ABSTRACT

To explore the possibility of implementation of non-conventional thermo-chemical processes, namely pyrolysis and gasification aided pyrolysis, for material recovery from printed circuit boards, in details, the present research focused in the following directions – (i) Evaluation of product distribution and dynamics of pyrolysis and gasification aided pyrolysis of FR-2 and FR-4 PCBs in laboratory scale; (ii) Assessment of suitability of pyrolysis and gasification aided pyrolysis to be used as pre-treatment process for material recovery from e-waste and supply chain performance of e-waste processing plant (iii) Assessment of large scale implementation of pyrolysis and gasification aided pyrolysis using the predictions of process modelling using standard software (ASPEN PLUS); (iv) evaluation of sustainability of pyrolysis and gasification aided pyrolysis processes for material recovery from e-waste through life cycle analysis, economic analysis and qualitative social analysis considering the three pillars of sustainability — environment, economics and social. It was found from the kinetic analysis that average activation energies for FR-2 VPCB, FR-2 WPCB, FR-4 VPCB and FR-4 WPCB are in the range of 89.26 – 121.1 kJ/mole; 58.93 – 116.99 kJ/mole; 156.09 – 194.94 kJ/mole and 57.15 – 101.1 kJ/mole respectively. 623K was determined to be the best temperature for maximum resource recovery from WPCBs. The optimization of mixed WPCB pyrolysis reveals that ratio of individual PCBs in the mixture plays the key role for maximum recovery of metal, glass fibre and pyro-oil. Experimental investigation of steam gasification aided pyrolysis was carried out with the aim of quality upgradation of pyro-gas. It was found that steam gasification aided pyrolysis significantly improves the quality of the pyro-gas and also helps in bromine fixation in the char. Three frameworks have been developed for integrated Material Recovery E-waste (MREW) facilities, without (option -1) pyrolysis, with pyrolysis (option -2) and with steam gasification aided pyrolysis (option -3) and generalized qualitative energy and environmental analysis has been carried out using the principles of LCA. Process modelling of pyrolysis and steam gasification aided pyrolysis of mixed WPCB has been carried out using ASPEN plus. These models were able to simulate acceptable results consisting of compositions of pyro-oil, char, metal mixture, glass fibre and syn-gas, metal mixture and glass fibre respectively. The supply chain model developed for MREW facilities were able to predict the timelines for plant performance improvement. Volume of carbon dioxide and energy consumption emerged as the most important parameters while energy consumption was the most sensitive parameter for an MREW facility. Sustainability analysis of MREW facility has been carried out considering environmental, economic and social perspectives. It has been

revealed by the LCA analysis that global warming, fossils resource scarcity, ozone formation human health, ozone formation terrestrial ecosystems, fine particulate matter formation and water consumption are the highest impact categories for both pyrolysis and steam gasification aided pyrolysis. However, the negative impact of recovery of metals, glass-fibre and gaseous fuel offsets the overall impact of the processes revealing pyrolysis and steam gasification aided pyrolysis to be green processes. From the economic analysis it was found that both pyrolysis and steam gasification aided pyrolysis of PCBs are economically viable with 4.86 years and 8.54 years of payback period. The qualitative analysis reveals that society will be benefitted with the use of recycled products, fuels and the use of eco-friendly technologies. It is expected that the outcomes of this research work will be helpful in presenting a roadmap towards sustainable recovery of materials i.e., metals, glass fibre, char and fuels i.e., pyro-oil and pyro-gas from electronic and electrical wastes, specifically the waste printed circuit boards of both FR2 and FR4 types.