# Improvement of Wood Fuel Pellet Quality Using Sustainable Sugar Additives

Magnus Ståhl,* Jonas Berghel, and Karin Granström

The global production and use of wood fuel pellets has increased significantly in recent years. The raw material and the energy required to dry it are the main production costs. Therefore, it is crucial to minimize energy consumption, production costs, and the environmental impact associated with wood pellets. However, these changes should not negatively affect the quality of the pellets. One way to achieve these goals is to use additives. This work investigates how different types of sugar additives affect both the energy needed by the pellet press and the durability and oxidation of the produced pellets. When sugar was used as an additive, the energy use was practically unaffected. When molasses and SSL were added, a small decrease in energy use was observed (6 to 8%) for admixtures up to 1 wt.%; however, when more molasses was added, the energy use increased. Using these additives increased the bulk density (7 to 15 %) and durability (10 to 20 %) of the pellets. The storage of the pellets also caused a small increase in durability (1 to 3 %). Volatile organic compounds were produced as oxidation peaks within the first two months of storage; thereafter, the peaks tapered off.

*Keywords: Wood fuel pellet; Additives; Molasses; White sugar; Spent sulphite liquor; Energy efficiency; Durability; Storage*

*Contact information: Environmental and Energy Systems, Karlstad University, SE-651 88 Karlstad, Sweden; *Corresponding author: magnus.stahl@kau.se*

## INTRODUCTION

The use of dried and processed biofuels has increased significantly in recent years, and the global market is still growing. In 2014, the estimated global level of wood pellet production reached 27 million metric tonnes (MT) (Kopetz *et al.* 2015), and it is expected to reach approximately 50 MT by 2020 (Mergner 2014). In 2014, more than 75% of the pellets were consumed in Europe (Kopetz *et al.* 2015), making Europe the largest pellet consumer in the world. The main reason behind this surge in pellet usage is the EU 2020 targets for renewable energy sources. Based on these targets, the wood pellet market in Europe is expected to grow even further (Monteiro *et al.* 2012; Goh *et al.* 2013). Wood fuel pellets, preferably made from sawdust or shavings, are used in large and small-scale applications. Due to an increase in the trade and use of pellets by small-scale customers, an increased demand for high quality pellets is likely to force pellet producers to improve upon pellet properties and to broaden the raw material base. Most of the pellets, however, are transported in bulk in large vessels and trucks, which sets equally high demands for high quality pellets.

Increased production leads to increased competition within the worldwide pellet market, as well as an increased price for sawdust. The increase in competition implies decreasing pellet prices, and coupled with the anticipated rise in the price of electricity, it means that pellet manufacturers will have lower profit margins. The raw material, energy demands for drying pellets, and labour are the main costs in pellet production (Mani *et al.* 2003; Thek and Obernberger 2004; Uasuf and Becker 2011; Monteiro *et al.* 2012). The raw material may contribute to the total production cost of more than 40% (Uasuf and Becker 2011). Therefore, pellet producers must be energy-efficient to meet increased demand and to utilize the raw materials efficiently, while also working towards sustainable development.

Efficiency could be increased with the proper additive. An additive is a pressing aid comprising a maximum of 2 wt.% of the pressed mass (SS-EN 14961-1 2010). Additives occur frequently in the pellet industry, and the most commonly used additives are starch, lignosulphonate, dolomite, corn or potato flour, and vegetable oils (Stelte *et al.* 2012). Additives make it possible to broaden the raw material base, increase pellet quality, and decrease production energy (Nielsen 2008; Ståhl and Berghel 2011; Berghel *et al.* 2013; Tarasov *et al.* 2013).

Starch has been used extensively as a gluing agent. In plywood gluing tests and particleboard production, starch and sugar have synergistic adhesive properties (Tondi *et al.* 2012). 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 (Kuokkanen *et al.* 2011). Starch grade additives (native wheat and potato starch as well as oxidised cornstarch) increase pellet durability while decreasing the electricity used in the pellet press (Ståhl *et al.* 2012). Oxidized corn starch showed the best result, compared to native starches; when 2.8 wt.% corn starch was added, the average electricity use was reduced by 14% (Ståhl *et al.* 2012). Tarasov *et al.* (2013) concluded that every type of starch increased the mechanical durability of the pellets to a certain limit, as the addition of 7 wt.% starch makes the final product dry, which negatively affects its durability. The pellet industry uses less than 2 wt.% starch due to its cost (native wheat and potato starch cost about 500 to 600 €/MT according to Solam GmbH, Emlichheim, Germany) and the rules that govern additives. Furthermore, good results regarding pellet durability and decreased electricity consumption have already been shown at 0.5 wt. % (Ståhl *et al.* 2012). Another crop rich in starch is cassava. Cassava was used as an additive up to 5% in wood pellets. The result showed an increased durability and an increased amount of fines (Larsson *et al.* 2015). Instead of using an industrially produced product, such as starch, it is possible to use a by-product such as lignin. Berghel *et al.* (2013) showed that kraft lignin increases the mechanical durability and length of pellets, and dry lignin is preferable to wet lignin. Kuokkanen *et al.* (2011) concluded that lignosulfonate increased durability and increased the production of pellets but the amount must be less than 0.5% to keep the sulphur concentration below the limit set in the European standard SS-EN 15210 (2010).

Water-soluble carbohydrates act as binders in pellets (Kaliyan and Morey 2008; 2010). In ultraviolet auto-fluorescence (UV-AF) images of pellets, water-soluble carbohydrates act as solid bridge binders (Kaliyan and Morey 2010). Highly viscous binders, such as molasses, generate strong bonds that are very similar to solid bridges. Water-soluble carbohydrates are composed of monomeric units of sugars such as glucose and fructose, which are found in white sugar, molasses, and spent sulphite liquor. These products are different forms of sugars from different stages in the sugar production value chain. White sugar is for human consumption, while molasses is a white sugar by-product that is used in animal feed. Spent sulphite liquor is a residual product of the pulp and paper industry that has very little use.

White sugar is crystallised sucrose that is extracted from either sugarcane or sugar beets. As crystallized sugar is removed, other extracts are left in the form of molasses.

Molasses (with a cost of about 2000 €/MT, Dansukker AB (Arlöv, Sweden)) has been used as an additive in wood fuel pellets in Germany (Thek and Obernberger 2012). It is a thick opaque fluid, brown to dark brown in color, with a different smell than sugar beet molasses; it has a sweet taste and a bitter aftertaste. It is completely soluble in hot and cold water. While beet sugar molasses has a higher raw protein content, sugar cane molasses has higher antioxidative effects (Valli *et al.* 2012). This property may affect the shelf-life and self-ignition risk of molasses-containing pellets, making it an interesting candidate as an adhesive. Spent sulphite liquor is a rest-product from the sulphite cooking of wood chips. The major compounds of the spent sulphite liquor are hemicellulosic sugars, such as mannose, xylose, and glucose, as well as sulphonated lignin (Lennartsson 2012). The potential of converting sulphite pulp waste streams to sources of sugars, from which higher value bioproducts can be made, is interesting from both an economical and a resource efficiency perspective. It is also in line with the current trends in the bioeconomy.

This work investigated how white sugar, molasses, and spent sulphite liquor additives affect the energy required by the pellet press and the durability and oxidation of the produced pellets. Molasses and spent sulphite liquor were expected to be superior additives compared with pure white sugar, as the former by-products contain starch, sugars, and antioxidants that have potential to enhance durability.

## EXPERIMENTAL

### Materials

Fresh sawdust composed of 90% Norway spruce (*Picea abies*) and 10% Scotch pine (*Pinus sylvestris*) was used to produce pellets. The sawdust was produced at a local sawmill (Stora Enso Wood Products, Grums, Sweden). The wet sawdust was air-dried on a belt dryer at 75 °C until it reached 10% (wb). The sawdust was ground using a 5-mm sieve. Water was added to the dried sawdust in a diagonal mixer until the moisture content was 10.9 or 13.0 ± 0.1% (wb). The materials were completely mixed after 5 min. The sawdust was stored in the mixer for 2 days to reach a uniform moisture content.

Three different sugar products were used in this study: white sugar from Dansukker AB (Arlöv, Sweden), molasses from Granngården AB (Malmö, Sweden), and spent sulphite liquor (SSL) from Nordic Paper Seffle AB (Säffle, Sweden). White sugar (*Beta vulgaris*) is a regular consumer sugar. Its sucrose content is 99.9 wt.%, and the water content of white sugar is 0.05 wt.%. Molasses is a viscous by-product of the refinement of sugar beets into white sugar. Molasses contains 44 wt.% sucrose, 25 wt.% water, 9.8 wt.% protein, and 8.2 wt.% ash. SSL has a carbohydrate content of 42.8 g/L (Lennartsson 2012) and a water content of 78.6% (wb).

### Methods

The pellets were produced in a production unit that is located in the Environmental and Energy Systems department at Karlstad University, Karlstad, Sweden (Fig. 1). The system contains the following: (1) a diagonal mixer; (2) a conveyor screw; (3) a Kahl mixing conditioner, Type MK 200; (4) an inlet screw feeder; (5) a Kahl C33-390 pelletising press with a flat die and a maximum output of 300 kg/h (Kahl Group 2015); (6) a volumetric feeder for additives; and a cooling tower. In the pelletizing press, the sawdust is pressed through the flat die by pan grinder rollers. The die has a 9-hole radius with 52 holes on each row, totalling 468 holes. It has a working width of 75 mm, a hole diameter of 8 mm, a total thickness of 50 mm, a relief depth of 20 mm, and a hole inlet diameter of 10.2 mm. The inlet tapers 17°, and it has no cutting blade. The open area of the die is 64%. The effective compression length in this study was set at 30 mm.

The additive was supplied at the inlet of the mixing conditioner (3) through a volumetric feeder (6). The volumetric feeder consists of a hopper, a gearbox, and an agitator that rotates above the screw to maintain a constant additive flow and to prevent bridging. As the volumetric feeder throughput depends on the screw speed and the additive, it was calibrated accordingly. The output for the additive was determined as a function of the frequency of the screw.

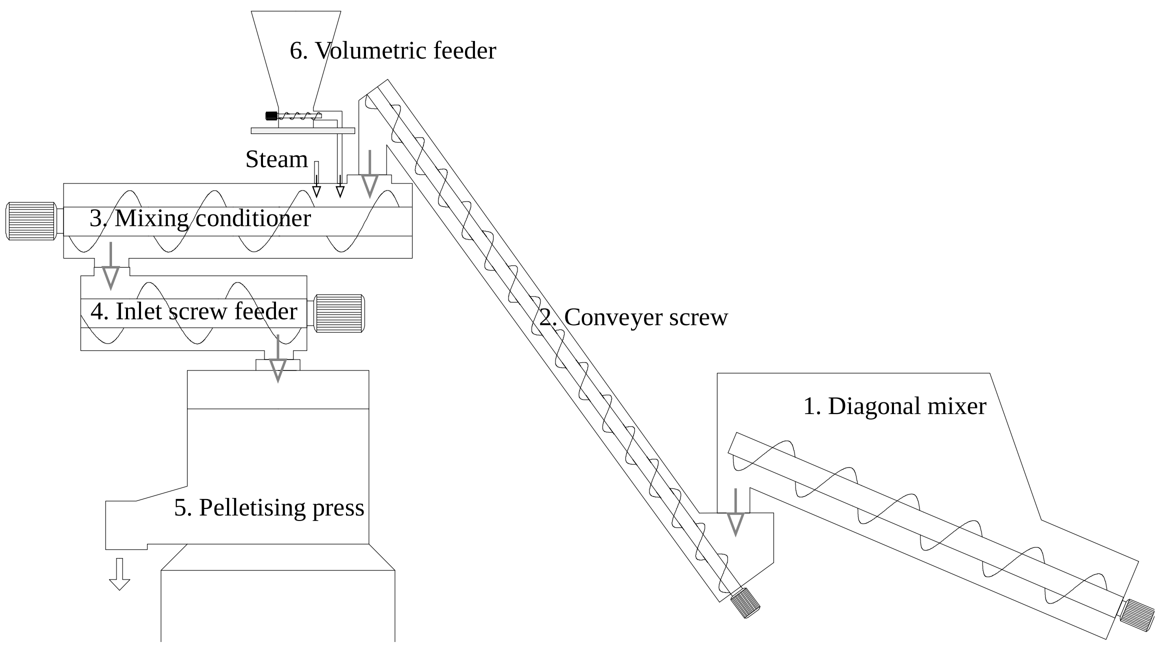


**Fig. 1.** Pellet production unit at Karlstad University

The continuous feed pellet machine was run until stationary conditions were obtained. Before each new additive test, there was a break-in period of 10 min to ensure stationary conditions. Every test run lasted for 5 min. The feed control for the dried sawdust was set at a fixed rpm, corresponding to approximately 85 kg of sawdust/h. The additive flow was subsequently increased through the volumetric feeder, going from 0.5 to 2.0% based on the weight percentage of the pressing mass dry base.

During pellet production, samples of approximately 300 g of dried and conditioned sawdust were taken every 15 min, resulting in a total of 15 samples. The moisture content of the cooled pellets was examined by analysing one sample from each 5 min test, *i.e.*, a total of 13 samples. SSL tests were performed on a separate occasion, but with similar settings as the white sugar and molasses tests.

To study the effects of sugar, molasses, and SSL during storage, the pellets were stored for 5.5 months. The amount of hexanal formed and the durability of pellets was examined. Durability is included in the European standard SS-EN 15210 (2010). The shelf life was gauged by quantifying the hexanal formed during storage, as hexanal results from the oxidation of fatty extractives.

During the tests, the following parameters were logged every 10 s: the die temperature, screw frequency, current consumption of the pelletizing machine, and the pressure from the rollers on the die (commonly referred to as the die pressure). The die temperature was measured using a Pt-100 thermometer to an accuracy of ± 0.5 °C. The current load was measured to an accuracy of ± 1%. The average power consumption and the average energy consumption for alternating currents were calculated from the measured current load as previously described (Ståhl *et al.* 2012). The pressure from the rollers was measured with an accuracy of ± 1.25 bar. The low variability of the die temperature and the pressure from the rollers indicated stationary and stable conditions.

Every pellet test run was separately cooled to ambient room temperature in a box with a perforated bottom. The pellets were sieved before testing and comparison was made with the quality parameters of the Swedish and/or European standards. Moisture content (%, wb) for the sawdust and the pellets was determined according to SS-EN 14774-1,2 (2009). The bulk density (kg $m^{-3}$) was determined according to SS-EN 15103:201029 (2010) by measuring the weight of a 5-L bucket filled with cooled pellets; the mechanical durability was determined according to SS-EN 15210 (2010) and presented as the percentage of pellets. Hexanal was measured with static headspace/gas chromatography (SHS-GC). Briefly, 0.5 to 0.6 g of pellets were heated with 5 mL of water in a 10-mL sealed vial at 80 °C for 30 min. The headspace gas (0.5 mL) was injected into a gas chromatograph with flame ionization detector (GC-FID), a Clarus 480 from Perkin Elmer, fitted with a capillary column (J&W Scientific, DB5-MS, 30 m × 0.25 mm), with the temperature programmed at 40 °C for 2 min, 15 °C/min, 70 °C for 5 min, 15 °C/min, and 200 °C for 7 to 25 min. Helium was the carrier gas, and the detector was set to 200 °C. In this method, the coefficient of variation has previously been determined as 11% (Granström 2010), but in this study, it was 20% for duplicate analyses.

The pellets were stored in a controlled laboratory setting to avoid the undue influence of temperature and humidity fluctuations. They were stored in unclosed black plastic bags at 18 °C and approximately 55% humidity, and they were protected from direct light. Pellets with 2 wt.% white sugar, molasses, and SSL were analysed for their hexanal content after three weeks, then every week during the first 70 days, and finally less frequently until the experiment was terminated at 182 days. The period of half a year, *i.e.*, 182 days, was chosen since it represents the seasonal storage time in Sweden. That is for pellets produced in the spring and later sold in the late autumn. The durability of the pellets with 0, 0.5, 1, or 2 wt.% white sugar, molasses, and SSL added was tested immediately after production and after 182 days of storage.

If the statistical error was not stated in the standard, it was specified in the Results section. The error was calculated for specific energy use, material flow, and moisture content. Standard deviation was used for the load current. For pellet length, bulk density, and durability, the significance of the results was tested with a t test, where $\alpha = 0.05$. For the hexanal data, a coefficient of the variation was reported.

## RESULTS AND DISCUSSION

Table 1 shows the data logged on the pellet machine and the moisture content of the raw material and pellets. The addition of white sugar, molasses, and SSL before pelletizing the sawdust affected the cohesiveness of the pellets, as shown by an increase in durability and a higher bulk density (Figs. 2 and 3).

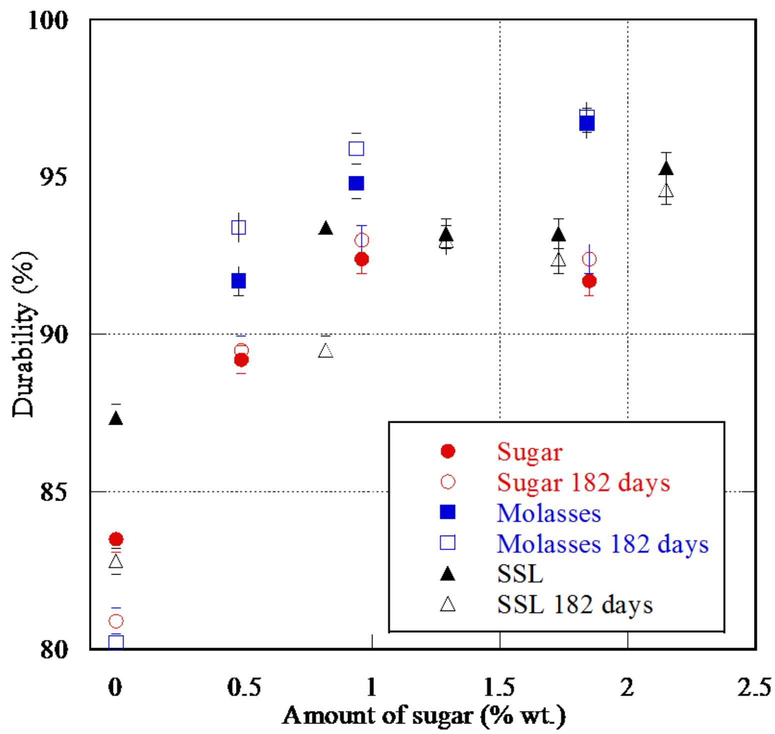


**Fig. 2.** Durability versus the amount of additive on the production day and after being stored for 182 days. The three additives are white sugar, molasses, and spent sulphite liquor

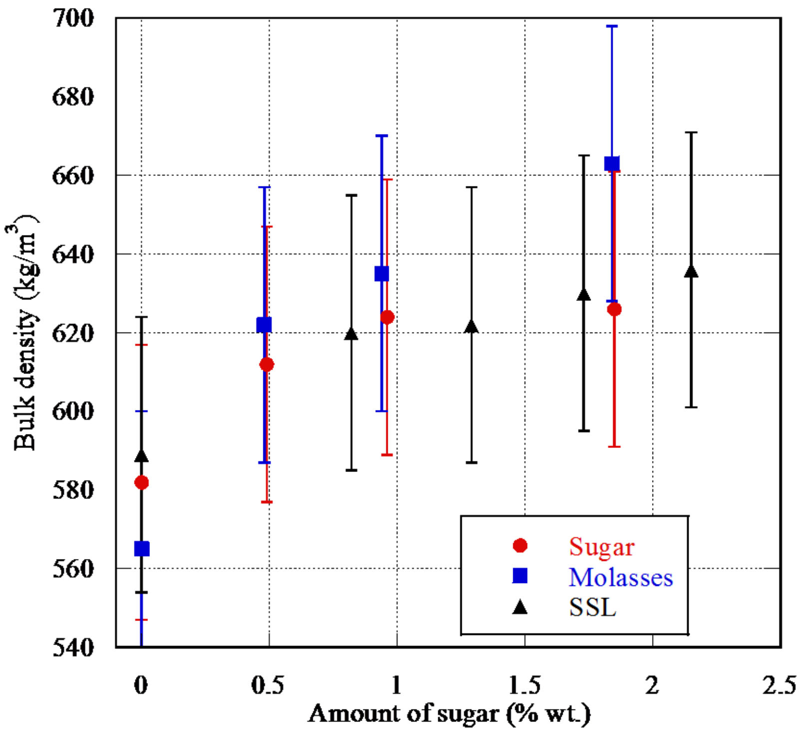


**Fig. 3.** Bulk density at varying amounts of the white sugar, molasses, and spent sulphite liquor additives

The durability increased with increased amounts of white sugar, molasses, and SSL. Figure 2 also shows that the pellets with no added sugar did not meet the standard requirements. The durability of the pellets after 182 days of storage showed a small but significant improvement in durability (1 to 3%). The water also worked as a binder and strengthened the durability, but for this test series, the water content in the inlet material and in the produced pellets was almost constant (Table 1). Samuelsson *et al*. (2012) showed that the durability has low sensitivity for changes in moisture content for wood pellets produced from fresh sawdust. As the moisture content cannot explain the differences in durability, the differences were due to the sugars that affect bonding during pelletising. Finding the optimal sugar mixture will likely lead to further improvements in pellet durability. Molasses is a good alternative if the goal is to minimize the problems associated with the amount of fines or crumbling. The bulk density increased when the amount of white sugar, molasses, and SSL increased. Molasses produced the largest increase in bulk density; however, there was a large degree of uncertainty in the measurements, affecting the interpretations of the results.

**Table 1.** Measured Data and Moisture Contents during Pellet Production

| Test Run | Amount of Additive (wt.%) | Load Current (A) | Inlet MC (%, wb) | MC after Mixer (%, wb) | Pellet MC (%, wb) | Material Flow (kg of DS/min) |
|---|---|---|---|---|---|---|
| No additive 1 | 0.0 | 20.8 | 10.9 | 13.5 | 6.3 | 1.37 |
| Sugar | 0.49 | 22.1 | 10.9 | 13.5 | 6.7 | 1.43 |
| Sugar | 0.96 | 22.2 | 10.9 | 13.5 | 6.2 | 1.46 |
| Sugar | 1.85 | 22.8 | 10.9 | 13.5 | 5.9 | 1.52 |
| No additive 2 | 0.0 | 20.8 | 10.9 | 13.5 | 6.3 | 1.38 |
| Molasses | 0.48 | 20.7 | 10.9 | 13.5 | 6.5 | 1.46 |
| Molasses | 0.94 | 21.2 | 10.9 | 13.5 | 6.4 | 1.49 |
| Molasses | 1.84 | 22.8 | 10.9 | 13.5 | 5.9 | 1.53 |
| No additive 3 | 0.00 | 19.9 | 12.7 | 15.6 | 8.0 | 1.34 |
| SSL | 0.82 | 21.9 | 12.7 | 15.6 | 7.3 | 1.47 |
| SSL | 1.29 | 21.2 | 12.7 | 15.6 | 7.5 | 1.43 |
| SSL | 1.73 | 21.6 | 12.7 | 15.6 | 7.9 | 1.44 |
| SSL | 2.15 | 21.7 | 12.7 | 15.6 | 8.3 | 1.46 |

Additives are known to affect the energy use of the pellet press. When sugar was used, the energy use was practically unaffected (Fig. 4). When up to 1 wt.% molasses was added, there was a small decrease in energy use, which is favourable for the producer and the environment. When more molasses was added, the energy use increased, which is most likely due to the difference in stickiness of the additives and their associated lubricating effects. When 0.5 wt.% SSL was added, a small decrease in energy use was observed; when more SSL was added, the energy use remained at the same level.

The SSL pellets should be compared with no additive 3, and both exhibited a nearly continuous higher hexanal level than the other pellets (Fig. 5). As this difference was found both in the pellets with and without additives, it was considered to be an effect caused by the wood used in the pellet production process. There was no statistically significant difference with or without SSL, meaning that this additive did not increase the oxidation.

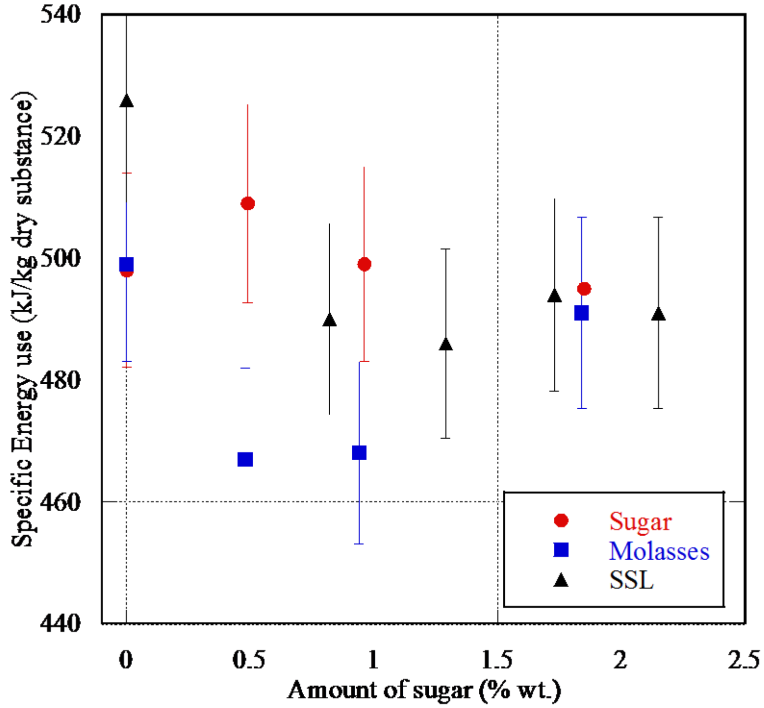


**Fig. 4.** Specific energy use with varying amounts of the white sugar, molasses, and spent sulphite liquor additives

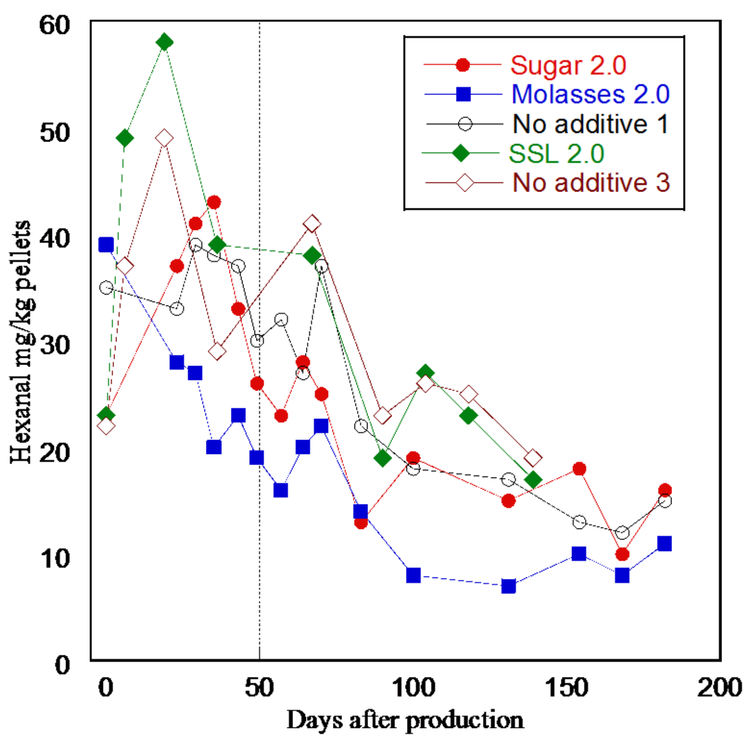


**Fig. 5.** Hexanal in pellets with no additives or white sugar, molasses, and spent sulphite liquor additives. No additive 1, Sugar, and Molasses were made on one occasion, No additive 3 and SLL another (same batch of sawdust but the pellets are produced at separate occasions)

Hexanal production peaked within the first two months and then decreased (Fig. 5). Approximately a third of the peak hexanal concentration remained after 100 days. The sawdust held a notable level of hexanal immediately after production (time 0), which implied that the fats in the wood were already oxidized to some extent. In other studies, hexanal production started at low levels, peaked 20 to 40 days after pellet pressing, and levelled off after 80 days, with a maximum level of 25 or 60 to 100 mg/kg (Granström 2010; Ståhl *et al.* 2012). Here, the sugar-added pellets peaked in the observed time of those studies, and pellets without additions peaked as well (except for an extra peak at 60 days). However, the molasses-containing pellets displayed an almost continuous decline. The peaks were within the previously observed concentrations, but the concentrations reached a plateau after 100 days. The high initial hexanal level was not due to the additives, as the pure wood pellets were also affected. Thus, this effect was due to the wood used.

The most interesting effect of the additives was the unusual shape of the hexanal plot of the pellets containing molasses. Hexanal is formed through the oxidation of fatty acids in a self-catalysing free radical chain reaction, and its concentration normally increases, peaks, and decreases as the radicals are neutralised. The effect of molasses in the pellets was consistent with the effect of antioxidants, which capture free radicals and stop their reactions. It has been observed previously that molasses has antioxidative properties (Valli *et al.* 2012). Because sugar cane molasses has a notably higher antioxidative effect than the sugar beet molasses used in this study, it would be useful to examine sugar cane molasses as an additive in wood pellets.

If sustainability, with regard to $CO_2$ emissions, food security, and competing land use when using pellet additives, is an important issue for researchers, companies, and governments then the industrial rest-product SSL should be chosen as an additive. It is preferable to molasses, which is used as feed, and sugar, which is used as food. In conclusion, SSL is the most favourable and recommended additive for the production of fuel pellets.

## CONCLUSIONS

1. Concentrations of 0.5 to 2 wt.% of white sugar, molasses, and spent sulphite liquor were added to wood sawdust, which was pelletized in an industrial scale pellet press. The resulting pellet quality, energy use, and extractive oxidation were evaluated.
2. All additives increased the bulk density and the durability of the pellets.
3. The energy use decreased when SSL and molasses were used as additives. For SSL, a small decrease was seen at 0.5 wt.%, but adding more SSL had no effect on the energy use. For molasses, a small decrease in energy use was seen for admixtures up to 1 wt.%, and adding more molasses increased the energy use. After adding white sugar, the energy use was practically unaffected.
4. The pellets stored for 182 days showed a small increase in durability. The oxidation of the wood extractives peaked after two months, and molasses seemed to have an antioxidative effect.

## REFERENCES CITED

Berghel, J., Frodeson, S., Granström, K., Renström, R., Ståhl, M., Nordgren, D., and Tomani, P. (2013). "The effects of kraft lignin additives on wood fuel pellet quality, energy use and shelf life," *Fuel Processing Technology* 112, 64-69. DOI: 10.1016/j.fuproc.2013.02.011

Goh, C. S., Junginger, M., Cocchi, M., Marchal, D., Thrän, D., Hennig, C., Heinimö, J., Nikolaisen, L., Schouwenberg, P. P., Bradley, D., *et al*. (2013). "Wood pellet market and trade: A global perspective," *Biofuels, Bioproducts and Biorefining* 7(1), 24-42. DOI: 10.1002/bbb.1366

Granström, K. M. (2010). "Emissions of hexanal and terpenes during storage of solid wood fuels," *Forest Products Journal* 60(1), 27-32. DOI: 10.13073/0015-7473-60.1.27

Kahl Group. (2015). "Wood pelleting", (https://www.akahl.de/en/products/pelleting-of-biomass/machinesplants/detail//show/ wood-pelleting/), Accessed 6 January 2016.

Kaliyan, N., and Morey, R. V. (2008). "Binding mechanisms of corn stover and switchgrass in briquettes and pellets," in: *2008 ASABE Annual International Meeting*, Providence, Rhode Island.

Kaliyan, N., and Morey, R. V. (2010). "Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switchgrass," *Bioresource Technology* 101(3), 1082-1090. DOI: 10.1016/j.biortech.2009.08.064

Kopetz, H., Haara, K., and Kummamuru, B. V. (2015). "WBA global bioenergy statistics 2015," World Bioenergy Association, (http://worldbioenergy.org/content/wba-launches-global-bioenergy-statistics-2015), Accessed 18 December 2015.

Kuokkanen, M. J., Vilppo, T., Kuokkanen, T., Stoor, T., and Niinimäki, J. (2011). "Additives in wood pellet production - a pilot-scale study of binding agent usage," *BioResources* 6(4), 4331.

Larsson, S., Lockneus, O., Xiong, S., and Samuelsson, R. (2015). "Cassava stem powder as an additive in biomass fuel pellet production," *Energy & Fuels* 29(9), 5902-5908.

Lennartsson, P. R. (2012). *Zygomycetes and Cellulose Residuals: Hydrolysis, Cultivation and Applications*, Ph.D. Dissertation, Chalmers University of Technology, Göteborg, Sweden.

Mani, S., Tabil, L. G., and Sokhansanj, S. (2003). "An overview of compatation of biomass grinds," *Powder Handling and Processing* 15(3), 160-168.

Mergner, S. (2014). "The dynamics of global pellet markets growth prospects and price scenarios," in: *4th Central European Biomass Conference*, Gratz, Austria.

Monteiro, E., Mantha, V., and Rouboa, A. (2012). "Portuguese pellets market: Analysis of the production and utilization constrains," *Energy Policy* 42, 129-135. DOI: 10.1016/j.enpol.2011.11.056

Nielsen, N. P. K. (2008). "The effect of LignoBoost kraft lignin addition on the pelleting properties of pine sawdust," in: *World Bioenergy Conference and Exhibition on Biomass for Energy*, Jönköping, Sweden, pp. 120-124.

Samuelsson, R., Larsson, S. H., Thyrel, M., and Lestander, T. A. (2012). "Moisture content and storage time influence the binding mechanisms in biofuel wood pellets," *Applied Energy* 99(), 109-115.

SS-EN 14774-1. (2009). "Solid biofuels – Determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method," Swedish Standards Institute, Stockholm, Sweden.

SS-EN 14961-1. (2010). "Solid biofuels - Fuel specifications and classes - Part 1: General requirements," Swedish Standards Institute, Stockholm, Sweden.
SS-EN 15103. (2010). "Solid biofuels – Determination of bulk density," Swedish Standards Institute, Stockholm, Sweden.
SS-EN 15210. (2010). "Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 1: Pellets," Swedish Standards Institute, Stockholm, Sweden.
Stelte, W., Sanadi, A. R., Shang, L., Holm, J. K., Ahrenfeldt, J., and Henriksen, U. B. (2012). "Recent developments in biomass pelletization - A review," *BioResources* 7(3), 4451-4490. DOI: 10.15376/biores.7.3.4451-4490
Ståhl, M., and Berghel, J. (2011). "Energy efficient pilot-scale production of wood fuel pellets made from a raw material mix including sawdust and rapeseed cake," *Biomass and Bioenergy* 35(12), 4849-4854. DOI: 10.1016/j.biombioe.2011.10.003
Ståhl, M., Berghel, J., Frodeson, S., Granström, K., and Renström, R. (2012). "Effects on pellet properties and energy use when starch is added in the wood-fuel pelletizing process," *Energy & Fuels* 26(3), 1937-1945. DOI: 10.1021/ef201968r
Tarasov, D., Shahi, C., and Leitch, M. (2013). "Effect of additives on wood pellet physical and thermal characteristics: A review," *ISRN Forestry* 2013, Article ID 87693. DOI: 10.1155/2013/876939
Thek, G., and Obernberger, I. (2004). "Wood pellet production costs under Austrian and in comparison to Swedish framework conditions," *Biomass and Bioenergy* 27(6), 671-693. DOI: 10.1016/j.biombioe.2003.07.007
Thek, G., and Obernberger, I. (2012). *The Pellet Handbook: The Production and Thermal Utilization of Biomass Pellets*, Routledge, London, UK.
Tondi, G., Wieland, S., Wimmer, T., Schnabel, T., and Petutschnigg, A. (2012). "Starch-sugar synergy in wood adhesion science: Basic studies and particleboard production," *European Journal of Wood and Wood Products* 70(1-3), 271-278. DOI: 10.1007/s00107-011-0553-z
Uasuf, A., and Becker, G. (2011). "Wood pellets production costs and energy consumption under different framework conditions in Northeast Argentina," *Biomass and Bioenergy* 35(3), 1357-1366. DOI: 10.1016/j.biombioe.2003.07.007
Valli, V., Gómez-Caravaca, A. M., Di Nunzio, M., Danesi, F., Caboni, M. F., and Bordoni, A. (2012). "Sugar cane and sugar beet molasses, antioxidant-rich alternatives to refined sugar," *Journal of Agricultural and Food Chemistry* 60(51), 12508-12515. DOI: 10.1021/jf304416d

Article submitted: December 18, 2015; Peer review completed: January 31, 2016; Revised version received and accepted: February 9, 2016; Published: February 17, 2016.
DOI: 10.15376/biores.11.2.3373-3383