ABSTRACT

For the last few decades, the rapid growth of electronic industry has led to an increase in the spent li-ion or lithium-ion battery (LIB) waste, which subsequently has been posing a threat to the entire ecosystem as the waste disposal and management practices are still poor and outdated. All of this waste should be disposed of in a way specifically designed or permitted for them. But, as of today, due to the rising quantities, most of the wastes does not get segregated and end up as composite waste in landfills/dumpyards.

Ineffective hazardous waste management affect local communities practically in all countries. The wastes when come into contact with natural water produce toxic liquids (leachates) which are harmful for soil as well as the surrounding environment. The improper disposal of waste batteries can result in toxic metal contamination and pollute ground and surface water, soil, air, flora, fauna and also affect humans. The numerous negative effects of the waste dumping and the ever growing environmental awareness worldwide has created an urgent need to assess the toxicity/environmental impact of disposal/dumping of these wastes, which has further led to the development of numerous leaching procedures.

The current study has summarized the studies using globally available leaching tests. The past literature has been assessed thoroughly, describing the various types of leaching tests, the parameters and factors affecting the test results and the general scope and limitations. Delphi method has been applied to select some of the conventional leaching tests, which are the TCLP test, SPLP test, ASTM D 3987 test, EN 12457 test, GB 5086.1-1997 test and JLT-13 test. These tests were evaluated on the basis of chosen criteria; namely, leaching performance, cost, time duration, the ease of conducting experiments, and applicability/appropriateness to various use-case

scenarios. After generating an order of preference and finalizing the relative importance for each of the criterion (using AHP and Entropy method), tests were compared using an appropriate MCDA method (AHP and PROMETHEE-II) for determining the ranking. Out of the conventionally available tests, ASTM D 3987 was determined to be the best performing one.

Now, considering the research gaps found on the basis of literature study, one of the most important one that seems to grab attention is the time which these tests require for leaching and evaluation. In order to reduce experimental cost, maximize leaching efficiency, decrease time duration of leaching procedure and increasing the ease of experimentation (by reducing labour time), alternate leaching procedures were proposed. These procedures were based on the sonication technique, which has been previously studied as an extraction process but not researched to its potential.

Numerous combinations of the sonication-based procedures (under two sets) for leaching metals out of spent li-ion battery waste were conducted. The first set consisted of procedures using different extraction fluids (extraction fluids for TCLP, SPLP & NEN and deionized water) for different time durations (10-60 min; 6 durations with 10 min time interval). For the second set, a novel hybrid leaching approach (sonication for 10-90 min, 9 durations with 10 min time interval along with TCLP with reduced mixing times of 1,2 and 3 hours) was applied. The metal leaching efficiencies of all the procedures were calculated using TCLP leaching results as benchmark. Upon calculating leaching efficiencies for every metal, a leaching coefficient that represents leaching performance of relevant metals (Li, Co, Ni and Mn for the current study) was calculated for all the procedures. Based on leaching coefficient values, best time duration for maximum leaching (i.e., highest leaching coefficient) was selected.

The methods with best time durations for maximum leaching from all the types of alternate procedures (within sonication with different extraction fluids and the hybrid approach of sonication and reduced TCLP mixing times) were compared with the conventional TCLP as well as ASTM D 3987 (best according to the previous results in this study). The comparison was conducted on the basis of the four of the criteria shortlisted by Delphi (leaching performance, cost, time duration, and the ease of conducting experiments), and a preferential order was established for each one. Now the relative weights of all the criteria were determined using AHP, fuzzy AHP and Critic method. After finding out the orders of preference and the relative weights, the alternate procedures as well as TCLP and ASTM D 3987 tests were compared using another appropriate MCDA method (TOPSIS) for determining the ranking.

The final results indicated that sonication for 50 minutes using TCLP extraction fluid is the best alternative among all the adopted hybrid as well as conventional approaches. Although this procedure has relatively low leaching coefficient compared to conventional TCLP, its top ranking is due to its better performance in terms of experimental cost and time duration.

Keywords: Lithium-ion battery (LIB) waste, leachate, metal contamination, conventional leaching test, assessment criteria, sonication, MCDA methods, ranking.