Fuel Processing Technology 152 (2016) 350–355

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Research article

Energy efficiency, greenhouse gas emissions and durability when using additives in the wood fuel pellet chain

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ARTICLE INFO

Article history:
Received 8 March 2016
Received in revised form 21 June 2016
Accepted 23 June 2016
Available online 6 July 2016

Keywords:
Pellet production
Additive
Energy use
Carbon dioxide equivalents
Durability

ABSTRACT

The use of renewable resources for bioenergy should be performed to support sustainable development. Since the use of bioenergy has increased significantly worldwide in recent years and biomass is made of limited resources it must be used efficiently and with a low environmental impact. The wood fuel pellet industry has the possibility to meet these criteria; however, it also has the potential for improvements. This work investigates how the additives, cornstarch and molasses, affect: the electricity consumption of the pellet press, the emission of Carbon dioxide equivalents (CO_2 eq.) from the production of wood fuel pellets in three different countries with different emissions from electricity, the durability of the pellets and its effects on energy efficiency. The results show that pellet production is more energy efficient when additives are used, and that the amount of CO_2 eq. increases with an increased use of additives. In countries with a low usage of fossil fuels for electricity production, the global warming impact gets higher due to the additives; while in countries that use a lot of fossil fuels to produce electricity, the global warming impact will be reduced because of the additives by up to 1%. The increased global warming impact from the additives can be balanced by the decrease in the reduced amount of rejected material within the production. That is because the durability of the pellets increases with an increasing amount of additive.

1. Introduction

On the path towards a more sustainable world, the use of renewable resources in a bioeconomy is increasing. The bioeconomy concept [1] has developed globally over the past ten years, especially within the field of biofuel cropping for bioenergy production [2,3]. A bioeconomy comprises a transformation of the energy sector, as well as a change to increase productivity in food production [3,4]. Within the field of bioenergy, biomass resources replace fossil fuels for electricity, heating and transportation devices. The global potential for biomass is large; although according to Johnson (2009) [5], the estimated potential varies significantly between different studies.

Using biomass for energy conversion is one way of reducing global greenhouse gas emissions; however, it is important that the resources are used efficiently, striving for low emissions and with concern about how to use land for other human needs like the production of food. In some cases, both industry and guiding agencies presume biomass as carbon neutral [5], this could indicate that there is less ambition to handle environmental issues and the resilience of the bioenergy systems. In several life-cycle assessments or footprint studies, carbon gas emissions are exclude when biomass is combusted [5], however when utilising forest material, the time perspectives and what happens in the recycling of biomass can influence the outcome significantly [6,7]. Land use will influence resilience, since it impacts on biodiversity and the soil quality, which is important for many different life support functions also water quality may be effected [8]. Another concern with using crops for bioenergy is the competition of land use and the impact it may have on food security [3]. Some lifecycle studies of biofuels either take alternative land use into account to address how the carbon stock might be influenced or the food security issue [9]. The issue of competing land use has been the focus of several studies during the last few years, e.g. [10, 11]; and in the life cycle studies, methods to assess the environmental effects of land use have been developed, e.g. [12,13].

Worldwide, the production and use of wood fuel pellets is growing [14]. Increased production leads to increasing competition within the worldwide pellet market, and an increase in the prices of raw materials. All of this, together with the anticipated rising prices of electricity, means that pellet manufacturers will have profitability difficulties, since it is a low margin business. Nevertheless, the wood fuel pellet industry has the potential for improvements and for a production increase. However, it is of the utmost importance that improvements made at the pellet plant are made from a wider system perspective and result in more energy efficient production, reduced environmental impacts, lower costs (energy use and cost of raw materials are the

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http://dx.doi.org/10.1016/j.fuproc.2016.06.031
0378-3820/© 2016 Published by Elsevier B.V.

main costs in pellet production) and an improved pellet durability. Additionally, considerations to other sustainability aspects, e.g. alternative land use and social implications, have to be accounted for.

From the perspective of the pellet producer, energy use, production cost and the number of satisfied customers are some of the most important issues. However, from an environmental perspective, the emissions of CO_2 eq. are also important. Wood fuel pellets are often produced from sawdust and shavings according to their standard size, moisture content, heating value, etc. The European standard for pellets facilitates trade between producers and consumers, as well as the technological development of equipment [15]. The production of wood pellets involves several steps, e.g. drying, hammer milling, the pressing of the pellets, the screening of fines and storage. Production of high durability pellets requires that the sawdust has been dried to a sufficient moisture content, and that the particle size distribution is optimal. Furthermore, the actual compression has to be done with the right pressure, temperature and retention time, e.g. to avoid fines and breakages during their transportation in the mill. The pellets are screened for fines before packaging or delivery. The fines are returned to the production line [16]. The amount of fines in the industrial process is estimated to be about 5 to 7% of the produced pellets, according to a Swedish producer of wood fuel pellets.

The total use of energy in the pellet chain is dominated by heat in the drying process, followed by electricity consumption in the pellet press. This work focuses on electricity consumption in the pellet press, since this step uses high amounts of electricity. The electricity consumption in the pellet press contributes to CO_2 eq. emissions, but the amount of CO_2 eq. emissions depends on how the electricity is generated. When estimating the effect of electricity generation on global warming, the specific energy source is important. Electricity consumption in countries where most electricity is generated from wind and hydropower has a lower global warming impact, than in countries where the electricity is generated from fossil fuels.

Adding different types of biomaterial from annual crops is one approach to achieve an increased energy efficiency and pellet quality. In some earlier works, the effects of using such additives on pellet quality and electricity consumption in the pellet press have been investigated [17–19]. The term additive is used to describe the amount of pressing aids of up to a maximum amount of 2 weight (wt.) % of pressing mass [15]. Rapeseed cake showed that the electricity consumption in the pellet press decreased while the durability of the pellets decreased [18]. Starch has been used extensively as a gluing agent. Starch in the form of potato flour and potato residue has been tested as binding material in pellet production and had a positive effect on compactness and durability [19,20]. The addition of starch grades, native wheat and potato starch and oxidised cornstarch and potato starch all increased the durability of the pellets, and decreased the electricity consumption in the pellet press. The oxidised cornstarch showed the best result: when 2.8% of cornstarch was added, the average electricity consumption was reduced by 14% [21]. Using a different kind of sugar assortment as an additive has been investigated in other different areas. Molasses as an additive has been used in wood fuel pellet production in Germany [22]. Mišljenović et al. 2016 shows that molasses as an additive in wheat straw pellets strengthen pellets produced at temperatures below the glass transition of lignin [23]. Thomas et al. 1997 discusses the effects of molasses used in animal feed pellets [24]. In cement production the use of molasses shows a higher compressive strength in the cement [25]. In this work two different additives were tested, the rest product molasses and cornstarch.

Private customers/homeowners require the highest quality pellets. They require pellets with uniformity and a high durability to meet their demands for trouble free heating [26–29]. Homeowners demand quality more than large-scale users, as they have a relatively simple conversion installation that often does not have advanced controls or professional management (trained personnel supervision, fully automatic equipment) [30]. Those users do not want pellets to crumble and generate high amounts of fines, since this causes a lot of problems to pellet stoves [16,31,32]. Therefore, it is crucial for pellet producers to achieve the highest quality pellets with a high level of durability, from a practical handling aspect as well as an efficiency aspect [28].

The purpose of this work is to present the weaknesses and advantages when additives are used in wood fuel pellet production by focusing on electricity efficiency, greenhouse gas emissions, pellet durability and production costs.

The aim is to calculate and analyse the change in: electricity consumption, emissions of CO_2 eq. (using a simplified model with CO_2 eq. data from the literature) and durability of the pellets when molasses and cornstarch are used as additives in the wood pellet production process using three different electricity mixes (in Sweden, OECD Europe and non-OECD Europe). The global warming impact of the two different aspects of pellet quality, such as their higher durability and the reduced amount of rejected material within production, are calculated. The land use concerns regarding the additives and the cost of using additives are also briefly discussed.

2. Method

The raw materials used for the production of the pellets at a Swedish sawmill were fresh sawdust of 90% Norway spruce (*Picea abies*) and 10% Scotch pine (*Pinus sylvestris*). The wet sawdust was dried with air in a Stela belt dryer at a low inlet temperature of 75 °C until it reached 10% (wb) [33]. The sawdust was ground using a ϕ 5 mm vibrating screen. The dried sawdust was conditioned to 11–12% (wb) in the diagonal MAFA mixer (type D2) by adding water. Then, the sawdust was stored in the diagonal mixer for 2 days to reach uniform moisture content. The moisture content (%, wb) for the sawdust and the pellets was determined according to [34].

One additive used was molasses, which is a viscous by-product of refining sugar beets into white sugar. Molasses from Granngården AB is normally used as animal feed, and it has a sucrose content of 44% and a water content of 25%. The selected cornstarch additive is a commonly used product. The modification chosen for this investigation was oxidation. Solam GmbH supplied the starch with a water content of 12%, more details are presented in Ståhl et al. (2012) [21].

An industrial pellet production unit is located at Environmental and Energy Systems at Karlstad University, Sweden [35], see Fig. 1. The pellet press has an Amandus Kahl C33–390 press with a flat die with a hole diameter of 8 mm and a maximum output of 300 kg/h. The wood fuel pellets with molasses as an additive were produced in a similar way to when the cornstarch was used, see [21]. The continuous feed pellet machine was run until stationary conditions were obtained. Before every new test, there was a break-in period of 5 min with the current additive to ensure that there were stationary conditions. Every test run lasted for 5 min. The feed control for the dried sawdust was set at a fixed rpm that corresponded to approximately 90–100 kg of sawdust/h, unsieved. Measured by weighing the produced pellets after each test run, on a Radwag WLC 12/30/C1/K weighing machine. Every pellet test run was separately cooled to ambient room temperature in a box with a perforated bottom, the cooling time is less than 10 min. The additive flow was subsequently increased through the volumetric feeder, going from 0.48% to 2.8% based on weight-% of pressing mass dry bases.

During the tests, the die temperature, the screw frequency, the electricity consumption (current) of the pelletising machine, and the pressure from the rollers on the die ("die pressure") were measured every 10 s. The die temperature was measured using a Pt-100 thermometer to an accuracy of $\pm$0.5 °C. The current load was measured to an accuracy of $\pm$1%. From the current measured load, the electricity consumption was calculated per dry substance produced pellets (see Table 1) according to the method described in Ståhl and Berghel (2011) [18]. The pressure from the rollers was measured with an accuracy of $\pm$1.25 bar. The low variability of the die temperature and the pressure from the rollers indicated stationary and stable conditions.