Impact of different harvest times on ash fusibility of energy grasses

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Abstract

Hutla P., Jevič P., Strašil Z., Kočica J., 2012. **Impact of different harvest times on ash fusibility of energy grasses**. Res. Agr. Eng., *58*: 9–15.

Five different energy grass plants (reed canary grass, tall fescue, orchardgrass, tall oatgrass, red top) were identified and studied for the purpose of determining the fuel energy qualities of the plants' mass while focusing on ash fusion temperatures. The plants were cultivated on four different locations and harvested in various times of the year (early summer, autumn and spring of the following year). It was found that the ash fusion temperatures of plants harvested in early summer were substantially lower in comparison with the autumn and spring harvest. The analysis of the composition of the ashes gathered from samples of grass plants harvested in early summer contained a substantially higher level of potassium, higher level of sodium and higher level of anions Cl^- and PO_4^{3-}. SiO_2 is the most represented component in all of the ashes, with the late harvest having approximately 2–3 times higher level than the early one.

Keywords: solid biofuel; ash fusion temperature; melting point; renewable energy sources; biomass

Many different plant materials may be used for manufacturing of solid biofuels. Their comprehensive classification is included in the ČSN EN 14961-1 (2010). However, only those materials, which are readily available in relatively abundant quantities and suitable forms, are of practical importance. Aside from the wooden biomass, it is the plant biomass that is important for its straw pulp, as well as the grass cultivated for its high-energy quality and for the material harvested from permanent fields as part of agro-environmental measures, e.g. mowing and removing of the biomass.

In the Czech Republic, the permanent grass fields occupy approximately 907,000 ha which represents a yearly production of about 3 million tons of hay. The energy grass is becoming an important source of materials for solid biofuel production. The final form of the manufactured fuels is most commonly a bale with a circular or square cross section as well as a heating briquette or a pellet.

The fuel energy parameters of the energy grass as biofuels was sufficiently described and documented in literary sources (Malaťák, Vaculík 2008). In those, ash fusibility was recognized as an important feature which determines the quality and usefulness of the end product. In principle, it has been acknowledged that the ash fusion temperature from the solid fuels, e.g. bio fuels, is required to be as high as possible. In practice, a sufficient level is 1,000–1,100°C. These requirements are generally

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. 2B06131.

fulfilled by biofuels produced from trees, either from established forests or fast-growing plantations (Havlíčková 2008). On the contrary, low levels are typically identified in case of straw pulp (Hutla, Mazancová 2009) where the identified ash fusion temperatures are 700–800°C. The fuel qualities of the mentioned harvested plant materials were investigated also in terms of dependency on the time (season) of the harvest. It was discovered that the fuel quality of reed canary grass, harvested in spring has substantially increased (Burvall 1997). The content of alkaline materials and chlorine has lowered by 2 to 6 times, which, among others, contributes towards an increase in ash fusion temperature from 1,070 to 1,400°C. Similar results, also in case of reed canary grass (Geber, Tuvesson 1993) were noted in terms of significant lowering of chlorine content in the spring harvest, as well as an increase of ash fusion temperature from 940 to 1,600°C.

The later, e.g. the spring, term of harvesting has a positive influence on the biomass quality of reed canary grass, however, there is an increase in the material loss (Yates et al. 2001) and decrease of N, P and K content in the biomass. Of course, most of the research includes data related to the qualities of the plant ashes without considering the term of their harvest during which the ash qualities were examined (Toscano et al. 2008). Twenty different plant materials were separated into three groups, based on the content and qualities of their ashes. The wood materials proved to be of optimum quality in comparison with plant biomass and materials containing starches which are known for low ash fusion temperatures. The ash fusion temperature in any given plant material can be subsequently manipulated by using specific additives. Research was done on the influence of several additives (kaolin, limestone, lime, dolomite, ophite, alumina). In the case of five different kinds of biomass (thistle biomass, brassica carinata, barley straw, almond shell, olive oil extraction residue) it was found that the ash fusion temperature increased (Llorente et al. 2008).

MATERIAL AND METHODS

Selected species of grasses, those potentially suitable for manufacturing of solid biofuels, were cultivated during the span of two years at several locations. The grasses were harvested in different terms: in summer, in autumn and some were left at the location through the winter and harvested the following spring. The harvested materials were subjects to examination of the ash fusibility in order to confirm the fuel energy parameters. The method consist of making-up of mixture from pulverized ash and starch, out of which little cones 10 mm high are created. The cones are dried and then put in the electric furnace with eye sight. Then the temperature increases. At the ash deformation temperature (t_{DT}) the first sings of rounding of the edges of the test pieces due to melting occurs. At the sphere temperature (t_{ST}) the cone in transformed to the spherical form. The formation is spread out over the supporting tile in a layer at the ash flow temperature (t_{FT}). The selected material samples were subjects to an analysis regarding the presence of various elements in the ashes. Method of atomic absorbing spectrometry was used for this. The used apparatus was AAS1 (Carl Zeiss, Jena, Germany). Content of anions was gathered by ionic chromatograph ICS-1000 (Dionex, Sunnyvale, USA).

The following are the species identified as energy grasses:
– reed canary grass (*Phalaris arundinacea* L.)
– tall fescue (*Festuca arundinacea* Schreb.)
– orchardgrass (*Dactylis glomerata* L.)
– tall oatgrass (*Arrhenatherum elatius* L.)
– red top (*Agrostis gigantea* Roth.)

Table 1 identifies the four locations and their characteristics used for the cultivation of the energy grasses. The location Sokolov is situated on mine dumps in Sokolov coal-mining area, 3 km northeast from the city of Sokolov, Czech Republic.

RESULTS AND DISCUSSION

In 2007, two plants (reed canary grass and tall fescue) were harvested in the location Prague-Ruzyně during the spring and autumn seasons. The fuel energy qualities and element analysis is shown in Table 2. As shown in this table, the fuel energy qualities are not dependent on the term of the harvest when comparing the harvest of the material being done in the autumn and then the following spring. The ash fusion temperatures of ash-melting values are relatively high and in practice they make possible to produce fuels which most likely will not be subject to smelting of ashes in the heating chambers.

In 2008, energy grasses were cultivated at the location Sokolov and harvested in early July and

Table 1. Characteristics of experimental cultivation locations

Experimental place	Prague-Ruzyně	Lukavec u Pacova	Sokolov (mine dump)	Bratkovice u Příbrami
Location	50°04'N 14°26'E	49°37'N 15°03'E	50°14'N 12°39'E	49°44'N 13°59'E
Above sea level (m)	350	620	570	446
Soil kind	clayey-loamy	sand-loamy	clayey (uncovering)	sand-loamy
Soil type	brown soil	kambisoil	anthropogenic	brown soil
Average temperature of air during a year (°C)	7.7	6.8	7.1	8.0
Average summary of rainfall during a year (mm)	517	686	650	632
pH (KCl)	5.6	6.1	6.0	3.9
P (Mehlich II) (mg/kg of soil)	124.9	131.0	100	22[1)]
K(Mehlich II) (mg/kg of soil)	126.0	166.0	170	180[1)]

[1)]Mehlich III

at the end of October. The fuel energy analysis is shown in Table 3. From the listed values it is clear that the fuel energy qualities are quite similar in the case of all samples, with the exception of the ash fusion temperatures. These values are greatly dependent on the term of the harvest. The values related to the autumn term of reed canary grass correspond to the values shown in Table 2.

As a follow-up, in 2009, energy grasses were cultivated at the location Ruzyně, again subject to the summer and autumn harvesting. Selected qualities, in this case content of water, ashes and ash fusion temperatures are shown in Table 4. The plants were repeatedly cultivated and studied at the same location in 2010 (harvest spring 2010 and June 2010). The findings are shown in Table 5. The data in both

Table 2. The fuel energy parameters of reed canary grass and tall fescue (Prague-Ruzyně 2007)

Sample	Unit	Reed canary grass		Tall fescue	
		autumn	spring	autumn	spring
Water	% (w)	6.11	7.01	6.68	6.98
Volatile matter	% (w)	69.59	67.39	68.21	66.39
Involatile matter	% (w)	16.72	18.18	17.72	18.72
Ash	% (w)	7.58	7.42	7.38	7.90
C	% (w)	41.93	42.30	41.88	41.90
H	% (w)	5.68	5.71	5.66	5.80
N	% (w)	0.923	0.725	0.893	0.731
S	% (w)	0.28	0.15	0.30	0.19
O	% (w)	37.73	38.20	36.99	37.20
Cl	% (w)	0.20	0.10	0.17	0.09
Combustion heat	MJ/kg	18.61	18.32	18.43	18.40
Heating value	MJ/kg	17.41	17.12	17.20	17.18
Ash					
t_{DT}	°C	1,180	1,150	1,110	1,100
t_{ST}	°C	1,190	1,170	1,160	1,160
t_{FT}	°C	1,200	1,210	1,190	1,210

Table 3. The fuel energy parameters of energy grasses (Sokolov 2008)

Sample	Unit	Reed canary grass		Tall oatgrass		Orchardgrass	
		summer	autumn	summer	autumn	summer	autumn
Water	% (w)	6.49	6.55	5.57	6.82	6.29	7.49
Volatile matter	% (w)	69.06	69.51	71.34	71.02	70.31	68.99
Involatile matter	% (w)	17.21	15.25	15.25	13.83	16.60	15.86
Ash	% (w)	7.24	8.69	6.84	8.33	7.52	7.66
C	% (w)	41.57	41.21	43.18	41.82	42.33	42.71
H	% (w)	5.17	5.19	5.41	5.56	5.56	5.29
N	% (w)	1.28	0.62	0.98	1.07	1.18	0.76
S	% (w)	0.07	0.16	0.11	0.11	0.15	0.08
O	% (w)	38.18	37.58	36.91	36.29	36.97	36.01
Cl	% (w)	0.119	0.101	0.096	0.099	0.047	0.069
Combustion heat	MJ/kg	16.91	16.79	17.40	17.21	17.22	17.65
Heating value	MJ/kg	15.63	15.50	16.07	15.84	15.86	16.32
Ash							
t_{DT}	°C	780	1,130	770	910	770	1,120
t_{ST}	°C	820	1,170	780	940	780	1,130
t_{FT}	°C	850	1,210	810	985	810	1,150

tables clearly confirm the fact that energy grass harvested in June has a substantially lower ash fusion temperature in comparison with the later harvests. Examination of the element composition of the ashes, including anions followed. The results related to Table 5 are shown in Table 6. Samples of the ashes from plants harvested in June contain carbon as a result of fusion of this element with the actual ashes prior to its oxidation. Above all, Table 6 shows fundamentally higher content of potassium

Table 4. Some fuel energy parameters of energy grasses (Prague-Ruzyně 2009)

	Harvest	Water	Ash	t_s	t_{DT}	t_{ST}	t_{FT}
		% (w)		°C			
Reed canary grass	June	7.52	9.52	710	760	790	820
	October – 2nd mow	7.68	10.21	1,050	1,150	1,160	1,185
	October – 1st mow	7.81	9.91	1,140	1,200	1,240	1,260
Tall oatgrass	June	7.90	8.12	690	790	820	840
	October – 2nd mow	7.68	7.82	1,160	1,300	1,320	>1,340
	October – 1st mow	7.58	14.22	1,125	1,280	1,290	1,310
Orchardgrass	June	8.01	8.51	750	770	790	800
	October – 2nd mow	8.24	9.67	1,140	1,160	1,180	1,235
	October – 1st mow	7.82	9.70	1,080	1,200	1,220	1,250
Tall fescue	June	7.90	8.23	710	810	830	860
	October – 2nd mow	8.03	7.34	1,020	1,080	1,100	1,140
	October – 1st mow	8.11	8.53	1,050	1,130	1,160	1,230

Table 5. Some fuel energy parameters of energy grasses (Prague-Ruzyně 2010)

	Harvest	Water	Ash	t_S	t_{DT}	t_{ST}	t_{FT}
		% (w)		°C			
Reed canary grass	spring	6.69	8.43	>1,200	>1,340	>1,340	>1,340
	June	6.91	8.91	700	835	890	910
Tall oatgrass	spring	6.89	7.58	1,150	>1,340	>1,340	>1,340
	June	6.22	6.24	680	790	830	850
Orchardgrass	spring	7.29	7.65	1,100	1,260	1,280	1,300
	June	7.26	8.05	730	740	760	770
Tall fescue	spring	7.12	8.11	>1,200	>1,340	>1,340	>1,340
	June	7.21	8.40	700	835	860	885

in the ashes from the June-harvested grasses. Potassium has the potential to act as a melting agent, which might explain the low ash fusion temperature as well as fusion of carbon. These samples have also shown a higher content of sodium, however, in a substantially lower rate. In terms of anions, the content of Cl^- and PO_4^{3-} is fundamentally different in each of the harvests. There is also a great difference in the content of SiO_2 which is the largest component of the ashes, being 2–3 time higher in case of the later harvest.

To confirm the conclusions from the location Ruzyně, qualities of the energy grass ashes were also studied at the location Lukavec, Czech Republic. The grass was harvested in spring 2010. The results are shown in Table 7. These data also confirm relatively high ash fusion temperatures from the spring-harvested plants.

Table 6. Elements composition and content of anions of energy grasses (Prague-Ruzyně 2010)

Sample	Harvest spring				Harvest June			
	reed canary grass	tall oatgrass	orchardgrass	tall fescue	reed canary grass	tall oatgrass	orchardgrass	tall fescue
	% (w)							
Ca	1.78	4.54	5.61	2.82	1.91	2.58	2.42	2.62
Mg	0.35	1.21	1.56	1.59	0.98	0.92	1.27	1.62
Na	0.21	0.29	0.35	0.49	0.55	0.74	1.46	0.73
K	1.00	1.85	2.12	1.12	22.11	28.07	36.33	33.89
Fe	0.22	0.87	0.59	0.11	0.285	0.041	0.076	0.091
Mn	0.08	0.076	0.21	0.038	0.068	0.026	0.094	0.075
Zn	0.03	0.015	0.024	0.028	0.011	0.015	0.016	0.015
Cu	0.02	0.028	0.017	0.018	0.009	0.014	0.017	0.012
F^-	0.013	0.013	0.005	0.007	0.009	0.006	0.004	0.005
Cl^-	0.11	0.188	0.069	0.17	5.96	3.89	9.34	9.19
NO_3^-	0.018	0.051	<0.01	0.012	0.021	0.035	<0.01	<0.01
PO_4^{3-}	0.66	0.410	0.56	0.52	1.88	2.69	4.89	4.38
SO_4^{2-}	0.84	0.938	1.57	0.92	4.11	1.37	2.98	3.30
SiO_2	89.28	76.70	75.36	78.12	50.85	40.84	24.47	25.35

Table 7. Some fuel energy parameters of energy grasses (Lukavec, harvest spring 2010)

	Water	Ash	t_S	t_{DT}	t_{ST}	t_{FT}
	% (w)		°C			
Reed canary grass	11.29	3.66	1,050	1,315	1,340	>1,340
Tall oatgrass	25.29	8.14	1,050	1,120	1,160	1,190
Orchardgrass	9.97	6.55	900	1,020	1,040	1,070

Table 8. Some fuel energy parameters of energy grasses (Bratkovice, harvest June 2010)

	Water	Ash	t_S	t_{DT}	t_{ST}	t_{FT}
	% (w)		°C			
Reed canary grass	7.19	4.64	860	835	890	970
Tall oatgrass	7.08	4.74	880	860	920	940
Tall fescue	7.89	4.89	1,020	1,040	1,060	1,080
Red top	6.99	5.18	860	840	860	880

Additionally, for comparison reasons, qualities of ashes produced by similar energy plants grown at the experimental field at Bratkovice, Czech Republic were also investigated. The field's soil contains an increased amount of heavy metals as a consequence of earlier mining activities. The following energy grasses were utilized: reed canary grass, tall oatgrass, tall fescue and red top. The findings about the selected fuel energy parameters are shown in Table 8. The findings regarding the values of ash fusion temperatures confirm once again the earlier findings regarding relatively low values in case of the grasses harvested in June.

CONCLUSION

The findings related to the values of ash fusion temperatures of energy grasses correspond to the values noted in earlier research. The value findings related to plants harvested in June are however substantially different from plants harvested in the later terms, e.g. late summer, autumn and spring of the following year. These conclusions could have impact on the production of solid biofuels made of these plants. For the same reason, it is more advantageous to use plant material which has a higher ash fusion temperature. During the burning of the solid fuels made of these materials, there is no smelting of the ashes in the heating chambers, or the level of smelting might be acceptable.

There is a possibility of using grasses for fuel production from permanent grass fields, which were funded according to the Decree of Government No. 79/2007 Coll. related to conditions and implementation of agro-environmental measures. The one condition for obtaining the funding is that the field is mowed at least twice a year – once by July 31 and once by October 31. It is obvious that in these cases, the plants from the first harvest will be a less a desirable material for production of solid biofuels.

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Received for publication April 18, 2011
Accepted after corrections June 10, 2011

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