CONCLUSION
Cyclic voltammetry and square wave voltammetry were employed to investigate the efficiency of electrodepositing Pb and Cd from very dilute simulated wastewater solutions onto two carbon based electrodes – one obtained commercially, the glassy carbon electrode (GCE) and the other self fabricated activated carbon paste electrode (CPE). These metals were studied in both the single and mixed cation systems under various conditions such as varying pH and concentration, in the presence of a coexisting metal cation and excess malonic acid. Special emphasis was also put in investigating the selectivity of separating such metals from the mixed cation systems under similar conditions.

Based on the results obtained, Pb can be deposited efficiently onto both the carbon electrodes under the various conditions (effect of pH and concentration) employed despite the greater nucleation overpotential required to deposit this metal onto a foreign substrate. The deposition of Pb from a very low concentration of 0.1ppm is also possible provided lower sweep rates or longer preconcentration time is employed. The incipient electrodeposition potentials of Pb(II) are found to be more anodic as the concentration is increased, a trend in accordance with the values predicted by the Nernst equation. There is, however, almost negligible effects of pH on these values especially at high concentrations of Pb(II).
CONCLUSION

The reverse phenomenon is, however, observed for the deposition of Cd onto these electrodes at pH 3 & 5 in the systems without the presence of complexing ligand. At pH 3, poor efficiency of Cd deposition is reflected in the absence of stripping peaks for Cd. The absence of these stripping peaks in this case is suspected to be caused by the interfering reaction of hydrogen evolution that is predominant at this pH and occurs at almost similar potential range as the reduction of Cd(II), which therefore result in either too little Cd could be deposited or premature dissolution of Cd. However, such interference can be minimized to improve the deposition of Cd by employing a longer deposition time. This is evident in the square wave voltammograms of Cd(II) at a very low concentration of 0.1ppm where some success of this approach is observed.

When the pH of the system is increased to pH 5, the deposition of Cd onto both the electrodes are found to improve slightly. This is evident in the presence of poorly defined stripping peaks for Cd in the resulting voltammograms. It is suggested in this study that these poorly defined stripping peaks could be due to the interfering effect of another electrochemical reaction that is prone to occur at higher pH according to Brennsteiner, A. et.al.\textsuperscript{36} and the Pourbaix diagrams. The products of this reaction such as \( \text{H}_2 \) and \( \text{OH}^- \) are suspected to affect the deposition of Cd. The incipient electrodeposition potentials for Cd(II) at pH 3 could not be obtained by the method employed in this study as no stripping peaks for Cd(II) are observed. Only those for Cd(II) at pH 5 are obtained and they are found to be very cathodic compared to those predicted by the Nernst equation.
CONCLUSION

However, when Cd is deposited from mixtures containing another coexisting cation such as Pb(II) at both pH, the stripping peaks for Cd are generally found to be better defined and can increase proportionally in height/area when the concentration of Cd(II) is increased. Such observations reflect that the deposition of Cd is more efficient on a Pb surface compared to the C surfaces and this could be due to the higher hydrogen overpotential characteristic of the Pb surfaces that reduces the interference caused by the hydrogen evolution. Despite this, difficulties are still observed when depositing Cd from mixtures that contain a low concentration of Cd(II) (1ppm) and a substantial amount of Pb(II) (20ppm) at pH 3 for both electrodes.

It can also be concluded that these metals can be selectively separated from the mixtures by electrodeposition onto the carbon electrodes at pH 3 and 5, based on the good resolution of stripping peaks of Pb(II) and Cd(II) at almost all the ratios employed in this study. This finding is supported by the significant difference of the incipient electrodeposition potentials, $E_d$ of Pb(II) and Cd(II) ($\approx 150 \text{mV to } 290 \text{mV}$) when present in mixtures. The $E_d$ values for Pb(II) in the mixed cation systems are found to be not affected by the presence of Cd(II) in the system. For the case of Cd(II) in these mixed cation system, it was found to be more anodic than those obtained in the single cation systems, which reflect the enhancement of Cd deposition when Pb(II) is present in these mixtures.
The addition of complexing ligand such as malonic acid in excess amount into the single and mixed cation systems are investigated as one possible approach to improve the efficiencies of electrodepositing Pb and Cd onto the carbon electrodes at both the pH as well as to increase the selectivity of separating Pb(II) and Cd(II) when present in the mixtures. This ligand is found to have no significant effect on the deposition of Pb from the single cation systems and also the deposition of Pb and Cd from the mixed cation system. This is because the Pb-malonate and Cd-malonate complexes formed in these systems are labile and tend to dissociate to form free cation again, thus showing no effect on the features in the voltammograms as well as the $E_d$ values.

Observations are different when malonic acid is added into the Cd(II) single cation systems. Improved efficiency in depositing Cd onto the carbon electrodes is observed at pH 3 and 5 where more enhanced stripping peaks are evident in the resulting voltammograms. This is also reflected in the $E_d$ values of Cd(II) which are generally more anodic than systems without malonic acid.

It is believed that malonic acid can also act as a buffer in these systems which minimizes the interference caused by either the evolution of hydrogen or dissociation of water, hence enhancing the deposition of Cd. Besides that, malonic acid can also accelerate the electrodeposition of Cd by improving the electron transfer via the formation of an activated intermediate Cd(II)-L-Electrode Surface as reported by Vargalyuk, et.al.\textsuperscript{56}