A feasibility to utilize wood of low-value deciduous species in charcoal production

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The feasibility of low-value deciduous tree species grown in Latvia as well as their wastes and wood residues for charcoal production has been assessed. The composition and yield of charcoal and liquid products of wood pyrolysis, depending on the species, vegetation conditions and tree anatomical elements, have been determined. The effect of charcoal properties (density, compression strength) upon its applicability has been studied. Factors affecting the yield and composition of pyrolysis products have been discussed.

Key words: vegetation conditions, pyrolysis, charcoal, liquid products of pyrolysis.

Introduction

Charcoal production in Latvia in which deciduous tree species are mainly used, producing lump charcoal with lump sizes of 4 to 8 cm for use in household, restaurants and the recreation industry, has been recently under dramatic development. The produce is exported mainly to the Western Europe, and only less than 10% of it is realized on the local market. In traditional charcoal production, broad-leaved tree species (e.g. beech and birch) are used. This was connected with charcoal utilization in industry, where its density and mechanical strength were most important. For barbecue charcoal, these properties are not strictly regulated, therefore, it is possible to use also deciduous tree species, thereby extending the raw material base.

After Morozov (1979), bushes and underwood comprise 68%, alder 13%, birch 5%, bird-cherry tree and 2% osier, aspen, rowan-tree and other wood species used mainly as firewood, not finding other applications, which makes their procuring unprofitable. Similar problems arise in case of felling residues such as branches and topwood as well as hardwood sawmilling residuals. Therefore, charcoal production could be one of the solutions to this problem, simultaneously increasing the feasibility of utilizing wood. In the literature, data on charcoal yields from the most applicable tree species, i.e. birch, Norway spruce and Scots pine are mainly available, although data on low-value deciduous tree species are scarce. Therefore, it was important to establish the wood pyrolysis product yields of these species as well as the properties and quality of charcoal obtained, depending on the tree anatomical elements used and vegetation conditions to assess the suitability of these tree species, less in demand, for charcoal production.

Materials and methods

Wood of appropriate deciduous tree species such as birch (*Betula pendula*), grey alder (*Alnus incana*), bird-cherry tree (*Padus avium*), aspen (*Populus tremula*), willow (*Salix caprea*), rowan-tree (*Sorbus aucuparia*) for experiments was procured in the Cesis district, the civil parish of Rauna, by felling growing undamaged trees as well as utilizing decayed wood (marble rot-damaged birch wood and dry rot-damaged alder wood) from stacks of firewood. The wood was sampled in two essentially different vegetation conditions, i.e. uplands forest site type (birch grove) and wet peat site type (bog-land) ones. From debarked wood samples, small blocks with sizes of 2x2x2 cm were prepared, which were dried to a relative moisture content of 6 to 8%. The wood samples were pyrolysed in a 2 L laboratory retort with electric heating, equipped with a vapour-gas outlet, which is connected with a condenser. The temperature was measured in the retort centre with a thermocouple, simultaneously regulating the heating so that the average heating rate did not exceed 2°C/min until a final temperature of 500°C was reached.

The charcoal obtained was evaluated according to the methods specified in the German Standards DIN 51718, 51719 and 51749, while the liquid products were analysed as described by Sprince, Zhurinsh, Zandersons (1997).

The longitudinal crushing strength was determined for charcoal regular prism-shaped specimens without visible defects. The apparent density of the charcoal samples was determined according to the method suggested by Bronzov, Vasilevskaja (1973), preliminary drying them until an oven dry condition was reached.

Table 2. Qualitative characteristics for charcoal obtained

Tree species	The moisture content (%)	Volatiles (%)	The ash content (%)	Fixed carbon (%)
Birch	1.08	13.20	0.75	86.05
Decayed birch	3.11	13.08	0.80	86.12
Alder	3.73	14.02	0.80	85.18
Decayed alder	2.24	15.26	1.01	83.73
Bird-cherry tree	3.92	15.85	1.05	83.10
Aspen	2.02	15.54	0.84	83.62
Willow	1.86	11.11	1.13	87.76
Rowan-tree	2.96	17.12	0.89	81.99

Results

The yield of the charcoal and liquid products obtained as well as the volatile condensable products eduction rate depending on temperature, as a result of pyrolysing the above mentioned deciduous tree species, are represented in Table 1. No essential differences were observed for the charcoal yield, since the highest charcoal yield, i.e. 31.49%, was observed for birch, and the lowest one, i.e. 29.01% for aspen. At the same time, the difference in the liquid products yield for undamaged and decayed wood was by far higher, i.e. 51.8% and 45% for alder. Qualitative characteristics for charcoals obtained

Table 1. Charcoal and pyrolysis liquid products yields from o. d. wood (%)

Tree species	Liquid products yield at temperatures (^{0}C)						Charcoal yield
	120	200	280	350	450	500	
Birch	2.2	6.9	13.1	39.1	49.6	50.9	31.49
Decayed birch	3.8	8.2.	16.2	35.6	46.5	48.0	30.83
Alder	1.6	7.2	12.2	27.7	50.2	51.8	30.01
Decayed alder	4.3	9.1	17.4	35.0	43.7	45.0	30.77
Bird-cherry tree	2.1	6.1	14.0	35.9	48.0	49.9	30.41
Aspen	2.2	8.7	13.1	33.4	47.5	52.9	29.01
Willow	4.6	10.7	20.6	41.4	49.3	51.1	29.51
Rowan-tree	5.7	10.1	16.8	35.4	51.2	52.8	29.59

were determined (Table 2), all of them conforming to the German Standard DIN 51749. In addition, the longitudinal crushing strength was established to be 262.3, 171.6. 195.9, 225.9, 237.1, 208.6, 146.1 and 83.6 kg/cm^2 for birch, alder, bird-cherry tree, aspen, willow, rowan-tree, decayed birch and decayed alder, respectively. In its turn, apparent density values were determined to be 345, 290, 378, 245, 317, 370, 310 and 244 kg/cm^2 for birch, alder, bird-cherry tree, aspen, willow, rowan-tree, decayed birch and decayed alder, respectively. The composition of liquid products of pyrolysis, depending on the tree species, is tabulated in Table 3. The highest liquid products yield in terms of oven dry wood (not taking into account water) was observed for birch, i.e. 37.1%, and the lowest for bird-cherry tree, i.e. 23.8%. To estimate the effect of the tree vegetation conditions and wood anatomical elements upon the yields of charcoal and volatiles, birch and alder trunk, topwood and branch wood samples taken from the two essentially different wood vegetation types, i.e. bog-land and birch grove, were pyrolysed. The results obtained are given in Table 4. It has been established that the pyrolysis products yield is affected by both the tree species vegetation conditions and wood anatomical elements. For example, in comparison to stem wood, the charcoal yield from topwood and branch wood is decreased, while the liquid products yield diminishes only for birch grove grown trees, and increases for bog-land grown trees. Charcoal from branch wood is characterized by a two-fold (from 1.3 to 1.95%) ash content, as compared to stem wood (from 0.75 to 0.85%).

Discussion

It is known that charcoal yield depends on the tree species. For example, carbonization of conifers such as spruce and pine wood in retorts with indirect heating at 450° C provides a higher charcoal yield than for birch, a deciduous tree, i.e. 37.8 and 31.8%, respectively, which is accounted for by a higher content of lignin and extractives (especially resin acid) in softwood, as is specified in the Technology of the forest chemistry industry (1987). For deciduous tree species, it was tempting to assume that the charcoal yield depends directly on wood density: the more dense the wood, the higher the charcoal yield. However, it is not so. To a certain extent, this seeming discrepancy is based on the

Table 3. Liquid product composition and yields depending on the trees species

Tree species	Yield from o. d. wood (%)								
	Acids	Esters	Aldehydes	Furfural	Ketones	Alcohols	Tars		
							Settled	Dissolved	Total
Birch	9.29	3.24	1.20	3.15	0.61	2.59	6.50	8.47	14.02
Decayed birch	7.35	2.01	0.80	2.15	0.57	2.10	4.85	5.85	10.70
Alder	8.30	2.32	0.71	1.39	0.31	2.28	5.46	6.19	11.65
Decayed alder	6.57	2.09	0.58	1.62	0.40	1.92	7.60	5.81	13.41
Bird-cherry tree	8.18	2.17	0.62	1.39	0.62	1.62	3.01	6.22	9.23
Aspen	7.68	1.96	1.01	2.42	0.50	2.17	5.65	7.73	13.38
Willow	8.04	2.31	0.85	2.05	0.50	2.89	7.37	7.66	15.03
Rowan-tree	7.80	2.24	0.66	1.21	0.80	1.80	4.73	6.36	11.09

Table 4. Pyrolysis products yields from o. d. wood, in % depending on vegetation conditions and tree anatomical elements

Tree species	Forest site type	Tree anatomical elements	Charcoals		Liquid products									
			Yield	Ash (%)[1]	Total	Acids	Esters	Aldehydes	Furfural	Ketones	Alcohols	Tars		
												Settled	Dissolved	Total
Birch	Wet peat	Trunk	30.6	0.85	27.26	8.75	2.21	0.76	1.90	0.75	2.48	3.56	6.85	10.41
		Topwood	29.4	1.1	30.73	8.05	2.69	0.88	1.93	0.52	2.55	7.65	6.46	14.11
		Branches	29.8	1.3	32.68	8.59	2.95	0.83	2.34	0.68	2.92	8.12	6.25	14.37
	Uplands	Trunk	31.3	0.75	35.75	9.29	3.94	1.20	3.15	0.61	2.59	6.50	8.47	14.97
		Topwood	27.4	1.25	30.62	8.10	2.64	0.96	1.92	0.46	2.67	8.30	5.578	13.87
		Branches	27.7	1.8	28.30	6.57	2.17	0.89	1.81	0.43	2.20	7.58	6.65	14.23
Alder	Wet peat	Trunk	31.5	0.8	27.34	7.90	2.18	0.71	1.49	0.70	2.48	4.85	7.03	11.88
		Topwood	32.4	1.75	36.30	9.85	2.71	0.71	2.60	0.26	3.00	9.54	7.62	17.16
		Branches	31.5	1.75	33.49	9.10	2.51	0.67	1.99	0.56	2.65	9.69	6.32	16.01
	Uplands	Trunk	31.2	0.8	33.46	6.95	2.07	0.37	0.90	0.62	1.49	6.07	4.46	10.53
		Topwood	30.2	3.1	28.51	7.80	2.22	0.38	1.42	0.36	2.34	8.61	5.38	13.99
		Branches	30.9	1.95	29.53	7.57	2.35	0.57	1.64	0.59	2.52	8.49	5.80	14.29

[1] from charcoal mass

two types of reactions proceeding during pyrolysis. In the first type reactions, high-molecular components and simple low-molecular weight substances are formed, with a simultaneous increase in the condensation and aromatization degree in the carbonization residue. In the second type reaction, these low-molecular weight substances tend to interreact, forming new high-molecular compounds which, as a result of repeated pyrolysis, tend to carbonize and precipitate on cell walls. Hence, the longer the retention time of volatile products of pyrolysis in wood, the higher the chance for these compounds to interreact, increasing the charcoal yield. The retention time is directly connected with the diffusion rate of thermal decomposition products, which decreases with increasing wood density. However, thermal conductivity and thermal decomposition rate augment with increasing wood density. At the same time, the microscopical structure and anizotropic properties of wood as well as different composition of cellulose, lignin, hemicellulose and extractives for different wood species also contribute to the process (Connor, Viljoen, 1997). For example, in high-porosity wood (e.g. aspen wood), rise in temperature proceeds rapidly and unevenly. As a result, charcoal and liquid substances yields drop, while the gas amount rises.

As seen from Table 1, the charcoal yield rises in the sequence: birch> bird-cherry tree> alder> rowan-tree> willow> aspen, while their density, as is specified by

Polubojarinov (1976), rise in the sequence: birch> rowan-tree> aspen> alder> willow, which testifies that it is not possible to forecast the charcoal yield only according to wood density. Distinctions in the yield, even for aspen wood, as compared to birch wood, are negligible, i.e. only 2.5%, while in the case of birch and alder, wood rot diminishes the yield slightly, since it tends to damage primarily wood components such as hemicellulose and cellulose, which are characterized by the lowest charcoal yield when carbonized. From the technological viewpoint, the carbonization equipment productivity is very important and depends upon wood density, since, at equal capacities e.g. in the case of oven dry aspen wood, the weight will be 1.34 times lower than in the case of birch wood. Hence, the charcoal yield in terms of the weight from one apparatus turn-over will be also lower. In the same way, wood density affects the charcoal apparent density which decreases as the carbonization increases up to 450°C, and then is practically unchanged (Bronzov, Vasilevskaja, 1973). Hence, when obtaining charcoal in practice, at temperatures of 450 to 550°C, i.e. at a constant apparent density, its piling volume will be dependent mainly on the carbonized wood species or their mixture composition. It is interesting to note that Doats (1985), when summing up the data on carbonization of a whole range of tropical tree species, observed a general correlation between wood and charcoal densities. However, it does not mean that, for different wood species with equal density, the charcoal density could not differ even twice. The data on the apparent density of charcoal produced from Latvian deciduous tree species indicate no direct relationship with the initial wood density. This testifies that the charcoal yield and properties depend not only on wood density, but also on its composition and structure or even the anatomical elements. In contrast to birch charcoal, increased density values for bird-cherry tree and rowan-tree charcoal, as well as a relatively high density for willow, are rather surprising. This indicates that the above mentioned species will not cause any problems for charcoal production practice if a packing designed for a definite weight of birch charcoal is used. These problems arise in packing alder charcoal (not mentioning aspen), since the difference in the necessary volume, as compared to birch charcoal, is noteworthy. Therefore, firm packing by shaking up should be carried out, resulting in an increased formation of charcoal siftings. It should be mentioned that alder charcoal is characterized by the lowest longitudinal crushing strength, while that for decayed birch and alder charcoal tends to decrease twice.

The apparent density of decayed wood is practically the same as for undecayed alder, while the longitudinal crushing strength is lower. At the same time, it should be mentioned that charcoal obtained from decayed wood whose utilization is not recommended for the above mentioned reason formally conform to the German Standard DIN 51749 (Table 2). It should be mentioned that, in practice, the process conditions are very important since numerous cracks and inner cavities are formed in the lump charcoal at a very high rate of rise in temperature. These inner imperfections impair not only mechanical strength, but also apparent density.

As seen from Table 1, tree species influence the pyrolysis liquid products yield, and the eduction rate is low. Greater distinctions are observed as regards the composition of thé liquid products (Table 3). The yields of acids, alcohols, tars, etc. from birch wood are considerably higher than for other species. As in the case of charcoal yield, wood rot reduces the liquid products yield, too. In this case, its composition varies depending on the rot type, i.e. acid, ester, alcohol and tar amounts for decayed birch wood tend to decrease. However, the fact that the tar yield increases mentioned in Technology of the forest chemistry industry (1987) was not confirmed. In its turn, for decayed alder wood, only a decreased acid yield was observed, the tar yield being increased.

The birch and alder pyrolysis liquid products yield and composition are affected also by the vegetation conditions, i.e. the forest site type (Table 4), although the results are not unambigous. Thus, for birch grove grown birch, increased ester, aldehyde and furfural yields are observed, as compared to bog-land grown birch. However, in the case of alder, the opposite phenomenon is observed, i.e. it is exactly the bog-land grown alder that is characterized by increased acid, aldehyde, furfural, alcohol and tar yields. The influence of tree anatomical elementss is most obvious in case of the total tar yield for alder, which is almost 1.5 times higher for branch wood and topwood as compared to stem wood. At the same time, the liquid products yield from plants grown stem wood is highest, and that for bog-land grown wood is lowest. It should be obviously remembered that, in fact, wood is a catalytic system, since it contains various inorganic salts acting as a catalyst (Bridgwater, 1994) which, depending on the concentration, changes the thermal decomposition products yield. This explains why by far higher carbon yields are obtained when pyrolysing isolated wood components, i.e. cellulose, lignin and hemicellulose in contrast to wood, since the salts concentration tends to decrease during the separation process. Hence, as the amount and composition of mineral substances in wood vary depending, for example, on the forest site type, changes in the composition and yield of wood thermal decomposition products are possible. This partially explains also the fact why the liquid products yield from topwood and branches with the higher mineral substances content (which is indicated by the increased ash content in the charcoal) is increased, while charcoal yield is diminished. From the aforementioned it follows that the wood pyrolysis process is affected by a whole range of factors which are connected with the wood itself, not mentioning the parameters of the pyrolysis process itself. Further research would provide a more profound understanding of the effect of wood from trees grown in different forest site types upon the pyrolysis products yield and properties, especially in the case of obtaining new materials and products.

Conclusions

1. Deciduous tree species such as grey alder, bird-cherry tree, aspen, willow and rowan-tree, common for Latvia, are suitable for the production of lump charcoal for applications such as household, barbecue and the recreation industry. The use of aspen wood charcoal is limited, while that of decayed wood is inadmissible.

2. Both the yield and composition of charcoal and liquid products of wood pyrolysis are affected by the tree species, its anatomical elements and vegetation conditions, i.e. the forest site type. Factors affecting the yield and composition of wood pyrolysis products have been discussed.

References

Bridgwater A. V. 1994. Catalysis in thermal biomass conversion. Applied catalysis, A: General, 116: 5–47.

Bronzov O. V., Vasilevskaja S. I. 1973. Evaluation of charcoal in terms of apparent density. Lesokhimija I podsochka, 7: 10 (in Russian).

Connor M. A., Viljoen M. H. 1997. Relationships between wood density, wood permeability and charcoal yield. In: Developments in thermochemical biomass conversion, 1: 82–96.

Doat J. 1985. C.T.F.T. Research into wood pyrolysis. Proceedings of Symposium on Forest Products Research International - Achievements and Future, Pretoria, 12–24, p. 1.

Morozov E. F. 1979. Furfural production. Lesnaja promyshlennost', Moscow, 200 pp. (in Russian).

Polubojarinov O. I. 1976. Wood density. Lesnaja promyshlennost', Moscow, 159 pp. (in Russian).

Spince B., Zhurinsh A., Zandersons J. 1997. Chemical analysis of wood pyrolysis liquid products (unpubl.)

Technology of the forest chemistry industry. 1987, Lesnaja promyshlennost', Moscow, 352 pp. (in Russian).

ВОЗМОЖНОСТИ ИСПОЛЬЗОВАНИЯ МАЛОЦЕННЫХ ВИДОВ ДЛЯ ЗАГОТОВКИ ДРЕВЕСНОГО УГЛЯ

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Резюме

Исследовались возможности использования древесины лисьвенных пород, произрастающих в Латвии, а также ее отходов для производства древесного угля. Установлено, что ольха (*Alnus incana*), черемуха (*Padus avium*), осина (*Populus tremula*), ива (*Salix caprea*), рябина (*Sorbus aucuparia*) являются пригодными для производства древесного угля, используемого в домашнем обыходе и в рекреационной индустрии. Выход и состав древесного угля как и жидких продуктов пиролиза зависит от лесорастительных условий.

Ключевые слова: литственные породы, отходы, древесной уголь.