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Analysis of biomass and waste gasification lean syngases combustion for power generation using spark ignition engines

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A R T I C L E I N F O

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A B S T R A C T

The paper presents a study for food processing industry waste to energy conversion using gasification and internal combustion engine for power generation. The biomass we used consisted in bones and meat residues sampled directly from the industrial line, characterised by high water content, about 42% in mass, and potential health risks. Using the feedstock properties, experimentally determined, two air-gasification process configurations were assessed and numerically modelled to quantify the effects on produced syngas properties. The study also focused on drying stage integration within the conversion chain: either external or integrated into the gasifier. To comply with environmental regulations on feedstock to syngas conversion both solutions were developed in a closed system using a modified down-draft gasifier that integrates the pyrolysis, gasification and partial oxidation stages. Good quality syngas with up to 19.1% – CO; 17% – H_2; and 1.6% – CH_4 can be produced. The syngas lower heating value may vary from 4.0 MJ/N m^3 to 6.7 MJ/N m^3 depending on process configuration.

The influence of syngas fuel properties on spark ignition engines performances was studied in comparison to the natural gas (methane) and digestion biogas. In order to keep H_2 molar quota below the detonation value of $\leqslant$4% for the engines using syngas, characterised by higher hydrogen fraction, the air excess ratio in the combustion process must be increased to [2.2–2.8].

The results in this paper represent valuable data required by the design of waste to energy conversion chains with intermediate gas fuel production. The data is suitable for Otto engines characterised by power output below 1 MW, designed for natural gas consumption and fuelled with low calorific value gas fuels.

1. Introduction

The continuous evolution of society includes the development of industry sectors that represent waste generation sources with respect to the environment. The food industry has also increased its production capacity as well as final residues generation. A particular branch of this activity sector is represented by the meat processing industry that generates considerable quantities of solid waste that cannot be disposed of without neutralization due to the health risk potential. The residue mass fraction delivered by meat processing varies from 28% for chicken to 48% for sheep and goat of the (Attorney General). About 1/3 of the meat processing industry feed in flow will result in residues to be disposed each year worldwide. For the moment two main solutions are applied for waste neutralization and disposal: the processing into a meat and bone meal (MBM) and the incineration. Both solutions require additional energy supply and the waste generators must pay for the disposal of these residues (Cascarosa et al., 2012). The landfill cannot be used due to the presence of potential pathogens (Russ and Meyer-Pittroff, 2004). The trend line in waste management policy, according to current regulations and directives, limits the waste quantities disposed of by landfilling (European Commission).

The authors' previous research revealed a high energy potential of the meat processing industry waste such as: chicken feathers, skins, fats, bones and offal. (Marculescu, 2012). These residues represent an important energy source even if their physical structure and the presence of water rise a series of problems mainly related to the mechanical behaviour and the global energy efficiency of the waste to energy conversion processes. As a result, the challenge consists in establishing the optimum process and operating parameters for waste valorisation (Rada, 2014). However, the conversion solution must contain at least one stage of high temperature treatment for completely neutralization of any health risk source. Usually this type of waste comes from distributed small capacity

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Table 1
Proximate analysis of residues.

Feedstock	Humidity (%)	Volatile (%)	Fixed carbon (%)	Inert (%)
Dried	0	66.30	6.40	27.30
Raw	41.70	38.65	3.73	15.91

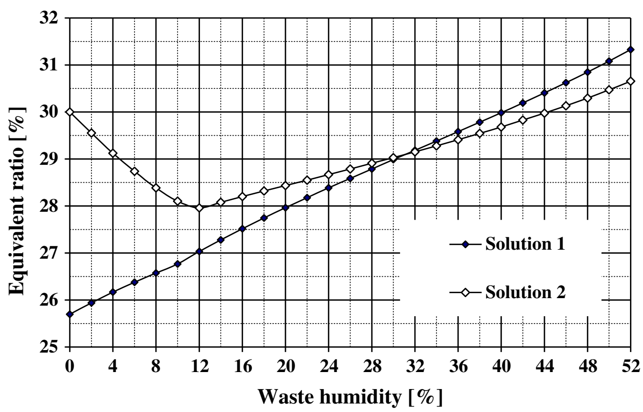

Fig. 1. Gasification equivalent ratio vs. feedstock humidity.

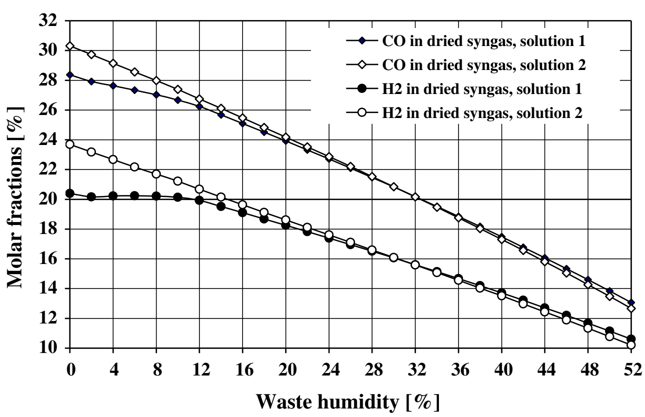

Fig. 2. Main combustible gases concentration in dried syngas.

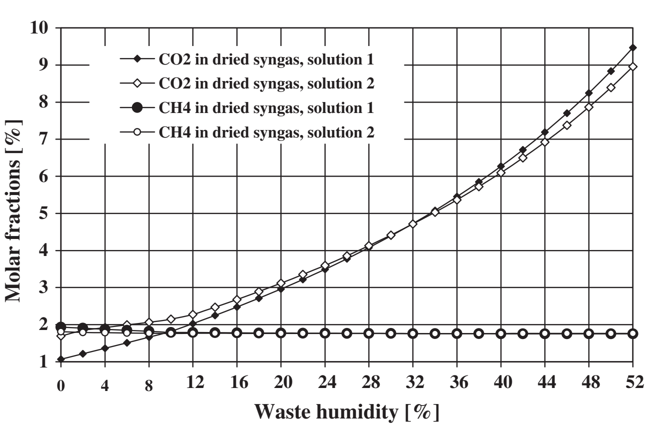

Fig. 3. Variation of CO_2 and CH_4 fractions in dried syngas for the two proposed solutions.

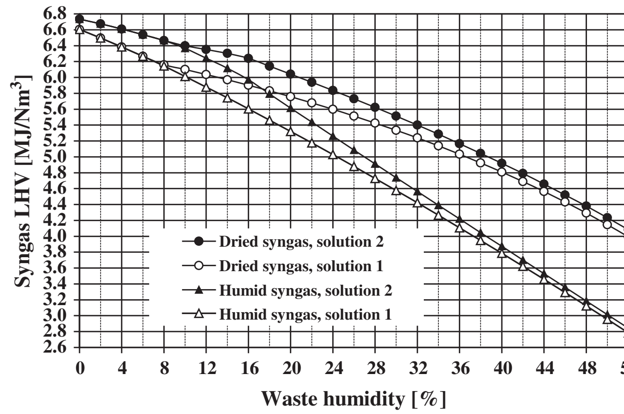

Fig. 4. Variation of syngas LHV.

sources, therefore there is high interest in valorising it in small and medium scale power plants, but not exclusively. Additionally, the use of incineration and steam turbines cycles for small capacity power units is affected by the scale factor which strongly influences the Rankine–Hirn thermodynamic cycles efficiency. The discontinuous availability of waste feed-in flow also limits the steam turbines applications that cover the base of the electrical load. Due to certain characteristics of the waste related to its fast biodegradability and its potential health risk, the possibility for waste storage is limited (in the case of food processing industry waste – meat/bones residues). With respect to these restrictions the interest for alternative fuels has emerged (Ionescu et al., 2013). The production of superior alternative fuels that can be used both in the energy and transport sectors can represent a viable valorisation of this type of waste which is currently disposed of at high costs through incineration.

To face such problems one viable option can be the waste gasification and the production of gas fuel to be used in internal combustion engines mainly because of their tolerance to fuel quality standards, low scale applications and waste source time availability (Cascarosa and Gasco, 2012). Due to biomass/waste variety as well as to the gaseous bio-fuel production technologies there is a continuous interest in studying the influence of these parameters on internal combustion engines performances. The main performance indicator of an internal combustion reciprocating engine is the global efficiency. The assignment of the term depends on the delivered energy type: electricity only, or cogeneration. In our case, by changing the fuel type, from natural gas to a lean gas, the term "performance" refers not only to electrical efficiency, but also to the decrease of power output compared to the reference value (given by producers, in the technical specifications for the engines designed for burning natural gas). The paper presents the results of a current research on Otto engines (also suitable for cogeneration applications), characterised by power output under 1 MW, designed for natural gas consumption and fuelled with low calorific value gaseous bio-fuels. The large range of these variables leads to a wide variety of low quality gaseous bio-fuels with different physical–chemical properties (Deublein and Steinhauser, 2008). Our study focused on analyzing these gaseous bio-fuels composition using data both from engineering literature and our calculations. Using this piece of information, a series of specific physical–chemical data was calculated to highlight the main differences between these gases and methane. These differences affect the design and performances of Otto engines when shifting the use from natural gas to gaseous bio-fuels.

This paper presents the results of a research study carried on bones and meat residues for syngas production together with the influence of various parameters on gas composition and the global energy efficiency of the conversion chain.