A study comparing conventional heating and microwave assistance heating to recover metals from Municipal Solid Waste

Mariam Khan
PI: Mohammad Ahmad Salim AlGhouti
Mustafa S. Nasser, Khalid Al Saad, OON Ee Heng
Qatar University, Department of Biological and Environmental Science

Abstract

This study investigates and compares microwave heating radiation with conventional heating. Incinerated Municipal Solid Waste (IMSW) bottom ash (BA) and fly ash (FA) was utilized to to recover various metals including Co, Cr, Cu, Fe, Mn, Zn, Pb, Al, Cd, Ba, Mg and V using various acid leaching agents i.e. HCl, HNO_3 and H_3PO_4 were utilized and several parameter were altered in order to determine the most effective conditions. The current study concluded that microwave assisted leaching method is effective to recover most of the metals. In addtion, metals from MSW-BA were much easier to recover in contrast with MSW-FA. 71% of Co, 75.69% of Cr, 56.19% of Cd, 35.23% of Ba and 30.2% of Pb using 2M of HCl and 3M of H_3PO_4. While 1.48% of Cr, 0.93% of Fe, 1.19% of Mn, and 1.18% of Al were extracting using HCL and H_3PO_4 from MSW-FA. It was also confirmed that higher power and longer contact time had a positive effect on metal recovery. From cost analysis point of view, microwave assisted leaching was fraction of the cost for conventional heating making this method comparatively sustainable, energy efficient and safe

Introduction

1. Microwave assisted extraction (MaE) is one of the most employed alternative extraction techniques (Kaderides et al., 2019).
2. Some of the advantages include lower extraction time, reduced in energy consumption, easy to control, high extraction efficiency and low solvent consumption (Rahmati et al., 2019 & Su et al., 2019**).** The irradiation from microwave causes the temperature of the solvent to rapidly elevate. While the energy penetration from microwave to the solvent causes quick elevation of temperature to build the internal pressure inside vessel.
3. When heating a complex reactant such as MSW ashes, in a close vessel, it causes internal pressure to increase due to the high vapor pressure of the liquid(acids) which cause the temperature of the reactant to increase above the solvent's boiling point.
4. The high temperature can also reduce the solvent viscosity and surface tension which causes an increase in the solvent's ability to penetrate the reactant's (sample) matrix which results in mass transfer of the solutes.
5. Microwave assisted leaching (MaL) can be opted as reliable alternative technique as it requires less energy, reduces solvent consumption and shorten extraction time which makes it an environmental friendlier option to recover metals from MSW ashes

Objective

1. To determine the most optimum acids for microwave radiation and conventional heating.
2. To manipulate various parameter in order to determine the most effective conditions.
3. To evaluate which is the best method by comparing microwave radiation and conventional heating method in order to recover maximum metals from Municipal Solid Waste bottom ash (MSW-BA) and Municipal Solid Waste fly ash (MSW-FA).

Methods and Materials

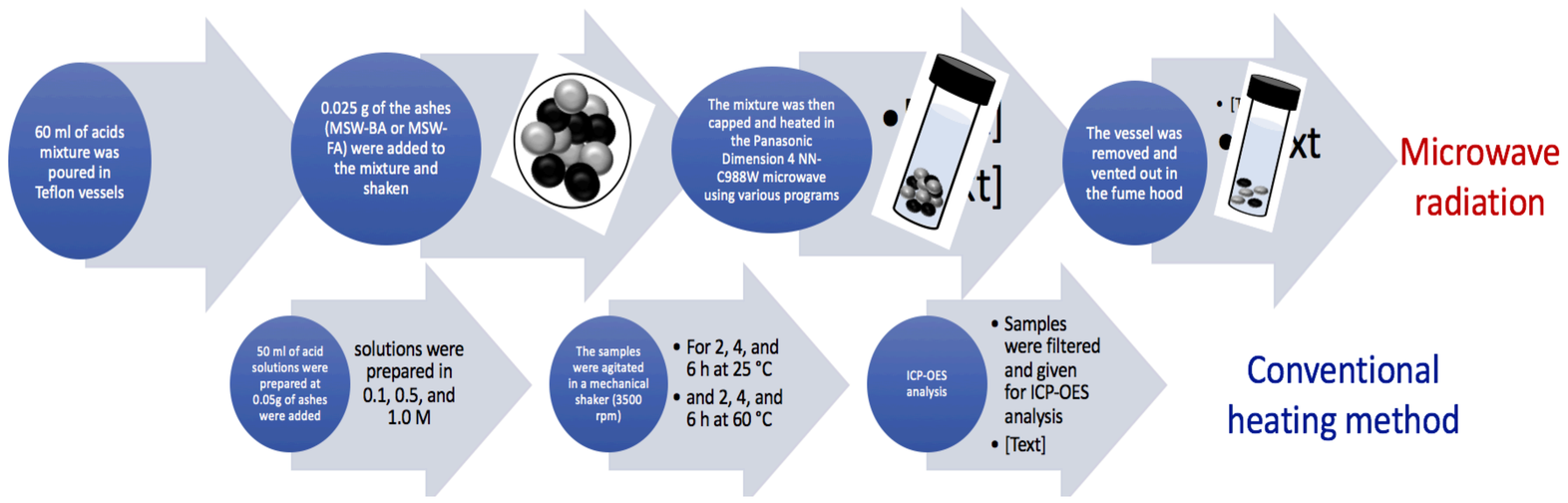

Figure 1: schematic diagram of the method used to carried out this study

Discussion

Metal recovery

- ICP-OES results allowed to assess the metal recovery percentage from the raw ashes which were calculated.
- By conventional heating it was concluded that Co was unable to be recovered. While microwave radiation was able to recover more than 75% Co.
- The highest percentage of metals recovered from MSW-BA using conventional heating were Cd (8.7%), Cu (~8%) and Fe (6.9%). 70% of Co, 78% of Cr, ~60% of Cd, and 35.21% of Ba were recovered using microwave radiation.
- Even for MSW-FA Co was unable to be recovered using conventional heating as well as microwave radiation.
- The results fot both heating method were similar this is perhaps due to the complex nature of the ashes. In which the metals are binding with each other.
- In addition, it can be said conventional heating was a better option. In terms of percentage recovery.

Influence of time and power on metal recovery using microwave radiation

- To investigate the impact of time and power on metal recovery, HCl and H_3PO_4 in various ratio concentration and ratio were prepared and utilized.
- It was found that prolonged solution interaction with ashes had a adverse effect. With increase in extraction time from 5 minutes to 10 minutes.
- For Instance, 0.44% of Fe was extracted using in 5 minutes while the percentage decreased to 0.22% when the time was increased to 10 minutes. Similarly, 1.13% of Cr was recovered from MSW-FA in first 5 minutes the percentage also decreased to 0.72% after 10 minutes.
- In addition, MSW-BA and MSW-FA were also treated with different power 22% (lowest) and 55% (highest). Power value higher than 550 W(55%) was not used in order to avoid the possibility of sample loss due to splashing of boiling solution over the vessel
- It was found that the removal of metals at higher power showed higher efficiency when time was kept constant. For instance, Co was removed 0.66% using 20% power, with the increase in power the percentage almost increased to 1.57%.
- Similarly, 0.89% of Cr was removed from MSW-FA, the percentage increased to 1.13% when the power was increased to 55%. This can be explained due to HCl being a strong polar material which absorbed more microwave energy which might have caused decomposition.

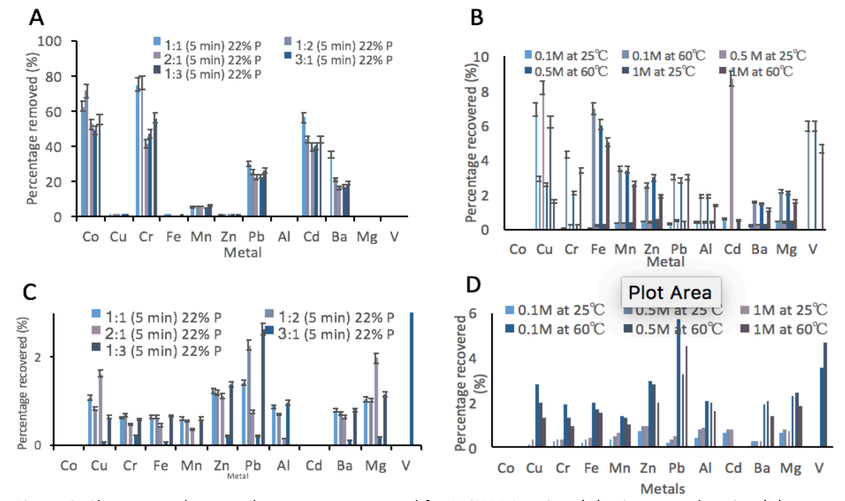

Figure 2: Shows metal removal percentage removal for MSW-BA using (A) microwave heating (B) conventional heating. And for MSW-FA using (C) microwave heating and (D) conventional heating

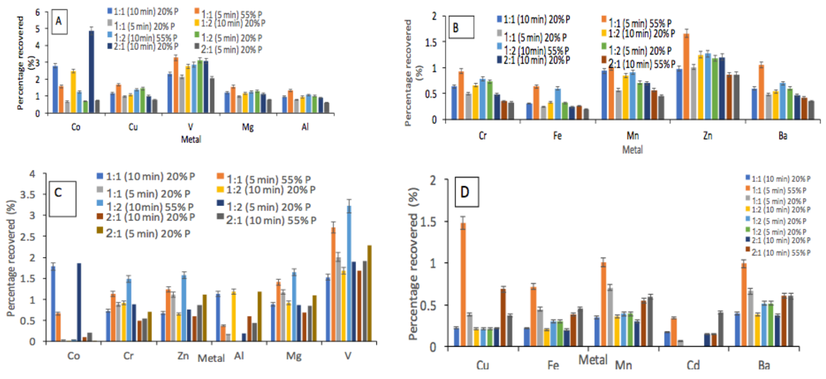

Figure 3: A) 2M HCl and 3M H_3PO_4 (B) 5M HCl 5M HNO_3 (C) 3M HNO_3 and 2M H_2O_2 for MSW-BA (D) 2M HCl and 3M H_3PO_4 (E) 5M HCl and 5M HNO_3 and (F) 2M of HCl and 1M HNO_3

Cost analysis

For cost analysis, the management of MSW-BA and MSW-FA were calculated for microwave heating and conventional heating. All material, and energy consumption were determined in reference to functional unit. According to figure 4A and 4B the around 0.58 QAR is required to leach metals from 0.025g of MSW ashes using microwave technique while 7.84 QAR is required to do the same task using conventional heating. Cost analysis helps to assist whether a certain method is economical or not.

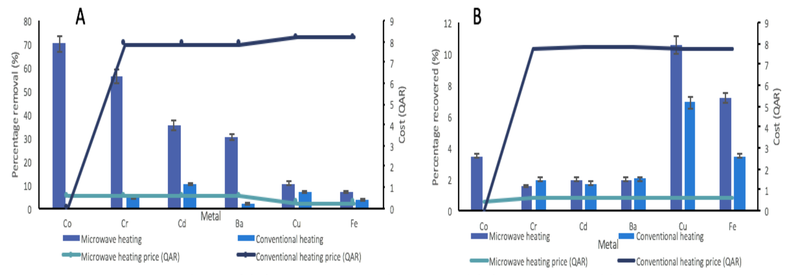

Figure 4: Cost analysis of (A) microwave radiation and (B) conventional heating

Conclusions

In this study, domestic microwave assisted leaching was investigated. The current study holds a promising potential to recover metals particularly Co, Cr, Cd, Ba and Pb. From MSW-BA and Zn, V, Mg from MSW-FA. Microwave- assisted leaching is a fast and consequently energy efficient way to recover metals. The method utilized in this study required low amount of leaching acid and deliver high metal recovery efficiency, 71% of Co, 75.69% of Cr, 56.19% of Cd, 35.23% of Ba, 30.2% of Pb. The results were also compared with our preliminary research which investigated removal of metals using conventional heating and found that not only is microwave recovery is much more effective but also cost effective. Even though, this study delivered efficient results in the laboratory, it remains to be investigated whether it may be applied in a practical installation.

Acknowledgement

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Reference

Kaderides, K., Papaoikonomou, L., Serafim, M., & Goula, A. M. (2019). Microwave-assisted extraction of phenolics from pomegranate peels: Optimization, kinetics, and comparison with ultrasounds extraction. *Chemical Engineering and Processing - Process Intensification*, *137*, 1–11. doi: 10.1016/j.cep.2019.01.006
Rahmati, Shahrooz, et al. "Effects of Different Microwave Intensity on the Extraction Yield and Physicochemical Properties of Pectin from Dragon Fruit (Hylocereus Polyrhizus) Peels." *Bioactive Carbohydrates and Dietary Fibre*, vol. 18, Apr. 2019, p. 100186, 10.1016/j.bcdf.2019.100186. Accessed 15 Oct. 2019.
Su, D.-L., Li, P.-J., Quek, S. Y., Huang, Z.-Q., Yuan, Y.-J., Li, G.-Y., & Shan, Y. (2019). Efficient extraction and characterization of pectin from orange peel by a combined surfactant and microwave assisted process. *Food Chemistry*, *286*, 1–7. doi: 10.1016/j.foodchem.2019.01.200
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