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ASPECTS ON RESIDUAL BIOMASS TO GAS FUEL CONVERSION USING AIR AS OXIDIZER

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This paper presents the experimental results and process analysis of residual food waste air gasification. The experiments were conducted on a batch tubular reactor at laboratory scale, using air at atmospheric pressure as oxidizer. Temperature and equivalent ratio (ER) were varied to assess the optimum process parameters for this particular type of biomass. The temperature was varied between 650°C and 850°C, and the ER between 0.25 and 0.35. The process performance was evaluated in terms of syngas specific energy content, carbon conversion efficiency and cold/hot-gas efficiency.

Keywords: conversion efficiency, food waste, gasification, renewable energy

1. Introduction

Society continuous evolution demands more resources and energy. The industrial sectors are developing too with increasing wastes production from biomass, municipal solid waste and other fields [1, 2, 3, 4].

The food processing industry only generates annually millions of tonnes of wastes. In 2012 were produced more than 300 million of tonnes of meat [5], its production having a slight increase in the last few years, after a dropping in the early 2000's [6, 7]. Depending on the processed cattle type, and each country's food culture, the meat processing waste represents up to 35% of the animal weight [8]. For example, the waste quota that remains after pork meat processing is 13% in Poland, and 38% in Canada [9].

The meat processing waste consists in skin, fat, bones, offal etc. [10]. Before 1994 this residue was processed into meat and bone meal (MBM) and used to feed the ruminants. Nowadays, the UE banned the use of MBM as food supply, since is responsible for spongiform encephalopathy (BSE) disease transmission to caw [10, 11]. Other options for disposal of this waste were studied, such as combustion, co-combustion with coal, and even pyrolysis [11-13]. Several

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problems were found when investigated this options of waste disposal, such as an increase in nitrogen oxides and dioxins, the presence of heavy metals and furans [11, 13, 14].

In this study are presented laboratory experimental results and process analysis of air gasification conducted on organic residues. The product consists of residues from food processing industry as a mixture of pork bones and meat. These residues are common residues from meat processing industries.

The residues were dried and mechanically grinded before being submitted to primary and ultimate analysis. The results presented in Table 1 were presented in previous works of the authors on this type of feedstock [10, 15].

Table 1

Proximate and ultimate analysis [10, 15]

Feedstock		
Moisture	41.70	[%]
Ash	15.91	[%]
Volatiles	38.65	[%]
Fixed Carbon	6.40	[%]
C	41.48*	[%]
H	5.99*	[%]
N	4.30*	[%]
O	20.93*	[%]
LHV	19.2	[MJ/kg]

*dry basis

2. Material and methods

The gasification experiments were conducted on a laboratory scale batch tubular reactor that can accommodate up to 200 g of solid sample. The active zone is electrically heated and air is fed in at controlled ER [16].

The reactor was first heated at the processing temperature. The sample (10 grams) was placed in the refractory steel crucible and introduced in the reactor. The air was feed in at ambient temperature and atmospheric pressure at a controlled rate of 1 l/min using a flow meter.

The produced gas was analyzed in real time through a flue gas probe connected to a gas analyzer. The gas analyzer utilized was a TESTO 350-XL with infrared CO_2 detector.

For this study nine experiments were conducted at three different temperatures 650°C, 750°C, and 850°C. At each processing temperature, three values of equivalence ratio (ER) 0.25, 0.30 and, 0.35 were investigated.

In gasification processes the gasifying agent strongly influences the process run and products formation through the equivalence ratio. The ER is defined as the ratio between the actual air introduced in the reactor, and the stoichiometric air needed for the complete combustion of the sample [17, 18]:

$$ER = \frac{\text{actual air}}{\text{stoichiometric air}} \tag{1}$$

The gasification process can be evaluated by several performance indicators. Consequently, the quality of the produces gas can be evaluated with respect to its composition and lower heating value (LHV). For example, non-combustible gas fractions quotas in the syngas, such as carbon dioxide (CO_2) and nitrogen (N_2) should be low, so it is aimed to minimize their concentrations [17-19].

To evaluate the process efficiency, three process parameters can be calculated: carbon conversion efficiency (CCE), cold-gas efficiency (CGE), and hot-gas efficiency (HGE) [17, 19].

The CCE is the ratio between the amount of carbon in the carbon-based constituents of syngas (CO, CH_4, C_nH_m, CO_2 etc.), and the amount of the carbon in the feedstock [17, 19].

The CGE is the ratio between potential energy output and the energy input. It is calculated for the applications where the produced gas is used in internal combustion engines, and it must be cooled before engine intake [17, 19]. The CGE is defined as:

$$CGE = \frac{LHV_g \cdot M_g}{LHV_b \cdot M_b} \tag{2}$$

where: - LHV_g – lower heating value of the gas;

- LHV_b – lower heating value of the biomass;

- M_g – quantity of syngas produces for a specific quantity of biomass (M_b) [17, 19].

The HGE is calculated when the hot gas is used for thermal energy generation and it is burned in furnaces or boilers, and doesn't require cooling, or in other applications where its sensitive heat is recovered. The HGE is defined as [17]:

$$HGE = \frac{LHV_g \cdot M_g + M_g \cdot c_p (T_g - T_0)}{LHV_b \cdot M_b} \tag{3}$$

where: - LHV_g – lower heating value of the gas;

- LHV_b – lower heating value of the biomass;

- M_g – quantity of syngas produces for a specific quantity of biomass (M_b)

-T_g – gas temperature;

-T_0 – ambient temperature [17, 19].

Equation 3 does not consider the latent heat of water vapors because all the water vapors are consumed in the process for hydrogen generation (shift reaction: $C+H_2O \rightarrow CO+H_2$).

3. Results and discussion

The gasification product contains carbon monoxide, hydrogen, carbon dioxide, nitrogen, methane and other hydrocarbons, depending on the feedstock elemental composition and the oxidizing agent used in the process. Gas composition influences its lower heating value, which along with the quantity of the gas produced represents one criteria of evaluation for the gasification process.

Fig. 1. presents the variation of LHV with the Equivalent Ratio for different processing temperatures.

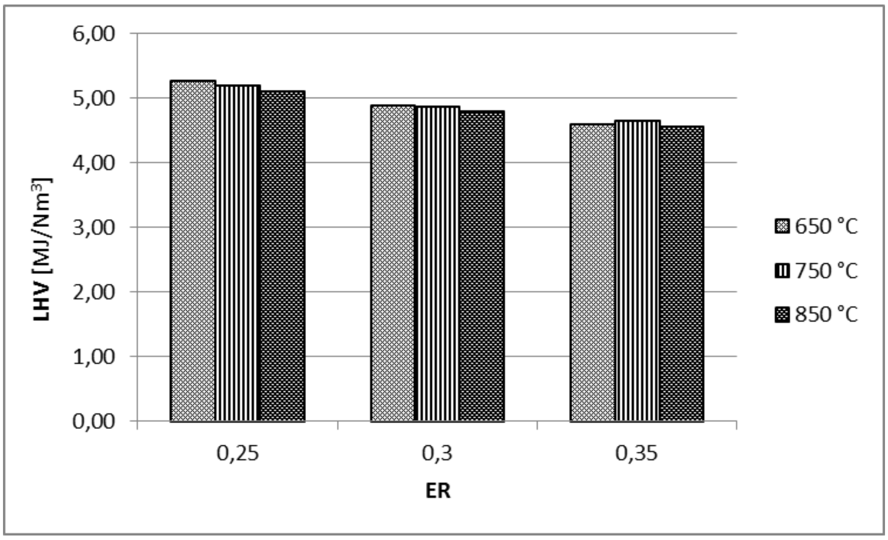

Fig. 1. Variation of syngas LHV with ER

It can be observed that the LHW of the gas is dropping with ER increase, and at the same ER it is dropping with the temperature increase. The exception is given by the last case (ER = 0.35) were the LHV is higher at 750°C compared to the LHV obtained at 650°C. Nevertheless, the LHV doesn't vary in wide ranges, 4.57 MJ/Nm^3 (T = 850°C and ER = 0.35) to 5.28 MJ/Nm^3 (T = 650°C and ER = 0.25).

The carbon conversion efficiency variation is presented in Fig. 2. We can observe that the CCE is increasing with increasing ER. The maximum value of the CCE is obtained at 750°C while the minimum is obtained at 850°C independently of ER value. Regarding to this performance parameter, we can say that the optimum processing parameters are 750°C and ER = 0.35, when CCE is about 80%.

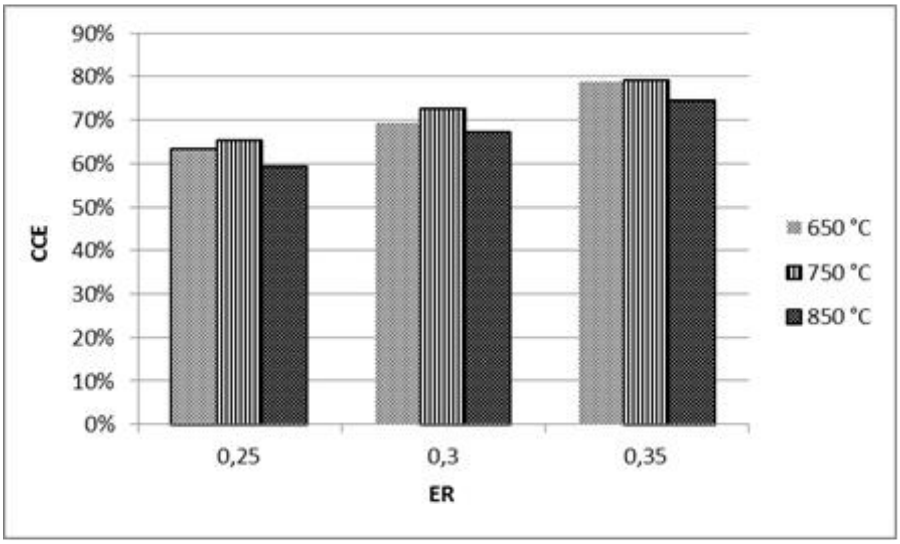

Fig. 2. Variation of CCE with ER

In Fig. 3. is presented the variation of CGE with ER at different process temperature. We can observe that the cold-gas efficiency is increasing with the increase of ER. For ER = 0.25 and ER = 0.30, the CGE is dropping with temperature increase, but for ER = 0.35 the maximum is reached at 750°C. As for CCE, the optimum process parameters are 750°C and ER = 0.35, were the CGE is about 60%.

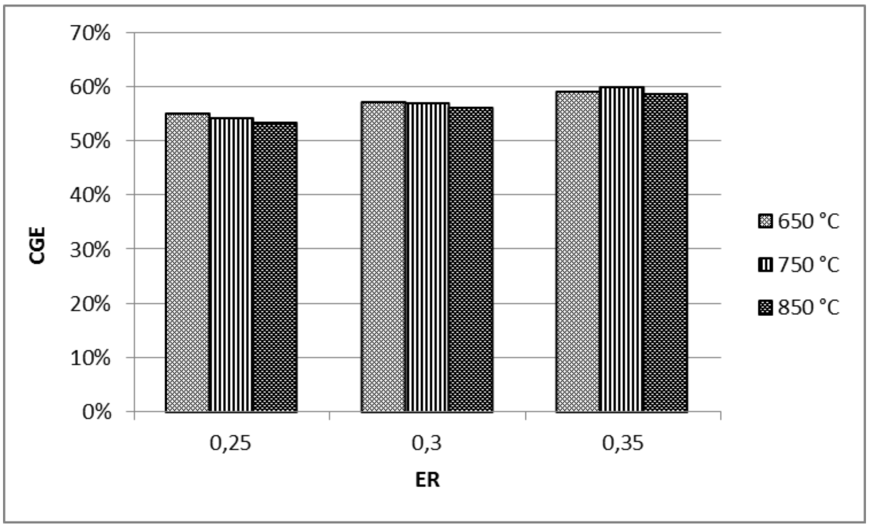

Fig. 3. Variations of CGE with ER

Fig. 4. presents the variation of HGE parameter with ER at different processing temperatures.

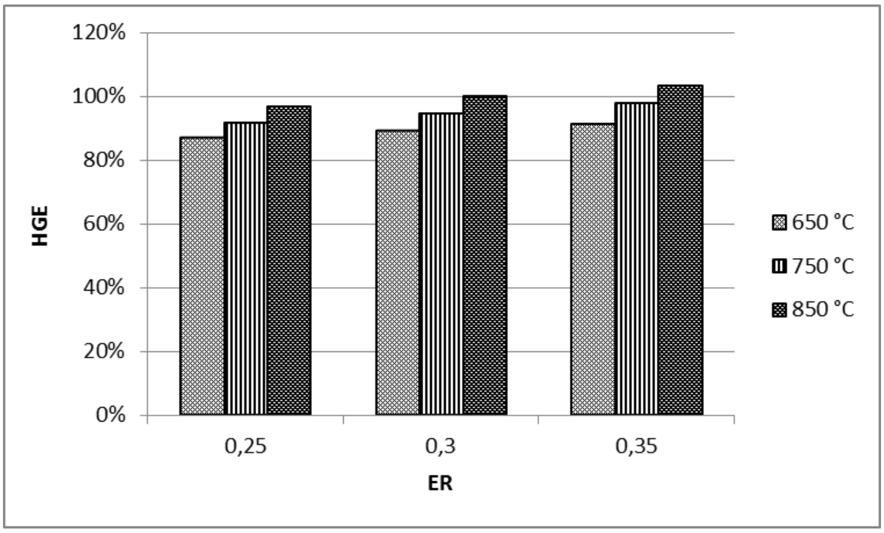

Fig. 4. Variations of HGE with temperature and ER

The HGE has an increasing tendency with the temperature rise and ER increase. For ER = 0.35 and 850°C, the value of HGE exceeds 100% because the reactor is electrically heated and the thermal energy provided exceeds the gasification heat demand.

The experiment was conducted on a laboratory tubular batch reactor electrically heated. Therefore, thermal energy was added to the gasification process. That's why the Hot Gas Efficiency of the process is higher than 100%, because it includes the additional heat of the reactor. Given the reactor volume and sample mass (10 grams) the heat provided by the reactor is much higher than the one required by the reaction. Nevertheless, this situation is common to each experiment and the HGE trend is not affected by it.

4. Conclusions

Gasification is a process with an evolution difficult to predict due to many parameters that influence it, such as biomass type (its elemental composition, physical properties of biomass, particle dimension), process parameters (temperature, pressure, ER, biomass flow rate, oxidant flow rate), the type of the gasifier, and the gasifying agent. The temperature and equivalent ratio are the parameters that can be adjusted continuously for the process control.

Following laboratory experiments we've established that for this particular type of biomass, a mixture of pork bones and meat, the optimum gasification processing parameters are 750°C and ER=0.35, with respect to process energy efficiency (carbon conversion efficiency and cold-gas efficiency).

The syngas maximum LHV of 5.28 MJ/Nm^3 is obtained at 650°C and ER = 0.25 while the lowest, 4.57 MJ/Nm^3, is obtained at T = 850°C and ER = 0.35.

The study highlighted the influence of operating parameters on fuel gas specific energy content and gasification process energy efficiency.

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