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CONFERENCE PROCEEDINGS CONTENTS

SECTION ECOLOGY AND ENVIRONMENTAL PROTECTION

COMPARATIVE ENVIRONMENTAL ANALYSIS OF WASTE PROCESSING METHODS IN PAPER RECYCLING

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ABSTRACT

The paper deals with processing the waste generated in paper recycling: initial waste of paper mill and sludge after wastewater treatment. The authors have analyzed characteristics of the waste of paper recycling generated in paper recycling plant near Kyiv (Ukraine): calorific value, moisture and ash content. The heating value of waste of paper recycling range from 6.5 to 24 kJ/kg and significantly depends on moisture content. Potential environmental impact depends largely on the physical and chemical characteristics of the waste, first of all on humidity and composition. For comparative analysis, investigated waste (a mixture of initial waste of paper mill and sludge, equal weights) has been thermally processed by several existing methods (used in thermal processing of other waste types): incineration in rotary kiln, incineration in grate incinerator and plasma melting. Each equipment had the same minimal gas cleaning system configuration. The environmental performance of waste processing was experimentally identified. The concentrations of the most common pollutants emitted into the air were measured: fine particles (dust), nitrogen oxides, carbon monoxide, sulfur dioxide and hydrogen chloride. Incineration in rotary kiln had over-limit emissions for dust and carbon monoxide, hydrogen chloride concentration was close to the limit. For nitrogen oxides and sulfur dioxide limit excess was not observed. Grate incinerator provided over-limit concentrations for all measured substances except nitrogen oxides. The greatest excess was observed for dust and carbon monoxide (7-8 times). When using plasma melting the authors have measured over-limit concentration only for nitrogen oxides. The data received indicate that regarding to environmental performance the best incineration method for recycling paper waste among those analyzed is plasma melting. Besides, one can assume that minimal gas cleaning system for such incinerators is not enough to capture pollutants effectively.

Keywords: waste paper, paper recycling waste, thermal processing, waste processing, environment

INTRODUCTION

It is known, that waste paper is characterized by one of the highest recycling level among all waste types and it is widely used to produce a large number of new products. Also, paper recycling plants are among Europe's largest producers of alternative energy

[1]. Volume of recycling paper is constantly growing. According to research [2], this is not only due to the improvement of technology, but also due to awareness by natural resources depletion.

However, during the recycling of waste paper containing impurities, new waste is generated. Waste composition and both physical and chemical properties depend on the quality and type of paper as is shown by the authors [3]. Initial waste is generated just after paper mill. This waste contains paper fibers (cellulose and its derivatives) and many other substances: polyethylene, polypropylene, polystyrene, polyethylene terephthalate (PET), fluorocarbon-based polymers, polyvinyl chloride, polyamide, fillers and binders, surfactants, adhesives, bleaches, traces of heavy metals and other [4, 5, 6, 7]. Also, this waste contains textiles and metal inclusions. Besides, after further operations of waste paper recycling, other waste is generated. This is wastewater sludge containing the remains of paper fibers, fillers and fine particles [6].

The specific form of such waste causes problems with its disposal. This is especially true for biosludge formed during biological treatment. Thus, the need of new waste processing arises. One of the most common ways of such waste handling is incineration for energy production. The incineration process can be not very efficient due to the high moisture and ash content of waste. Besides, the authors [10, 11] indicate that incineration for energy production in some cases can be even more efficient comparing to recycling, depending on the input and assessment criteria. Landfilling is also used, but it is much worse option due to environmental consequences (for example, the authors [8, 9] have proved negative effect of substances, contained also in waste of paper recycling, on living organisms).

From an environmental point of view, the main shortcomings of paper recycling waste incineration are potentially high levels of air pollution, including chlorine-containing compounds, and heavy metals concentrated in the ash. Thus, depending on the composition, physical and chemical characteristics of the waste and incineration method, an expensive gas cleaning system may be required. In order to reduce the incineration costs and provide compliance with emissions standards, it is worth to analyze the environmental performance of different methods that can be used for paper recycling waste incineration.

MATERIALS AND METHODS

To make valid conclusions regarding to various incineration technologies, the authors have analyzed the waste of paper recycling generated in paper recycling plant near Kyiv (Ukraine). These include: initial waste generated in paper mill and wastewater sludge (final waste of paper production – dewatered sludge of wastewater treatment system, consists mainly of cellulose fibres). The following parameters were measured: calorific value (calorimeter B-08-MA), moisture content (drying cabinet SNOL-3,5.3,5.3,5/3,5-I1), ash content (electric oven SNOL 8,2/1100).

For comparative analysis, investigated waste (a mixture of initial waste of paper mill and sludge, equal weights) has been thermally processed by several existing methods (used in thermal processing of other waste types): incineration in rotary kiln, incineration in grate incinerator and plasma melting. Each equipment had the same minimal gas cleaning system configuration: neutralization of acid gases by lime,

capturing filter for fine particles, soda injection solution for nitrogen oxides capturing. The environmental performance of waste processing was experimentally identified. The concentrations of the most common pollutants emitted into the air were measured: fine particles (dust), nitrogen oxides, carbon monoxide, sulfur dioxide (gas analyzer TESTO-335) and hydrogen chloride (gas analyzer UG-2). Measurements were carried out just after the gas cleaning system.

RESULTS AND DISCUSSIONS

Characteristics of the paper recycling waste

The initial waste of paper recycling mostly includes packaging tape (65%), mainly consisting of polyethylene or PVC film. Besides, there are also other polymers and textiles. Therefore, it is possible to use such waste for energy production as the initial waste mainly consists of polymers with high calorific value (see Table 1).

Table 1.

The calorific value of polymers in the initial waste of waste paper recycling

Type of polymer	Calorific value, kJ/kg
Polyethylene	47767
Polystyrene	37800
Polypropylene	45670
Polyethylene terephthalate (PET)	21270
Fluorocarbon-based polymers	8130
Polyamide	31000
Polyvinyl chloride (PVC)	21000
Textile	27470
Mean value	30013

The results of waste characteristics measurement (Table 2) indicate a significantly greater energy potential of initial waste (waste of paper mill).

Table 2.

Characteristics of the paper recycling waste

Parameter	Waste	
	Initial waste of paper mill	Sludge
Net calorific value, kJ/kg	14150	4400
Moisture content, %	43.7	59.5
Ash content, %	10.1	44.4

In case of priority of waste processing over energy production, the initial waste of paper mill and sludge can be mixed. If this is done in equal weights, the total calorific value of the mixture is about 24000 kJ/kg for absolutely dry mixture. Moisture content significantly reduces calorific value (see Table 3).

Table 3.

Estimated calorific value of initial waste of paper mill and sludge mixture (equal weights)

Moisture content, %	Calorific value, kJ/kg
0	24229
10	19952
20	17103
30	12826
40	9262
50	6486

For measured moisture content, the calorific value of waste investigated is reduced more than twice. Therefore, it is essential to dry the waste before incineration. High moisture content, as well as high content of volatile substances in the paper recycling waste, strongly influences the incineration process, as also indicated in the research [12].

The environmental performance of thermal processing of paper recycling waste

Grate incinerator is the simplest and most common thermal method of waste treatment. It is characterized by low power consumption. However, during the incineration, there are about 25-30% of unburned waste remained on the grates, refractory slag and ash containing toxic substances (e.g. heavy metals) are also generated. These require special handling and disposal on special landfills creating new environmental problem. Another disadvantage is the need for significant excess air to ensure the completeness of waste incineration, which causes air emissions increasing.

Plasma melting method is more advantageous regarding to the environment. There are no hydrocarbons (including dioxins) in the emissions due to the high temperature (up to 3000°C). However, for the same reason, there is increased nitrogen oxides content. However, the undeniable disadvantage is huge energy consumption in order to provide high temperature. This results in large operational costs strongly limiting this method use.

The incineration in a rotary kiln has limited application due to technical features and is mainly used for hazardous waste combustion. The relatively low incineration efficiency for the waste similar to those under investigation causes the need for complex and expensive gas cleaning system.

Waste incinerators are designed so that the temperature of the gas generated during the waste incineration rise to at least 850°C for at least two seconds by the most unfavorable conditions. Besides, since waste of paper recycling usually contains a significant amount of polymers including those chlorinated, then according to [13] the required incineration temperature must be at least 1100°C. This is due to the need for dioxins and furans decomposition. When using grate incinerator this temperature is quite difficult to achieve, additional burner using fossil fuel is required. Considering this, plasma melting method is more environmentally friendly (incineration temperature is up to 3000°C). Although, nitrogen oxides emissions are increased as mentioned above.

Considering the measured concentrations of pollutants generated during the incineration of paper recycling waste, one may say that none of the methods investigated (with minimal gas cleaning system) ensure 100% compliance with European environmental standards (see Table 4).

Table 4.

Results of pollutant concentrations measuring, mg/m^3

Substance	**Waste incineration method**			
	Rotary kiln	**Grate incinerator**	**Plasma melting**	**EU limit [13]**
Dust	11	85	5	10
Nitrogen oxides	50	137	211	200
Carbon monoxide	190	337	8	50
Sulfur dioxide	43	68	12	50
Hydrogen chloride	9	17	2,5	10

Dust

Only use of plasma melting complied with air emissions standard. A significant limit excess was observed for grate incinerator.

Nitrogen oxides

Limit excess was measured only for plasma melting (explanation is given above). Much less nitrogen oxides emissions were found in rotary kiln.

Carbon monoxide

The same situation as for dust emissions: complying with standards for plasma melting, and strong excess for grate incinerator.

Sulfur dioxide

The use of rotary kiln and plasma melting complied with air emissions standard.

Hydrogen chloride

The concentrations below the limit were observed in plasma melting and rotary kiln with value close to the limit in latter incinerator.

Regarding to waste incineration methods, the results are as follows. Incineration in rotary kiln had over-limit emissions for dust and carbon monoxide, hydrogen chloride concentration was close to the limit. For nitrogen oxides and sulfur dioxide limit excess was not observed. Grate incinerator provided over-limit concentrations for all measured substances except nitrogen oxides. The greatest excess was observed for dust and carbon monoxide (7-8 times). When using plasma melting the authors have measured over-limit concentration only for nitrogen oxides.

The data received indicate that regarding to environmental performance the best incineration method for recycling paper waste among those analyzed is plasma melting. Besides, one can assume that minimal gas cleaning system for such incinerators is not enough to capture pollutants effectively.

It should be noted that incineration of paper recycling waste in the fluidized bed incinerators is also used. Such incinerators, according to the authors [14, 15], produce a large amount of carbon monoxide and dust, which is associated with high ash content in the waste of paper recycling. Also, the authors [12] studied the incineration of paper recycling waste with wood waste. However, these technologies were not studied in this paper due to technical reasons.

CONCLUSION

Comparative analysis of thermal methods of paper recycling waste processing has shown that the potential environmental impact depends largely on the physical and chemical characteristics of the waste, first of all – on humidity and composition. Existing thermal methods and equipment for other waste types processing with minimal cleaning systems allow efficient processing of paper recycling waste, but do not provide the necessary level of environmental protection.

According to the results of laboratory measurements of pollutants concentrations, we can conclude that none of the methods under investigation with minimal gas cleaning system provides the appropriate treatment in accordance with regulations. Some advantage in environmental performance has plasma melting method, although it produces more nitrogen oxide emissions and is the most expensive at the same time.

The worst environmental performance has grate incinerator. The highest over-limit pollutants concentrations were observed for dust and carbon monoxide. Also, the results obtained show that minimal gas cleaning system for incineration of paper recycling waste is not enough to capture pollutants effectively.

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