Valorising Indian Municipal Solid Waste: A Feasibility Study

EPSRC Pioneering research and skills

UNIVERSITY OF LEEDS

Daniel Chernick, Katherine Graves, Katy Honour, Thomas Penney, Scott Wiseman

1. Introduction

- India generates 133,760 tonnes of MSW per day (**1**)
- Rate of waste generation ranges from 0.17 - 0.62 kg/c/day, which is increasing at a rate of 1 - 1.3% per year (**1**, **2**)
- More than 90% of MSW in India is disposed of in open landfill, which is least favoured waste management method, as shown in figure 1, right (**1**, **3**)
- Valorisation of Indian MSW would move India up the waste hierarchy

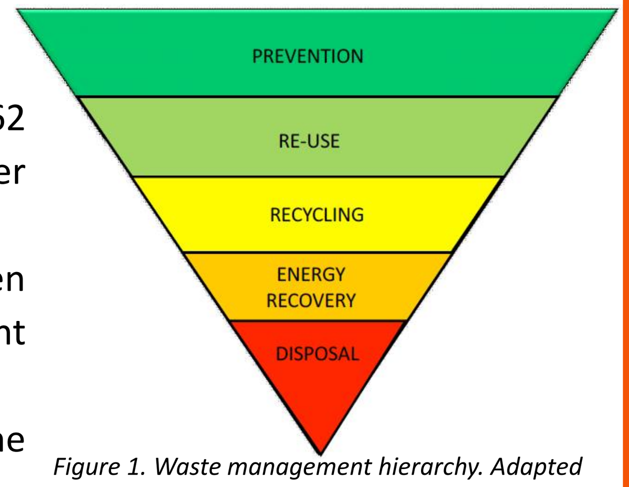

Figure 1. Waste management hierarchy. Adapted from (4)

2. Indian MSW

Variation of MSW composition across India was investigated. Data was used from 141 sources found through a systematic literature review.

27 states of India were split into 6 regions: North, East, South, West, Central and North-East; MSW was split into nine categories: wet organic (WO), yard (Y), paper (Pa), plastic (Pl), wood (W), textile (T), other recyclables (OR), inert (In) and miscellaneous (Mi).

ANOVA testing was performed to find statistically significant (SS) differences between regions. Components with SS differences were:

- Wet organic (North-East and North, West, East)
- Textile (North and North-East)
- Wood (East and North-East)
- Inert (North and North-East)

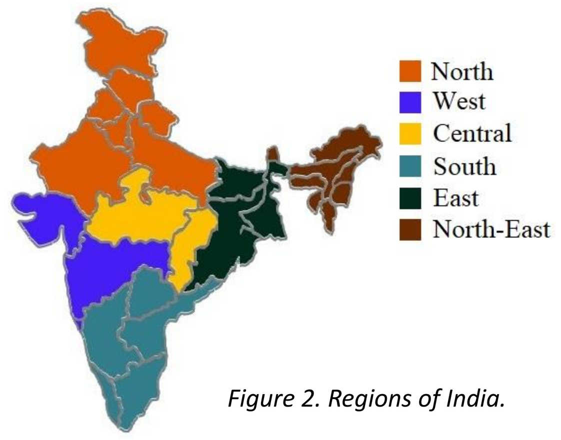

Figure 2. Regions of India.

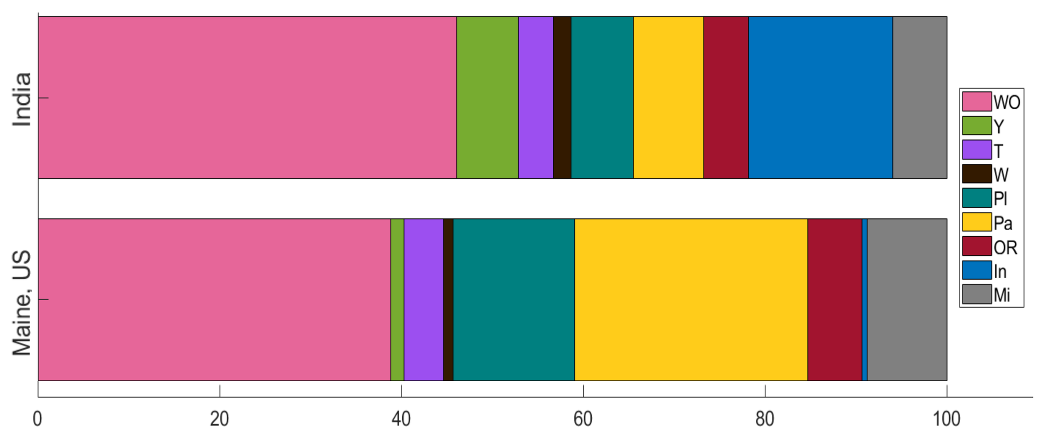

Figure 3. MSW composition for India and Maine, US in wt%.

Main differences between India and US waste:

- India has higher WO, Y and I content, making Indian waste more dense
- US has higher proportion of Pa and Pl

3. Feedstock Characterisation

Processing MSW produces both a fibrous pulp and a organic residual solids (ORS) waste stream. These two materials were characterised using Pyrolysis-Gas Chromatography/Mass Spectrometry (Py-GC/MS) to explore the types of components retained in each sample and with a biochemical method to examine the structural carbohydrates (**4**).

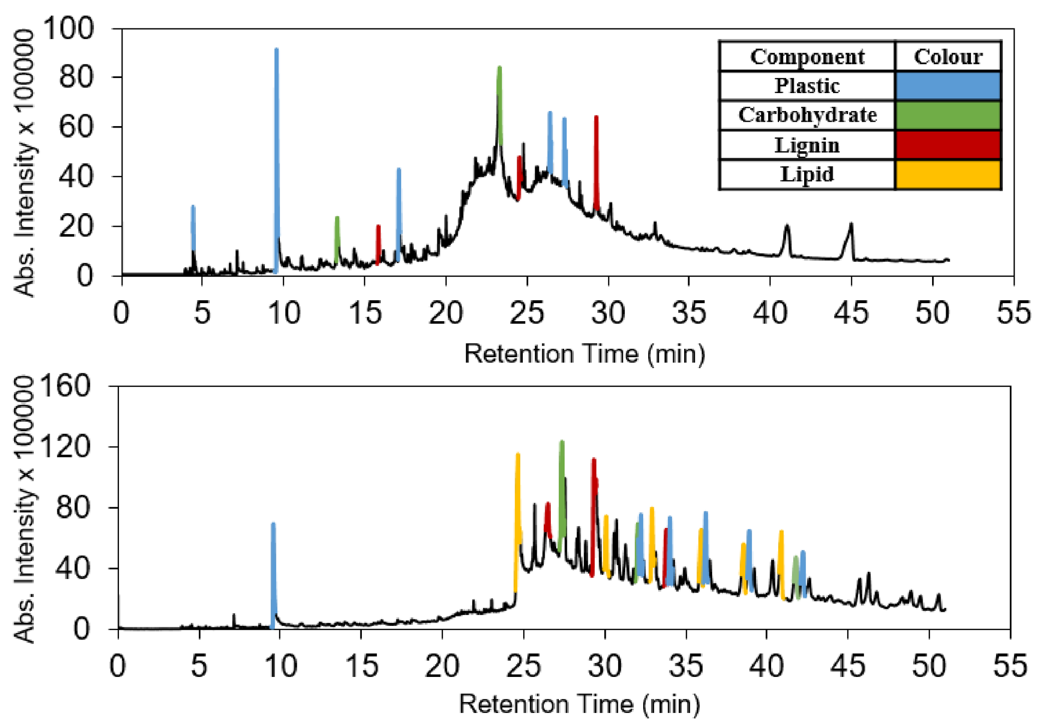

Figure 4. Py-GC/MS of MSW-derived pulp (top) and ORS (bottom).

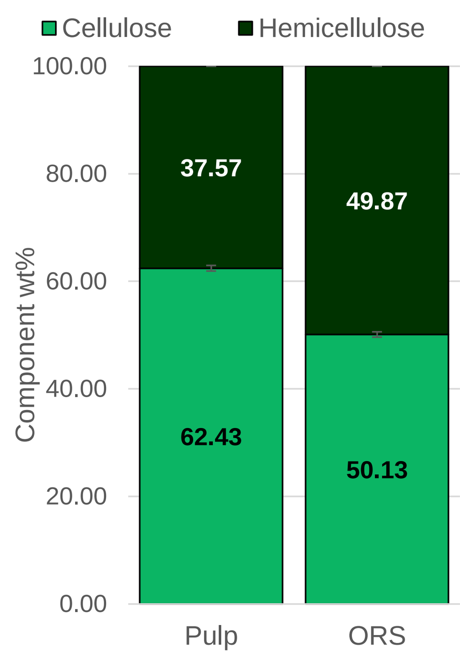

Figure 5. Wt% of Cellulose and Hemicellulose in Pulp (left) and ORS (right).

As figure 4 shows, processing of MSW removes the soluble fraction (lipids with some plastics and lignin). Processing MSW also concentrates the cellulose wt% in the pulp (figure 5) , which allows its exploitation for sugar extraction.

4. Sugar Extraction

MSW can contain high proportions of cellulosic material, which is a polymer of glucose. Glucose can be used as precursor for a range of high value products such bio-fuels, solvents and plastics figure 6. To decompose the cellulose enzymes can be used in enzymatic hydrolysis where, with optimum conditions, up to a 90% conversion rate is possible (**5**). The hydrolysis by-product post-hydrolysis solids (PHS) could be used as a solid fuel.

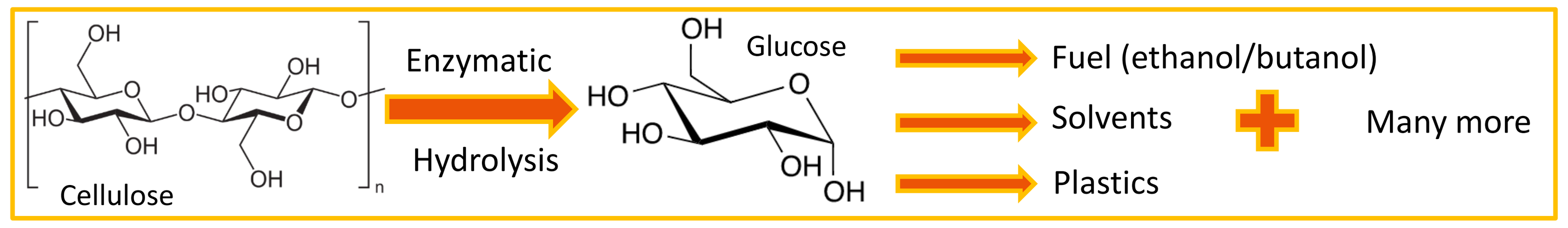

Figure 6. Reaction schematic for hydrolysis.

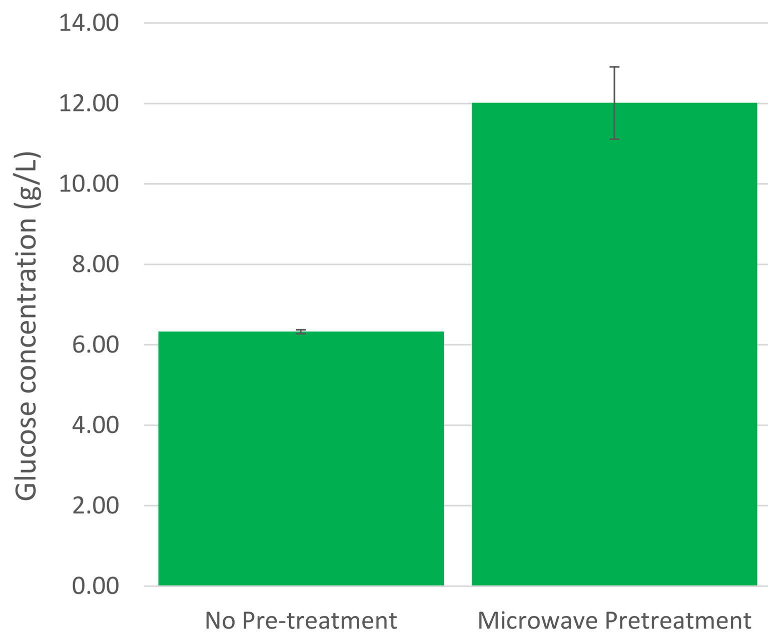

Figure 7. Glucose concentration with & without pre-treatment.

A pre-treatment such as microwave irradiation can be incorporated into the process to disrupt the resistant structure of lignocellulosic fibres.

Microwave irradiation increases the availability of cellulose molecules for the enzymes, improving hydrolysis rates and glucose yield. Figure 7 illustrates the difference in glucose yields between enzymatic hydrolysis with and without microwave pre-treatment.

5. Hydrothermal Upgrading

MSW-derived fuels can have many issues that can affect their use as a combustion fuel, these include (**3**):

- Highly heterogeneous
- High in alkali and alkaline earth metals
- Low energy density
- Undesirable ash behaviour

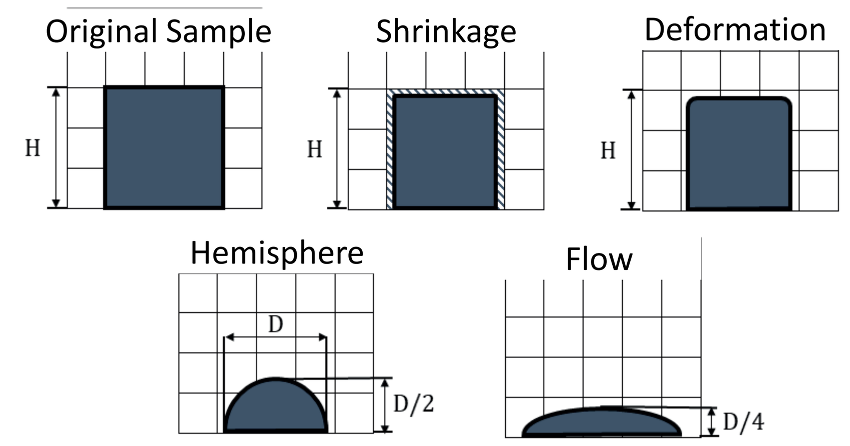

Figure 8. Characteristic ash behaviours. Adapted from (6).

Hydrothermal carbonisation (HTC) was used to upgrade fuel properties and ash behaviour of the PHS. Effects of HTC at 150 °C, 200 °C, and 250 °C on the ash behaviour was determined using ash fusion testing. Temperatures of the characteristic ash behaviours, shown in figure 8, were determined to the nearest 10 °C.

Ash fusion temperatures increased as HTC temperature increased, shown in figure 9. The improved ash behaviour reduces the risk of slagging and fouling.

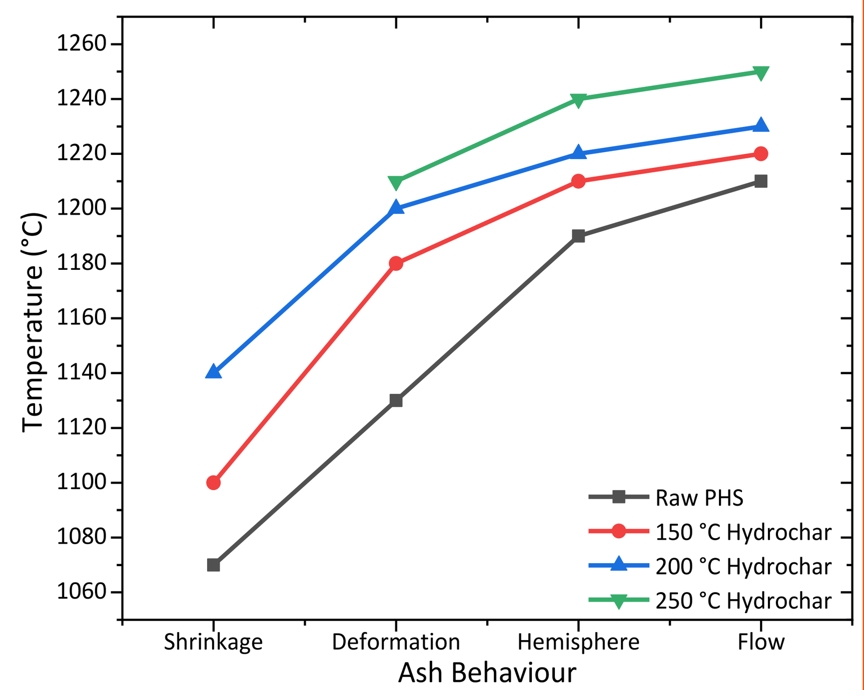

Figure 9. Ash fusion results after HTC.

6. Process Efficiency

HTC has two product streams; a solid hydrochar and process waters which contain between 15% – 20% of the organic content. Energy can be recovered from both these products. Anaerobic digestion (AD) is a useful tool for recovering energy from the organic content dissolved into the process waters.

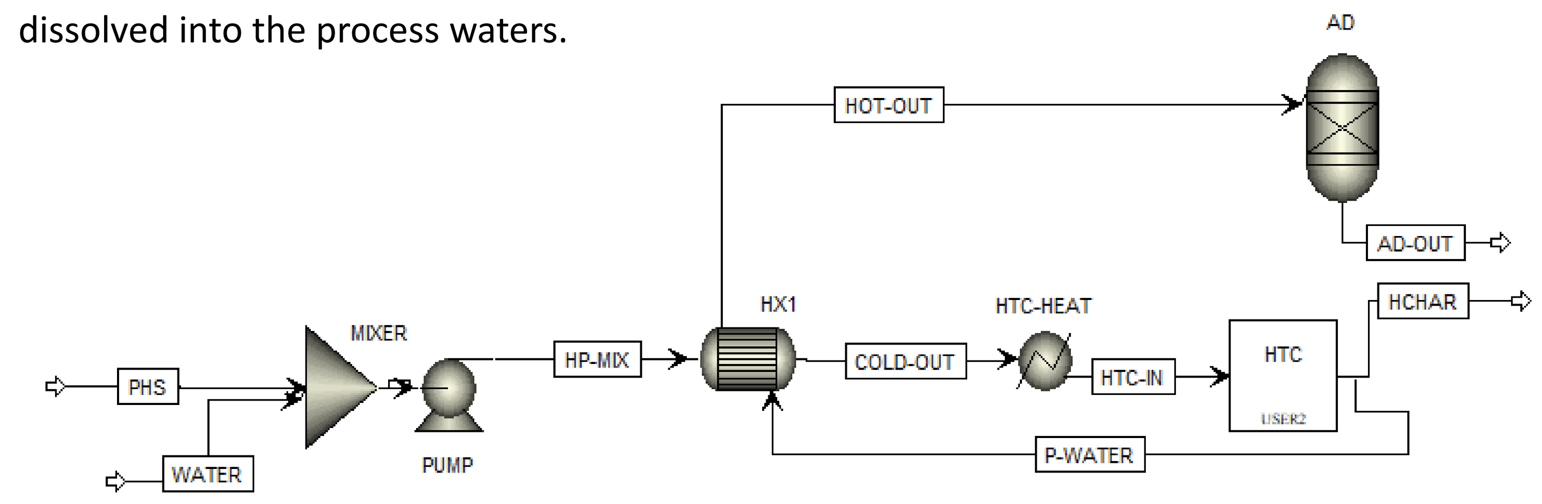

Figure 10. An Aspen Plus simulation of HTC and AD of PHS.

Figure 10 shows the system built in Aspen Plus to simulate the HTC of PHS and AD of the process waters. The energy and material streams flowing through this system boundary were calculated and analysed to determine the efficiency of processing PHS to generate hydrochar and biogas.

From HTC at 150 °C, a 77% hydrochar yield was obtained. These conditions resulted in 26% of the energy flowing into the system being stored in the hydrochar and 27% stored in the biogas. Therefore, 53% of the energy in the system was recovered and 47% was used in upgrading and processing the PHS.

7. Conclusions

Implementing this process could move India up the waste management hierarchy which would have the additional effect of reducing methane emissions from the open landfills commonly used in India.

Due to the difference in the composition of Indian MSW compared to western countries, the product yields would change. Paper content in Indian MSW is much lower than westernised waste, which reduces the cellulose content, thus a decreased sugar yield would be expected. Indian MSW has a higher wet organic content, which could generate increased volumes of ORS, a potential AD feedstock. Depending upon what the target product is from this process could affect its feasibility.

8. Future Work

- Repeat all the work using a feedstock representative of the composition of Indian MSW
- Investigate a wide range of microwave conditions including different temperatures and pressures
- Determine if different solvent systems for the sugar extraction process increase the glucose yields
- Investigate the combustion performance of the hydrochars produced
- Include pre-treatment and hydrolysis in the model to determine the efficiency of the whole process
- Determine the effects of seasonal variation on the MSW composition

Acknowledgements

We would like to thank our supervisors: Dr Richard Bourne, Dr Costas Velis, Dr Valerie Dupont, Prof John Blacker, and Dr Andrew Ross for their support throughout the project.

A special thanks to fellow Bioenergy CDT students Aaron Brown, Fernando Climent Barba, Oliver Grasham, and Iram Razaq. Along with Josh Cottom, Jeanine Williams, Jack Williams, Kashif Shazad, Simon Lloyd, Adrian Cunliffe, Karine Alves Thorne, Lucy Leonard, and James Hammerton.

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