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THE COMPARISON OF USING VARIOUS TYPES OF GASEOUS FUEL IN LIME PRODUCTION

USPOREDBA KORIŠTENJA RAZLIČITE VRSTE PLINOVITOG GORIVA U PROIZVODNJI ŽIVOG VAPNA

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Review article

Abstract: *In lime production drive fuel is the most significant factor in determining the price, competitiveness and sustainability of a product on the market. The comparison and analysis of partial or total usage of synthetic gas obtained by wood chips gasification were carried out. The technological process of lime production in the Maerz furnace was described, and fundamental technical and economic parameters of using and/or substituting natural and synthetic gas were graphically and analytically presented. The impact of price alterations and distance radius related to the supply of wood chips on annual drive fuel costs was analyzed. The reduction in annual drive fuel costs by using synthetic gas was quantified. A full analysis of the applicability of wood chips gasification plant from the aspect of technical and technological conditions, cost-effectiveness, sustainability and ecological effectiveness within a concrete lime production process is required.*

Key words: *lime, Maerz furnace, natural gas, synthetic gas, cost-effectiveness.*

Pregledni rad

Sažetak: *U proizvodnji živog vapna pogonsko gorivo je najutjecajniji faktor u formiranju cijene, konkurentnosti i održivosti proizvoda na tržištu. Uspoređeno je i analizirano djelomično ili potpuno korištenje sintetičkog plina dobivenog rasplinjavanjem drvne sječke. Opisan je tehnološki proces proizvodnje živog vapna u Maerzovoj peći, te su grafički i analitički prikazani osnovni tehnički i ekonomski parametri korištenja i/ili supstitucije prirodnog i sintetičkog plina. Analizirani su utjecaji promjene cijena i polumjera udaljenosti dobave drvne sječke na godišnje troškove pogonskog goriva. Kvantificirano je smanjenje godišnjih troškova pogonskog goriva primjenom sintetičkog plina. Nužna je cjelovita analiza primjenjivosti postrojenja za rasplinjavanje drvne sječke s aspekta tehničkih i tehnoloških uvjeta, ekonomičnosti, održivosti i ekološke učinkovitosti u konkretnoj proizvodnji živog vapna.*

Ključne riječi: *živo vapno, Maerzova peć, prirodni plin, sintetički plin, ekonomičnost*

1. INTRODUCTION

The main raw material for lime production is limestone with the density amounting to around 2600 – 2750 kg/m^3 and the percentage of CaO amounting to 30 – 55 %. In technological processing lime granulation of 40 – 80 mm with low humidity, below 2 %, is usually used. During lime production, gaseous fuel is combusted in a furnace of a suitable capacity in direct contact with the raw material at the temperature between 850 °C and 1050 °C. The average thermal energy consumption for the production of 1 ton of lime ranges between 960 kWh and 1050 kWh, i.e. between 99.8 m^3 and 109.1 m^3 of natural gas, whose mean lower heat of combustion amounts to 9.6222 kWh/m^3 [1]. The block diagram of lime production process is shown in figure 1. Due to the price increase of natural gas and the fact that its percentage in the output price of a mass unit of lime is increasing, which significantly affects the competitiveness on the market, the possibility of using gaseous fuel obtained from renewable biomass has been looked into. For the purpose of cost reduction and the sustainability of the plant whose nominal capacity amounts to around 200 t/day of lime, the comparison and analysis of partial or total usage of synthetic gas obtained by wood chips gasification were carried out.

2. TECHNOLOGICAL PROCESS OF LIME PRODUCTION

The technological process of lime production is shown in the schematic in figure 2. [1]. The stone is transported from the warehouse to the sieve, after which the stone with granulation amounting to 40-80 mm is transported onto scales, and then by an adapted inclined transport to the Maerz furnace filling system.

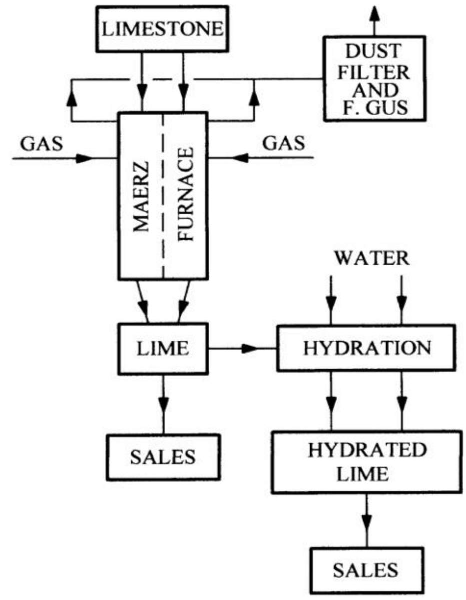
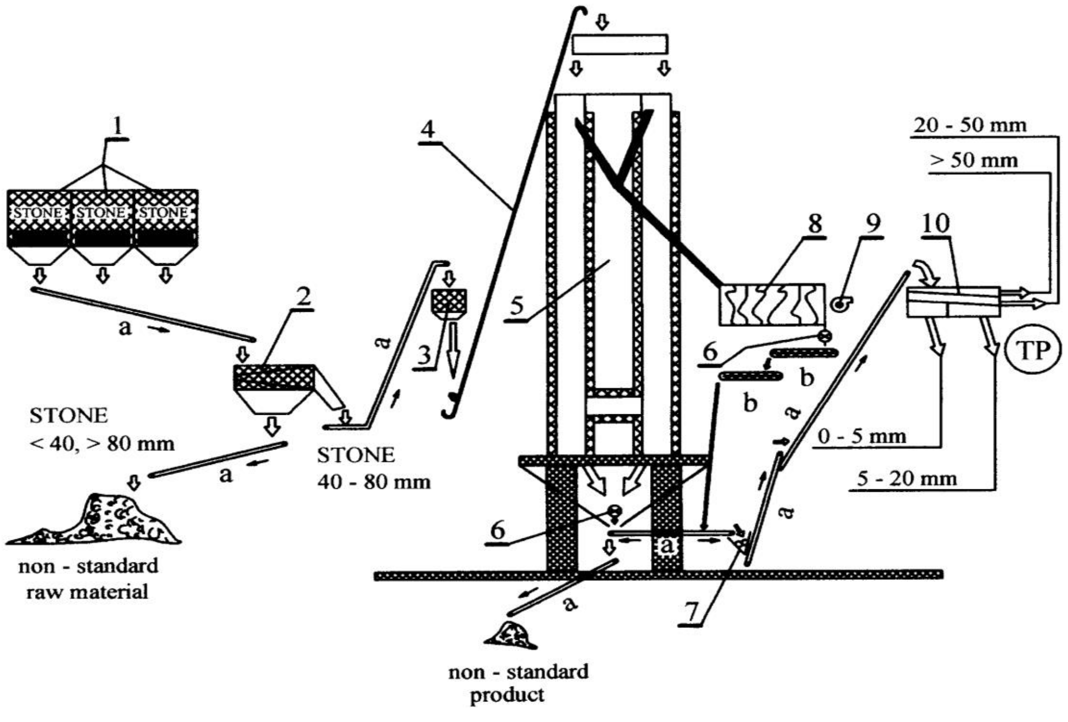


Figure 1. Block diagram of lime production

The stone (raw material) with granulation amounting to below 40 mm and above 80 mm is removed from the technological process. Through the infeed hopper and two distribution flaps, shaft 1 and shaft 2 of the Maerz furnace (figure 3) are interchangeably fed. At the top of shaft 1 and shaft 2 there are 15 burners per shaft. Directly above the gaseous fuel inlet the combustion air is fed in the combustion zone. The maximum thermal effectiveness of the Maerz furnace amounts to Q_{MF} = 6.29 MWh for the production of around 200 tons of lime in a single day [1]. By means of simultaneous filling of the shaft with stone and combustion of gaseous fuel and movement of the raw material and burning gases in the same direction, the contribution is made to the quality of stone baking and high efficiency of the process. Lime calcining finishes at the height of the connection channel between shaft 1 and shaft 2 at the temperature of around 1100 °C. The obtained heat is not completely used for lime calcining.



1. Stone warehouse 2. Stone sieve 3. Scales 4. Transporter 5. Maerz two-shaft furnace
6. Dosing feeder 7. Lime mill 8. Dust and flue gas filter 9. Dedusting ventilator
10. Primary lime sieve a – belt conveyors b – worm conveyors
TP – Further technological processing

Figure 2. The technological process of lime production

Therefore, through the opening of each shaft fresh air is blown in, which cools the lime from the active shaft. The mixture of air and combusted gases with the temperature of around 1000 °C flows through the connection channel from shaft 1 into shaft 2, where the total amount of air with the cooled gas mixture is used for the protection of burners from dust and overheating (shaft 2), as well as for pre-heating the stone inserted in shaft 2, whereat the combustion air in shaft 2 is pre-heated to around 700 °C. Operation reversion of each shaft depends on the finishing of limestone calcining process, i.e. leaving a certain amount of lime at the bottom of the furnace. During the reversion time the shaft (1 or 2), that is entered by a mixture of combustion products and air, is filled by a certain amount of stone that is pre-heated and the process is interchangeably repeated. The height of the pre-heating zone amounts to between 3 m and 5 m, the height of the active combustion zone amounts to 6.3 m, and the height of the cooling zone amounts to 4.4 m. According to practical experience, in vertical shafts 1 or 2 the lime production process in the active shaft lasts between 8 and 15 minutes, depending on the stone type, whereas reversion lasts around 1 minute. Shafts 1 and 2 are interchangeably filled with stone, and lime is constantly emptied from the bottom of both shafts. Depending on the given capacity, the mass of the dosed stone amount is constant. The change in capacity depends on the combustion duration time and the number of dosing a stone amount in a single hour. After milling, lime is transported to be graded through the primary sieve, and then to the final technological processing.

The operating pressure of gaseous fuel amounts to 400mbar, whereas the operating pressure of the combustion air and fresh air for cooling within regulation boundaries amounts to between 350 mbar and 400 mbar. The output gases with the maximum temperature of 160 °C are purified by bag filters before being released to atmosphere. Due to high thermal load, furnace walls are coated with high-quality brick and additional insulation material.

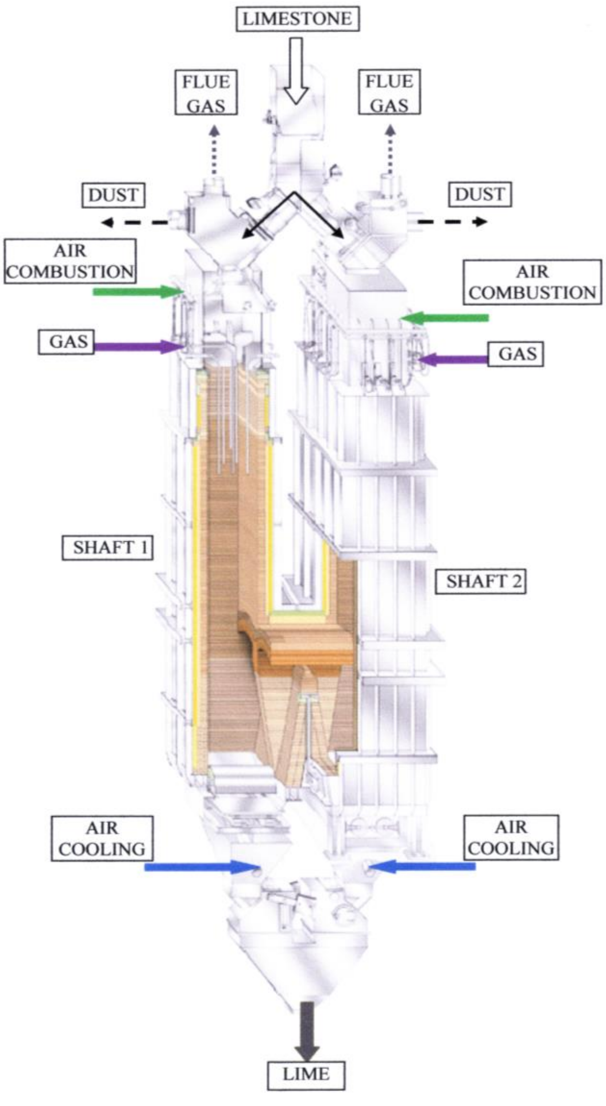


Figure 3. The scheme of Maerz furnace [1]

2.1 Production parameters – natural gas

The quantified values of annual lime production and energy balance at the combustion of natural gas in the Maerz furnace are shown in table 1.

Table 1. Annual lime production and energy balance – natural gas

Description	Values
Lime production m_l, t/a	56160
Natural gas consumption V_{NG}, m^3/a	5724770
Average thermal effectiveness of natural gas, kWh/m^3	9.62
Average lower heat of combustion of natural gas $H_{d,NG}$, MJ/m^3	34.64
Overall thermal effectiveness, kWh	55084812
Consumed energy, MJ	198306033
Consumed energy, MJ/t, lime	3531,3
Price of natural gas, €/m^3	0.416
Overall cost of natural gas, €/a	2381504

The average daily production during one year amounts to around $m_{l,d}$ = 153.86 t/day, which is around 23 % lea than the maximum nominal capacity of the Maerz furnace. Due to equipment and assembly maintenance, a lower number of working hours per year of the Maerz furnace is possible, which conditions the oscillation of daily capacities to the maximum value in individual time intervals. The consumption of natural gas (NG) and synthetic gas (SG) is determined by the following relation:

$$V_{NG(SG)} = \frac{Q_{MF}}{H_{d(NG,SG)}} \quad m^3/h. \tag{1}$$

The annual consumption of natural gas (NG) or synthetic gas (SG) is determined by the following equation:

$$V_{NG(SG),a} = V_{NG(SG)} \cdot 8760 \quad m^3/a. \tag{2}$$

3. SYNTHETIC GAS FROM RENEWABLE BIOMASS

By means of gasification, solid biomass (wood chips) is transformed into combustible synthetic or reactor gas applicable for combustion in furnaces or gas device plants. It is estimated that by means of gasification a single mass unit of woods chips with moisture of up to 20 % results in around 90 % of synthetic gas and around 10 % of ash/charcoal.

The main phases in the gasification process are: drying of wood chips at the temperature of around 200 °C, oxygen-free pyrolysis up to the temperature of 500 °C, followed by reduction and oxidation at temperatures between 900 °C and 1200 °C. The basic components of the obtained synthetic (reactor) gas are: CH_4, CO, H_2, CO_2, N_2 and negligible amounts of ethane and propane.

The amount of each synthetic gas component depends on the temperature and pressures at which the process develops and on the type and structure of biomass. Due to the presence of harmful substances (nitrogen and sulphur compounds, tar…), synthetic gas is purified after the gasification, and especially to a high degree of purity if it is used for direct combustion in the furnace [2, 3, 4].

Although technological procedures are continuously developed and upgraded, the most frequently used procedure is biomass gasification in the fluidized layer and in the updraft fixed bed gasifier (figure 4a.) and downdraft fixed bed gasifier (figure 4b.) [3, 5, 6].

In the updraft fixed bed gasifier it is possible to carry out the gasification of biomass (wood chips) sized between 5 mm and 100 mm with moisture amounting to 50 %. In downdraft fixed bed gasifiers the gasification of biomass (wood chips) uniformly sized between 20 mm and 100 mm with moisture amounting up to the maximum of 20 % is carried out. The minimum thermal effectiveness of the reactor amounts 10 kW, and the maximum one, depending on the construction, between 10 MW and 20 MW. In downdraft fixed bed gasifiers pyrolysis products pass through a hot gasification zone of charcoal, which contributes to the significant reduction in the tar percentage in the reactor gas. In this case, if the reactor gas is used for internal combustion engine drive, the gas purification plants are simpler and cheaper [3, 5, 6, 7].

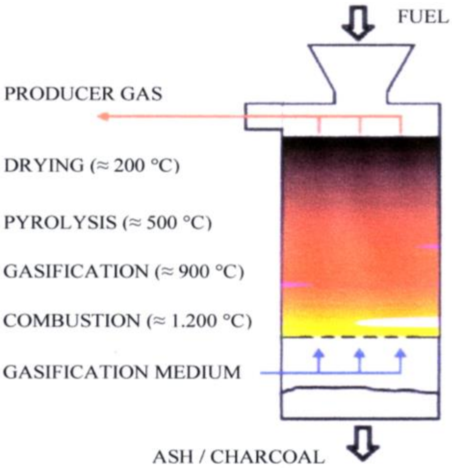


Figure 4a. Diagram of the updraft fixed bed gasifier

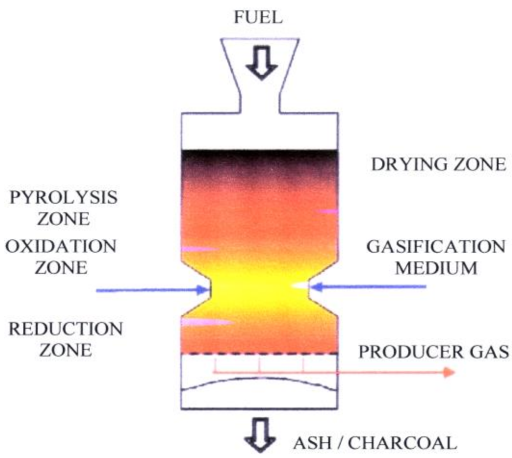


Figure 4b. Diagram of downdraft fixed bed gasifier

3.1 Synthetic gas characteristic

The chemical composition of reactor (synthetic) gas from biomass (wood chips) with average percentages of individual components is shown in table 2.

Table 2. The chemical composition of synthetic (reactor) gas from biomass (wood chips)

Component	Average volume proportion, %	Volume proportion, % (calculation)	Lower heat of combustion, H_d, MJ/m^3
CH_4	1.5 – 2.5	2.5	35.7
CO	18 – 24	22	12.6
H_2	14 – 17	16	10.79
CO_2	10 – 11	10.5	0.0
N_2	45 – 52	49	0.0

The lower heat of combustion of the reactor (synthetic) gas is determined according to the following relation:

$$H_{d,SG} = 0,025 \cdot H_{d,CH_4} + 0,22 \cdot H_{d,CO} + 0,16 \cdot H_{d,H_2} . \qquad (3)$$

In a concrete case the calculated lower heat of combustion of the reactor (synthetic) gas amounts to $H_{d,SG}$ = 5.3909 MJ/m^3 ≈ 5.4 MJ/m^3. At the reactor exit synthetic gas with the temperature of around 600 °C cools up to the maximum temperature of 50 °C. For its cooling from around 600 °C to 50 °C, 717.86 kJ/kg of heat is consumed at the mean synthetic gas temperature $c_{p,SG}$ = 1.3052 kJ/kg,K. By means of a compressor at a suitable operating preset pressure the cooled synthetic gas enters into the combustion zone in the Maerz furnace.

3.2 Characteristic of biomass – wood chips

It is difficult to determine the composition of the produced wood chips according to wood types. They are of various energetic values that significantly depend on moisture content per mass unit. The moisture content in the produced wood chips mass m_S ranges between u = 20 % and u = 50 %. From the absolutely dry wood chips mass unit – atro mass (m_{atro}) of all wooden remnants around q_E = 5.2 kWh/kg of thermal energy is obtained. The assessment of the thermal effect Q_E of biomass – wood chips m_{WC} of any moisture is determined by the following relation:

$$Q_E = m_{WC} \cdot \left(1 - \frac{u}{100}\right) \cdot q_E \quad \text{kWh}. \qquad (4)$$

According to (4), from 1 ton of wood chips of the average moisture content u = 35 % around $Q_{E,35}$ = 3380 kWh is obtained, while from 1 ton of wood chips of the average moisture content u = 20 % around $Q_{E,20}$ = 4160 kWh of thermal energy is obtained. Heat of combustion of wood chips with u = 20 % amounts to $H_{dC,20}$ = 14976 kJ/kg, while regarding wood chips with u = 35 % it amounts to $H_{dC,35}$ = 12168 kJ/kg [8, 9].

Wood chips mass m_{WC} with moisture content u = 35 % for gasification (f_i – wood chips mass gasification content = 0.9) and the synthetic gas production m_{SG} is determined according to the following relation:

$$m_{WC} = \frac{m_{SG}}{f_i} \cdot \frac{H_{dC,20}}{H_{dC,35}} \quad \text{kg/h}. \quad (5)$$

Synthetic gas mass is defined by the following equation:

$$m_{SG} = V_{SG} \cdot \rho_{SG} \quad \text{kg/h}, \quad (6)$$

whereat synthetic gas density amounts to ρ_{SG} = 0.9517 kg/m^3 at the temperature of around 50 °C.

3.3 Calculation values – synthetic gas

Calculation values of full substitution of natural gas by synthetic gas obtained by gasification of wood chips with moisture content amounting to u = 35 % for the annual lime production m_v = 56160 tons are shown in table 3.

Table 3. Annual lime production – synthetic gas, calculation values

Description	Values
Lime production m_l, t/a	56160
Synthetic gas consumption V_{SG}, m^3/h	4193
Synthetic gas consumption V_{SG}, m^3/a	36733133
Average lower heat of combustion of synthetic gas $H_{d,SG}$, MJ/m^3	5.4
Synthetic gas density ρ_{SG}, kg/m^3	0.9517
Synthetic gas mass m_{SG}, kg/h	3990.7
Synthetic gas mass m_{SG}, kg/a	34958923
Average lower heat of combustion of wood chips H_{dC}, kJ/kg	12168
Bulk density of w. chips ρ_{BDC}, kg/m^3	330
Wood chips gasification content f_i	0.9
Wood chips mass m_{WS}, kg/h	5454
Wood chips mass m_{WS}, kg/day	130896
Wood chips mass m_{WS}, t/a	47777
Wood chips volume V_{VC}, m^3/h	16.53
Wood chips volume V_{VC}, m^3/day	396.7
* Wood chips volume V_{VC}, m^3/a	123955

*Volume is reduced by the warehouse capacity of wood chips conditioned by a one-day transport discontinuation in each week during the year.

4. COMPARISON AND ANALYSIS OF RESULTS

The diagram in figure 5 represents the quantified values with different substitution contents of natural gas by synthetic gas obtained by wood chips gasification with humidity content amounting to u = 35 % for the annual lime production in Maerz furnace.

For the average purchase price of 1 m^3 of natural gas C_{NG} = 0.416 €, i.e. the average price of 1 kg of natural gas $C_{av,NG}$ = 0.5546 € (ρ_{NG} = 0.75 kg/m^3) and the average purchase price of prepared wood chips to the distance radius from the location of synthetic gas consumption of around 50 km C_{WC} = 40 €/ton, the graphs in figure 6 comparatively present the costs for various substitution relations of natural gas by synthetic gas.

For using synthetic gas obtained by wood chips gasification the construction of a suitable plant with a biomass warehouse in the vicinity of lime production is required. Around 11.2 kg of wood chips with moisture content amounting to u = 35 % is necessary for the gasification and obtaining of synthetic gas for the substitution of 1 kg of natural gas. By full natural gas substitution ($H_{d,NG}$ = 34.64 MJ/m^3) by synthetic gas ($H_{d,SG}$ = 5.40 MJ/m^3) drive fuel costs are reduced by approximately 20 % at annual production of 56160 tons of lime in the Maerz furnace.

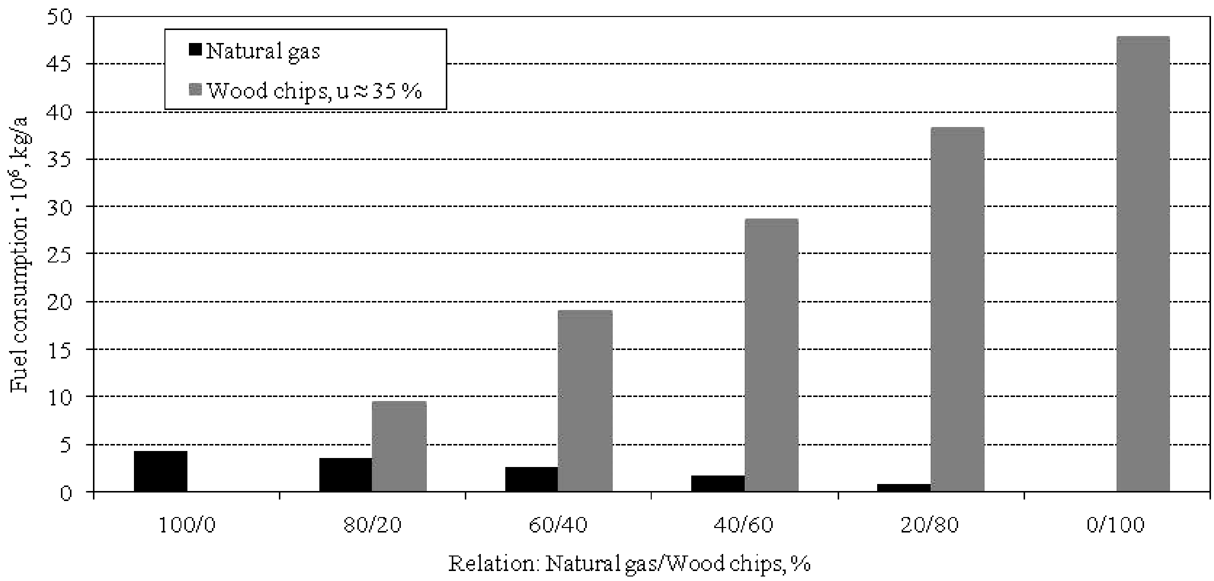


Figure 5. Natural gas substitution by synthetic gas from wood chips

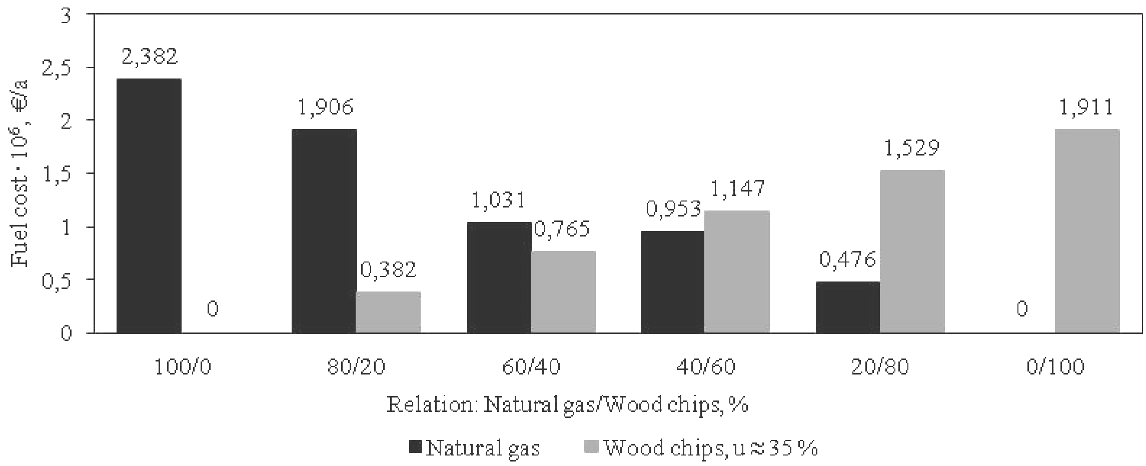


Figure 6. Annual costs of drive fuel for various relations between natural and synthetic gas

By reducing the price of wood chips of the aforementioned technical characteristics by approximately 25 % (C_{WC} = 40 €/ton) and the supply radius to the maximum distance of 30 km from the gasification plant and usage of synthetic gas, the annual drive fuel costs in lime production are reduced by 40 % at full natural gas substitution. At a natural gas price higher by around 10 % than the stated value and its full substitution by synthetic gas from wood chips supplied from a maximum distance of 50 km from the Maerz furnace, the annual drive fuel costs would reduce by approximately 27 %, and if wood chips were supplied from the distance radius of 30 km, the annual costs would reduce by around 45 %.

The substitution proportion of natural gas by synthetic gas depends on a range of significant parameters. A greater content of synthetic gas results in the increased cost-effectiveness of lime production in the overall annual fuel consumption.

5. CONCLUSION

The cost-effectiveness of lime production of a higher annual capacity (56160 tons) in the Maerz furnace depends on the drive fuel price. Due to the price increase of natural gas and influence on the competitiveness of a lime mass unit, the comparison and analysis of partial or total usage of synthetic gas obtained by wood chips gasification were carried out. The technological process of lime production in the Maerz furnace was described, and basic technical and economical parameters of the usage and/or substitution of natural and synthetic gas were presented. The influence of price alterations and the wood chips supply distance radius on annual drive fuel costs was analyzed. According to the current unit process of natural gas and wood chips, the application of synthetic gas would reduce the annual drive fuel costs in lime production in the Maerz furnace by around 20 % up to maximally 45 %. The justifiability of substituting natural gas by synthetic gas depends on a range of technical, economical and ecological parameters. It is recommendable to observe the technical and technological conditions and characteristics of the biomass gasification plant in detail, as well as its applicability, sustainability and ecological effectiveness in a concrete lime production process.

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