PROSPECTS FOR CO-FIRING OF CLEAN COAL AND CREOSOTE-TREATED WASTE WOOD AT SMALL-SCALE POWER STATIONS

by

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If a small-scale clean coal fueled power plant is co-fueled with 5% of creo-sote-treated used-up sleeper wood, the decontamination by carbonisation at 500 °C in an indirectly heated rotary kiln with the diameter 1.7 m and effec-tive length 10 m can be realised. It should be included in the "3R Clean Coal Carbonisation Plant" system, which processes coal. It will improve the heat balance of the system, since the carbonisation of wood will deliver a lot of high caloricity pyroligneous vapour to the joint furnace of the "3R Clean Coal Carbonisation Plant". Pine wood sleeper sapwood contains 0.25% of sulphur, but the average pine sleeper wood (sapwood and heartwood) 0.05% of sulphur. Most of the sulphur is lost with the pyroligneous vapour and burned in the furnace. Since the "3R Clean Coal Carbonisation Plant" is equipped with a flue gases cleaning system, the SO_2 emission level will not ex-ceed 5 mg/m³. The charcoal of the sapwood portion of sleepers and that of the average sleeper wood will contain 0.22% and 0.035% of sulphur, respec-tively. The increase of the carbonisation temperature does not substantially decrease the sulphur content in charcoal, although it is sufficiently low, and the charcoal can be co-fired with clean coal. The considered process is suit-able for small power plants, if the biomass input in the common energy bal-ance is 5 to 10%.

If the mean distance of sleepers transportation for Central and Eastern Eu-rope is estimated not to exceed 200 km, the co-combustion of clean coal and carbonised sleepers would be an acceptable option from the environmental and economic points of view.

Key words: *co-combustion, Clean Coal, railway sleepers, carbonisation, charcoal, creosote-treated wood*

Introduction

The aim of the EU Directive 2001/77/EU is to reduce the share of fossil fuel in production of electric power and, along with that, to restrict effluents into the atmo-sphere. Therefore, all countries of the EU are obliged to increase the production of heat and electric power using renewable resources. One of options is co-firing of coal and bio-mass. Co-combustion of coal with used creosote-treated railway sleepers after their de-contamination by thermal treatment would be an acceptable solution for utilization of im-pregnated waste wood and is in conformity with the Directive.

Creosotes are especially suitable for protection of wood being in permanent contact with earth and water. It is considered that creosotes can be burned without any residues in specially arranged furnaces so that impregnated wood could be disposed without any problems after use. However, the main components of creosotes are polycyclic aromatic hydrocarbons, of which some compounds, especially benzo[a]pyrene, were classified as carcinogenic. In the European Union, limitations are imposed in the Directive 94/60/EC. Creosotes, containing more than 50 mg/kg of benzo[a]pyrene, must be labeled toxic in all nations of the EU. Though the classification of benzo[a]pyrene as a carcinogenic substance does not currently apply where its concentration is less than 50 mg/kg, the recent conclusions of the EU Scientific Committee on Toxicity, Ecotoxicity and the Environment have revealed that creosote has a greater potential to cause cancer than it had been previously believed and exceeds the limits permissible under the existing legislation. The European Commission's October 2001 Directive, which takes effect from June 30, 2003, bans the sale of the wood preservative creosote to consumers.

Our investigations have demonstrated that the mean combustion heat of creosote-treated pine sleeper wood is 19300 kJ/kg, while that of the sapwood portion, containing 27% of creosote, is even 20790 kJ/kg at the moisture content $w = 10.8\%$ wet basis. Therefore, impregnated sleeper wood is an excellent fuel for co-combustion with coal. Nevertheless, one has to be aware of the release of polycyclic aromatic hydrocarbons, of which some are carcinogens. They are the cause of harmful dust in rooms of crushing departments. In some studies, analysing the exhaust gases from small-scale heating furnaces burning railway sleepers, higher emissions of hydrocarbons have been found, which are also found in the creosote itself. Oxidative decomposition and mineralisation takes place between 400 and 600 °C with a maximum at 540 °C. High temperatures are ordinary in the furnaces of powdered coal-fired power plants [1, 2]. One of the primary goals and achievements of co-firing of biomass together with coal or lignite was the reduction of SO_2 and CO_2 emissions of fossil fuel origin. Due to the replacement of primary fossil fuel, the emission of CO_2 originating from biomass is not accounted for.

If the combustion temperature is high and if a good intermixing of the fuel and air in a combustion chamber is ensured, co-combustion of creosote- and pentachlorphenol-treated sleeper wood and coal in pulverised coal utility boilers does not increase the amount of dioxins, furans, polycyclic aromatic hydrocarbons, HCl and dust in stack gases. Since railway sleepers have very high disposal landfill costs, there will be interest to use these positive results of the investigation as a help for utilities dealing with permitting issues related to co-firing of PCP/creosote-treated wood [3].

In the co-combustion of coal and biomass, there are separate independent fuel feeding systems due to different kinds of fuel handling. This inconvenience can be prevented if brittle carbonised biomass is used, since then the physical properties of charcoal and coal are similar. Another advantage of the carbonised biomass co-firing will be possibly the lack of a high unburned carbon content in the bottom ash, which is observed even if only up to 10% of ground wood is co-combusted with coal [4]. Thermal decontamination of waste wood (railway sleepers, demolition wood) eliminates the volatile products from the fuel and the impact of the individual peculiarities of the secondary fuel on the performance of the boiler is diminished. Therefore, in a carbonised form, a great

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variety of waste fuel can be used simultaneously. If creosote-treated sleeper wood is used, no additional energy is needed for the pyrolysis reactor of any kind. Pyrolysis in this case is an attractive option of pretreatment, because sleepers cannot be ground in coal milling equipment to the required dimensions for co-combustion in a pulverised coal or lignite-fired power plant. This treatment is necessary to assure an adequate burn-out in the boiler due to the short residence time of the fuel in the furnace.

We suppose that, for the time being, pyrolysis of used sleepers is a good option to overcome the strict requirements of the regulations set on burning of sleepers in boiler houses. The charcoal prepared at 400 to 600 °C practically does not contain benzo[a]-pyrene and is a clean fuel for industrial use. Due to a high creosote content in the sleeper wood found in our sleeper specimens and reported for mean creosote concentrations in European sleepers, the caloricity of the pyroligneous vapour would be high enough to cover not only the heat consumption of the process, but also for other uses: drying, heating-up or as a pyroligneous vapour itself to be burned as a reburn fuel to reduce the NO_x emission [5].

Thermal decontamination of solid fuels is based on the principle of volatilisation of noxious and unwanted components or their decomposition products together with the pyroligneous vapour during thermal treatment. Since, in the case of railway sleepers, the principal product is clean charcoal (clean fuel), pyroligneous vapour is used as a gaseous fuel and burned in a furnace to produce the heat carrier for maintaining the carbonisation process.

Results and discussion

We used the results of pyrolysis of creosote-treated wood in a laboratory pilot-scale thermoreactor with a stirrer as a base for calculations. The apparatus and process of pyrolysis are described elsewere [6]. The most characteristic experiments were chosen. The characteristics of the carbonisation process and the quality indices of the obtained charcoal are listed in tab.1.

During the studies of charcoal formation in the presence of creosote in the wood structure by the Electron spin resonance method, it has been established that soaking with creosote favours the formation of more homogenous plane condensed structures of carbon in charcoal. Such a turbostratic structure of charcoal is more apt to grafitisation and has well-organised polyaromatic carbon strata. It has been demonstrated that these structures actively react with air oxygen at high temperatures, which is a good characteristic of a fuel.

To gain more practical information about the starting materials and the products of pyrolysis of creosote-treated pine wood sleepers, calorimetric heating values and the sulphur content were determined. Heat of combustion was determined using a Parr Instrument Co. oxygen bomb calorimeter. For determination of the sulphur content, in accordance with the prescriptions of the company, the bomb's washing water solution was used. The method corresponds to the basic ASTM method for sulphur. Determination of sulphur as sulphate was carried out spectrophotometrically using barium chromate [7]. The results are summarised in tab. 2.

Table 1. Charcoal properties and characteristics

Raw material	Units of measure	LSIWC pilot-scale reactor with a stirrer (externally heated rotary kiln prototype)		
		Creosote-treated railway sleeper average wood chips (heartwood + sapwood)		
Process characteristics				
Wood moisture content	% wet basis	10.4	10.4	10.4
Maximum temperature	°C	400	455	560
Mean heating rate	°C min. [1]	12.7	8.7	18.0
Charcoal yield	% on the o. d. wood	28.3	23.3	20.1
Charcoal characteristics				
Ash content	% on the o. d. mass	1.8	1.5	1.6
Volatiles	% on the o. d. mass	27.9	19.1	13.9
Fixed carbon	% on the o. d. mass	70.3	79.4	84.5
Sulphur content	% on the o. d. mass	0.035	0.035	0.048
Combustion heat	MJ/kg	29.209	29.858	31.610

Table 2. The higher heat of combustion and sulphur content of creosote-treated wood and its carbonisation products

Products	Higher heat of combustion [MJ/kg]	Sulphur content [% on the o. d. mass basis]
Railway sleeper wood Sapwood Average (sapwood + heartwood) sample: – small sapwood portion – broad sapwood portion	 20.79 19.20 19.32	 0.25 0.047 0.059

Charcoal
 Sapwood   – max temperature 400 °C
    – max temperature 500 °C
    – max temperature 600 °C
 	
 Average (sapwood + heartwood) sample:
    – max temperature 400 °C
    – max temperature 450 °C
	
	 32.50
	 31.91
	 33.76
	
	 29.21
	 30.27
		
		 0.25
		 0.22
		 0.20
		
		 0.035
		 0.035

Tar Supernatant tar – max temperature 400 °C – max temperature 600 °C Settled tar (average wood sample)	 36.84 33.76 23.43	 0.59 0.55 0.27

Since the flue gases of pyroligneous vapour combustion are the heat carrier for maintaining the pyrolysis process, we have calculated the main characteristics of the combustion and summarised the results in tab. 3.

Table 3. Characteristics of the combustion process of pyroligneous vapour

Characteristics	Units of measure	Wood moisture content 10.4% wet basis	Wood moisture content 20% wet basis
Heat of combustion	MJ/kg*	11.63	9.64
Theoretical amount of air	m³/kg	3.90	3.28
Theoretical amount of nitrogen	m³/kg	3.08	2.59
Theoretical amount of three-atomic gases	m³/kg	0.69	0.58
Actual amount of three-atomic gases	m³/kg	0.79	0.68
Theoretical amount of water vapour	m³/kg	1.08	1.1
Total amount of water vapour	m³/kg	1.08	1.1
Total amount of flue gases	m³/kg	5.34	4.7
Temperature of combustion: 　　– adiabatic 　　– actual	 °C °C	 1322 1057	 1239 991

* All values on 1 kg of pyroligneous vapour

Most of sulphur is concentrated in tars. Settled tar contains 0.27% in the average, but the supernatant tar layer even 0.59% of sulphur. Since the total amount of tars is up to 20% on the o. d. wood mass basis (tab. 2), they comprise 0.86 g of sulphur in the average if calculation is made on 1 kg of wood. The tars render the majority of heat during the combustion of pyroligneous vapour since the calorimetric heating value of settled tar is 23425 kJ/kg, while that of the supernatant tar layer, which contains distillates of creosote, is even 35790 kJ/kg. A substantial amount of creosote distillates' vapour is obtained if pine wood sleeper sapwood specimens are carbonised. We suppose that the creosote distillate vapour will be the main component of beech wood railway sleepers' pyroligneous vapour, since these used-up sleepers contain up to 150 kg/m³ of creosote.

During the pyrolysis of 1 kg of oven-dry pine wood sleepers with the actual mean moisture content w = 20% wet basis in a rotary kiln, 1.01 kg of pyroligneous vapour is formed. If combustion is carried out at the air excess factor 1.1, the amount of flue gases is 4.7 Nm³. During carbonisation of average (sapwood + heartwood) pine wood railway sleepers, 1 kg of oven-dry wood releases 0.5 g of sulphur in the form of 1 g of sulphur dioxide. Consequently, the concentration of SO_2 in flue gases is $1000/4.7 = 213$ mg/Nm³. The respective concentration of SO_2 in flue gases, if creosote-treated sapwood or beech wood sleepers are carbonised, would be 830 mg/Nm³.

In accordance with the best available technologies (BAT), the SO_2 emission level is set at 200-300 mg/Nm^3 (reference $O_2 = 6\%$) [4]. This emission level is set for the power plant capacities 50-300 MW$_t$. The intended 3R Clean Coal Carbonisation Plant (3R CCCP) will be equipped with a flue gases' cleaning system – a high efficient multi venturi off-gas scrubber, ensuring the SO_2 concentration level in flue gases less than 5 mg/Nm^3 [8].

From the ecological point of view, an important quality characteristic of each solid fuel is the content of heavy metals in its ash. The presence of heavy metals in ash seriously hampers the disposal of ash. Therefore, we incinerated the charcoal sample to ashes by heating in an open crucible at 750 °C, and studied the composition of creosote-treated wood charcoal ash by the atomic absorption spectroscopy method (tab. 4).

Table 4. Content of heavy metals in preservative-treated wood charcoal ash [mg/kg]

Metals	Creosote-treated sleeper wood (average specimen)	Pine wood (control)
Arsenic	53	37
Chromium	483	52.1
Copper	357	373
Zinc	588	2990
Lead	13.6	31.9
Cobalt	7.19	4.51
Iron	49129	1452
Cadmium	4.79	5.56
Mercury	< 0.2	< 0.2

Certainly, some authors point out that the ashes produced by laboratory ashing procedures do not typically reflect the actual furnace operating performance due to differences in temperature, different levels of excess air and in-bed turbulence. However, in our case, the extremely high iron content and increased chromium concentration of the creosote-treated sleeper wood ash is due to rail wear and tear, while the five-fold zinc amount of the control ash specimen may be caused by different soil compositions of the corresponding forest stands. Some increase in the concentration of arsenic must be mentioned.

Appraisal of co-combustion technology perspectives

As an example, we are considering a small co-generation power plant with a total capacity of 60 MW. It is anticipated that the co-generation power plant will be the consumer of the clean multi-fuel: pulverised clean-coal [8] and pulverised carbonised biomass. The corresponding biomass is out of service used-up creosote-treated railway sleeper wood. In the carbonised form, it turns to a more homogenous, handy and energy dense fuel almost free of sulphur and noxious polycyclic aromatic hydrocarbons. The charcoal is a brittle material and certainty can be milled in the equipment designed for pulverisation of coal in a common flow of fuel. The aforementioned power plant, by consuming of 10890 kg/h of clean coal, will produce 312 GJ/h of heat energy.

To substitute 5% of the total energy output by biomass, 15.6 GJ/h should be produced by combustion of 15.6/0.0325 = 480 kg/h of charcoal (0.0325 – heat of combustion

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of charcoal, GJ/kg). The charcoal yield, in the average, is assumed to be 23.5% on the oven dry wood mass basis if the carbonisation is performed in a continuous action externally heated rotary kiln. To obtain the necessary amount of charcoal, 2042 kg/h of o. d. railway sleepers must be carbonised.

It means that 3.8 solid m³ of railway sleepers should be crushed and carbonised per hour, since, in accordance with the technical characteristics of the rotary kiln-type apparatus, the wood must be crushed to hogged chips measuring 1-4 mm. The used-up railway sleepers should be delivered to the 3R CCCP [8] in their initial form – pieces measuring approximately 2.5-2.7 × 0.14-0.21 × 0.25 m. The material flow of the railway sleeper carbonisation section of the 3R CCCP is given in tab. 5.

Table 5. Amounts of the raw material, products and emissions into the atmosphere of the railway sleeper carbonisation section of the 3R CCCP co-operating with a 60 MW power plant

Materials and products	Unit of measure	Bioenergy share 5%	
		1 h	1 year
Charcoal	t	0.48	4205
Railway sleepers (o. d.)	t	2.04	17870
– moisture $w = 20\%$	t	2.54	22250
	solid m³	3.8	33290
– hogged chips bulk	m³	11.08	97061
Pyroligneous vapour (wood $w = 20\%$)	t	2.06	18046
Actual amount of consumed air (air excess factor $\alpha = 1.1$)	Nm³ 10³	7.44	65174
Amount of emitted CO_2	Nm³ 10³	1.4	12264
	t	2.76	24178
Amount of flue gases	Nm³ 10³	96.8	847968
Amount of emitted SO_2 (before cleaning of stack gases)			
– pine wood railway sleepers	kg	2.16	18922
– beech wood railway sleepers	kg	7.96	69730
(after cleaning of stack gases in facilities of the 3R CCCP			
– pine wood railway sleepers	kg	0.04	350
– beech wood railway sleepers	kg	0.04	350

Since used-up railway sleepers are scattered in a rather waste territory, they should be gathered and transported via a terminal (wood yard) and processed (crushed) at a carbonisation plant. It means that transloading, accumulation and seasoning up to a 20-30% moisture content will take place at a wood-yard. Such terminals (wood-yards) of railway sleepers may be arranged at railway junctions. Since more than 90% of timber is

transported by trucks in Europe for transportation of railway sleepers, trucks with 2-3 stacks are assumed as a mean option. Of course, in the case of the railway sleepers transportation, the conveyance by train may be even more environment-friendly and less expensive than the transport by trucks, but the management problems would set up the choice.

Two stage crushing and shredding is recommended: 1st stage (primary) shredder – final particle size 150-400 mm; 2nd stage (secondary) shredder – final particle size ~ 40 mm. To achieve the final necessary granularity (1-4 mm) of wood particles, the particles of the secondary shredder must be milled in a hammer mill – up to a 1-4 mm particle size. The preliminary information on appropriate equipment is given in tab. 6.

Table 6. Wood comminution equipment for hogged chips production from railway sleepers

Operation	Product measure [mm]	Equipment type	Capacity [t/h]	Drive [kW]
Primary shredding	150-400	Primary shredder	25	2×110
Secondary shredding	up to 40	Secondary shredder	25	160
Milling	1-4	Hammer mill	30	250

The power demand of the grinding of biomass is lower than 2% of the biomass heating value. Such a power demand meets the requirements of pulverised fuels and is economically acceptable [9].

Our experiments on a laboratory pilot-scale thermoreactor modeling a rotary kiln have demonstrated that, if the kiln's wall temperature is 400-450 °C at the delivery end and 600-630 °C at the discharge end, and the starting coefficient of fullness is 0.4, then the duration of the carbonisation process is 45 minutes. To achieve a capacity of 0.72 t charcoal per hour, a kiln measuring 1.7 m in diameter and 10 m of effective length should be installed.

The pyroligneous vapour is of high caloricity (see tab. 3), and the amount of the heat obtained by burning-up of the pyroligneous vapour (moisture content of sleepers – 20% wet basis) is $2060 \times 9.64 = 19858$ MJ/h, which is used to keep up the pyrolysis process. The ratio of heat to 1 kg of the obtained charcoal would be $19858 : 480 = 41.4$ MJ/kg. Such an index value by far exceeds the mean value of this index of the charcoal making industry praxis, namely, 8.8 to 18.0 MJ/kg depending on the wood moisture and the type of apparatus [10]. Such a highly positive carbonisation heat balance is well combined in the common work of the 3R CCCP by supporting the temperature regime of the coal carbonisation kilns.

If sleepers are transported by trucks, 840 trailer loads (maximum permissible load 27 t), and, in the average, 111 t of fuel consumed (mean calculated distance 235 km) will be needed per year. Due to transportation, 375 t of fossil origin greenhouse gases (CO_2) will be emitted per year (calculated in accordance with [11]). This amount is quite insignificant in comparison with the carbon dioxide emission of a small power plant co-fired with carbonised railway sleepers (tab. 7).

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Table 7. Co-generation power plant, 60 MW
(review of 1 hour operation fuel and combustion products)

Fuel, % on the total energy output		Clean Coal Energy output		Biomass Energy output		Flue gases [t]			Ash [t]
Clean Coal	Biomass (charcoal)	Amount [t]	Heat input [GJ]	Amount [t]	Heat input [GJ]	Total	CO$_2$ fossil	CO$_2$ biomass	
100	–	10.9	312	–	–	136	34.0	–	1.43
95	5	10.4	296	0.48	16	135	32.4	1.4	1.37
90	10	9.9	281	0.96	22	135	30.8	2.7	1.31

The considered process is suitable for small power plants since, if the biomass input in the common energy balance is 5 to 10%, the mean distance of the sleepers transportation should not exceed too much 200 km. The co-combustion of the carbonised railway sleepers and clean coal is an acceptable option from the environmental and economic points of view.

Conclusions

Pretreatment of railway sleepers by carbonisation not only detoxifies creosote-treated wood, but makes it a more homogeneous, handy and high-caloricity fuel. The carbonisation process is energetically self-sufficient and environmentally friendly, since the 3R CCCP technology includes a high-efficient multi venturi off-gas scrubber.

The considered process is appropriate for small-scale power plants, because railway sleepers and other kinds of waste wood are not fit for long distance transportation.

Acknowledgments

References

[1] Marutzky, R., Waste Management of Wood Treated with Preservatives – Possibilities and Problems, *Holz als Roh- und Werkstoft*, *48* (1990), 1, pp. 19-24
[2] Becker, L., Matuschek, G., Lenoir, D., Kettrup, A., Thermal Degradation of Wood Treated with Creosote *J. Anal. Appl. Pyrolysis*, *57* (2001), 1, pp. 15-36
[3] Freeman, M., O'Dowd, W., Hargis, R., Brown, T., James, R., Pilot-Scale Air Toxics Results for PCP/Creosote-Treated Wood Co-Firing for Pulverised Coal Combustion Applications,

Proceedings on CD, 17th Annual International Pittsburg Coal Conference, Pittsburg, PA, USA, 2000, pp. 1873-1890

[4] ***, European Power Plant Suppliers Association LF/EIPPCB/LCP, Draft 2, Version March 2003, pp. 318-319, www.eppsa.org/BATLCP

[5] Storm, C., Unterberger, S., Hein, K. R. G., Pyrolysis of Biomass as Pre-Treatment for Use as Reburn Fuel in Coal-Fired Boilers, in: Progress in Thermochemical Biomass Conversion (Ed. A.V. Bridgwater), Blackwell Science Ltd, Oxford, London, Edinburgh, 2001, pp. 1433-1451

[6] Zandersons, J., Gravitis, J., Kokorevics, A., Zhurinsh, A., Bikovens, O., Tardenaka, A., Spince, B., Studies of the Brazilian Sugarcane Bagasse Carbonization Process and Products Properties*, Biomass and Bioenergy, 17* (1999), 3, pp. 210-219

[7] Busayev, A. I., Simonova, L. N., Analytical Chemistry of Sulphur (in Russian), Nauka Publishers, Moscow, 1977

[8] Someus, E., "3R" Solid Fuel Preventive Pretreatment Cleaning, Clean Fuels for Cost Efficient Clean Energy, 2003, www.terrenu.net/cleancoal

[9] Kircherer, A., Görres, J., Spliethoff, H., Hein, K. R. G., Biomass Co-Combustion for Pollutant Control in Pulverised Coal Units, *Proceedings*, 2nd APAS Task-Group Meeting Co-Combustion, 1994, Esbjerg, Denmark, pp. 45-51

[10] Shulgin, Y. N., Efremov, L. M., Analysis of Energy Consumption in the Charcoal Production (in Russian), in: Coll. Articles of CNILHI, Forest Industry Publ. House, Moscow, 1988, pp. 5-16

[11] Schwaiger, H., Zimmer, B., A Comparison of Fuel Consumption and Greenhouse Gas Emissions from Forest Operations in Europe, European Forest Institute, Discussion paper 10, 2001, pp. 33-51

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