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# INDUSTRIJSKA ENERGETIKA I ZAŠTITA ŽIVOTNE SREDINE U ZEMLJAMA JUGOISTOČNE EVROPE

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## SADRŽAJ / *CONTENTS*

problems of its collection, preparations for its transportation, transportation and storage. These problems are less significant and easier to handle if the biomass is used for energy purposes near places of its collection, in enterprises dealing with agricultural production, where the obtained energy – heat – could be used for heating of greenhouses, stables, poultry raising farms, offices, etc.

In the Agricultural Corporation PKB, Belgrade, one of the largest agricultural companies in Serbia, there are over 2000 ha of soya plantations. Each year after the harvest over 4000 tons of soya straw remains. This straw is baled, and is not used for energy purposes further on. At the same time, there is a need for heating of greenhouses inside the company, with the total greenhouse area to be heated equal to 5 ha. Until now, a technology for efficient combustion of baled material of this size has not been developed in Serbia. In the European Union, some technical solutions for solving these problems have been adopted, and for balled straw combustion cigar burner combustion is recommended.

In the Laboratory for Thermal Engineering and Energy at the "Vinča" Institute in Belgrade, efforts have been made to develop a clean technology for utilizing baled biomass for energy production. As a result, an energy production facility, a real-scale hot water boiler for greenhouse and office heating, with thermal power of 1.5 MW and combustion of large soya straw bales with dimensions 0.7x1.2x2.0 m, has been designed and built. The boiler consists of the furnace section, lined with refractory (heat-accumulating) material, and the gas-to-water heat exchanger section. The boiler house is placed on the fields at PKB Corporation, in the immediate vicinity of the greenhouse complex.

In the paper, some results obtained during the development of a boiler, with combustion of baled straw from agricultural production based on the principles of cigarette combustion, are presented. The boiler had been tested in order to examine the quality of combustion of large soya straw bales. Average lower heating value of this fuel is 13700kJ/kg. Practical investigation performed with a few type of baled biomass, soya and rape seed straw. The tests were followed by adequate temperature measurement in a several places of boiler, and with measurements of combustion gases composition. The main advantages and capabilities of cigar burner method for baled straw, which can be seen as an optimal technological way of combustion of large bales, are shown in the paper.

**Keywords:** Biomass; Straw; Boiler; Combustion; Bales.

## SAGOREVANJE DRVNOG OTPADA U INDUSTRIJI NAMEŠTAJA

Dušan GORDIĆ[1], Milun BABIĆ[1], Novak NIKOLIĆ[1], Dubravka JELIĆ[1], Davor KONČALOVIĆ[1]

Implementiranje različitih tehnika minimiziranja otpada u preduzeću čija je delatnost proizvodnja nameštaja, ima za cilj povećanje efikasnosti i profita istog, kroz redukciju materijala i sirovina kao inputa svakog proizvodnog procesa, reorganizovanje procesa proizvodnje sa tendencijom recikliranja i reupotrebe pratećih nus produkata, boljeg upravljanja i organizaciju procesa, kao i smanjenje negativnog dejstva pomenutog otpada na prvenstveno zdravlje zaposlenih u ovom preduzeću kao i na okolnu životnu sredinu kroz zagađenje zemlje, vode i vazduha. Jedna od mogućih opcija minimiziranja generisanog otpada se ogleda kroz instaliranje i upotrebu kotlova za sagorevanje (spaljivanje) drvnog otpada, u obliku drvnih odsečaka i prašine, nastalog najvećim delom tokom izvođenja operacija primarne obrade, mašiniranja (glavne obrade) i brušenja. U radu su prikazana svetska iskustva u korišćenju proizvedene toplotne energije u procesu sagorevanja drvnog otpada kao i uticaj istog na životnu sredinu. Istovremeno izvršena je analiza drvnog otpada koji nastaje u jednom domaćem preduzeću industrije nameštaja za sagorevanje.

**Ključne reči:** drvni otpad, sagorevanje, industrija nameštaja.

## WOOD WASTE COMBUSTION IN THE FURNITURE INDUSTRY

The implementation of various techniques for waste minimization in the company with furniture manufacturing activity, has the aim to increase efficiency and profits of the same, through the reduction of materials and raw materials as a inputs of every manufacturing process, manufacture reorganizing with a tendency of reusing and recycling of associated by-products, better management and process organization as well as reduction of the negative effects of the mentioned waste primarily on the health of company employees as well as the surrounding environment through pollution of land, water and air. One of the generated waste minimization possibility is reflected through the installation and use of boilers for combustion (incineration) of wood waste in the form of chips and dust, generated primarily during the execution of the primary processing, main processing (machining) and sanding operations. The world experiences in the use of thermal energy produced in the wood waste combustion process as well as its impact on the environment are presented in this paper. At the same time the analysis of the generated wood waste in one domestic furniture industry company for combustion is considered.

**Key words:** wood waste, combustion, furniture industry.

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# THE COMBUSTION OF THE WOOD WASTE IN THE FURNITURE INDUSTRY[1]

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## INTRODUCTION

The aim of the implementation of various waste minimization techniques in a company with furniture manufacturing activity is to increase efficiency and profits of the same. These are achieved through the reduction of materials and raw materials as input of each manufacturing process, reorganizing the production processes with a tendency for recycling and reusing associated by-products, better process management and organization as well as reduction of the negative effects of waste primarily on the employees health as well as the environment through pollution of land, water and air.

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One of the possibilities for generated waste minimization is the installation and use of boilers for combustion (incineration) of wood waste in the form of wood chips and dust, generated largely during the processes of the primary machining, main machining and sanding. The combustion of the mentioned waste is a waste minimization technique which contributes to the heat production which can be used either for heating the production spaces or other facilities through the production of hot water or hot air, or for the manufacturing processes through the provision of industrial steam and for electricity generation. Produced energy by the boilers is also possible to use for combined production of heat and electricity (cogeneration). The main advantage of this waste minimization technique in comparison to the others is the fact that energy comes from renewable energy source (wood) which reduces the use of fossil fuels while reducing GHG emissions. In this case, the fact that the ash generated during the combustion of wood chips and dust makes only 0.5% of the total volume of wood waste is wood waste minimization [1]. This presents its significant volume reduction, its quantity, and among other things, reducing its disposal costs. Before a more detailed introduction to this waste minimization technique and its possible negative impact on the environment, it is necessary to be familiar the process of burning this type of waste.

## THE WOOD COMBUSTION PROCESS

A wood as raw material in a furniture manufacturing company is primarily consisted of carbon, water (moisture) and various volatile compounds. Depending on the type of final product - furniture, and its origin (furniture from the MFC, HDF, MDF boards, etc.), wood waste can also contain various other compounds in the form of used resins, adhesives, coatings, etc.

The boiler combustion process involves introduction of wood waste in the form of wood chips and dust in the boiler furnace and the provision of air. For the efficient burning of wood waste it is necessary to continually control the combustion process which is related to the maintenance of appropriate combustion temperature, mixing of fuel and air (amount of oxygen) and a time to keep fuel gases. The value of the combustion temperature, which takes place in boilers of these purposes ranges from 850 ˚C to 1050 ˚C [1]. While on one side, the lower combustion temperature causes the incomplete combustion including carbon monoxide generation, higher temperature causes the melting of ash which in that form can stick to the furnace walls and affects the inefficient combustion process and the boiler operation. Temperature that causes ash melting depends on the type of wood waste used as fuel for heat generation. For example, for MFC combustion it is necessary to maintain the temperature around 850 ˚C and for the MDF combustion around 1050 ˚C [1].

Good mixing of the fuel (fuel gases) and air (oxygen) provides efficient combustion of the fuel. Theoretically, for a specific type of fuel the required amount of air for its combustion is determined. Due to the varying quality of the fuel and its dimensions the theoretical amount of air is not sufficient for its complete combustion. Therefore, in the boiler furnace a higher quantity of air is introduced, which in some cases can cause the lowering of the combustion temperature or the incomplete and inefficient combustion. The level of fuel mixing is affected by various parameters such as the size of boiler furnaces, speed, density and viscosity of the generated gases, introduced air, etc.

The fuel gases include compounds that are contained in the wood waste and generated by heating the same. Time to keep these gases must be sufficient to provide the mixing of the uncombusted gases from wood with the air in order to burn them. The time is influenced by the size and type of waste to be burned. For smaller dimensions of wood waste less time is needed. For wood waste from treated wood more time is needed comparing the waste from untreated wood. The above mentioned incomplete combustion not only affects the efficiency of the boiler but also the emission of GHG gases. Incomplete combustion leads to the formation of carbon monoxide, hydrocarbons, nitrogen oxides and other compounds that have a negative impact on the environment. On the other hand, with fuel combustion an unavoidable by-product – ash appears which is largely allocated in the bottom of the boiler, as well as in certain percentage (2-10%) in the flue gases that are through the chimney emitted to the atmosphere.

When speaking about the combustion process it is necessary to say something about the heating value of the wood waste that is burned in the boiler installed for that purpose. The heating values of wood waste depend on the type of wood and its moisture. It should also differentiate the heating values of the wood waste made from treated or untreated wood. Wood waste that would be burned includes wood chips, wood dust from raw lumber, MFC, MDF, as well as pellets or briquettes, which also can be burned at the same time in the boiler plant.

As for the heating value (lower heating value - LHV) of pellets produced in countries such as Austria, Sweden or Germany concerns, standards defines its value of ≥ 18 MJ/kg, ≥ 16.9 MJ/kg and 17.5 - 19.5 MJ/kg, respectively [2]. Standards for the pellets (and briquettes) produced in Serbia do not exist and considering that the current production of pellets in our country is focused on exporting to the EU, the producers in Serbia produce pellets according to the EU importing counties standards (Austria, Germany, ...). LHV of the briquettes is approximately equal to the same for the pellets. For example, LHV of the briquettes made from the wood chips or wood dust is about 20.034 MJ/kg and 19.485 MJ/kg, respectively [3]. In the case of combustion of untreated and treated wood, as is the case in a furniture company that installed the boiler for their combustion, their LHV is about 17.6 MJ/kg for untreated wood and 18.9 MJ/kg for treated wood [4]. Some companies as a raw material for furniture manufacturing use MFC, MDF or HDF boards with the LHV of 16.479 MJ/kg, 17.413 MJ/kg and 19.401 MJ/kg, respectively [5]. To make sense of the energy content of mentioned wood waste Table 1 gives values for LHV of domestic coals in MJ/kg.

**Table 1.** The values of LHV of domestic coals in MJ/kg [6]

| Name and origin of coal | LHV (MJ/kg) |
|---|---|
| Lignite - Kolubara | 6,110 - 7,389 |
| Lignite - Kostolac | 7,830 - 11,207 |
| Lignite - Pljevlja | 8,110 - 14,348 |
| Brown coal - Soko | 14,746 - 20,444 |
| Brown coal - Rembas | 13,653 - 21,583 |
| Stone coal - Jarando | 25.665 – 27.607 |

## THE POSSIBILITIES FOR USING HEAT PRODUCED IN THE WOOD WASTE COMBUSTION PROCESS

The most furniture manufacturing companies uses thermal energy produced in the wood waste combustion process, for heating production facilities (with air or water). The available thermal energy is possible to use for heating only during the heating season (in our country from October to April). That is why other possibilities of using thermal energy are developed, through: the production of electricity during the CHP process, the process of cooling, the sale of thermal and electric energy, or for certain manufacturing processes. Among other things, thermal energy can be used for the operation of kilns for wood drying, certain postfinishing processes and other manufacturing processes that require the production of hot water or industrial steam.

In countries such as Denmark, Netherlands and Austria, companies that sale thermal energy produced in the wood waste combustion process to district heating company or directly to customers can be found [1]. Also one of the options of using thermal energy is the option of driving absorption refrigeration system (chiller) for the production of chilled water for the needs of any production process of another company or cooling needs during the summer period. However, recently the most attention is paid to the cogeneration process using the wood waste combustion boilers. The advantages of this option are related to the possibility of using the available thermal energy for electricity production out of the heating season, the use of produced electricity for the production processes or to its sale to the company that distributes the same. Thus, for example in Austria or the UK, electricity produced in the furniture manufacturing company is sold to the electricity distribution company at a price of 0.15 and 0.07 €/kWh, respectively (data for 2005.; today prices are even higher) [1]. For electricity production, steam turbines with power usually less than 1 MWe and the efficiency ranges from 6 - 20% are used [1]. They are suitable for boiler variable load regimes and are less sensitive to the presence of different compounds in the wood as a result of its processing.
An example of efficient use of produced thermal energy is the company Biostrom (Austria), which annually process 22000 tons of wood waste (Fig. 1) [1]. Wood waste includes a mix of pellets, as well as wood treated in various furniture manufacturing processes.

**Fig.1.** The Biostrom company (Austria): Introducing a wood waste in the boiler plant (left) and the view of electricity generating plant (right) [1]

Because in this company treated wood that contains different compounds from its processing is used as a fuel, the same company has also installed the boiler with furnace with 20 m height in order to ensure sufficient time to keep the fuel gases (about 2s), where the maximum combustion temperature is 1100 ˚C. They also has installed ceramic filters for purification of outlet flue gases, with emissions of CO < 30 mg/m$^3$ and particles < 3 mg/m$^3$. The boiler plant produces 10 MW of thermal energy from which 2 MW is supplied for district heating, 6 MW is separated for electricity production, from which 1.2 MWe is sent to the electric distribution grid. The rest of the generated heat is transported to the neighbouring company for the production of bottles for driving absorption refrigeration systems for the production of water temperature of 5 ˚C [1].
Oram Fabrications Ltd Company (United Kingdom), which produces the working tables for the kitchen and bathroom, also presents a positive example of efficient use of thermal energy produced in wood waste combustion process. Wood waste that is burned in the boiler of 2 MW power is composed of wood chips and boards of MDF. Produced thermal energy is used for heating the entire company and for driving roller hydraulic press for laminating [1].

## THE IMPACT OF THE WOOD WASTE COMBUSTION PROCESS ON THE ENVIRONMENT

The burning of the wood waste leads to the generation of various gases and particles as a result of chemical reactions of compounds contained in wood waste (carbon, hydrogen, water, sulphur, ammonia and other compounds) with oxygen, initiated by bringing the heat or burning the wood waste. As unavoidable by-products of combustion, certain gases (along with particles of ash and unburned waste) are considered very harmful gases to the environment. First of all, this includes carbon dioxide, carbon monoxide, nitrogen oxides, hydrocarbons, particles of ash and unburned waste, methane.

Depending on the type of burned wood waste or the presence of different compounds in it as well as the combustion conditions (complete or incomplete), some of these gases will be generated in some situations. However, the gas that will be generated at any time during the combustion of the wood waste is carbon dioxide which is a consequence of the reaction of carbon in wood and oxygen. It should be noted that this gas during the analysis of the negative impact of the wood combustion does not present hazardous pollution gas because the $CO_2$ is absorbed by the wood during its formation (the photosynthesis process).

As it has already mentioned, low combustion temperature causes the creation of conditions of incomplete combustion, leads to formation of carbon monoxide, soot, as well as methane and nitrogen oxides ($N_2O$). During the combustion of the treated wood waste halogen organic compounds that contain chlorine, bromine and fluorine or heavy metals (copper, chromium, arsenic), that have very negative impact on the health and safety of people, can be emitted. Because of the negative effects of emissions of the harmful substances generated by the wood waste combustion, their emission limits (The European Waste Incineration Directive (2000/76/EC)) are defined, with the aim of reducing their impact on the environment. The Directive (2000/76/EC) relates to the incineration of different types of waste including wood waste combustion. Within it the limitations on the pollution of air and also land and water are defined [7]. The above Directive is of particular importance for Serbia because of our tendencies regarding to EU membership. Table 2 points out the values of average daily allowable emissions (particles, organic compounds, HCl, HF, $SO_2$, NO, $NO_2$) from waste incineration plants [8].

**Table 2.** The values for average daily allowable GHG emissions (particles, organic compounds, HCl, HF, $SO_2$, NO, $NO_2$) from the waste incineration plant [8]

| | |
|---|---|
| Particles | 10 mg/m$^3$ |
| Organic compounds expressed by total carbon | 10 mg/m$^3$ |
| Hydrogen chloride (HCl) | 10 mg/m$^3$ |
| Hydrogen fluoride (HF) | 1 mg/m$^3$ |
| Sulphur dioxide ($SO_2$) | 50 mg/m$^3$ |
| Nitrogen monoxide (NO) and nitrogen dioxide ($NO_2$) for new and old plants with capacity great then 6 t/h incinerated waste | 200 mg/m$^3$ |
| Nitrogen monoxide (NO) and nitrogen dioxide ($NO_2$) for new and old plants with capacity of 6 t/h and less of incinerated waste | 400 mg/m$^3$ |
| Carbon monoxide | 50 mg/m$^3$ |

The values of allowed emissions of heavy metals and their compounds, obtained by measuring conducted every 30 minutes and 8 hours are shown in Table 3 [8].

**Table 3.** The values of allowed emissions of heavy metals and their compounds, obtained by measuring conducted every 30 minutes and 8 hours [8]

| | 30 minutes | 8 hours |
|---|---|---|
| Cadmium (Cd) and its compounds, expressed by the cadmium | $0.05\ mg/m^3$ | $0.1\ mg/m^3$ |
| Thallium (Tl) and its compounds, expressed by thallium | | |
| Mercury (Hg) and its compounds, expressed by mercury | $0.05\ mg/m^3$ | $0.1\ mg/m^3$ |
| Antimony (Sb) and its compounds, expressed by antimony | | |
| Arsenic (As) and its compounds, expressed by arsenic | | |
| Lead (Pb) and its compounds, expressed by lead | | |
| Chromium (Cr) and its compounds, expressed by chromium | | |
| Cobalt (Co) and its compounds, expressed by cobalt | $0.5\ mg/m^3$ | $1\ mg/m^3$ |
| Copper (Cu) and its compounds, expressed by copper | | |
| Manganese (Mn) and its compounds, expressed by manganese | | |
| Nickel (Ni) and its compounds, expressed by nickel | | |
| Vanadium (V) and its compounds, expressed by vanadium | | |

The Directive indicates that it is possible to burn wood waste, raw lumber, waste from MFC, MDF, HDF, wood dust, in cases where the emissions of organic halogen compounds and/or heavy metals are in the permissible limits. Related to this, a company which covers the surfaces (edges) of the furniture pieces with PVC strips during the wood manufacturing process or uses (among other things) materials that contain copper, chromium, arsenic, chlorine (hydrogen chloride (for the wood painting)), bromine, fluorine, can not burn such treated wood (waste) in order to meet the requirements regarding the emissions of harmful substances prescribed by the mentioned directive [9].

As for the existence of laws and regulations that in Serbia prescribe the possibility of the combustion of wood waste as fuel, two main regulations exist: Regulation on emission limit values, methods and periods of measurements (Sl.Gl. 35/1997) and Regulation on imission limit values, methods of measurements and criteria for the determination of measuring spot (Sl.Gl. 30/1999), where wood waste is treated as biomass [2]. Table 4 presents the limits for GHG emissions during the biomass combustion in boilers [2].

**Table 4.** The limit values of GHG emissions during the biomass combustion in the boiler [2]

| | Capacity (MWth) | | |
|---|---|---|---|
| | > 1 - 50 | > 50 - 300 | > 300 |
| | $mg/m^3$ | $mg/m^3$ | $mg/m^3$ |
| Particles (dust) | 50 | 50 | 50 |

| | | | |
|---|---|---|---|
| Carbon monoxide (CO) | 250 | 250 | 250 |
| Nitrogen dioxide ($NO_2$) | 500 | 400 | 200 |
| Organic compounds expressed by total carbon | 50 | 50 | 50 |

Both regulations are necessary to amend or supplement in accordance to the same defined and adopted within the EU. Under the same regulation for boilers with power less than 1 MWth Standard JUS M.E6.110 is applied, that is adopted twenty years ago and it does not prescribe the limit values of emission of harmful substances [2].

## THE WOOD WASTE COMBUSTION IN THE SERBIAN FURNITURE MANUFACTURING COMPANY

The furniture industry in Serbia, according to the Republic Bureau of Statistics, currently employs over 15000 employees in over 2000 companies and 3000 workshops, which are mostly privately owned. The largest number of private companies is ranked as a "small companies" (91.7%). Medium-sized companies participate with 7.1%, and large companies with the remaining 1.3% [10]. As an example of analysis of possibility of wood waste combustion, the company "Novart" from Kragujevac is considered. For the manufacturing purposes company as raw materials uses MFC, MDF and HDF. The production program is consisted of over 100 different elements and annually over 50000 of different furniture pieces are made. Table 5 shows the results of the analysis of the energy content of wood waste materials annually generated within the company during the processing operations of the board materials. Thereby, it was taken into account only the amount of waste wood material that can be used for combustion according to the Waste Incineration Directive (2000/76/EC). Physical and chemical properties of the board materials were taken from [5]. The analysis shows that the energy content of the wood waste generated during a standard operational year is around 40 toe. Taking into account the number of companies of this industrial branch in Serbia, it is clear that the potential of waste wood material usage is substantial.

**Table 5.** The characteristics of the wood waste generated in the Novart company

| Wood waste | MFC | MDF | HDF |
|---|---|---|---|
| Density (kg/$m^3$) | 694.5 | 715.5 | 879 |
| Lower heating value (MJ/kg) | 16.479 | 17.413 | 19.401 |
| Amount of the waste ($m^3$/god) | 115.36 | 16.27 | 7.23 |
| Energy content of the waste (GJ/god) | 1320.257 | 202.708 | 123.297 |
| Total energy content (GJ/god) | 1646.262 | | |
| Total energy content (TCE/year) | 56.167 | | |
| Total energy content (toe/year) | 39.32 | | |

TCE - tonne of coal equivalent
toe - Tonne of oil equivalent

## CONCLUSION

Conducted analysis of generated wood waste and its energy content indicates the existence of possibilities for its combustion in order to obtain thermal energy for heating the manufacturing and business facilities of the company, for electricity production with the previously installation of steam turbine, or for the simultaneous production of electric and thermal energy. The mentioned world experiences and case studies unequivocally prove that. The waste combustion also leads to the significant reduction of its quantity and the need for its disposal and associated costs while increasing efficiency and profits of the company without a negative impact on the environment. Conducted analysis shows the significant possibility of the combustion of the generated wood waste, with high-energy content (in the range of high quality brown coal). It can contribute to the increasing of the efficiency and profits of the furniture manufacturing companies while reducing the negative impact of mentioned waste on the environment as a result of disposing of the same in landfills.

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