PhD Thesis Summary

THEORETICAL AND EXPERIMENTAL RESEARCH ON METHODS OF ENERGY RECOVERY FROM MUNICIPAL SOLID WASTES

Thesis for the Degree of Doctor of Philosophy
at
University Politehnica Timişoara
on Mechanical Engineering
by

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Foreword

PhD thesis has been developed over the work done within the Research Center for Thermal Machines and Equipments, Transport and Environmental Pollution of Mechanical Faculty of theUniversity Politehnica Timisoara. The research focuses on the idea of exploiting the energy potential contained in municipal household waste produced by urban settlements.

Given the significant calorific value (energy content) that characterize this type of waste and pollution massive landfill that are not subjected to environmental management, energy recovery was monitored simultaneously yield and reduce the risk of pollution.

This paper addresses all those interested or wishing to specialize in the intergratedwastemanagement system, with an emphasis on (i) applications for energy recovery of household waste (the concept of "waste-to-energy") and (ii) waste storage ecological conditions resulting from the incineration of household waste. For energy recovery are analyzed four case studies, two for capturing landfill gas and two for thermal treatment of waste by mass burning ongrate incinerators.

The landfill gascapturing is a BAT technology that can be implemented on the existing waste landfill disposals with the aim to reduce the greenhouse effect generated by the biomethane contained in the landfill gas mixture. By a proper threatment, the captured methane can be easely recovered on a combined heat and power - CHP facility or neutralize into a flare facilty.

Thermal treatment by mass incineration on grate is ment to recover the combustible fraction contained into municipal solid wastes, which, by combustion process, releases enough amount of energy to be recovered into CHP facility.

Following thermal treatment results in a significant amount of by-products of combustion in the form of slag and ash, and other waste products from the flue gas treatment plant, which is normally stored in landfill disposal, thus creating the real hazards environmental pollution (water, air, soil). Through this research proposes a new method of landfilling by applying commonly used technology for dense slurry disposal and storage of slag and ash from lignite power plants.

The innovative concept is based on using fly ash and desulphurisation products related to coal incineration as a binder material to stabilize by solidification of pollutants contained inrelated household waste incineration residues.In this regard there were experienced a series of recipes, with a laboratory hidraulic mixer specifically designed (and executed)for dense slurry preparation. The experimental results demonstrate the possibility of stabilizing the heavy metals contained in municipal solid waste incineration residues into the ash rock produced by the dense slurry technology.

For experimental measurements, data analysis and interpretation there were used top precisions equipments and appliances from leading research center mentioned before and from Renewable Energy Research Institute - ICER. The experimental results are valuable and try to protect them through a patent application request.

I believe that research work developed in presented thesis is a scientific basis for future research that will subject renewable energy recovery sources or landfilling in an environmentally-products resulting from the thermal treatment by mass incineration of municipal solid wastes.

Timişoara, September, 2015 Mihail Reinhold Wächter

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Thesis topic and research findings respond to topical issues on energy recovery from municipal waste incineration and related solidification/stabilization treatment for MSW incineration residues, in order to reduce the impending impact of pollution on the environment.

The thesis is divided into seven chapters covering current topics in the field of integrated waste management, punctualapplications by handling of case studies, experiments conducted on the laboratory hydraulic mixer and analysis conducted with top laboratoryequipmentsfromUPT and ICER.

Analyzes and interpretation of experimental data wereconducted in an interdisciplinary team with specialists in the technique of using the measuring apparatus and related methods. Thus tests carried out on the experimental batches under investigation and interpretation of the results were developed under high standardsconditions.

1. INTRODUCTION

The introduction chapter emphasizes the importance of the topic, concerns at european and national level about topic, and the reasons for choosing the research objectives and tasks established for scientific research.

Increasing the amount of household waste is directly proportional to the trend of population growth in urban areas. In recent decades there have been considerable efforts to find solutions more efficient and sustainable for medium and long term impact regarding the municipal solid waste management, in an environmentally sound manner with minimal impact on the environment. This is reflected in lowering pollution limits imposed by legislation issued by the European Union, which are becoming more restrictive.

Therefore the integrated waste management system is to provide solutions in this regard. Under the framework of integrated waste management, the thermal treatment of municipal solid waste (MSW) is a feasible solution with impact on medium and long term, to significantly reduce the amount of waste landfilling, and also allowing for waste hygienization. For waste incineration plants equipped with modern technology (BAT), waste volume is reduced up to 95-96%, depending on waste composition. Selective recycling of household waste is stongly influenced by inhabitans participation in this regard, so on top with over 60% of waste recycled is Germany and Austria, and in last place is Romania with only 1%.

On this background, considering the restrictions imposed by EU legislation (Directive No. 33/2003 /EEC) onto MSW landfill disposals, waste incineration is the one of the most suitable solutions.

On the other hand *finding alternative energy sources* is also a very highly debated topic of current research teams worldwide. In response to these problems was developed the concept of "Waste-to-Energy", which has proven to be a sustainable solution in this regard. This concept involves the energy recovery contained into MSW in an environmentally sound manner with minimal impact on the environment. The implementation the W-t-E concept, involves the development of new modern technologies for waste incineration, flue gases treatment and combustion by-products landfilling.

The managing and treatment of the residues arised from MSW incineration represents a topical issue. Following incineration process results in a significant amount of slag, ash and flue gas treatment residues. Most of these residues ends in landfill disposals.

Yet, the major environmental concerns in relation to the short-and long-term impact of landfilling of MSWI residues are connected with the risk of leaching and subsequent release of potentially harmful substances, particularly inorganic salts and metals/trace elements, into the environment (soil, water, air). In order to solve these problems there are several management methods such as sintering ash, vitrification or stabilization/solidification.

The treatment of the MSWI residues by stabilization/solidification method is rendered to be one of the most applied technique. This method can be used to encapsulate harmful chemical compounds by absorption, hydration or precipitation reactions, by means of using a binder matrix. The aim of this process is to create new compounds in a stable form that encompassing the harmful elements, which are non-hazardous or less hazardous than the raw (initial) material.

Following professional experience, I saw the opportunity to stabilize MSW incineration residues into coal fly ash matrix, obtained by commonly used technology for dense slurry applied for lignite power plants. This idea has pushing me foreward to deepen the studies under a scientific research.

In this respect, the research study goals were established, which can be divided in two main categories:

A. *Theoretical research goals*– which were analyzed the technical and critical solutions and techniques for treatment and energy recovery of MSW applied and implemented at global and european level.

   In this regard have been identified: (i) methods for capturing of landfill biogas in order to energy recovery or neutralization, (ii) the characteristics and methods of available thermal treatment of MSW, (iii) treatment methods for MSW incineration resudues and (iv) reducing the impact of pollutants generated by existing landfills.

B. *Applied research and experimental goals*–which were analyzed four case studies that focus on energy recovery from MSW, and was developed through experimental investigation an innovative concept for MSW incineration residues by stabilization/solidification method.

   Case studies 1 and 2 were conducted for landfill biogas capture generated in existing MSW disposals; and for case studies 3 and 4 was analized the energy recovery form waste incineration into mass burn on grate incineration units.

   The residues investigated for the conducted experiments, were provided from three different MSWI units abroad, with different combustion technologies: (i) mass burn on grate incinerator, (ii) incineration into stationary fluidized bed and (iii) incineration into circulating fluidized bed.

2. ENERGY RECOVERY METHODS FOR MUNICIPAL SOLID WASTES

Chapter two gives a brief summary, made under international flow of knowledge over the last eight years mostly, on energy recovery methods by thermal treatment of MSW and the capturing of landfill biogas generated by existing waste disposals.

There were presented essentially all phases that are developing on the MSW stream, from the waste generation to the last residues that ends in landfill disposals. In this respect, there were analized following topics:

- *Energy characterization of MSW* - which describes the energy content of the waste, according to waste generation ways and the heterogeneity of forming material waste. For this purpose was given the quantity of waste at the European level for a period of 10 years (2003-2013) and four methods for the calculation of calorific value of MSW, which reflects their energy content.
- *Particularities of energy recovery from MSW* – outgoing from the technological process flow of integrated waste management system, resulting in energy recovery method of the landfill biogas capture and thermal treatment by incineration respectively.
- *Incineration residues arised from MSW combustion* – which emphasizes the quantities of residues (slag and ash) related to the incineration process, and the amounts of residues arised from flue gas treatment (FGT) unit, that is specific to certain technology applied. The FGT residues are most pollutant because they concentrate and retain the toxic elements (heavy metals mostly) contained and resulting from incineration process.

3. LANDFILL BIOGAS CAPTURE FROM MSW DISPOSALS

This chapter describes the approach and existing methods in terms of biogascapturing from existing landfill disposals. It was emphasizes constructive types and dimensioning calculus for extraction wellsof the landfill gas (LFG) and separation methods of methane from LFG, in order to be energy recovered in a CHP unit.

This chapter also presents case studies 1 and 2 dealing with LFG capture for two landfill disposals from Cluj county, namely the (1) from Pata Rat respectively (2) from Dej. In the 1st case study is described in detail the active LFG extraction method, which collect and transport the LFG in order to be neutralize into a flare system; and on the 2nd case study was investigated the passive LFG extraction which is ment to be implemented in order to mentain the stability and safty of the landfill disposal.

The investigated case studies 1 and 2 are based on technicaldata providedby the tender specifications for the closure of non-compliant MSW landfills, in the county of Cluj, made available by local authorities in the field.

4. THERMAL TREATMENT OF MSW BY INCINERATION

Chapter four analysis and describes the: (i) the mechanism of the MSW incineration , (ii) combustion chemical reactions, (iii) available methods and technologies for thermal treatment of MSW incineration and (iv) case studies 3 and 4 that analyzes two MSW incineration units.

*The MSW incineration mechanism*explicitdescribethe stages of wastecombustion phases and the mass transformation as well. Here is described primary combustion stage which develops in four stages: (1) drying phase, (2) volatilization, (3)solid mass burn-down and (4) final burn down of char; respectively, secondary combustion stage where is achived the complete distruction of the unburned gases, vapors, particulates released from the primary combustion process. In the secondary combustion stage is highlighted pollutants destruction efficiency depending on the temperature in the combustion chamber (furnace) and residence time of gases in the area.

The combustion chemical reactions (oxidation) reflects the amount of energy released by incineration process. Here, was presented in details the importance of

the air excess (λ) that plays a decisive role at each combustion stage. There were described the formation of incineration residues that results from the combustion process in conjunction with the temperatures and the air excess (λ) specifics for the each phase of combustion. To achieve complete combustion that involving low emissions and maximum energy recovery, excess air ratio has a decisive role in carrying out chemical reactions of combustion. This fact were reflected by the amount of oxygen present in each stage/combustion zone.

There were presented methods and incineration technologies which are most suitable for thermal treatment of mixed MSW. In this respect incineration methods are explained (to) mass burn on grate incinerators, (b) fluidized bed incinerators and (c) in rotary kilns incinerators, withparticularities for each type and category of waste.

The 3th case study describes and analyzes the MSWI unit from KRV Arnoldstein Austria, which is equipped with technology "state-of-the-art" in terms of grate incineration systems, which otherwise is the most common method use for thermal treatment of MSW.The MSWI unit has implemented a very effective combustion technology,which is based on the increase concentration of oxygen in the primary combustion air, and sintering the coarse ash by reintroduction into the mass of incinerated waste. The case study was developed through an internship at incineration unit. Thus was possible to study and analyze the whole technological process, to collect operation data and to take samples of MSW incineration residues for experimental purpose. Based on these data it was possible summaries for the determination of performance indicators incineration unit, indicators required by EU legislation (Directive 2008/98 / EC).

The 4th case study is based on data from a technical offer accepted for implementation on the industrial incineration units on the industrial platform of CET Sud Timisoara power plant. By using those data, was possible to develop a study concerning to analize the design and sizing of incineration unit.The peculiarity of this MSWI is that in this unit the sizing was based on two fuels with different calorific values. The basic fuel is meant to be sorted household waste (Hi = 10800 kJ/kg) and bio-coal (Hi = 17650 kJ/kg) as secondary fuel.Secondary fuel flow was limited in normal operation of incineration unit because of high calorific value. Therefore, this fuel can be used to control the combustion temperature in the combustion chamber (furnance) by adjusting the feed rate.

5. MANAGEMENT OF RESIDUES ARISED FROM MSW INCINERATION

Chapter five presents and describes: (i) a summary of management methods, (ii) treatment of MSW incineration residues and (iii) a novelty of treatment of MSW residues by using new solidification/stabilization method.

Management methods related to MSW incineration residues explicitly presents the impact of landfill disposals and the potential danger to contaminate the environment through leaching phenomenon that is specific to those types of disposals. There were described the phenomenon of leaching which develops into filling material (residues) under the influence of environment moisture (rain, snow), water is considered to being the main medium for the transfer of pollutants between deposit and the environment.This phenomenon has an impact on the environment in the short, medium and long term. Thus leachate concentrations of pollutants contained in such deposits are limited by law and monitored by environmental authorities in each country (whether or not an EU member).

There were presented methods for treating residues from the MSW incineration from implemented industrial scale facilities or still in the research phase, which are most popular at world and european level. Based this aspects were presented (a) the method of extraction and separation of pollutants, (b) the method of chemical stabilization, (c) solidification method and (d) the heat treatment method. To emphasize the effectiveness and cost of implementing each method, or some combination of them it was drawn up a table (Table 5.1) that consider this aspects.

Contributions relating to the novel method of treatment by solidification of pollutants contained in specific residues of MSW incineration is quantified by: (a) technical description and principle of the method, (b) the presentation of chemical reactions of cementation/solidification underlying the proposed technology and (c) design, sizing and construction of the experimental hydraulic mixerused in laboratory to investigate innovative method proposed.

Contributions are reflected in the novelty of the proposed method for landfilling of MSW incineration residues by applying commonly used technology for dense slurry disposal and storage of slag and ash from lignite power plants. The innovative concept is based on using fly ash and desulphurisation products related to coal incineration as a binder material to stabilize through solidification process the pollutants (heavy metals mostly) contained in MSW incineration residues.The present study relates to research and analyze of results accomplished on a small scale facility upon the encapsulation of the solid waste incineration residues into coal fly ash rock matrix, thus reducing the leaching risks and making the landfilling possible.

The Hydraulic Mixer device designed and used in the experimental research was tested also "on-site" at CET Sud Timişoara power plant on conducted experiments , in order to create a new recipe of dense slurry mixture that includes the flue gas desulphurisation by-products, for maintaining the transport hydraulic characteristics through piping systems on to final disposal placed at 7.2 km at Utvin.

6. DEVELOPED EXPERIMENTS FOR STABILIZATION/SOLIDIFICATION OF MSW INCINERATION RESIDUES INTO DENESE SLURRY METHOD

This chapter covers the experimental research conducted on the designed experimental device (hydraulic mixer) and UPT/ICER laboratories, concerning the innovative method proposed for stabilization/solidification of the MSW incineration residues into ash rock matrix. In this respect there were carried out: (i) the chemical composition of the ash used, (ii) determining the recipe for the preparation of the dense slurry mixture, (iii) analysis of the structure and crystallizing forms of the ash rock, (iv) analyzing the concentrations of heavy metals in leachate, (v) the interpretation of results and (vi) the applicability of the results.

Analyzing the chemical composition of the investigated ashes is essential to identify on one hand, the chemical elements which participates on the cementation chemical reactions, and, on the other hand, to identify the pollutants that are meant to be stabilized into ash rock matrix. Investigated ashes fall into two categories (a) binder material, represented by electrostatic fly ash and the flue gas desulphurization by-product, related to coal (lignite) incineration; and (b) represented by toxic by-products that consists of slag, fly ash and flue gas treatment residues related to the MSW incineration.

For the binder material, there were examined the composition of the oxides, that consists in elements concentration pozzolanic ash (SiO_2, $Al2O_3$ and Fe_2O_3) and the elementary chemical composition of desulfurization residue, which was determined

the concentrations of the compounds on the basis of calcium (CaO, $Ca(OH)_2$, $CaSO_3$, $CaSO_4$, $CaSO_3$, $CaCO_3$) which activates and accelerates the solidification/cementing chemical reactions. The binder material represents the basic structure of the ash rock matrix after cementation chemical reactions, crystallized in various forms, which, through their structure encapsulates and binds toxic pollutants from waste incineration (in this case heavy metals). Fly ash and desulphurisation residue and were taken from CET Sud Timisoara lignite power plant.

For toxic residues, there were experimentally analyzed the content and concentration of heavy metals (As, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Zn, etc. - see Table 6.3), and the resulted values were compared with the maximum allowable centrations for toxic materials established by the legislation (Environment Ministry Order no.95/12/02/2005, issued on the basis of the European Council Decision 2003/33/EC and Article 16 of Annex II of EU Directive 1999/31/EC). Thus it was revealed that they are toxic waste, and may not be landfilled without appropriate treatment. The toxic residues analyzed were taken from incineration units with different combustion technologies (a) MSWI KRV Arnoldstein - grate mass burning , (b) MSWI Niklasdorf Styria - stationary fluidized bed combustion and (c) MSWI Gluckstadt - circulating fluidized bed combustion. The first two incinerators are in Austria and the last one is in Germany. By analyzing these residues there were demonstrated that regardless of the incineration process applied on MSW, concentrations of heavy metals associated combustion residues are the same.

Analysis of heavy metal concentrations was made by the method FRX (Fluorescence Radiation X) on a device XL3t FROM $GOLD^+$ Thermo Scientific in ICER laboratories. The preparing recipe for the dense slurry shows the related proportions of mixture between solid phase (ash) and the liquid (water) and the form and preparation of samples investigated. In this regard are presented the mixing recipes on four batches and the embodiment of the mold of the dense slurry. Mold design and construction has an important role to obtain quality samples without cracks or crevices in the ash rock. Construction and design of the molds are carried out in a proper concept. Here it was shown how to prepare samples for the test leaching according to the related standards (SR-EN 12457-2003).

Analysis of the structure and forms of ash rock crystallization was done by analyzing the ash rock matrix with XRD method (X-Ray Diffraction) on a Rigaku Ultima IV Diffractometer device (with Kα radiation=0.154 nm) in the ICER laboratories. In this regard we were investigated four ash rock batches. Based on the obtained results were identified by comparison with the crystal forms of the spectra in the database ICDD (International Centre for Diffraction Data). As a result of the spectral analysis there were identified the way in which the heavy metals are bound in the crystal structure of the ash rock.

Analysis of the heavy metals leachate concentrations was performed by gravimetric method using ICP-MS machine Aurora 90 BRUKER made in ICER laboratories. Values obtained results were compared with the maximum permitted levels for inert materials imposed by legislation (Environment Ministry Order no.95/ 12/02/2005).

By interpreting experimental data values there were demonstrated that the ash rock is an inert material that can be landfilled with no environmental problems. This indicates that proposed innovative method of stabilizing related to the toxic incineration residues arise from MSW thermal treatment through encapsulation into the ash rock matrix produced by the dense slurry technology is a feasible method for landfilling this kind of residues.

Applicability of the results are based on experimental results which confirm and support the value and importance of the proposed method for stabilization/ solidification of the waste incineration residues . Applying the proposed method can be easily implemented, in the case of MSW incineration units build on industrial site, or near by power plants operating on coal. This ensures the binder material represented by fly ash and desulphurization residue from coal combustion process.

Landfilling of the incineration residues through the dense slurry technology is reducing the cost of transport and the treatment cost for these type of residues, in addition physico-chemical characteristics of the landfill surface created thereby are superior to conventional alternatives.

7. CONCLUSIONS AND CONTRIBUTIONS

Chapter seven presents conclusions and focus on the scientific contributions realized during research conducted during doctoral studies. Here is comprised the achievements of predetermined goals and directions of research remain open for future scientists. In this respect, a brief summary of chapter seven is:

- Analysis and critical technical point solutions and techniques for treatment and energy recovery for municipal solid waste applied and implemented at global and european level.

- Studying of four case studies which analyzes punctual methods of energy recovery of household waste, of which two are for capturing biogas generated by existing MSW landfills and two for thermal treatment by mass incineration of MSW on grate systems.

- Developing of the innovative treatment concept the residues related to MSW incineration through stabilization/solidification of the pollutant through encapsulation into ash rock matrix obtained with the dense slurry technology.

- Design, dimensioning and construction of the experimental device Hydraulic Mixer used in the preparation of the dense slurry, which develops the ash rock through solidification process.

- There were conducted a set of experiments investigated on original laboratory device and related conclusions, from where results an innovative solution for treating waste solidification related to MSW incineration.

- Experimental evaluation of the properties of retention of heavy metals in the rock matrix through analysis and interpretation of heavy metals concentrations found in the investigated ash rock leachate.

- Study and analyzing of the combustion efficiency of MSW by (i) the technology of combustion primary air enrichment with oxygen (oxygen boosting), and (ii) sintering of the coarse ash through reintroduction into the mass of waste incinerated on grate systems.