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INTERREG III A
Southern Finland Estonia

COMPOSITION OF REED MINERAL MATTER AND ITS BEHAVIOR AT COMBUSTION

Aadu Paist, Ülo Kask, Livia Kask

INTRODUCTION

The purpose of this study was to increase our knowledge of chemical composition and melting behaviour of summer and winter harvested reed ash. In order to do this, we studied chemical composition of different sample ash (ashed in temperature 550°C) using conventional liquid phase chemistry method, elementary analyses in ENAS OY Jyväskyla Finland and determined the ash melting temperatures.

Ash melting temperatures was done according to technical specification CEN/TS 15370-1 (ISO 540) and by extracting melting behaviours from the ternary phase diagram K_2O -

REED AS SOLID FUEL

Ultimate analysis of reed

The elemental composition of organic mater of winter reed is analyzed in Vario EL CHNOS elementary analyzer and results are given in Table 3 and Table 4.

Table 3. Elemental composition of winter reed, %

Element	Ranges		Average
C	46.96	48.34	47.5
H	5.50	5.60	5.6
O	42.75	43.84	43.3
N	0.23	0.34	0.3
S	0.03	0.09	0.04
Cl	0.05	0.18	0.1

Table 4. Elemental composition of summer reed, %

Element	Ranges		Average
C	46.13	47.11	46.5
H	5.93	6.42	6.2
O	39.7	42.2	40.7
N	0.57	1.17	1.0
S	0.12	0.45	0.2
Cl	0.28	0.48	0.4

Moisture

Figure 2 illustrates the reed moisture content dynamics on years 2002 2005.

As solid fuel reed is rather specific, in natural condition suitable moisture content 18-20% for combustion facility is achieved not before March-April on some years even earlier.

Table 5. Content of some elements of ash winter reed, mg/kg (analyzed by ENAS Oy Jyväskyla, Finland)

Element	Ranges		Average
Ca	22 300	22 800	22 500
Mg	5 600	15 500	9 700
Na	14 300	70 700	36 633
K	35 700	80 200	57 300
Mn	1 200	3 700	2 033
Cd	0,30	0,73	0,47
Cr	30	76	46
Cu	30	89	55
Pb	33 - 39		36
Ni	9	11	10
Zn	140	490	297
S	12 400	31 800	19 067
Fe	1 500	2 300	1 967
Al	1 200	1 900	1 467
P	5 400	8 600	6 867
Cl*	0.05	0,18	0,14

*, % on dry bases

Ash melting behaviors

The method used for the determination melting of ash was done according to technical specification CEN/TS 15370-1. The fuel reed was ashed at the temperature of 550 °C. In the ash-melting test, the external shapes (shrinkage, deformation, hemisphere and flow of cylindrical pellets with height 3 mm and diameter equal to the height) were identified using high temperature microscope MOD 2 (Carl Zeiss), operated at temperature 200-1 500 °C. The temperature increase in the furnace was 10 °C/min. The four temperatures are identified as shrinkage starting temperature SST, deformation temperature DT, hemisphere HT and flow temperatures FT (Table 6). Test atmosphere oxidizing.

Figure 1: Moisture content of reed as received basis M_{ar} =18 20%, low calorific value as received basis

$q_{net,ar}$ = 14-15 MJ/kg, ash content dry basis A_d = 2-4%

Calorific value

The heat related during the combustion of fuel samples is measured in adiabatic calorimetric bomb in standard condition (CEN/TS 14918:2005).
Winter and summer reed calorific values and energy density on 20% moisture E_{20} are given in Table 1 and Table 2.

Table 1. Calorific values of winter reed, MJ/kg

Calorific value MJ/kg	Ranges		Average
q_b	18.62	19.16	18.92
$q_{gr,d}$ (dry matter)	18.62	19.16	18.91
$q_{net,d}$ (dry matter)	17.48	18.01	17.77
$q_{net,20}$ (20% moisture)	13.68	14.86	14.17
E_{20}, MWh/t	3.80	4.13	3.94

Table 2. Calorific values of summer reed, MJ/kg

Calorific value MJ/kg	Ranges		Average
q_b	18.33	18.77	18.51
$q_{gr,d}$ (dry matter)	18.31	18.75	18.49
$q_{net,d}$ (dray matter)	17.02	17.44	17.21
$q_{net,20}$ (20% moisture)	13.16	13.49	13.31
E_{20}, MWh/t	3.65	3.75	3.70

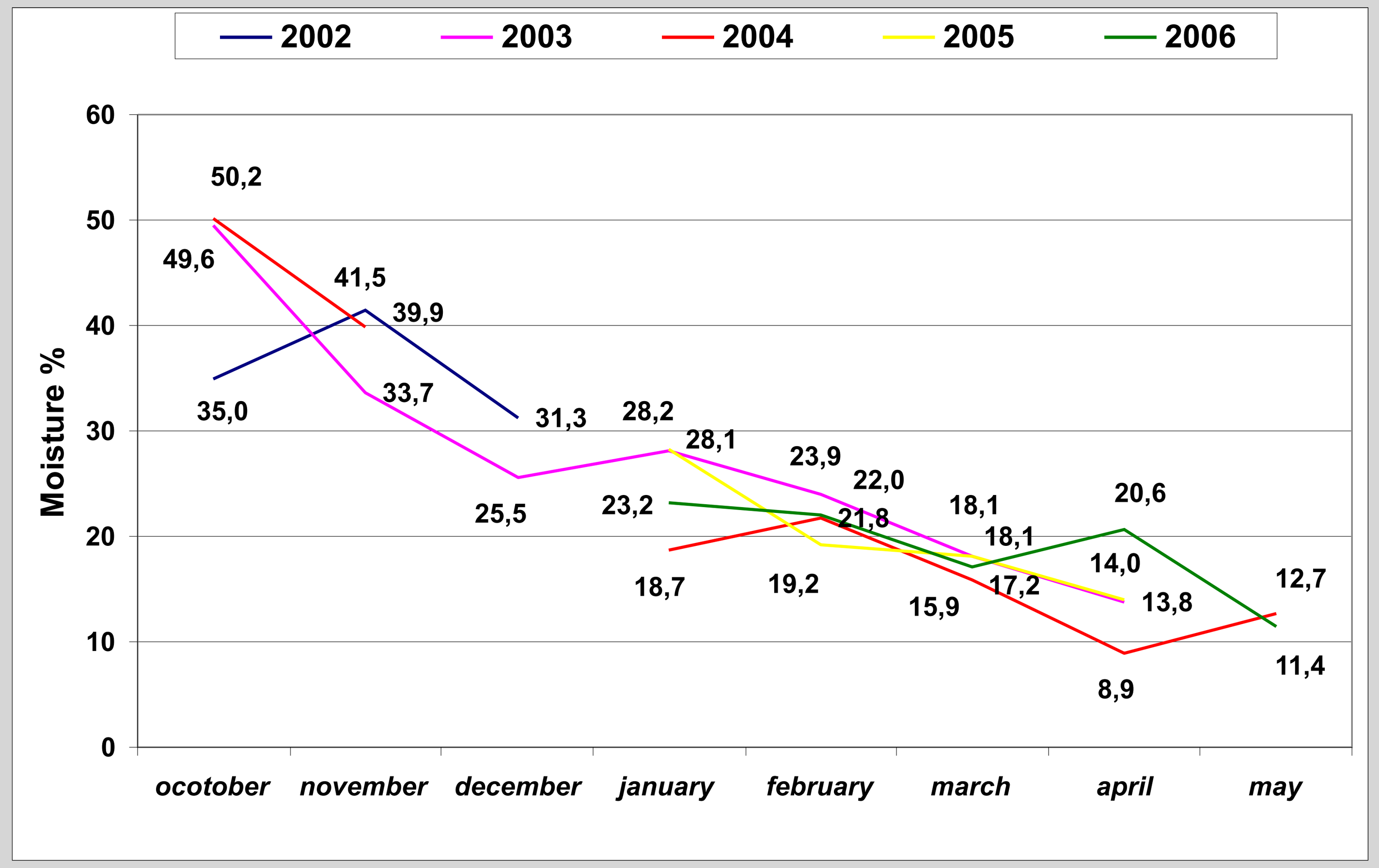

Figure 2: Reed moisture content dynamics 2002-2005

Ash, ash chemical composition.

Ash is formed from the minerals present in the fuel: but also a portion of the organic matter can be converted to ash and a portion of the mineral matter can volatilize.
The reed was ashed at 550±10 °C and chemical composition was determined using conventional liquid phase chemistry and detected by flame photometry. Ash content of the winter reed is within the range 2.1 4.4% average 3.2% and for summer reed essentially higher 4.1- 6.2% average 5.4% (Figure 3 and 4, Table 5).

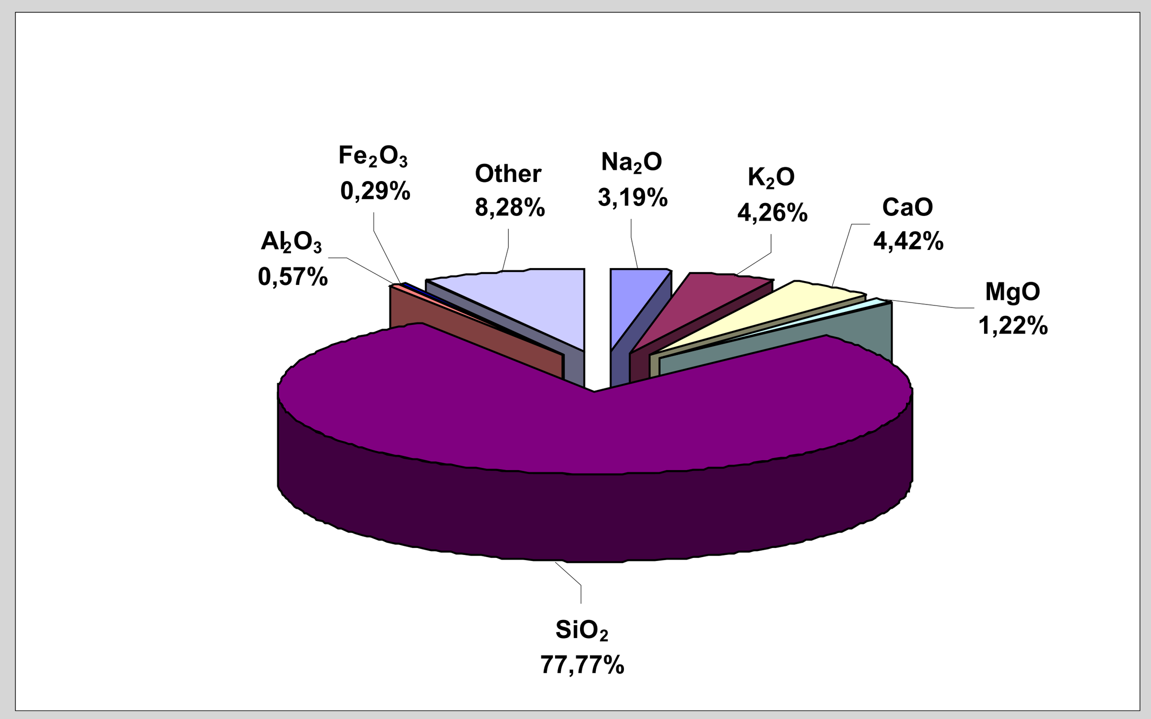

Figure 3: Chemical composition of winter reed ash, %

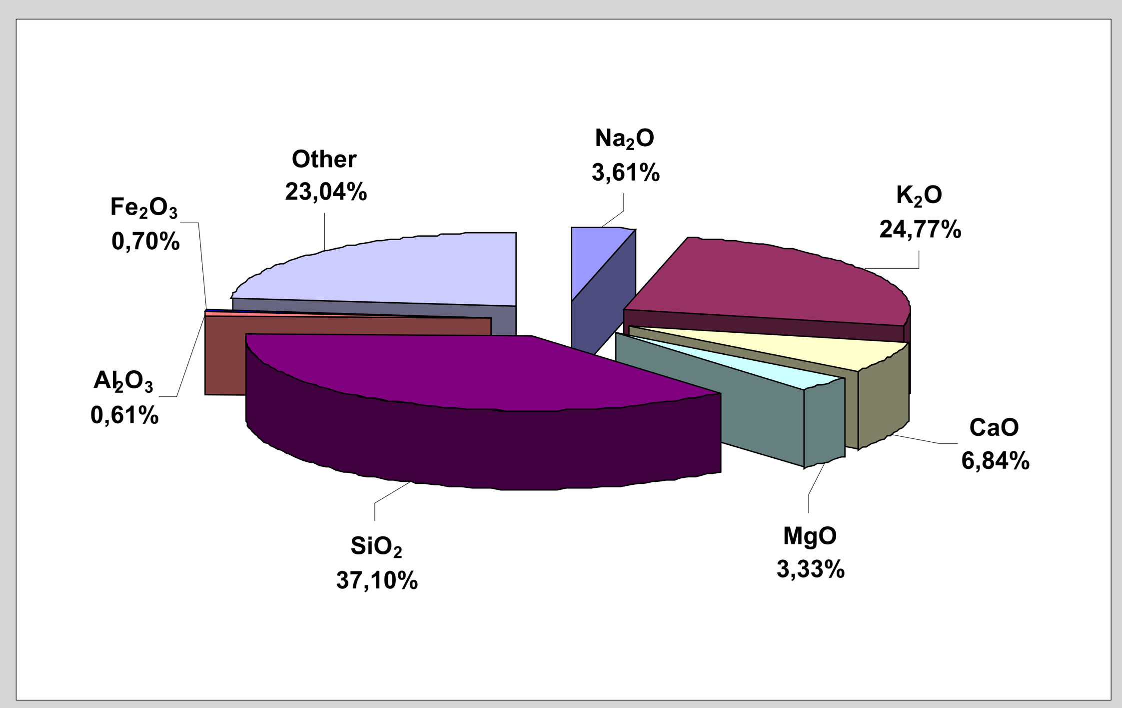

Figure 4: Chemical composition of summer reed ash, %

Table 6. Fusion and melting temperatures of ash of winter and summer reed, °C.

Temperatures	Winter reed Ranges	Summer reed Ranges
SST	790 1 270	580 - 730
DT	1 040 1 380	760 -1 030
HT	1 230 1 400	910 1 150
FT	1 270 1 450	990 -1 170

COMBUSTION TESTS

The first combustion tests were carried out in the boiler laboratory of Tallinn University of Technology (TUT). Small boiler with screw-feed equipment, mechanical fuel mixing hopper and stocker burner with nominal capacity of 250 kW was used. The first industrial test was made in district heating company Kuressaare Soojus Ltd where reed (waste from thatch building material) mixed with waste wood and successfully burned in the wood fuel boiler.

Reed as a fuel is very specific and therefore needs special furnaces and burning techniques. Burning

Crushed (refined) reed in a furnace, the volume of ash heap (residue) rather big, with loose structure, which prevents falling without mechanical stirring.

CONCLUSIONS

Reed as solid fuel for boilers is necessary to harvest certainly in winter, when the nutrients and minerals are leaved to the roots and leaves are fallen town. The winter harvested reed in this study showed low moisture and ash content compare with summer reed. The summer reed ash more melting occurred in the lower temperature range (<1 200°C) and for winter reed more melting occurred in the higher temperature range (>1 300°C). The most dominating ash forming elements in reeds are SiO_2, K_2O and CaO.

The K_2O-CaO-SiO_2 ternary diagram could therefore be useful for predicting melting behaviors of reed from different growing sites and seasons. Reed fuel properties and combustion tests showed that reed is promising renewable energy source.

ACKNOWLEDGEMENTS

The work was partially financed by the EU program Interreg IIIA project Reed Strategy for Finland and Estonia, and by the Ministry of Interior Affairs of Estonia.

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REED AS SOLID RENEWABLE BIOFUEL FOR ENERGY PRODUCTION

Aadu Paist, Ülo Kask

INTRODUCTION

Reed (*Phragmites australis* or *P. communis*) is a tall perennial grass in the family *Poaceae* which stands are common in Estonia, Sweden, Finland and many other places in Europe and North America. The total area of Estonian wetlands is 27 000 hectares, where is growing high productivity biomass 5- 6 t/ha per year, and in winter time average moisture content of reed is 20% and energy density 3,9 MWh/t. The total primary energy potential of harvestable reed from potential mowing area (13 00 hectares) is 290 GWh/y.

Laboratory combustion tests were carried out in Tallinn University of Technology in the boiler with stocker burner (250 kW capacity). Industrial tests in Kalevi Boiler Plant, Kuressaare (4 MW Saxlund boiler).

REED BEDS IN ESTONIA

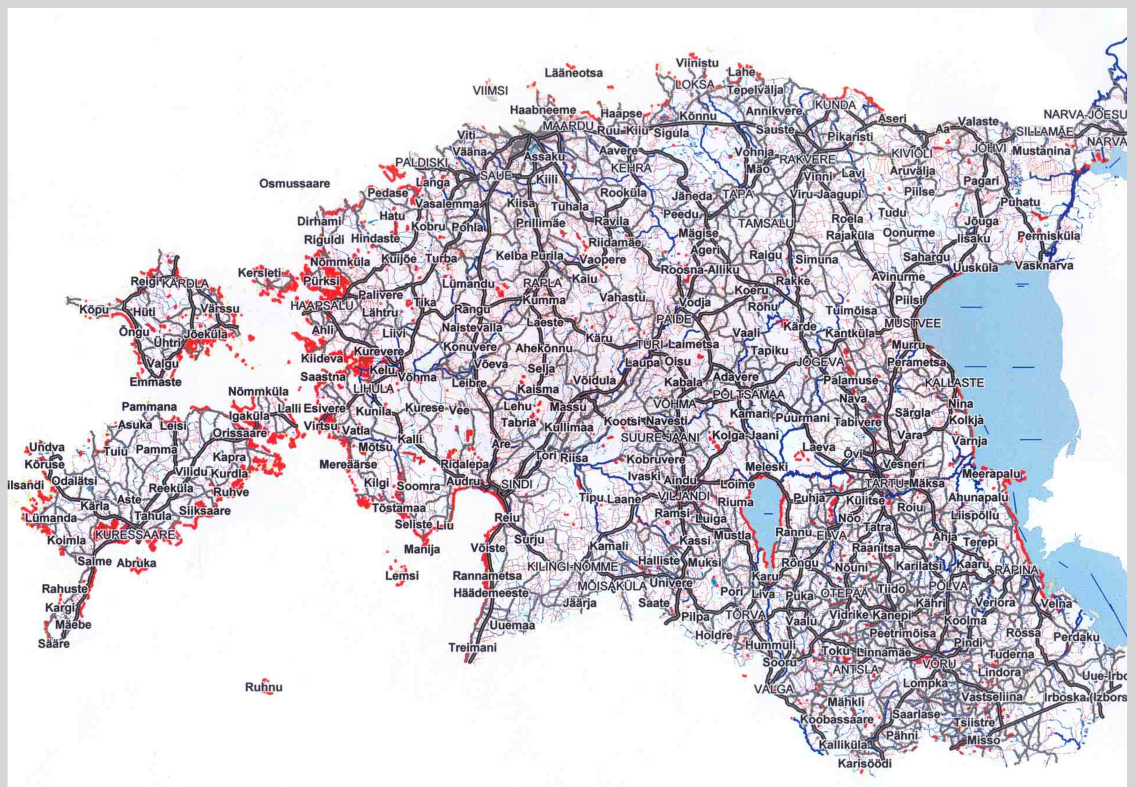

Figure 1. Location of reed beds in Estonia

Table 1. Calorific values of winter reed, MJ/kg: MWh/t

Calorific value MJ/kg	Ranges	Average
q_b	18.62 – 19.16	18.92
$q_{gr,d}$ (dry matter)	18.62 – 19.16	18.91
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Elemental composition

The elemental composition of organic mater of winter reed is analyzed in Vario EL CHNOS elementary analyzer and results are given in Table 2.

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Element	Ranges	Average
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Ash content and ash composition.

The reed was ashed at 550±10 °C and chemical composition was determined using conventional liquid phase chemistry and detected by flame photometry. Ash content of the winter reed is within the range 2.1 - 4.4% average 3.2% (Figure 4, Table 3).

Table 4. Fusion and melting temperatures of winter and summer reed ash, °C.

Temperatures	Winter reed Ranges	Summer reed Ranges
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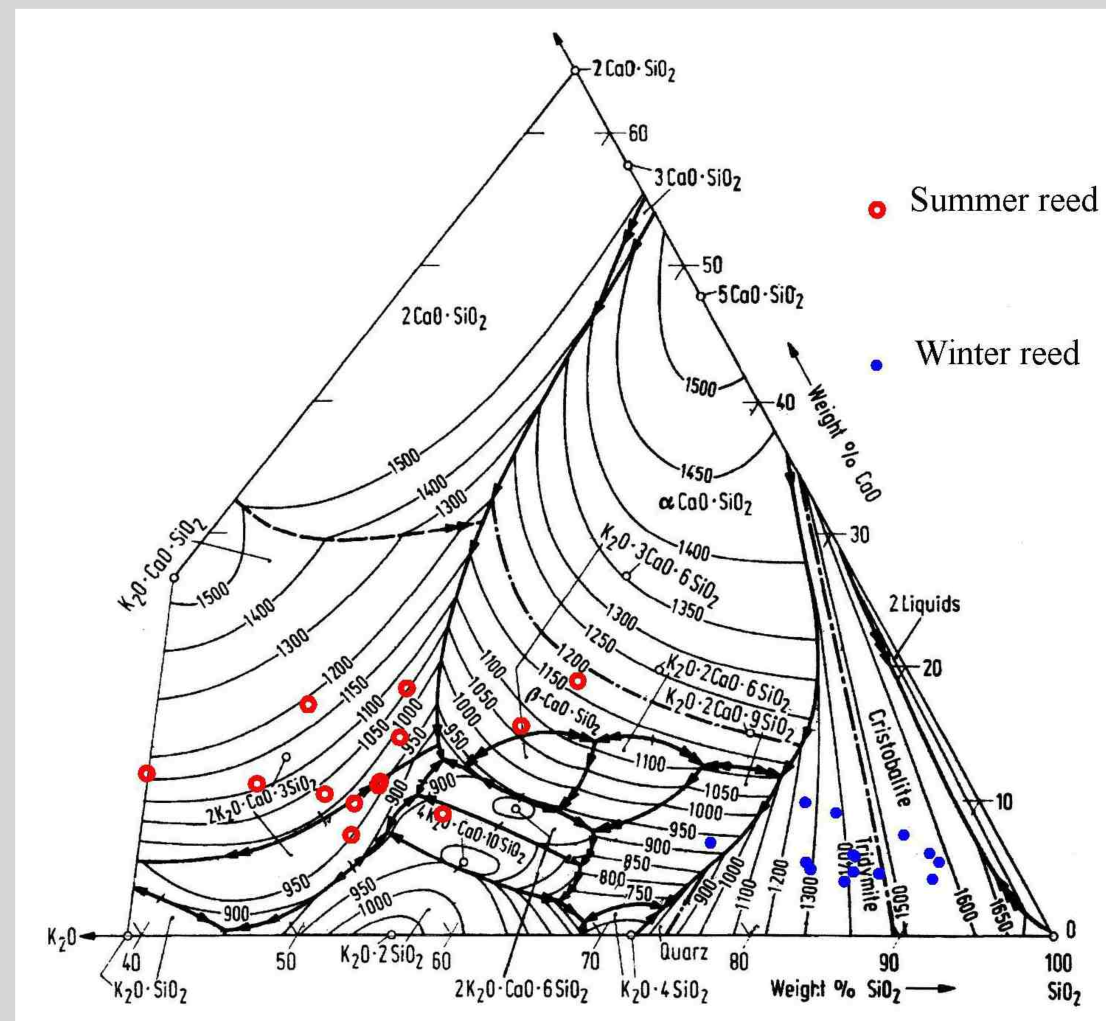

Figure 5. Ternary diagram with solidus temperatures and composition of the different samples of reed

REED PROPERTIES AS A FUEL

Moisture

Figure 2 illustrates the reed moisture content dynamics on years 2002- 2005.

As solid fuel reed is rather specific, in natural condition suitable moisture content 18-20% for combustion facility is achieved not before March-April on some years even earlier.

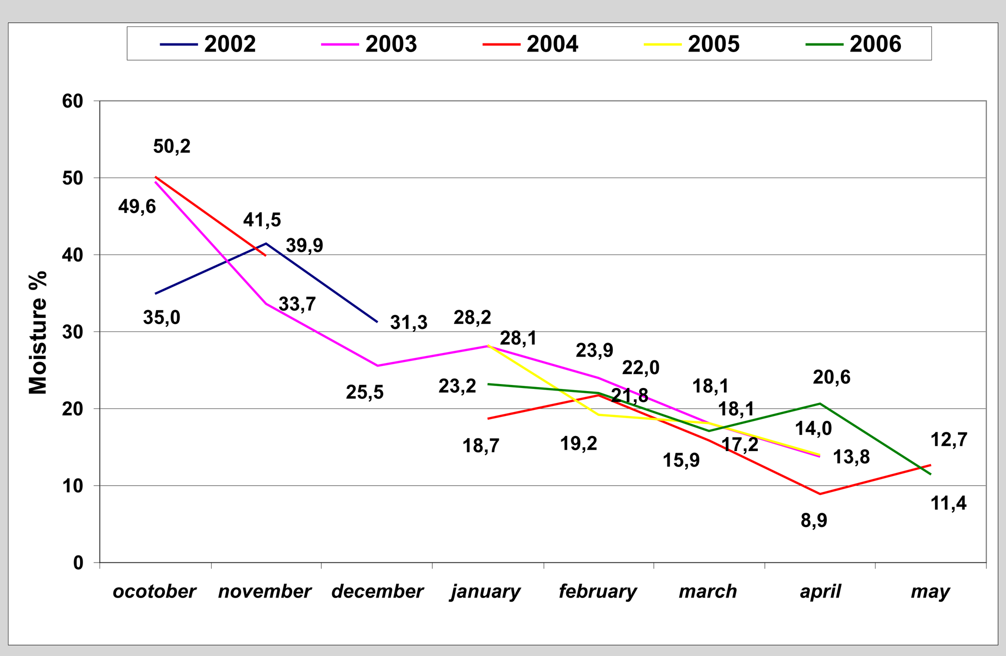

Figure 2. Reed moisture content dynamics 2002-2005

Calorific value

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Winter reed calorific value and energy density on 20% moisture E_{20} are given on Figure 3 and Table 1.

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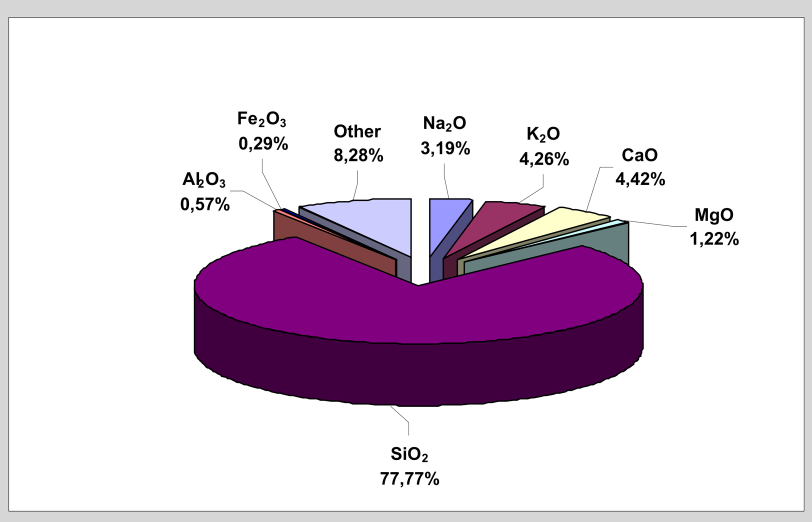

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P	5 400 – 8 600	6 867
Cl*	0.05 – 0,18	0,14

* %, analyzed in TUT

Ash-fusibility (melting temperatures)

The method used for the determination melting of ash was done according to technical specification CEN/TS 15370-1. The fuel reed was ashed at the temperature of 550 °C. In the ash-melting test, the external shapes (shrinkage, deformation, hemisphere and flow of cylindrical pellets with height 3 mm and diameter equal to the height) were identified using high temperature microscope MOD 2 (Carl Zeiss), operated at temperature 200-1500 °C. The temperature increase in the furnace was 10 °C/min. The four temperatures are identified as shrinkage starting temperature SST, deformation temperature DT, hemisphere HT and flow temperatures FT. Test atmosphere oxidizing (Table 4).

Figure 5 shows the K_2O-CaO-SiO_2 ternary diagram with solidus (initial melting) temperatures and the composition of the different summer and winter reed samples used in the study. Most of the winter reed ash samples are found in the Si-rich corner with initial melting temperatures 1250-1550°C.

PREPARING OF FUEL REED

For pressing of reed pellets the Agri 20 device is used. The reed pellets diameter was 8 mm and length from 8-40 mm.

Figure 6. Reed pellets

REED COMBUSTION TESTS

Laboratory combustion tests with crushed reed and co-combustion tests with wood chips were carried out in the boiler (250 kW) supplied with stocker burner . Reed pellets tests made in boiler Pelle (30 kW). Industrial co-combustion tests with bark and saw dust are made in 4 MW Saxlund boiler. Share of reed was about 7-10 % by weight. The burned reed gave additionally 5.5 - 6 MWh of heat.

CONCLUSIONS

Reed as solid fuel for boilers is necessary to harvest certainly in winter. The winter harvested reed showed low moisture and ash content compare with summer reed. The winter reed ash melting occurred in the high temperature range (>1300°C) wich has in good correlation with trenary diagram.

Reed fuel properties and combustion tests showed that reed is promising renewable energy source. It is technically suitable and economically visible to replace up to 10% of wood fuel with reed in coastal areas. The best way to burn reed pellets would be the underfeed stocker burner. The combustion of reed pellets in small boilers (10-30 kW) needs future investigations.

ACKNOWLEDGEMENTS

The work was partially financed by the EU program Interreg IIIA project Reed Strategy for Finland and Estonia, and by the Ministry of Interior Affairs of Estonia.

The opportunities to use *Phragmites australis* to energy production in heating systems of Estonia

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INTRODUCTION

Reed develops naturally as reed-beds and can be found on floodplains, waterlogged depressions and estuaries. Nutrients are moved down into the rhizomes and the above-ground portions of the plant die back for the season.

The wetlands in Estonia are covered by 2 7.000 hectares of *Phragmites australis*. Nowadays the most important use of reed beds is thatching industry.

The aim of this work is to analyze the use of *Phragmites australis* pellets to produce energy in Estonia, and the conditions of burning tests (ash content, fusibility of ash and gaseous emissions) with an evaluation between winter and summer time.

MATERIAL AND METHODS

To this work, were collected samples in some different wetlands covered with *Phragmites australis*, which can represent all Estonia. It was cut all the plants in one square meter, weight and measured the size. At least send to laboratory and use the methodology (Table I).

Table I - Summary of methodologies used for fuel, ash and gases analysis of *Phragmites australis*.

	Methods
Fuel	
Productivity	Measure the weight of 1 square meter of reed plants
Caloric value and Energy content	Measure in adiabatic calorimetric bomb IKA C 5000 according with ISO 540
Moisture content	Sample dried in air at 105 ± 2ºC
Contents on dry matter	Vario EL CHNOS elementary analyzer
Ash	
Ash Content	Heated to 550 ± 25ºC (oxidising atmosphere)
Elemental composition of reed ash	Used of conventional liquid phase chemistry and detected by flame photometry
Fusibility of ash	2g of ash in high temperatures until melting

Table II - Elemental contents in dry matter in 2006.

Elemental Contents in dry matter	Winter 2006	Summer 2006
C	47,52 %	46,5 %
H	5,56 %	6,2 %
O	43,34 %	40,7 %
N	0,30 %	1,0 %
S	0,04 %	0,2 %
Cl	0,10 %	0,4 %

Table III - Chemical composition of reed ash at 550ºC, in 2006.

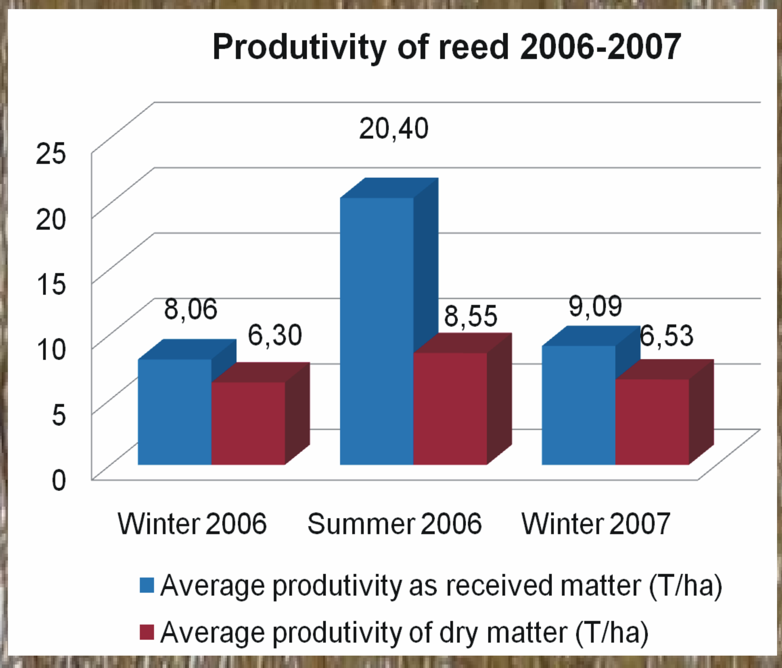
Chemical composition on ash	Winter 2006	Summer 2006
SiO_2	65,34 – 85,00	25,90 – 48,33
Fe_2O_3	0,13 – 0,84	0,17 – 1,69
Al_2O_3	0,10 –1,69	0,11 – 1,12
CaO	3,25 –7,27	4,02 – 11,53
MgO	0,40 –1,78	1,87 – 4,88
Na_2O	1,45 – 8,47	0,87 – 10,98
K_2O	1,96 – 9,05	14,89 – 31,33
Others	1,57 – 19,40	17,28 – 33,5

Table III - Average of oxygen, water vapor and gas emissions from the burning tests.

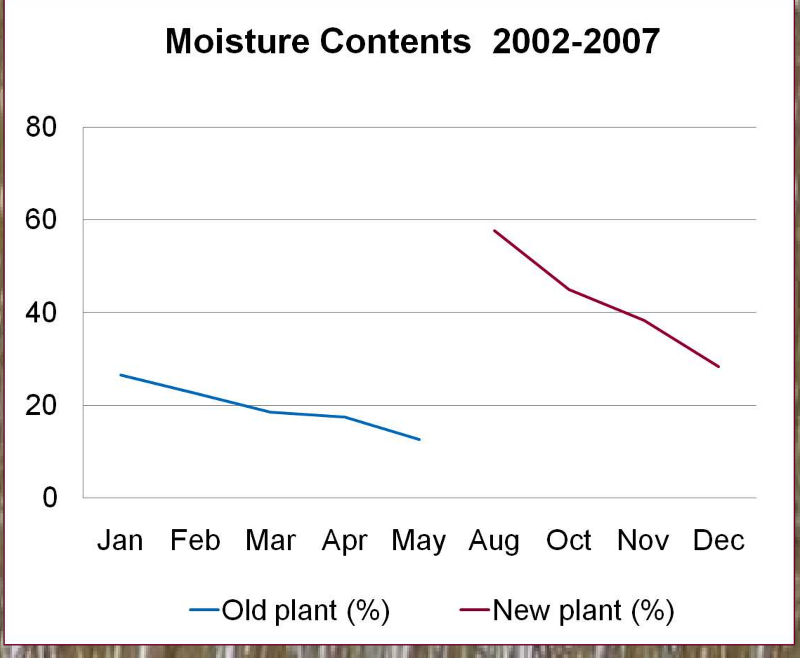
Gaseous Emissions – Components	Mean values
O_2 (%)	12,76
Water vapor H2O (%)	5,86
CO_2 (%)	6,09
NO (ppm)	78,47
SO_2 (ppm)	13,36
CO (ppm)	103,25
HCl (ppm)	7,02
CH_4 (ppm)	1,22

RESULTS

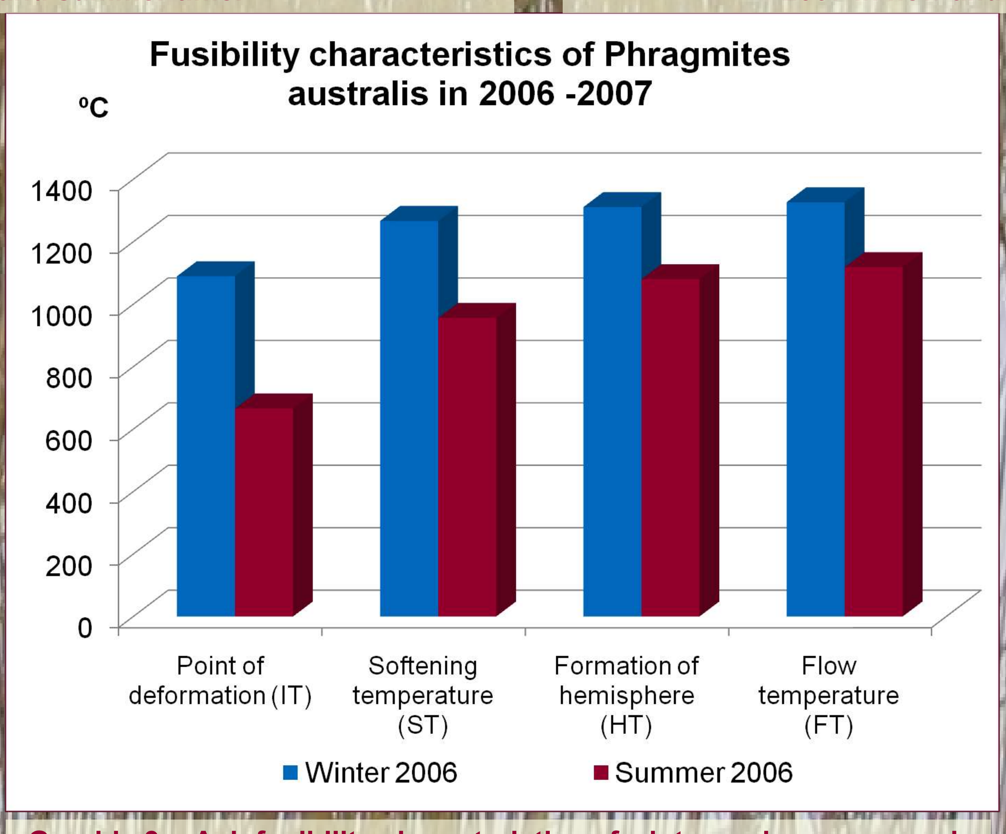
- **The productivity is higher in summer time than in winter (Graphic 1);**
- **In summer time, the level of moisture content is higher than in winter time. In winter the plants are frozen (Graphic 2);**
- **The organic matter of fuel is mainly consists by C, O and H. The content of N, S and Cl in the reed samples harvested in winter is low. The summer reed contains more N, S and Cl, unfavourable for burning compared with in winter harvested reed (Table II);**
- **The chemical composition of ash demonstrates that reed is a better fuel in winter time than in summer (Table III);**
- **The levels of alkali metals and sulphur content in ash are lower in winter time. It is also important for boiler metal selection (Table III);**
- **The ash content was significantly higher in summer (5,4%) than in winter time (3,2%);**
- **Fusibility of as presented higher temperatures in the winter than in summer harvested reed (Graphic 3);**
- **In gaseous emissions: when the levels of O_2 were lower, the levels of CO_2, NO and water vapour were higher (combustion working well); when O_2 decreased the combustion conditions changed and more CH_4 and CO were released (combustion not so good) (Table IV);**
- **The calorific value and energy density are also higher in winter time (14,2 MJ/kg and 3,94 MWh/t) than in summer (13,31 MJ/kg and 3,70 MWh/t).**



Graphic 1 - Average productivity of Estonian reed beds in winter and summer time.



Graphic 2 - Dynamics of moisture content since 2002 until 2007 in new and old reed-beds.



Graphic 3 - Ash fusibility characteristics of winter and summer reed.

CONCLUSIONS

b)The winter time reed harvests are more successful as a fuel, because the conditions of burning are better (moisture content, fusibility of ash, energy content, etc.) when the nutrients and minerals are stored in the roots and the leaves have fallen down.

b) The maxim um production of energy from burning of reed beds is 290-300 GWh in Estonia, (0,8% of all energy consumption in Estonia) but the all area can not be used in the same year. Ecologically is better not to cut all reed beds at the same time, because they also have an significant importance to biological systems.

c) Beside producers of reed thatches (roofs) and insulating materials may become competitors or suppliers who harvest reed for making fuel for local boiler houses. The demand of this product (biomass fuels) will increase in Estonia nearest future.

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