CHEMICAL ENGINEERING TRANSACTIONS, Volume 12, 2007
Edited by Jiri Klemeš

Waste and biomass utilisation focused on environment protection and energy generation

Petr Stehlík
Brno University of Technology,
Institute of Process and Environmental Engineering (UPEI VUT)
Technická 2, Brno, Czech Republic
E-mail: stehlik@fme.vutbr.cz

Thermal processing of waste and biomass is a challenge for investors and operators as well as researchers due to many inherent difficulties connected with these processes. The views presented in this contribution may be summarised in four following general theses: (1) waste disposal is a necessity, (2) waste and biomass may both be considered as renewables, (3) waste-to-energy is an option preferable to land filling and (4) abatement of emissions is a key point in thermal treatment technologies. Several examples demonstrating this approach are included.

1. Introduction

Serious problems are currently solved in the field of environmental protection (Ludwig et al. 2003, Kiely 1997). The challenge facing concerned citizens and decision-makers is a formidable one: To identify and implement long-term solutions that are safe, socially acceptable, and cost-effective. Such amount of wastes, which is produced either by inhabitants (municipal solid waste - MSW) or by industrial companies (industrial and hazardous waste - IHW) requires to use efficient ways of waste disposal. The recent focus on incineration has been on environmental consequences, not on performance (Kuehn et al. 1998). In particular, the limitations, as well as the advantages of incineration are being increasingly recognized. At present, incineration is not a waste disposal method but rather a waste processing technology.

Another global challenge is to achieve sustainable delivery of energy in the 21st century and on the other hand to solve environmental problem – green house gases emissions – that markedly participate, according to scientific climatic change models, in the sequential change of the climate . (Holmes et al. 1993). The total energy consumption grows significantly every year and during the last year, it has risen by 4.3 % (EIA 2005). This growth is mainly attributable to the increasing consumption in Asia, for example the energy consumed in China was last year by 15.1% higher that the year before (BP 2005). Moreover, price of energy increases drastically.

Incineration of waste can be considered as a certain form of recycling energy contained in materials taking into account that the energy was consumed during their production. Then we speak about waste-to-energy technology (WTE). WTE is also referred to as thermal processing of wastes including energy utilization. This means combustion of waste (incineration) is performed not only to substantially reduce its volume but also to produce clean, reliable and renewable energy.

Waste processing is described in many books (e.g. Ludwig et al. 2003, Mihelcic et al. 1999, Brunner 1996, Santoleri et al. 2000, Niessen 1995), therefore it is not necessary to go into details. Once the problem of waste treatment is to be solved, we have to be familiar with the waste character, composition, state (whether solid, liquid, gas and/or a mixture) etc., further with currently used technologies for the waste processing (to be able to make the selection and trade-offs) and other factors. The main waste processing technologies are related to waste type and its origin and include municipal waste incinerators and hazardous waste incinerators.

Selection of a convenient waste treatment method needs to conform to the applicable local environmental legislation. National environmental legislations are far from uniform; large variations can be found when comparing different countries. The differences among emission limits of EU, USA and China are displayed in Table 1 as an example.

Table 1 Environmental limits for emissions from incineration

Pollutant	Units	EU	USA	China
Dust	mg/Nm^3	10	24	80
CO	mg/Nm^3	100	62.5-187.5	150
NO_x	mg/Nm^3	200/400	308-370	400
SO_2	mg/Nm^3	50	85.7	260
HCl	mg/Nm^3	10	41.3	75
Hg	mg/Nm^3	0.05	0.08	0.02
Cd+Tl	mg/Nm^3	0.05	0.02	0.1
As+Co+Ni+Cr+Pb+Cu+Mn+V+Sb	mg/Nm^3	0.5	0.2	1.6
Dioxins/furans	$TEGng/Nm^3$	0.1	0.1-0.3	1.0

2. Selection of technologies

For a selection of waste processing technology various criteria have to be respected. First, in most cases it is necessary to “hand-tailor” the technology from case to case. For a customer there is usually a choice of best available technologies (European IPCC Bureau 2005a). However, only few of them (sometimes none) are applicable for the given purpose. Then a creativity and all-round potential of the technology supplier plays a key role.

2.1 General criteria of technology selection

To select an optimum technology, it is necessary to take into account primarily the following information:

- type and amount of waste to be treated
- whether thermal processing is really the best way (first of all it is necessary to strive for maximum recycling and material utilization of waste, e.g. processing of biodegradable part of waste by anaerobic digestion, aerobic digestion, composting etc. (Kiely 1997, European IPCC Bureau 2005b)

- costs of available alternative waste treatment technologies
- valid environmental regulations
- potential for energy utilization
- other priorities (using waste as alternative fuel e.g. in cement works, region where the incinerator is to be built – e.g. unit for processing MSW/IHW in smaller towns, etc.)

3. Examples of progress in thermal processing of waste

This section surveys some recent achievements of the author's research group in the area of thermal processing of waste.

A close cooperation between research and industrial practice represents an optimum combination to meet the challenges in the field of thermal processing of wastes. Original equipment for thermal treatment of waste gases (for details see Dvorak et al. 2005) can be considered as a result of this approach called "from idea to industrial application". Schematic layout of the unit for the IHW treatment with highlights of the latest achievements of the presented research is displayed (in a simplified form) in Figure 2.

3.1 Operation optimization of rotary kiln

Evaluation of incineration plants from the point of view of auxiliary fuel consumption required for achieving the required temperatures in the after-burner stage, it is necessary to emphasize the influence of the thermal regime of the rotary kiln and the heat value of the waste. It can be shown (Bebar et al. 2002) that the demands on consumption of auxiliary fuel in the burners of the after-burner chamber, resulting from requirements on temperature in the chamber, are considerably increased when the temperature of the flue gas exiting the rotary kiln is decreased. However, practical experience says that thermal regime of the rotary kiln cannot be chosen arbitrarily. To avoid massive formation of deposits on the inside wall of the rotary kiln, it is necessary to operate the kiln outside the "dangerous" temperature range, lying usually between 900°C and 1100°C.

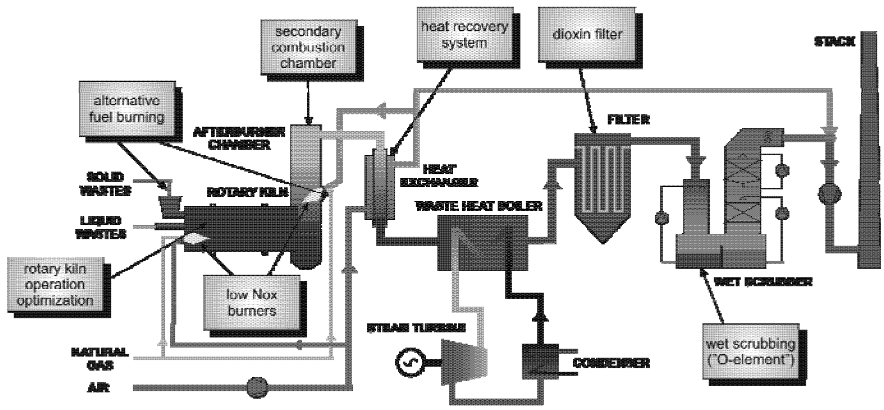

Figure 2 Layout of an industrial waste incinerator with research areas highlights

3.2 Alternative fuel burners

Burners in rotary kilns are seldom given special attention, but this is only true for common gaseous, liquid and solid (coal) fuels. Recently, due to the rising costs of the noble fuels, operators of energy-intensive processes like cement and burned lime production need to consider ways for decreasing the energy bills. A solution that is gaining popularity involves the use of specific types of waste as a substitute for a significant part of the noble fuels. However, such approach requires customised burners according to the specific type of alternative fuel (waste), as described e.g. in (Boran et all. 2005).

3.3 Secondary combustion chambers

Secondary combustion chamber constitutes in fact a reactor enabling completion of oxidation reactions of various undesirable species, released from the first stage of incineration. The reactions require for their completion namely high temperatures, sufficient amount oxygen and sufficiently long residence time. Therefore, optimised design of secondary combustion chambers is not a simple problem, considering both performance criteria and investment costs. More on the possibilities for the design optimisation may be found in e.g. (Hajek et al. 2005).

3.4 Low-NOx burners

The formation of nitrogen oxides, which belong among the most closely monitored pollutants, depends on the type of fuel, temperature and flow fields in the combustion chamber. Specific burner design depends mostly on the fuel to be fired, on the character of the flame (shape, length, width, momentum), and on the application (boiler, secondary combustion chamber, etc.). Development of low-NO_x burners is an art on its own; for more information see e.g. (Hill and Smoot 2000).

3.5 Heat recovery system

Heat recovery in units for the thermal processing of various types of wastes can be without any doubts considered as one of the most important parts of these processes. Design of equipment for utilization of energy contained in the flue gas from the thermal treatment of wastes (incineration) and their placement in the process is one of key factors in these technologies. In design and operation of heat recovery systems it is necessary to take into account characteristics of heat transfer equipment and their specific features as well as those of process fluids. Mostly the energy from off-gas is used for combustion air pre-heating and for steam production in waste heat boilers (heat recovery steam generators – HRSG). Often, special types of radiant recuperative heat exchangers must be used, preventing fouling and enabling easy access for mechanical cleaning.

3.6 Dioxin filter

Dioxins (collective name for polychlorinated - dibenzo-p-dioxins and dibenzofurans) belong among the most dangerous pollutants being considered as extremely toxic substances. Their elimination from the products of incineration (solid residues, flue gas) is vitally important. It is therefore very attractive to employ technologies that actually destroy dioxins instead of only collecting them. The latest achievement in this respect is the catalytic filtration technology REMEDIA^{TM} of the company W.L. Gore & Associates Inc., which combines fabric filtration (collection of particulate matter) with catalytic destruction of dioxins. Information on the performance of this technology recently applied in a municipal waste incinerator may be found e.g. in (Xu et al. 2005).

3.7 Wet scrubbing

For the cleaning of flue gas in industrial waste incinerators, where the pollutants include SO_2, HCl and HF, Venturi wet scrubbers are often used. A novel equipment called "O-element", which has in some flow regimes lower pressure drop than the conventional Venturi scrubber, has been recently investigated as reported in (Dvorak et al. 2005).

3.8 Processing of waste as alternative fuel

Thermal processing of waste does not mean only its disposal; it is also material and energy utilization (waste-to-energy). Substituting fuel by mining gas that has no other use is an example of waste gas utilization. It is a specific application that was realized in a pulp plant situated in former mining area (for details see Boran et al. 2005). In this case mining gas substitutes natural gas in thermal treatment unit for sludge incineration. For this purpose a special "dual" burner for combustion of both fuels was designed.

3.9 Waste to energy

The best way of using steam, which is generated in many waste-to-energy processes, is a combined heat and power generation (CHP), i.e. the simultaneous production of power and steam with lower parameters (steam pressure within 0.2 to 1.2 MPa) for heating purposes. There are several options of technical solution, e.g. it is possible to use both back pressure steam turbines and condensing bleeder turbines with one or more extractions (see Pavlas et al. 2005).

3.10 Waste gas treatment and off-gas cleaning

Within the framework of research on cleaning of various off-gases, polluted by different classes of compounds, the following pollutants have been addressed:

- Volatile organic compounds (VOCs), halogenated organic compounds (HOC) and CO
- NO_x, SO_2, HCl, HF
- Particulate matter (fly ash) and PCDD/F (dioxins and furans)

Description of novel units developed in the course of this research may be found in Dvorak et al. 2005.

4. Conclusion

The paper provides a brief description of the features of thermal processing of various types of waste. Presented in the first part of the paper is a discussion related to trade-offs in the selection of a convenient technology that contributes to illuminating the way to the development of new pieces of equipment and/or technologies, described in the second part of the paper.

5. Acknowledgements

The author gratefully acknowledges financial support of the Ministry of education, youth and sports of the Czech Republic within the framework of research plan No. MSM 0021630502 "Waste and Biomass Utilisation focused on Environment Protection and Energy Generation".

6. References

Ludwig Ch., Hellweg S., Stucki S., 2003, Municipal Solid Waste Management, Springer-Werlag, Germany

Kiely G., 1997 Environmental Engineering, McGraw Hill, UK

Kuehn T.H., Ramsey J.W., Threlkeld J.L., 1998, Thermal Environmental Engineering, Prentice-Hall Inc., USA

Holmes G., Singh B.R., Theodore L., 1993 Handbook of Environmental Management and Technology, John Wiley & Sons Inc., USA

BP, 2005, Statistical Review of World Energy 2005, available from www.bp.com

EIA (Energy Information Administration), 2005, International Energy Outlook 2005, Report No.:DOE/EIA-0484(2005), available from www.eia.doe.gov

Mihelcic J.R., Auer M.T., Hand D.W., Honrath R.E., Perlinger J.A., Urban N.R., Penn M.R., 1999, Fundamentals of Environmental Engineering, John Wiley & Sons Inc., USA

Brunner C.R., 1996. Incineration Systems Handbook, ICI, USA

Santoleri J.J., Reynolds J., Theodore L., 2000, Introduction to Hazardous Waste Incineration, Second Edition, Wiley-Interscience, New York

W.R. Niessen, 1995 , Combustion and Incineration Processes, Marcel Dekker Inc., USA

European IPPC Bureau, 2005a, Reference Document on the Best Available Techniques for Waste Incineration, Brussles, available on http://eippcb.jrc.es,

European IPPC Bureau, 2005b, Reference Document on the Best Available Techniques for Waste Treatment Industries, Brussles, available on http://eippcb.jrc.es

Dvorak R., Bebar L., Stulir R., Stehlik P., 2005, 1st International Conference & Exhibition on Thermal Treatment and Resource Utilization of Wastes, Beijing

Bebar L., Martinak P., Hajek J., Stehlik P., Hajny Z., Oral J., 2002, App. Thermal Eng., 22, pp. 897-906

Boran J.,Houdkova L., Stehlik P., 2005, 1st International Conference & Exhibition on Thermal Treatment and Resource Utilization of Wastes, Beijing, 2005

Hájek J., Petr P., Šarlej M., Kermes V., Dvořák R., Stehlík P., Oral J. and Šikula J., 1st International Conference & Exhibition on Thermal Treatment and Resource Utilization of Wastes, Beijing, 2005

Hill S.C., Smoot L.D., 2000, Prog. En. Comb. Sci., 2000, 26: 417-458

Xu Z., Chang W., Sun H., Mongami Y., 2005, 1st International Conference & Exhibition on Thermal Treatment and Resource Utilization of Wastes, Beijing

Pavlas M., Bébar L. and Stehlík P., 2005, 1st International Confetrence & Exhibition on Thermal Treatment and Resource Utilization of Wastes, Beijing