Investigation of mass transfer in plasma-based ozonation of organic micropollutants using phenol as a model compound

P. Kaweesa, M. O. Daramola, S. A. Iwarere

Sustainable Energy and Environment Research Group (SEERG), Department of Chemical Engineering, Faculty of Engineering, Built Environment and Information Technology (EBIT), University of Pretoria, Hatfield, Pretoria 0002, South Africa.

Abstract: The mass transfer non-thermal plasma produced ozone was studied in water with phenol compound. Response surface methodology, Box-Behnken design method was used to derive optimal reactor conditions as 10 kV (voltage), 5 kHz (frequency) and 4 L/min (O_2 gas flow), yielding 4.10 mg/L gaseous O_3 in 20 minutes. The venturi injector (VI)/ the nano bubble stone (NB) synergy gave a higher K_La of 4.92 x 10^{-7} min^{-1} implying more O_3 dissolution for higher micropollutant removal.

1. Introduction

The increasing level of organic micropollutants (OMPs) in water and their recalcitrant behaviour to existing treatment methods has posed new challenges to ozonation as a water treatment method [1]. Ozone (O_3) is a longer-lived reactive oxygen species (ROS) that can be produced in a dielectric barrier discharge plasma (DBDP) system by subjecting air (or O_2) to an electric field, followed by its ionisation within the region between two powered electrodes. The half-life of aqueous phase O_3 ranges from 20-30 minutes at 20 ºC [2]. Ozone can effectively oxidize specific OMPs to complete mineralization [3]. However, the much-desired degradation efficiency of OMPs is hampered by the mass transfer of ozone in the contaminated solution matrix.

2. Methods

This study focused on enhancing the elimination of mass transfer of plasma generated O_3 during degradation of OMPs using phenol as a model pollutant. Phenols and their reaction substituents are toxic to humans and aquatic organisms, and are characterized with carcinogenicity, hepatic problems and harmful effects to red blood cells [4]. Our everyday life system interacts quite often with phenol substances, due to their occurrence in polycarbonates, detergents, herbicides and pesticides, fire retardants and plant systems (lignin) [5]. Thus, with such a wide variety of use, phenol is commonly used as a model contaminant.

The DBDP reactor was driven by O_2 gas concentrated by pressure swing adsorption (PSA) principle from compressed air. The produced O_3 interacted with water via a venturi injector (VI) and a 50 mm diameter nano-bubble air disc stone (NB) made of ceramic sand. To determine the optimal ozone yield in gas phase, DBDP reactor operating parameters (voltage, V, frequency, f and O_2 flow rate, Qg) were optimized using the response surface methodology (RSM) based on Box-Behnken design (BBD) method. The MT was evaluated with volumetric mass transfer coefficient (K_La). The study also investigated effect of the operating variables such as solution pH, temperature, liquid flow rate, oxygen flow rate and ozone gas flow rate on MT during the degradation.

3. Results and Discussion

The current results show that, the condition (V, f, Q_g) = (10 kV, 5 kHz, 4 L/min) yielded maximum average gaseous O_3 of 4.10 mg/L in 20 minutes. This condition resulted in K_La = 4.49 x 10^{-7} min^{-1} while utilizing the nano bubble stone (NB) under a pH of 3.03 compared to K_La = 3.96 x 10^{-7} min^{-1} without a MT device. The venturi alone (VI) achieved, under liquid flow rate of 300 mL/min, a K_La of 4.11 x 10^{-7} min^{-1}. Improved O_3 transfer was realized with VI/NB synergy yielding a higher K_La of 4.92 x 10^{-7} min^{-1}. The K_La quantifies the effectiveness of O_3 transfer from gas to liquid phase. A higher K_La obtained with VI/NB system implies more O_3 was transferred to liquid in a unit time, which could translate into more effective oxidation of the pollutant because more aqueous O_3 is available. The results give positive insights and basis for further investigations into enhancement of plasma produced O_3 dissolution for potential efficient contaminant degradation.

4. Conclusion

The elimination of MT of plasma produced O_3, for destruction of target OMPs was studied with phenol as a model pollutant. The optimal DBD reactor conditions resulted in gas phase O_3 yield of 4.10 mg/L in 20 minutes. In liquid phase, under 10 kV (voltage), 5 kHz (frequency), and 4 L/min (O_2 flow rate) the MT facilitated by VI, NB and VI/NB combination gave K_La values as 4.11 x 10^{-7} min^{-1}, 4.49 x 10^{-7} min^{-1} and 4.92 x 10^{-7} min^{-1} respectively against K_La = 3.96 x 10^{-7} min^{-1} without a device. The higher K_La as achieved in VI/NB combination imply more ozone dissolution and consequently better contaminant oxidation.

Acknowledgement

This material is based upon work supported by Water Research Commission (WRC) of South Africa, under project No. C2022-2023-00897 and the University of Pretoria, Department of Chemical Engineering.

References

[1] Lim et al., Water Res., 213−118053 (2022).
[2] Tomiyasu et al., Inorganic Chem., 2962-2966 (1985).
[3] Dai et al., RSC Advs., 24649-24654 (2015).
[4] William et al, IntechOpen, p.Ch. 17 (2017).
[5] Stewart and Stewart, Oxford: Academic Press, 2682-2689 (2008).