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EXPERIMENTAL STUDY OF THERMAL PYROLYSIS OF TURKEY FEATHERS

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Abstract

The analysis of chemical composition of turkey feathers reveals over 50% mass content of carbon. Unfortunately, the feathers contain also over 13% by weight of nitrogen and over 2.5% of sulfur. The significant presence of nitrogen and sulfur in turkey feathers indicates potential danger to the environment.

The experiments of thermal pyrolysis of turkey feathers were done from a perspective of energy production potential out of gaseous products.

The products of thermal pyrolysis were mainly gas and liquid. The calorific value of pyrolysed feathers is comparable with the one of hard carbon. It gets higher for higher temperatures. The calorific value of gaseous products of turkey feathers at 850°C was maximum and it equalled 16.7 MJ/Nm^3.

Introduction

The consumption of poultry in Poland as well as Europe increases (*Annual Report of AVEC*. 2014). The trend is permanent and there are many reasons for that. The popularization of poultry is caused by its nutritive values, which help decrease cardiovascular diseases morbidity of human. The increase of poultry consumption was also caused by the occurrence of animal epidemic of cattle and pigs during the last two decades (eg. Creutzfeldt-Jakob disease).

In 2011 Poland was the fourth country in Europe regarding to poultry production which was 1300 thousand tons. Turkeys have a significant share in poultry production estimated at 340 thousand tons annually (BIEGAŃSKI 2014).

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The production of such significant mass of poultry means a production of a considerably huge amount of feathers, which are mainly waste (KWIATKOWSKI, KRZYSZTOFORSKI et al. 2012). It is due to the characteristics of the production process of poultry including mechanical collection of the feathers. The annual production of poultry feathers in Poland comes to 70 thousand tons (KRAJCZYŃSKA 2010). In turn, the amount of acquired turkey feathers is estimated on a level of several dozen of thousand of tons. Such a big mass of feathers presents a serious problem considering logistic and waste disposal issues.

There have been several approaches to the utilization of feathers (BUMLA et al. 2012). Feathers have been used as a fertilizer. There have been attempts of production of fabric out of feathers (WOOL 2010). They might be added to plastic for auto parts (KOTA et. al. 2014). Owing to their strength they make plastic parts more durable.

Probably the most often applied method of feathers utilization is the thermal one. Considering the chemical composition of feathers it is probably the best solution to choose. There are two most popular methods of thermal utilization of feathers: gasification and pyrolysis (DUDYŃSKI et. al. 2012, KWIATKOWSKI et. al. 2012).

Commonly, gasification and pyrolysis are considered to be the same process, which is wrong (GIRODS et.al. 2009). Gasification requires reduced amount of oxygen to carry out the process. The amount of oxygen must be limited to ensure that combustion will not occur. Whereas pyrolysis is a thermal decomposing of organic material in absence of oxygen.

Pyrolysis may be processed as thermal or plasma one. Regular source of heat is sufficient to obtain processing temperatures up to 1000°C. Plasma pyrolysis requires far more heat which requires using a plasma source.

The main purpose of the experiment was to decompose turkey feathers. The crucial point of interest is the composition of gaseous products of thermal pyrolysis.

Material

Turkey feathers are not a homogenous material. There are several varieties of feathers which depends on what part of a turkey's body they cover. The examples of turkey feathers are shown in Figure 1*a* (powder down) and Figure 1*b* (quill). The shape and structure of the feathers have a significant influence on heat transfer in the reactor and this way they also influence the course of thermal pyrolysis. Turkey feathers acquired through mechanical harvesting are in fact deformed and torn and they create a shapeless mass (Fig. 1*c*).

Fig. 1. Examples of turkey feathers: *a* – powder down, *b* – quill, *c* – post-production feathers

In order to carry out the analysis of chemical composition, the turkey feathers were dried in an electric drier and then shredded.

The feathers were subject of the research and computation of their calorific value. In order to carry out that task, a KL-11 Mikado calorimeter was applied. The feathers obtained directly from the production line characterize with considerably high moisture contents ranging from 30% to 60%. For that reason the analysis was carried out using a dried sample. The investigation

showed that the Low Heating Value (LHV) of the dried feathers was equal to 20.37 MJ/kg and High Heating Value equalled 21.8 MJ/kg. These values are comparable with these of hard carbon.

The chemical composition analysis of turkey feathers (elementary composition) was done by Flash 2000 CHNS/O thermal analyzer and S8 Tiger X-ray fluorescence spectrometer with wavelength dispersion (WX-XRF). The results of the chemical analysis were presented in Table 1.

Table 1

Elementary composition of turkey feathers

Component elements of dry feathers	Amount [%]
C	51.5
H_2	7.4
O_2	23
N_2	13.1
S	2.5
Cl	0.23

The analysis revealed the reasons of the high calorific value of feathers: C and H_2 comprise almost 59% of their composition. The analysis revealed presence of: N_2 (13.5%) and S (2.54%). The presence of these two elements in such a significant amount may lead to the synthesis of many toxic chemical compounds in high temperatures (especially in O_2 atmosphere).

Experimental

The purpose of the research was to utilize turkey feathers by thermal Pyrolysis and produce combustible gas (DUDYŃSKI 2012, BUAH 2007). The experiments have been carried out in the Institute of Fluid Flow Machinery of the Polish Academy of Sciences in Gdańsk. The reactor used in the experiment could reach maximum temperature of 900°C (BREBU et.al. 2011). The reactor is a welded construction, mainly made of heat-resistant steel. It is cylindrical shaped and its internal diameter equals 98 mm. It is equipped with an external induction heating system. There is a possibility to supply the reactor with inert gas (eg. Argon) by a dedicated additional stub pipe (provided).

The test – stand for the thermal pyrolysis of turkey feathers is presented in Figure 2. The reactor is equipped with a set of thermocouples which task is to control temperature inside of it. The pyrolytic gas leaving the reactor is put through the cooler and then directed to the scrubbers. The gaseous products are collected in tedlar bags.

The purpose of the experiment was to determine the influence of temperature in the reactor on concentration of the gaseous products of the pyrolysis. The sample of turkey feathers was placed into the reactor. After tight closing of the reactor, it was subjected to heating at the constant speed of 18°C/min. The amount of the gaseous products of the pyrolysis was investigated at the following temperatures: 400°C, 500°C, 700°C, 850°C and 900°C.

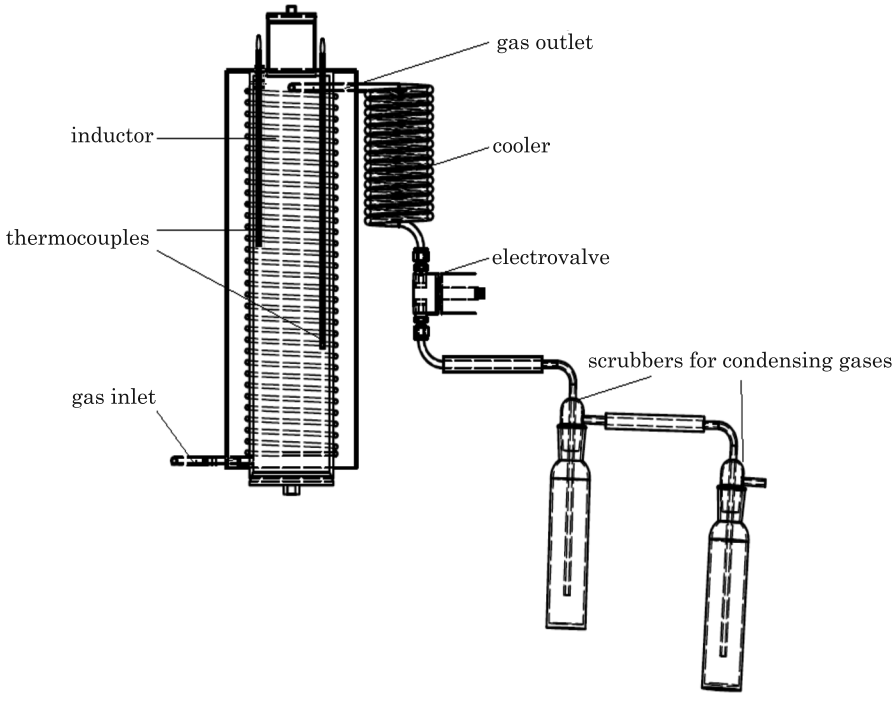

Fig. 2. Scheme of thermal pyrolysis test – stand of turkey feathers

The pyrolysis analysis showed formation of three states of the products: char, liquid and gas (KIM 2007). Their yields depended significantly on the process temperature. The amount of the formatted char reached value of 15.42% at 400°C and decreased to 1.86% at 900°C.

In the case of gaseous products of the pyrolysis their production increased when the temperature raised from 400°C to 700°C (Fig. 3). Further increase of the temperature caused decreasing of the gaseous products concentration: at 900°C the concentration dropped to 75%.

The amount of liquid products equalled 1.39 % for 400°C and monotonically increased up to 900°C, reaching finally the value of 23.14%.

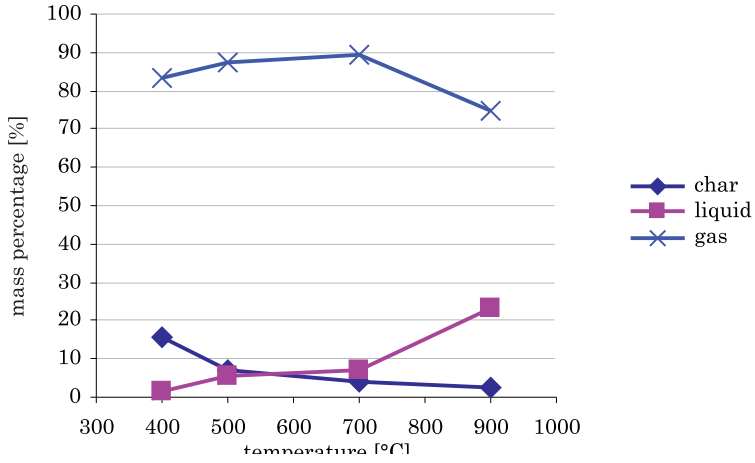

Fig. 3. Influence of pyrolysis temperature of turkey feathers on yields of products

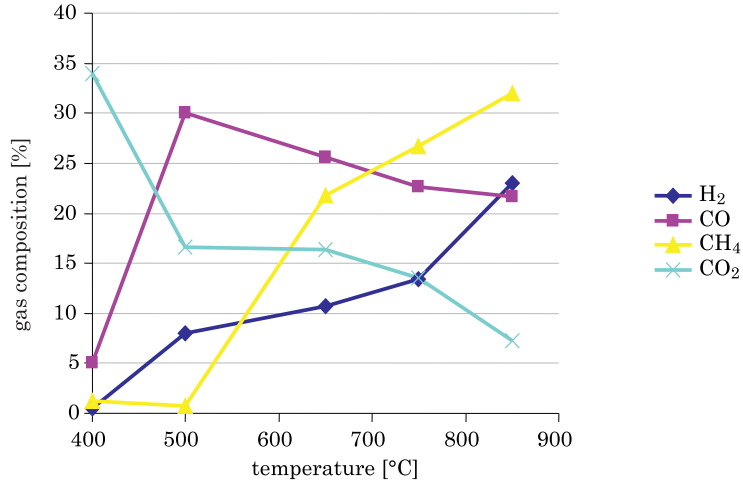

Fig. 4. Course of gas products concentration during thermal pyrolysis of feathers

The increase of temperature caused the increase of H_2 and CH_4 concentration. However, it decreased the CO_2 concentration (Fig. 4). On the other hand the CO concentration changed non monotonically: it increases with the increase of temperature up to 500°C and a further rise of the temperature causes a drop of it. The H_2 concentration for 400°C reaches the level of 0.5% and rises up to 23% at the temperature of 850°C. In the case of CH_4 analogically, its concentration rises from 1.2% to 32%. In the case of CO_2, for the same range of temperature, the concentration decreases from 35% down to 7%. The CO concentration reaches its maximum value at 500°C (30%).

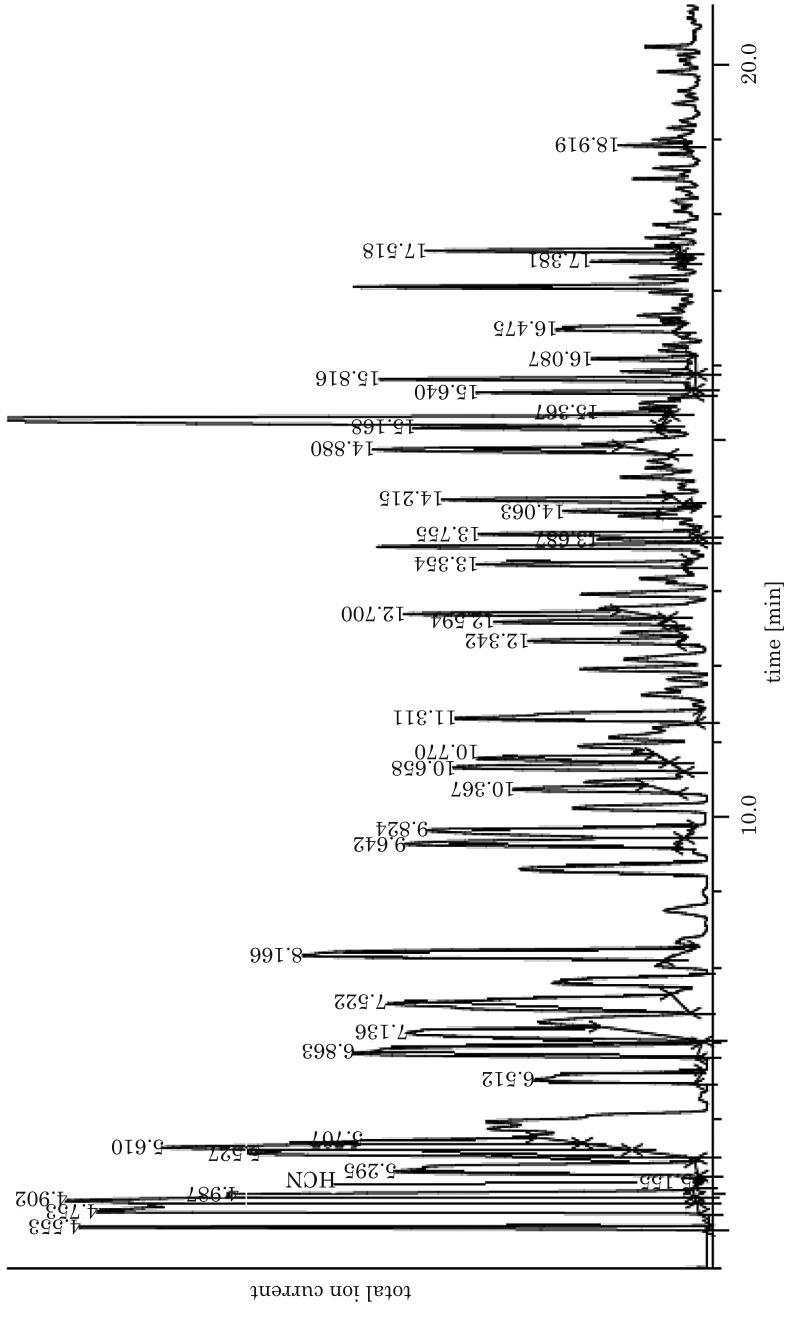

Fig. 5. Absorption spectrum showing presence of HCN in liquid products of thermal pyrolysis of feathers

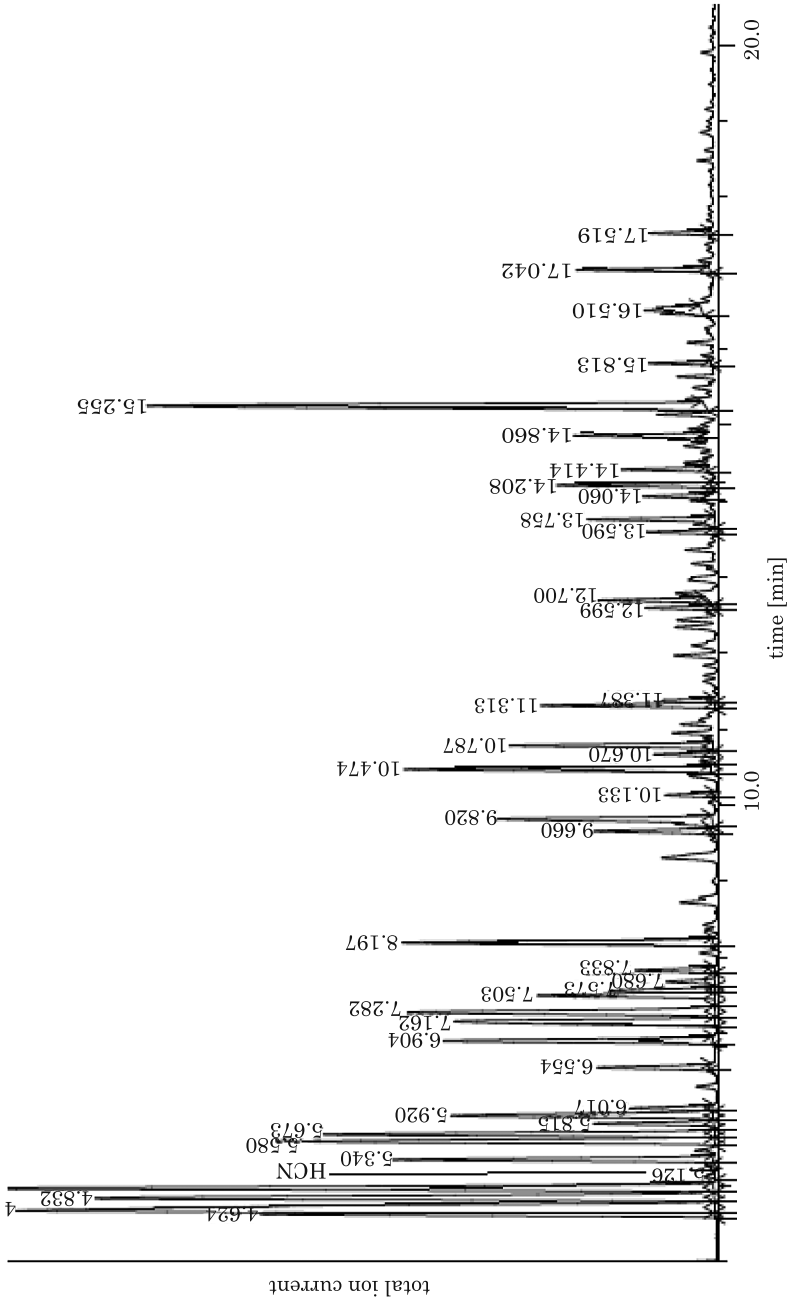

Fig. 6. Absorption spectrum showing presence of HCN in gaseous products of thermal pyrolysis of feathers

The calorific value of turkey feathers has been calculated on the basis of the gaseous products analysis. The minimum value of 1.2 MJ/Nm^3 was obtained at 400°C while the maximum value was obtained for 850°C and it was equal to 16.7 MJ/Nm^3. The noticeable increase of the calorific value was caused by high content of CH_4 and H_2 at higher temperatures of the pyrolysis, at stable amount of carbon.

Sulfur contained in the feathers (Tab. 1) will be a potential threat if the gaseous products of the pyrolysis would be used as a fuel for energy generation. N_2 present in the turkey feathers (tab. 1) caused the synthesis of HCN in the pyrolysis products of the feathers (CZEPANKO 2010). That dangerous substance for the environment was identified in the liquid as well as in gaseous products of the pyrolysis (SENOZ 2011). The presence of the chromatographic bands of HCN is visible in the GC-MS spectra (Fig. 5, 6). The HCN band in the liquid products spectrum is visible at 5.092 min and in the gaseous products spectrum at 5.126 min.

Conclusions

The thermal pyrolysis research confirmed that this is the effective method of utilization of turkey feathers. In accordance with earlier assumptions, the pyrolysis products of turkey feathers have significant energy potential.

The gaseous products of the thermal pyrolysis might be used as energy source. Special precautions have to be taken with the gaseous products since they contain HCN. It is also present in the liquid products. Presence of S and N_2 will have negative consequences during production of energy in the process of combustion of the gaseous products, because it will lead to creation of SO_x and NO_x in the outgoing gas. To keep the process of combustion friendly and safe to the environment, an installation for energy generation should be equipped with an efficient and effective filtrating and cleaning system.

There was observed a monotonically increasing synthesis of the liquid products: 1.39% at 400°C to 23.14% at 900°C. The course of synthesis of char was monotonically decreasing: 15.42% at 400°C to 1.86% at 900°C. The course of synthesis of gaseous products was not monotonic. It was increasing from 83.19% at 400°C up to 89.54% at 700°C and then decreased to 75% at 900°C.

The raise of the process temperature caused the monotonic increase of the concentration of H_2 from 0.5% to 23%. Over 500°C the concentration of CH_4 was increasing. It reached 32% at 850°C. The concentration of CO_2 monotonically decreased from 35% to 7%. And finally, the concentration of CO is non monotonic: it increased from 5% at 400°C to 30% at 500°C and then decreased to 21% at 850°C.

There was observed the increase of the calorific value of the gaseous products of pyrolysis for higher process temperatures. The maximum calorific value was obtained for 850°C and it was 16.7 MJ/Nm^3.

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