Fuel Processing Technology 122 (2014) 58–63

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Efficiency of small-scale firewood processing operations in Southern Europe

Marco Manzone [a], Raffaele Spinelli [b,c,]*

[a] University of Turin, Via Leonardo da Vinci, 44, I-10095 Grugliasco, Turin, Italy
[b] CNR — IVALSA, Via Madonna del Piano, Pal. F, I-50019 Sesto Fiorentino, FI, Italy
[c] AFORA — University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, Queensland 4558, Australia

ARTICLE INFO

Article history:
Received 27 November 2013
Received in revised form 19 January 2014
Accepted 21 January 2014
Available online 7 February 2014

Keywords:
Biomass
Energy
Productivity
Forestry
Beech

ABSTRACT

The study determined the performance of small-scale commercial firewood processing operations under the typical work conditions of Southern Europe. In particular, five units were tested, fed with the same 2.1-m long beech (*Fagus sylvatica* L.) logs. All machines were tested with sorted and unsorted logs. Productivity varied between 1.1 and 2.1 t h^{-1}, and cost between 20 and 39 € t^{-1}. There were significant differences between machines, which may partly be attributed to operator effect. Feeding the machines with sorted logs had a significant effect on the productivity of all machines on test, increasing productivity by 40% and reducing cost by 34%. Fuel use varied between 1.3 and 2.8 l t^{-1}. The energy balance was always very favorable. The ration between output and input was never smaller than 59 to 1 and peaked at 130 to 1. In other words, processing required about 1% of the energy contained in the firewood — or 1.7% in the worst case. The productivity figures reported in this experiment were much lower than reported for Northern Europe, which seems to confirm the significant effect of regional work conditions – especially different wood species – on firewood processing performance.

1. Introduction

The global consumption of firewood is estimated at over 1.5 billion m^3 per year [1]. Use is especially intense in the developing countries, where it accounts for 80% of the total supply of primary energy [2]. India uses about 300 million m^3 of firewood per year, and China over 180 million m^3 [3]. However, traditional chopped firewood is still widely used in all industrialized countries, especially in rural areas [4]. Here, firewood was never completely supplanted by fossil fuels and it enjoyed a revival in recent years with the oil crisis [5]. In fact, Europe still uses more traditional firewood than any other industrial energy wood product [6]. Although refined solid biofuels (e.g. pellets and briquettes) are increasingly popular in Europe, their consumption is still minor compared to traditional firewood [7]. In modern countries like Finland, Norway and Sweden firewood still satisfies between 20 and 25% of the heating needs of detached households [8–10] and hovers around 5 million m^3 per year and country. Firewood consumption is even higher further south. It reaches 22 million m^3 in France [11] and 18 million t in Italy [12]. Overall, modern Europe still uses over 100 million solid m^3 of firewood per year, about twice as much as Canada and the US together [13]. What is more, available statistics may be underestimating the size of the traditional firewood market, where transaction often goes unrecorded.

Compared to other fuel types, traditional chopped firewood benefits from decentralized availability and a very simple production process. Once logs are extracted from the forest, fuel preparation only requires cross-cutting and splitting [14]. That allows manufacturing at a local level by individuals and small-businesses, even on a part-time basis. As a result, the production of firewood is often a small-scale activity run by farmers, forest owners and small rural entrepreneurs [15]. In Finland, the average firewood producer runs a part-time operation processing between 50 and 150 m^3 of firewood per year [16]. Larger industrial operations are found in Italy, but even there the average company is quite small [17]. For this reason, firewood production is important to rural development and forest management, especially where traditional coppice forests are prevalent [18].

However economically and socially efficient, the dominance of diffused small-scale rural companies implies a very limited capacity to attract interest from all major actors in the technology development sector. Firewood producers are so small to be virtually invisible, and they can neither fund research nor leverage substantial political support for R&D in the area. So far, there has been little research on traditional firewood. None of the major bioenergy conferences held in Europe during the last decade have addressed the future of traditional firewood [6].

In particular, firewood processing has received the least attention, possibly because it is considered a very simple operation, with little potential for dramatic improvement. The large productivity variation between existing systems is a good witness to the contrary [14], while the high frequency of work accidents highlights the urgent need for further development [19,20]. Firewood processing cost could be further

---

* Corresponding author at: CNR — IVALSA, Via Madonna del Piano, Pal. F, I-50019 Sesto Fiorentino, FI, Italy.
E-mail addresses: marco.manzone@unito.it (M. Manzone), spinelli@ivalsa.cnr.it (R. Spinelli).

0378-3820/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fuproc.2014.01.025

reduced through improved technology and work techniques, thus making firewood production safer and more competitive than it currently is [6]. At present, all the few recent studies on firewood processing performance come from Nordic Europe [14,15]. Looking further back, one finds more Nordic studies [21–23]. These are very good studies, but they cannot represent Europe as a whole. The work conditions encountered in Nordic countries are much different from those of Central and Southern Europe, where firewood production is much larger [3]. The main difference is with tree species: in Northern Europe, firewood is obtained mainly from birch (*Betula pendula* Roth.), pine (*Pinus sylvestris* L.) and spruce (*Picea abies* Karst.), while beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.) and hornbeam (*Ostrya carpinifolia* Scop.) are dominant further south. These species have dramatically different characteristics, especially for what concerns wood density (Table 1). Additional differences concern log length, which ranges from 2 to 6 m in Northern Europe, and from 1 to 2 m in Southern Europe, due to the different extraction methods [24,25].

Therefore, the goal of this study was to determine the performance of commercial firewood processing operations under the typical work conditions of Southern Europe. In particular, we endeavored to determine the productivity, cost and energy use of firewood processing with a range of different machines, under two different sorting alternatives.

2. Materials and methods

Firewood processing trials were conducted in the Piemonte region, north-western Italy. The authors identified 5 commercial operations, run by rural entrepreneurs and considered representative of the small-scale commercial operations of Southern Europe. The sample represented a wide range of small-scale firewood processing equipment, specifically designed for crosscutting and splitting firewood logs into stove wood. The main differences between the models on test were in the crosscutting device and the splitting force, the latter always exerted through a hydraulic wedge device. All the main crosscutting devices were represented, including disc saw, chainsaw and band saw (Table 2). Crosscut pieces were automatically moved to the splitter, except for the band saw unit, where the cut piece was manually positioned onto the splitter plate. This specific machine adopted an older traditional design, and was served by two operators instead of one. All other machines were served by one operator only, since the cross-cutting/splitting sequence was automatic. All firewood processors were powered by old farm tractors, through the tractor's power take-off. Semi-stationary use at a log yard does not require a new tractor. One can use any prime mover, as long as the engine and the power take-off are still in good shape. Resorting to an old tractor allows a dramatic reduction of investment cost, which is especially important for small-scale rural companies.

The study was conducted in April and May 2012. At the time of the study, all machines were fed with 2.1 m long beech logs, which they processed into 35 cm long split stove wood. The target diameter of stove wood was 15 cm, for all machines. Logs with a diameter below 15 cm were not split. Processed wood was semi-fresh, with a moisture content between 35 and 40%. Moisture content was determined with the gravimetric method on three 500-g samples per machine. All machines were operated by experienced professionals, who had run them for several years and knew them well. These operators were reputed as reliable and motivated, as they were the companies' owners or co-owners.

Machines were observed while working at the company's log yard. The study compared two different work techniques, with and without log sorting before processing. In the sorted treatment, the machines were fed with selected logs with a small-end diameter between 18 and 25 cm. In the unsorted treatment, the same machines were fed with a mix of small and large logs, with a small-end diameter between 8 and 30 cm. All machines were equipped with rubber-belt conveyors and discharged their product into bin trailers. Each observation consisted of a full 8-hour work day. Each combination of machine and technique was replicated three times, for a total of 30 observations, or 30 work days.

The experiment consisted of a typical time and motion study [26]. Work time was determined with stopwatches, including all delays up to a maximum duration of 30 min [27]. Meal time was excluded from the records. Firewood output was determined by taking all bin trailers to the certified weighbridge available at the log yard. Individual log size was not determined, but log size was considered to be the same for all tests, since 1) all the wood had been sourced from the same supplier, 2) the wood was obtained from a coppice stand and was relatively homogeneous and 3) each observation (one day of work) contained a very large number of logs.

Machine costs were estimated with the method developed within COST Action FP0902 [28]. Fuel consumption was measured by starting each working day with a full diesel tank and refilling the tank at the end of the working day, after allowing for the machine to cool down. Machine owners provided their own estimates for insurance cost and maintenance cost. Machine owners also declared an annual production between 300 and 1200 t, which was used to estimate a mean annual usage of 500 h. Labor cost was assumed to be 15 € per hour, inclusive of indirect salary costs. The calculated operational cost of all teams was increased by 20% to account for overhead costs [29]. Further detail on cost calculations is shown in Table 3.

Both direct and indirect fossil energy use were estimated, reflecting the same principles followed by [30] in his energy analysis of Italian agriculture. Direct energy use was estimated by multiplying the measured diesel consumption by the energy content of 37 MJ l^{-1} [31], and then inflating this value by 1.2 in order to account for the additional fossil energy used in the production, transportation and distribution of diesel fuel [30]. The indirect use represented by machine manufacture, repair and maintenance was estimated as 44% of direct energy use [32]. No allowance was made for the embedded energy of a barn for housing the machines, on the assumption that machines used in forestry often rest outdoors, or under very simple makeshift structures, with a negligible energy content. Results are shown in Table 3. The energy content of beech firewood with a 38% moisture content was estimated at 10,520 MJ t^{-1}, using the methods reported by Magagnotti and Spinelli [26].

Data were analyzed with the Statview advanced statistics software [33]. Since data distribution violated the normality assumption, the statistical significance of the eventual differences between machine models was tested with Scheffe's test, which is particularly robust against such violation. The significance of differences between work

Table 1
Physical characteristics of some tree species used for firewood.

Common name	Latin name	Density at 15% mc kg m^{-3}	Compression strength N mm^{-2}	Shear strength N mm^{-2}	Bending strength N mm^{-2}	Modulus of elasticity N mm^{-2}
Norway spruce	*Picea abies* Karst.	450	38	6.5	73	15,000
Scots pine	*Pinus silvestris* L.	550	45	7.6	97	13,750
Silver birch	*Betula pendula* Roth.	650	59	6.0	120	13,000
Beech	*Fagus sylvatica* L.	730	61	8.0	118	14,700
Common oak	*Quercus robur* L.	820	61	9.8	108	12,500
Hornbeam	*Ostrya carpinifolia* Scop.	820	48	8.5	133	12,560

Note: from [39].