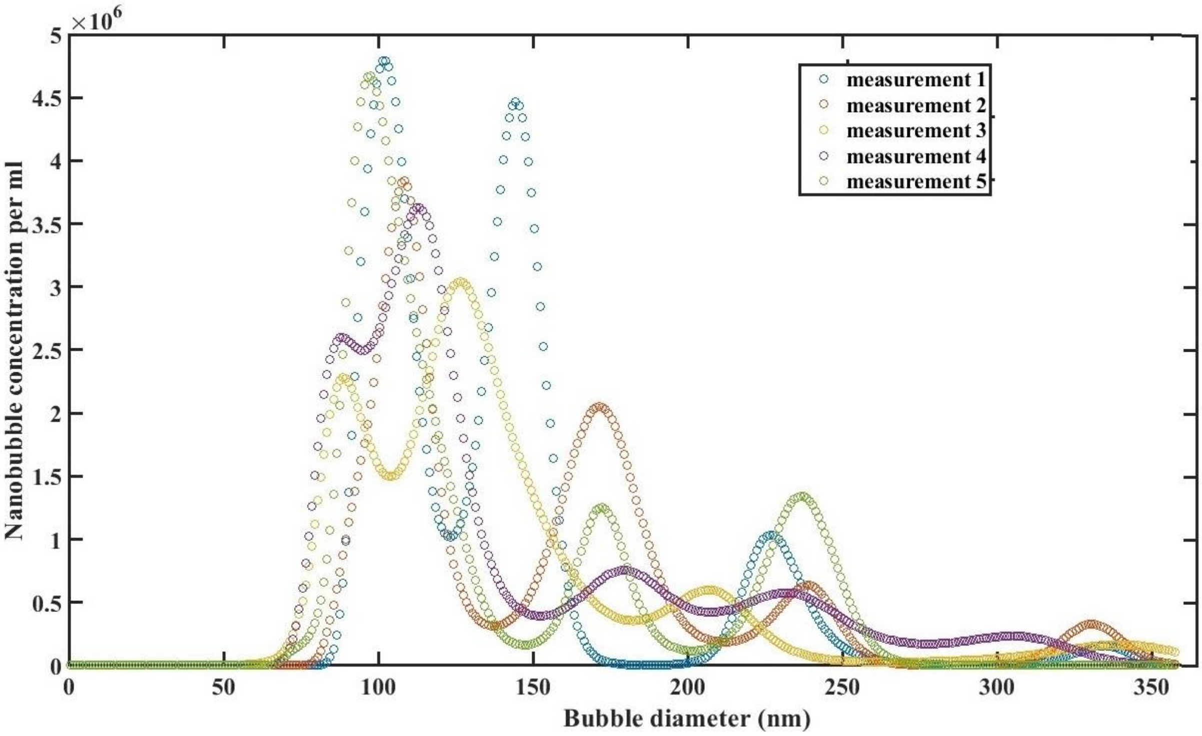

Figure 2. Concentration of nanobubbles per ml in water-oxygen nanobubbles suspension

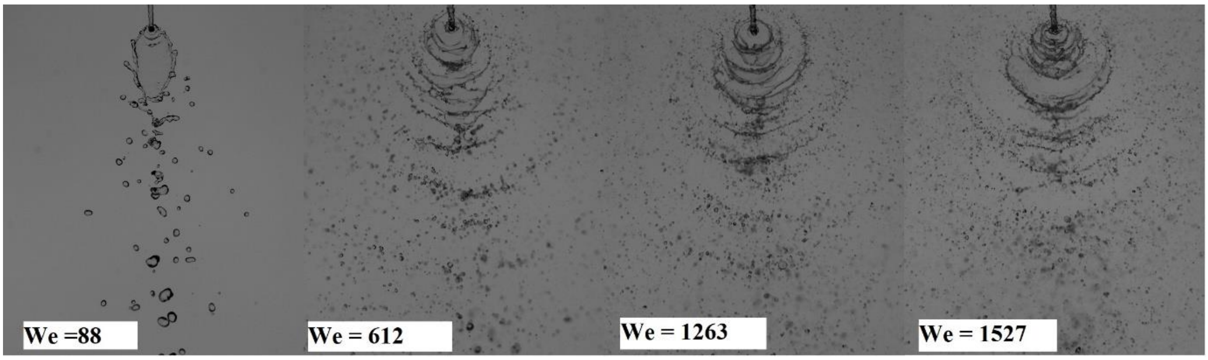

Figure 3. Liquid sheet break-up images of nanobubble water suspension for increasing Weber number.

The general observation of liquid sheet break-up from impingement jet atomization is that the sheet break-up length reduces with an increase in Weber number (equation [1]) [5]. In our study with pure water, sheet break-up lengths reduce with an increase in Weber number. For nanobubble water suspensions, a slight reduction in sheet break-up length is observed for the range of Weber number currently studied. The sheet break-up dimensions for nanobubble water suspensions are relatively lower than that of pure water for a similar Weber number. This reduction in sheet break-up is attributed to the suspension's lower surface tension compared to pure water. The surface tension value for nanobubble suspension was reduced by almost 3%. To compare the sheet break-up length of water and the suspension, we take We 1450 and 1527 respectively and we get a 25% reduction in non-dimensional sheet break-up length. This reduction in break-up length for a wide range of Weber numbers needs to be studied.

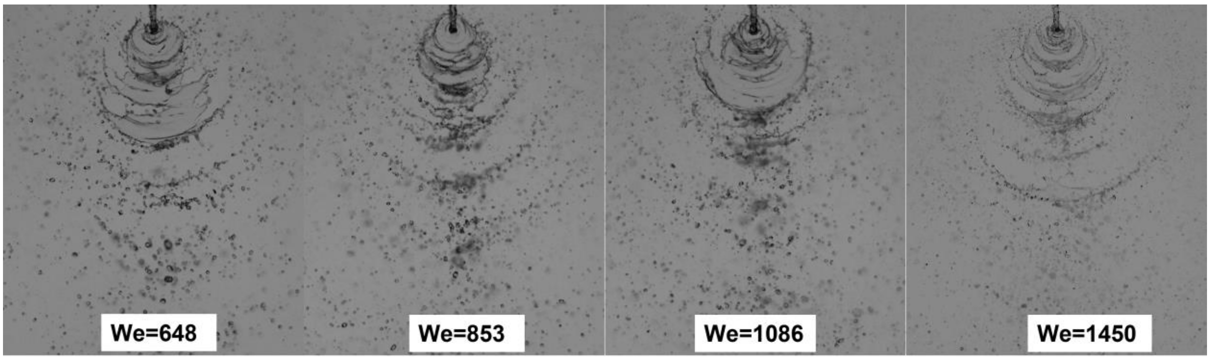

Figure 4. Liquid sheet break-up images of water for increasing Weber number.

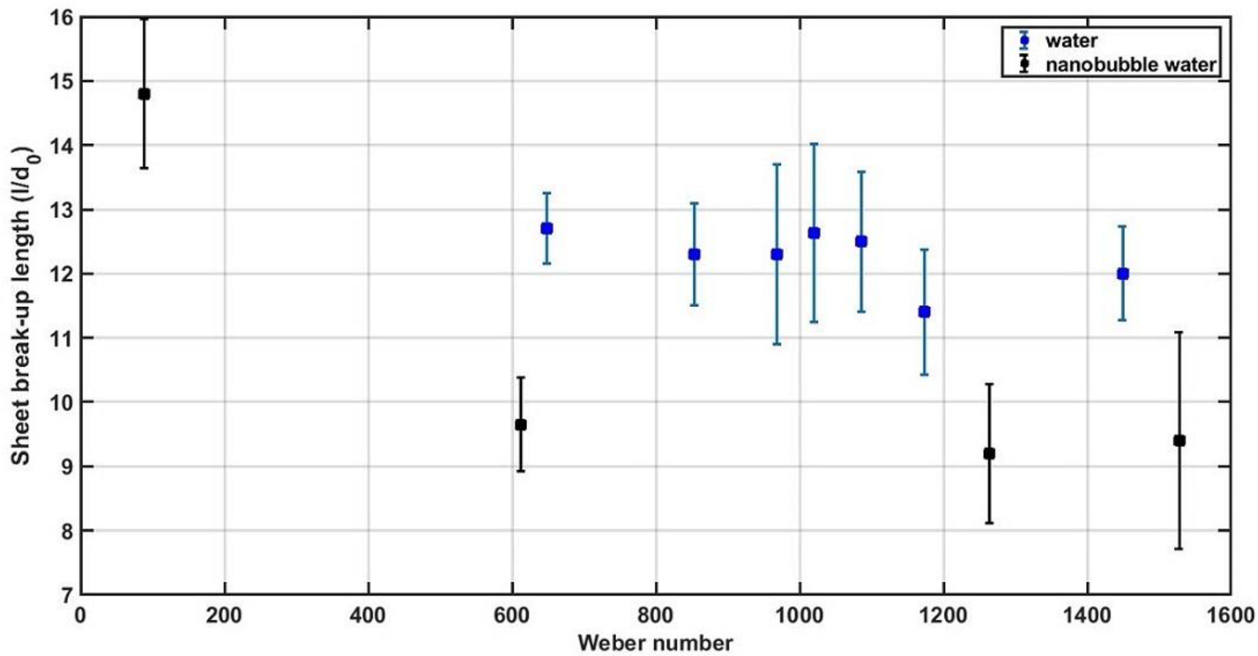

Figure 5. Liquid sheet break-up images of nanobubble water suspension for increasing Weber number.

Conclusions

The gas nanobubbles suspensions on water is found to show reduction in sheet break-up length compared to pure water sheet break-up length for Weber number below 1700.

Nanobubbles generated in water has reduced the surface tension of the water is seen as the main contributor for the reduction in sheet break-up length.

Acknowledgments

We acknowledge the financial support provided by LPSC, ISRO India, and SERB DST, India.

Nomenclature

ρ density [kg m^{-3}]
We Weber number
d_0 orifice diameter [m]
u jet velocity [m s^{-1}]
σ surface tension [N m^{-1}]

References

[1] Sovani, S. D., Sojka, P. E., Lefebvre, A. H., “Effervescent atomization,” Progress in Energy and Combustion Science, Vol-27, 2001, pp. 483,521.
[2] Oh, S. H., Han, G. J., Kim, J., “Long term stability of hydrogen nanobubble fuel,” Fuel 158, 2015, pp. 399, 404. doi: 10.1016/j.fuel.2015.05.
[3] Mehta, R. N., Chakraborty, M., Parikh, P. A., “Nanofuels: Combustion, engine performance, and emissions,” Fuel, Vol-120, 2014, pp. 91,97.
[4] Nakatake, Y., Kisu, S., Shigyo, S., Eguchi, T., Watanabe, T., “Effect of nano air-bubbles mixed into gas oil on common-rail diesel engine,”Energy, Vol-59, 2013, pp.233-239.
[5] Saurabh, A., Deshmukh, D., Nath, S., Agarwal, D. K., Vivek, K., Kabiraj, L., “Impingement atomization of Carbopol gels,” AIAA Propulsion and Energy 2020 Forum, 2020.
[6] Baek, G., Kim, S., han, J., Kim, C., “Atomization characteristics of impinging jets of gel material containing nanoparticles,” Journal of non-Newtonian fluid mechanics, Vol-166 21-22, 2011, pp.1272,1285. https://doi.org/10.1016/j.jnnfm.2011.08.005.