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The combined effect of plastics and food waste accelerates the thermal decomposition of refuse-derived fuels and fuel blends

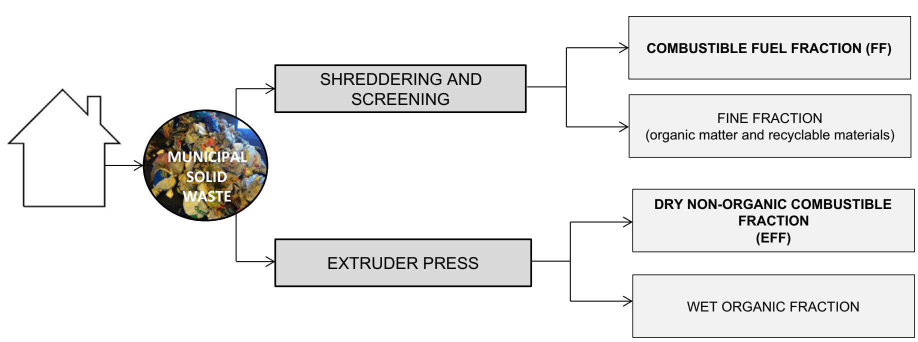
Mar Edo [a,b], Vitaliy Budarin [c], Ignacio Aracil [d], Per-Erik Persson [e], Stina Jansson [a,*]

[a] Department of Chemistry, Umeå University, SE-901 87 Umeå, Sweden
[b] Industrial Doctoral School, Umeå University, SE-901 87 Umeå, Sweden
[c] Green Chemistry Center of Excellence, Department of Chemistry, University of York, Heslington, York Y010 5DD, UK
[d] University Institute of Chemical Processes, University of Alicante, P.O. 99, Alicante, Spain
[e] Vafabmiljö AB, SE-721 87 Västerås, Sweden

HIGHLIGHTS

- Shredding and screening reduces the chlorine content in MSW fuels by up to 64%.
- Recovered wood and virgin wood exhibited similar combustion behaviour and properties.
- Reactivity in fuels increased with the food waste content.
- A combination of plastics and food waste in a fuel matrix accelerates its decomposition.

GRAPHICAL ABSTRACT



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ABSTRACT

Mechanical treatments such as shredding or extrusion are applied to municipal solid wastes (MSW) to produce refuse-derived fuels (RDF). In this way, a waste fraction (mainly composed by food waste) is removed and the quality of the fuel is improved. In this research, simultaneous thermal analysis (STA) was used to investigate how different mechanical treatments applied to MSW influence the composition and combustion behaviour of fuel blends produced by combining MSW or RDF with wood in different ratios. Shredding and screening resulted in a more efficient mechanical treatment than extrusion to reduce the chlorine content in a fuel, which would improve its quality. This study revealed that when plastics and food waste are combined in the fuel matrix, the thermal decomposition of the fuels are accelerated. The combination of MSW or RDF and woody materials in a fuel blend has a positive impact on its decomposition.

1. Introduction

The impact of fossil fuels on the environment and human health has led to a search for alternative fuel sources able to replace fossil fuels in terms of energy capacity, but also with a reduced environmental impact. In other words, our society is facing the challenge of finding new sustainable fuels, and biomass and waste materials are among those with the potential to replace fossil fuels.

Almost 1.9 billion tons of household waste also known as municipal solid waste (MSW) are generated globally every year, which means about 218 kg/person annually [1]. Of the MSW collected: 19% is recycled, 11% is used in energy recovery processes and the rest ends up in landfills or dumps [1]. Almost 4.5 Mtons of

* Corresponding author.
E-mail addresses: mar.edo@umu.se (M. Edo), vitaliy.budarin@york.ac.uk (V. Budarin), nacho.aracil@ua.es (I. Aracil), per-erik.persson@vafabmiljo.se (P.-E. Persson), stina.jansson@umu.se (S. Jansson).

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MSW (460 kg/person annually) were produced in Sweden during 2013, of which 32% was recycled, 15% was used in biological treatment and 52% was sent for energy recovery [1,2]. MSW incineration significantly reduces the volume of the waste and sanitizes it. In addition, combining MSW incineration with energy recovery (Waste-to-Energy, WtE) is an effective method of waste disposal. However, the heterogeneity and high moisture content of MSW make pre-treatment necessary to enhance its properties as fuel. Shredding and sieving is widely used to convert MSW into a more efficient fuel by reducing its particle size, separating out materials that can be recycled, such as ferrous and non-ferrous metals, and reducing the amount of wet material, such as food waste, than can be used for other purposes. Another emerging mechanical treatment involves extrusion of MSW in a hydraulic press providing a dry waste fraction for combustion. This fraction is mainly composed by plastic, paper and cardboard. Both shredding and extrusion reduce the food waste content from the processed combustible fraction which is subsequently known as refuse-derived fuel (RDF).

Removing food waste from the MSW would probably result in higher quality RDF. In addition, food waste could be more efficiently used for the production of biogas and compost. Food waste, paper and plastics are the main source of chlorine in MSW [3,4]. Power plants operating with RDF have high corrosion rates in their boilers due to the presence of chlorine in the fuel, which increases the maintenance costs of the plants. In addition, chlorine is responsible for the formation of toxic chlorinated pollutants such as dioxins and furans [5].

On the other hand, biomass has become one of the most in-demand renewable energy sources in recent years since it is considered to be carbon-neutral. Woody biomass generally has low ash content, a high concentration of volatiles [6] and higher energy content compared to MSW [7]. Other woody materials, such as recovered wood from demolition and construction activities, are also being used in WtE processes but they have not been as extensively studied as other types of biomass.

Production of fuel blends by combining woody materials and MSW has great potential with regard to both environmental and economic benefits compared to MSW-only fuels. The total chlorine content (TCC) of the fuel would be lower, which may reduce the risks of corrosion problems in the boilers and potential emissions of chlorinated organic compounds to the air. In addition, combustion behaviour and energy content of the fuel blend could be improved resulting in more efficient combustion. There is a lack of knowledge about how mechanical treatments applied to MSW influence its composition and properties and, by extension, its co-combustion behaviour, when combined with wood for the production of fuel blends.

Thermal analysis (TA) is a reliable technique used extensively for simulating thermal processes since it readily provides information about the thermal decomposition and combustion behaviour of a fuel. TA has been used extensively for the study of the co-combustion of biomass and coal or lignin blends [8–14] and even MSW and coal blends [15]. However, there are few studies considering the co-combustion of woody materials and MSW or RDFs. Grammelis et al. [16] focused on pyrolysis and combustion characteristics of the components of RDFs, while Muthuraman et al. [15,17] compared co-combustion characteristics of coal with MSW treated hydrothermally and wood. Synergies between RDF and biomass in a fixed-bed reactor were studied by Gehrmann et al. [18].

The current work used simultaneous thermal analysis (STA) to examine the combustion behaviour of different fuel materials and their blends. Two different types of woody materials (virgin softwood pellets and recovered wood chips) and three different waste materials (one MSW as collected and two RDFs obtained by mechanical treatment) were combined in two different fuel blend ratios. The aim of this study was to investigate how two different mechanical treatments applied to MSW influence the composition and combustion behaviour of the RDF. It also examines how the combustion behaviour of different fuel blends is influenced by the fuel matrix and the fuel blend ratios. Finally, the differences when recovered wood is used instead of virgin softwood were investigated. The results obtained will provide useful information for the production of fuel blends.

2. Materials and methods

2.1. Individual fuels and their preparation

Five different fuel materials were tested and used for the production of fuel blends – two woody materials, one MSW and two RDFs:

1. *Virgin wood pellets* (WP). Commercial softwood pellets (mix of pine and spruce) used for domestic heating.
2. *Recovered wood chips* (RW) from industrial, construction and demolition activities.
3. *Municipal Solid Waste remains* (MSWr). This is the remaining fraction after food waste has been collected separately from MSW on an individual basis in households. It mainly comprises plastics, paper, cardboard, textiles and food waste, and it may contain 5–20 wt.% food waste, depending on the efficiency of the separation of food waste in the source households.
4. *Fuel Fraction* (FF). By shredding and screening the MSWr in a grinder (Doppstadt DW 3060) and a 100 mm drum-screen (Doppstadt SM 518) two fractions are obtained: a fine fraction and a coarse (fuel) fraction. The fine fraction contains mainly incombustible materials and food waste, which can be used in compositing or anaerobic digestion processes. The fuel fraction (FF) is a RDF suitable for combustion. It mainly contains plastic and paper compounds and may contain up to 5 wt.% food waste due to inefficiencies in the screening process.
5. *Extruder Fuel Fraction* (EFF). By compressing MSWr in an extruder hydraulic press (*VM Press*®) the waste is separated into two fractions: a wet fraction mainly comprising food waste suitable for biological processes and a dry fraction rich in combustible materials such as paper, plastic or cardboard. The dry combustible fraction, also considered to be a RDF, may contain up to 2% food waste. Hereafter, it will be referred to as the extruder fuel fraction (EFF).

All fuels except WP were collected from a recycling centre and waste treatment plant sited in southern Sweden and owned by VafabMiljö AB. For each individual fuel, a standardized quartering procedure was performed to ensure a 25 kg representative sample of each type. Since the amount of sample used in the tests was very low, it was important to perform thorough grinding and homogenization to ensure representative and homogenous samples for analysis. Prior to analysis, samples were air dried and metal and glass pieces were removed manually from the waste materials and RW. Next, samples were homogenized, ground using a Retsch SM 200 cutting mill and sieved to ⩽1 mm and homogenized again. Finally, materials were ground again and sieved to ⩽500 μm and further homogenized prior to analysis (see Figs. S1–S3 available in supplementary material about FF and EFF production and sampling and sample preparation respectively).

2.2. Fuel blend preparation

Fuel blends were prepared by combining all the individual fuels in two different waste:wood ratios: (i) 80:20 and (ii) 60:40 by