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Review

STEAM INFLUENCE ON BIOMASS GASIFICATION PROCESS

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This paper describes the study of biomass gasification and biomass gasification efficiency increasing with the assistance of steam supply into the atmospheric fluidized bed gasifier. Gas composition and lower heating value dependence on steam temperature and its input volume are also researched.
Key words: biomass, steam gasification.

Utjecaj pare na proces rasplinjavanja biomase. U radu je opisana studija rasplinjavanja biomase i učinkovitost rasplinjavanja biomase koja raste uz pomoć opskrbe parom u atmosferski fluidizirani sloj reaktora. Istraženo je da sastav plina i donja ogrijevna vrijednost ovise o temperaturi pare i njezinom ulaznom volumenu.
Ključne riječi: riječi: biomasa, rasplinjavanje uz pomoć pare.

INTRODUCTION

Reserves of noble fossil fuels are constantly decreasing along with increase of atmospheric CO_2 emissions coming from combustion processes. Current trends aim to preserve primary energy sources to the maximum and replace them with alternative fuels. Various forms of biomass and waste seem to be a promising energy source in the Czech Republic. These renewable energy sources cannot completely replace fossil fuels and become a prevailing source of energy; however, they may be a helpful regional supplement of utility energy, i.e. source of heat and electricity. Environmentally friendly disposal of these alternative fuels is among the major advantages of this technology.

Basic physical-chemical process behind energy from biomass and waste is incineration and gasification. Biomass incineration is a fully mastered process nowadays. Process of wood incineration is successfully performed in stoker-fired boilers and fluidized bed boilers and wood also serves as an auxiliary fuel in large-scale fluidized bed boilers and pulverized fuel boilers. Combined incineration of coal and biomass is currently widely used in boiler houses, heating plants with back pressure turbines and in power plants. Incineration of biomass only is mostly effective in local boiler houses in regions with decent availability of waste biomass.

Other method of energy obtaining from biomass is biomass gasification. Thermochemical gasification is a conversion of organic matter into gas with low lower heating value (LHV) (CO, H_2, CH_4, CO_2, N_2, H_2O). Gasification process is carried out in high temperatures, typically around 750 up to 1,000 °C. Partial oxidation of gasified material (gasification using air or oxygen) commonly supplies heat for endothermic reactions. Gasification using air is a more common technology. Produced gas is suitable for operation of boilers, engines and turbines; however, it is not suitable for transfer via gas lines due to low LHV (4–7 MJ/m^3) and undesired composition.

Gas comprises trace amounts of higher hydrocarbons such as ethane and ethene, small particles of charcoal and ashes, tar and other substances. Gasification process consists of the following steps:

- drying which evaporates the moisture,
- pyrolysis which produces gas, gaseous tar and oils and residual charcoal,
- gasification or partial oxidation of solid charcoal, pyrolysis of produced tar and gas.

Once the solid fuel is heated up to 300–500 °C temperature with no oxidation agent present, pyrolysis transfers the fuel into solid charcoal, condensable hydrocarbons or tar and gases. Relative yield of the gas, liquid and charcoal mostly depends on heating speed and final temperature. Generally speaking, pyrolysis is much faster to occur than gasification and therefore gasification is the decisive step that influences particular composition. Gaseous, liquid and solid products of pyrolysis react with oxidation agent, commonly air, and form gases (CO, CO_2, H_2) and small amounts of HC gases. Gas composition is affected by various factors, e.g. composition of initial input, water content, reaction temperature and degree of oxidation of pyrolysis products.

Advantages of gasification compared to incineration are as follows:

- Cogeneration with higher heating plant module which produces more electricity and saves more primary fuels.
- Transformation of solid fuel with large specific volume into gaseous fuel which may be incinerated in heat engines; substitution of imported gaseous fuels.
- Potential to use various alternative solid fuels, e.g. waste.
- Reduction of CO_2 and other harmful emissions.

On the other hand, biomass gasification is a more complex technology compared to incineration. Strongest disadvantage and main technical problem of gasification units with heat engines is sufficient cleaning of produced gas from tar and solid particles. So far, no reliable solution has been presented worldwide for successful commercial application.

Typical gasification media

Gasifying agent - moderator has an essential effect on the process efficiency and yield and composition of the gas. The following are used as gasification media: CO_2, hydrogen (processes utilizing both agents are currently being researched), air, oxygen, steam and their combinations. All types of moderator have their benefits and disadvantages, which are discussed below.

- Air is the most common media used as it is the most readily available one. It is also the cheapest and it presents no operational problems. However, produced gas contains large share of nitrogen (up to 50 %), which decreases its lower heating value to 4–7 MJ/m^3.

- Application of oxygen is related to high costs and risks associated with production of pure oxygen and its usage in the gasification process with enriched air. Produced gas contains low amounts of nitrogen and has medium lower heating value (ca. 10 MJ/m^3). Oxygen is commonly used in pressurized gasification.
- Gasification using steam is a highly endothermic process. Energy necessary for thermal decomposition of the fuel is supplied either from external source (mostly via circulation of sand or catalytic material heated to operational temperature of the reactor, i.e. 850 °C) or from partial oxidation of the fuel, which results in partial incineration. Therefore, mixture of steam with oxygen (lower heating value of the gas ca. 14 MJ/m^3) or with air (lower heating value of the gas ca. 8 MJ/m^3) is most commonly commercially used. Higher partial pressure of H_2O in reactor will lead to higher conversion of solid char thus to higher yield fuel. [5]

INFLUENCE OF STEAM ON THE GASIFICATION PROCESS

Influence of steam on gas quality depends on the type of gasification medium, its temperature, gasification ratio, ratio of steam to biomass (S/B ratio) and on various other conditions influencing gasification process (Figure 1). Indicators of quality include lower heating value of the gas (its composition), amount of gas, purity of gas and amount of tar (or its composition).

Gasification ratio expressed as oxygen/ carbon (O/C) influences amount of incinerated fuel and consequently the heat released in reactor and composition of produced gas. Experience proved that optimum ratio of excess air (a) equals a=0.23–0.35. But the ratio depends on amount of energy required for successful endothermic reactions in the generator.

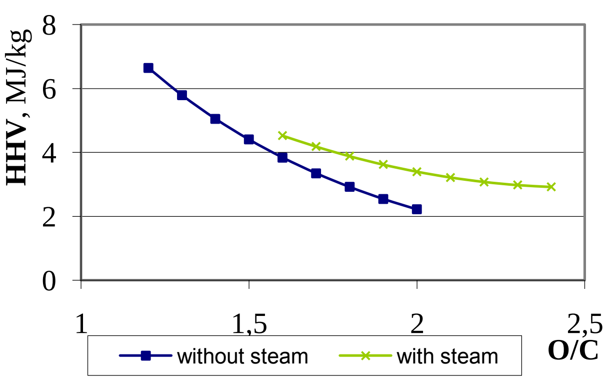

Figure 1. Effect of supply of steam on higher heating value (HHV) of dry gas (T=750–800 °C, a=0.38–0.43) [3]

Slika 1. Učinak opskrbe parom na gornju ogrijevnu vrijednost (HHV) suhog plina (T=750–800 °C, a=0.38–0.43) [3]

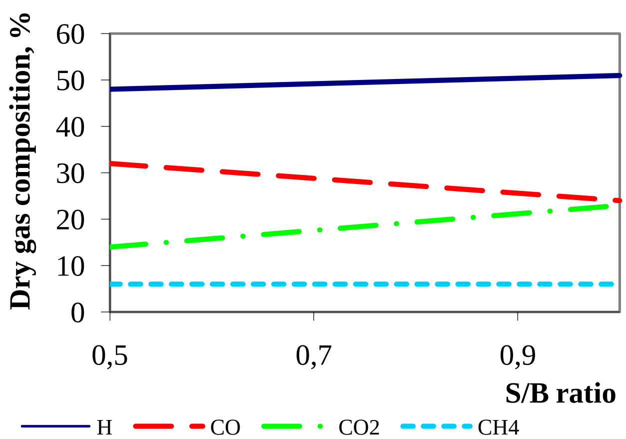

Figure 2. Composition of dry gas in relation to S/B ratio [1]

Slika 2. Sastav suhog plina u odnosu na S/B omjer [1]

S/B ratio is a ratio of amount of steam to biomass; the higher the ratio, the higher the amount of H_2 and CO_2 and the lower the amount of CO (Figure 2). The total amount of produced gas also increases [1].

Influence of input steam temperature

Input steam temperature greatly influences the gasification process and final composition of the gas. Reaction with steam is endothermic and further cooling of generator by low-temperature input steam has a significant negative impact.

For optimum gasification process, it is recommended that the input steam temperature reaches the temperature inside the reactor, most often 850 °C. Steam then does not cool the process and there is no need to supply energy from external sources or by partial incineration of the fuel. Chemical reactions of steam of temperature similar to the temperature inside the reactor are fast (according to equation 2 or 4) and we may assume that all steam heated to this temperature reacts in the generator and has no negative impact on the gas composition (i.e. moisture). However, heating of steam to such high temperatures is both an energy and financially intensive process and therefore there is no commercial application of this technology.

Supply of steam at the point of saturation (about 120 °C for atmospheric devices) is another extreme. Steam of this temperature has negative impact both on temperature in the reactor and on composition and lower heating value of the gas. It also increases energy intensity of the process and reaction is too slow if the temperature is low. Only small share of steam reacts and the rest creates major moisture of produced gas. Low temperature of supplied steam also increases fuel consumption for specific gas production. Generally speaking, supply of low temperature steam has identical impact as very moist fuel (around 60 %).

Technically plausible solution consists of supply of steam preheated to 300–400 °C. Experience proved that supply of 300 °C steam slightly increases amount of oxygen for partial oxidation. This fact does not have negative impact on total balance compared to increase of lower heating value.

BENEFITS OF GASIFICATION WITH STEAM

Benefits for lower heating value

Main products of gasification process are CO and H2 and their share increases along with supply of steam. Advantages of steam are subsequently proved in amount and lower heating value of produced dry gas. Literature shows wide range of produced gas composition, which may be attributed to different research laboratory conditions. We present results from FICFB-gasifier demonstrating impact of S/B ratio on gas composition [2].

Table 1. Table of lower heating value and composition of gas for 850 °C gasification temperature with different ratio of steam/fuel [2]
Tablica 1. Tablica donje ogrijevne vrijednosti i sastava plina za temperaturu rasplinjavanja od 850 °C s različitim omjerom para/gorivo [2]

steam/fuel ratio	LHV	H_2	CO	CO_2	CH_4
kg/kg	MJ/m^3	%	%	%	%
0	4.5	10	35	16	5
0.3	7	38	33	15	9
0.5	9	40	31	17	8
0.7	12	42	28	18	6

Benefits for tar formation

Supply of steam in gasification systems without external heat sources decreases operational temperature and this may have negative impact on tar formation [3]. On the other hand, higher partial pressure of H_2O in reactor will lead to faster tar reduction reactions (steam reforming and dry dealkylation) and it decreases tar content in generated gas [5] (Figure 3). Literature states that tar composition produced in the process of steam supply is of such a nature that it may be easily eliminated by industrial catalysts (e.g. nickel) or natural catalysts (dolomite, olivenite) [4].

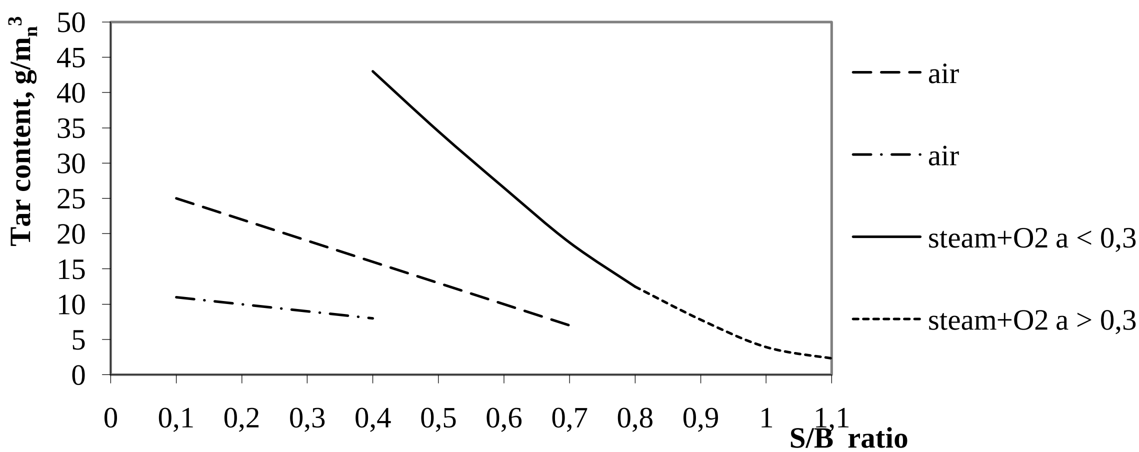

Figure 3. Tar content in the gas in relation to S/B ratio regarding various gasification media [4]
Slika 3. Sadržaj katrana u plinu u odnosu na S/B omjer s obzirom na rasplinjavanje različitih medija [4]

CONCLUSION

Benefits of using the steam and air mixture compared to gasification using only air may be summed up as follows:

- Produced gas is basically nitrogen-free, lower heating value is greater than 13 MJ/m³.
- Very low tar content.
- Gas quality independent of fuel moisture.
- Equipment compactness and wide range of fuels.
- Application of catalytic material into the bed and its regeneration in incineration zone.

Institute of Power Engineering at the Faculty of Mechanical Engineering, Brno University of Technology has researched elimination of tar produced in biomass and waste gasification in fluid generator. This mostly concerns high-temperature, stable tar whose cracking is considerably difficult.

As mentioned in the presented text, supply of steam in gasification reactor has positive impact on gas composition and its lower heating value. Tar content does not decrease; however, tar elimination in tested catalysts should be easier and more efficient.

Acknowledgements

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