Plasma Effect on Physical Properties of Water (Surface Tension, Viscosity and Contact Angle)

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Abstract: This study focuses on the need for experimental determination of PAW physical properties, namely surface tension, viscosity and contact angle. The results of this study experimentally found that plasma addition lowers the surface tension of water at room temperature, increases the viscosity of water at high temperatures and lowers the contact angle of droplets formed on glass surfaces at room temperatures. Potential factors influencing these changes include plasma alteration of the mesoscopic structure of water at low temperatures and plasma additives acting as foreign particles in water at higher temperatures.

Keywords: PAW, Physical properties, surface tension, viscosity, mesoscopic structure.

1. General

In a study of washing out efficacy of plasma activated water (PAW) on fresh produce surface [1], it was observed that PAW physically removes the bacteria while deactivating it. The reactive oxygen and nitrogen have been attributed to the deactivation of pathogens; but it is not able to explain this removal behaviour. This physical removal had given initial insights into the possible surfactancy behaviour of PAW. The modified free energy equation [1] of water accounting to plasma addition indicates that, plasma addition results in water favouring amorphous structure at low temperatures, which is usually found at high temperatures and is characterized by low surface tension and viscosity. Studies focusing on the physical properties of water namely thermodynamic and transport properties are limited. This paper experimentally studies the changes occurring to the physical properties of water, namely surface tension and viscosity, with plasma addition.

2. Experiments Details

PAW produced with gliding arc plasma was used in this study. The pH of PAW is 2 − 2.9 compared to 5.5- 6 of distilled water.

The surface tension measurements were performed using pendant drop method with OpenDrop software [2] to calculate the surface tension. The viscosity measurements were performed with calibrated Canon-Fenske viscometer with an accuracy of 0.16%. The contact angle made by droplets of PAW on glass slides was measured using Open Drop software [2].

3. Results and Discussions

The Surface tension of PAW of two pH's 2.5 and 2.78 were measured using pendant drop tensiometry, at room temperature of 18 degrees Celsius. The results obtained are shown in the figure 1.

The result of this study agrees with the suggestion by J He et al [1], that plasma addition changes the structure of water from crystalline to amorphous; and results in lower surface tension compared to water. As plasma affects the surface tension of water, plasma addition influences the thermodynamic properties of water.

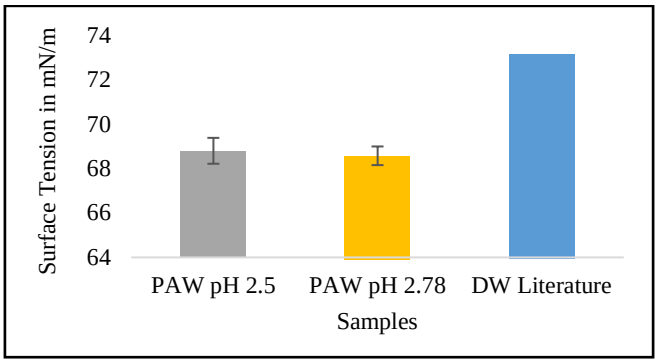

Fig. 1. Surface tension of plasma activated water, the surface tension of distilled water (DW) shown for reference.

The viscosity of PAW was measured from 10 - 40 degree Celsius with the help of Size -25 Canon- Fenske viscometer and a water bath. The viscosity results obtained for measurement temperatures between 10 – 40 ° C is shown in figure 2.

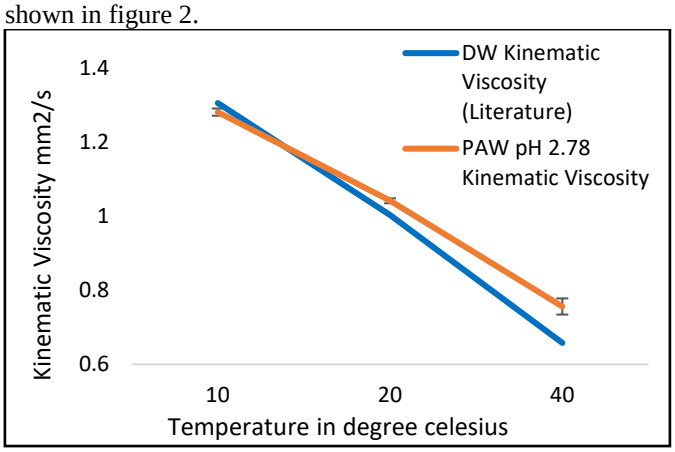

Fig 2. Viscosity of PAW from 10 – 40° C; the viscosity of distilled water (DW) shown for reference.

From results, the viscosity of PAW at low temperatures is lower than that of distilled water. It is because, as we have seen with surface tension, plasma activation results in

water attaining amorphous structure at low temperature, which is characterised by low viscosity and surface tension. The low viscosity effect is not very significant because of plasma additives present in PAW. The low viscosity trend reverses with increase in temperature when the effect of plasma additives takes over the mesoscopic structure change.

Plasma additives result in PAW to have significantly higher viscosity than distilled water by 12.8 % at 40° C. The viscosity of PAW is slightly lower than water viscosity at low temperatures but as temperature increases the viscosity of PAW increases.

This behaviour can be understood with the following: at low temperatures the mesoscopic structure of water is crystalline and that of PAW is amorphous. At identical temperatures, liquids with amorphous structure are less viscous than liquids with the more viscous crystalline structure. As temperature increase, crystalline structure of water gradually changes to amorphous structure. As PAW has additives present in it compared to water, its viscosity increases with increase in temperature. The viscosity of PAW at 40 degrees Celsius is significantly higher than that of water by 12.6%.

The contact angle made by PAW of pH's 2.47, 2.68, 2.85, on a glass microscope slide was measured. The results obtained while measuring the contact angle of PAW are summarized in figure 4. The contact angle of distilled water measured in the same set up is shown for measurement accuracy indication, the value obtained for distilled water contact angle agreed with the literature reports of ~ 55 °; the value obtained was 54.5°.

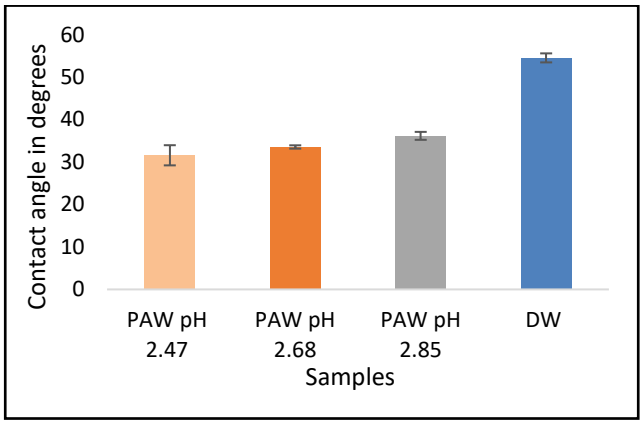

Fig 4 - Contact angle made by PAW and DW (Distilled Water) on glass slides

PAW has lower contact angle compared to the distilled water used for PAW production, by an average of 20°. PAW displays lower contact angles at lower pHs or higher plasma production powers. Therefore, plasma addition increases the surface energy during interaction between the glass surface and water.

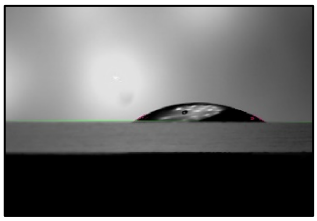

Fig 6 - PAW droplet making 31° on glass surface

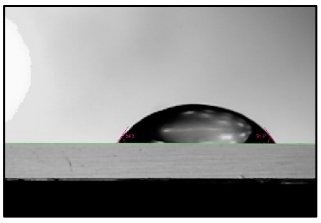

Fig 7 -Distilled water droplet making 54° on glass surface

4. Conclusions

1. The physical properties of water change with plasma activation.
2. As a solution, PAW behaves non-ideally; since the percentage change occurring to physical properties with plasma addition are higher than the percentage of plasma species added to it.
3. Plasma addition lowers the surface tension of water by 6.1%; plasma addition decreases the temperature required for mesoscopic transition from crystalline to amorphous structure, resulting in lower surface tension in PAW relative to normal water.
4. Plasma addition increases the viscosity in water by 12.8% at higher temperatures; plasma foreign additives lead to this increased viscosity in PAW. The high viscosity effect of plasma additives is inhibited at low temperatures due to amorphous structure.
5. The contact angle made by water on glass surface is reduced with plasma activation by 36%, thus the surface energy during interaction of water with glass is increased with plasma activation.
6. The changes occurring to the physical properties of water with plasma activation can be attributed to water attaining amorphous structure at lower temperatures and presence of plasma additives at higher temperatures.

7. References

[1] He, Jinjie, et al. "Effects of plasma on physical properties of water: nanocrystalline-to-amorphous phase transition and improving produce washing." arXiv preprint arXiv:2204.05888 (2022).

[2] Berry, Joseph D., et al. "Measurement of surface and interfacial tension using pendant drop tensiometry."

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