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ENERGY RECOVERY OF BONE WASTE AS HEAT SOURCE

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Abstract: Modern food industry concerning meat producers produce high amounts of bone waste. Bones represent biggest portion of zoo-mass waste which must be destroyed for hygienically reasons. Bones also have long durability and it is taken long time to decomposing this material microbiologically. We already know way to destroy this waste by crushing and making meat and bone meal. However, feeding with meat-and-bone meal can cause animal diseases. Because of that we try to prove combustion as a suitable way to get rid of this waste. Everything can be cleansed by flames and combustion also release energy captured in bone tissue. This energy can be used as heat or transformed to electric current also. But the other side, bone burning also has its emission problems that this work is trying to solve.

1 Introduction

1.1 Bone waste statistics

The bones form the supporting structure of most living creatures. The bones form a composite consisting of many small lamella particles that give them immense strength even at low weight. Average bones weight up to 18% of the total weight of the animal, it makes up the largest part of waste in zoo-mass industry. Although animal breeders try to reduce the bone-to-meat ratio by breeding it is not possible to reduce the bone mass of animals without limit. Therefore, bone waste will always make a high proportion in zoomass. About 130 billion kg of animal bone residues from pork, beef, poultry and fish is produced in global slaughter industry every year as a side stream to their core business. The biggest producers are India and Brazil, which have more than 50 % of world market.

Bone waste can be divided according to hardness into soft and hard. Softer bones are produced by small animals like fish or birds and they are easier to use. The highest proportion of bone waste forms bigger animals such as pigs and cattle (Figure 1). Their bones are harder and contains a higher ratio of inorganic component it's causes lower calorific value. Nevertheless, they make up the largest volume of bone waste without having a clear use. The weight of bovine and pork bones is about 25% of total weight of animal. One cow has 207 bones in the body that make up the weight which is about 250 kg of his weight. One pig has 216 bones and it is made up around 75 kg of his weight.

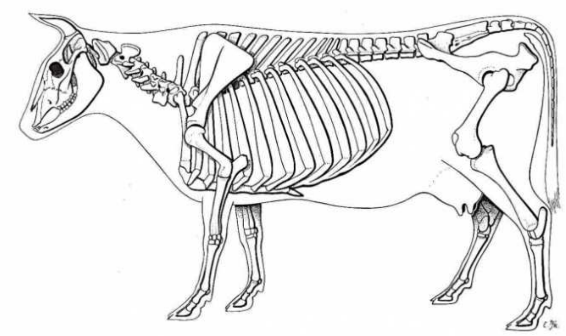

Figure 1 Cattle skeleton

1.2 Bone waste management solutions

Bone waste, on the one hand, needs to be hygienically and ecologically disposed of and, on the other hand, we can use it for energy. Energy saved in bones can only be used in two ways. Making meat-and-bone meal for feeding animals and for combustion [1,2].

1.2.1 Livestock feed

The production of meat and bone meal is verified by the long history of its production and application on the market. Feeding livestock on this energy, protein, and mineral-filled diet proved to be eastern and effective. But still some, scandals such as mad cow disease have also been shown. This disease is caused by feeding the herbivores on a fleshy diet. What's mean that not every animal should be eat this. Some meat-and-bone meal from infected animals is even banned from being used as feed, because it can also even cause disease to the rear carnivores.

Production of meat-and-bone meal also requires milling in shredders or mills. Bone grinding is also in itself energy intensive. Exceptions are bones from poultry and fish, which on the one hand are very small and fragile but are easily digestible sources of nutrients which can be used again as a nutritional supplement for fish and poultry. Especially regarding cattle their bones are high durable and hard. Their grinding is problematic and requires expensive technologies.

1.2.2 Incineration

For these reasons we try to proof incineration as a right way to using this material. Incineration of bones is very old process used by humans for centuries too (Figure 2). The combustible part contained in the bone tissue is simply broken down when the ignition temperature is reached. In doing so, there is an energy-saving and hygienically suitable degradation of bone waste. However, in today's modern age, increased emissions and related legislation are forcing us to verify the environmental aspects of the incineration of bone waste. Because incineration also entails certain risks, mainly associated with emissions and quality of combustion process. Our article deals with the aforementioned risks and evaluates the possibility of burning bone waste in terms of emissions, ash content and heat output [3,4]. We hope that our article will show ways to burning bones ecologically and brings clean renewable energy to us.

Figure 2 Bone samples

2 Theoretical analysis

2.1 Chemical content of bone

Bone tissue is composed of two essential components that are distributed in the bone in the right ratio (Table 1). They are called organic and inorganic, and dwellings have an important impact on animal life. The inorganic portion gives the animals support and stability, and the organic again supplies the bone with energy-rich nutrients [5]. The main constituent of bone is the inorganic portion which forms a resistant solid structure crosslinked with organic fibres. The organic part acts as a catalyst and causes chemical reactions with the inorganic component, allowing it to build or decompose. Without it, bone would be like an ordinary limestone rock.

Table 1 Chemical composition of a bone

Chemical element	Ca	C	P
Percentage (%)	39.12	25.23	17.01
Mass (mg/kg)	212.25	136.89	92.29
Content (ppm)	391167	252279	170086
H	N	S	Other
3.90	3.88	0.08	10.78
39.02	38.40	0.75	58.49
39023	38404	755	107791

2.2 Bones flammability

Bone burning is a cheap and easy way to get rid of bone waste by breaking down chemical bonds in bone tissue while releasing energy. Bone tissue is composed of an organic and an inorganic component. The organic constituent is formed by elements forming exothermic combustion reactions known as C, H, N and S. However, the increased content of elements such as sulphur and nitrogen have a negative impact on emissions formation. These elements form collagen and bone lubricant in bone tissue.

Inorganic elements together with water form a ballast part of the bone. Evaporation of water consumes heat and thus reduces the calorific value of the bone fuel, but she can be removed by drying using waste heat [11][12]. The major problem with bone burning is formed by inorganic minerals, mainly represented by calcium and phosphorus, but also by elements such as Mg, Na, K, ... These elements account for up to 50% of the bone content and are transformed directly into the ash content [8,9]. Some of them even produce endothermic reactions such as calcium and thus consume heat. The temperature required to react calcium hydroxide to calcium oxide is 1000 °C, which means that even this problem can be solved with good cooling of the combustion chamber [10-12].

The inorganic part of the bones forms a bone ash, which is a valuable raw material. The production of bone ash has been known for long time, and records of the production of lime from bone ash are already mentioned in the Bible. Well-burned bones are easily broken down into dust and have versatile applications as production of ceramics, lime plastering, cement additive or fertilization because it contains a high phosphorus content [13-15].

$$Ca_3(PO_4)_2 \rightarrow CaO + P_2O_5 - 4121\ kJ.mol^{-1} \quad (1)$$
$$CaCO_3 \rightarrow CaO + CO_2 - 635\ kJ.mol^{-1} \quad (2)$$
$$C + O_2 \rightarrow CO_2 + 393\ kJ.mol^{-1} \quad (3)$$
$$N + O_2 \rightarrow NO_2 + 626\ kJ.mol^{-1} \quad (4)$$
$$S + O_2 \rightarrow SO_2 + 297\ kJ.mol^{-1} \quad (5)$$
$$\frac{1}{2}O_2 + H_2 \rightarrow H_2O + 286\ kJ.mol^{-1} \quad (6)$$

The mentioned chemical reactions (1-6) show the formation of final bone burning products with energy balance.

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3 Experimental measurements

3.1 Determination of basic parameters

Before performing the measurements, we determined the basic properties of bone fuel as chemical composition, moisture content, content of flammable substances and ash by means of the thermogravimetric analyser LECO TGA701.

Calorimeter LECO AC 500 was used to determine gross calorimetric value and calorific value was determined from the formula where we subtracted the heat dissipated by moisture in the fuel.

We also determined melting point of bone ashes by ash fusion determinator LECO AF700. Pyramid sample from bone ash withstood a maximum temperature of equipment which was at 1500°C. Because of it we had to search for answer in other sources. We can see stability of bone ash with comparison to other samples from phytomass ash on figure 4. All measured bone material parameters can be seen in following table (Table 2).

Table 2 Basic bone properties

Moisture (%)	4.04
Volatile flammable (%)	45.06
Fixed carbon (%)	2.46
Ash (%)	48.45
Ash melting point (°C)	1670
Gross calorimetric value (MJ/kg)	10.93
Calorimetric value (MJ/kg)	9.98

3.2 Determination of performance and emission parameters

Bone samples were dried using waste heat from fireplace insert (Figure 3). During the experiment, hunk samples of pig and bovine bones were burned. The weight of one loading was 7 kg. The bones were burned on grate in a modified 18kW automatic boiler. Boiler preheating was ensured by spruce wood and bones were inserted right into the hot spruce embers. Performance of the device was measured during the measurement. The following pictures document the burning process.

Figure 3 Bone samples burning

During the experiment were measured the solid particulate emission values as well as the gaseous emission values recalculated on 10% oxygen content in the flue gas. Carbon monoxide emissions accounted for the largest share which have been caused by imperfect combustion of bones due to insufficient oxygenation in the automatic boiler as well as low temperatures in the combustion chamber. Emissions of CO even decrease performance of boiler. We also noted a higher proportion of NO emissions due to N content in bones. On the other hand, the temperature rise in the combustion chamber was directly proportional to the increase in NO emissions (Figure 4). It is more likely to burn bones at lower temperatures in combustion chamber. Low sulphur emission values were probably due to the sulphur low sulphur content and especially by the reaction of sulphur with calcium content of the bones. TZL values showed an increased concentration of mainly dangerous smaller spectrum particles. But these could also be influenced by better conditions in the combustion chamber.

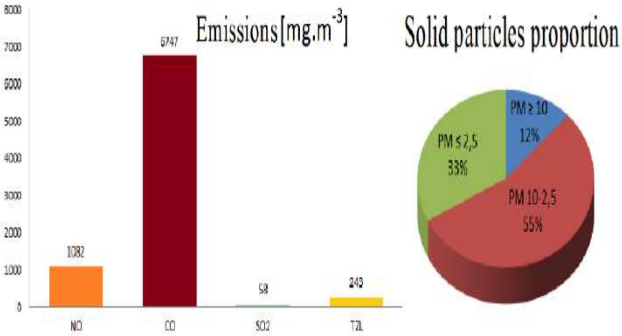

Figure 4 Average emission values during bone combustion

In the beginning, the burning was smooth and the boiler output increased to 8 kW. Subsequent loss of power was caused by the burn-out of the firing spruce wood. The bones themselves were able to maintain average power of only 2.5 kW. The temperature in the combustion chamber began to decrease, and thus the performance of the device decreased too. Although the bones continued to burn, they eventually cooled down and died out. Bones failed to burn completely, what caused increasing the heat loss by mechanical unburnt fuel parts as we can see in following picture (Figure 5).

Figure 5 Ash melting point test and imperfectly burned bones

4 Conclusion

4.1 *Results of combustion*

The results of the experiments proved that the bones are not able to burn as a separate fuel in a classic small heat source with respect to the emission limits and performance parameters of the combustion equipment. Due to their low flammable content and high ash content, they were unable to deliver the required heat output even for proper firing themselves. Subsequently we began to monitor imperfect combustion that affected emissions. However, we have also been able to monitor the positive effect of calcium content on sulphur emissions that were kept low throughout the measurement and sometimes we didn't even notice any. Bone burning itself, however, proved to be inefficient and non-ecological.

4.2 *Solutions for combustion*

There would be several solutions as choosing the right combustion plant and better fuel processing before combustion. Right combustion plant relates to the right combustion technique and adaptation the combustion plant to achieve optimal conditions in the combustion chamber as combustion temperature and air supply. This can decrease emissions and can provide better performance of equipment, however, when burning clean bones, it will still be necessary to provide flue gas cleaning by means of separators or a flue gas scrubber. For this reason, it will be necessary to focus on bone fuel processing.

Bone fuel processing seems to be the best solution for its combustion. It solves main problems which is chemical composition, the shape and size of bones what causes insufficient oxygenation and temperature maintenance in embers. First opportunity requires to break bones into smaller pieces and mixing them witch high calorimetric value fuels on classical grate boilers. Second opportunity requires to mill bone waste to bone meal and then use bone dust as additive to pellets. This solution is suitable for automatic boilers and even solve problems with low melting points of some biomass fuels because of high melting point of bone ash which increases the overall melting point of the mixture.

Bones can be used as an additive to fuels with a higher calorific value and possibly higher sulphur content, such as coal. Fuel with a higher calorific value is able to provide the temperature needed for perfect bone burning and the bones are able to incorporate the necessary emission-inhibiting minerals into the combustion process. The final bone-burning product should be a brittle easily breakable bone dust suitable for further use.

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Review process

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