Nutrient recovery from Wet Biomass in Hydrothermal Carbonization as an Innovative Approach toward the Circular Economy; A Review

***S. Zare*, M.H. Sarrafzadeh*, M. Rezaei, O. Tavakoli**

UNESCO Chair on Water Reuse, School of Chemical Engineering, College of Engineering, University of Tehran, Tehran, Iran (Email: zare.saeed@ut.ac.ir ; sarrafzdh@ut.ac.ir *)

Introduction

In contrast to the linear economy, the circular economy aims to tackle global challenges, such as climate change and pollution, by recycling and reusing waste. Through waste valorization strategies, biomass is highly significant in the circular economy regarding energy provision and input resource applications for other processes. Increasing global demand for crops, limited nutrient resources, and production costs of fertilizers have led to the expansion of more scientific research in wet biomass valorization to achieve nutrient recovery [1]. In recent years, hydrothermal carbonation (HTC) as a thermochemical process of wet biomass treatment has been attracting the attention of researchers. This process has many advantages, including simplicity, processing wet feeds, and relatively low-temperature process conditions. The two main products of the HTC process are hydrochar (HC) and hydrolysate (HL). Hydrochar is a carbon-rich solid with widespread usage as fuel source, adsorbent, and soil conditioner [2]. As a liquid effluent of the process, the hydrolysate is a good source of nutrients that could replace the current fertilizers. In recent years, depending on the input feed, the recovery of several nutrients such as phosphorus (P), nitrogen (N), and potassium (K) from hydrolysate has received significant attention [3].

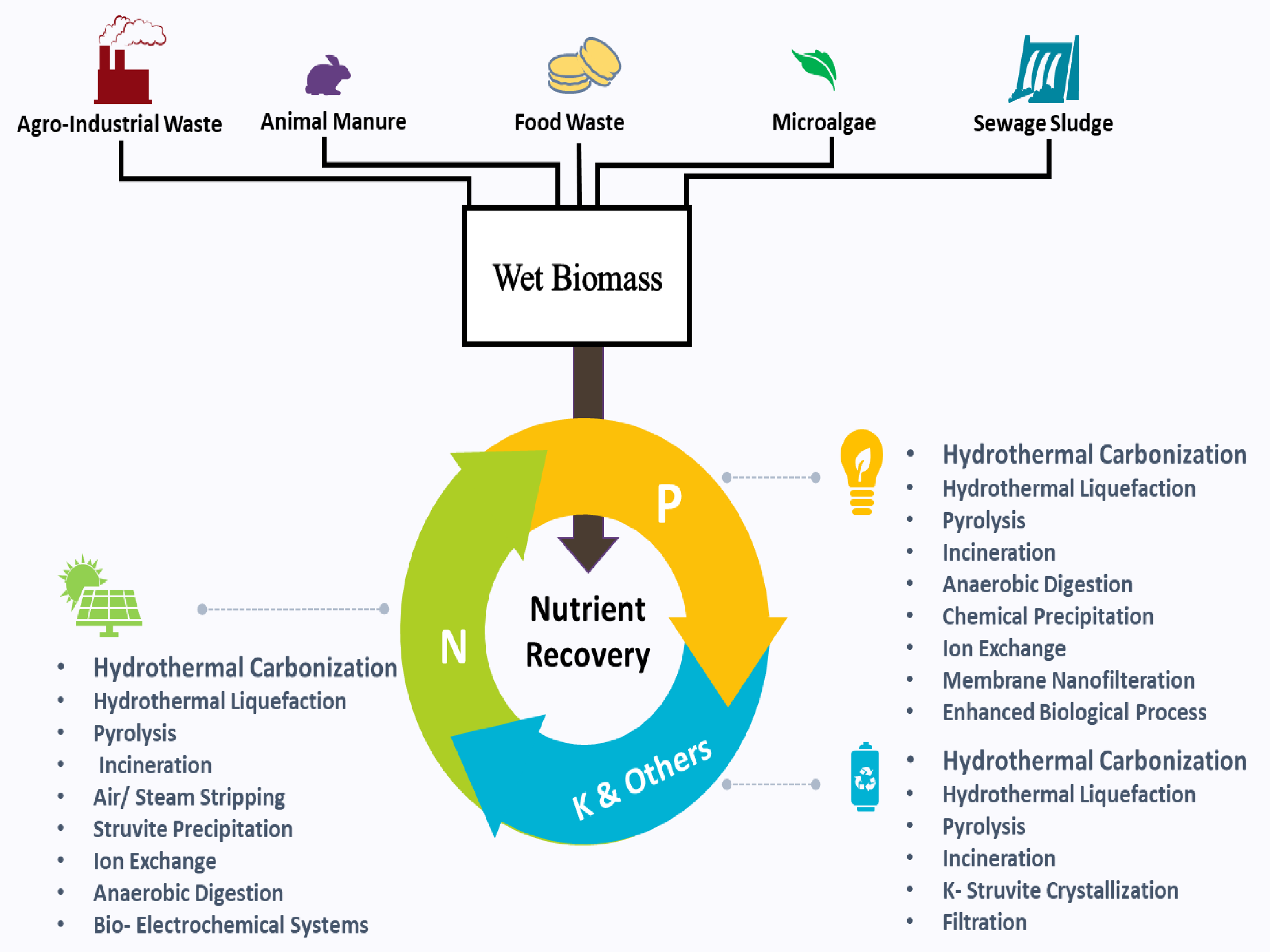

Figure 1: Nutrient recovery technologies from wet biomass

Results & Discussion

One of the circular economy milestones is the approach of converting low-value waste into more valuable products. Integrating HTC with other nutrient recovery strategies is considered an efficient, sustainable waste management strategy that alleviates the burden of waste incineration and landfilling while simultaneously developing economic benefits.

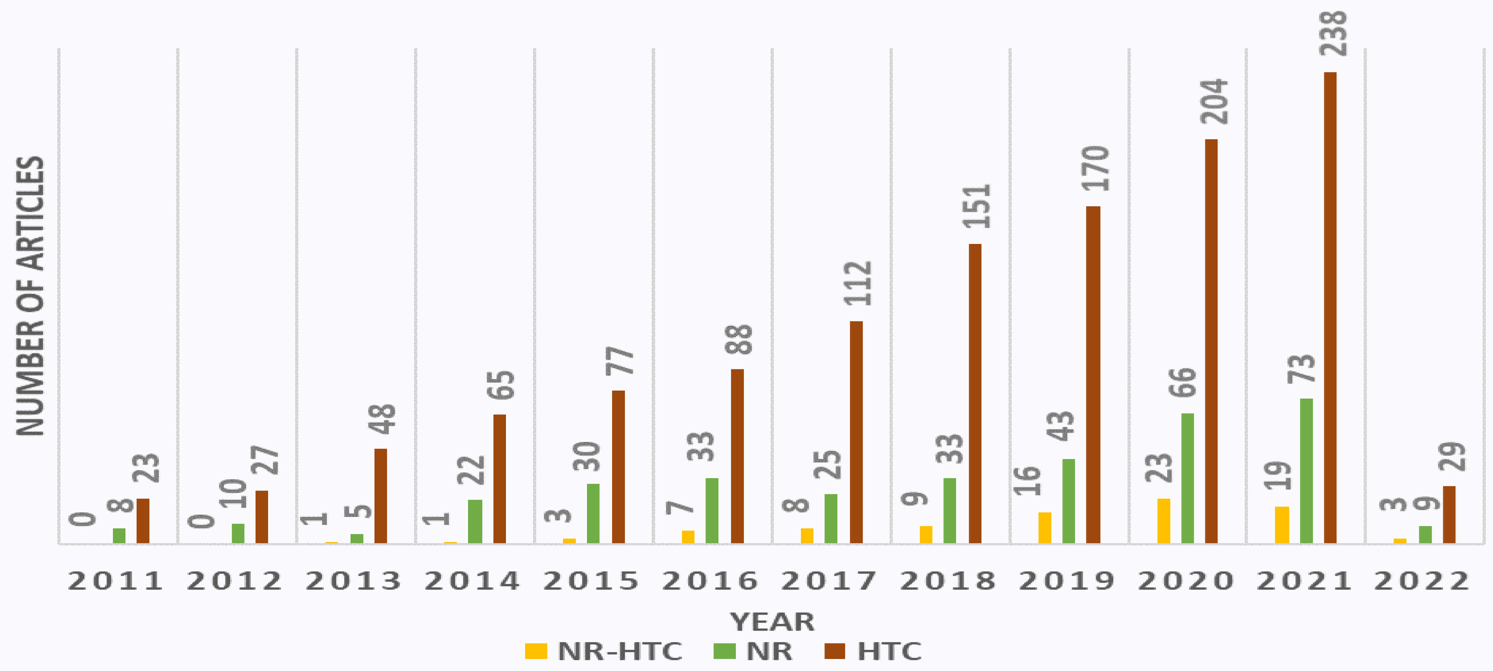

Figure 2 : Number of articles on HTC, NR, and HTC-NR vs. year

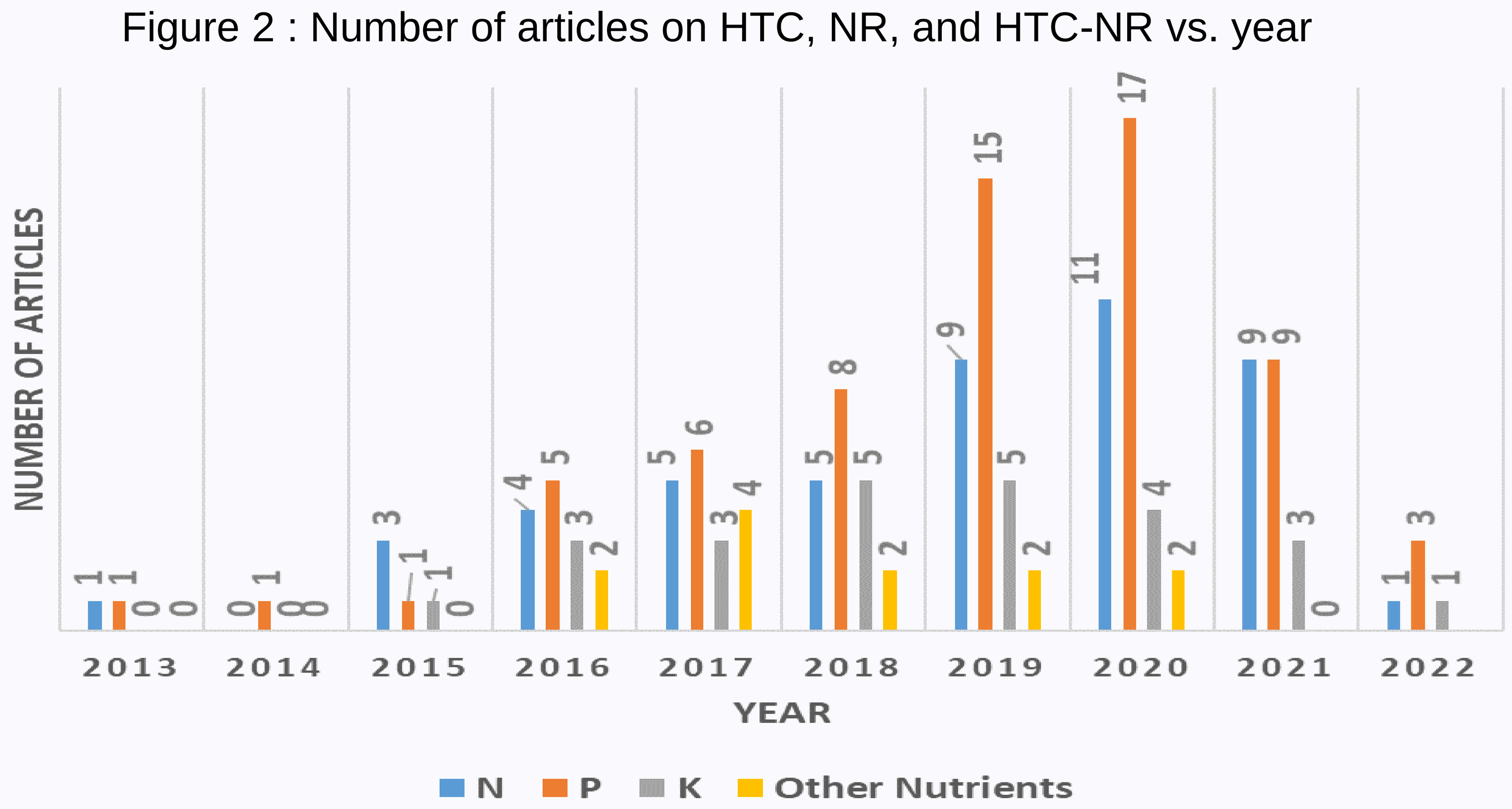

Figure 3 : Number of articles on the recovery of each nutrient vs. year

As depicted in Fig 2 and Fig 3, an increasing trend in the number of published papers on HTC and nutrient recovery methods clearly proves this increasing attention toward HTC as a means of waste valorization. Furthermore, Fig 3 indicates that most researchers have focused on P reclamation from wet biomass rather than N and K, which shows the key role of P reclamation in the life of animals, humans, and plants as an essential resource-depleting element.

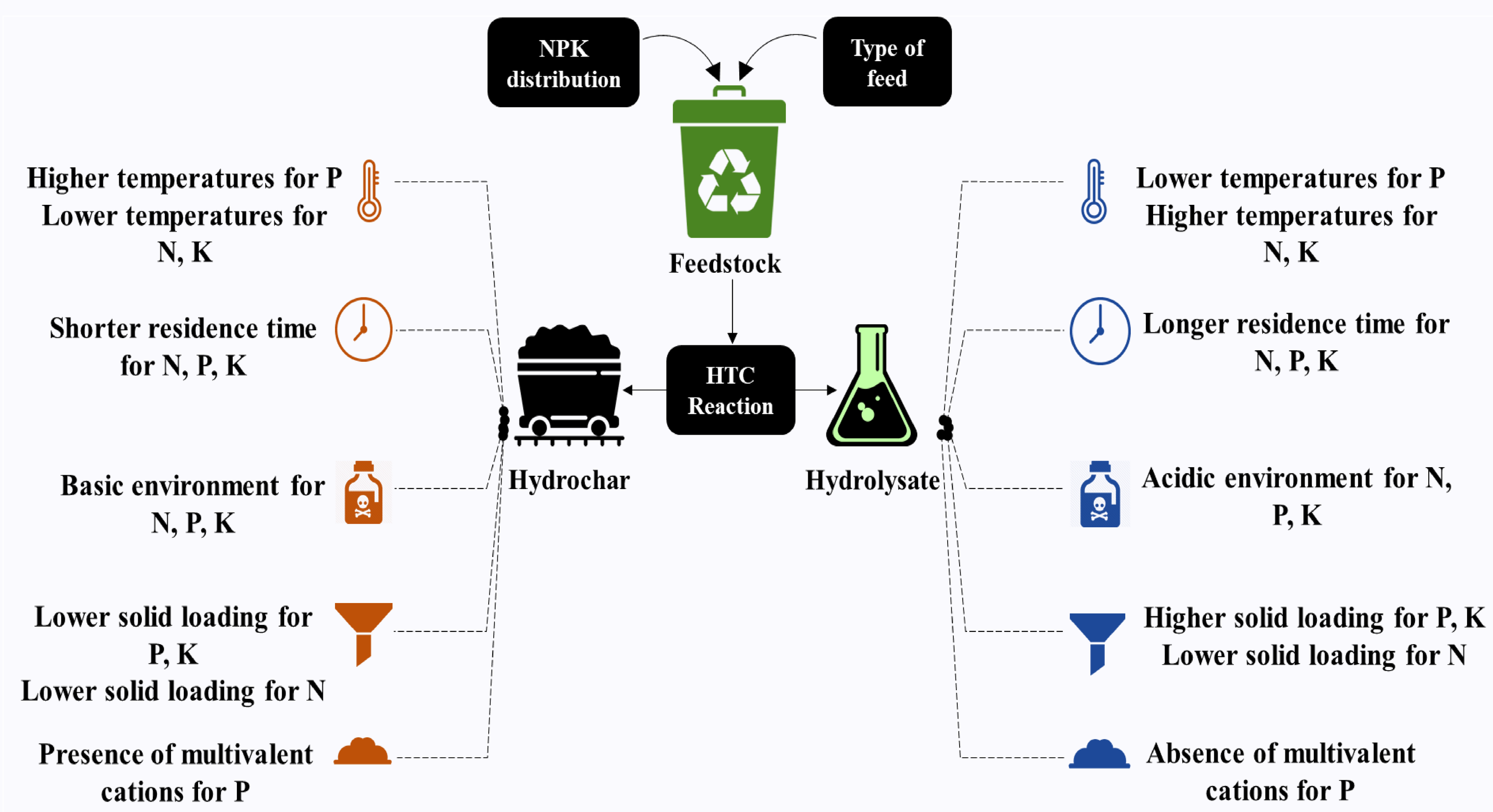

Figure 4 : Governing factors on the fate of NPK

When nutrients are considered targets for various reclamation and valorization strategies in wet biomass, understanding how specific parameters affect the fate and solubility of the nutrients is of great importance for the efficiency of HTC. As demonstrated in Fig 4 for N, P, and K, these nutrients are most affected by the reaction temperature, residence time, pH-adjusting additives, type of feedstock, solid loading, presence of multivalent cations, and the nutrients speciation [4].

The biomass source is the first factor that plays a crucial role in the fate of nutrients. Due to the strong dependency of process efficiency on initial organic and inorganic biomass contents, nutrients speciation, and ash content, the elemental composition of the biomass needs to be measured. Studies have deduced that prolonging residence time and using acidic catalysts favor NPK solubilization into HL while increasing reaction temperature only benefits N and K transformation into HL. Higher solid loading promotes P and K migration into the liquid phase and N densification within HC. The fate of multivalent cations, including Ca, Mg, and Al, also becomes critical since they facilitate the formation of insoluble phosphate-bound salts and immobilize P within HC [5].

Based on recent studies, even though HL is highly rich in nutrients, reaction temperature, the origin of organic matter, and addition of catalysts may promote the solubilization of some heavy metals (e.g. Pb, Cr, Cd, and Hg) and increase COD in the liquid effluent. Therefore, more research is required to nullify the hazardous environmental outcomes of HL discharge into farmlands.

Conclusions

This paper aimed to investigate the HTC process and its effluents as an innovative way for waste valorization toward the circular economy model. The global increase in food and fuel demand, environmental challenges, and resource depletion have led researchers to seek sustainable green technologies. In recent years, HTC has attracted the scientific community's attention as a means of waste valorization. Hydrolysate, the liquid effluent, has a high potential to be utilized as a recirculation medium for HTC, Microalgae cultivation, and a substitute for commercial fertilizers. This study shows that HTC integration with other nutrient recovery strategies provides a sustainable waste management approach. The author suggests that In order to achieve the milestone of energy and nutrient recovery in the circular economy, more research is needed to optimize the governing factors on the fate of nutrients, reduce COD and immobilize heavy metals in HL, and develop scale-up models of HTC-NR industries around the world.

References

[1] Aragon-Briceno, C.I., Pozarlik, A.K., Bramer, E.A., Niedzwiecki, L., Brem, G., 2021. Hydrothermal carbonization of wet biomass from nitrogen and phosphorous approach: A review. Renewable Energy, Volume 171, Pages 401-415
[2] Rezvani, F., Sarrafzadeh. M.H., Seo. S.H., Mock. O.H., Phosphorus optimization for simultaneous nitrate-contaminated groundwater treatment and algae biomass production using Ettlia sp.,2017. Bioresource Technology, Volume 244, Part 1, Pages 785-792
[3] Xiong, J.B.,Pan, Z.Q., Feng, X.X., Huang, J.H., Lai, F.Y., Chen, S.W., 2019. Study on the hydrothermal carbonization of swine manure: the effect of process parameters on the yield/properties of hydrochar and process water. Journal of Analytical and Applied Pyrolysis, Volume 144, 104692
[4] Qaramaleki, S.V., Villamil, J.A., Mohedano, A.F., Coronella, C.J., 2020. Factors affecting solubilization of phosphorus and nitrogen through hydrothermal carbonization of animal manure, ACS Sustainable Chemistry and Engineering. 10.1021/acssuschemeng.0c03268
[5] Dai, L., Yang, B., Tan, F., Li, H., Zhu, N., He, M., Ran, Y., Hu, G., 2017. A synergistic combination of nutrient reclamation from manure and hydrochar up-gradation by acid-supported hydrothermal carbonization. Bioresource Technology, Volume 243, Pages 860-66