Energy Recovery from Industrial Feather Waste by Gasification

Constantin Stan

***Abstract*—The paper presents the results of research study focused on gasification process applied to industrial feather waste for syngas production. The waste used for the experimental campaign was sampled from a local slaughterhouse, directly from the poultry processing line to preserve the product real characteristics. Based on physical-chemical composition, established experimentally, steam gasification process using a laboratory scale tubular batch reactor was used. The results offer efficient solutions to poultry process industry, one of the fastest growing sectors from food industry with considerable amounts of waste generation annually by increasing the competitiveness and energy recovery. The composition of syngas consists in high percentage of H_2 up to 43%. The study results contribute to a new vision of going green, improving the sustainability of communities and the health of human and finally offering a solution regarding the waste management of a problematic industrial waste.**

***Index Terms*—Energy recovery, industrial feather waste, gasification, syngas.**

I. Introduction

Poultry processing industry waste is a solid waste resulting from poultry slaughterhouses composing of feathers, bones, claws, blood, head and skins. Poultry feathers are the most keratinous waste that exists (91%), small quantity of lipids 1% and 8 % water [1]. The poultry processing industry has known in the last years a very fast and vertically development [2]. Currently, worldwide is showing the strongest growth in output of any category of meat. The generation of feather waste only in the European Union (EU-28) in 2014 was 3.1 million tons [2]. This huge industry is generating annually big quantities of waste, that according to European Union must be neutralized in special incineration plants [3]. This involves a series of problems for the environment by air pollution generated by incineration process in formation of harmful gases [4].

Due to current management solution of industrial feather waste and the anticipated introduction of more stringent environmental legislation, the generation of electricity and heat from feathers using high temperature processes alternative to combustion, could be a promising solution. Gasification is the thermochemical process that appears to be the best option [5], [6].

By using a waste to energy conversion solution, a part of the industrial electricity and heat consumption of the slaughterhouses can be covered. The solution proposed within this study is the waste to energy conversion using gasification process. The paper presents the feasibility of gasification as alternative solution to incineration to obtain a superior fuel in the form of syngas. Generation of renewable energy from industrial feather waste can be a sustainable strategy to the response of the worldwide energy and climate change challenges.

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II. Experimental Set-up

A. Product Characterization

To preserve the product real characteristics, for the experimental study, waste feathers from a local slaughterhouse were used. The raw feathers were not clean, but they were mixed with other residues from the slaughter line that increased the humidity content up to 70%. In previous work of the author the physical-chemical characterization of the sample was performed as proximate and elemental analysis [7], [8] (Table I).

TABLE I: Proximate and Elemental Analysis of Feather Waste

Feather waste	Proximate analysis (% db)			Elemental analysis (% db)						HHV[d] (kJ/kg)
	VM[a]	FC[b]	Ash	C	H	N	S	O[c]	Cl	26139
	92	6.5	1.5	60.6	8.5	8.7	4.8	13.3	2.6	

[a] volatile matter
[b] fixed carbon
[c] by difference
[d] high heating value

The elemental composition of the waste has revealed important quantities of carbon – 60.6% and 8.5% hydrogen but also some negative aspects regarding the presence of pollutants as nitrogen, sulphur and chlorine. The energy potential of the waste was established using a calorimeter IKA C 200 and the high heating value was 26139 kJ/kg (dried sample).

B. Installation

The gasification process was conducted using a laboratory tubular batch reactor that can be adjusted for different processes, designed and operated within Renewable Energy Sources Laboratory from Polytechnic University of Bucharest [9] (Fig. 1).

The installation enables the continuous treatment of solid products under different processes. The inner volume of the refractory steel tube is 4 dm^3 and the process temperature can be adjusted between 20 – 1300 ℃. The refractory steel tube is 60 mm in diameter and has a total length of 750 mm. The isothermal active zone of the crucible is 300 mm and within this zone the sample is placed. The working temperature and

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heating rate can be set depending on process parameters. Inside the crucible there is a thermocouple with which the temperature of the sample can be monitored. The reactor has inlet and outlet nozzles for different experimental configurations: air, nitrogen or steam and a condensable hydrocarbons fraction separation system. The condensable fraction can be collected for future analysis. The syngas composition is analyzed in real time in a gas chromatography – mass spectrometry apparatus (model Shimadzu QP2010 Plus).

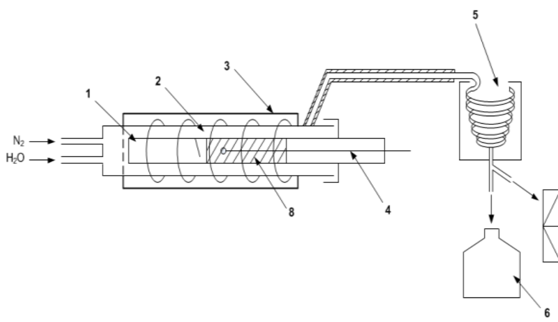

Fig. 1. Tubular batch reactor.

1. Refractory steel crucible; 2. Refractory steel tube; 3. Electrically heated chamber; 4. Thermocouple; 5. Condensable hydrocarbons fraction separation system; 6. Collector; 7. Gas analysis system; 8. Sample

III. Results and Discussion

A. Process Run

The steam gasification process was used in the experimental campaign conducted at atmospheric pressure. The use of steam as gasification agent is one of the most effective and efficient solution to generate a fuel with increased hydrogen content [10]. There was some major motivation that conducted the use of steam gasification for the waste feathers: the removing of components as nitrogen and water to increase the heating value of the fuel, to remove the high nitrogen and sulphur content from the fuel to prevent emissions in atmosphere and to reduce the C/H mass ratio.

The sample was heated to a specific temperature like the process at industrial operating conditions at 850 ℃. The operation conditions at industrial scale are different from experimental size units, mainly because of the heat and mass transfer mechanisms which influence the process end products. Nevertheless, their mass distribution is quite similar. In the crucible were placed approximately 150-200 g of sample which has been previously dried and grounded. The steam flow rate was 3.1-6.2 g/min.

B. Syngas Composition

After 15 minutes of sample introduction into the reactor, the gasification conditions were reached, and the gas flow was directed to the GC-MS apparatus. In Fig. 2 is presented the qualitative analysis of the syngas composition.

The main component in gas composition is H_2 reaching 43% followed by CO with 25% and CO_2 with 23%. The percentage of hydrogen in steam gasification is far better than fast pyrolysis followed by steam reforming of char [11]. The C_nH_m mainly methane is found in not significant proportion, only 5% as well as water vapors, 4%. The medium calorific value as expected due to important quantity of H_2 has a good value reaching 9500 kJ/Nm^3.

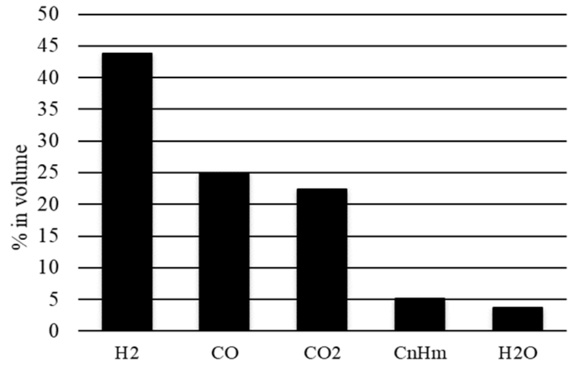

Fig. 2. Syngas composition.

Many researches have been carried out in steam gasification which shows that the hydrogen yield is thrice as compared to air gasification [12].

Steam gasification generates more syngas, hydrogen, energy and higher apparent thermal efficiency than pyrolysis [13].

C. Energy Balance

To calculate the energy consumption of the gasification, the data from the experimental campaign regarding complete characterization of waste feathers was used. Consequently, was calculated the specific energy consumption for steam production and gasification sequences. To make a perspective regarding the product energetic valorization, the mathematical model used in calculation is a theoretical one. The computation was assessed for a waste flow of 1 kg/s and different humidity content in the range from 70% to 10%. The steam gasification process is highly endothermic and the energy necessary for chemical reactions was calculated based on the product activation energy.

The energy consumption for the gasification process to convert the waste into syngas is calculated with formula (1):

$$Q_{gasif} = m_{carbon} * E_a + (m_{carbon} * c_{p\_carbon} + m_{inert} * c_{p\_inert}) * (T_{gas} - T_{inlet}) \quad \text{kJ/kg}_{char} \quad (1)$$

where: E_a - activation energy [kJ/kg]; m_{carbon} - mass of fixed carbon in the char [kg]; m_{inert} - mass of inert fraction in the char [kg]; T_{gas} - gasification process temperature [K]; T_{inlet} - char feed-in temperature [K].

The energy required for steam production, including the vaporization and superheating from saturation temperature to gasification temperature, is given by:

$$Q_{vap} = m_{water} * [\lambda_v(373K) + \int_{T_i}^{373K} c_{p\_water}^{liq} dT + \int_{373K}^{T_{gas}} c_{p\_water}^{vap} dT] \quad \text{[kJ]} \quad (2)$$

where: m_{water} – mass of water for steam generation [kg]; λ_v – water vaporization heat [kJ/kg]; c_{p_water} – water specific heat liquid and gaseous phase [kJ/kgK^{-1}]; T_i – water feed-in temperature (15 ℃); T_{gas} – gasification temperature (850 ℃).

In Fig. 3 is presented the energy consumption for steam generation and gasification process.

The highest quantity of energy, approximately 5000 kJ, is consumed for the gasification of the product with the lowest humidity.

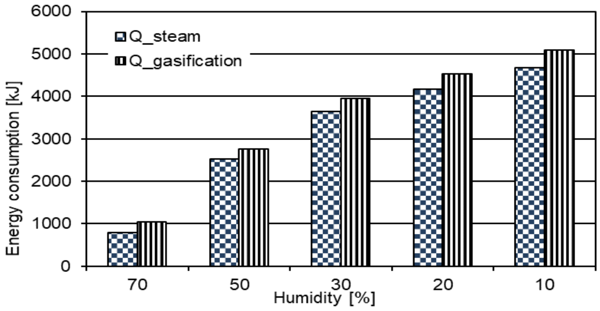

Fig. 3. Energy consumption for the gasification of waste feather.

As the waste water content decreases the energy consumption for steam production increases from 800 kJ at 70% humidity to 4600 kJ at 10% humidity. Consequently, for the steam gasification process the energy required for steam production, including the vaporization and superheating from saturation temperature to gasification temperature is minimum when using high humidity content waste and maximum when using dried products. In the real case when the waste humidity is 70% the steam is obtained from the pyrolysis process without additional energy consumption.

The computed results based on experimental data are presented in Fig. 4. It can be observed the influence of humidity on electric energy generation for the feather waste steam gasification.

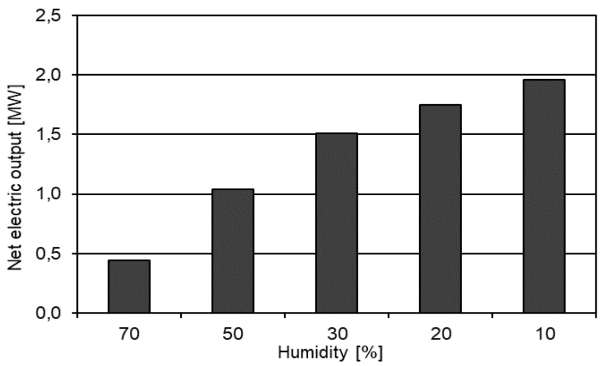

Fig. 4. Net electric output using steam gasification process.

The thermodynamic cycle uses an internal combustion engine, Diesel-Gas type. The energy efficiency considered in calculation was chosen according to each equipment characteristics and power range. The results show that for the complete dried product it can be obtained approximately 2 MW electric energy.

As the waste humidity increases the net electric power output decreases till it reaches its minimum of 0.4 MW at 70% humidity. The results were obtained for a feed-in flow of 1 kg/s of waste equivalent to 86.4 tons/day. This quantity is specific to medium – high capacity slaughterhouses.

Because of the high humidity content of the product the proposed process configuration could represent a viable solution for generation of renewable energy from feather waste.

IV. Conclusions

The paper presents the results of the research in the field of waste to energy conversion using advanced thermal processing. A particular type of waste was used – industrial waste feathers. The product has the highest keratin content that can be found in the industrial waste streams, up to 91%. Based on experimental results the paper presents solutions for this waste neutralization and energy potential recovery. The high heating value of waste feathers (dry basis) is about 26139 kJ/kg. This value recommends the chicken feathers waste for thermal treatment processes with energy generation alternative to the current disposal through incineration. The syngas composition established experimentally revealed important H_2 fraction (45%) and a good low heating value of 9500 kJ/Nm^3. Due to the high-water content of the waste the first option for energy conversion was the steam gasification process aiming for re-use of steam generated in drying sequence as gasification agent. At 70% humidity the net electric output is 0.4 MW increasing to almost 2 MW when using waste with 10% humidity. As waste humidity decrease proved to be non-economic below 50%-40% and the waste treatment with energy recovery using combustion processes cannot be applied in this case, the atmospheric pressure steam gasification is the only solution that could produce 0.4 to 1 MW_{el} .

Consequently, a waste that today is disposed at high costs can become a renewable source of energy if the appropriate conversion solution is used.

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References

[1] T. Korniłłowicz-Kowalska and J. Bohacz, “Biodegradation of keratin waste: Theory and practical aspects,” *Waste Management*, vol. 31, pp. 1689-1701, 2011.

[2] I. Aranberri, S. Montes, I. Azcune, A. Rekondo, and H. J. Grande, “Fully biodegradable biocomposites with high chicken feather content,” *Polymers*, vol. 9, p. 593, 2017.

[3] C. Font-Palma, “Kinetics and modelling of gasification of poultry manure and litter: An overview,” *Energy Conversion and Management*, vol. 53, pp. 92-98, 2012.

[4] I. Vermeulen, “Environmental impact of incineration of calorific industrial waste: Rotary kiln vs. cement kiln,” *Waste Management*, vol. 32, pp. 1853-1863, 2012.

[5] M. Dudynski, K. Kwiatkowski, and K. Bajer, “From feathers to syngas – Technologies and devices,” *Waste Management*, vol. 32, pp. 685-691, 2012.

[6] E. Cascarosa, G. Gea, and J. Arauzo, “Thermochemical processing of meat and bone meal: A review,” *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 942-957, 2012.

[7] C. Mărculescu and C. Stan, "Poultry processing industry waste to energy conversion," *Energy Procedia*, vol. 6, pp. 550-557, 2011.
[8] C. Mărculescu, C. Stan, and A. Badea, "Energetic potential assesment of poultry processing industry waste," *Environmental Engineering and Management Journal*, vol. 11, pp. 1821-1826, 2012.
[9] C. Mărculescu and C. Stan, "Pyrolysis treatment of poultry processing industry waste for energy potential recovery as quality derived fuels," *Fuel*, vol. 116, pp. 588-594, 2014.
[10] P. Parthasarathy and K. S. Narayanan, "Hydrogen production from steam gasification of biomass: Influence of process parameters on hydrogen yield - A review," *Renewable Energy*, vol. 66, pp. 570-579, 2014.
[11] C. Mărculescu, V. Cenusa, and F. Alexe, "Analysis of biomass and waste gasification lean syngases combustion for power generation using spark ignition engines," *Waste Management*, vol. 47, pp. 133-140, 2016.
[12] N. Nipattummakul, I. Ahmed, S. Kerdsuwan, and A. K. Gupta, "Hydrogen and syngas production from sewage sludge via steam gasification," *Int J Hydrogen Energy*, vol. 35, pp. 11738-11745, 2010.
[13] C. Mărculescu, "Comparative analysis on waste to energy conversion chains using thermal-chemical processes," *Energy Procedia*, vol. 18, pp. 604-611, 2012.

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