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Utilization perspectives of wood and bark of the invasive species of Ailanthus and Acacia in the production of pellets

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Abstract

Energy production has always been an issue of major importance to humanity, as it is considered to be crucial for its existence and development. The species of acacia (*Robinia pseudoacacia* L.) and ailanthus (*Ailanthus altissima* (Miller) *Swingle*) are both fast growing, of low requirements in water, air temperature and soil nutrients and tend to be invasive to habitats of various conditions. Consequently, these two species could potentially contribute to forest and wooden biomass generation and be utilized in solid biofuels production, which is part of our national commitment to Europe (Directive 2003/30/EK, Kyoto Protocol etc.). More specifically, in this research work, wood and bark material of ailanthus and acacia are examined, in order to investigate the most crucial thermal characteristics of them, referring to higher heating value (HHV) and ash content, and therefore clarify the potential of their use as raw material in pellets production. Different ratios of the studied wood species in mixture are examined, in order to investigate the material ratio that provides satisfying calorific value, while at the same time fulfills the requirements for low ash contents of the standard (ISO 17225-2) for pellets production.

Keywords: ailanthus, biomass, energy, heating value, pellets

Introduction

In recent years, especially the last decade, the use of wood pellets for energy and electricity generation has increased worldwide, as well as in Greece. Pellets consists a form of standardized biological fuel for the preparation of which, no use of adhesives or chemical additives is being involved, only high pressure steam, which makes them totally environmentally friendly (Bergman and Zerbe, 2004). The only substance that acts as an adhesive for the final product after hot compression is lignin. The product formed is characterized by high consistency, low moisture content (<10%), up to 1% ash (ISO 17225-2 domestic) and high density (> 650 kg / m^3), which allows combustion and high heating of the yield (4063-4541 kcal / kg) (Wu et al., 2005).

The calorific value varies between forest species and between regions of the same species and factors such as soil fertilization, the growth density, species, moisture and ash, determine the energy value obtained from the material (Voipio and Laakso 1992). Therefore, the investigation of the thermal characteristics of different species seems to be of great importance for understanding their behavior and their proper use as biofuels.

Acacia

As the demand for wood and wood products are increasing worldwide in recent years, the research above wood utilization of fast-growing species such as acacia intensifies. Because of the excellent physical and mechanical properties of wood and its suitability for numerous uses, acacia attracts the interest. It is used in furnishings, replacing other species traditionally used in the past, and it is applied in the manufacture of upholstered furniture, covering in that way the color variations of its surface. It is suitable for the production of floor parquets, due to its high hardness, wooden frames, linings, partitions/spacers, beams, bridge supports, pallets, sleepers, but also as laminated timber, first of all because its logs are usually small in diameter having defects and when these defects can be removed, products and structures of high added value could be produced, while secondly the wood exhibits very satisfying adhesiveness. Acacia wood, which is unsuitable for structural uses can be used as biomass for energy production, or be channeled as a raw material in the production of welded products.

The wood of the acacia has a high calorific value. It has narrow pores and high density, so fire spreading takes place at a relatively low speed. The properties of wood make it also ideal for the production of pellets and for this purpose, it is demanded in very large quantities by the production plants. The heat produced by the acacia wood combustion seem to be of great intensity, with radiation energy, and occasional squeaks (Keresztesi 1988). Therefore, acacia is suitable for charcoal and firewood, but also suitable for raw material for the production of more complex solid biofuels and energy (Adamopoulos et al. 2007). It exhibits good ignition even when the wood has high moisture content. These advantages of acacia combined with its fast growth, especially in younger age, have led to the establishment of experimental plantations of acacia for biomass production. Stringer and Carpenter 1986 refer that plantations of acacia can be used for this purpose, because acacia has an intensive growth at an early age, especially in poor and barren soils and vigorous proliferation. The existence of large areas of acacia cultivation in the poor soils (mines, etc.) points out the usefulness of these of short rotation crops (2-10 years), as an alternative source of energy (Adamopoulos and Voulgaridis 2003). According, also, to Converse and Betters (1995), who calculated biomass yield equations of the species in intensive cultivation plantations of short rotation, taking into account climatic and soil factors and management measures, acacia is suitable as an alternative crop for biomass production through the establishment of intensive crop plantations of short rotation, due to the resistance against drought, rapid growth and its ability to bind nitrogen. Acacia can combine a small (<20 years) or medium (30-60 years) short rotation period, depending on the purpose of plantation (biomass, firewood or technical wood).

Biomass production in short rotation of acacia plantations depends on many factors, most important of which is the origin, variety or clone, planting pattern, the experimental design (pure or mixed plantations), the type of planting material (seedlings or cuttings, dimensions of crops, milling, fertilization, irrigation, plant protection, dilution), as well as soil and climatic conditions. The biomass production of acacia has been reported to vary between species, varieties and clones with a large production (dry weight), ranging from 8 to 35 tns / ha / year, depending on the number of trees / ha, local conditions and cultivation care.

Ailanthus

Ailanthus altissima (Miller) *Swingle* = A. glandulosa Desf. = A. peregrine = Toxicodendron altissimus Mill.), a native species of China and Oceania, was originally transported to France in the 1740s and a few years later in England (1751), as well as several European countries. In North America it was transferred in 1784 (Kowarik and Saumel 2007). In Greece, it seems that it was first moved by Othonas to the royal garden of that times, which now is the national garden. The species is commonly known as tree-of-heaven. In China ailanthus is traditionally used in medicine, its foliage is used in breeding of silkworm and its wood as a timber for various constructions and as firewood. In the rest of the world, it was initially transported as a decorative species and was placed in parks, squares, tree trunks, etc., despite the fact that its disadvantages were very soon discovered.

It grows very easily with seeds and grows even in poor and barren soils, in the zone of broadleaf leaves and in the warmer area of deciduous trees up to 1000 m altitude in Europe. It is a fast growing species (considered to be the most fast-growing species of North America) and is very easy to be installed in residential areas, as it withstands high atmospheric pollution (Kowarik and Saumel 2007). In the landlocked European countries it has been established in residential areas and is considered to be the most frequently occurring non-native tree-species, as in the wider area of the city of Thessaloniki (Krigas and Kokkini 2004). Because of its ease of installation and the aggressiveness of its root system, it causes damages to foundations, archaeological sites, etc., is considered to be a weed and undesirable species in residential areas (Faseas 2008). Since 1950, several ailanthus plantations have been established in various European countries, mainly for the protection of arid, heavily corroded, places of sloping land and slopes of streets disturbed by mining soil activities (Austria, Russia, etc.) forestry and afforestation (Czech Republic, Hungary, etc.), and less in the silkworm breading and the production of honey (France) (Kowarik and Saumel 2007). At the same time, research is being carried out in various countries (USA, Australia, India, etc.) on the possibility of using ailanthus in biomass plantations (of short rotation from 2 - 5 years) and its use in multi-purpose agro-forest systems (Kowarik and Saumel 2007, Tsiontsis 1997, Demirbas 2001).

Nowadays, ailanthus has a commercial value only locally, used in woodworking, in case furniture, in wooden houses construction and as firewood in North America, in shipbuilding, toys, and especially in the match industry in India and as firewood and pulp and paper production in several countries (Gurney 1987, Kumar et al. 2001, Alden 1995, Kowarik and Saumel 2007). The sapwood of ailanthus is yellowish and the heartwood appears to be from yellow till greenish. It can be easily dried, treated, glued and finished and exhibits attractive designs on radial and tangential surfaces (Gurney 1987). Some physical and mechanical properties of ailanthus wood were studied by Moslemi and Bhagwat (1970), its chemical composition was studied by Demirbaş (2001), as well as its heating value and behavior as a fuel (1997). Ailanthus wood was found to respond satisfactorily to wood pulp production and successfully to the production of particleboards and fibreboards (Moslemi and Bhagwat 1970). The separation of lignin from the wood, in order to produce wood pulp was studied by Kucuk (2005).

The purpose of the specific research work was to study the basic thermal characteristics of acacia and ailanthus wood species and the bark material of these species, knowledge of which is essential for their utilization in the production of solid biofuels (pellets).

Methodology

The research material consisted of three (3) individual native trees of *Ailanthus altissima* (Mill.) *Swingle*, 11, 13 and 14 years old, and 3 trees of *Robinia pseudoacacia* L., 15-20 years old, harvested from the Botanical Garden of Finikas in Thessaloniki (Faculty of Forestry and Natural Environment) (Greece). The material obtained from the bottom of the logs was used to prepare the specimens, from the base till the breast height. Initially, pieces of 5 cm thickness were shaped, using parallel sawing process, which remained in a sheltered place to dry naturally. The material was then left to a room at the temperature of 20°C and a relative humidity of 65%, i.e. in order to simulate to a moisture content of about 10%.

The raw materials were crushed with the help of a "Chipper" portable crusher (Figure 1). The dimensions of the pieces were reduced to a representative sample of about 0.5 kg. Additionally, all the materials were gently dried for at least two weeks in a ventilated chamber at 60 ± 1 °C until a constant mass (humidity up to 4-5%) and milled using a Wiley mill with a 0.7 mm sieve.

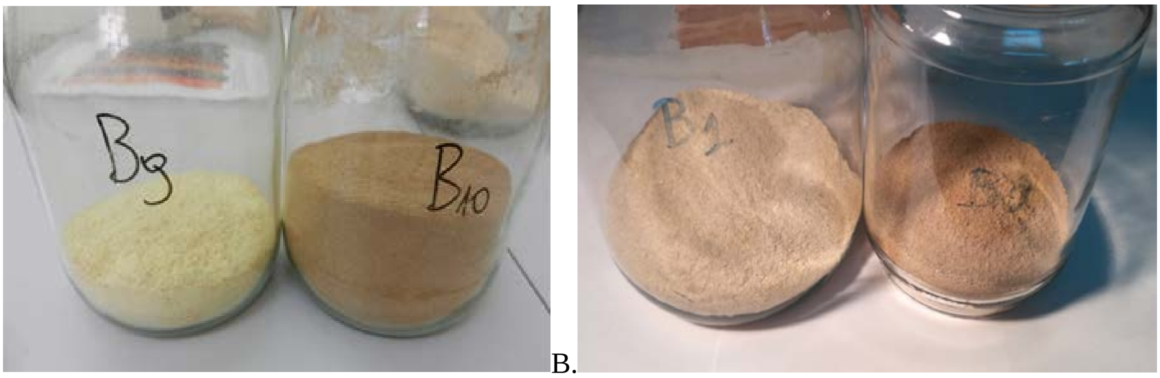
A
B.

Figure 1 A. Sawdust material of acacia wood on the left and bark on the right, B. Ailanthus pure wood on the left and bark material on the right

For the determination of ash, the methodology of EN14775: 2010 was used. To ensure complete incineration, the process was repeated until the mass changes were <0.2mg. The ash content on a dry basis was calculated according to equation (1):

$$Ad = \frac{m_3 - m_1}{m_2 - m_1} * 100 \qquad (1)$$

,where Ad is the ash content (%), m_1 is the mass of the empty crucible (g), m_2 is the mass of the crucible plus the dried test sample (g) and m_3 is the mass of the crucible plus ash (g).
The ash measurements were carried out in 3 replicates for each material.
Moisture content was determined according to EN 14774-3:2009. The calorific value was expressed with Higher Heating Value (HHV), which is the absolute value of the specific energy combustion, in joules per unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under specified conditions. HHV was determined in a Parr 1261 isoperibol bomb calorimeter, according to the method described in the European Standard EN 14918:2009 (Figure 2). Sample pellets with mass of 1.0 ± 0.1 g and diameter of 13 mm were produced using a hydraulic pellet press applying a load of about 7t for 1min. The pellets were weighed to the nearest 0.01 g in a crucible and then placed inside a Paar 1108 oxygen combustion bomb in contact with 10 cm of pre-weighed platinum ignition wire. The bomb was subsequently charged with oxygen (purity of 99.7 %) at 30 ± 2 bar and submerged in a stainless steel bucket containing 2000.0 ml of distilled water. Prior to filling the bucket, the water was conditioned in a waterbath at 33 ± 0.5 °C. The calorimeter jacket was maintained at constant temperature by circulating water at 35 °C to maintain slightly higher temperature than the final temperature of the calorimeter and assure that evaporation losses were minimized. The HHV measurements were carried out in 6 replicates for each material. Prior to beginning the above measurements, the calorimeter was calibrated and validated with 6 individual calibration runs using benzoic acid pellets. HHV values were expressed in kcal/kg. Sulphur and chlorine adjustments were not carried out because they are present in low concentrations in wood fuels (Lehtikangas 2001).

Figure 2 A. Pellet press with its accessories, B. Parr 1261 isoperibol bomb calorimeter

Afterwards, a theoretical estimation of the fuel characteristics of pellets produced from the selected species was implemented. This was based on the bark and wood ash content as well as the calorific values that had been determined, taking into account the various barked stem diameters of the raw materials. Hence, the following equations (2, 3) were used:

$$ASH = a_1 \frac{z}{100} + a_2 \frac{100 - z}{100} \qquad (2)$$

,where ASH is the total ash content (%), Z is the bark percentage (%), a_1 is the ash content of bark (%) and a_2 is the ash content of wood (%).

$$HHV = b_1 \frac{z}{100} + b_2 \frac{100 - z}{100} \tag{3}$$

,where HHV is the total HHV (kcal/kg), b1 is the HHV of bark (kcal/kg) and b2 is the HHV of wood (kcal/kg).

Mean values were compared with ANOVA (α = 0.95, LSD) using SPSS Pasw statistics 18, while the graphs were created in MATLAB 2016a.

Results and Discussion

According to the results (Table 1), both wood species revealed quite satisfying level of higher heating value (HHV), fulfilling the energy quantity requirements, specified by the standard ISO 17225-2 (ISO 18125). These values were not found to differ significantly between one another. The material of bark presented higher heating value, compared to the corresponding values of pure wood, concerning both of the species studied. Specifically, bark of ailanthus was found to have 2.20% higher HHV than the respective value of ailanthus pure wood, while the bark of acacia was found to be 11.11% of higher heating value compared to acacia wood.

Table 1 Thermal characteristics of acacia and ailanthus species

Property		**Ailanthus**		**Acacia**	
		Wood	**Bark**	**Wood**	**Bark**
ASH (%)	**mean**	0.69%	7.69%	1.40%	7.03%
	SD	0.07%	0.06%	0.04%	0.12%
	CV	10.67%	0.82%	2.89%	1.69%
	n	3	3	3	3
HHV (kcal/kg)	**mean**	4308.82	4403.66	4226.24	4695.93
	SD	2.57	14.07	12.20	13.11
	CV	0.06%	0.32%	0.29%	0.28%
	n	6	6	6	6
LHV (kcal/kg)	**mean**	2958.70	3076.92	2876.12	3369.19
	SD	2.57	14.07	12.20	13.11
	CV	0.09%	0.46%	0.42%	0.39%
	n	6	6	6	6

The ash content values of both species was found to be very low, with ailanthus to exhibit the lowest content value (0.69%) and acacia higher value (1.40%), which corresponded to a statistically significant difference. Ash content value of ailanthus fulfilled the ash content requirements of the best quality class EN plus A1 of the standard ISO 17225-2, referring to pellets production, for residential use, while the ash content of acacia makes this species suitable to fulfil the requirements of quality class EN plus B for residential use. As it was expected, the bark material coming from both species demonstrated very high ash content values, compared to pure wood and as a result, they did not meet the ash content requirements of the categories for residential, not even for industrial uses (class I3) of the respective standard. Specifically, bark of ailanthus was found to have 1014.5% higher ash content value, compared to the respective value of ailanthus pure wood, while the bark of acacia was found to have 402.1% higher ash content compared to acacia pure wood.

Generally, the ash content consists one of the most significant thermal characteristics of a fuel, since it is very crucial for the proper function and the maintenance of the heating equipment (boilers etc.), as well as the convenience of the user.

According to Table 2, where several mixture proportions of the studied materials were investigated, the participation of ailanthus bark by 5-15% as raw material in pellet production, mixed with ailanthus wood (85-95%) would yield an ash content low enough to fulfil the requirements of quality class EN plus B for residential use, while a 20-25% participation of bark categorizes the material into the quality class I3, which corresponds only to industrial uses. Similarly, the participation of acacia bark till the percentage of 10% in the raw material of pellet, in mixture with acacia pure wood (at least 90%) would ensure the fulfillment of the quality class EN plus B requirements for residential use, while a participation of bark by 15-25% would categorize the material in quality class I3. Additionally, by mixing all the materials studied in this research, in a ratio of 45% ailanthus wood, 5% ailanthus bark, 45% acacia wood, 5% acacia bark or in a ratio of 65% ailanthus wood, 5% ailanthus bark, 25% acacia wood, 5% acacia bark, the ash content of the pellets produced would be low enough to fulfil the specifications of quality class EN plus B of the respective standard for residential use.

Table 2 Ash content (%) estimation of different mixture proportions of the studied materials

Ailanthus		Acacia		ASH (%)
Wood	Bark	Wood	Bark	
95	5	-	-	**1.04**
90	10	-	-	**1.39**
85	15	-	-	**1.74**
80	20	-	-	2.09
75	25	-	-	2.44
-	-	95	5	**1.68**
-	-	90	10	**1.96**
-	-	85	15	2.24
-	-	80	20	2.53
-	-	75	25	2.81
45	5	45	5	**1.68**
65	5	25	5	**1.53**

Consequently, the bark material of ailanthus and acacia should not be used as raw material of biomass in pellets production by themselves, but only under the term of a small percentage participation, in combination with the presence of pure wood of these species that presented low enough ash contents or other species of similar ash contents.

Conclusions

Acacia and ailanthus are two commonly found, fast-growing hardwood species of very satisfying physical and mechanical properties that can be utilized, according to the results of this research, also in the production of solid bio-fuels (pellets, briquettes etc.). Both wood species presented high enough HHV (kcal/kg), that fulfil the energy quantity requirements, specified by the standard ISO 17225-2, and parallel quite low ash content values (%), especially the wood of ailanthus species (0.69%). Ash content value of ailanthus fulfilled the ash content requirements of the best quality class EN plus A1 of the standard ISO 17225-2, referring to pellets production, for residential use, while the ash content of acacia makes this species suitable to fulfil the requirements of quality class EN plus B for residential use. Therefore, the involvement of acacia or ailanthus wood in pellets material could greatly increase the calorific value of the solid biofuel, maintaining the ash content of the fuel in low enough levels. The bark of both species presented so high ash content values, that they could not be used as biofuels by themselves, but only if they are involved in specific mixture proportions with material of pure wood, characterized by significantly lower ash contents, in order to achieve biofuel of the highest heating value and the lowest possible ash content. Specifically, the utilization of ailanthus bark in a participation till 15% mixed with pure ailanthus wood, as well as the involvement of acacia bark in pellet production material with a maximum participation of 10% mixed with pure acacia wood would result in the fulfillment of EN plus B class requirements (in ash content) for residential uses. Bark of both species could participate maximum at the percentage of 25% mixed with pure wood in the production of pellets for industrial use.

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