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Research article

A systematic study of ring-die pellet production from forest and agricultural biomass

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ABSTRACT

Continuous global growth in the pellet production industry and renewable energy policy targets have driven interest in under-utilised lignocellulosic biomass. In this comprehensive study, pelleting trials were systematically carried out using a pilot-scale ring-die pellet press with eight different biomass feedstock; logging residues, pine bark, wheat straw, reed canary grass, coppiced willow, poplar and beech. A standard spruce/pine sawdust blend was pelleted as a reference material.

Pellets were produced from feedstock at four different moisture content levels, through two press channel lengths and three replicate steady-state sampling periods. A total of 192 batches of 8 mm diameter pellets were produced within a press channel length and moisture content range of 30–60 mm and 9–17% respectively. Pellet production had a range of 141–206 kg h^{-1} and relatively good pellet quality was achieved for a majority of the studied feedstock. The best pellet batches had a mechanical durability and bulk density range of 91–99% and 532–714 kg m^{-3} respectively, corresponding to an energy density range of 8.3–12.5 GJ m^{-3} (as received). The extruded pellet temperature ranged between 99 and 131 °C and was correlated to pellet bulk density for hardwoods, pine bark and forest residues. The normalised energy (reference value of 1) used in pelleting all materials varied between 0.76 and 1.3 being highest for the hardwoods and lowest for straw and forest residues.

1. Introduction

The wood pellets that are available in the current global market are produced predominantly from spruce and pine sawdust and cutter shavings. These raw materials are by-products of wood-processing industries and feedstock availability is thus linked to the productivity of the wood-processing sector. Since the turn of the century, global fuel pellet production has increased steadily and today exceeds 26 million tonnes (2015) annually [1]. Demand for lignocellulosic pellets from biobased chemical and material processing industries is expected to increase due to the logistical advantages of pelleted materials – high density, enhanced stability in storage and ease of handling and process feeding. Such qualities are just as relevant in these supply chains as they are in the energy sector.

Forest and agricultural biomass resources are available in large volumes [2]. Minimum feasible energy estimates of these materials (2006) in the EU15 alone consist of forest residues (86 PJ a^{-1}), forest industry by-products (830 PJ a^{-1}), cereal straw and maize residues (470 PJ a^{-1}). There is also an enormous resource potential from other agricultural by-products and energy crop cultivation [3]. To be able to meet the increasing demands from a diversified market for biomass pellets, new knowledge needs to be developed on the pelleting of these non-conventional lignocellulosic biomass.

Fuel pellets are tested to comply with international pellet quality standards (Table 1). The goal of pelleting is to achieve high pellet quality, durable pellets having a high bulk density [4]. Press channel length (PCL), feedstock moisture content (MC), steam conditioning, and - to some extent - additives, are the adjustable factors utilised for process control to meet these standards [5,6] and during steady-state operation, the die and extruded pellet temperature as well as compressional force will tend to some equilibrium value.

Pelleting results are, however, to a great extent ruled by the frictional properties of the feedstock as they generate both direct and indirect feedback effects on pressure and process temperatures [5]. In current practice, feedstock dependence is established by a trial-and-error procedure for each individual feedstock and sometimes each

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Table 1
ENplus pellet quality requirements [23].

Property	Unit	ENplus A1	ENplus A2	ENplus B
Diameter	mm	6–8		
Length	mm	3.15 < L ≤ 40		
Moisture content	% a.r	≤10		
Ash content	% a.r	≤0.7	≤1.2	≤2.0
Mechanical durability	% a.r	≥98.0	≥97.5	
Fines (< 3.15 mm)	% a.r	≤1.0		
Net calorific value	$MJ\,kg^{-1}$ a.r	≥16.5		
Bulk density	$kg\,m^{-3}$	≥600		
Additives	% a.r	≤2.0		
Nitrogen	% d.b	≤0.3	≤0.5	≤1.0
Sulphur	% d.b	≤0.04	≤0.05	
Chlorine	% d.b	≤0.02		≤0.03
Ash deformation temperature	°C	≥1200	≥1100	

Symbols refer to a.r = as received, d.b = dry basis.

production batch. First the right press channel length has to be found which is viable for pellet production; it must not produces only fines nor block the die. Further on, adjustments of moisture content and steam conditioning are performed, to search for settings where high pellet quality can be obtained. Additional fine tuning of the factors and the need for an additive is evaluated and, at the end of this procedure, an optimal combination of all factors is found for each feedstock.

The binding mechanisms and even the source of interparticle bonding in durable pellets are not fully understood and still a topic of speculation. The conventional narrative on bonding maintains that the lignin content of wood is important for pellet quality, even though lignin makes up only a minor fraction (21–32%) of temperate wood species [7]. Optimal compression and extrusion through the die heats the feedstock leading to the so-called softening of lignin [8]. Exceeding the glass transition temperature for a sufficient portion of the polymers in wood is necessary in order to achieve a sufficient bonding area [9]. When freshly pressed hot pellets are cooled, re-hardening of the lignin component is what contributes to pellet stability and strength. What has also been observed, however, is that strong pellets can be made from wood polysaccharides, such as hemicelluloses (xylan and arabinogalactan), which contain no lignin [10]. What is clear is that the story on bonding mechanisms in pelleted lignocellulosic materials is still being written. Single-pellet laboratory studies have contributed to knowledge on biomass densification [11–14] but systematic pilot-scale studies are essential due to their relevance for industrial production. Several pilot-scale studies have been carried out on pellets from unconventional feedstock including materials such as bark and logging residues [4,15,16], energy crops [17,18], cereal straws [19,20] and municipal solid waste [21,22]. What connects many studies in this field is their focus on demonstrated pellet properties without due consideration of production variables. Practical hands-on knowledge used behind the scenes during pellet production and in decision-making processes is frequently absent in scientific reporting. It is not uncommon, for example, that pellets are produced for a study by a commercial partner and there can be an inherent assumption that pellet quality is as good as possible. Alternatively, the details of process optimisation, if it has been done, are outside the scope of reporting. Moreover, pelleting studies which use a broad range of feedstock types are rare due to resource limitations. Working with an industrial or pilot-scale process is costly due to the required infrastructure, personnel and raw materials. Investigating a range of feedstock types, combined with variation of process parameters will necessarily lead to a large experimental matrix, meaning greater production volumes, more analysis and higher cost.

1.1. Purpose of the study

There is a clear need for broader studies in pellet making to understand how emerging forest and agricultural feedstock will influence the production process. Investigations require a systematic approach in production, sampling and analysis in order to obtain a bigger picture of material behaviour within realistic production intervals. This study aims to determine how pellet characteristics depend on PCL, feedstock moisture content, energy input, extruded pellet temperature and feedstock type. The results are interpreted from the viewpoint of pellet producers and guidelines are presented for utilisation of non-conventional feedstock materials in pellet making.

2. Materials and methods

2.1. Location, apparatus and feedstock

Pelleting trials and pellet characterisation work described herein was carried out at the Biomass Technology Centre of the Swedish University of Agricultural Sciences in Umeå, Sweden.

Eight types of feedstock were used in this study, representing both Northern and Southern European climatic zones (Table 2). Beech (*Fagus* ssp.) and poplar (*Poplar* ssp.) stem wood chips originated from France, while willow (*Salix* ssp.) chips, reed canary grass (*Phalaris arundinacea*), wheat straw (*Triticum* ssp.), Scots pine (*Pinus sylvestris*) forest residues, and Scots pine bark chips were sourced from Sweden. An industrial standard softwood stem wood sawdust blend (55–60% Norway spruce (*Picea abies*) and 40–45% Scots pine) was used as a reference feedstock. Additional information on feedstock includes their geographic origin, collection date, and duration of storage before pelleting (Fig. 1).

2.2. The pellet production process

Upon receiving, non-dry feedstock was dried at 40 °C using a belt dryer or an in-house flatbed dryer. All material was shredded to 15 mm in size using an industrial shredder (Micromat 2000, Lindner-Recyclingtech GmbH, Austria), loaded into 1 m^3 bags, and stored in a covered unheated storage until the day before pelleting.

The pellet production process is depicted in Fig. 2. Feedstock was first reduced in size using a hammer mill (Vertica DFZK, Bühler Nordic, Sweden) with a 4 mm circular sieve size and pneumatically conveyed to a blender. Water was then added to obtain feedstock batches with specific moisture, calculated on wet basis. Each feedstock batch was transferred to plastic barrels, sealed and labelled. The mass of prepared feedstock batches ranged from 75 to 100 kg.

Table 2
Feedstock used in the study and their characteristics.

Feedstock	Label	Place of origin	Collection date (dd.mm.yyyy)	Storage time before pelleting (months)
Norway spruce & Scots pine stem wood (55–60%/40–45%)	REF	Umeå, Sweden	N.A.	2
Beech stem wood chips	BEC	Toulouse, France	28.07.2016	10
Willow chips from short rotation coppice	SAX	Enköping, Djurby gård, Sweden	04.11.2015	21
Poplar stem wood chips	POC	Toulouse, France	28.07.2016	9
Reed canary grass	RCG	Umeå, Sweden	00.05.2010	82
Wheat straw	WST	Mälardalen, Sweden	09-10.2015	25
Scots pine forest residues	FOR	Robertsfors, Sweden	15.09.2015	18
Scots pine bark	SPB	Hällnäs, Sweden	25.08.2015	26