Improvement of Wood Fuel Pellets Quality Using Sustainable Sugar Additives

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Abstract:

The production and use of wood fuel pellets, preferably made from sawdust or shavings, have increased significantly worldwide in recent years. The cost of raw material together with the energy demanding process of drying represents the main cost factors in pellet production. Efforts to decrease the energy used and the production cost as well as the environmental impact should proceed without affecting the quality of pellets negatively. One method to achieve this is to use additives. This work investigates how sugar and molasses affect the energy needed by the pellet press and the durability and oxidation of the produced pellets, both immediately after production and after 5.5 months of storage. The addition of sugar caused no effect on energy use and oxidation, but increased bulk density and durability. The addition of molasses caused a small decrease in energy use for admixtures up to 1 wt% but an increased energy use for admixtures of 1-2 wt%, increased bulk density and durability, and decreased storage oxidation. Stored pellets had a small increase in durability and their hexanal production peaked within the first two months.

Keywords:

Additives, Energy, Molasses, Sugar, Pellets.

1. Introduction

The use of dried and processed biofuels has increased significantly worldwide in recent years. In 2012, the estimated global wood pellet production reached almost 22 MT (million metric tonnes) and expected to reach 35 MT [1]. During the same year, more than 80 % of produced pellets were consumed in Europe, which made Europe the largest pellet consumer in the world and the market is still growing. The main reason behind this is the EU's 2020 targets for renewable energy sources. Based on these targets, the energy market experts expect the wood pellet market in Europe to grow to about 25 MT by 2020 [2, 3]. Wood fuel pellets, preferably made from sawdust or shavings, are used in large and small-scale applications. Due to increased trade and use of pellets by small-scale customers, an increased demand on pellet quality is likely to force pellet producers to improve upon pellet properties and broaden the raw material base.

Increased production leads to increasing competition within the worldwide pellet market, and increasing prices of raw material. This, together with anticipated rising prices of electricity, means that pellet manufacturers will have profitability difficulties since it is a low margin business. The raw material and the energy demand of drying represents the main cost factors in pellet production, together with personal costs [3-6]. Thus, it is important that all available raw materials can utilise resources efficiently, preferably to support sustainable development, and that the energy efficiency for pelleting processes increases.

A solution could be using a proper additive. The term additive is used for amounts of pressing aids up to a maximum amount of 2 wt. % of pressing mass [7]. Additives occur in the pellet industry and the most commonly used additives are starch, lignosulphonate, dolomite, corn or potato flour, and some vegetable oil [8]. The use of additives increases the possibility to broaden the raw material base, as well as to increase pellet quality and decrease the energy use during combustion, the latter has been shown in earlier works [9, 10].

Since ancient times, starch has been extensively used as a gluing agent. In plywood gluing tests and particleboard production, starch and sugar have shown synergic adhesive properties [11]. Using starch grade additives (native wheat and potato starch and oxidised corn starch) has shown that the durability of pellets increased while the electricity use of the pellet press decreased [12]. The oxidised corn starch showed the best result; when 2.8% of corn starch was added, the average electricity use was reduced by 14% [12]. Tarasov et al. [13] concluded that all types of starch increase the mechanical durability, but too much starch will make the final product dry which negatively affects the durability. Recently, it has also been reported from the industry that the overuse of additives, such as starch, can cause trouble during combustion, such as clogging. These issues have to be taken into consideration.

Instead of using an industrial produced product such as starch, it is possible to use a by-product like lignin. Berghel et al. [9] showed that Kraft lignin increases the mechanical durability and the length of pellets, and that dry lignin is preferable compared to wet.

Another type of additive that could be used for pellet production is different kinds of sugar and by-products from sugar production, like molasses. Molasses is not commonly used as an additive in wood fuel pellets; instead it is mainly used as an additive in animal feed or as a fermentation agent in feedstock. The sugar in beet molasses is predominantly sucrose, followed by glucose and fructose. Molasses is a viscous by-product of the processing of sugar beet and sugar cane into sugar. It is a thick opaque fluid from brown to dark brown in colour, with a smell that is peculiar to sugar beet molasses, with a sweet taste and a bitter aftertaste. It has complete solubility in hot and cold water. The main difference between beet and cane sugar molasses is that beet sugar molasses has a higher raw protein content. Additionally, sugar cane molasses has a notably higher antioxidative effect than sugar beet molasses does [14], which may affect the shelf-life and self-ignition risk of molasses-containing pellets, making it an interesting candidate as an adhesive.

This work investigates how sugar additives affect both the energy needed by the pellet press and the durability and oxidation of the produced pellets. The hypothesis tested is that the by-product molasses will be a superior additive compared to pure sugar, as the former contains both starch and sugars to enhance durability and also antioxidants to lessen oxidation. Further, both sugar and molasses ought to affect the energy use in the press positively.

2. Method

The raw material used for the production of pellets was fresh sawdust of 90% Norway spruce (*Picea abies*) and 10% Scotch pine (*Pinus sylvestris*) produced at a local sawmill that uses frame saws. The wet sawdust was dried in air in a belt dryer at a low inlet temperature of 75 °C until it reached 10% (wb). The sawdust was ground using a 5 mm sieve. The dried sawdust was conditioned to 10.9 and 13.0 ± 0.1% (wb) in the diagonal mixer by adding water to the appropriate moisture content. The sawdust was then stored in the diagonal mixer (by which the materials were completely mixed after 5 min) for 2 days to reach uniform moisture content.

Two different types of sugar products were used in this study: white sugar from Dansukker AB and molasses from Granngården AB. White sugar is regularly a consumer sugar. Its sucrose content is 99.9% and the water content of white sugar is 0.05%. Molasses is a viscous by-product of the refinement of sugar beets into white sugar. Molasses from Granngården AB, used as animal feed, has a sucrose content of 44%, a water content of 25%, a protein content of 9.8% and an ash content of 8.2%.

The pellets were produced in a production unit located at Environmental and Energy Systems at Karlstad University, Karlstad, Sweden (see Figure 1). It consists of (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 (a description of the machine can be downloaded from www.akahl.de/akahl/en/products/biomass_pelleting/), and (6) a volumetric feeder for additives and a cooling tower.

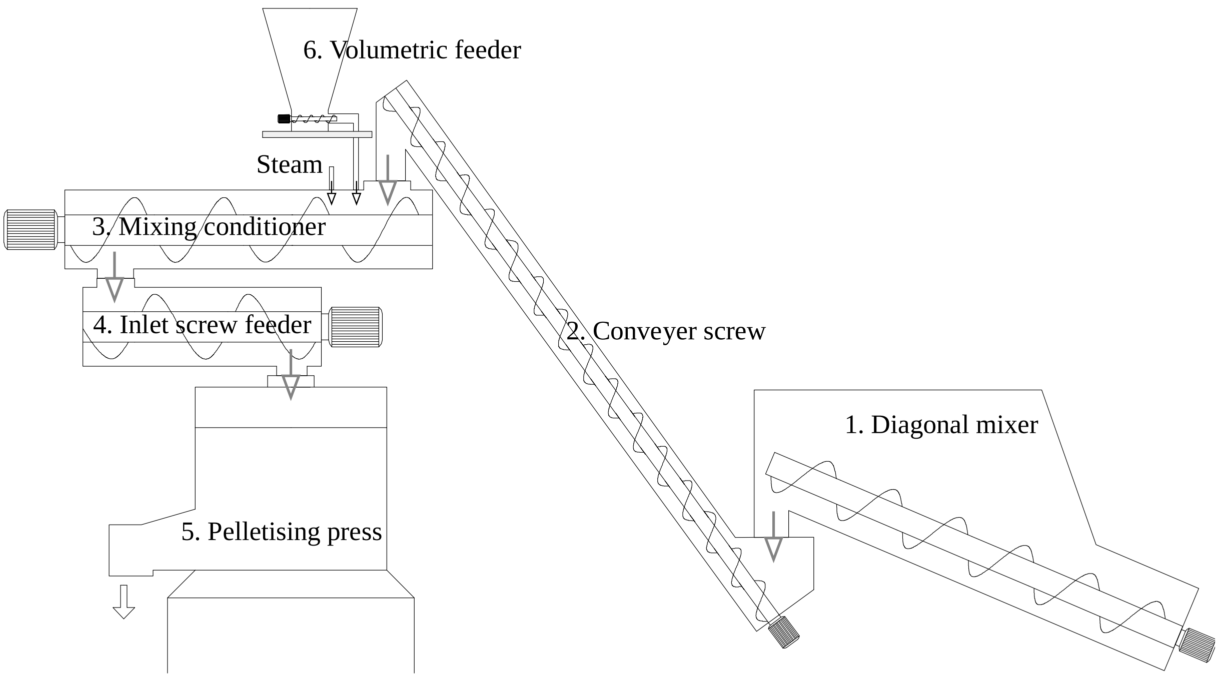

Figure 1. Pellet production unit at Karlstad University.

In the pelletising 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, which sums up to a total of 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 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 chosen to be 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. The volumetric feeder throughput depends upon the screw speed and the kind of additive. This means that the volumetric feeder has to be calibrated. The output for the additive was determined as a function of the frequency of the screw.

The continuous feed pellet machine was run until stationary conditions were obtained. Before every new test, there was a break-in period of 10 min. with the current additive 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 pressing mass dry bases. The additive moisture content for used assortments was 0.05% for white sugar and 25.0% for molasses.

During the test production of pellets, samples of approximately 300g of dried sawdust and conditioned sawdust were taken every 15 min., which resulted in a total of 10 samples. The moisture content of the cooled pellets was examined by taking 1 sample from each 5 min. test, i.e. a total of 8 samples.

To study the effects of the sugar and molasses on the pellets during storage, the pellets were stored for 5.5 months. The extent to which storage affects pellets with and without sugar and molasses with reference to amount of hexanal formed and durability was examined. Of these properties, durability is included in the European standard. The shelf life was gauged by analysing the amount of hexanal formed during storage, as the formation of hexanal signifies the oxidation of fats.

During the tests, die temperature, screw frequency, current consumption of the pelletising machine and pressure from the rollers on the die (“die pressure”) were measured every 10s. The die temperature was measured using Pt-100; the error in the measurements is ±0.5 °C. The current load was measured with an accuracy of ±1%. The pressure from the rollers was measured with an accuracy of ±1.25 bar. The die temperature and the pressure from the rollers indicate stationary and stable conditions.

The test sample for pellets was separately cooled to ambient room temperature in a box with a perforated bottom. The test sample was sieved, before being analysed. The analysis was performed by testing and comparing the produced pellets with the quality parameter settings in the Swedish and/or European standards. The tested parameters were: moisture content (%, wb) for sawdust and pellets determined according to SS-EN 14774-1,28; bulk density (kg m^{-3}), determined according to SS-EN 15103:201029 by measuring the weight of a 5 L bucket filled with cooled pellets; mechanical durability, determined according to SS-EN 1521030 presented as the percentage of pellets; hexanal, determined by static headspace gas chromatography (SHS-GC)by heating 0.5-0.6 g pellets with 5 ml water in a 10-ml sealed vial in 80°C for 30 minutes and injecting 0.5 ml of the headspace gas into a GC-FID; a Clarus 480 fitted with a capillary column (J&W Scientific, DB5-MS, 30 m x 0.25 mm) with the temperature program 40 °C for 2 min., 15 °C/min., 70 °C for 5 min., 15 °C/min., and 200 °C for 7 min, using helium as the carrier gas and the detector set to 200 °C.

If the statistical error was not stated in the standard, it was commented on in the data/results in each section. The error of measurement was used for specific energy use, material flow and moisture content. The standard deviation was used for load current. For pellet length, bulk density and durability, the significance of the results were tested with a t test, where $\alpha = 0.05$. For hexanal formation, the coefficient of variation was 30% for duplicate analyses though the coefficient of variation for this SHS-GC method has previously been determined as 11% [15].

From the current measured load, the average power consumption and average energy consumption for alternating currents were calculated according to the method described in a previously published study conducted at Karlstad University [12].

The pellets were stored in a controlled laboratory setting to avoid undue influence of the temperature and humidity fluctuations. They were kept indoors in unclosed black plastic bags at 18 °C and at about 55% humidity, protected from direct light. Pellets with 2% sugar, 2% molasses or no additive at all, were analysed for hexanal content after an initial three weeks and then every week during the first 70 days then less often until the experiment was terminated after 182 days of storage. The durability of pellets with 0, 0.5, 1, or 2% of sugar or molasses added was tested, both immediately after production and after 182 days of storage.

3. Results and Discussion

It is clear that the addition of white sugar and molasses before pelletising sawdust of 90% Norway spruce (*Picea abies*) and 10% Scotch pine (*Pinus sylvestris*) affects the cohesiveness of the pellets, which is confirmed by higher bulk density and increased durability. The results from the tests are summarised in Table 1, which shows the results from the logged data on the pellet machine and the outlet moisture content of the pellets.

Durability increased with increased amounts of white sugar and molasses (Figure 2). Pellets with no sugar added had not passed the demands in the standard. The strength after 182 days of storage showed a small but significant improvement. Water also work as a binder and strengthen durability, but in this test series, the water content in the inlet material and in the produced pellets was almost constant, see Table 1, which removes water content as a variable. The differences in strength must be sought in bonding mechanisms affected by sugars in the pellet process. Further work towards finding an optimal sugar mixture is likely to lead to further improvements in pellet durability. Molasses is an alternative when the goal is to minimise the problems during usage.

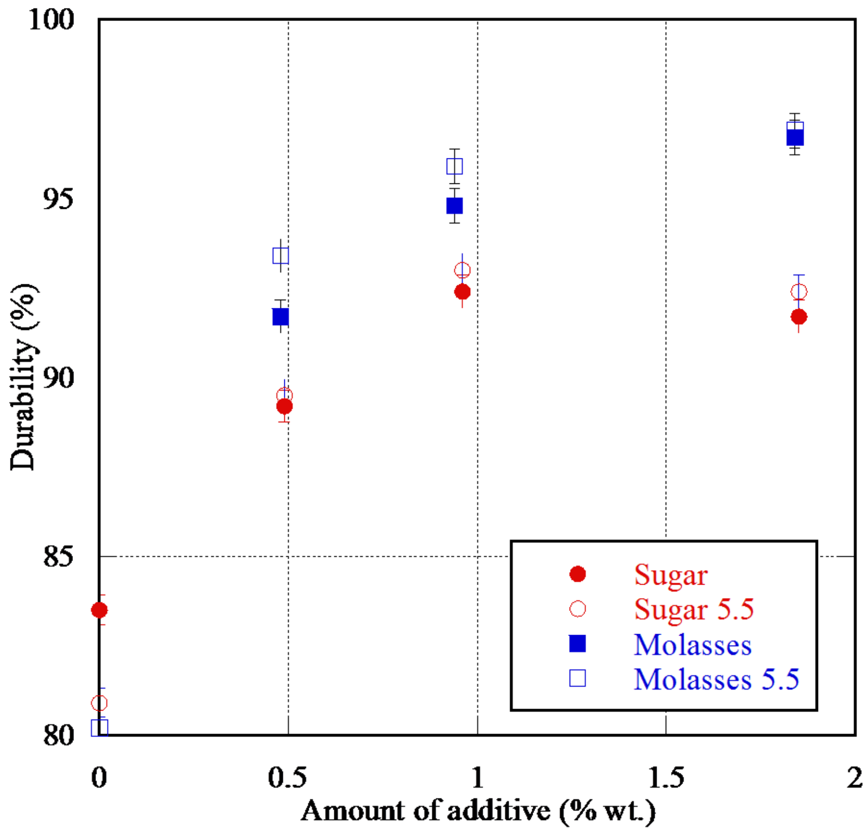

Fig. 2. Durability for varying amounts of additives, directly after production and after 5.5 months.

Bulk density increases when the amount of sugar and molasses are increased (Figure 3). Molasses had the largest increase in bulk density. There was, however, a large uncertainty in the measurements.

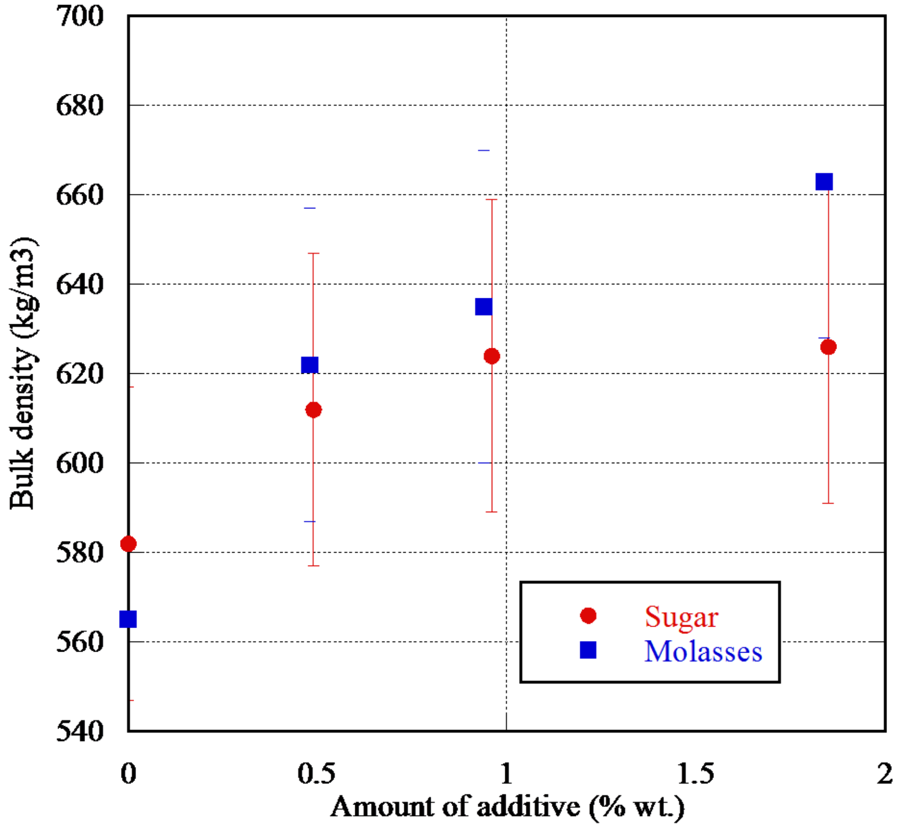

Fig. 3. Bulk density at varying amounts of additive.

Earlier work shows that the use of additives affects the energy use in the press. As seen in Figure 4, sugar used as an additive has no effect on energy use. With the addition of molasses, a small decrease in energy use was seen for admixtures up to 1 wt. %, which is favourable for the producer and the environment, but if more molasses is added, the energy use of the press increases. The different properties of the additives regarding stickiness and lubricating effects thus manifest in the energy use for pellets enriched with varying amounts of molasses.

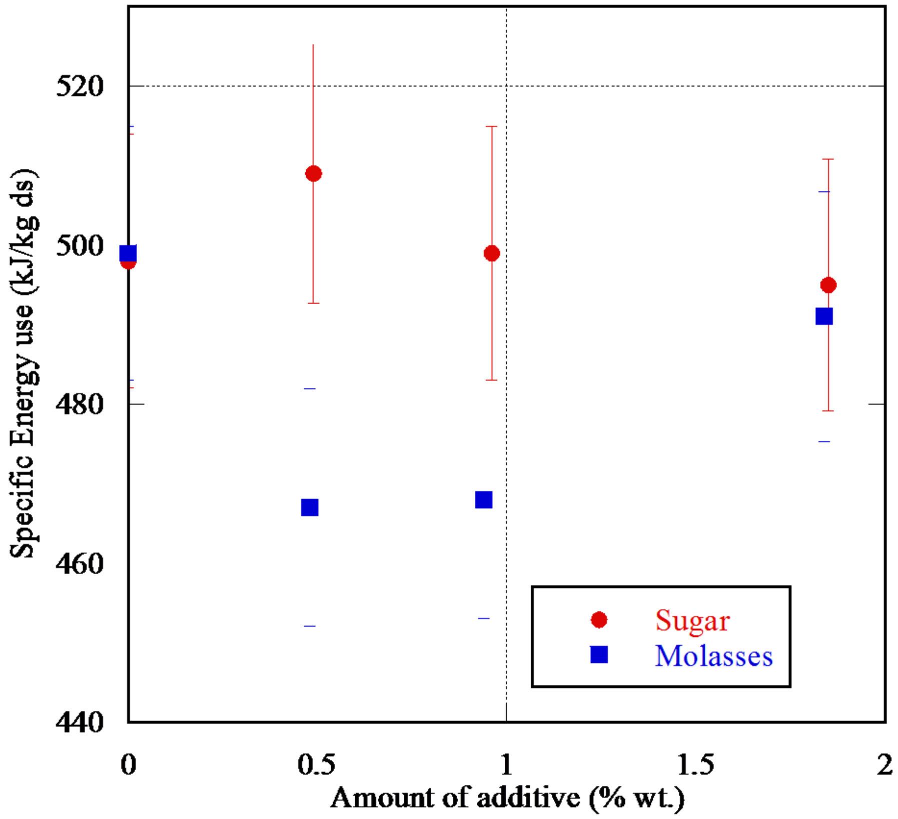

Fig. 4. Specific energy use versus the amount of additive.

Table 1. Results from pellet tests and measured data during pellet production. MC=moisture content. DS=dry substance.

Test run	Amount of additve (%)	Load current (A)	Pellet MC (%, wb)	Inlet MC (%, wb)	MC after mixer (%, wb)	Material flow (kg of DS/min)
0-test 1	0.0	20.8	6.3	10.9	13.5	1.37
Sugar	0.49	22.1	6.7	10.9	13.5	1.43
Sugar	0.96	22.2	6.2	10.9	13.5	1.46
Sugar	1.85	22.8	5.9	10.9	13.5	1.52
0-test 2	0.0	20.8	6.3	10.9	13.5	1.38
Molasses	0.48	20.7	6.5	10.9	13.5	1.46
Molasses	0.94	21.2	6.4	10.9	13.5	1.49
Molasses	1.84	22.8	5.9	10.9	13.5	1.53

The hexanal production peaks within the first two months and then tapers off (Figure 5). Approximately a third of the peak hexanal concentration remains after 100 days. The sawdust held a notable level of hexanal right after production, at time 0, which implies that the fats in the wood were already oxidised to some extent.

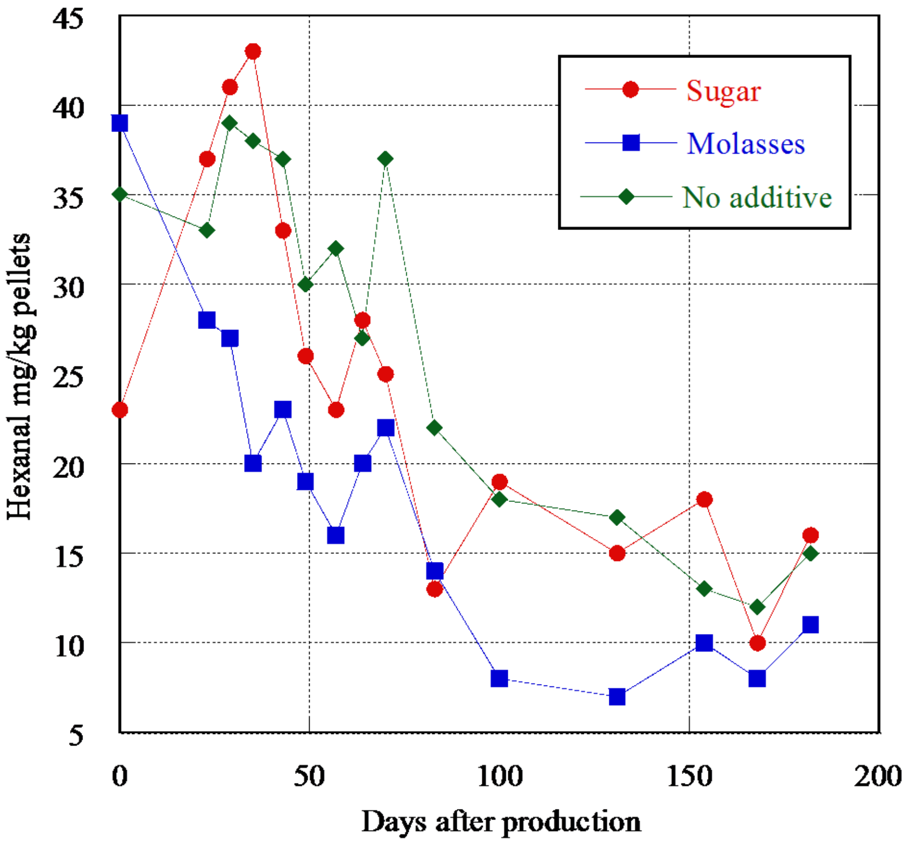

Fig. 5. Hexanal formed over time.

In other studies, hexanal started at low levels, peaked 20-40 days after the pressing of pellets and then levelled off after 80 days [15, 16], with a maximum hexanal level of 25 [15] or 60-100 mg/kg [16]. Here, sugar 1.85% peaked at the previously observed time, just as 0-test 2 did except for an extra peak at 60 days, but molasses 1.84% displayed an almost continuous decline. The peaks are within previously observed concentration ranges. The hexanal concentrations reached a plateau after 100 days after which no further decline occurred. The high initial hexanal level was not due to the additives, as the pure wood pellets were also affected, and can thus be considered an effect of the sawdust used.

The most notable effect of the additives chosen was the unusual shape of the hexanal plot of the pellets containing molasses. As hexanal is formed through the oxidation of fatty acids, a self-catalysing free radical chain reaction, its concentration would normally increase, peak, and then decrease as the radicals were neutralised. The effect of molasses in the pellets is consistent with the effect of antioxidants, which should capture free radicals and thus stop radical reactions. It has been observed before that molasses has antioxidative properties. As sugar cane molasses has a notably higher antioxidative effect than the sugar beet molasses used in this study, it would be valuable to examine the effect of using sugar cane molasses as a pellets additive.

4. Conclusion

Sugar and molasses has been added by 0.5–2 wt. % in wood sawdust before pelletizing in an industrial scale pellet press. The pellet quality, energy use and hexanal production were evaluated. Sugar and molasses as additives in wood pellet production increases the bulk density and the durability of the pellets. When molasses is added, a small decrease in energy use is seen for admixtures up to 1 wt. %.

The storage of pellets also shows a small increase in durability after 182 days and that the hexanal production peaks within the first two months and then tapers off.

The use of the additive is a solution to produce more durable pellets. But adding an additive always entails an increased cost of production and therefore other cheaper alternatives must be evaluated. When using additives in pellet production, researchers as well as companies and governments, must take sustainability aspects into consideration, e.g., effects that the use of additives has on the climate, food security and competing land use. That is why molasses, which is a by-product, are preferred compared to sugar as additives in the production of fuel pellets.

5. References

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