MUNICIPAL WASTES AND LANDFIELD GASES UTILIZATION - RENEWABLE RESOURCE OF ENERGY AND MATERIALS

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ABSTRACT

Urbanization and industrialization, have been fundamental causes of environmental pollution (of water, air and land) which the cities were unable to handle. There is already enough evidence of the fact that the role of technology in environmental matters is moving in two important directions: sustainable development, dealing primary with global problems, and preventive technology, designed to reduce the environmental effects of processes, operations, and products. Treatment plants for industrial and municipal wastes, emission controls for incinerators, and safe landfills for waste disposal were developed to control air, water, and land pollution. Now, this 'end-of-pipe' treatment technologies are still the way of environmental protection philosophy, particularly in the developing countries. New environmental standards demand more and more rigorous preventive environmental protection technologies, therefore further development of industrial production requires the rational use of natural sources of raw materials and energy. Production and the use of goods with the minimum municipal and industrial wastes and the development of recycling technology provided closed cycle of materials. Main principles for the development and exploitation of the technology with the minimum or without waste materials and energy are: the use of renewable sources of material and energy, maximum use of waste materials and waste energy, waste minimisation and reduction of energy losses in the production, development of new industrial processes operating with minimum material and energy losses in products exploitation period and after that, and the responsible use of natural sources, products and energy in the field of industry and consumption.

Key words: energy, renevable resources, environmental pollution, municipal waste, landfield gases,

Introduction

Urbanization and industrialization, have been fundamental causes of environmental pollution (of water, air and land) which the cities were unable to handle. There is already enough evidence of the fact that the role of technology in environmental matters is moving in two important directions: sustainable development, dealing primary with global problems, and preventive technology, designed to reduce the environmental effects of processes, operations, and products. Treatment plants for industrial and municipal wastes, emission controls for incinerators, and safe landfills for waste disposal were developed to control air, water, and land pollution. Now, this 'end-of-pipe' treatment technologies are still the way of environmental protection philosophy, particularly in the developing countries. New environmental standards demand more and more rigorous preventive environmental protection technologies, therefore further development of industrial production requires the rational use of natural sources of raw materials and energy. Production and the use of goods with the minimum municipal and industrial wastes and the development of recycling technology provided closed cycle of materials. Main principles for the development and exploitation of the technology with the minimum or without waste materials and energy are: the use of renewable sources of material and energy, maximum use of waste materials and waste energy, waste minimisation and reduction of energy losses in the production, development of new industrial processes operating with minimum material and energy losses in products exploitation period and after that, and the responsible use of natural sources, products and energy in the field of industry and consumption [1].

Characteristics of municipal solid waste (MSW)

Solid waste in the broadest sense includes all the discarded solid materials from municipal, industrial, and agricultural activities. Residential and commercial areas, together with some industrial operations, are the sources of "nonhazardous" MSW. Production of MSW in Western Europe varies between 0.8 and 1.4 kg per person per day [2]. Factors influencing the composition of MSW include such factors as: climate (wet or dry areas), frequency of collection, prevalence of home garbage grinders, social customs, per capita income, usage of packaged and preserved foods, degree of urbanisation, and industrialisation of the area.

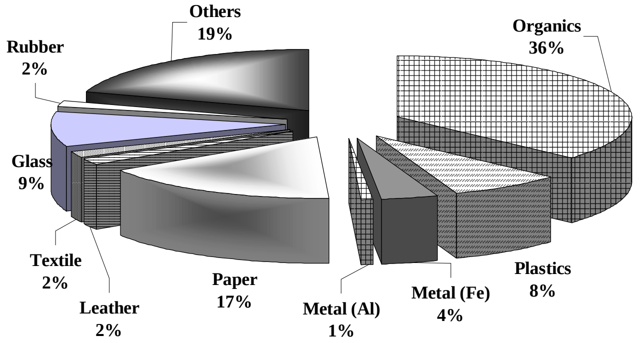

Figure 1. MSW composition in Belgrade

MSW is difficult to characterise because of the diversity of its components, many of which should not be "wasted". Due to the heterogeneity and variability of MSW it is necessary to carry out a statistically designed sampling survey by which the average quantities and composites of waste can be accurately estimated [3]. Figure 1 shows the composition of MSW in Yugoslavia [4, 5, 6, 7].

The density of MSW varies with waste composition (moisture and ash content) and the degree of compaction. Typical values, as shown in [5, 8], range from 100-300 kg/m^3 for uncompacted waste, 180-450 kg/m^3 in collection vehicle (compaction track), to 750-800 kg/m^3 for landfilled refuse. The moisture content of MSW varies from 15% to 40%, depending on the waste composition and the weather (temperature, humidity, and precipitation) (Table 1).

Table 1. Moisture and ash content of solid wastes

Component	Moisture, % mass		Ash, % mass
	range	typical	range or typical
MSW (as collected)			
Food wastes	50-80	70	5.0
Paper and cardboard	4-10	6	1.2-22.5
Plastic	1-4	2	0.5-4.4
Textile	6-15	10	6.5
Leather	8-12	10	9.0
Glass	1-4	2	96-99+
Cans, metals	2-4	3	94-99+
MSW (compacted)	15-40	25	n.a.

MSW contains about 50% volatile (combustible) matter, with roughly equal proportions of moisture and ash (inert) solids. Because of the volatile content, the amount of waste is often reduced by burning and heat produced is utilised as a means of disposal. Table 2 indicates typical energy contents (heat values) for various combustible materials, including uncompacted solid waste, which may have energy content from 9300 to 14100 kJ/kg.

Table 2. Typical energy content for combustible materials [4, 9]

Material	Typical energy content
MSW - per weight unit of refuse	10500 kJ/kg
MSW - per weight unit of combustibles	23200 kJ/kg
MSW - per weight unit of plastics	32800 kJ/kg
Primary sewage sludge	17700 kJ/kg of dry solids
Digested sewage sludge	9100 kJ/kg of dry solids
Lignite Kolubara (dry, pulverised -5+0)	16659 kJ/kg
Methane	49000 kJ/kg or 35880 kJ/m^3

Thus, energy content of MSW varies greatly depending on waste composition. Recent waste composition in developed countries has been characterised by growing ratios of paper and plastics, leading to much higher heat values than before. Higher heat values, however, are not always welcome. Some old incinerators, accepting waste with much higher heat values than their design specifications, are now experiencing difficulties during operation. When comparing MSW with other fuels, the energy required for shredding and classification of the refuse should be considered, as should the difference in operating efficiency between the incinerators and the other types of furnaces. As it is shown in [10], the energy required for shredding of the biomass depends on the way of grinding, and there are 75-240 kJ/kg of ground biomass (0.57-1.86% of the energy content).

The developing countries differ widely in their state of development and in their economic welfare. Nevertheless, they share in varying degrees a number of common problems: rapid population growth, urbanisation and overcrowding of large cities, poor transportation service, lack of planning, inadequate organisational and legislative provisions, and unsatisfactory public participation. Consequently, the solutions are needed in the following key issues [11]:

1. health and environmental protection at a level of cost that can be locally sustained,
2. development of systems based on local climate, physical, economic and social factors,
3. local production of efficient tools and equipment,
4. the achievement of high productivity of labour and the equipment,
5. education of the public,
6. vocational or professional training for mid-level and top management.

Solid Waste Management

Solid waste management comprises integrated systems for management of wastes, including waste reduction, collection, transport, recycling, energy recovery, treatment and disposal in the most economical way consistent with the protection of public health and the natural environment. The activities associated with management of solid wastes from the point of generation to the final disposal have been grouped into six functional elements identified in Figure 3 [7].

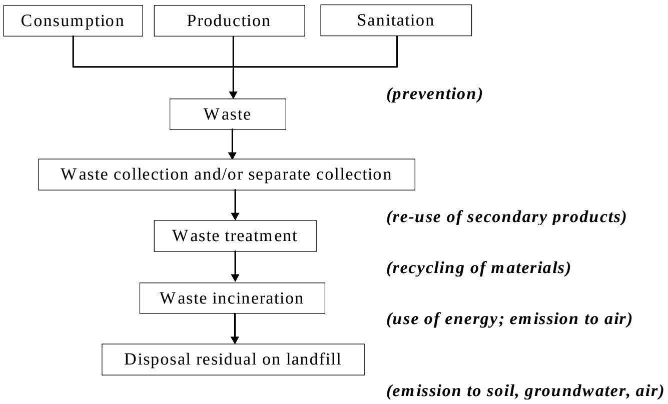

Figure 3. Waste management chain

The main elements of the waste management strategy are: use waste as a resource of secondary products, materials and energy (Figure 4); connect and control all steps of the waste disposal chain; make sure that at the end all of the non-reusable waste is correctly landfilled; minimize the risk of jeopardizing public health and environment; introduce the "polluter pays" principle.

The handling, storage and processing of solid wastes at the source before they are collected is the second of the six functional elements in the solid waste management system. Regulations in many countries now require separation of recyclable materials into components such as paper, aluminium, glass, and plastic, immediately at the source, by the resident. Source reduction is the highest-ranking component of the solid waste management because it represents means of reducing the economic costs and environmental impacts associated with waste handling. MSW may be processed on-site at residential, commercial, and industrial buildings to reduce waste volume and/or recover recyclable materials. MSW is collected in various ways, including door-to-door collection, station based collection, and fixed container-based collection. After source reduction, recycling is the most important practice within the MSW management hierarchy. Materials recovered from MSW can be reused as "resources" only where a market for them exists. However, material recovery facilities are independent plants performing one or all of the following functions: (•) the recovery of recyclables from source-separated or mixed MSW, and (•) the removal of contaminants from waste in order to prepare a clean feedstock for combustion or composting.

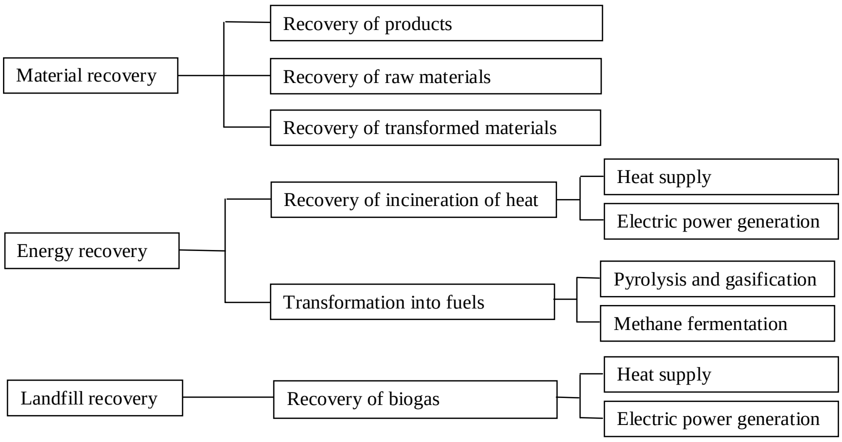

Figure 4. Types of resource recovery from wastes [5, 12]

Within an integrated waste management concept, modern energy-from-waste plants with state-of-the-art pollution control mechanisms are the major proven, safe and reliable options that can help closing the 'garbage gap' left over by other waste management techniques [8, 13, 14, 15]. On the average, MSW management in 18 countries in Europe, Japan and USA shows that approximately 30% of MSW is incinerated, 60% is placed in landfills, only 5% is composted, and the final 5% goes to material recycling.

MSW may be burned directly in incinerators (a process called mass-burning) or converted to more efficient residue-derived-fuel-RDF (prepared from previously shredded and separated MSW, and palletised into solid fuel particles). There are several types of incinerators in use but the most common are mobile-grate hearths (with roller-Dusseldorf grate, reciprocating-Volund grate, reverse reciprocating-Martin grate, rocker grate, or L-stocker), rotary kilns, fixed hearts, multiple hearths and fluidized beds [16, 17]. Rotary kilns, and fixed and multiple hearts are particularly well suited to solid, liquid, and gaseous industrial and hazardous wastes, preferably in "rotary kiln+post-combustion chamber" design when it can reach high or very sensitive (narrow) range of combustion temperatures (Figure 5) [18, 19, 20, 21, 22].

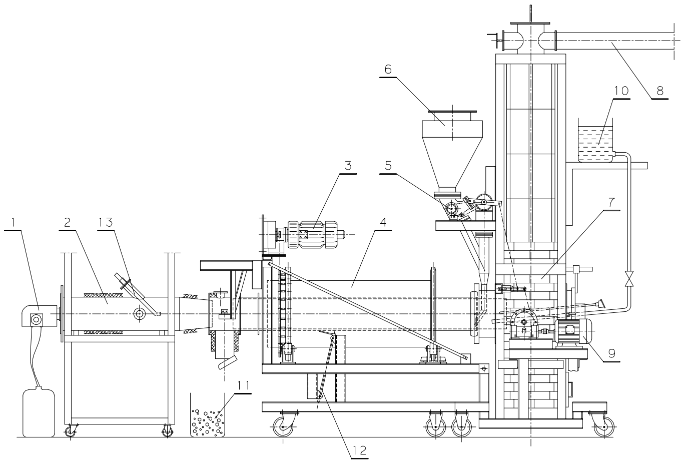

Figure 5. Rotary kiln facilities for solid and liquid waste destruction and material recovery built on Belgrade Faculty of Mechanical Engineering 1-burner, 2-mixing and combustion chamber, 3-electromotor for kiln rotation, 4-rotary kiln, 5-feeder, 6-solid waste hopper, 7-post-combustion chamber, 8-flue duct, 9-mechanism for waste feeding, 10-wastewater (liquid waste) tank, 11-slag (ash) outlet, 12-inclination adjuster, 13-cooling air

In order to be effective, incineration of MSW will depend on the optimisation of the four following parameters: temperature, residence time, oxygen availability, and turbulence. Energy recovery from MSW or RDF combustion is accomplished in either waterwall combustion chambers or in waste heat boilers (with superheater, evaporator and economiser). The study shows that the net electric output varies from 30% to 35%, but if the heat is also utilised then the efficiency can be raised by 2-3 times and so may be as high as 80%.

The most difficult problem associated with incineration is air pollution control, especially the removal of fine particulates and toxic gases (including dioxin). Pollutant emissions from MSW incinerators regulated in the Republic of Serbia include CO (50 mg/m^3), SOx (40 mg/m^3), NOx (70 mg/m^3), particulate matter (5 mg/m^3), heavy metals (from 0.05 mg/m^3 for Hg and Cd to 0.5 mg/m^3 for An, Pb, Cu, Cr and others), acid gases (10 mg/m^3 for HCl and 1 mg/m^3 for HF), and dioxins and furans (0.1 ng TEq/m^3) (at 0^{o}C, $1.013\cdot10^5$ Pa, dry gas, oxygen content of 11 or 17%) [22]. In order to fulfill the rules future MSW combustion plants will be provided with automatic continuos combustion and emission monitoring systems. Flue gases must be subjected to the following treatments [5, 23, 24]:

(•) cooling or heat recovery (dilution, gas/water cooling systems),

(•) dust separation (cyclones, multicyclones, electrostatic filters, baghouse filters, fabric filters, wet scrubbers),

(•) scrubbing (dechlorination, desulphurisation, removal of metals by dry, semi-dry, or wet processes),

(•) finishing treatments (deNOx reactors, activated carbon filters for PCDD/F and heavy metals),

(•) possible reheating and suction towards the stack.

A laboratory-scale fluidised-bed reactor (FBR) fuelled by synthetic waste was used to study the influences of the waste composition (moisture, ash, S, and Cl content), and combustion and flue gas process parameters on the formation of acid gases and their wet treatment [5, 25, 26]. When a FBR was operated with "good combustion practise", and a wet scrubber, with water solution of $Ca(OH)_2$ and NaOH (5% and 10% solution), near the optimal temperature for flue gas treatment (60-90^{0}C), results show that 98% of SOx and HCl can be captured in the one stage.

The bottom ash is frequently used as a roadbed material. Fly ash and other scrubber residues will increasingly have to be stabilised either by cold stabilisation and solidification with cement or by thermal processes such as vitrification [27]. Waste water from flue gas and fly ash wet scrubbing has to be treated, whether or not discharged at a later stage. Incinerator capital costs of about 200 million DEM per 1000 t of daily capacity (with flue gas treatment) and operating costs of 50 DEM per ton are typical. Unit costs for smaller centres are much greater, so that the use of incinerators is limited to large cities [16]. As a conclusion, even though MSW is a dirty fuel, the clean technologies required by European regulations or equivalent ensure that the emissions will be lower than most conventional combustion technologies with much cleaner fuels [28, 29].

Besides combustion, thermochemical processes for waste utilisation include pyrolysis and gasification, which begins to gain acceptance, especially in the Netherlands, Germany and Switzerland [30, 31, 32]. The reaction kinetics of the gasification process are quite complex and still the subject of considerable debate. Theoretical calculations of the waste thermal reaction equilibrium are applied for understanding of the course and intensity changes of process parameters (e.g. product composition) with variation of other parameters [16, 33].

Anaerobic technique is the process used for production of methane from solid wastes, which include both reactor fermentation and fermentation in bioreactor cells constructed in landfills. Biological waste treatment can include composting of mixed or source-separated wastes, anaerobic reactor fermentation, or fermentation in bioreactors constructed in landfills.

A landfill bioreactor cell consists of a wall defined unit, with a separate gas collection system consisting of horizontal drains, and a separate collection system for leachates. The bottom of the cells should be covered with a layer of low permeability (clay, bentonite, plastic liners). The size of the reactor cells depends on the total amount of waste treated per day. As a rule, one reactor cell should be filled within two years. Most of the methane will be extracted during a 10-15 year period. The total yield of biogas extracted from a reactor cell has been estimated to approximately 200-250 m^3 per tonne of treated waste, or about 15-20 m^3 of biogas per tone of waste per year, with the heat content of about 20000 kJ/m^3. After the removal of trace components, biogas can be used to fuel internal combustion engines that drive electricity generators. Landfill reactor cells are net sinks for organic carbon and thus play an essential role in confronting increased CO_2 concentration in the atmosphere [34, 35].

Landfilling involves the controlled disposal of non-recyclable solid wastes on or in the upper layer of the earth's mantle. This method aimed at distinguishing it from the typical unsanitary open dump, is mostly used in developing countries. The area needed for landfilling of MSW is about 1 ha/yr for every 25000 people, and the volume may be calculated by the equation's given in [36]. Important criteria in the implementation of sanitary landfills include site selection, landfilling methods and operations (compacting, covering), occurrence of gases and leachate in landfills, movement and control of landfill gases and leachate, and landfill design (Figure 6) [5, 8, 36].

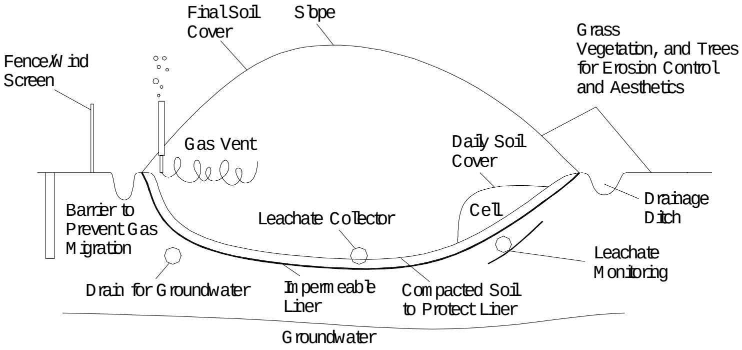

Figure 6. Cross section through a sanitary landfill

The use of the three-component system for the determination of the characteristics of the process of burning of low-value fuels and MSW

In designing the processes and equipment for burning MSW, diagram " $W^r - A^r - (COMB)^r$ " is frequently used (Figure 7). Basing upon this diagram, the area in which the waste can freely burn without the need for using additional fuels (liquid or gaseous), or for enriching the combustion air with the technical oxygen can be determined.

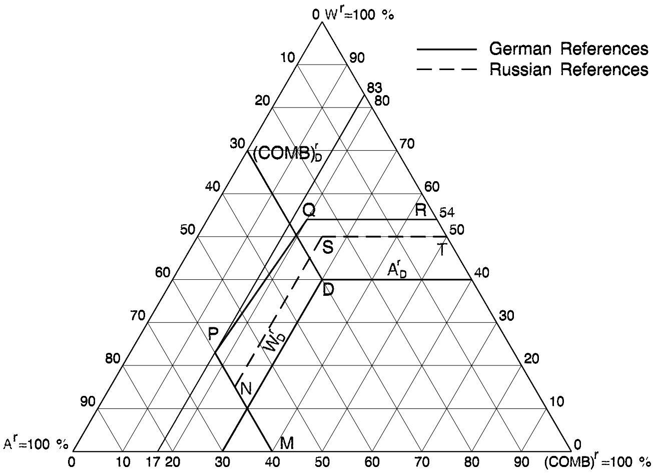

Figure 7. Diagram " $W^r - A^r - (COMB)^r$ "

According to the German reference literature, MSW can burn autothermally if the mass contents of the moisture (W^r) and ash (A^r) correspond to the composition inside the area defined by the apices M, P, Q, R and $(COMB)^r$, while according to the Russian literature, they correspond to the area defined by the apices M, N, S, T and $(COMB)^r$ (Figure 7). Theoretical and experimental investigations [37, 38, 39] (combustion of the waste with structure M_1 in Figure 7) have shown that the region of the autothermal waste combustion can also be outside polygon $MPQR(COMB)^r$.

In order to define the area of the autothermal burning in the three-component system diagram, it is necessary to derive an analytical expression for the theoretical temperature of combustion. Figure 8 gives the constant temperature of combustion lines $t^r = 900^0 C$ at $\lambda = 1.0$, to the corresponding values of the quantity – a, for the waste of the composition $\mathrm{C}^g = 47.33\%$, $\mathrm{H}^g = 6.53\%$, $\mathrm{O}^g = 45.55\%$, $\mathrm{N}^g = 0.14\%$, $\mathrm{Cl}^g = 0.15\%$, $\mathrm{S}^g = 0.30\%$, $\mathrm{F}^g = 0\%$, $\mathrm{W}^g = 0\%$, $\mathrm{A}^g = 0\%$.

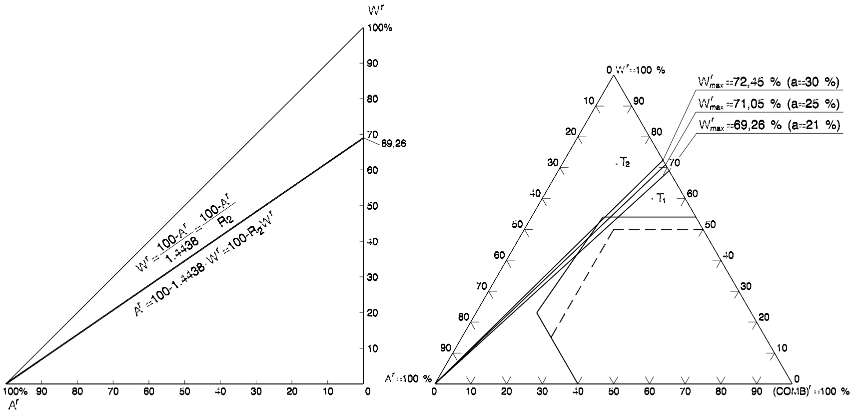

Figure 8. The constant temperature of combustion lines $t^r = 900^0 C$ for paper with coatings

If the mass content of the moisture and ash in the waste corresponds to point $T_1(\mathrm{W}^r + \mathrm{A}^r = 70\%)$, the waste will burn autothermally, whereas in the case of the mass content of the moisture and ash of $\mathrm{W}^r + \mathrm{A}^r = 85\%$ (point T_2, Figure 1.2), in order to rech the temperature of 900^{0}C in the furnace it will certainly be necessary to add fuel even in the case of enriching the air by using technical oxygen up to $a = 30\%$.

The diagram in Figure 8 shows that in burning highly moist fuels – $(\mathrm{W}^r)_{max} = 70 - 75\%$ the liquid oxygen adds little to moving the boundary values of the part of the moisture of (W^r_{max}) at a given temperature. For these cases of burning the problem is solved with the application of the procedure of recirculation of the heat quantity [39, 40].

The lines of the constant heating value in diagram "$\mathrm{W}^r - \mathrm{A}^r - (COMB)^r$" can be used in the corresponding analyses of the volume and temperature of the burning products, particularly in the cases where the structure of the basic waste component with no moisture and ash (e.g., in the case of paper and plastics) varies, and, in addition to that, if the mass content of the moisture and ash in the components is variable.

Figure 9 shows the lines $t^r = const.$ and $H_d^r = const.$ for two waste components: paper with coatings and plastics. The manner of analysis of this kind offers the possibility of determining the areas of the autothermal burning of waste with the minimal value of the low heating value. Point A shows, that, for instance, the plastics of the low heating value $H_d^r = 2000\text{kJ/kg}$ (with the corresponding content of W^r and A^r) can, at $a = 21\%$ and $\lambda = 1.0$ burn autothermally at the theoretical temperature of 1400^0C.

The reference literature data [41] indicate that the minimum value of the low heating value that is sufficient for the autothermal burning at $t^r = 900^0\text{C}$ amounts to about 3000kJ/kg. During the research [37], the waste materials with the lower heat power were burning autothermally at about 2000kJ/kg.

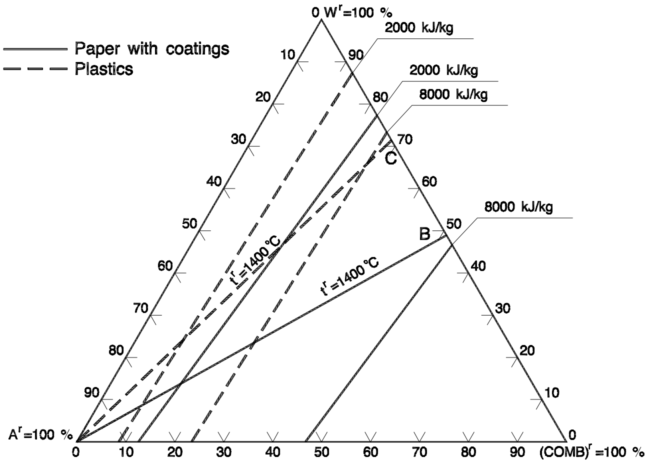

Figure 9. The lines of the constant temperature of combustion ($\lambda = 1.0; a = 21\%$) and the lines of the constant low heating value

The lines of the constant volume of the burning products in diagram "$\mathrm{W}^r - \mathrm{A}^r - (COMB)^r$" can be useful in the analyses of heat exchange, problems of the emissions of the solid particles from the furnace, and loading the equipment for separating solid, liquid and gaseous pollution components from the flue gases.

Figure 10 shows the lines of the constant volume of the combustion products for coated paper and plastics. At $\mathrm{W}^r = 0$ and $\mathrm{A}^r = 40\% = 0.4\text{kg/kg}$ (point A) the volume of the combustion products is: plastics - $V_{rw}^r = 3.7\text{m}^3\text{/kg}$, coated paper - $V_{rw}^r = 2.0\text{m}^3\text{/kg}$.

From the viewpoint of the analysis of the processes of combustion waste and low value fuels and the analysis of the process of purifying the flue gases, it is also necessary to calculate the flue gases volume per unit of the heat quantity imported with the waste into the furnace (Figure 11). The quantity $(V_{rw}^s)^r$ is the volume of the moist products of burning the working fuel (waste) per heat of 10^3kJ imported with the working fuel into the furnace.

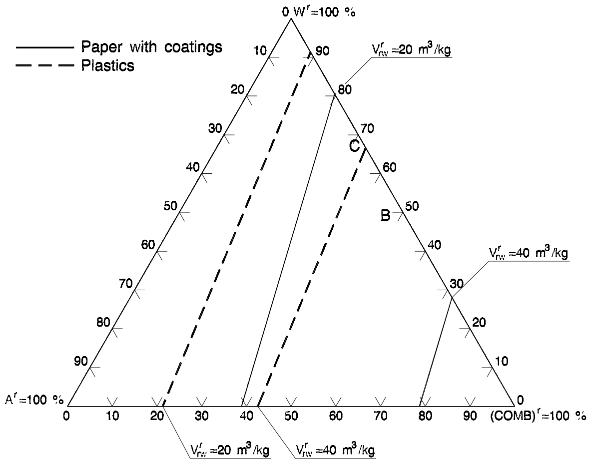

Figure 10. The lines of the constant volume of the burning products ($\lambda = 1.0; a = 21\%$)

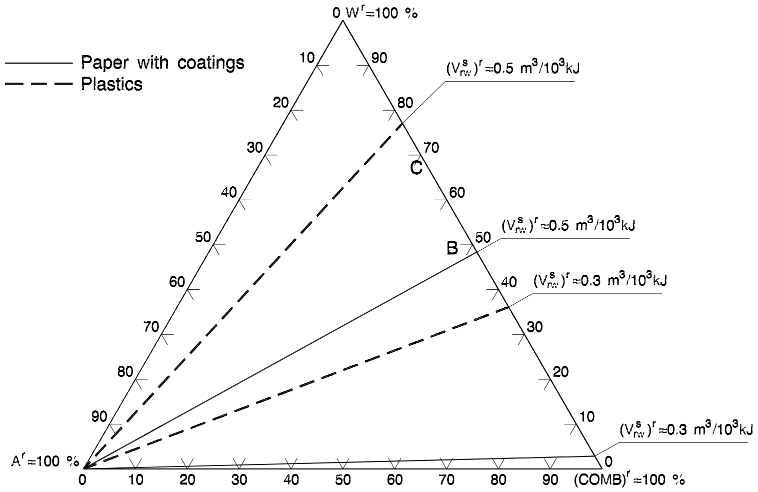

Figure 11. The lines of the constant volume of the burning products

In addition to the representation of the lines mentioned (t^r, H_d^r, V_{rw}^r), diagram "$W^r - A^r - (COMB)^r$" also offers the possibility of constructing other lines that characterise the suitability of the waste as a fuel, (e.g., the constant working capability line, the line of the heat loss in the discharged gases), which shows a prominent degradation of the waste potential as a fuel, due to the corresponding large content of moisture in the waste.

Conclusion

In our country modern waste management policies and the practice are in the early stage. The evaluation of waste management options can be undertaken in a number of different ways (financial costs, revenues, environmental effectiveness). As it is described in [20], multicriteria evaluation of six waste disposal options (landfill, incineration and RDF, each with and without recycling) resulted in RDF with recycling as the best option. Nevertheless, experience in the fields of combustion of solid fuels, transport and the use of produced electric and heat energy, and raw material treatments represent an important base for fitting of the existing equipment and for building of contemporary equipment for collecting, classification, transformation, incineration and composting of MSW.

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