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Biomass feedstock analyses

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Valtion teknillinen tutkimuskeskus (VTT), Vuorimiehentie 5, PL 2000, 02044 VTT
puh. vaihde (90) 4561, telekopio 456 4374

Statens tekniska forskningscentral (VTT), Bergsmansvägen 5, PB 2000, 02044 VTT
tel. växel (90) 4561, telefax 456 4374

Technical Research Centre of Finland (VTT), Vuorimiehentie 5, P.O.Box 2000, FIN-02044 VTT, Finland
phone internat. + 358 0 4561, telefax + 358 0 456 4374

VTT Energia, Energian tuotantoteknologiat, Biologinkuja 3-5, PL 1601, 02044 VTT
puh. vaihde (90) 4561, telekopio (90) 460 493

VTT Energi, Energiproduktionsteknologi, Biologgränden 3-5, PB 1601, 02044 VTT
tel. växel (90) 4561, telefax (90) 460 493

VTT Energy, Energy Production Technologies, Biologinkuja 3-5, P.O.Box 1601, FIN-02044 VTT, Finland
phone internat. + 358 0 4561, telefax + 358 0 460 493

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ABSTRACT

The overall objectives of the project "Feasibility of electricity production from biomass by pressurized gasification systems" within the EC Research Programme JOULE II were to evaluate the potential of advanced power production systems based on biomass gasification and to study the technical and economic feasibility of these new processes with diffrent type of biomass feedstocks. This report was prepared as part of this R&D project. The objectives of this task were to perform fuel analyses of potential woody and herbaceous biomasses with specific regard to the gasification properties of the selected feedstocks. The analyses of 15 Scandinavian and European biomass feedstock included density, proximate and ultimate analyses, trace compounds, ash composition and fusion behaviour in oxidicing and reducing atmospheres.

The wood-derived fuels, such as whole-tree chips, forest residues, bark and to some extent willow, can be expected to have good gasification properties. Difficulties caused by ash fusion and sintering in straw combustion and gasification are generally known. The ash and alkali metal contents of the European biomasses harvested in Italy resembled those of the Nordic straws, and it is expected that they behave to a great extent as straw in gasification. Any direct relation between the ash fusion behavior (determined according to the standard method) and, for instance, the alkali metal content was not found in the laboratory determinations. A more profound characterisation of the fuels would require gasification experiments in a thermobalance and a PDU (Process development Unit) rig.

PREFACE

The report has been prepared as part of a larger R&D project on "Feasibility of electricity production from biomass by pressurised gasification systems" within the EC research programme JOULE II (project JOU2-CT92-0226). The overall objectives of the project were

- to evaluate the potential of advanced power production systems based on biomass gasification,
- to study the technical and economical feasibility of these new processes with different type of biomass feedstocks.

The objectives of the task discussed in this report were to perform fuel analyses of potential woody and herbaceous biomasses to address the suitability of biomass feedstocks for gasification processes.

The work was carried out at the Technical Research Centre of Finland, VTT Energy, over the years 1993 - 1994.

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Espoo February 1996

Carl Wilén
Antero Moilanen
Esa Kurkela

CONTENTS

1 INTRODUCTION

The project involved an assessment of biomass use in different parts of Europe and the collection of biomass properties data. In addition to a literature review [1], laboratory analyses were performed for the fuels chosen for the study. The results of the laboratory analyses are discussed in the present report. The work was based on the experience of VTT Energy gained from PDU-size pressurised gasification tests with some of the fuels, primarily for Northern wood and straw biomasses.

2 FEEDSTOCKS

The fuels for the analyses were chosen to represent typically three significant biomass sources (Table 1). The agricultural and European biomasses are herbaceous crops.

Table 1. Feedstocks chosen for analyses.

Scandinavian biomass feedstocks		European biomasses
Woody biomasses	Agricultural biomasses	
Wood chips Forest residue chips Pine (*Pinus*) bark Spruce (*Picea*) bark Willow (*Salix*) Pine (*Pinus*) sawdust	Barley straw (*Avena sativa*) Wheat straw (*Triticum*) Rapeseed (*Brassica napus*) Flax (*Linum usitatissimum*) Reed canary grass (*Phalaris arundinacea*)	Sorghum (*Sorghum vulgare*) Miscanthus (*Miscanthus sinensis*) Kenaf (*Hibiscus cannabinus*) Cane (*Arundo donax*)

2.1 WOODY BIOMASSES

Wood chips are generally used in Scandinavia in small and middle-sized distric heating centres and power plants. The wood chips chosen for the analysis are whole tree chips, mainly pine.

Forest residue chips are made of small wood, branches and tops, i.e., from the residue formed when harvesting industrial wood. These chips also include the green parts (needles) and the proportion of bark is higher than in chips made of whole trees. Two types of forest residue chips (conifer trees: pine and spruce, incl. stem, bark, branches and needles) were used in the analyses: One batch of chips was produced in Finland and dried and ground for gasification tests at VTT, and the other was produced in Sweden, sieved to <10 mm particle size, dried and further ground. In sieving, ash and other impurities enriched in the <10 mm fraction and, consequently, the ash content of the sample increased to an exceptional level.

Bark formed in pulp mills and in mechanical wood processing is mainly used as fuel in pulp industry. The pine and spruce bark samples chosen for the analyses are from sawmills, in which different barks can be separated. The bark samples contained to some extent stemwood residues from debarking.

The willow sample was harvested from the Kopparnäs test culture area of Imatran Voima Oy, located in Southern Finland. The sample was cut immediately prior to the essential harvesting period in the winter of 1994. Hence, the sample did not contain leaves. The sample was ground as such, and the ratio of bark and wood represents the whole plant.

Sawdust consisted of pure pine sawdust and did not contain bark. The same type of sawdust had been used for fuel in gasification experiments at VTT.

2.2 HERBACEOUS CROPS

About one third of the annual 6.3 million tonnes straw yield in Denmark consists of wheat straw and less than a half of barley straw. In Finland, about a half of the straw yield totalling about 2.2 million tonnes consists of barley straw. The straw yield ranging 1.2 - 1.8 tons of dry matter per hectare and year depends on local conditions and species. The wheat straw chosen for additional analyses had been harvested in Denmark in the summer of 1993. The straw was chosen for the VTT gasification tests to represent a straw type with a relatively high ash fusion point. The barley straw had been harvested at a farm in Southern Finland in the summer of 1993.

Rapeseed straw and flax had also been harvested at a farm in Southern Finland in the summer of 1993. The flax was of seed flax. So-called fibre and combustible fractions were separated mechanically from the flax. The fibre fraction represents the part of flax suitable for fibre raw material, for example, in pulp mills. The rest, i.e., the core of the stalk (= shive), is suitable for energy use. The fuel analyses, except for ash analyses, were carried out separately for the whole flax straw sample and for the separated combustible fraction.

Reed canary grass had been cultivated at the experimental station of the Agricultural Research Centre of Finland in the summer of 1992. Grass overwintered and was harvested in the spring of 1993 after snowmelt. Reed canary grass is a general plant in Finland, natural growing sites being shores, roadsides and meadows. It is tentatively cultivated for energy use in Sweden on an area of about 5 000 ha. Yields of 5 - 7 tons of dry matter per hectare and year have been achieved.

Sorghum, Miscanthus, kenaf and cane represent Central and South European biomasses. These fast-growing plants have a potential production rate of 15 -

25 tons dry matter per hectare and year. The biomasses were delivered in bales by ENEL, Italy, to VTT Energy. In addition, a chopped Miscanthus sample was delivered by DMT, Germany. Normal fuel analyses were carried out for this sample.

Grain sorghum is grown world-wide, and especially in China, Asia and Africa in large quantities. Sweet sorghum is well adapted to south and mid European conditions. Most cultivated sorghums have a high potential productivity, and due to a wide variability in genus, this productivity can be directed towards grains, total biomass for forage or energy production, sugar and fibres. The stem of sorghum is straight and robust, height on average 100 - 150 cm. The leaves resemble those of maize.

Miscanthus is a perennial C-4 grass with the origin in East Asia. Within the frame of the European Miscanthus Network, research on the mechanism of planting, harvesting and breeding has been carried out in several EC countries. Dry matter yields of 25 - 30 t/ha have been reached with Miscathus Sinensis "Giganteus".

Kenaf is an annual fibre plant related to cotton and native to central Africa. In tropical conditions it can grow 4 - 6 m high, in Italy usually about 3 m. The plant has two types of fibre: the outer, bast fibres, used for cellulose and paper, and the inner, core fibres, used for animal bedding and forage, absorbent material and particle board.

The common cane grows along rivers, fields, etc., and can reach the height of 2 - 4 m. The hollow stem is nearly covered by sheath leaves.

3 TREATMENT OF FUELS

The wood-derived biomasses were delivered dry in batches of 0.2 - 1 m^3 in part chipped and dried to <10 % moisture content. The barks and willow were dried in a heating chamber (at 80 °C). The straws and the South European energy crops were delivered in bales dried to <10 % moisture content to reach storage durability. Representative samples were taken from all fuels, and analytical samples of about 20 l were ground from them with a cutting mill equipped with a 6 mm sieve disc. In this way, relatively comparable samples with regard to particle size were obtained from the fuels. The energy plants kept their stem form, the length of stems and fibres being <10 mm.

The analytical samples and the analysis results were considered to represent satisfactorily the fuel batches delivered to the laboratory. The results cannot be considered to represent these fuels in general. The woody biomasses and the European and Scandinavian straws are presented in Appendix 2.

4 FUEL ANALYSES

4.1 DENSITY

The density of fuels is measured as bulk density by weighing a certain volume. In laboratory measurements, a small fuel amount of, for example one litre, is weighed for practical reasons. Weighing is carried out without shaking the sample. The method gives rather different results especially when elastic and tractable fuels are concerned.

In these density analyses, a so-called FEM method [2] was used in addition to the method described above. Determination of volume weight with the FEM laboratory method is generally used by machine manufacturers in dimensioning equipment for bulk material, if no other value of volume weight is available. The method is described briefly below.

The FEM volume weight measurements were carried out with a 500 cm^3 vessel shown in Figure 1 by filling the vessel to the brim through the funnel, by dropping the vessel to its base with 3 mm amplitude 1 000 ± 50 times and by measuring the change in volume. This operation was repeated until the difference of two consecutive measurements was <50 cm^3. The final loaded volume weight is calculated from this last volume and denoted as "compacted bulk density". In studies carried out earlier for compressible peat it was found that this compacted bulk density correlates well with the real volume weight of the fuel in bins and intermediate storages [3].

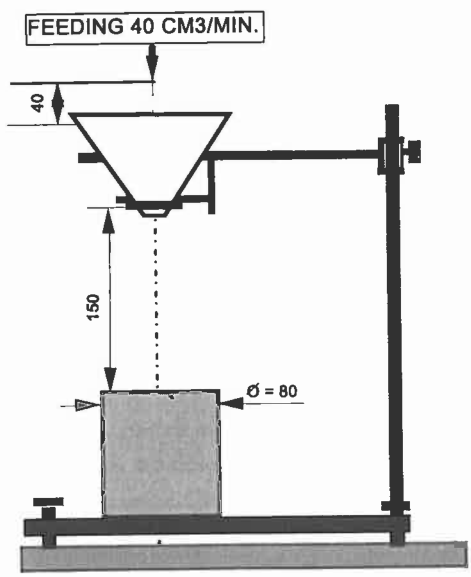

Figure 1. Equipment for measuring bulk density [2].

By measuring the weight of the filled vessel before shaking the so-called "loose bulk density" is obtained. This density corresponds better than the compacted one to a situation experienced, for instance, in a conveying screw or on a belt conveyor. The degree of compacting, expressed in %, gives an indication of the compactibility of the biomass fuel.

4.2 PROXIMATE AND ULTIMATE ANALYSES

The ash and volatile matter contents of the dry samples were analysed in a Leco TGA-500 instrument according to DIN 51719 and DIN 51720. The moisture content of the fuel samples was determined according to DIN 51718. This moisture content represents that of the dried sample when analysed, not the actual production or utilisation moisture.

The C, H, and N contents of the dry samples were determined with the Leco CHN-600 analyser and the sulphur content with the Leco Sulphur analyser SC32 according to ASTM D 4239.

The lower and higher heating values were determined according to DIN 51900. Proximate and ultimate compositions and heating values are given on dry basis.

4.3 TRACE COMPOUNDS

The concentrations of alkali metals and chlorine were determined directly for the fuel samples using the INAA method (instrumental neutron activation analysis). The concentrations are given on dry basis. The analyses were carried out by VTT Chemical Technology.

4.4 ASH ANALYSIS AND ASH FUSION TEMPERATURE

The elemental analysis of ash was carried out by ICP technique (inductively coupled plasma-atomic emission spectrometry) as two parallel determinations. The analyses were carried out by VTT Chemical Technology. The biomass samples were ashed at 500 °C to minimise losses. The ash samples were then dissolved with the aid of lithium tetraborate metal for the ICP analyses.

The ash fusion temperature was determined in oxidizing and reducing atmosphere according to ASTM D 1857 with the Leco AF-600 analyser. The method was developed for analysing coal and coke ashes to evaluate the ash behavor in processes. The method proved to suit poorly for biomass ashes.

On the other hand, no better standardised method for describing the sintering tendency of biomass ashes was available, according to which the sintering tendency and fusion behavior of biomass ashes can be determined. The standardized method was used as a basis for evaluating differences in the behavior of the fuels. It also offers the means of linking the measured ash fusion behavior to practical experience gained from other fuels. However, a measuring method of sintering temperature based on the determination of the strength of a pellet formed from the ash has been presented as a non-standardised method in the literature [4, 5]. In connection with the results, values found in the literature for the sintering temperatures of different biomass ashes are presented in this report. According to the standard method the fuels are ashed at 815 °C, i.e., sintering may occur already in the ashing stage. In this sense the method does not describe ashing and sintering of the fuel, for example, in fluidised-bed gasification. Contrary to the standard method, the agrobiomasses had to be ashed at 650 - 700 °C to prevent the ash from melting or hardening. Ash fusion is recorded optically by monitoring rounding of the tip of a pyramid formed from the ash and the fusion of the pyramid by continuous height and width measuring. If the measured sample behaves differently from a standard sample, it is not possible to determine characteristic points unambiguously. Visual examination and evaluation of characteristic points had to be accepted for most biomass samples.

5 ANALYTICAL RESULTS

The analytical results are presented numerically in Appendix 1. The fuels were divided into three main groups according to Table 1. In the following, the analytical data are briefly compared with each other and their characteristics are assessed with regard to gasification. The discussion is based widely on the experience of VTT from gasification tests with various biomasses and coal grades in pressurised and atmospheric fluidised-bed gasifiers and on the knowhow acquired by participating in semi-commercial and commercial ventures on biomass gasification.

5.1 DENSITY AND HANDLING PROPERTIES OF FUELS

It is difficult to compare bulk densities of different biomasses with each other, if no exact knowledge about their physical appearance is available. To make a comparison possible, all biomasses used in this study were ground with the same equipment to obtain about the same particle size distribution for all fuels. The moisture content of the fuels was also relatively homogeneous, ranging from 5 to 10%. Hence, the measured bulk densities are also comparable. The sieve analysis of certain fuels is shown in Figure 2. The mean particle size D_{50}, described by the mesh of the sieve dividing the fuel sample in two equal parts, were for the different fuel categories as follows:

Woody biomasses:	D_{50} = 0.8 - 2 mm
Agricultural biomasses:	D_{50} = 0.7 - 2 mm
European biomasses:	D_{50} = 0.9 - 1.3 mm

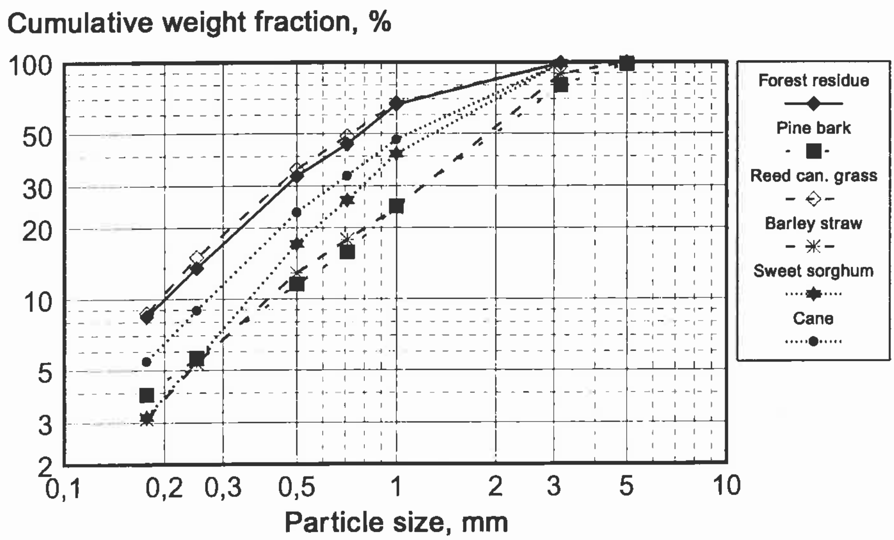

Figure 2. Sieve analysis of certain biomass fuels.

The bulk densities measured with the FEM method are shown in Figure 3. Both compacted and non-compacted volume weights and compactibility are given. The bulk density of ground Nordic wood biomasses is in the range of 200 - 350 kg/m^3 and that of agrobiomasses 60 - 120 kg/m^3. The Italian agrobiomasses are more thick-stemmed and treelike than the Nordic ones and their bulk density range from 80 to 220 kg/m^3.

The compactibility of wood biomasses was fairly insignificant and that of crop straws fairly significant. Flax chop contained long fibre bundles, which gave a very elastic character to the chop. The compactibility of hard-stemmed straws, like rapeseed and Italian kenaf and cane, was slighter than that of straws in general.

The biomasses are usually difficult to handle due to their unhomogeneity, small bulk density, poor flow characteristics and dusting. In gasification pro cesses, the greatest difficulties are often found in the feed of biomasses into the reactor. The difficulties are significantly greater if a pressurised process is concerned.

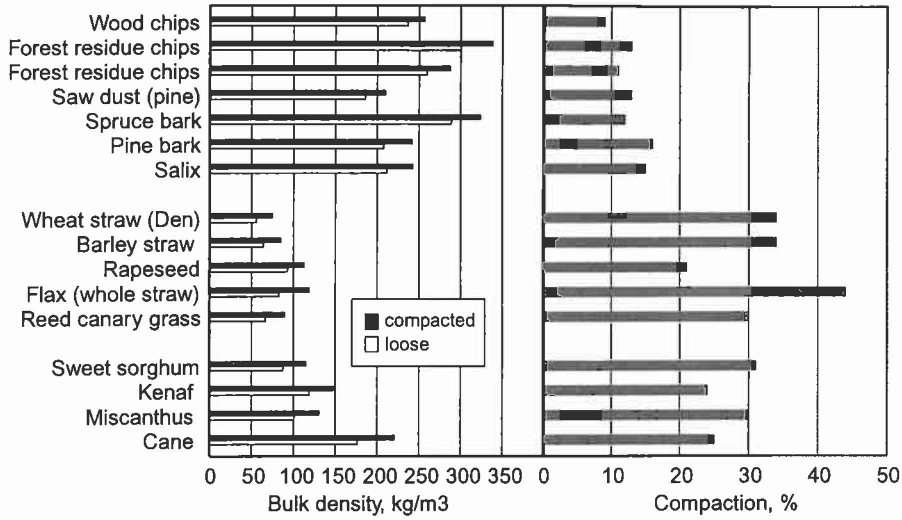

Figure 3. Volume weights of fuels measured with the FEM method.

The fuel to be fed into the fluidised-bed gasifier should be chopped or chipped. In general, intermediate and feed bins based on free gravimetric flow are not reliable feed systems for biomasses. The feed bins should be so-called live bottom bins, and the feed should be carried out with a screw conveyor. In pressurised gasification processes, the feed bin has to be pressurised with inert gas to the operation pressure of the gasifier. If the fuel is compactible and light, the amount of gas required for pressurisation increases significantly and consequently, the costs of pressurisation increase.

Light and compactible straw chop flows very poorly and can cause arching also in the live bottom bins mentioned above. A tractable biomass is compacted in course of time significantly due to its own weight. Hence, the fuel can form very stable bridging in feed bins already during shutdowns of a couple of hours.

5.2 CHEMICAL ANALYSES

The proximate and ultimate analyses of the fuels are shown in Figures 4 and 5. The highest content of fixed carbon was measured for wood bark and for bark-containing wood and forest residue. In this respect, the agrobiomasses were equal to pure saw-dust. There was no significant difference between the volatile contents of different fuels. The agrobiomasses contained, however, usually clearly more ash than the wood-derived fuels. Depending on the composition and sintering characteristics of ash, the gasification and combustion of the fuel is usually hampered by a high ash content. The ash content of reed canary grass was significantly higher than that of the other agrobiomasses. The lower heating value (LHV) of the agrobiomasses was on average 8 % lower than that of wood biomasses.

The nitrogen content of agrobiomasses was higher than that of wood-derived biomasses. The nitrogen content of pure sawdust was very low, 0.08%, and that of barks and bark-containing chips about 0.4%. The nitrogen content of the agrobiomasses ranged within rather wide limits, 0.4 - 1.4%, depending on the type of the fuel. The nitrogen content has a significant effect on NO_x emissions from gas combustion. The nitrogen contained in the fuel is converted to ammonia in gasification. This ammonia causes NO_x emissions in gas combustion.

The difference in sulphur content was also significant. The sulphur content of wood fuels increased when the bark content was increased, being however low, about 0.03%. The sulphur content of the agrobiomasses varied within wide limits and was manifold compared with that of wood fuels. The highest S content, 0.55%, of this material was measured for miscanthus and the lowest 0.01% for pine sawdust.

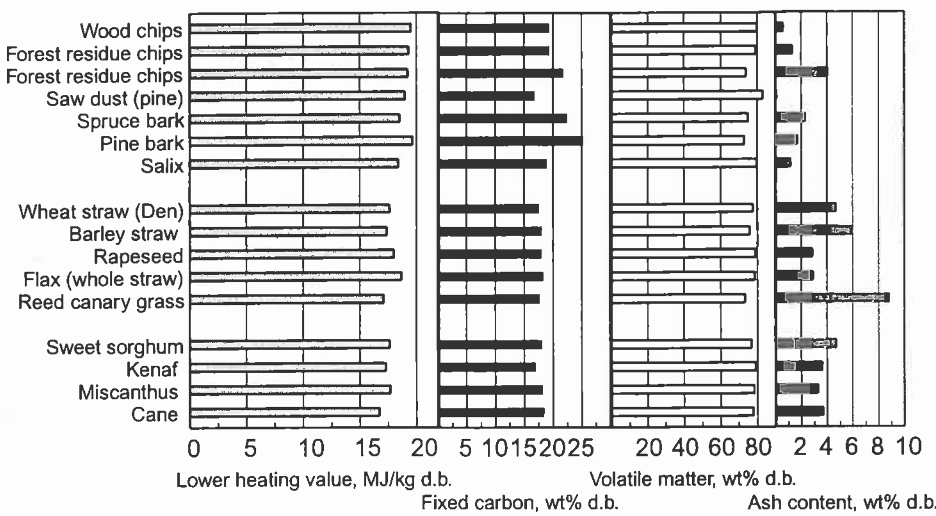

Figure 4. Proximate analysis of the fuel samples.

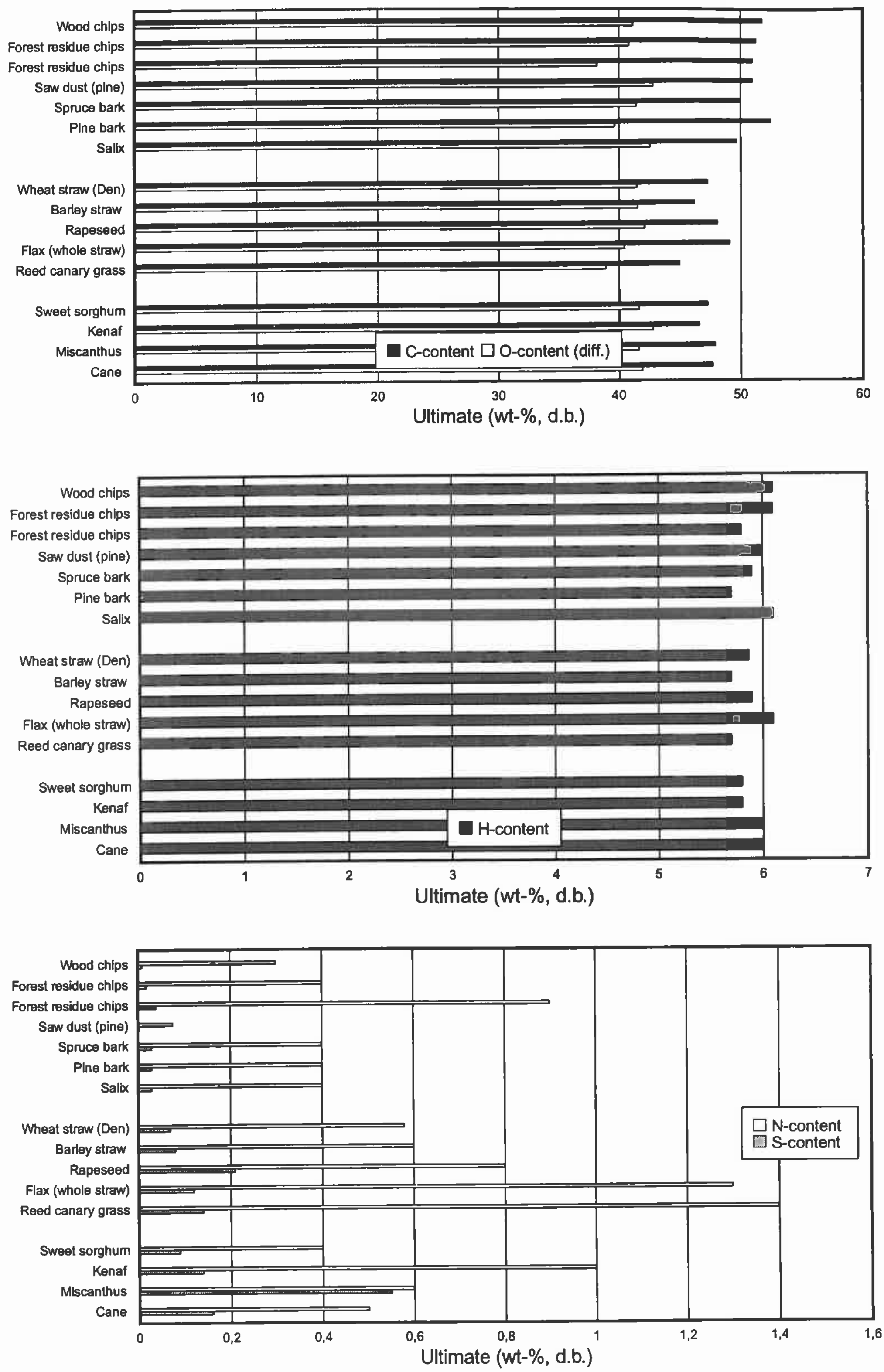

Figure 5. Ultimate analysis of the fuel samples.

The Na, K and Cl contents and the total alkali metal content of the fuels are shown in Figure 6. The forest residue samples having a high ash content had also an exceptionally high sodium content. The alkali content, in particular the potassium content, of Salix grown on agricultural land was also high, apparently due to fertilization applied to the culture.

The alkali and chlorine content of agrobiomasses ranges within rather wide limits depending on culture conditions. The soil and fertilisation have a decisive effect on the alkali content of the fuels. Hence, the variations can be significant also for the same species and are usually very difficult to anticipate. The alkali and chlorine content of strawlike biomasses is also affected by the harvesting method. If the straw is left after cutting on the field for a longer time, the content of these substances is reduced due to loosening of leaves and to weather conditions. For example, the alkali and chlorine content of reed canary grass harvested in the spring is usually 5 - 10% lower than that of hay harvested in the autumn. This has been found to have a significant effect on the ash fusion behaviour of reed canary grass.

The alkali content of the Italian agrobiomasses, in particular the potassium and chlorine content, was higher than that of the other straw biomasses (except for Finnish barley). The culture conditions may have of decisive significant in this respect as well.

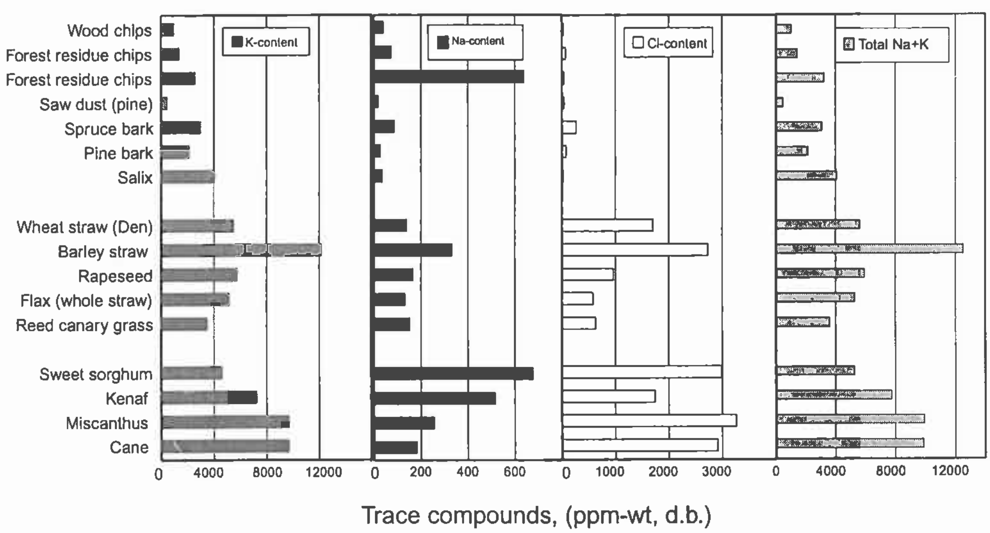

Figure 6. Trace compounds and total alkali content.

5.3 ASH ANALYSES

The ash composition of the fuels is shown in Figure 7. The most significant differences between the ashes were as follows:

- In general, the biomass ashes contain high amounts of silicon, calcium and potassium.
- The aluminium, iron and titanium contents of the ash of the wood fuels was high compared with those of agrobiomasses
- The silicon content of reed canary grass, the sulphur content of rapeseed and the phosphorus content of Salix, rapeseed and flax are high.
- The titanium content of forest residue ash is significantly high compared with that of the other wood fuels
- The magnesium content of pure sawdust is high.
- The sodium, potassium, silicon and sulphur contents of agrobiomass ashes is usually higher than those of wood biomass ashes.

5.4 SINTERING/FUSION BEHAVIOR OF ASH

The ash fusion behaviour of the fuels was studied both in oxidizing and reducing atmosphere. Numerical results are presented in Appendix 1. The behaviour of ash is described according to the standard by deformation points: initial deformation temperature (IT), softening temperature (ST), hemisphere temperature (HT) and fluid temperature (FT). As mentioned earlier, the behaviour of ashes of certain fuels was so vague that the deformation points had to be estimated visually. For a number of ashes, in particular for high-fusing ashes of Salix, rapeseed, flax and kenaf, the discernment of different phases was impossible. In these cases, the ash pyramids shrank during the test (no hemisphere) and finally fused very quickly. The ash of low-fusing ashes, such as barley ash, swelled strongly during fusion, which also hampered the interpretation. The method suited satisfactorily for wood fuels and barks.

The deformation of two ash samples, reed canary grass (No. 7) and sweet sorghum (No. 11), at reducing atmosphere at 1 060 ^{o}C is shown in Figure 8. The ash of sweet sorghum fused and swelled, while the ash of reed canary grass did not deform except for the colour.

The ash fusion of different fuels is shown in Figures 9 and 10 by presenting the temperature area of IT $\rightarrow$ FT both in oxidizing and reducing atmospheres.

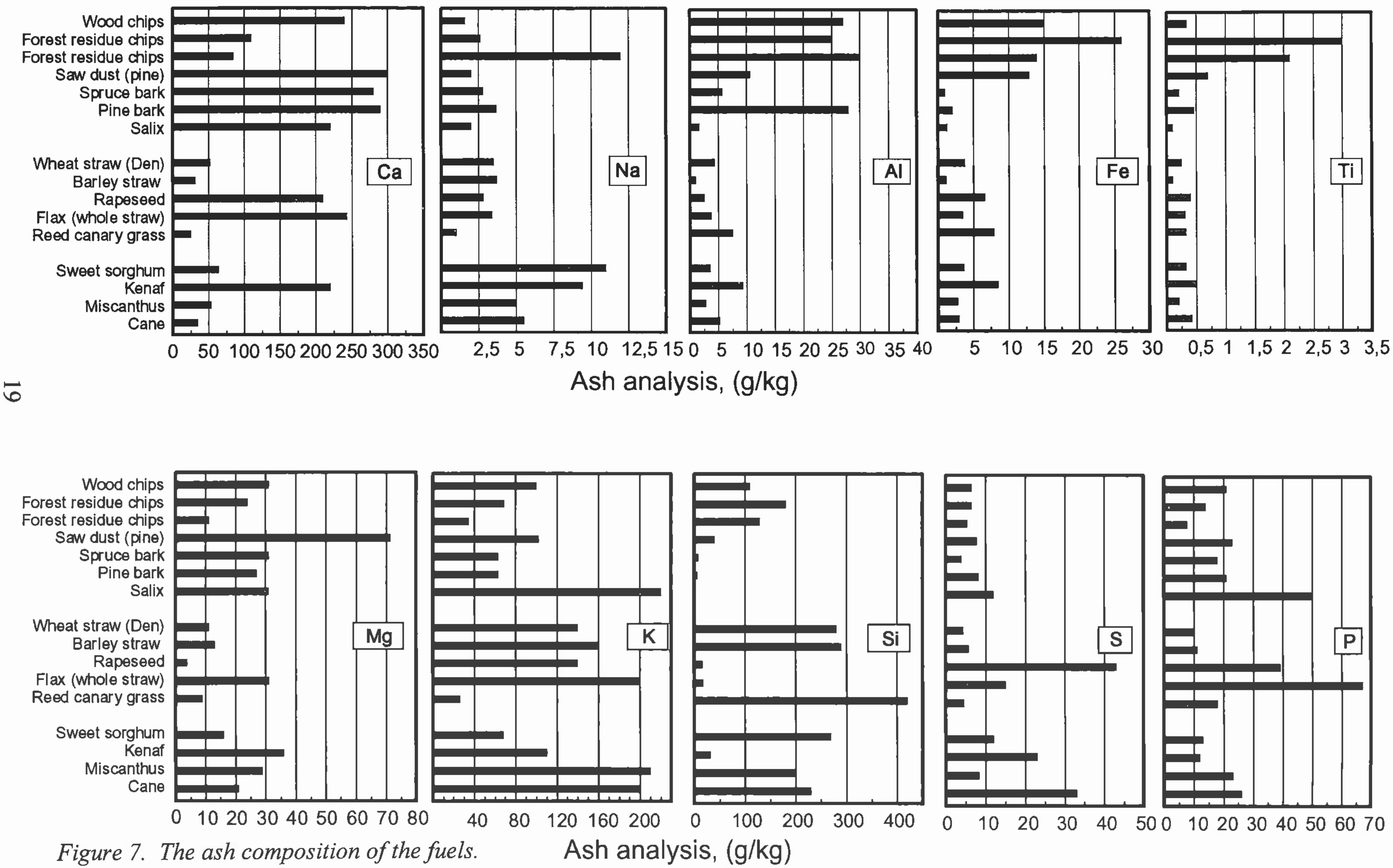

Figure 7. The ash composition of the fuels.

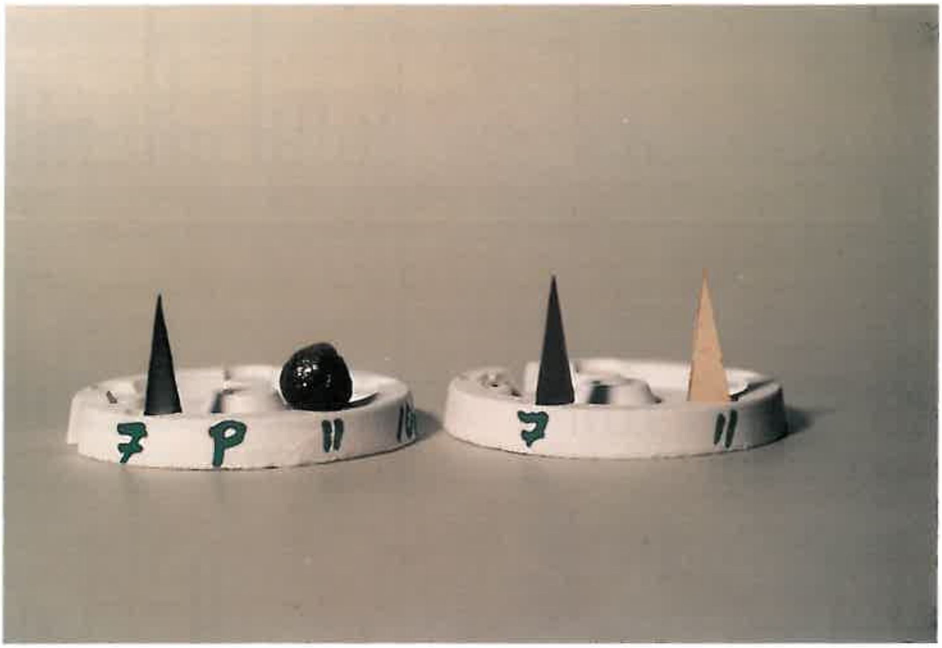

Figure 8. Ash fusion at 1 060 °C in reducing atmosphere. Reed canary grass (No. 7) and Sweet sorghum (No. 11).

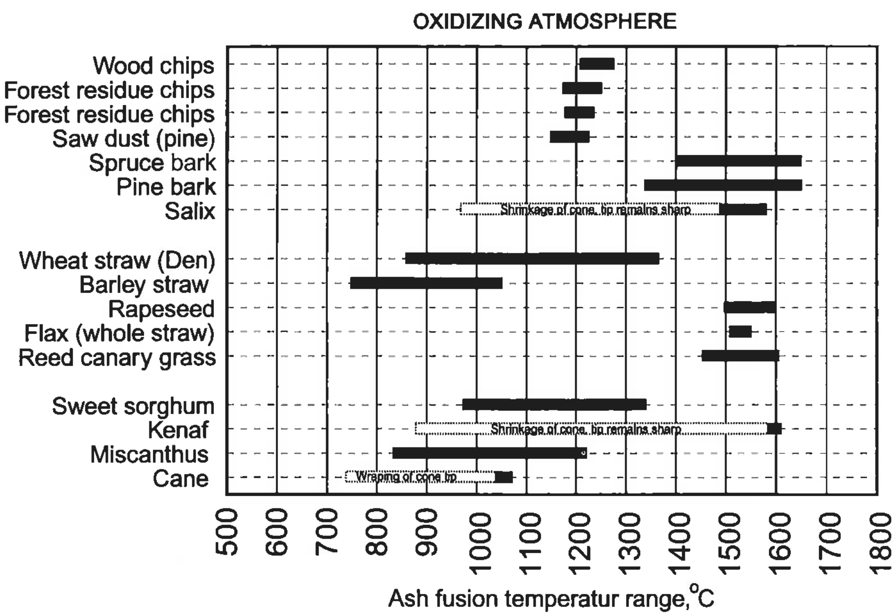

Figure 9. The ash fusion range of fuels in oxidizing atmosphere.

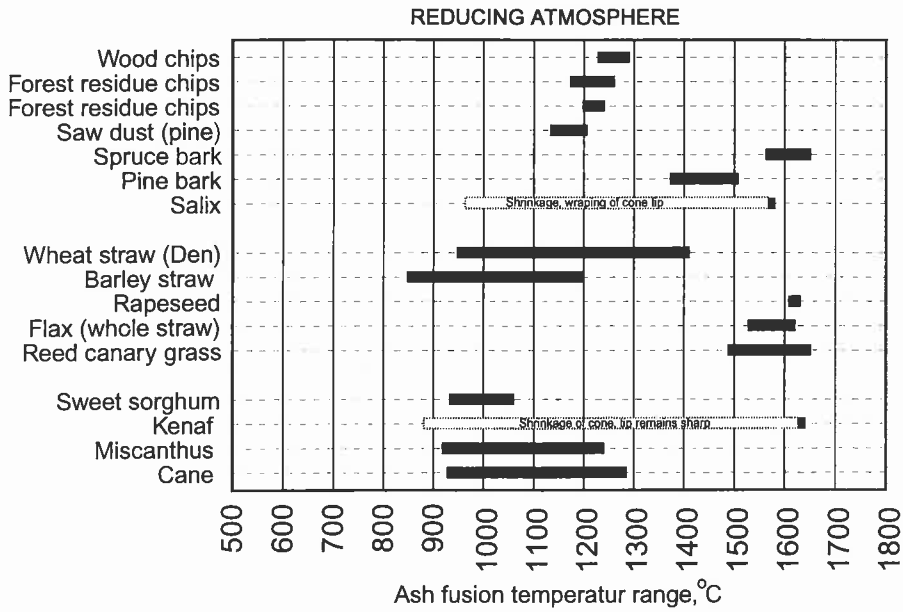

Figure 10. The ash fusion range of fuels in reducing atmosphere.

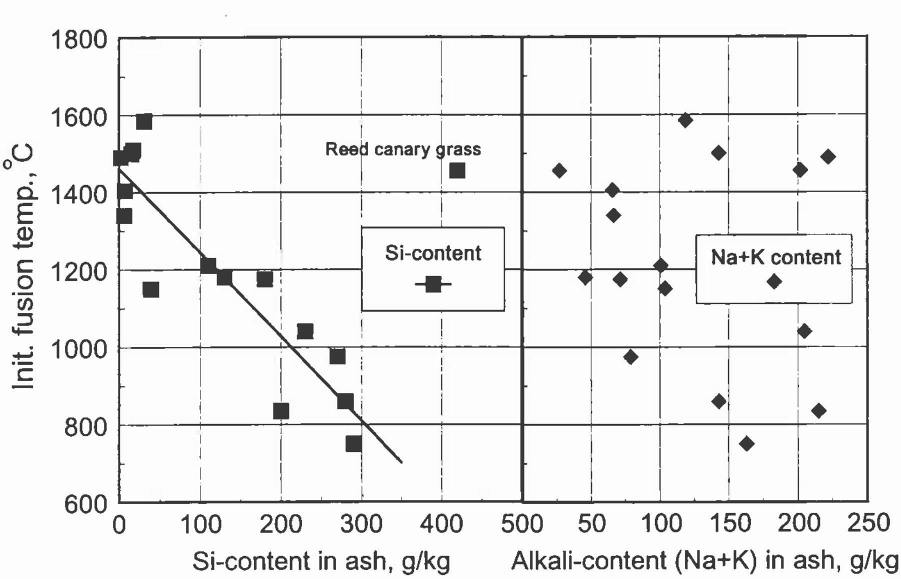

Figure 11. The effect of the silicon content of fuel ashes on the temperature of initial deformation of ash. Correlation coefficient $R^2=0.82$. No dependence was found between the alkali contents and the ash fusion.

The problematic ashes mentioned above are seen either as very short or very long fusion ranges. It was also found that the ash fused usually at slightly higher temperature in reducing atmosphere.

Although the ash fusion behaviour of biomasses is rather variable and difficult to characterise, the effect of certain parameters related to ash composition are briefly discussed in the following. Ash fusion is described by the temperature of initial deformation (IT) in oxidizing atmosphere.

No interdependence between the ash fusion and the alkali content (Figure 11) or the chlorine content of the fuel was found, although the alkali correlates with the slagging and fouling behaviour of ash in biomass combustion [10]. However, the silicon content of the fuel ash correlated nearly linearly with ash fusion in such a way that the temperature of initial deformation (IT) fell while the silicon content increased (Figure 11). Of the biomasses studied, only the ash of reed canary grass deviated clearly in this respect. Its silicon content was, as was mentioned earlier, significantly higher than that of the other wood- and agrobiomasses. A corresponding correlation was also observed in reducing atmosphere.

When the detrimental ash behavior (i.e., slagging and fouling) was evaluated on the basis of the ash fusion tests, it was observed that the prediction is not successful. For example, the melting temperatures measured according to standard methods (ASTM, ISO, etc.) for *Salix* were much too high compared to the problematic behavior of ash in gasification [6]. The recent studies of the behavior of various biomass ashes in fluidized-bed combustion at VTT showed a clear correlation between the ash sintering behavior in the laboratory tests and in the fluidized-bed of a small-scale reactor carried out for ash-sintering studies [7]. Hence, a better indicator for ash behavior seems to be the measurement of sintering temperature [5, 4]. Table 2 presents sintering temperatures of various biomass ashes obtained from the literature [8, 9].

Table 2. Sintering temperatures measured for biomass ashes [8, 9].

Sample	$T_{sintering}$, °C
Reed canary grass	800 - 900
Wheat straw A	700 - 750
Bagasse	800 - 850
Bagasse leaves	850 - 950
Wheat straw B	650 - 700
Olive stones	950 - 1 050
Forest residue	>1 000
Lucerne	625 - 650
Eucalyptus	700 - 750

6 CONCLUSIONS

On the basis of the laboratory analyses of the fuels studied, the following conclusions can be drawn from their suitability for gasification, focusing, in this report, especially on their suitability for gasification:

- Wood-derived fuels, such as whole-wood chips, forest residue, bark and willow, can be processed with chipping technique for both fixed-bed and fluidised-bed gasification. In applications, in which electricity is generated from gas with diesel or gas turbine technology, the fuels should usually be dried to < 15 % moisture content. The agrobiomasses in straw form require a more efficient pretreatment. The straw and energy hay should usually be pelletized or briquetted for fixed-bed gasification. Chopped straw can also be used in fluidised-bed gasification provided the characteristics of chopped straw, for example, compressibility and low density, have been considered in the design of handling and feed equipment. In Nordic conditions, the straw biomasses should also be dried to the moisture content required by the gasification.

- The high ash content usually indicates a more difficult behaviour of the fuel in fluidised-bed gasification. In this respect, the Nordic straws and reed canary grass are problematic. Difficulties caused by ash fusion and sintering in straw combustion are generally known. The difficulties are usually related to the high alkali content of these fuels. However, any direct relation between the ash fusion behaviour and the alkali content was not found in the laboratory determinations. The ash of reed canary grass harvested in the spring fuses at a fairly high temperature and should not cause problems in normal gasification conditions.

- The ash and alkali content of wood bark is higher than those of pure wood or whole-wood chips. Despite of this, the ash fusion temperature of bark was higher than that of wood in the analyses.

- The ash and alkali contents of the European biomasses harvested in Italy resemble those of the Nordic straws. Their chlorine content is slightly higher. It is expected that they behave to a great extent as the straw in gasification. Their physical characteristics are more close to those of wood and hence their pre-treatment is apparently easier than that of straws.

- The problems related to the combustion and gasification of wood-derived biomasses are fairly wellknown. The most essential uncertain factors in the use of agrobiomasses are related to their ash behaviour. It is difficult to draw any unambiguous conclusions from the behaviour of these fuels in gasification on the basis the composition and fusion behaviour of ashes. Wide variations in the ash composition and other characteristics of agrobiomasses may give cause for the hypothesis that difficulties will be met in the use of these fuels both in the feed and stable gasification of the fuel and in the purification and clean combustion of the product gas.

- A more profound characterisation of the fuels would require gasification experiments in a thermobalance and a PDU (Process Development Unit) rig.

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BULK DENSITY OF BIOMASS FEEDSTOCKS

	Bulk density (loose) *			Bulk density (FEM) **		
	kg/m^3	kg d.b./m^3	moisture %	kg/m^3 compacted	kg/m^3 loose	compaction, %
Northern Woody Biomasses						
Wood chips	238	229	3.87	257	237	9
Forest residue chips Finnish	313	293	6.30	339	301	13
Forest residue chips Swedish, high ash	271	254	6.32	288	260	11
Saw dust (pine)	177	150	15.30	210	186	13
Spruce bark	289	274	5.25	324	289	12
Pine bark	230	219	4.74	242	208	16
Salix	227	222	2.39	243	212	15
Agricultural Biomasses						
Wheat straw (Danish)	79	71	10.25	75	56	34
Barley straw (Finnish)	82	73	11.53	85	64	34
Rapeseed	110	101	8.35	113	93	21
Flax (whole straw)	126	115	8.35	119	83	44
Flax (shive)	114	106	6.60	111	85	31
Reed canary grass	88	81	7.68	90	67	30
European Biomasses						
Sweet sorghum (Italy)	107	99	7.04	115	88	31
Kenaf (Italy)	138	128	7.52	148	119	24
Miscanthus (Italy)	139	131	5.74	131	101	30
Cane (Italy)	219	206	5.77	221	177	25

* 1 litre batch, not shaken
** Féderation Européenne de la Manutention

PROXIMATE ANALYSES AND HEAT VALUES

	Proximate (wt% d.b.)			Heat value (MJ/kg d.b.)		
	Volatile matter	Fixed carbon	Ash	HHV	LHV	Moisture (%) (as received)
Nothern Woody Biomasses						
Wood chips	80.0	19.40	0.60	20.89	19.56	3.87
Forest residue chips Finnish	79.3	19.37	1.33	20.67	19.34	6.30
Forest residue chips Swedish, high ash	74.1	21.85	4.05	20.54	19.27	6.32
Saw dust (pine)	83.1	16.82	0.08		19.03	15.30
Spruce bark	75.2	22.46	2.34	19.83	18.54	5.25
Pine bark	73.0	25.28	1.72	20.95	19.70	4.74
Salix	79.9	18.92	1.18	19.75	18.42	2.39
Agricultural Biomasses						
Wheat straw (Danish)	77.7	17.59	4.71	18.94	17.65	10.25
Barley straw (Finnish)	76.1	18.02	5.88	18.68	17.43	11.53
Rapeseed	79.2	17.94	2.86	19.33	18.04	8.35
Flax (whole straw)	78.8	18.27	2.93	20.04	18.71	8.35
Flax (shive)	78.6	19.59	1.81	20.19	18.86	6.60
Reed canary grass	73.5	17.65	8.85	18.37	17.13	7.68
European Biomasses						
Sweet sorghum (Italy)	77.2	18.06	4.74	18.91	17.65	7.04
Kenaf (Italy)	79.4	16.97	3.63	18.58	17.32	7.52
Miscanthus (Italy)	78.5	18.19	3.31	19.03	17.72	5.74
Cane (Italy)	77.9	18.40	3.70	18.06	16.75	5.77
Miscanthus (Germany)	79.3	18.40	2.30	19.43	18.13	8.60

ULTIMATE ANALYSES AND TRACE COMPONENTS

	Ultimate (wt% d.b.)						Trace components (ppm-wt, d.b.)		
	C	H	N	O (diff.)	S	Ash	Na	K	Cl
Nothern Woody Biomasses									
Wood chips	51.8	6.10	0.30	41.19	0.01	0.60	42	983	42
Forest residue chips Finnish	51.3	6.10	0.40	40.85	0.02	1.33	76	1377	76
Forest residue chips Swedish, high ash	51.0	5.80	0.90	38.21	0.04	4.05	640	2604	<50
Saw dust (pine)	51.0	5.99	0.08	42.82	0.00	0.08	20	480	<50
Spruce bark	49.9	5.90	0.40	41.43	0.03	2.34	89	3003	279
Pine bark	52.5	5.70	0.40	39.65	0.03	1.72	29	2133	85
Salix	49.7	6.10	0.40	42.59	0.03	1.18	37	4058	37
Agricultural Biomasses									
Wheat straw (Danish)	47.3	5.87	0.58	41.49	0.07	4.71	140	5480	1710
Barley straw (Finnish)	46.2	5.70	0.60	41.54	0.08	5.88	333	12188	2737
Rapeseed	48.1	5.90	0.80	42.13	0.21	2.86	166	5768	965
Flax (whole straw)	49.1	6.10	1.30	40.45	0.12	2.93	133	5147	588
Flax (shive)	50.3	6.10	0.60	41.12	0.07	1.81	87	3362	381
Reed canary grass	45.0	5.70	1.40	38.91	0.14	8.85	154	3479	639
European Biomasses									
Sweet sorghum (Italy)	47.3	5.80	0.40	41.67	0.09	4.74	678	4614	2996
Kenaf (Italy)	46.6	5.80	1.00	42.83	0.14	3.63	517	7254	1748
Miscanthus (Italy)	47.9	6.00	0.60	41.64	0.55	3.31	259	9702	3266
Cane (Italy)	47.7	6.00	0.50	41.94	0.16	3.70	183	9706	2922
Miscanthus (Germany)	48.6	6.00	0.30	42.72	0.08	2.30	27	3027	1405

ASH ANALYSES AND ASH FUSION TEMPERATURES

	Ash, %	Ash analysis (g/kg)										Fusion Temperature (°C), oxid.atm.				Fusion Temperature (°C), red.atm.			
		Ca	Na	Al	Fe	Ti	Mg	K	Si	S	P	Init. deform	Softening	Hemispher	Fluid	Init. deform	Softening	Hemispher	Fluid
<u>Nothern Woody Biomasses</u>																			
Wood chips	0.60	240	1.6	27.0	15.0	0.34	31.0	100	110	6.5	21.0	1210	1225	1250	1275	1230	1240	1245	1290
Forest residue chips Finnish	1.33	110	2.6	25.0	26.0	3.00	24.0	69	180	6.5	14.0	1175	1205	1230	1250	1175	1225	1245	1260
Forest residue chips Swedish, high ash	4.05	85	12.0	30.0	14.0	2.10	11.0	34	130	5.4	7.7	1180	1190	1205	1235	1200	1210	1225	1240
Saw dust (pine)	0.08	299	2.0	10.6	12.9	0.70	71.2	102	39	7.8	22.9	1150	1180	1200	1225	1135	1165	1185	1205
Spruce bark	2.34	280	2.8	5.7	1.0	0.21	31.0	63	7	3.9	18.0	1405	1550	1650	1650	1565	1580	1650	1650
Pine bark	1.72	290	3.7	28.0	2.1	0.46	27.0	63	6	8.2	21.0	1340	1525	1650	1650	1375	1504	1506	1507
Salix	1.18	220	2.0	1.6	1.3	<0.1	31.0	220	2	12.0	50.0	1490				1570			1580
<u>Agricultural Biomasses</u>																			
Wheat straw (Danish)	4.71	52	3.5	4.3	3.8	0.25	11.0	140	280	4.4	9.9	860	1030	1045	1365	950	1040	1060	1410
Barley straw (Finnish)	5.88	32	3.7	<1	1.2	<0.1	13.0	160	290	5.7	11.0	750			1050	850			1200
Rapeseed	2.86	210	2.8	2.5	6.6	0.40	3.8	140	15	43.0	39.0	1500			1600	1610			1630
Flax (whole straw)	2.93	243	3.4	3.8	3.5	0.31	31.0	199	17	15.0	67.0	1510			1550	1530			1620
Flax (shive)	1.81																		
Reed canary grass	8.85	25	<1	7.5	7.9	0.32	8.9	26	420	4.5	18.0	1455	1530	1585	1605	1490	1534	1610	1650
<u>European Biomasses</u>																			
Sweet sorghum (Italy)	4.74	64	11.0	3.5	3.7	0.32	16.0	68	270	12.0	13.0	975	1090	1257	1340	935			1060
Kenaf (Italy)	3.63	220	9.4	9.4	8.5	0.49	36.0	110	31	23.0	12.0	1585			1610	1630			1640
Miscanthus (Italy)	3.31	54	5.0	2.7	2.8	0.20	29.0	210	200	8.4	23.0	835	1005	1020	1220	920	1000	1170	1240
Cane (Italy)	3.70	35	5.5	5.2	3.0	0.42	21.0	200	230	33.0	26.0	1040	1050	1065	1070	930	1040	1080	1285

WOODY BIOMASSES AND EUROPEAN AND SCANDINAVIAN STRAWS

Figure 1. Miscanthus.

Figure 2. Kenaf.

Figure 3. Sorghum.

Figure 4. Cane (Arundo donax).

Figure 5. Straws of sorghum, kenaf and cane (Italy).

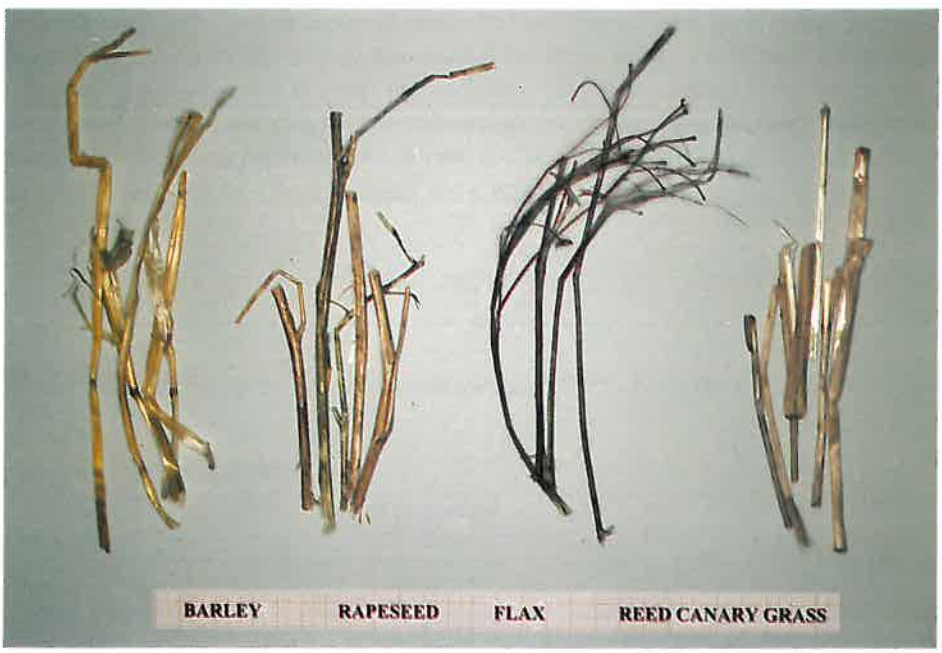

Figure 6. Strawsof barley, rapeseed, flax and reed canary grass (Finland).

Figure 7. Woody biomasses: wood chips, forest residue and crushed pine bark.

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Wilén, Carl
Moilanen, Antero
Kurkela, Esa

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Biomass feedstock analyses

Abstract

The overall objectives of the project "Feasibility of electricity production from biomass by pressurized gasification systems" within the EC Research Programme JOULE II were to evaluate the potential of advanced power production systems based on biomass gasification and to study the technical and economic feasibility of these new processes with diffrent type of biomass feedstocks. This report was prepared as part of this R&D project. The objectives of this task were to perform fuel analyses of potential woody and herbaceous biomasses with specific regard to the gasification properties of the selected feedstocks. The analyses of 15 Scandinavian and European biomass feedstock included density, proximate and ultimate analyses, trace compounds, ash composition and fusion behaviour in oxidicing and reducing atmospheres.

The wood-derived fuels, such as whole-tree chips, forest residues, bark and to some extent willow, can be expected to have good gasification properties. Difficulties caused by ash fusion and sintering in straw combustion and gasification are generally known. The ash and alkali metal contents of the European biomasses harvested in Italy resembled those of the Nordic straws, and it is expected that they behave to a great extent as straw in gasification. Any direct relation between the ash fusion behavior (determined according to the standard method) and, for instance, the alkali metal content was not found in the laboratory determinations. A more profound characterisation of the fuels would require gasification experiments in a thermobalance and a PDU (Process development Unit) rig.

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