Combustion of Reeds in a 3 MW District Heating Plant

Hannes Kitzler, Christoph Pfeifer, and Hermann Hofbauer

***Abstract*—Reed (phragmites australis) from the Lake Neusiedl in Austria is investigated as energy source for thermal utilization. Reeds represent a cheap, locally available and renewable feedstock which is not used today. This paper presents the investigations and experimental results of thermal utilization of reeds in a 3 MW_{th} commercial district heating plant dedicated for combustion of wood chips. The results of fuel analysis show that reed is a high quality straw-type biomass with an ash deformation temperature of over 1400 °C. For the test runs, chopped reed was mixed with wood chips in various ratios. The results show that the higher sulphur and chlorine content in reed causes slightly higher SO_2 (25 ppm) and HCl (1.6 ppm) content in the flue gas. However, with higher ratios of reed in the feedstock no increasing of environmental harmful components such as dioxins and heavy metals can be measured. At the end of the test runs a short period of combustion with pure reed was carried out. It could be proven that reed is a suitable feedstock for commercial district heating plants.**

***Index Terms*—Combustion of reed, phragmites australis, renewables, straw-type biomass**

I. Introduction

Climate change is still under discussion and measures have to be taken to avoid further increasing of greenhouse gases in the atmosphere. In 2004 the United Nations presented that the world population will rise to almost 8.9 billion by 2050 [1]. Rising prosperity, especially in India and China, will cause an increase in energy consumption in the future. In the fourth assessment report 2007 [2] the Intergovernmental Panel on Climate Change (ICPP) prognoses an increase of the earth surface temperature between 1.1 and 6.4 °C until 2100, depending on the CO_2 content in the atmosphere.

In the last years, the European Union has been supporting biomass as renewable energy source to reduce CO_2 emissions [3]. Within the project ENEREED, Vienna University of Technology together with the University of Applied Sciences Burgenland investigates possibilities for thermal utilization of reeds. Around Lake Neusiedl in Austria up to 22,000 to/a [4] reed grows each year but only a small part is currently used. Today, reed is used in the building industry as roof or insulation material [5] for this reason, only high quality reed (so called class 1) can be used. Gamauf, 2000 [4] divided the quality of reeds in 4 different classes. Class 1 is young-reed, class 2 and 3 are young-reed with increasing amount of old-reed and class 4 is only old-reed. For combustion test runs presented in this paper only classes 2 and 3 were used. Class 4 is not usable for thermal utilization because of its low heating value and class 1 reed is preferably used for construction purposes and not for combustion. One of the main purposes for reed utilization is the extension of feedstock portfolio for district heating plants or for other heating devices e.g. as additional fuel in cement industry. Brandweiner [6] investigated very detailed the thermal utilization of reeds in one cement production plant located in Mannersdorf, Austria. The extension of feedstock portfolio would offer more flexibility and would give economic advantages for operators of such plants.

Reed (phragmites australis) is a widespread plant in the world [7-9]. A reeds stock of about 100,000 km^2ca be found worldwide, thereof 3,000 km^2in Europe [10]. Table 1 shows some of the largest reed stocks worldwide.

TABLE I: Worldwide Resources of Reed

Country	Area [km^2]	Literature source
Sowjet-Union	55,000	Rodewald-Rudescu, 1974 [10]
China	8,540	Gamauf, 2000 [4]
Danube Delta	2,000	Rodewald-Rudescu, 1974 [10]
Poland	600	Rodewald-Rudescu, 1974 [10]
North Korea	300	Rodewald-Rudescu, 1974 [10]
South Korea	200	Rodewald-Rudescu, 1974 [10]
Hungary	262	Rodewald-Rudescu, 1974 [10]
Austria – Lake Neusiedl	60	Brunner, 2008 [11] and Gamauf, 2000 [4]

A. Properties of Reed

Reed is a fast growing plant and belongs to the family of sweet grasses [5]. It grows in wetlands or in standing, shallow water. The reed plant can be divided into rhizome, underwater stem and over water stem, see Fig. 1(a). Furthermore, Fig. 1(b) shows a picture of reeds at Lake Neuwied.

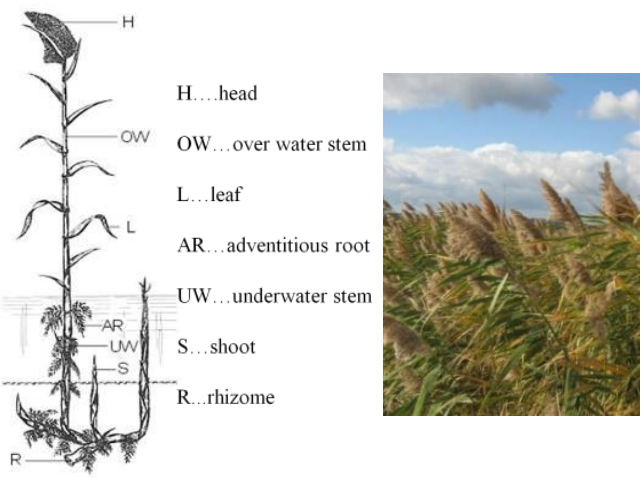

Fig. 1. (a) Structure of reeds, (b) Picture of reeds plants

Manuscript received July 10, 2012; revised June 3, 2012. This work was financial supported by the Austrian “Climate and Energy Fund” (carried out within the research promotion scheme “NEUE ENERGIEN 2020” and co-funded by the Government of the Province of Burgenland, Lafarge Zementwerke GmbH and Herz Energietechnik GmbH.

Authors are with the Institute of Chemical Engineering at Vienna University of Technology, Getreidemarkt 9/166, 1060 Vienna, Austria (e-mail: hannes.kitzler@tuwien.ac.at, christoph.pfeifer@tuwien.ac.at, hermann.hofbauer@tuwien.ac.at).

The rhizome fixes the stem to the ground, filters the nutrients out of the water and is important for the growth. The reeds around Lake Neusiedl can grow yearly up to 4 m in height whereas in other regions reeds can grow up to 8 m in height. The underwater stem has plenty of adventitious roots to supply the plant with water. For thermal utilization only the over water stem is suitable.

In Austria, legislative regulates that the harvest period of reed is in winter from 15th November to 15th of March. During this period the content of water, ash and nutrients (N, K, Cl, P, Mg) is decreasing [12].

The reed used during the test runs as well as for fuel analysis were harvested from February to March.

II. Test Facility

A flow sheet of the district heating plant, which was used for the investigations, is shown in Fig. 2. Biomass - in this case different mixtures of reed and wood chips - is burned with air by a conventional grate combustor. The biomass is combusted on an inclined stationary stair grate with three different zones. In the first zone, biomass is dried and devolatilized. In the second zone, biomass is burned and the third zone is important for complete combustion to ensure very low carbon content in the remaining ash. To control the combustion temperature as well as the emissions in the flue gas, secondary and tertiary air is blown into the combustion chamber. In addition, flue gas is recirculated to ensure low emissions (especially NOx-emissions) and to enable part-load operation. After the combustion chamber the hot flue gas is led through a tube bundle heat exchanger. The heat exchanger supplies the heat to the local district heating system. The heating plant supplies the heat to over 250 local consumers. The flue gas is cleaned with a multi-cyclone and an electrostatic precipitator downstream to the chimney. The sampling point for analysis of the composition of the flue gas is located between the multi-cyclone and the electrostatic precipitator as shown in Fig. 2.

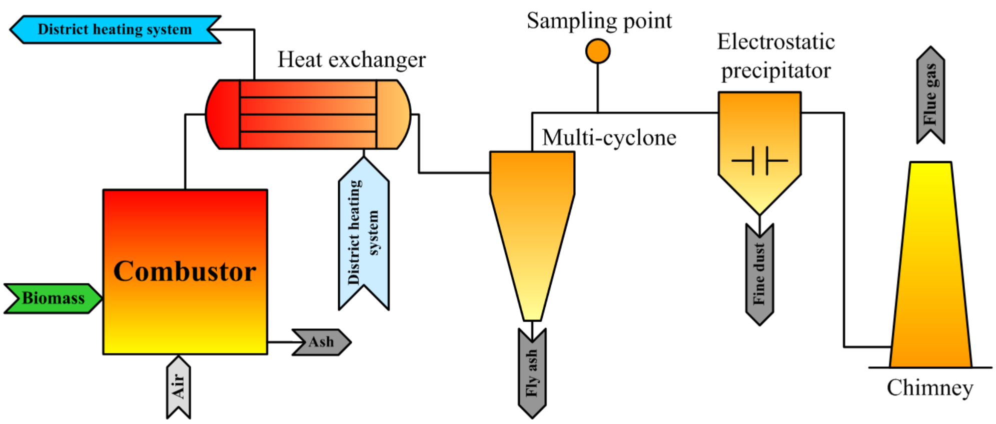

Fig. 2. Basic flowsheet of the 3 MWth district heating plant in Güssing, Austria

III. Analytical Equipment

A. Fuel Analysis

The fuel analyses were carried out by the Test Laboratory for Combustion Systems at the Vienna University of Technology. The CHN analysis to determine the content of carbon, hydrogen and nitrogen were accomplished by the Microanalysis Laboratory of the University of Vienna. All the analyses were performed according to DIN standards.

B. Gas Measurement

The gas measurements during the experiments were done online. Rosemount Multicomponent Analysers measured the flue gas components CO, CO_2, NO_x, SO_2 and O_2. The content of HCl was measured discontinuously with impinger bottles and IC analysis. For the organic carbon content a flame ionic detector (FID) was used.

C. Emissions

All emissions (CO, NO_x, SO_2, HCl, dust content, heavy metals, dioxides and furans) were measured according to the waste incineration regulation [13] valid in Austria.

IV. Experiments and Results

A. Characterization of the Fuels

Reed was analyzed before it was used as feedstock in the district heating plant. Therefore, the reed belt around Lake Neusiedl (60km²) was divided into three areas (north, middle, and south) and from each area, two to three samples were taken for analyses. Table 2 shows the results of the proximate and ultimate analyses of the reed samples compared to typical values for straw, miscanthus, energy crops and wood.

Table II shows that reed fits very well to the row of biomasses with respect to the ultimate analysis. Reed has a relatively low content of nitrogen, sulfur and chlorine and a high ash deformation temperature compared to the other fuels. The high ash deformation temperature is a result of the high silica and calcium content in the remaining ash.

For thermal conversion such as combustion or gasification, high ash deformation temperatures and low contents of N, S and Cl, as in reed, are preferred. The analyses of reed, shown in Table 2, fits very well compared to other straw type biomasses (e.g. miscanthus, straw) found in literature [15].

TABLE II: PROXIMATE AND ULTIMATE ANALYSIS OF REED (PHRAGMITES AUSTRALIS) COMPARED TO STRAW, MISCANTHUS, ENERGY CROPS AND WOOD

	unit	reeds	straw [15]	miscanthus [15]	energy crops [15]	wood [15]
water content, raw	wt %	12.43 ± 0.98	–	–	–	–
ash content, db	wt %	7.47 ± 2.04	4.8 – 12.2	3.9	4.1 – 4.4	0.5 – 2.0
carbon content, db	wt %	45.48 ± 1.21	42.5 – 47.5	47.5	44.0 – 48	47.1 – 49.8
hydrogen content, db	wt %	5.84 ± 0.18	5.1 – 6.0	6.2	5.8 – 6.4	6.1 – 6.3
oxygen content, db	wt %	40.52 ± 0.96	39.1 – 43.8	41.7	40.9 – 44.6	43.2 – 45.2
nitrogen content, db	wt %	0.47 ± 0.11	0.42 – 1.11	0.73	1.08 – 1.41	0.13 – 0.54
sulphur content, db	wt %	0.07 ± 0.02	0.082 – 0.27	0.15	0.11 – 0.18	0.045 – 0.015
chlorine content, db	wt %	0.15 ± 0.05	0.19 – 0.81	0.22	0.09 – 0.34	0.004 – 0.006
ash deformation temperature	°C	1409 ± 64	839 – 1336	973	833 – 977	1283 – 1426
lower heating value	kJ/kg	16187 ± 401	15800 – 17700	17600	17000 – 17700	18400 – 18800

B. Combustion Test Runs and Results

The test facility is a 3 MW_{th} heating plant and it is connected to a local district heating system with over 250 industrial as well as private consumers. The series of test runs lasted 4 days. At the first day only wood chips (0% reed) were burned to verify a reference point. At the second day 50% reed with 50% wood chips and at the third day 30% reed with 70% wood chips were examined. At the fourth day 100% reed was tried to incinerate in the heating plant.

On each day, the measurements started at 9 a.m. and ended at 5 p.m. In this time period, the power of the plant varied between 1.5 MW_{th} and 3 MW_{th}, depending on the heat supply demand to the district heating system. For evaluation of the system performance, illustrated in Table 3, periods of 1 to 2 hours with nearly constant conditions were used.

The presented gas components were measured at the sampling point shown in Fig. 2. For the measurement of organic bound carbon (C_{org}) a flame ionization detector (FID) was used. The content of dioxins, furans, heavy metals, dust, HCl, and HF were discontinuously measured. The dust and mercury content were sampled over half an hour. The dust content is much higher than allowed, but the sampling point is situated before the electrostatic precipitator. No dust measurement was carried out after the electrostatic precipitator but it can be assumed that the emission limits is fulfilled after the electrostatic precipitator. Heavy metals were sampled over 90 minutes whereas the dioxins and furans were measured over 6 hours. All components were measured according to the waste incineration regulations [13] valid in Austria.

Fig. 3-5 and Table III present the gaseous emissions dependent on the ratio (in wt-%) of reed in the feedstock. In Figures 4-5 the SO_2 and HCl contents are increasing with increasing reeds ratios in the feedstock. This is plausible, because the sulphur content as well as the chlorine content is higher in reed than in wood chips.

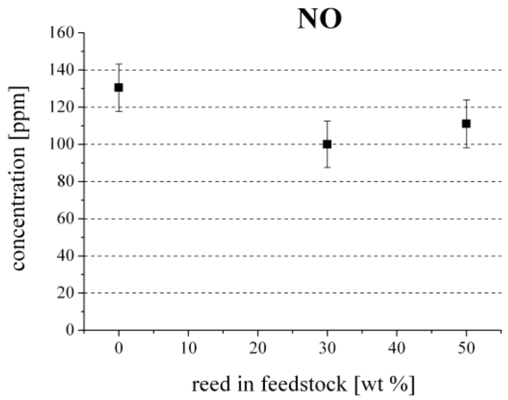

Fig. 3. NO concentration in the flue gas

TABLE III: OPERATION AND MEASUREMENT DATA FROM THE EXPERIMENTS

system data	unit	0% reed, 100% wood chips	30% reed, 70% wood chips	50% reed, 50% wood chips	limit[1] for half-hour average [13]
power	kW	2800 ± 430	2660 ± 180	2630 ± 240	-
combustion temperature	°C	880	836	934	-
flue gas temperature	°C	202	205	206	-
CO2 content, db	vol %	8.37	8.89	9.20	-
Corg content, db	mg/Nm³	1.1	3.0	0.7	10
HCl content, db	mg/Nm³	0.8	1.4	1.7	10
SO2 content, db	mg/Nm³	9.3	16.3	27.3	50
NO and NO2 content as NO2, db	mg/Nm³	272	207	231	300
CO content, db	mg/Nm³	30.5	30.2	14.4	100
dust content	mg/Nm³	209	71.3	84.8	10
Hg content	mg/Nm³	0.0004	0.0004	0.0004	0.05
Σ Cd, Tl	mg/Nm³	0.006	0.007	0.007	0.05[2]
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/Nm³	0.489	0.127	0.165	0.52
dioxins and furans	mg/Nm³	0.0276	0.0092	0.0307	0.1[3]

[1] This limit would be applied for a heating plant using only reed as feedstock up to 2,000 kg/h.
[2] Average value between 0.5 and 8 hours
[3] Average value between 6 and 8 hours

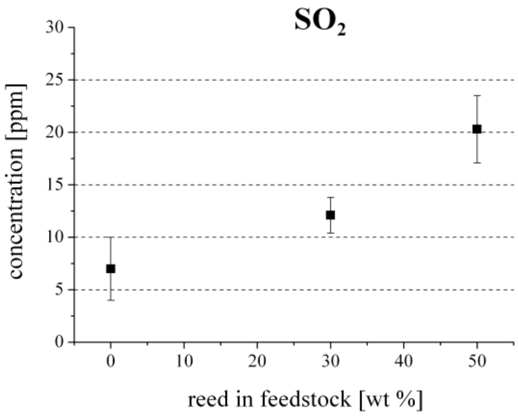

Fig. 4. SO_2 concentration in the flue gas

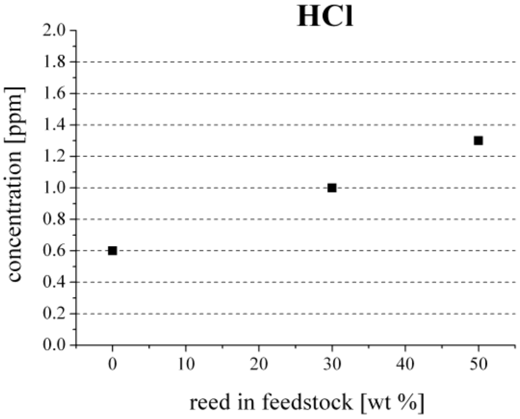

Fig. 5. HCl concentration in the flue gas

However, all emissions are below legislation limits for waste incineration in Austria, which is in good agreement with European legislation limits. In order to allow comparison with other combustion plants, all measured emissions shown in Figures 3-5 and Table 3 are calculated referred to an oxygen content of 13.0% in the flue gas.

After the test runs with mixtures of reeds and wood chips, a short run with 100% reed was carried out. It came to feeding problems during this run since the hydraulic push floor, which transports the fuel from the bunker to the combustion chamber, blocked. The reason is that the feeding system is designed for wood chips and not for reed. It would be necessary to adapt the feeding system if 100% reed should be used whereas no operational problems for the combustion occurred even when the plant was operated with 100% reed..

V. Conclusions

The fuel analysis results show, that reed can be classified as good quality straw-type biomass. Several values are even comparable to woody biomass (cf. Table 2). The ash melting temperature for reed is higher than that for typical woody biomass. This is due to a high silica and calcium content in the ash. Generally, reed has a high ash content, which has an adverse effect on the energy density.

The results of the combustion test runs show, that reed is a suitable feedstock for conventional biomass district heating plants. Up to 50% (based on energy) reed mixed with wood chips in the feedstock no problems occurred, neither at the feeding system nor at the flue gas emissions. At the end of the test runs a short run with 100% reed was carried out, but problems with the feeding system occurred during the run. If only reed should be used in a heating plant, it would be necessary to adapt the feeding system for light, fibrous materials. All in all, the experiments showed that reed is a cheap and renewable energy source and it can expand the fuel portfolio for such heating plants.

Acknowledgment

The authors are highly indebted to the research partners in this project. The scientific partners beside Vienna University of Technology are the University of Applied Sciences, Burgenland and the civil engineering consulting company TB Dr. Beckmann.

References

[1] United Nations, World Population to 2300 - Economics & Social Affairs, New York, June 2004. [Online]. Available: http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf,

[2] K.E. Trenberth, P. D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, et al., Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

[3] B. Blok, "Renewable energy policies in the European Union", *Energy Policy*, 34, pp. 251 – 255, 2006.

[4] N. Gamauf, "Satellitenbildauswertung des Schilfgürtels am Neusiedler See zur Ermittlung von Rohstoffpotenzialen," Ph.D. dissertation, University of Natural Resources and Life Sciences, Vienna, Austria, 2000.

[5] P. Pfaller. (May 2009). Schilf, Neusiedlersee-Wiki, Available: http://www.neusiedlerseewiki.at/Schilf, 23th of May 2011

[6] O. Brandweiner, "Thermische Nutzung von Schilf im Zementwerk Mannersdorf", M.S. thesis, University of Applied Sciences, Burgenland, Austria, 2006.

[7] W. Granéli, "Reed Phragmites australis (Cav.) Trin. ex Steudel as an energy source in Sweden", *Biomass*, vol.4, pp.183-208, 1984.

[8] P.J. Hocking, C.M. Finlayson, A.J. Chick, "The biology of Australian weeds. 12. Phragmites australis (Cav.) Trin. ex Steudel", *Journal of the Australian Institute of Agricultural Science*, vol.49, pp.123-132, 1983.

[9] M. Van der Werff, "Common reed", in: Rozema J, Verkleij J.A.C., eds. *Ecological responses to en.ironmental stress*, The Netherlands, Kluwer Academic Publishers, pp.172-182, 1991.

[10] L. Rodewald-Rudescu, *Das Schilfrohr - Phragmites communis TRINIUS. E.*, Stuttgart: Schweizerbart'sche Verlagsbuchhandlung, ISBN 978-3-510-40038-6, 1974.

[11] C. Brunner, Leitfaden für Logistiksysteme und Rohstoffmanagement im Burgenland", Federal Ministry for Transport, Innovation and Technology (BMVIT), Vienna, 2008.

[12] S. Landström, L. Lomakka, S. Andersson, "Harvest in spring improves yield and quality of reed canary grass as bioenergy crop", *Biomass and Bioenergy*, vol. 11, pp.333-341, 1996.

[13] Federal Ministry of Agriculture, Forestry, Environment and Water Management and Federal Ministry of Economy, Family and Youth, Änderung der Abfallverbrennungsverordnung (AVV Novelle 2010)", BGBl. II Nr.476/2010, 2010.

[14] Y.-C. Wang, C.-H. Ko, F.-C. Chang, P.-Y. Chen, T.-F. Liu, Y.-S. Sheu, T.-L. Shih, C.-J. Teng, "Bioenergy production potential for aboveground biomass from a subtropical constructed wetland," *Biomass and Bioenergy*, vol.35, pp. 50-58, Jan. 2011.

[15] M. Kaltschmitt, H. Hartmann and H. Hofbauer, *Energie aus Biomasse - Grundlagen, Techniken und Verfahren*, 2nd ed., Springer Heidelberg, 2009, ch.9, pp. 333-461.

Hannes Kitzler was born 1982 in Vöcklabruck, Austria started his technical education in 1997 with a secondary college for chemical engineering. After gaining his Matura in 2002 he studied chemical process engineering at Vienna University of Technology from 2003 to 2009. He graduated with his master thesis about pressurized air gasification of biomass. Since November 2009 he has been working in the research group Gasification and Gas Cleaning at the Institute of Chemical Engineering as a junior researcher. The current focus of research is set on thermal utilization of reeds as well as on dual fluidized bed gasification technology with a focus on alternative biogenic feedstock.

Christoph Pfeifer received a Dipl.-Ing. in Chemical Engineering and a Dr. techn. in Mechanical Engineering at the Vienna University of Technology, Austria both with works on catalytic tar removal for the dual fluidized bed gasification process. He is leading the working group Gasification and Gas Cleaning since 2010. He is involved in the development of an innovative new concept for dual fluidized bed gasification process, cold flow modeling of fluidized bed systems as well as steam reforming of tars from gasification processes.

Hermann Hofbauer received a Dipl.Ing. in Mechanical Engineering and Dr. techn. in Chemical Engineering at the Vienna University of Technology, Austria. He was appointed as full Professor for Chemical Engineering at the Vienna University of Technology in 1997. He is Head of the Chemical Engineering Department and leading the research division of Chemical Process Enginnering and Energy Technology. He is key researcher at the competence centre BIOENERGY 2020+ and chairman of the scientific board. He is author or co-author of more than 250 scientific publications in the field of thermal biomass conversion. He has got numerous grants for his work on biomass gasification and synthetic biofuels.