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TECHNOLOGY-RELATED LIMITATIONS DURING WOOD GAS CO-FIRING IN INDUSTRIAL FURNACES

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ABSTRACT
One option to reduce greenhouse gas emissions is the use of renewable energy sources including wood biomass. Wood biomass is not directly usable as a fuel for various industrial furnaces. If we want biomass to replace a portion of the fossil fuel the easiest way is to use a gasifier where biomass is gasified with presence of air. Combustible wood gas is then collected and used in a furnace replacing a portion of fossil fuel. Fossil-fuel-replacement ratio is very strongly influenced by the composition and thermodynamic and transport properties of wood gas which depend strongly on biomass composition, especially moisture content. For low temperature district heating systems, only the quantity of energy is important. In a case of high temperature industrial furnaces the production technology dictates process parameters. Because of these limitations generally we cannot completely replace the fossil fuels. The article will present the analysis of important technology-related limitations involved in wood-gas and natural gas co-firing during the lime burning.
Keywords: wood chips, gasification, flue gas, lime kiln

1. INTRODUCTION
The transition from fossil fuels to renewables is one of the goals of world's energy politics. One of realistic options is to gradually increase the use of wood as a fuel. Wood biomass is not directly applicable as a fuel for most of industrial furnaces. Nevertheless biomass can replace a certain portion of the fossil fuel if it is gasified prior to burning. The easiest and the cheapest way is an external gasification unit. The combustible wood gas is then collected and introduced to the furnace for final combustion without any intermediate cooling or cleaning. This way all the energy from wood is transferred to the furnace. The advantage of such a system is that only a minimal modification of the existing firing system is required. Normally there are limitations that cannot be neglected [1, 2]. This article deals with these technology-related limitations in a case of wood gas co-firing in an annular-shaft kiln for lime burning. The main factors like air ratio, wood chips water content and overall fuel costs are analyzed.
Figure 1 shows an example of annular-shaft kiln for lime burning. The first portion of combustion air is introduced to the kiln from the bottom. It removes the heat from the quick lime which is moving downwards. The second portion of combustion air comes from regenerative heat exchanger and is used for driving the ejectors. Less than 20 % of total air (secondary air) is introduced directly to burners. If we want to replace a portion of fuel oil or natural gas with wood gas some technology-related limitations apply. The first limitation is the preservation of flue-gas mass flows passing through respective kiln sections and their ratios. The second limitation is the preservation of flue-gas-temperature level in the combustion chamber and vertical temperature profile of the kiln. During every fuel replacement it is essential that the basic parameters in the furnace and heat-transfer surfaces

do not change significantly. In some industrial processes like lime production and metal or minerals melting only high temperature heat is required. For example lime burning requires the heat between 830 °C and 1300 °C [3].

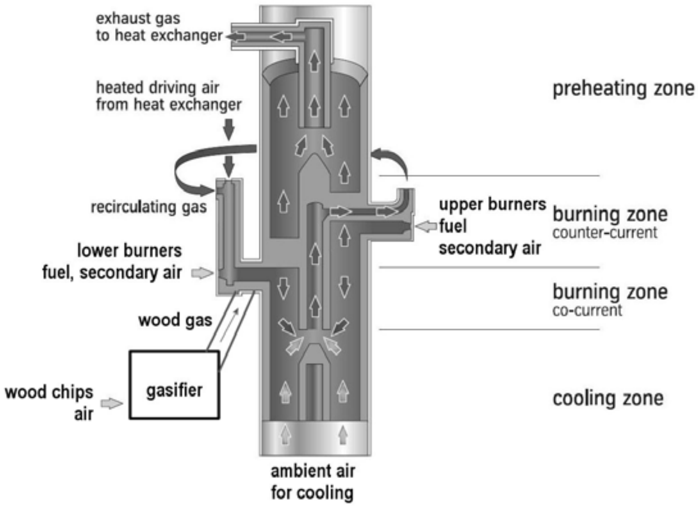

Figure 1. Annular shaft kiln for lime burning [4] with wood chips gasifier

2. THERMODYNAMIC MODEL

The thermodynamic model of the kiln was built in IPSE Pro 5.0 software [5,6]. Figure 2 shows impacts of water content in wood chips and of air ratio in the gasifier on the quantity of natural gas that can be replaced by wood gas at lower burners.

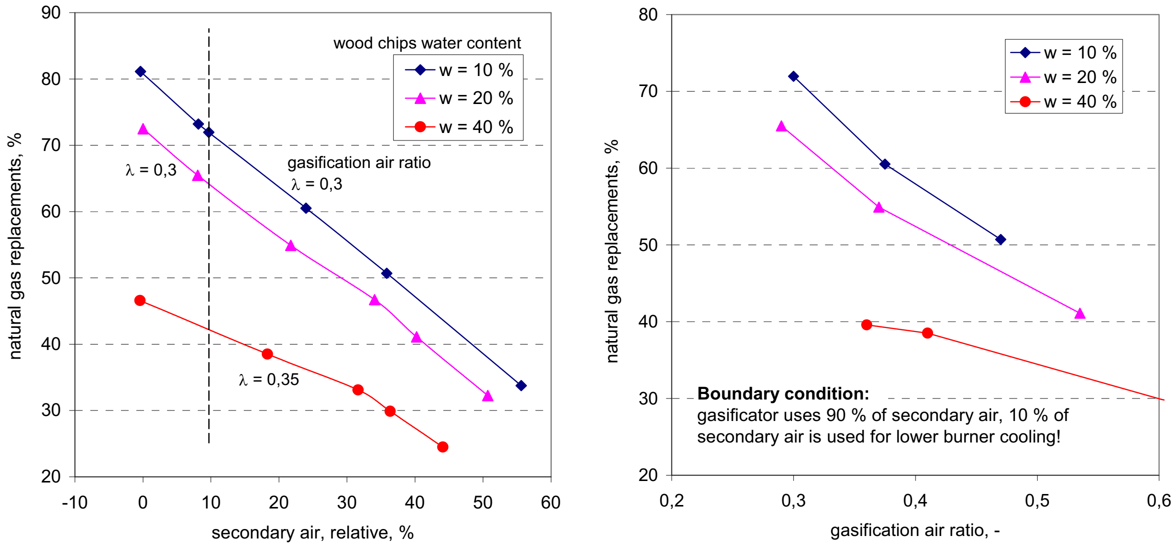

Figure 2. Impact of wood chips water content and gasification air ratio on natural gas replacements at lower burners

To preserve the mass flow of flue gas flowing through the kiln the air consumption of the gasifier can at most be equal to the air-consumption of lower burners. If the air consumption was higher it would mean that cooling and ejectors-driving air is being reduced. This would have an impact on mass and energy balances of the kiln meaning that the quality of the lime would deteriorate. Two important limitations defining the fuel-replacement rate during regular operation need to be emphasized. The first limitation arises from the fact that lower burners need to be cooled by means of secondary air. The minimal cooling air flow is at least 10 % of the original flow. The second limitation is the air ratio in the gasifier that is needed for a complete gasification of wood chips. In theory the minimal air ratio needs to be at least 0.25. In a gasifier which is actually a simple pre-combustion chamber, air ratios of >0.35 are achievable especially if the water content in wood chips is high. Figure 2 shows that water content in wood chips and gasification air ratio have a significant impact on the natural-gas replacement rate. Figure 3 shows natural-gas replacement rate for a 150 t/day kiln production. Ideally the total heat input introduced with the primary and the replacement fuel remains constant. Figure shows replacement rates for wood-chips with three different water contents (10 %, 20 % and 40 %). In the case of wood chips with 10 % water content the replacement line goes from A to B at constant heat input. Let us name point B a "breaking point". If we want to achieve a higher replacement rate, more air is needed for the gasifier. Due to the technology-related limitation requiring constant flue-gas temperature at combustion-chamber exit, additional air requires also additional fuel. This process is designated with the B-C line. In point C a 100 % wood-chips operation is reached. In point C the heat input with fuel is 6 % higher than in point B. If water content in wood chips is even higher, the replacement rate requiring no additional fuel consumption is positioned lower (point D). At 40 % water content it is almost impossible to replace a significant portion of natural gas without increasing the fuel consumption and a 100 %-wood-chips operation is not achievable at all. During regular operation ~70 % fuel-replacement rate (at lower burners) was achieved using wood chips containing ~20 % of water which is in very good agreement with the results of this thermodynamic simulation.

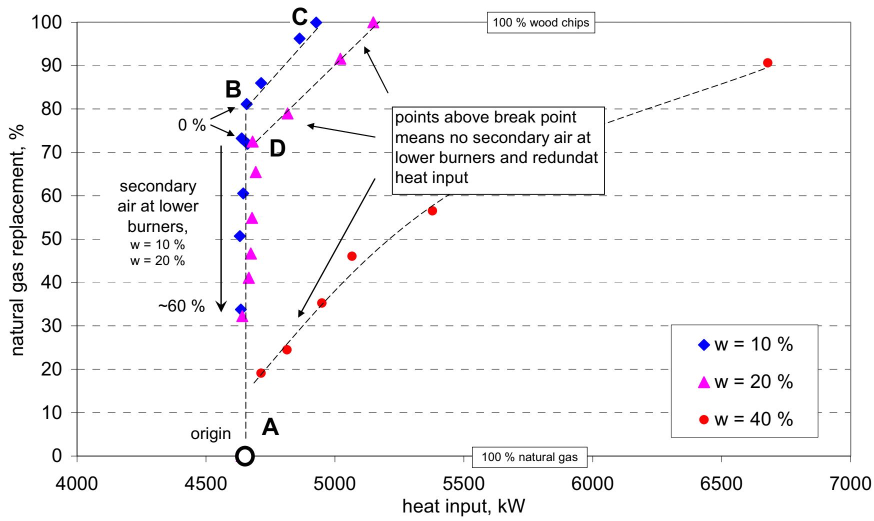

Figure 3. Thermodynamic relations among heat input and replacement rate

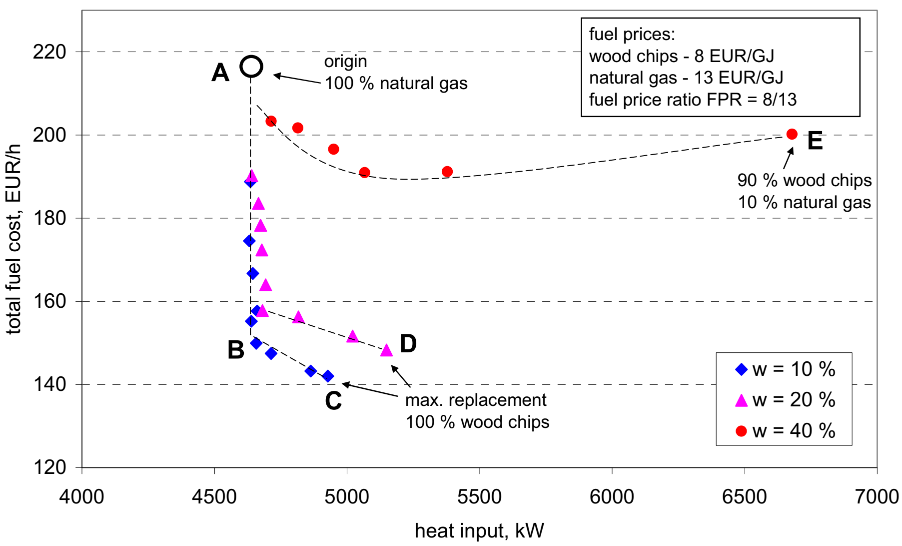

Figure 4. Fuel cost economy

Fuel costs in relation to the heat load are shown on Fig. 4. Slovenian fuel prices from autumn 2014 are taken into account: natural gas for industry ~13 EUR/GJ, wood chips ~8 EUR/GJ.
Regular 100 % natural-gas operation is designated with point A. Fuel costs are 217 EUR/h. During combined-fuel operation at constant heat load, fuel costs are reduced. In point B all the available secondary air enters the gasifier. If we force further fuel-replacement, fuel costs follow the BC line. Total fuel costs are still decreasing but at a lower rate due to increased fuel input. Point C represents 100 % wood-chips operation (10 % of water in wood chips). At higher water content in wood chips savings are reduced. Point D also designates 100 % wood-chips operation (20 % of water in wood chips). The AE curve represents the replacement of natural gas with wood chips containing 40 % of water. Fuel costs are reduced but at much slower pace.

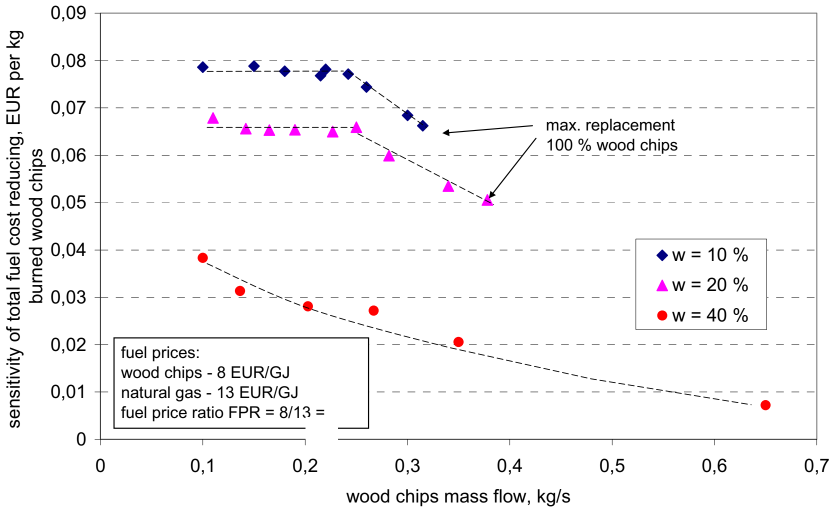

Figure 5. Sensitivity of total fuel cost reduction

Figure 5 shows the sensitivity of total fuel costs reduction in relation to wood-chips mass flow and water content. The sensitivity is in inverse proportion to water content in wood-chips. The sensitivity is constant until the “breaking point” where it starts to decrease.

3. CONCLUSIONS

Paper deals with co-firing of natural gas and wood gas at lower burners in an annular shaft kiln for lime burning. Wood gas is obtained from wood chips in gasifiers added to the kiln. In the thermodynamic model three basic technology-related limitations are taken into account: constant temperature in the firing chambers, constant mass flow of flue gas and limited amount of combustion air that is available for the gasifiers. The results of the thermodynamic model were successfully verified on the kiln with a capacity of 150 t/day of kiln.
Water content and gasifier air ratio have significant impact on the natural-gas replacement rate. Analysis of total fuel costs shows that fuel-costs savings are proportional to the dryness of wood-chips. During the partial or total replacement of the original fuel the most important factors are the quality of the product, fuel costs, availability of fuel and technology related limitations of the furnace.

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