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HOUSEHOLD WASTE MANAGEMENT. THE EUROPEAN EXPERIENCE

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The actual state of the household waste management is analyzed in the monograph. The characteristics and classification of waste are considered. The modern systems of household waste collection, transportation and disposal are analyzed. The schemes and technologies of household waste utilization and recycling are investigated. The scientifically based recommendations for solving the problem of household waste are proposed with account of the European experience.

The monograph will be useful for students in environmental studies, for specialist and experts in environmental protection and communal service, as well as for experts of research organizations.

У 67 **Управління та поводження з твердими побутовими відходами. Європейський досвід** (англійською мовою) / В.Г. Петрук, Ф. Сталдер, В.А. Іщенко, І.В. Васильківський, Р.В. Петрук, П.М. Турчик, С.М. Кватернюк, М.І. Ширнін, В.В. Воловодюк. – Вінниця: ТОВ «Нілан-ЛТД», 2016. – 184 с.

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У монографії проаналізовано сучасний стан управління та поводження з твердими побутовими відходами. Розглянута характеристика і класифікація відходів. Проаналізовано сучасні системи збирання, транспортування і розміщення відходів. Досліджено схеми і технології утилізації і рециклінгу побутових відходів. Запропоновані науково обґрунтовані рекомендації для вирішення проблеми побутових відходів із врахуванням європейського досвіду.

Монографія буде корисною для студентів екологічних спеціальностей, для спеціалістів та експертів з охорони навколишнього середовища та комунальних служб, а також для науковців.

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INTRODUCTION

The problem of household waste is actual and fairly acute for Ukraine. Volume of waste generation increases and its considerable part is accumulated at landfills and waste dump sites, which are placed, designed and maintained not in appropriate way. This has a consequence of negative impact on environment and human health. The coverage by a service of waste collection in many municipalities is insufficient, which leads to unallowed waste disposal and to negative impact connected to it. Current activities for waste generation decreasing and increasing of waste processing are poorly coordinated and they are not effective. The initiatives directed on the situation improvement should provide optimal use of available deficit financial resources and development in a direction, aimed not only on a compliance with requirements of possible future national regulatory documents and EU Right “Acquis Communautaire”, considering the purpose of Ukraine to join the EU. National strategy for household waste management provides complex base for development of household waste management system in Ukraine in a long-term prospect. This strategy will direct regions and municipalities of Ukraine in sustainable development of technical, institutional, regulatory and financial aspects of their household waste management systems, considering both national and EU legislation.

The main goal of National household waste management strategy is decreasing the generation and negative impact of all household waste types, as well as assistance for development in Ukraine the sustainable, clean and prosperous urban centres and villages. For achievement this purpose, the National household waste management strategy provides the improvement and development of household waste management system in the country. One aspect of National household waste management strategy is encouragement system creation for national and local authorities participation in the investment projects with benefits for all stakeholders. Preparing the joint roadmap for household waste management will conduce to union and coordination of all stakeholders. Therefore it will conduce to effective use of available resources and final solving of household waste problem in Ukraine.

Development of optimal waste collection, processing and utilization schemes is the main task when solving the household waste problem. Household waste landfilling is enforced and temporary measure, which does not solve the problem. Gradual replacing the landfilling by industrial processing is a basis for solution of household waste problem in world practice.

The actual state of household waste management is analysed in this book. The characteristics and classification of waste are considered. The modern systems of household waste collection, transportation and processing are analysed. The schemes and technologies of household waste utilization and re-use are investigated on the basis of available European experience.

The book is useful to students and post-graduates of ecological and heat power specialities, specialists of communal services, specialists of environment protection and researcher.

The actual data, tables, figures and formulas give the possibility to future specialists to organise their activity, taking into account understanding and logic interpretation of technological bases of household waste processing in Ukraine.

The authors will be grateful for all critical remarks and recommendations for further technological bases development of modern waste processing methods and profound research of technological aspects of the actual household waste problem for all regions of Ukraine.

The materials of this book are prepared by authors according to chapters: V. Petruk (introduction, chapters 1 and 5), F. Stalder (chapter 6), V. Ishchenko (chapter 5), I. Vasylkivskyi (chapter 2), R. Petruk (chapter 4), P. Turchyk (chapter 3), M. Shyrnin (chapter 1).

CHAPTER 1
ORGANIZATION OF HOUSEHOLD WASTE MANAGEMENT SYSTEM

1.1 Legal and regulatory structure of waste management

The legal and regulatory base, established in Ukraine to regulate legal relations in the field of household waste management, includes such basic laws and regulations:

Law of Ukraine **«About a waste»** (3/5/1998, with further changes);

Law of Ukraine **«About environment protection»** (6/25/1991, with further changes);

Law of Ukraine **«About maintenance of sanitary and epidemic well-being of the population»** (2/24/1994, with further changes**)**.

Despite the fact that household waste problem is socially more important than industrial waste problem, currently there is a legislative gap: the Law of Ukraine "About a waste" does not provide an effective system of household waste management, because it does not provide a clear mechanism for solving the problem, including the introduction of modern effective technologies of household waste processing. Besides, local authorities do not fully comply with the Law. Considering this fact, it is planned to work out the law project "About a household waste". It is expected that the law project will include a mechanism for solving the household waste problem by implementation of modern cost-effective technologies for household waste management. It also will include stimulation measures to attract investments (and consequently reduce budget costs for this area) and optimize the operation costs spending for waste management services.

The current Law of Ukraine "About a waste" involves the offences for which disciplinary, administrative, civil or criminal liability is imposed. In particular, the Code of Ukraine on Administrative offences involves administrative liability in the investigated area. Namely: rules violation of waste generation, storage, disposal, transportation, recycling, demolition and use (Article 32) is punished by a fine of 1 to 5 non-taxable minimums for citizens and 5 to 8 non-taxable minimums for officials. Hiding, distortion or failure to provide complete and accurate information on the requests of officials and public appeals about safety of waste generation and management (Article 32, note 3) is punished by a fine of 3 to 5 non-taxable minimums for officials.

According to the Law of Ukraine **"About a waste"** (Article 37, entitled "Control and supervision in the field of waste management"), state control and supervision is provided by authorized central executive body in the field of waste management (Ministry of Environmental Protection of Ukraine). Supervision of compliance with laws on waste management is provided by general prosecutor of Ukraine and subordinated prosecutors within the powers according to the law. Public control in the field of waste management is provided by public inspectors of environmental protection in accordance with applicable law.

"National Household Waste Management Strategy in Ukraine" (August, 2004) was developed by Ukrainian authority and Danish consulting company

COWI in cooperation with Ukrainian experts. Strategy development was financed by Danish Agency of Environmental Protection. The main goal of the National household waste management strategy in Ukraine is to reduce the generation volume and the negative impact of all household waste types, as well as to ensure sustainable development and cleanliness of Ukrainian towns and people's health. The strategy will help create an adequate approach to the development and improvement of household waste management system in Ukraine. The Strategy will make a contribution to integration and coordination of stakeholders activities. Therefore, it will conduce to the efficient use of all available resources.

The state building Standard of Ukraine "Landfills" (B.2.4-2-2005). The standard is relevant for landfill designing, reconstruction, technical re-equipment and recultivation. Standard is obligatory for application by authorities, customers (investors), project designers, contractors, other legal or physical persons, which are the subjects of enterprise activity in building regardless of ownership form.

Besides national laws and regulations there are regulations at the regional and local level in the field of waste management. For example, **the Law of Ukraine "About local government in Ukraine"**, which provides the powers of local authorities in the field of integrated waste management.

EU Directives in the field of waste management are arranged in four groups (Table 1.1). **Directive on waste (75/442/EEC)** includes basic principles of waste management in the EU. This Directive states the requirements for all types if they are not specifically regulated by other directives. Another part of the framework legislation on waste is **Directive on hazardous waste**, which determines the conditions of hazardous waste management, recycling and proper removal.

1.2 Basics of waste management system in municipalities

Historically, liquid and gaseous wastes (industrial water and air pollution) were always more visible and they were controlled and regulated primarily, while solid waste one could always take away or transfer it to landfill (that is simply remove in any way). Waste was often dumped into a sea in coastal settlements. Negative environmental consequences of such waste management (groundwater and soil pollution) sometimes appear after few years or even decades and they are very destructive.

That is why local authorities have to create waste management system in order to avoid the uncontrolled waste distribution in environment. Any waste management system consists of three subsystems: collection, transportation and processing.

Waste collection system involves sites for household waste collection. There are usually container sites with containers of 0.75-0.8 cubic meters capacity in Ukraine.

In the EU the system of separate waste collection is actively implemented, when people sort a waste in separate containers for glass, paper and others. In some countries waste is collected in bags made of a special plastic, which is destroyed after six months without polluting the environment.

Table 1.1. EU Directives in the field of waste management

Particular types of waste	**Framework legislation on waste management**	**Transportation, import and export of waste**	**Objects of processing and recycling**
Waste oils (75/439/EEC)	Waste Framework Directive (2008/98/EC)	Regulation 259/93 on the supervision and control of shipments of waste within, into and out of the European Community	Waste incineration (2000/76/EEC)
Titanium dioxide industrial waste (78/176/EEC)	Directive on hazardous waste (91/689/EEC)	Waste Shipment Regulation (1030/2006/EC)	Landfill of waste (99/31/EEC)
Sewage sludge (86/278/EEC)			Integrated Pollution Prevention and Control (96/61/EEC) (applied to some operations of recycling and removal)
Batteries and accumulators (06/1013/EC)			Industrial Emissions Directive (2010/75/EU)
Packaging and packaging waste (94/62/EC)			
Polychlorinated biphenyls and polychlorinated terphenyls (96/59/EC)			
Ship-generated waste and cargo residues (2000/59/EC)			
Waste electrical and electronic equipment (2000/95/EC)			
End of Life Vehicles Directive (00/53/EC)			
Restriction of Hazardous Substances Directive (11/65/EU)			
Waste Electrical and Electronic Equipment Directive (12/19/EU)			
Mining waste directive (2006/21/EC)			

The transportation system involves using of specially equipped vehicles to transport the waste to sites of processing and disposal.

The waste processing system consists of facilities where waste is processed for neutralization and volume reduction. Most waste in many countries is landfilled. Some part of waste is incinerated, organic waste is processed in some countries to compost, and some part of waste is recycled.

When developing the waste management schemes one has to take into account different interrelated aspects: continuous growth of household waste volume both in absolute values and per capita; change of household waste morphological structure and its continuous getting more complex due to hazardous components; negative people's attitude to the traditional methods of landfilling; rigidity of waste management legislative base adopted at all levels; development of new waste processing technologies, including modern systems of waste separation, incineration, composting; rise of costs for waste processing.

At the first stage of waste management scheme development one should specify morphological composition of different waste, analyze the existing waste management system, determine its advantages and disadvantages, identify funding sources, assess the legal basis of the entire system.

The positive situation in financial, organizational and social spheres helps to achieve the success on all the stages of waste management. In the case of negative situation in all of these spheres, the only possible consequence can be negative waste management, which often causes damage to the environment. In this case, significant additional costs will be required in the future to eliminate the consequences. For example, high-level payment for waste disposal at landfills in the 1990's caused the appearance of so-called unalloweded waste dump sites.

At the second stage of waste management scheme development the legislative and regulatory documents are analyzed, the direction of their correction is determined, taking into account the economic conditions in the municipality. The scheme of document processing is developed, the levels of centralization of the system as a whole and for each of its units are determined, the work scheme is improved. Then the functions of each organization involved in the waste management, its location and subordination are determined. The rules for data exchange between organizations are developed.

The third stage involves the technical aspects of waste management system creation. These are analysis and comparison of technologies for waste collection, transportation and processing with economic and environmental criteria. The results are used for choosing the most appropriate technical solutions for each case. Very important in this case are choose of sanitation facilities placing, route definition and transport schedule.

By the results of second and third stages of the scheme development, the cost calculation and the action plan to implement the waste management system are worked out.

The fourth stage includes consideration of possibilities to finance the waste management system. Modern efficient methods, including the use of modern garbage trucks, high-performance equipment for incineration and gas purification at plants as well as landfills equipping, require considerable costs. At the same time no one municipality in Ukraine has a balanced budget for waste management. There are no financial resources for investment. Therefore, for successful implementation of the developed waste management system it should be financed by several sources, including: the municipality budget, people (as waste producer), bank credits and international credits.

At the final stage the possibilities (capacities) of above mentioned funding sources are analyzed and the most perspective one have to be chosen. Also the payment approach of local authorities is determined.

The waste management system can not be developed once for all the country. It is developed and reconsidered in average every five years for each municipality or region, taking into account the geographical location, economical and social conditions.

The scheme is previously reviewed, approved and then implemented according to the plan.

Till now, in almost all countries a significant volume of household waste is landfilled. Disposal of household waste at landfills requires alienation of large land areas and high transportation costs. In the case of landfilling the useful components (in a waste stream) are lost and environment deterioration risk appears. The conditions for infection spreading and fire extension at the sites of waste disposal are created. The scheme of negative landfills impact on the environment is shown in Fig. 1.1.

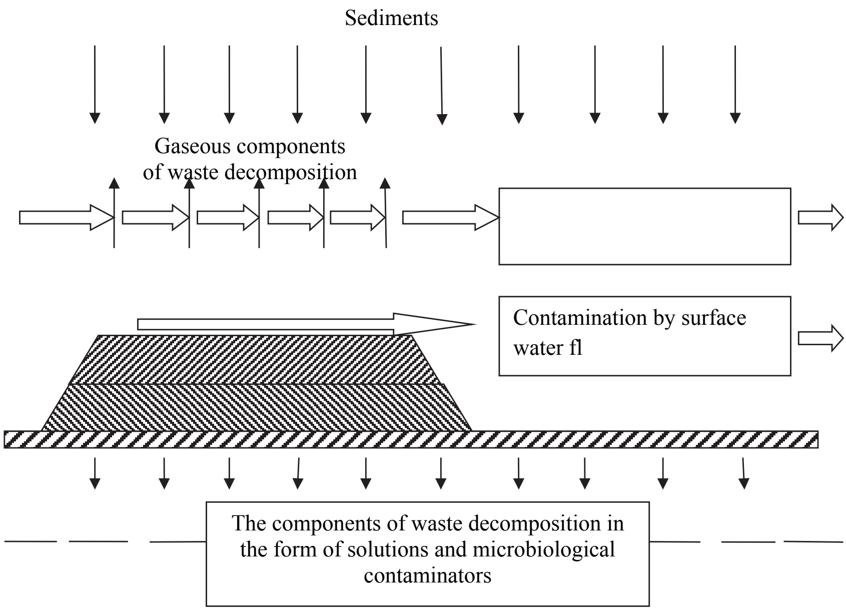


Figure 1.1. Landfill influence on environment

Therefore, waste is directed to industrial processing to solve the waste problems. Next methods of household waste industrial processing are applied: thermal processing (mostly incineration); bio-thermal aerobic composting (producing a fertilizer or biofuel); anaerobic fermentation (producing a biogas); separation (taking useful components for their reuse); complex processing (producing the products and energy from recycled materials).

Thermal processing of household waste (mostly incineration) is the most common and technically worked out method for industrial waste processing. In Europe about 25% of household waste is incinerated. The advantages of this method are as follows: reduce of waste volume up to 10 times, the possibility of heat recovery, and reduce of ground water or soil contamination risks by waste. The disadvantages are as follows: risk of air pollution, loss of valuable components, high ash and slag volumes, low recovery efficiency of ferrous metals from a slag and complexity of combustion process stabilization.

Biothermal aerobic composting (biochemical decomposition of organic part of household waste by microorganisms) is the second (by the prevalence) industrial method of household waste processing. At the first composting plants unseparated household waste were composted and, as a result, the final compost usually was of low quality, contaminated with heavy metals and did not find any application.

Anaerobic fermentation with producing the biogas, generated due to decomposition of organic waste, is the third method of industrial processing of household waste. There are numbers of installations to produce methane directly at landfills in US. In Germany and Japan biogas is produced from organic part of household waste, which is separated at special plants. Anaerobic fermentation is used in the cases of practical biogas necessity.

Household waste separation for recycling the valuable components is used since the 1960's. In different countries waste is separated at households by people or at waste separation plants. Separation as an independent operation does not solve the problem of sanitation and it is not the optimal method of household waste processing, because obtained components, except metals, are hard to implement and special facilities for their processing are necessary to establish.

According to experts, modern ecological and economic requirements are mitigated by complex processing of household waste, which includes a combination of separation processes, thermal and biological waste treatment. Very important in this case is separation, which changes the qualitative and quantitative composition of the waste, almost twice reduces the waste volume directed to incineration and composting, accelerates the composting process and improves its quality, stabilizes thermal processes and reduces gaseous emissions of harmful substances. The economic parameters of household waste processing technologies are given in the Table 1.2.

Table 1.2. Estimated economic parameters of different technologies for processing of household waste, USD per 1 ton.

Parameter	Technology						
	Landfilling	Incineration	Composting	Separation	Separation + Incineration	Separation + Composting	Complex processing
Investments	47	280	90	50	330	100	240
Operational costs	30	9,6	10	3,2	12,8	8,7	13,5
Part of unrecycled waste that have to be landfilled, %	100	30	30	95	15	55	8

The example of household waste management system in the Netherlands, based on complex processing (separation, thermal and biothermal processing, landfilling the minimal volume of non-recycled waste) is shown in Fig. 1.2.

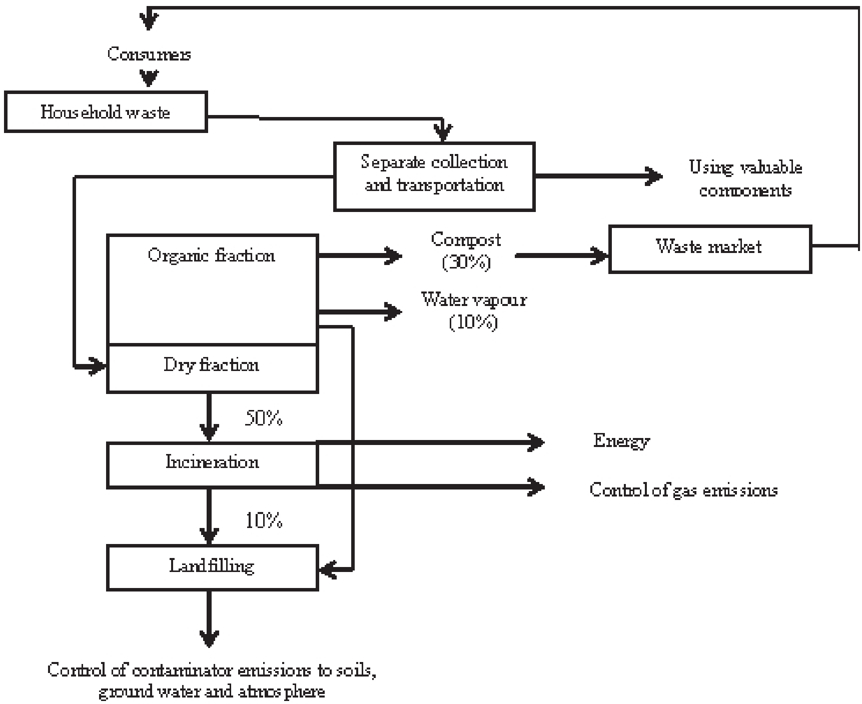


Figure 1.2. The scheme of household waste management in the Netherlands

1.3 The actual state of household waste management in Ukraine

Active movement and integration to the Europe Community recently is declared in Ukraine. But one of the requirements to achieve this is creating an effective system of waste sorting. Currently such a system does not exist.

Within the actual law on waste in Ukraine from January 1, 2018 the disposal of unsorted waste and toxic or harmful waste will be prohibited. The consequence of this law is a ban on usual landfills operation and their closure, which will increase the relevance of waste problem. Some local authorities prepare themselves in advance to these changes and do the preparatory work, creating the basis for waste sorting, plan budget funds and involve experts and scientists in the work, but others neglect due to lack of funds and experience.

It is well known that one of the factors slowing down the introduction of advanced recycling and waste management technologies is a low level of understanding of the waste problem relevance by people. Also, the inertia of this process is increased by insufficient funding, unwillingness to change, incorrect tariff policy, inadequate legislation.

However, there are examples of progressive implementation of urban development programs in the field of waste management in Ukraine.

One important stage of the waste management concept development is collection of detailed information on the current state of the problem. Figure 1.3 shows the areas of information collection for next developing the mechanisms of the existing system improvement and designing the effective concept of waste management.

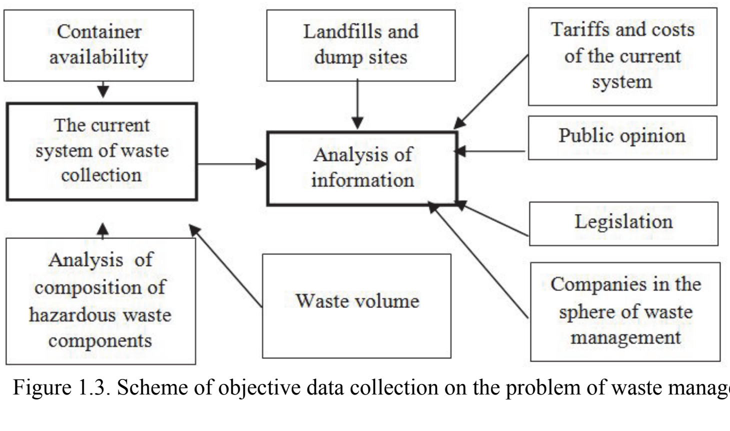


Figure 1.3. Scheme of objective data collection on the problem of waste management

The periodic waste collection is provided in only about 20% of the Ukrainian municipalities. Other territories are not covered by systematically waste collection. This causes a large amount of waste dump sites in unsettled areas.

Generally, the system of household waste management in Ukraine actually presented only by transportation the waste to landfills or dump sites. Sometimes even such a service is not provided.

The landfills analysis in Ukraine shows:

- state of most landfills is unsatisfactory, a lot of them do not meet the specified requirements and need to develop the measures for improving their conditions and to meet the requirements;

- average percentage of landfills fullness is about 25%, which allow to use them for a long time, but usually the biggest landfills and waste dump sites in district and regional centres are filled much more – about 80%. This fact requires immediate actions;

- average term of landfills usage is about 20 years and according to landfill passports they can be used for another 20-30 years. However, some biggest landfills are used for 40-60 years, which exceeds projected term of use and requires their immediate closure;

- the majority of landfills have an area of about 0.5-1 hectares, but some have an area of 3-5 hectares, which shows the high rate of their filling or long term of use, and therefore they require increased controlling;

- the limit exceeding of pollutants concentration is observed in soils near landfills.

Analysis of the waste management system in Ukraine shows the following key shortcomings:

- insufficient quantity of containers for waste collection (even in municipalities where waste is collected, very often there are no containers);

- a lot of communities are not covered by household waste management system;

- the lack of specialized vehicles for waste transportation in many communities (available only in larger districts centres), very high (80%) vehicles depreciation;

- very limited resources for development of household waste management infrastructure;

- producers focusing on their own economic interests associated with increased profits, and insufficient attention to the waste problem;

- very slow implementation of economic instruments to attract household waste recycling, lack of elaborated mechanisms for their application;

- inconsistency of main directions of household waste management policy at different governance levels;

- uncertainty and merger of appropriate organizations functions at regional, district or local level in household waste management;

- limited interaction between municipalities, small scale of resolved issues, which do not help to solve the waste problem as a whole;

- insufficient, incomplete, no real time information about qualitative and quantitative parameters of household waste management.

It should be noted that separate household waste collection is introduced only fragmentally and general system does not exist.

The problem of hazardous waste as household waste type is solved very slowly and their separate collection occurs only in a few places.

Legislation in household waste management at the national and regional levels as a whole is sufficient. There are accepted and valid national and regional programs of household waste management. However, the main problem is the lack of effective mechanisms of implementing the programs thesis at all levels.

Currently there are several bills pending in Parliament, regarding public commitment to sign contracts for waste management. Their adoption would give a significant impulse to solve the waste problem.

Contact with people during waste management has a very small scale. Mostly people do not have any information about problems, which can occur in the case of improper waste management and the possible solutions. Solving this issue could be the key to the future introduction of effective household waste management system.

The responsibilities and powers in household waste management sphere currently are transferred to the local level by legislation. At the same time, local authorities have very limited economic possibilities for the implementation of these powers. Most of the rural areas are not covered by any system of household waste management and many rural communities have no possibility to create their own system. Thus we have very difficult situation for local communities and local authorities in rural areas. It requires immediate actions by communities and local authorities to develop joint local plans of household waste management, the involvement and the effective use of all possible resources to create sustainable models of household waste management. This is only possible by combining the resources of communities, including inter-municipal cooperation.

General recommendations for environmental safety concept of Ukraine in the household waste management sphere are as follows.

1. The current system of household waste management in Ukraine is presented only by disposal at landfills and waste dump sites and needs radical change and improvement.

2. All state institutions, involved in household waste management, as well as the media have to conduct explanatory and educational activities regarding household waste management, in particular: releasing of promotional and educational leaflets, books, brochures; significantly increasing the quantity and quality of broadcasts on environmental issues, including those dedicated to the household waste problem; conducting the explanatory work in kindergartens, schools and other crowded places to inform people and for fundamental changing people conscience from the post-Soviet to ecological.

3. Focusing on the ideas of sustainable development during contacting with people: necessity of self-limiting, greening of life, transition from the harmful and dangerous technologies to modern and resource-saving eco-technologies, proper waste management (for public environmental organizations, students, environmentalists and others).

4. Sorting the household waste at first stage of their generation at houses or at the container places, as well as increased responsibility for the waste disposal in unauthorized places and other requirements of non-compliance with legislation in waste management.

5. Careful considering of all relevant environmental, buildings and sanitary norms and regulations during the development and implementation of new landfills.

6. Working out a clear scheme of maximally effective using of existing waste sorting stations, accounting the interests of local communities throughout whole Ukraine (for relevant state organizations and local authorities).

7. Considering the options of attracting the investments to solve the household waste problem (for state and local authorities).

8. Revising the tariffs for household waste management, because their low level does not allow to solve the waste problem.

9. Increasing the quantity of places where used materials are accepted and solving the problem of hazardous household waste separate collection.

10. Creating the eco-coordination centre of household waste management based on the working group and relevant experts, representatives of companies, local authorities and the public.

CHAPTER 2
HOUSEHOLD WASTE GENERATION, COLLECTION AND TRANSPORTATION

One of the most pressing and unsolved issues in most Ukrainian municipalities is the household waste management and the elimination of municipal landfills as significant sources of air, surface and underground pollution.

Although municipal landfills are usually situated outside the settlement, a lot of people responsible for ensuring the normal environmental conditions are not realize the danger of this waste.

For some reasons, this problem is not of first importance and its solving is postponed to a certain time.

Studies in many countries have shown that household waste collected in town/village and disposed at landfills negatively affects the same town/village through birds, animals, air flows. In other words, landfills do not improve the ecological situation in the town/village. Thus, landfills elimination problem must be solved everywhere and immediately, because there is trend to a constant expansion of its influence on the environmental conditions in populated areas.

Ukraine, as country with great population, needs urgent practical measures for solving the household waste problem. Only 2.5% of collected waste is processed. Every year large areas are allocated for additional landfills, while existing ones are overfilled. According to experts, now over 65 billion tons of waste is accumulated at landfills. This is a huge environmental hazard to municipalities. However, because of the different views on solving the problem in each region, sometimes not approved either theoretically or by available experience, the problem of household waste management and landfills elimination is not solved.

At the same time, household waste is a fuel. When world reserves of fossil fuels are depleted, and energy consumption in industry, urban and rural households grows rapidly, the priority tasks are identification of various alternative and renewable fuel resources and ensuring of their effective use. Therefore, the use of combustible waste as a fuel, including that of significantly impaired quality, will enable to replace fossil fuels (where it is possible), as well as enable to ensure their substantial savings. It should not be forgotten that the use of low quality household waste as fuel forms several problems, the most important among them is environment protection from pollution. Therefore, the industrial use of household waste should satisfy two important conditions:

- technological process must be zero-waste as much as possible, because if valuable materials (metal, slag, ash, broken glass, construction waste, etc.) will be transported to landfill again, the sources of pollution will still remain;
- the process of waste recycling and products obtaining must be harmless and suitable for use.

2.1 Volumes of household waste generation

Currently, each inhabitant in Ukraine generates in average 250-270 kg of household waste annually or about 0.7 kg per day. As the people's wellbeing and goods consumption are raised, the amount of household waste also increases. Up to 2020 it is expected to increase household waste generation in our municipalities to 285-290 kg per year or 0.8 kg per day.

For comparison, it should be noted that every inhabitant in Sweden generates 450 kg of household waste per year, in UK – 500kg, in Germany – 325 kg, in Denmark – 510 kg, in Australia – 720 kg, in Republic of South Africa – 500 kg.

The city with million people population currently generates about 260000 tons of household waste per year. If average height of waste disposals at landfills is 10 m and waste density is 0.8 t/m^3 annually required area for the landfill of such a city is 4.5 hectares.

Similar problems exist in other municipalities which also have no free areas for the landfill and the neighbourhood is a green zone. Waste accumulation happens in unexpected places, which deteriorate the environment.

2.2 Characteristics of household waste

The household waste composition is quite diverse and therefore unpredictable. We throw away everything that has no value for us.

Estimated morphological composition of household waste in Ukraine is shown in Table 2.1.

Table 2.1. Morphological composition of household waste

Component	Content in household waste, mass %
Paper, cardboard	33-35.6
Food waste	30-38
Wood	1.5-3.0
Metals	4-6
Textiles	4-7
Bones	0.5-2
Glass	5-8
Leather, rubber	1.6-1.8
Stone, construction waste	1-3
Plastic	1.7-2
Polymers	2.1-2.5
Other	2.1-4.1

Mostly, changes in the household waste composition in different seasons happen due to increase of food waste from 20-25% in spring to 40-55% in autumn. It is connected to consumption increasing of vegetables and fruits. Experience shows the increasing of paper and polymeric materials. Besides, content of the glass is constantly changing.

This indicates that the morphological composition of household waste is not constant for our municipalities. Therefore, waste composition should be determined periodically by a specialized organization for a certain municipality.

Considering that there are multicomponent systems in the household waste, the approximate morphological composition of household waste by components groups, consisting of homogeneous elements, are presented in Table 2.2.

More attention should be paid to heavy metals listed in Table 2.2. These are lead, cadmium, chromium, mercury, strontium, nickel, cobalt, copper, tin, barium, molybdenum, vanadium, zinc and others. Most of heavy metals are very dangerous to the human health and to the environment.

Table 2.2. Morphological composition of household waste by components groups consisting of homogeneous elements

Name of the group	**Content in household waste, mass %**	**Approximate composition**
Food waste	38	Food rests, bones
Sulphur-, fluoro- and chlorine-containing substances, hydrocarbons	5.5	Polymers, plastic, rubber, leather, textile, oiled rags, the rests of lubricant materials
Solid impurities	15.0	Dust, construction materials, glass
Metals	9.5	Metals, heavy metals, cans, metallic products
Organic fraction	32	Wood (wood dust, tree bark, chip, wood products), wrapping material (paper, celluloid), cardboard

The chemical composition of household waste is presented in Table 2.3.

The heating value of household waste is 850-1800 kcal/kg. Wide range of heat value is caused by variable humidity of household waste in different seasons: in winter and early spring humidity is less and varies slightly compared to the autumn, summer and late spring when the humidity is high and very variable.

Considering the presence of wet and sticky components, household waste has a tendency to arching, sticking to metal and other details. However, household waste is abrasive because of the broken glass, construction materials and metals presence.

Household waste during the storage is compacted and loses the flowability because of its humidity. Household waste has aggressive effect on metal and building constructions. The leachate is also aggressive and has the ability to cause a chemical corrosion.

Table 2.3. Chemical composition of household waste

Parameter	Average value, %
Ash content	28-44
Nitrogen	0.9-1.9
Calcium	2-3
Carbon	30-35
Phosphorus	0.5-0.8
Potassium	0.5-1
Sulphur	0.2-0.3
pH	5.0-6.5
Humidity	40-50

The composition of wastewater, taken from the bottom of the receiving hopper of incineration plant, is presented in Table 2.4.

Table 2.4. Composition of leachate

Parameter	Value
pH	6.8
BOD5	66.1 mg O_2/l
COD	1194 mg O_2/l
Suspended particles	910 mg/l
Cadmium	0.02 mg/l
Mercury	0.008 mg/l
Lead	0.43 mg/l
Fats and oils	5.13 mg/l
Ether-extracted substances	52 mg/l

2.3 Thermal-technical properties of household waste

During the study of household waste thermal processing, it is determined that by thermal characteristics waste is unconventional and renewable fuel that can be compared to brown coal. Despite high humidity and significant ash content in household waste, which corresponds to low-quality fuel and requires the use of a radically new combustion theory, waste can provide a considerable saving of fossil fuels.

The Table 2.5 shows the comparative characteristics of household waste and brown coal thermal-technical properties.

The main difference between these fuels is next one. Brown coal has a very homogeneous composition, while household waste is a mechanical mixture of components with different composition, properties and specific thermal characteristics. Therefore, the theory of fossil fuel combustion can not be fully applied to household waste. On the other hand, whereas not individual components have to be incinerated but mixture of waste, the combustion theory should be one for all components. In other words, the theory must be universal, able to ensure the completeness of incineration with maximal preventing of the harmful substances generation.

Table 2.5. Thermal-technical characteristics of household waste and brown coal

Title	Composition, %							Average content of volatile substances, %	Average lower heating value, MJ/kg
	C	H	O	N	S	A	W		
Household waste	18.5	2.6	12.7	0.7	0.2	21.2	44.1	55.1	5.78
Brown coal (Donetsk basin)	29.1	2.2	8.7	0.6	2.9	23.5	33	45.0	10.5

The main thermal-technical characteristics of each group of similar components are shown in Table 2.6.

The following key conclusions can be made from the Tables 2.5 and 2.6:

a) despite the wide variety of components in household waste, its thermal-technical characteristics (content of combustible components, content of volatile substances, heating value) have no significant differences from fossil fuel;

b) the content of volatile substances indicates that household waste as fuel is more reactivity-capable than any kind of fossil fuel;

c) household waste incineration produces less harmful sulphur oxides than brown coal;

d) the heating value, ensuring the stability of the combustion process, is too low (range from 3.8 to 8.7 MJ/kg depending on the humidity); that is why the stabilization of waste incineration process should be supported by using co-burning of additional (fossil) fuel (gas or oil fuel).

Table 2.6. Thermal-technical characteristics of household waste components

Component	Composition, %							Average content of volatile substances, %	Average lower heating value, MJ/kg
	C^P	H^P	O^P	N^P	S^P	A^P	W^P		
Paper	27.7	3.7	28.3	0.16	0.14	15	25	79	9.48
Food waste	12.6	1.8	8	0.95	0.15	4.5	72	65.2	3.42
Textile	39.4	4.9	23.2	3.4	1.1	8	20	84	15.7
Wood	40.5	4.8	33.8	0.1	—	0.8	20	67.9	14.4
Leather. rubber	65	5	12.6	0.2	0.6	11.6	5	49	25.78
Plastic	55.1	7.6	17.5	0.9	0.3	10.6	8	89	24.35
Other	13.9	1.9	14.1	—	0.1	50	20	54	4.6
Ash, slag	25.2	0.45	0.7	—	0.45	63.2	10	2.7	_
Polymers	47	5.3	27.7	0.1	0.2	11.7	8	60.2	18.2
Glass, stone, metal	-	-	-	-	-	100	-	-	-

During the incineration of household waste as a fuel in furnaces of incinerators the saturated or overheated steam with pressure 14-24 kg/cm^2 is produced. This heat can be used for transferring to external customers and for own needs. However, more efficient is transferring of produced heat to steam turbines to generate electricity. The steam from the turbines can also be used for own needs and for external consumers. In the city of one million people population annual mass of household waste (260000 tons) can provide 1741.6·10^6 Gcal of heat or 392,4·10^{10} kW·h of electricity. Such amount of energy could be produced by burning of 60000 tons of fossil fuel.

Thus, household waste is one of reliable sources of fuel, which can provide considerable economy of fossil fuel in each municipality.

2.4 Generation of household waste in Ukrainian regions

The generation of household waste in Vinnytsia region and other regions of Ukraine (Tables 2.7–2.10) is characterized by the fact that in the most densely populated and industrialized regions with a high percentage of urban population, waste generation is significantly higher than in agriculture regions.

Table 2.7. Volumes of household waste generation in Ukraine

Region	**Actual household waste generation**		**Total generation, tons**
	m^3/year per person	**tons/year per person**	
Vinnytsia	1.07	0.241*	749566
Volyn	1.22	0.275*	433918
Dnipropetrovsk	0.91	0.205*	106271
Donetsk	0.88	0.198*	132421
Zhytomyr	1.04	0.234*	542274
Zakarpattya	1.25	0.281*	571374
Zaporizhia	0.91	0.205*	623148
Ivano-Frankivsk	1.25	0.281*	616064
Kyiv	1.04	0.234*	701992
Kirovograd	1.17	0.263*	425318
Lugansk	0.88	0.198*	731924
Lviv	1.25	0.281*	993412
Mykolaiv	1.51	0.34*	448334
Odesa	1.51	0.34*	879656
Poltava	1.12	0.252*	620146
Rivne	1.22	0.275*	493616
Sumy	1.12	0.252*	46724
Ternopil	1.07	0.241*	497488
Kharkiv	1.12	0.252*	912078
Kherson	1.51	0.34*	44145
Khmelnytskiy	1.07	0.241*	5818
Cherkasy	1.17	0.263*	557458
Chernigiv	1.04	0.234*	475026
Chernivtsi	1.25	0.281*	408234
Total Ukraine			170298

* – waste density 0.225 t/m^3;

** – waste density 0.215 t/m^3.

The largest part of household waste is generated in major cities.

Table 2.8. Household waste generation volumes in largest towns of Vinnytsia region

Town	**Household waste generation volume, m^3**
Vinnytsia	
per year	400000
Ladyzhyn	
per year	11000
per day	30
per 1 person	1.1
Zhmerynka	
per year	98000
per day	270
per 1 person	1.05
Khmilnyk	
per year	28000
per day	76
per 1 person	0.99
Mogyliv-Podilskyi	
per year	41000
per day	112
per 1 person	1.41
Koziatyn	
per year	27000
per day	75
per 1 person	1.1

2.5 Normalization of waste generation and disposal volumes

Landfilling includes any operation related to waste disposal and storage.

Waste storage is realized at specially equipped sites with temporary neutralization to reduce the negative waste impact on environment. When storing the waste, the term of locating of each waste type in storage sites is usually set.

Waste disposal means its isolation, aimed at preventing the pollutants dispersion in the environment, excluding the further use possibility.

Waste is disposed at specially equipped areas intended for this purpose, in overground and underground buildings, which are situated both within companies and outside. These include landfills for both household waste and certain types of industrial wastes, as well as authorized landfills for household waste and non-toxic industrial waste.

The waste can be disposed by industry, associations, organizations and institutions regardless of ownership and subordination, individuals and others which carry out any activity resulted in the waste generation, with the exception of radioactive waste.

According to the environmental requirements, every waste producer is required to take measures to ensure the environment protection and to comply with actual environmental, sanitary-hygienic and technological rules and regulations. Separate waste collection by type, hazard classes and other indicators contributes to a high quality waste processing and rational waste disposal. Waste circulation can be allowed under the conditions of preventing of its harmful effects on the environment and human health during waste accumulation, transportation or recycling.

The waste generation, collection, accumulation, storage and primary processing are the parts of the technological process and they produce waste as well. This waste should be included in the technological and other regulatory and technical documentation. Therefore, the activity of waste producers should be aimed at reducing the waste volume (mass), the introduction of zero-waste technologies, transforming the waste to valuable materials and obtaining additional products.

All generated waste is normalized in order to ensure the environmental requirements of Ukrainian legislation, where waste producers have limits of waste generation and disposal. The main theses of waste disposal normalization are as follows:

- principle of permission, which considers the order of waste accumulation, storage and disposal, as well as the terms of waste transfer to companies for reuse, neutralisation and recycling;
- principle of environmental safety priority over all other interests;
- principle of environmental and economic feasibility of waste disposal;
- reducing the volume of unused waste;
- principle of payment for waste disposal (fee only for disposal, fee for disposal plus fee for environmental pollution, fee for disposal plus fee for environment pollution and plus fee for environment damage).

Normalization of waste disposal volume depends on the type of waste disposal:

- disposal – technological stage for waste accumulation as valuable materials for use in site of generation or for transferring to other organizations;
- disposal – as temporary waste storage in the absence of processing technology or transferring to other organizations during the period of finding the solution (technologies development and implementation). Under temporary storage one understands storage during one year plus the additional time according to approved plan for waste reuse or removal;
- disposal – as a long-term storage at special sites with the prospect of waste use;
- burial – as a method of waste removal with no prospect of use or with the prospect of use in a remote time.

All the waste accumulated or transported has to be normalized. For this purpose the norms of limited waste generation and limits on waste disposal are used. The waste amount above these norms or limits is over-limit.

Table 2.9. Norms of household waste generation in Vinnytsia region (non-residential buildings)

Object	Unit	Average daily		Average annual		Density, kg/m³
		kg	dm³	kg	m³	
Hospitals	One bed	0.64	2.16	235	0.79	300
Polyclinics	One visit	0.01	0.05			200
Hotels	One place	0.25	18	90	0.43	210
Dormitories	-	0.25	18	90	0.43	210
Sanatoriums	-	0.69	2.47	250	0.9	270
Kindergartens	-	0.33	1.08	79	0.26	300
Schools	One pupil	0.08	0.38	20		210
specialized schools	-	0.42	1.66	100	0.4	250
Universities and technical schools	-		0.46	24	0.11	220
Theatres and cinemas	One place	0.06	0.28	20		200
Organizations	One employee	0.27	1.18	70	0.3	230
Restaurants	One dish	0.09	0.27			300
Cafes, dining rooms	-	0.05	0.17			300
Supermarkets	-	0.32	1.42	100	0.44	230
Markets	-	0.09	0.22	33	0.8	400
Warehouses	m² of the square	0.09	0.22	33	0.8	400
Railway and bus stations	-	0.36	1.37	130	0.05	260

Table 2.10. Norms of household waste generation in Vinnytsia region (residential buildings)

Object	Norm of household waste generation per one inhabitant				Density kg/m³
	Average daily		Average annual		
	kg	dm³	kg	m³	
Buildings of good state without food waste separation	0.49-0.51	2.12-2.19	190-195	770-820	230-250
Buildings of poor state without food waste separation	0.93	2.57	340	940	360
Private buildings with garden areas	1.5	3.29	550	1200	460

The norms of waste limited disposal are set for each type of waste for one year, taking into account the needs and technical possibilities of waste disposal considering its volume and frequency of deliveries.

In case if the norm of waste disposal can not be identified, then the limit of waste disposal is used.

Limit of waste disposal is the volume or mass of waste allowed to dispose during the certain time period. It is defined considering the norms of material consumption and depending on the planned production volume, with exception of the waste volume or mass used or transferred to someone as recycled material. Any amount of waste, disposed without ensuring the environmental safety, is called over-limit of waste disposal.

Norms and limits of waste disposal are defined taking into account the principles and criteria of normalization, type of waste, site of disposal and balance of waste. Developed norms and limits are attuned with regional organisations of Ministry of Health Protection of Ukraine and Ministry of Ecology and Natural Resources of Ukraine.

The disposal of waste at facilities (landfills) is normalized according to their annual projected capacity. The costs of waste disposal at these landfills include cost for designing, cost for building and cost for operation.

The facilities not equipped and operated without appropriate projects must be checked by environmental expertise to assess their impact on the environment:

- in the case of positive environmental expertise conclusion, the limit is set depending on annual capacity of the facility with payment for waste disposal according to contract (without any other environmental payment);

- in the case of negative conclusion, all the disposed waste volume is considered as over-limit with an increased rate of payment (payment for waste disposal and environmental payment for disposal the waste polluting the environment);

- in the case of high-level environmental pollution, waste disposal at the facility may be reduced or restricted if contamination is extremely high.

According to the Law of Ukraine "About Environmental Protection" authorized and unauthorized sites for waste disposal and storage has to be inventoried (landfills, heaps, dumps, pits, quarries, out-of-operation mines, tunnels, underground cavities, bunkers and containers used for waste disposal). That means the systematization of all the information about sites of waste disposal, storage and burial, including:

- definition of areas occupied by sites for waste disposal, storage and burial;
- assessment of fullness and availability of free space for waste disposal, storage and burial;
- determination of all waste types at the sites of waste disposal, storage and burial;
- identification of waste of I-IV hazard classes presence at the sites of waste disposal, storage and burial;
- technical conditions assessment of waste disposal, storage and burial sites;
- environmental impact assessment of waste disposal, storage and burial sites;
- verification of creation the monitoring network of waste disposal, storage and burial sites;
- assessment of compliance of waste disposal, storage and burial sites with environmental, building, sanitary and other norms and regulations.

Inventory is not executed for recultivated or properly conserved sites of waste disposal after the expiration of their operation time.

During the inventory a special attention is paid to waste disposal sites situated at periodically flooded plains, washed-out banks, areas with danger of landslide, avalanche and mudflow, as well as areas near the boundaries of water protection zones.

Inventory is mandatory for all waste disposal sites occupying an area over 1 hectare or containing more than 1,000 tons or 5,000 m^3 of waste.

The inventory results should indicate the following information:

- title of the waste disposal object and its code. The codes of objects are approved as follows: 01 – landfills for the disposal and neutralization of industrial and household waste; 02 – authorized waste dump sites; 03 – sludge collection facilities; 04 – heaps, terrikons, slag dumps etc.; 05 – pits, quarries, out-of-operation mines, tunnels, underground cavities; 06 – wells for the liquid waste disposal; 07 – waste burial sites; 08 – long-time waste disposal sites located at plants; 09 – temporary waste disposal sites at industrial grounds; 10 – unauthorized waste disposal sites; 11 – artificial collectors, bunkers, containers and others;
- distance from the object to nearest settlement and water body (in kilometres) and occupied area (in hectares);
- size of sanitary protection zone for objects outside the plant (in square meters);
- volumes of all the waste at the disposal site (in thousands of cubic meters) and mass of waste of I, II and III hazard classes (in thousands of tons);
- level of waste disposal object fullness (in percentage) and projected capacity (in thousands of cubic meters per year);
- type of waste: industrial waste, municipal solid waste; wastewater; medical waste; agricultural waste; waste unsuitable for use as fertilizer;
- year of the object operating beginning and the planned closure year;
- list of the main toxic components of I and II hazard classes in the waste placed at disposal site;
- description of the environment monitoring system in the area of the waste disposal object;
- code of antifiltration screen which indicates the type of its construction according to sanitary regulations: A – soil screen (single-layer clay – A-1, double-layer clay – A-2, soil-bitumen-beton – A-3), B – beton and ferrous-beton screen (ferrous-beton – B-4, polymer-beton – B-5, film beton – B-6), C – asphalt-beton screen (single-layer with bitumen coating – B-7, double-layer with drainage layer – B-8, with bitumen-latex emulsion coating – B-9); D – asphalt-polymer-beton; E – film screens (single-layer of polyethylene film stabilized with soot – D-10, double-layer of polyethylene film stabilized by soot with drainage layer – D-11);
- existence and brief description of the system of surface and drainage water collection and purification, as well as the system of control wells;
- operating costs of the object.

The typical inventory document is complemented by explanatory note with assessment of waste disposal sites impact on the environment and additional information not included in the typical scheme.

Explanatory note should contain a map of waste disposal site, covering at least 75% of the accumulated waste. The map, made in the scale 1:500000, indicates major water objects and waste disposal sites by special signs.

The red signs on the maps indicate the most dangerous for the environment places of waste disposal. Completed typical inventory form and explanatory note are approved by the chief of regional organisation responsible for environment protection.

2.6 Household waste collection and transportation

2.6.1 Methods of household waste collection

In municipalities the household waste collection is realized with or without containers methods.

The **method without containers** should be used in those areas wherein the movement and maneuverability of garbage truck are limited. When the method without containers is used, then collection and loading of household waste in the garbage truck are provided directly by people or appropriate employees in the truck.

Waste collection with bins and bags

When garbage truck arrives, people take out waste bags and throw the waste into the truck. Such a system initially was developed to serve private houses and rural areas. This system is not convenient if people are absent at home when the garbage truck is arriving. Alternatively, people can put waste bags (bins) near their houses before leaving for work. It is most common in France, where waste is collected at night or early in the morning. Such a system does not exist in Ukraine. In order to increase the efficiency, waste bags (bins) have standard features. In some cases standard bags (bins) are given to people.

In Ukraine waste collection with bags is interesting also for another reason. This scheme can help to gain the trust of private houses inhabitants, who often refuse to sign a contract for waste collection because of poor service quality. People can buy labelled bags. The idea is to collect only labelled bags, bought by people. Such a system can demonstrate that service is of good quality because labelled bags are collected regularly.

According to the **method with container,** household waste is collected in containers situated at special places. Household waste collection is provided by a unitary system (waste is collected in one container) or by separate system (components of household waste are collected in different containers).

The coverage by waste collection service (i.e. part of waste that is collected) is ranged from about 20 to 98% in municipal private houses, from 80 to 100% – in municipal apartment buildings, and from 0 to 80% – in rural houses.

Containers can hardly be used for the private houses, because it is related to large distance that must be passed to throw the waste. Finally, only a small number of inhabitants pay for the waste service because it is not provided regularly. It is not easy to serve only those who pay. All these arguments prove the advantage of plastic bags for private houses. These bags can be "pre-paid", i.e. people buy them, paying some money corresponding to the number of bags. It is better than fixed monthly fee for waste management. In this case, the bags which have to be collected are appropriately labelled.

2.6.2 Types of containers

A container is part of waste collection system. There are stationary containers and mobile containers.

Stationary containers

There are containers of different capacity: 120 litres, 240 litres, 350 litres, 550 litres, 660 litres, 750 litres. They are easy to produce and do not require large costs. The weakness is the susceptibility of container's bottom to corrosion. The metal bottom is exposed to the impact of waste leachate and water accumulated between the beton ground and container. Equipping of places for containers by special roof, as well as making holes for leachate removing, could significantly improve the situation.

Widely used are waste containers with a capacity of 0.75 m^3, they often do not have lids and wheels. This type of container can not be moved manually and their emptying is possible only by the use of garbage trucks equipped with side loading device. The absence of lids causes intensive waste decomposition during warm season and waste freezing in winter, which complicates the emptying, transportation and further processing and recycling of household waste. In the case of out-of-time household waste collection, containers become a source of rodents and insects spreading, as well as a source of various infections.

In most cases a stationary containers with capacity of 750 litres are used in Ukraine. In the case of stationary container, truck drives itself very close to container and captures it at place of its arrangement. These operations can be made by garbage truck quite well regardless of the road quality and weather conditions.

The most cost-effective (costs per unit of container capacity) is the use of large containers (750 litres). After determining the type of container, one has to decide how many containers should be placed: 1, 2, 3, 4 or more. In average, in the case of daily waste collection, 1 such container is needed for 75 people. For example, in regional centre as Vinnytsia there are 2142 containers for municipal waste collection, including: 1380 containers without lids and wheels (volumes 0.7 m^3 and 1.2 m^3), 762 closed with wheels (volume 1.1 m^3).

Mobile containers

Use of mobile containers is very attractive. They look modern and have a volume 1,100 litres. Use of lids allows isolating waste from the environment. Containers with wheels are very good solution but they require high quality of the territory arranging. Empty metal container weighs around 80 kilograms and the loaded one weighs several hundred kilograms (one should account the fact that some construction waste often appears in the container). It has to be moved to the garbage truck tailgate. This is only possible if proper quality of roads is provided: horizontal plane or a small incline towards the road, the absence of bordures and dents which can damage the wheels, in-time snow removal. Such work is very expensive. Besides, if the container's wheels are broken, therefore repair process for containers should be perfectly provided.

Cube containers

This type of containers is sometimes used in for private houses. This is a container with capacity of 10 m^3, loaded by special manipulator in garbage truck. Garbage truck collects full container and takes back an empty one.

Thus, one can assume that for ensuring the best transportation time, the load capacity of garbage trucks should be increased. In this case we face with another problem. The road coverage and courtyards of residential buildings, where the containers are placed, can not withstand the load from the heavy vehicles driving. The maximal weight is 10 tons. Higher weight garbage truck quickly destroys the road surface. Therefore, until the roadway will be improved, the garbage trucks with weight up to 10 tons have to be used.

All organizations and companies have to place containers for household waste collection if waste volume exceeds 0.35 m^3 per day. This volume is calculated in accordance with approved norms of household waste generation for the appropriate type of organisation.

If the volume of household waste generation is less than 0.35 m^3 per day, then it is allowed to use containers of other organizations on contractual basis.

The time of waste storage in containers must not exceed the time established by applicable sanitary rules and norms. Cleaning and disinfection of containers should be in compliance with existing sanitary rules and norms as well.

The *containers area* must be horizontal, flat, with asphalt or beton covering, separated by trees. The distance to residential buildings, kindergartens, sport spots and recreation places has to be not less than 20 and not more than 100 meters. It is better to build such places in the corners of the courtyards.

The choice of such areas in Europe is explained by the prevalence of private cars. Every second citizen has a private car, i.e. more than 95% of families have at least one car. In such conditions it is possible to create a containers area for 2,000 inhabitants, if car parking near this site does not cause any problems. Another frequently used solution is the containers area on parking place at the hypermarkets, because people come there at least once a week. Logically, containers placed in such areas should have a large capacity (from 2 to 5 m^3 depending on the waste type). There are no so many cars in Ukraine: 1 car for more than 10 people. Thus, the above mentioned logic does not fit.

2.6.3 Vehicles for household waste collection and transportation

Most of the special vehicles for waste transportation operated in Ukraine are old, worn-out and should be replaced. Besides, widely used are relatively small vehicles, for example, GAZ-53 and ZIL-433362. Their efficiency is low if the distance from the waste collection area to landfill exceeds 5-10 km, while the average distance between the waste collection areas and landfills in Ukraine is about 17 km, in some regions – 35-40 km.

The quality and efficiency of garbage trucks of Ukrainian manufacturers are considerably lower by technical capabilities in comparison with European analogues. The disadvantages are inefficient hydraulic and compacting systems and others. However, the price is much more expensive for European vehicles (about 20,000€ for Ukrainian garbage truck and 150,000€ for German garbage truck).

Garbage trucks differ by:

- purpose (vehicles for waste transportation from residential, business and public buildings, vehicles for special waste transportation, vehicles for transportation of bulky waste, etc.);

- load capacity (mini-trucks with capacity of 7-10 m^3; middle size trucks with capacity of 16-26 m^3; large, heavy vehicles with capacity up to 100 m^3);

- waste loading mechanisms (side and back loading);

- equipment (for example, with or without mechanism of waste compaction).

In the long term perspective, the garbage trucks with side-loading devices which are mostly used in Ukraine should be replaced by vehicles with back-loading, equipped with lifting devices designed for small (120-240 litres) and for middle size (0.8-1.1 m^3) containers.

Ukraine can fully meet the demand for garbage trucks with several powerful machine-building plants, which are able to manufacture commercially both garbage trucks and accessories.

The largest part of costs for waste collection and transportation in Europe is salary. For one employee (driver or another worker) the company monthly pays few thousands of euros. Therefore, a specific work time per 1 kg of collected waste is minimized. Further, to avoid unnecessary rides the loading capacity of garbage trucks was increased.

CHAPTER 3
SOLUTIONS OF HOUSEHOLD WASTE PROBLEM

3.1 Basic principles of household waste management

Nowadays, the most common method of household waste management is disposal on landfills and dump sites. This is true at least for countries of poor economics (such as Ukraine) and developing countries. However, this form of waste management is unacceptable – both from environmental point of view (primarily) and taking into account resource potential. It is known that landfills are intended for a certain time of operation or for certain limited waste volume, which usually are small. In this respect, most Ukrainian municipalities have almost fully exhausted resources for waste disposal and landfills do not meet environmental requirements.

The negative environmental impact of landfills is as follows. Inappropriate conditions of waste disposal (which is typical for majority of municipalities) cause toxic substances with high probability to get into the soil, contaminating it and involving in natural circulation, infiltrating into groundwater, creating a significant risk to consumers of drinking water. Besides, regardless of the waste disposal conditions at landfills, there is periodical spontaneous combustion of waste, containing a lot of organic and highly flammable substances. This causes air pollution by harmful products of combustion – carbon monoxide, nitrogen oxides, dioxins, furans, and so on. Recently, also the issue of greenhouse gases coming into air has appeared as a result of waste decomposition on landfills. This has influence on global processes of climate change.

Apart from the negative environmental impact, waste is able to get benefits as well. This is because it can be a source of energy and a source of valuable resources to be reused. Therefore, the waste accumulation without its further use is even uneconomical.

All above mentioned facts indicate that household waste disposal on landfills and dump sites has to be prohibited, as it is in developed countries. Therefore, municipalities have to be directed according to the world practice of refusing from waste disposal and its maximal recycling.

The most environmentally acceptable ways of household waste management are as follows:

1. Mixed waste is sent to the sorting station, where valuable components are separated and the rest is burned.
2. Mixed waste is sent to the plant for refuse derived fuel (RDF) production. The combustible waste is separated, and the rest (except metals) is disposed on landfill.
3. Separate collection of waste that can be recycled (with further transfer to the sorting station) and rest waste (it is sent to landfill).
4. Separate collection of waste that can be recycled (with further transfer to the sorting station) and rest waste (it is sent to incineration plant).

5. Separate collection of waste that can be recycled (with further transfer to the sorting station) and rest waste (it is sent to RDF and/or compost-biogas plant).

6. Separate collection of waste that can be recycled (with further transfer to the sorting station), garden waste (for compost production) and the rest waste (it is sent to landfill).

7. Separate collection of waste that can be recycled (with further transfer to the sorting station), garden waste (for compost production) and the rest waste (it is sent to incineration plant).

8. Separate collection of different fractions of household waste for further recycling.

According to possibilities there are three key ways to solve household waste problem in Ukraine.

The **first** of the ways includes: development and implementation of economic instruments aimed at high-waste technologies replacement; taxation of primary raw materials, resource-intensive products and processes; introduction of innovation activity encouraging mechanisms in the development of low-waste, zero-waste, resource-saving and environmentally friendly technologies. This way includes both measures for reducing the total waste volume and measures for reducing the content of hazardous substances in the household waste.

The **second** way towards solving the problem includes the installation of facilities for the neutralization and destruction of most dangerous waste categories. Appropriate infrastructure includes installations and complex equipment for waste of various origin, as well as objects for residual products disposal. In this framework are the forming of system of hazardous waste management services and appropriate logistic, as well as rigorous licensing and environmental control in this area.

This way also includes:

- strengthening the control and restriction the use of dangerous substances that can get to a waste;

- organizing the monitoring of waste streams on the base of relevant information provision;

- methodological work on classifying the waste as hazardous (identification of waste that is not hazardous, as well as inert and household waste);

- establishing the requirements and rules for disposal (storage) of waste by hazard categories and development of hazard risk assessment methodology for environment and human health;

- development the methods and the procedure of contaminated areas rehabilitation.

The **third** way to solve the problem includes creation the collection and recycling system of most valuable waste components, including packaging materials and containers, electrical and electronic equipment, batteries and others.

The first way is a long time one, but it is aimed at solving household waste problem due to the elimination of causes. The other two ways are potentially more attractive in time, but they are aimed at elimination of the consequences of unresolved household waste problems. Therefore, the effective combination of all above mentioned ways is ideal.

Besides, it is necessary to take into account the difficult economic situation of Ukraine and the relatively low level of new low- and zero-waste technologies installation. Therefore, the most preferred today is the use of second and third ways of solving the household waste problem. They can be implemented by use of waste processing plants and incineration plants respectively, as well as by the introduction of effective system of separate household waste collection and use of waste sorting facilities.

3.2 Organization of separate household waste collection

It is well known that waste sorting is necessary for its further efficient use. In the reality, separate waste collection can get 70-80% of valuable resources contained in household waste. Without separate waste collection one can not extract more than 15%. The most effective separate waste collection is possible at places of its generation, i.e. in the case of sorting by the people. Some part of raw materials is returned to production cycle. Therefore, waste sorting will help to save non-renewable resources, to reduce environment pollution by reducing the waste volume coming to the landfill, as well as to reduce emission of greenhouse gases.

However, for the implementation of separate household waste collection there are two main obstacles.

The first obstacle is the lack of appropriate legal, social and economic conditions for the waste management system work, including incentives, fines and so on. That is, even if people have a desire to sort the waste, then it is inconvenient, unprofitable (or even impossible) to do it, and sometimes there is no assurance that this work will not be useless. Very important to know what happens with sorted waste, and is it really recycled or reused? Very often failures in separate waste collection are considered as a result of low environmental awareness and the people’s consciousness. At the same time, the work on increasing of environmental awareness in the field of waste management is very poor. The majority of organized separate waste collection systems are the projects of private investors without any state involving. The experience of developed countries confirms that household waste sorting and its further re-use / recycling is the only rational way to resolve the existing issues related to the waste.

The second obstacle is unpreparedness of people to household waste separation. In this case, they should have in their own house few containers for different waste categories. It is more simple for people to take away everything into one container. Therefore, until people will not be interested in changing the way of household waste management, there will not be positive changes.

It should be noted that there are some examples of separate household waste collection in Ukrainian municipalities. However, this is not enough for effective system. Besides, there is very poor informational support of separate waste collection.

There are several variants of separate household waste collection that can be applied in Ukrainian municipalities.

1. Detailed separation of household waste on the individual components at households. By this option it is expected to have 3 different (colourful) containers for individual components (plastic, glass, paper) and one container for the rest waste. The system can be expanded by using few more containers, e.g., for food waste, PET bottles and others. It depends on the demand for these components and their generation volume. Each component of household waste can be collected separately by garbage transport with one section. The more common in the world is the collection of all components at the same time by special vehicle with several sections. Separated components are then transported to place of compacting for further processing, recycling and selling. This variant has the highest efficiency: up to 80% of valuable components in household waste can be recycled. This variant requires active people participation, a lot of money for waste collection, but less costs for waste processing.

2. Separation on two fractions. Such a system refers to separate collection of wet (organic) fraction and mixed dry fraction. The last one consists mostly of waste that can be recycled (paper, glass, plastic, metal, etc.). This method includes the use of two separate containers or two bags (depending on the municipality) of different colours. The frequency of wet organic fraction transportation should be increased to prevent odour of organic waste decomposition and dry mixed fraction can be transported with lower frequency, when the container is full. This system requires the facilities for further sorting of mixed waste to make it suitable for further processing. In order to get a high people participation a thorough educational work and stimulation are required. This variant requires less resources for waste collection in comparison with the first variant (the less containers quantity, the less costs) and it is more convenient for people (waste is not separated on 4-5 flows, but only on 2). However, the efficiency of such a system is lower and corresponds to 45-70%. Besides, the economic benefit from the use of sorted valuable components is reduced, and more money is required for waste sorting and processing.

3. The system of collection points of recyclable components. For small municipalities, without resources to ensure separate household waste collection according to the above mentioned variants, the best way is encouragement of people to bring the recyclable components to collection points. This method can also be used in larger municipalities in combination with other variants. This system requires separation the recyclable components in places of generation and delivering them to the specified collection points. This collection points should have containers for one or more types of recyclable materials. Such collection points can be created in the same places where people usually leave their collected waste, if other option is not offered. The collection point can also be situated in the central places, such as near shopping centres, car parkings, gas stations). One way to implement this system is the automatic collection points for PET bottles (usually in supermarkets), where one can get a money throwing the bottles inside. The efficiency of such a system is about 30-45%.

People stimulation to separate waste collection

Some examples of people stimulation to separate waste collection are listed below.

A system of self-adhesive labels was implemented in one of the German cities. People do not pay a special monthly fee, but buy these labels and stick them on the waste bags. The worker of the garbage truck checks whether the label corresponds to waste type in the bag. Some labels for separated waste are free of charge, and the most expensive are stuck to the bag with mixed waste. This system provides a free choice for people: to sort their waste or not to sort. If people sort their waste, they pay less.

Local authorities in the UK regulates the cost of separate collection by charging fees for containers for mixed waste (as it is in Ukraine), and containers for composted and separated waste are for free. This means that people who sort the waste do not pay for waste service. This method of stimulation fits for rural areas and the private houses in Ukraine, where everyone is responsible for own waste. However, before such stimulation at least the simplest waste collection system in such areas should be implemented.

There are also discounts in many countries for those who are included in the separate waste collection scheme. This mechanism is more efficient for private houses in Ukraine. People in apartment buildings could get discount for separate waste collection as well. However, it would be more difficult to ensure such a scheme there, because there are still a lot of people who would not sort the waste, and the efforts of other inhabitants may be useless. The possible option is installing special containers, where mixed waste is hard to throw in. But the additional costs are needed in this case.

In Australia, for example, the bags with labels are used and prizes for participating in the scheme of separate waste collection are raffled. A label with barcode is attached to each bag for separate waste collection. The drawing is carried out weekly, then the winner bag is checked, and if there is properly sorted waste, people get a prize.

If separate waste collection competes with ordinary garbage containers, municipality has to organize it in a way to enhance its advantages to the maximum and to minimize its disadvantages. Considering the experience of developed countries, the next important points should be provided for effective separate waste collection:

- simplicity (the highest rates of separate waste collection is achieved if there is clear and simple service);
- convenience (if the system is not convenient, there is high likelihood of non-efficient separate waste collection);
- consultations (for explanation the peculiarities of separate waste collection);
- control (for example, labels on containers for separate waste collection and controlling the indicators of people participation and determining those who participate regularly and finding approaches to those who do not).

3.3 Waste sorting plants

Use of sorting plants allows to people do not separate household waste or separate only two fractions, when one of them (the waste that can be recycled) is transported to sorting plant to separate different types of valuable components. The purpose of such plants operation is creating a supporting facility for optimization the waste collection and recycling of valuable components.

Basically, the sorting plants can separate all kinds of waste. However, it is recommended to collect wet biodegradable food waste separately and avoid the contamination of recyclable components. The purpose of these plants is creating a support facility for optimizing the waste collection and recycling.

Sorting plants can be with low level of mechanization (mostly manual waste separating, they are cheaper), and with high level of mechanization (totally or partially automated waste separating). Although a manual sorting can provide better quality of materials, it is slow and requires high labour input. For some type of waste the manual sorting is limited, because it is difficult to distinguish some components, such as different types of plastic (HDPE or PVC or PET). These components are separated faster and better by automatic sorting system.

During household waste sorting at mechanized plants the following operations are carried out:

1. Waste unloading. Waste is unloaded into the receiving ladle. It is necessary to control the receiving ladle to have a volume not a smaller than garbage truck can unload. Otherwise the garbage truck waits until receiving ladle is empty.

There is a conveyor near the base of the ladle, and both are situated below the ground level. Some waste always falls in the waste pit. Therefore, it is necessary to ensure free access to there for cleaning.

2. Waste sifting. The first stage of mechanical sorting is sifting. Its purpose is removing pieces too small for manual sorting. Mostly rotating cylindrical sieve with holes diameter about 60-100 mm is used. Quite useful is the presence of devices for opening bags, since many people throw waste directly in bags without opening them. Pieces with diameter more than 100 mm continue their movement on the conveyor, while others are too small to use a manual sorting. However, the pieces with diameter smaller than 60 mm can contain ferrous metals (metal lids), which are easily separated by a magnetic separator. It is a rotating metal tape with an electromagnet placed above the conveyor. The metal pieces are attracted by the tape and removed from the conveyor in a special ladle. The remaining waste can not be sorted and should be landfilled.

3. Metals removal. The pieces larger than 100 mm also contain metal elements which can be separated by electromechanical method at the exit of the sieve. Another separator can remove cans and bottles for drinks. If the waste contains a lot of aluminium pieces, the electromechanical Foucault separator allows separating coloured metals.

4. Ballistic sorting. If there are a lot of plastic in the waste, they are separated using ballistic sorting. Waste is thrown to the opposite end of the conveyor, and light fraction falls on special collector.

5. Manual sorting of household waste on the special table. The work places (tables) are on both sides of the conveyor. Each worker pair take a certain type of components and throw it down through the hatch in a container placed under the sorting table. The economic efficiency of sorting plant depends largely on this area. This is the area where manual waste sorting is performed. Therefore, the requirements to ergonomics and human health ensuring in this area should be especially high. The key points are as follows:

- the movements of the operator: the operator takes the waste from conveyor and throws it into the appropriate container. It is necessary to provide the conditions when this movement is performed naturally. The distance to the opposite side of the conveyor should be taken into account, as well as whether operator is left-handed or right-handed;
- lighting: illumination on such places has not be less than 400 lux;
- ventilation: dust is raised during the sorting, there should be fume hoods provided in the sorting zone. It is not enough just to have a perforated ventilation pipe.

6. Pressing. After separating the recyclables fall into containers for storage and pressing to compact packages. Press has to be cleaned every time new material is coming inside (for example, when paper is changed by plastic bottles).

There are two methods of waste separation at sorting plants. They are negative sorting and positive sorting. The negative sorting includes the removal of extraneous (useless) components from the waste stream. The positive sorting includes the removal of recyclable materials from the waste stream. Sorting plants operation must correspond to the waste collection system in municipality. The project, implementation and operation of the plant would be different depending on the waste management system: positive sorting for the totally mixed waste and negative sorting for the waste collected separately.

Most Ukrainian projects are expected to use positive sorting of unseparated waste. The European Union has refused the positive sorting. Ukrainian installations often use European sorting schemes, which provide negative sorting.

Sorting of unseparated waste is no longer used in Europe for two reasons: economic non-profitability and technical complexity.

Economic non-profitability is explained by:

- necessity to sort the whole household waste volume to remove only 10% of the recyclable components. Therefore, the equipment specifications should be designed for processing the waste mass, which is 10 times more than useful mass (mass of recyclable components). This requires a lot of employees as well;
- cost of recyclable materials is not so high to cover the operations costs;
- it is necessary to process 90% of the waste mass, which is not of any interest and should be transported to the landfill or incineration plant.

Technical complexity is as follows:

- recyclable materials contaminated by wet organic waste should be removed;
- recyclable components are “lost” in the stream of mixed waste, and this prevents the use of some automatic systems, such as magnetic separators, electric separators Foucault, ballistic separators;

- the operation with mixed waste is associated with serious hygiene issues.

Taking into account the experience of developed European countries, the expected efficiency of the sorting plants for materials that can be recycled is about 10-15% (and for some waste types – 75-80%). This efficiency is significantly lower in comparison with separate waste collection. The experience of manual sorting of mixed household waste passed through containers and garbage trucks is negative. Such waste is very hard to sort manually. The job of people in this case is unattractive and unproductive, and separated recyclable components, paper in particular, are contaminated and little applicable.

If all the waste is collected together, there is no necessity of additional effort for waste producer (convenient at the organizational level). Accordingly, no additional costs for household waste collection are required. However, the large funds have to be spent for processing mixed waste, including separation at sorting plants. Besides, there is a significant likelihood of recyclable components contamination, resulting in decreasing of its quality, reducing the price and increasing the cost of cleaning.

3.4 Thermal processing of household waste

One of the first and easiest ways of household waste processing is the incineration. This process provides both waste removal and energy production, and partly the necessity of waste disposal with hard looking for the appropriate area. That is why incineration plants became widespread in the world as an alternative to landfills. However, gradually it became clear that use of incineration plants is not the best way of waste processing, because waste incineration potentially causes other environmental issue – air pollution.

It should be noted that before incineration the household waste in Europe has to be sorted and transferred (in many cases) to mechanical-biological treatment, which minimizes the unwanted substances to get in the combustion furnace and increases the environmental safety. Waste separation in Ukraine is mostly absent and therefore all the waste is incinerated together without any processing, which is environmentally unacceptable. Nowadays, for incineration of unsorted waste there are no appropriate technologies and technical solutions which completely exclude the emissions of hazardous substances to the environment.

To intensify the incineration process, waste humidity should be not more 40-45%. If the humidity exceeds this level waste is recommended to dry before the incineration. Considering that considerable part of Ukrainian household waste is presented by food waste, which mainly provides high humidity, there is need for additional equipment for waste drying.

It is difficult to control coming to incineration plants prohibited toxic wastes or such materials as PVC, which can emit a lot of hazardous substances during the incineration. Heavy metals depending on their properties are concentrated in the ash or emit into the air along with organic substances and unburned dust particles. Sulfur, carbon and nitrogen oxides, volatile organic compounds, including dioxins, polycyclic aromatic hydrocarbons and other chlorinated hydrocarbons are emitted into the air as well.

Besides, incineration plants do not remove the waste completely. Toxic slag and ash, generated during the burning, have 30% of the original waste mass and still have to be landfilled. In the process of incineration the waste water from gas washing (during the wet cleaning) and leachate (saturated by hazardous substances contained in the waste) are formed as well.

For air cleaning the system of multistage filters is used. Some gaseous contaminants can be removed quite easily. For example, acid gases can be collected using fabric filters. But other pollutants require more complex treatment facilities, such as activated carbon filters and electrostatic filters. To reduce dioxins concentration waste can be incinerated at high temperatures (over 1200°C), but this increases the content of other harmful substances such as nitrogen oxides.

The negative impact on soils can cause slag, ash, unburned components which have to be landfilled. Slag and ash have about 15-20% of the original waste volume and volatile compounds and dust only 3-5%. The slag consists of gravel, stones, glass, and metal inclusions. Very often the ash remaining after waste incineration is considered as hazardous and disposed at landfills for hazardous waste.

In addition, the potentially recyclable materials will be lost. The solution could be in at least producing the electricity or heat. But in this case one needs additional expensive installations.

Some time ago Germany faced the landfills issues and adopted a plan to build 120 incineration plats. As a result of protests only 20 plants were built, many federal lands have abandoned waste incineration and have started separate waste collection and recycling. The adoption of strict EU standards for waste incineration has led to the widespread closure of incineration plants and very expensive improving the existing plants.

In countries with adequate attention to environmental issues, up to half of capital costs for the construction of incineration plants are paid for air cleaning systems. Up to 1/3 of incineration plant operating costs are paid for the ash disposal.

Therefore, to ensure environmental safety during the waste incineration, very high costs and system of waste preparation are needed. For Ukrainian municipalities it is not very realistic now. Therefore it is more logical to use other ways of household waste management.

Much more promising for the environment are pyrolysis installations, which provide thermal waste destruction without oxygen access and melting of inorganic components. They are investigated and implemented as an alternative to waste incineration in developed countries. The pyrolysis technology has two main advantages over incineration:

- significantly lower air and water pollution;
- almost full utilization of potential material and energy resources contained in waste.

However, the cost of pyrolysis installations is very high, which prevents their widespread usage.

3.5 Environmental impact of household waste management

The environmental impacts of different household waste management ways are given in the Table 3.1.

Table 3.1. Impact of household waste management methods on the environment

Environment	Ways of household waste management		
	Separate collection	Use of sorting plants	Thermal processing
Air	Minimal possible impact of remaining unsorted waste	Dust emission	Emissions of CO, CO_2, SO_2, HCl, HF, NO_x, heavy metals, aromatic hydrocarbons, dioxins (last 2 groups are absent when pyrolysis is used)
Water	Low contamination by unsorted components which should be landfilled	Low contamination by unsorted components which should be landfilled Wastewater contaminated by hazardous substances, harmful microorganisms (leachate)	Potential sedimentation of pollutants particles in surface waters; aldehydes and chlorides in the water from wash cleaning of gaseous
Soil	Low contamination by unsorted components which should be landfilled	Low contamination by unsorted components which should be landfilled	Landfilling of ash and slug containing heavy metals and other hazardous substances

The above table shows that the most environmentally acceptable way of household waste management is separate collection followed by recycling of separated valuable components. The use of waste incineration is the least environmentally acceptable way of household waste management.

Each of the proposed methods of household waste management has a different ratio of required mental and physical work, and involves different degrees of waste producer involvement. Besides, each method has different capital and operating costs, requiring different levels of financial liabilities of people and local authorities. Finally, each way provides obtaining materials of different composition and quality, affecting the recyclables market. The choice of household waste management method depends on the existing and completeness of legislation in this area, as well as the control of its implementation. The choice of way also can be influenced by method of people stimulation to adapt to the chosen model of waste management.

One of the main goals of creating waste management system is reducing the risk to human health and risk of environmental pollution. Therefore, when choosing the method of removal, processing, recycling and utilization of waste, the possible negative consequences for human health and the impact on the environment have to be defined. Priority methods are those which eliminate negative effects or at least allow minimizing them.

Analyzing the environmental characteristics of different household waste management methods, one can conclude that the most environmentally acceptable is separate waste collection with further sale of separated recyclable components, which is also quite economically attractive and can be a significant factor in Ukrainian municipalities. It should be noted that all ways of waste management are characterized by considerable variability of incomes, which depend on many factors, and therefore in each case the individual approach is required. Along with the introduction of any household waste management method, it is necessary to ensure appropriate conditions for its implementation.

3.6 Recyclables processing

Glass waste processing

Glass waste utilization is expedient both environmentally and economically and it can be done almost in every municipality with a population of over 5-10 thousand people.

Glass waste is third by the volume in household waste composition.

From an economic point of view, the use of glass waste is a major source of raw materials in glass production. Worldwide, glass waste is used mainly for the production of glass tare (cans, bottles) since the requirements to chemical composition of the glass are less strict. During green glass boiling in Germany up to 70% of glass waste is used, brown glass boiling – up to 45%, colorless glass boiling – up to 25%.

The use of 1 ton of glass waste in glass production allows economy of 1.25 tons of other raw materials, including 250 kg of sodium carbonate. Glass waste processing does not require any additional heat consumption for glass formation, because its usage reduces the temperature of glass boiling and reduces 4 times fuel consumption compared to its need for processing of raw materials. Besides, the duration of the process is reduced. During the glass boiling usually up to 15-20% of the glass mixture is waste glass, and this content could be raised to 90%.

Along with sodium carbonate saving, recycling of glass waste reduces air pollution, reduces the total amount of solid waste, and thus reduces the area occupied by dumps and landfills, and allows 6% decreasing of energy consumption, 50% decreasing of clean water consumption, and 54% decreasing of natural resources consumption.

Glass waste is used for manufacture the mineral powder for road beton. This powder is an essential component of asphalt as well.

Glass waste can also be used for fiberglass production. Glass fibers in turn can be used for manufacture of isolating materials used in aggressive environments.

Paper waste processing

Paper waste can be in demand as raw material for the production of cardboard, roofing materials and others. It is known that 4 tons of paper waste can save 1 hectare of forest. However, paper contained in household waste is not suitable for above mentioned purposes: it is contaminated and has high humidity and other shortcomings. There is possibility to produce construction materials using paper waste as mixture with wood waste.

Recycling of paper waste to white office paper is expensive due to the need of printing ink discoloration, removing glued substances and fillers. That is why on practice paper waste is used mainly for production of wrapping paper and cardboards, newspapers and toilet paper, inner layers of cardboard. Use of recycled paper is not only economically profitable, but also saves many hectares of forests, because with the increase of paper production, the appropriate plants consume more wood, depleting forest resources.

Confederation of European Paper Industry (CEPI) has published data on the current state of the paper market and perspectives of paper recycling development in Europe. The European Declaration on Paper Recovery was adopted in 2000. As a result by 2005 more than 55% of the paper was recycled, increasing the paper processing by 10 million tons annually.

First of all, paper waste has to be sorted: cardboards, paper and newspapers are separated. Then paper waste is shredded by rotary or disc mill. In the milled paper mass, depending on the assignment, mineral fillers, as well as glued and coloring substances are added. The paper pulp is then got into the water pulper, working on the circulating water where the paper pulp is "unfolded".

Plastic waste processing

It should be noted that different plastic products are made of different polymers, and therefore require different methods of processing. Moreover, methods for processing of certain polymers may be totally unacceptable for processing of others.

If one considers the market of plastic products, the most widely used are drink bottles (PET-bottles). They are made of polyethylene terephthalate. One of the recycling methods for this and other types of plastic is incineration, but it is not environmentally acceptable in most situations (although some plastic waste has to be only burn – such as medical waste). Let us analyze other methods: mechanical, physic-chemical and chemical, which complement each other.

Mechanical method includes shredding the bottles in special installations followed by granulation with no change of their physical and chemical properties. The resulting granulate can be used to manufacture plastic products. There are many companies in the world engaged in PET-bottles processing. But in Ukraine they are only few. In Ukraine up to 10,000 tons of PET-bottles are recycled annually, while producing is around 100,000 tons. Besides, as a rule, granulate is mostly sold abroad, because the price of this raw material in Europe is much higher, and there are no enough consumers in Ukraine.

It should be noted that the most widely used line of PET bottles shredding can process only bottles uncontaminated by other waste. It means that such lines are suitable only for pre-sorted bottles. Separate waste collection is not established in majority of countries, and sorting plants are also very few. Thus, raw materials for efficient lines of PET bottles shredding are mostly not available. Besides, before shredding, one still needs to be sure that it is PET bottle, but not any other type of plastic. For bottles, taken from a landfill or from mixed waste, this is difficult to do. Sorting plants require expensive equipment for physical and chemical analysis of plastic in this case.

Physico-chemical and chemical methods used for PET recycling are as follows: waste destruction with the purpose of monomers obtaining (depolymerization), which are suitable for fibre and film obtaining; waste re-melting for products obtaining by injection moulding; pyrolysis (thermal processing without oxygen access at temperature 350-550°C); resedimentation from solutions with powder obtaining for coating; chemical processing (hydrolysis, glycolysis or methanolysis) for original substances obtaining (dimethyl phthalate, terephthalic acid, ethylene glycol) and their use as raw materials for polycondensation or as a supplement to original materials. Only injection moulding is used in Ukraine – large companies produce the preforms of PET bottles. Chemical methods are not widely used because of the economic inexpediency connected to the lack of Ukrainian companies needs in products of chemical PET processing.

It should be noted that the process of PET recycling could be more effective, but actually there is no manufacturing in Ukraine, where products of PET processing can be used. Therefore, even mechanical and physico-chemical processing of PET, if they are last stages of company activity, can not be considered as complete recycling. Further manufacturing the ready products from semi-finished products is needed. Such companies, taking a waste and giving the ready-to-use products, are very few in Ukraine. The reason is that complete recycling of PET includes thermal processing when useful properties can be easily lost. Therefore expensive foreign technologies are needed, which is financially unacceptable for many Ukrainian companies.

Nowadays very common are various plastic packages. They are made of low-density polyethylene (the majority) and high-density polyethylene or combinations of both. Besides packages, other common products are also produced from these types of plastic: food packages, pipes, various films, bottles for washing means, toys. Therefore polyethylene waste is the most widespread among polymer waste. There are many companies of polyethylene waste processing in Ukraine. In contrast to processors of PET bottles, some of the polyethylene processors provide the complete recycling, i.e. produce ready-to-use products from waste (pipes, roofing materials, plastic packages and containers, etc.). But for majority of these companies incomplete polyethylene recycling is typical. For example, polyethylene waste is shredded, cleaned, agglomerated and secondary polymer granules are produced. They are raw materials for further products manufacturing. The examples of complete polyethylene recycling in Ukraine are producing the tiles and other roofing materials or pipes.

Recently, the environment pollution by one-time cookware, produced mainly from polystyrene, becomes more widespread. Since this type of plastic is processed very difficult (due to the increased diffusion) and price for recycled polystyrene is almost the same as original one, its recycling is not widespread. After previous shredding polystyrene can be processed by above mentioned physico-chemical method (injection moulding), when the complete plasticizing and homogenizing of polymers are take place, by pneumatic forming (deformation of heated plastic by the influence of compressed air) and by extrusion (extruding the melted material through a special forming tool for obtaining the product with cross section of desired shape). The waste of one-time cookware (polystyrene waste) is processed by very few companies in Ukraine. However, processing includes only polystyrene cleaning and shredding.

There is certain complexity because of wide range of polymer materials by composition. Most packages consist of few different polymeric materials. That is why there is complexity of recycling.

Metal processing

Metals, particularly steel, are the best components for recycling. It is known that steel, smelted from scrap metal, is 20 times cheaper in comparison to steel smelted from the ore. When steel is recycled, there is 6 times reduced emissions, 4 times reduced water pollution and 16 times reduced the mass of solid industrial waste. There are thousands tons of small metal waste (cans, caps, jars, etc.) at landfills nowadays. Due to mechanical separating of black metals during waste sorting, this problem can be solved completely.

Electronic waste processing

A particular issue is processing of so-called "electronic waste", as well as other waste containing the remains of rare and noble metals. The technology of electronic waste processing allows selective dissolving and electrochemical separating of non-ferrous metals from noble metals and metals of platinum group As a result a concentrate of noble metals and metals of platinum group, metal powders of gold, copper, zinc, lead, and tin, is obtained. The proposed technology is based on selective dissolution of metals with controlled anode and cathode potentials using a universal electrochemical installation. Processing of the above mentioned metals by electrochemical method is carried out in two or three stages depending on the composition of processed materials. The first stage includes consecutive selective dissolution and extraction of lead, tin, zinc (as metal powders using sulfamic electrolyte with controlled potential, which allows obtaining of these metals concentrates with 80-90% purity). Anode sludge, generated at the first stage of electrochemical processing, is exposed to selective electrochemical dissolution with controlled potential to extract copper powder in a sulphuric acid electrolyte with a purity of 80-90%. Therefore, two-stage electrochemical processing results in formation of nonferrous metals concentrate (lead, zinc, tin, copper) and anode sludge, which is a concentrate of noble metals and metals of platinum group with impurities of sulphuric compounds of tin, copper and lead. The impurities are separated during the smelting process. The content of noble metals and metals of platinum group reaches 95-97%. At the third stage of electrochemical processing, the electrochemical dissolution of noble metals concentrate and platinum group metals is carried out in chloride electrolyte to obtain a silver chloride in the anode residue and a solution containing noble metals and platinum group metals. Then consecutive selective extracting of metals from the chloride electrolyte solution is carried out with controlled potential. At this stage metallic gold with a purity of 99.95% and extraction degree of 98% is obtained, as well as a concentrate of platinum group metals with the residual gold content (1-2%), while total amount of platinum group metals and gold is about 97.5%. The extraction degree of platinum group metals is 99.99%.

3.7 Adoption of European Directives on waste management in Ukrainian legislation

The signature of the Association agreement between the European Union and its Member States, of the one part, and Ukraine, of the other part, opens new possibilities and creates new standards in different spheres of public life, including waste management.

Sectoral questions of cooperation in the sphere of waste management are established in the Chapter 6 "The Environment" of the Title 5 "Economic and sector cooperation".

In the field of environment the implementation of the EU legislation for Ukraine takes place within eight sectors. In general, the EU environmental legislation is presented by 29 sources of law: EU Directives and Regulations in this sphere, establishing general rules and standards that must be transferred to Ukrainian legislation. In contradistinction to environmental legislation of Ukraine, which in is declarative many aspects, the sources of the EU law determine the quantitative and qualitative results that have to be achieved by each country within a certain period of time. The peculiarity of the EU Directives is that countries should adopt their legislation to achieve the goals set by the Directives, but they determine the methods of achieving themselves.

The legislation in the sphere of waste management (and its separate streams) is presented in EU by more than ten Directives. Three of them are included in the list of the Association Agreement:

- Directive 2008/98/EC on waste (framework);
- Directive 1999/31/EC on the landfill of waste;
- Directive 2006/21/EC on the management of waste from extractive industries.

The legislation and environmental policy of the EU have the task to prevent waste generation, to promote reuse, recycling and recovery of waste in order to reduce its impact on the environment. The priority aims are converting the waste to resources and reduction of its generation volumes.

Ukrainian legislation in this sphere, despite the developed regulatory base, not fully or only partly meets the EU requirements. Therefore, the implementation of above mentioned Directives is associated with significant changes and additions to Ukrainian legislation. Now Ukraine faces the necessity to switch to a new concept, in which the priority objectives of waste management provide move towards "circular" economy with cascading use of resources and minimizing the waste volume.

The implementation time of above mentioned three Directives by their different thesis is from 2 to 5-6 years.

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

The Directive introduces measures to protect the environment and human health by preventing or reducing the negative impacts of waste generation and management, as well as reducing general consequences of resources use and improving the efficiency of such use.

The Directive sets an ambitious goal – approximation of the European Union to "society of recycling". It gives the priority to recycling, encouraging the separate waste collection and the re-use of products. The Directive establishes the criteria of attributing the waste to the by-products category and procedures, after which the end of waste status is achieved (when waste is no longer considered as waste).

The basic reference points established in the Directive 2008/98/EC include the following:

A. Integration of environment and human health protection tasks with measures for maximizing the use of resource potential of waste.

B. Establishing the hierarchy of waste management priorities:

- prevention (of generation);
- preparation for reuse;
- recycling (processing);
- other utilization, including energy recovery;
- removal (disposal);

C. The order regulation of waste referring to the category of hazardous waste (appropriate criteria are set). By the European Commission Decision 2000/532/EC the list of waste is established, where dangerous waste is defined. The list is intended to provide a harmonization of waste classification in the EU. The criterion of waste attributing to dangerous is the presence of one or more properties listed in Annex III of the Directive on waste. The definition of danger is generally based on Community legislation on chemical substances, including limiting concentrations of hazardous components. The implementation of this thesis should be one of the most significant changes in the Ukrainian legislation on waste.

D. Introduction of the extended producer responsibility principle.

E. Requirements for waste management planning. The waste management plans have to be developed, taking into account the waste hierarchy, environmental safety, as well as the principles of self-sufficiency and proximity. The Directive regulates the content of plans, which have to cover all waste types and the entire country. The programs for preventing the waste generation should also be established. Such programs should be integrated into the waste management plans or other environmental programs. The quantitative and qualitative criteria for measures of preventing the waste generation have to be defined. Annex IV of the Directive on waste includes examples of measures to prevent the waste generation at the stage of its generation, as well as during the production and consumption of products.

F. Keeping the registers. The creating and maintaining of public registers of organizations in the field of waste management (operators of waste utilization and its removal, dealers and brokers, carriers) is expected. The above mentioned should contribute to greater openness of waste management and expanding the opportunities of public control.

Table 3.2. Schedule of the Directive 2008/98/EC objectives achieving in Ukraine

Stage of implementation	**Time**
Development and adoption of national legislation. The authorized body determination.	3 years
Preparing the plans of waste management in accordance with the 5-stage hierarchy of priorities and program of waste generation prevention.	
Setting the mechanisms of total costs covering according to the principle of "polluter should pay" and principle of extended producer responsibility.	5 years
Setting the permit system for business engaged in removal or disposal of waste with specific obligations of hazardous waste management.	
Establishment of the register of organizations involved in waste collection and transportation.	

Directive 1999/31/EC on the landfill of waste.

The purpose of the Directive 1999/31/EC is to reduce the negative impact on the environment and hazard to human health, which can occur during the time of waste disposal object existing.

The Directive is based on the following key theses:

1. Preventing or reducing the harmful effects of waste disposal on the environment and risk to human health.

To prevent greenhouse gases emissions and toxic leachates coming to surface and groundwater, the Directive requires to reduce the disposal of organic waste and sets a lot of technical requirements: collection of landfill gas and its burning, compacting of the landfill bottom and covering it by film, leachate collection, taking away and processing, covering the disposed waste by the ground layer and so on.

The Directive sets strict requirement for the operation permit of only disposal places which meet requirements set by the Directive. All other landfills have to be closed and recultivated. Further operation is allowed only for those landfills, which have economically expedient plan of complying with the requirements set by Directive.

There are more than 6000 landfills and waste dump sites in Ukraine. 21.2% of them do not meet environmental requirements (according to national law) and 14.6% are overfilled. Therefore, there are about 64.2% formally safe landfills.

Experts estimate the quantity of operating landfills meeting the requirements of the Directive no more than 5%.

2. Reducing of waste disposal.

Each country is obligated to reduce the amount of waste transported to landfills due to preventing of waste generation, processing and recycling, as well as the use of recovered materials or energy, which has to lead to the natural resources saving and preventing of non-efficiency land usage.

The Directive notes that measures to reduce biodegradable waste disposal, in the same time should encourage separate collection of such waste type. In order to reduce this waste, Member States have to develop national strategies on reducing of biodegradable waste landfilling.

3. Strengthening the financial guarantees.

The Directive appeals to Member States to introduce landfill operator liability in the form of financial guarantee to ensure the fulfilling of all obligations arising from the permit. This means including in the payment for waste disposal all the costs associated with creation and operation of waste disposal sites, as well as the expected costs for closure, including costs required for landfill aftercare during the next
30 years.

By the experience of Estonia, the costs for closure of old landfills include in average:

- covering by polymer material, etc., only in the case of existing threats to groundwater – 100,000 €/ha;
- for large landfills with area more than 5 hectares – 300,000 €/ha.

The closure cost of landfill near Tallinn (22 ha) in Estonia in 2006 was 8,000,000 €.

The Directive defines classes of waste disposal sites:

- disposal sites for waste, which is not dangerous, including:
  • municipal (household) waste;
  • non-hazardous waste of any other origin;
  • stable and chemically inactive hazardous wastes (e.g. solidified, glassed);
- sites for disposal of hazardous waste;
- sites for disposal of inert waste.

Table 3.3. Quantity of different landfills types in the EU (2010 year)

Country	Landfills		
	for hazardous waste	for non-hazardous waste (incl. household)	for inert waste
Czech Republic	34	157	78
Estonia	7	6	2
France	15	252	-
Italy	10	303	221
Latvia	2	11	0
Lithuania	1	10	3
Hungary	14	89	9
Poland	48	610	8
Romania	8	137	0
Slovenia	1	35	11
Norway	8	77	14

The Directive defines types of waste not allowed to dispose at landfills:

- biodegradable waste;
- liquid waste;
- waste that is explosive, caustic, oxidative, highly flammable when disposed;
- medical and other clinical waste generating in medicine and veterinary, which is infectious.

The Directive establishes the procedures of waste reception at landfills, which are defined in details in the Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC.

It is forbidden to dilute or mix the waste exceptionally for achieving compliance with characteristics allowed for disposal.

Table 3.3. Schedule of the Directive 1999/31/EC objectives achieving in Ukraine

Stage of implementation	**Time**
Development and adoption of national legislation. The authorized body determination.	6 years
Classification of waste disposal sites	
Preparing a national strategy to reduce biodegradable waste volume, that is landfilled	
Establishing the system of applying procedures and getting the permits, as well as the procedures of waste reception at landfills	
Establishing the procedures of control and monitoring during the landfills operation and closure, as well as the procedures of landfills aftercare to prevent their negative impact	
Developing the plans of existing disposal sites complying with the requirements of the Directive	
Setting the mechanism of costs calculation for waste disposal	
Ensuring the required waste processing before its disposal	

To implement all above mentioned stages there are 6 years. However, the annex to the Agreement also indicates that the Directive requirements apply immediately for new landfills set into operation after the signing of the Agreement. Therefore, the landfills started to operate after June 2014 have to comply with the European requirements for landfills, which at this stage is unlikely due to the absence of many requirements in Ukrainian legislation.

The Directive 1999/31/EC is one of the most expensive for implementation all its requirements.

3.8 Roadmap of household waste management system optimization

In Ukraine, as in most countries which are not developed, not many municipalities have clear strategic long-term scenario of household waste management. The programs of household waste management adopted by Ukrainian municipalities (mostly only regional centres) are mainly declarative and do not contain a clear actions order to solve the problem of household waste. Besides, due to the significant infrastructure and social-economic differences between large cities and small municipalities (district centres and villages), the latter can not effectively use existing programs intended for more or less big towns/cities.

Concept of household waste management in developed countries is clear with long term focus. However, these programs can not be totally used by municipalities in Ukraine due to social and economic differences between Ukraine and developed countries. For example, some theses of European concepts are based on strict implementation of the proposed solutions without the use of economic instruments. This is impossible in Ukraine. Besides, developed countries are many years ahead in the solution of household waste management issues. Therefore, our municipalities require a combination of the world's best strategies for household waste management and modern methods of its processing and recycling.

Based on numerous studies one can conclude that the most optimal way for Ukrainian municipalities is separate collection of organic and other solid household waste, with a gradual further separation of more fractions: plastic bottles, paper, glass and organic waste. The priority of separate waste collection is the isolation of wet organic fraction, which makes the rest waste more inert and prevents the formation of many hazardous substances.

The main principles of the proposed system are:

1. Waste preventing or minimizing.

2. Prevent or reduce the negative impact of hazardous waste on the environment and human health.

3. Providing expedient (technically and economically) use of waste as raw material and energy resource.

4. Development of the system of separate waste collection and processing and increase the quality of service in this area.

5. Environmentally safe removal of household waste.

Let us consider the key stages of implementing the optimal way of household waste management in Ukrainian municipalities.

Stage 1 (up to 1 year). Developing the municipal program of household waste management. Above mentioned roadmap can be a base of such program. It should contain the main principles of household waste management strategy for the near future, taking into account regional differences. The program must also include specific actions, necessary funding and timelines, based on the capability of local budget and potential of private investors involvement. The program should include clear and detailed mechanisms of the proposed optimal household waste management system. Duties and responsibilities of all participants should be clearly allocated. The official document must be adopted at the end. It will effectively help to solve the problem of household waste.

Stage 2 (constantly, until establishing a stable system of household waste management). Search for potential customers of sorted recyclable materials. It is important to do this before starting the waste sorting in order to avoid a situation when waste is sorted, but there is no place or company to take it out. Only if there are clear long-term agreements with customers of sorted materials, the efficient and cost-effective operation of the proposed system is possible.

Recyclables have to be sold after collecting and sorting. For example, any operation during waste packaging utilization should begin from searching the market opportunities for recycled materials. One must have long-term contracts, which include specific volumes of production and specific quality valuable sorted materials. Besides, processing plants have their own quality requirements for recycled materials. Obviously, the price for recycled materials varies depending on its quality.

Stage 3 (1 year). Installing of special containers for organic fraction along with usual containers for other waste, as well as use of available garbage trucks for transportation the organic fraction. It is also possible to use already installed containers, but their conditions do not allow avoiding unfavourable environmental consequences of waste accumulation and unloading (availability of lid to avoid contact of organic waste with rain/snow). The organic fraction can be composted with obtaining of organic fertilizer or used for biogas production. For this purpose it is necessary to make agreements with farmers interested in such raw materials. For the private houses, where establishing of container areas is irrational, each family should be provided at least two small containers (for organic waste and for the rest) and different kind of waste should be taken out from the near-house area at certain days. In favourable conditions farmers could completely process the organic fraction.

The next stage should take place in the same time as stages 2 and 3.

Stage 4 (minimum 3 years). Conducting an informational campaign and explanations among people to increase the efficiency of the household waste management system. For this purpose, the agitation and explanation, environmental and educational activities on waste management should be done, including:

- spreading of relevant promotional and educational leaflets, books, brochures;
- publishing in local media messages and articles related to the negative waste impact on the environment and its separate collection;
- increasing the number of local TV and radio broadcasts on environmental issues, including the household waste problem;
- conducting the explanatory work in kindergartens and schools with the purpose to inform people and for fundamental change of post-Soviet consciousness to eco-civilization one.

In the first period it is necessary to conduct an informational campaign on the necessity of separate organic waste collection. Only after establishing a system of household waste separation on two fractions and buying necessary additional garbage trucks, one can begin to conduct informational activities with people directed on waste sorting on more fractions.

To improve the efficiency of informational work it is advisory to use following effective activities:

- publication of scientific-popular literature, articles, leaflets, posters;
- exhibitions, movies screening.

It would be useful to conduct sociological polls of different people categories about their views on the household waste issue, people's willingness to participate in separate waste collection and so on. Such polls can be conducted periodically (at the beginning of informational campaign, during its carrying out and after its completion) to assess the efficiency of information support and people's readiness to waste sorting.

More about the informational work with people is presented in the following paragraph.

Introduction of separate waste collection requires extensive preparedness, because people have to change their behaviour and this creates additional inconvenience. But the task is quite achievable even in Ukraine, which is evidenced by past experience.

People will face with necessity of waste sorting at the kitchen and temporary waste storage prior to their throwing out to containers. You can not force people to sort dozen different materials, as the place in the house (flat) is limited. The key thought is the need to argue people, that they are able to organize themselves very well. In order to increase public awareness, it is necessary to carry out explanatory work with residents of each house.

Stage 5 (2 years). Stage-by-stage installation of special containers for separate waste collection, first of all in places easy to control and where potentially waste could be sorted more intensive. These places can be educational institutions and government organizations. Containers for separate waste collection should be placed on existing container areas, reducing the number of usual containers. Besides, it is expedient to arrange special centres for such containers in crowded places (near the shops, in town or village centre, at the market and so on). To ensure the quality of sorted materials, such centres should have limited access in certain hours and be monitored by the relevant employees.

At this stage it is also expedient to conduct a sociological poll to identify the main issues which appear in the process of separate waste collection, as well as to improve the introduced system of household waste management.

It is very important and responsible to encourage people to sort their waste. In practice, the most effective lever for people is financial one. In the initial stage of separate waste collection implementation, it is advisable to provide free waste service for those who sort the waste. For those who continue to produce mixed waste, the waste service should be more expensive. That would be a good incentive for people to sort the waste. Further, with increasing the number of people covered by separate waste collection, it is advisable to use current fee for waste service for people who sort the waste, and higher fee for those who do not.

It should be noted that the above mentioned system is effective for private houses. There can not be individual control in apartment buildings. Therefore, in this case, by the change in the cost of waste service the high efficiency can not be achieved. People can be offered some incentives for utility service payment if the waste is properly sorted by all the inhabitants of the building. It is advisable for this purpose to install special containers for certain waste types, which prevent the throwing of other waste, as well as to provide people by small waste bins with several compartments for different waste (in general, improved version of conventional buckets, which is also used).

Stage 6 (variadic, 1 year). When setting up an effective system of household waste management, the companies have to be found, which could produce some products from sorted recyclable materials. That would be more cost-effective in comparison with selling the recyclables to private organizations at low prices, because the raw material actually is got for free instead of buying it. Besides, it is complete waste recycling, which is environmentally acceptable.

Except the proposed key stages of optimal household waste management implementation, next recommendations and requirements can be specified for more efficient operation.

1. To eliminate the illegal waste dump sites in municipalities and surroundings. Special attention should be paid to areas with private houses, because there is the largest quantity of illegal waste dumps. Besides, the mechanism of such dumps preventing has to be provided in the future by including in municipal waste management program.

2. To establish or improve the existing system of hazardous household waste collection (primarily, the most common – fluorescent lamps and batteries) by organizing the collection points (for example, at gas stations, shops, etc.). Besides, the continuous control over the transportation and possible processing of hazardous household waste should be provided.

3. To provide the medical waste utilization, especially in hospitals where they are generated in great quantities. For this purpose a contract with appropriate organization has to be signed or special equipment has to be installed (the last is efficient if several municipalities act together).

4. To improve the conditions of existing container sites and comply them with legislation.

5. When the household waste separation system will be established in the future, it would be cost-effectively to organize manufacturing the goods from recycled materials instead of selling it.

6. After setting up the organic waste processing system, such waste type has to be prohibited to dispose at landfills already existing in developed European countries. This is done for avoiding the potential environmental problems at the landfills (spontaneous waste burning, leachate generation, etc.).

7. To organize social campaign of free household waste collection from old people who are physically disabled for separate waste collection. The employees of waste carrier or social service can be involved for this purpose.

8. To organize continuous monitoring of separate household waste collection.

Even separate household waste collection leaves some part of waste still disposing to landfills, where large volume of previously accumulated waste remains. Therefore, an important task of household waste management system in municipalities is improving landfills conditions and complying them with requirements of environmental legislation. For this purpose the following steps can be offered.

1. Solving the problem of landfills leachate. To do this, the drainage pipes must be installed at landfill to flow the leachate in special place for its subsequent disinfection.

2. Installing the equipment for biogas collection at landfills (system of drainage pipes with generator).

3. Controlling the waste composition when unloading it at landfills, as well as periodical covering of the waste by soil as it is required by the regulations.

The proposed roadmap of optimal household waste management implementation can be used in developing the local programs of household waste management. If it is correctly implemented, then the impact on environment is significantly reduced. Besides, very important is clear interaction between local authorities and the public, as well as explaining to people what and how they should do. Presented action plan takes into account the current state of Ukrainian municipalities. For efficiency increasing, in each case the regional differences must be taken into account, which could help or interfere to optimal household waste management implementation.

3.9 Recommendations for formation of public opinion on environmentally friendly household waste management

While forming the public opinion the following most efficient methods are recommended to use:

- method of stimulation: explaining the benefits as a result of certain actions;
- method of conviction: logical proof of a concept, moral position or process assessment. The public consciousness is not so much influenced by the concept and considering as by their proving. While assessing the information received, people approve their opinion or correct it. Making sure of the truth, people form their own system of views on the problem;
- method of influence: the influence on person for encouraging to specific actions. Effective implementation of this method can be achieved by the use of images, videos and so on.

There are two types of the means recommended to use fro influence on public opinion:

- mobilization, including agitation and propaganda;
- marketing, including the study of public opinion and appropriate correction of agitation.

The formation of public opinion on environmentally friendly household waste management is recommended in two directions:

1. Promotion of environmental knowledge about household waste composition and properties, ways and methods of preventing its harmful effect on the environment and human health.

2. Agitation of:

- necessity to keep cleanliness and properly maintain the municipality territory;
- preventing the formation of illegal waste dump sites;
- implementation of separate household waste collection.

While forming the public opinion, it is recommended to use active and passive forms of agitation.

Active forms include conversations, speeches, lectures, reports.

Passive forms include the publication of scientific-popular books and articles; visual agitation forms: leaflets, notes, posters; exhibitions; movie screenings; etc.

Passive forms of agitation should not be impersonal. Their content is recommended to target a specific audience: in some cases the newspapers and posters must contain a minimum of text and a lot of bright, coloured illustrations (e.g. for children), in other cases they must have more text material with one or few memorable illustrations.

While preparing the visual forms of agitation one has carefully to think about its design, text, title, place.

Depending on the number of people in target audience, their education level, interesting in the problem, age, etc., it is recommended to use different types of agitation: mass, collective, individual.

In order to form public opinion on environmentally friendly household waste management, the agitation is recommended to carry out by:

a) public education in the media:

- on TV and radio;
- in the press;
- in the internet;

b) public education at the places of residence, including:

- contact with people;
- joint work with authorities in pre-schools, schools and other educational organizations;

c) placing of agitation materials:

- in public transport;
- on packages;
- as external advertising;

d) organizing a mass events.

For the campaign of agitation, it is recommended to create, produce and reproduce the promotional materials, including:

- printed materials: leaflets, brochures, posters, manuals, books for children;
- audio materials, video materials, texts;
- educational materials on environmental education.

When carrying out the agitation, it is recommended to involve: organizations regulating the advertising and promotional activities at the state level (governmental organizations) and at the public level (non-governmental organizations); manufacturers, creative and research organizations operating in the field of advertising.

Public education in the media

The agitation of environmentally friendly household waste management in the media can be recommended as one of the main types of public opinion formation. This is because the media are characterized by such common features as:

- audience size, focusing and speed of information influence;
- strength, communicativity, constancy and multifactoriality of influence;
- propaganda, educational and informational influence;
- the great quantity of methods and forms of influence;
- availability, prevalence, dynamicity of information.

The choice of media for carrying out the agitation is recommended to make by the following criteria:

- popularity of the media or broadcast among the people;
- media circulation or number of viewers or listeners;
- fees for advertising space or time;
- availability in different regions.

The agitation on TV is recommended to carry out continuously. Publications in the press can be periodical and highlight certain aspects of environmentally friendly household waste management. For efficient agitation it is recommended to choose newspapers of different directions with large circulations, making it possible to inform a wider audience about the problem. The recommended frequency of publications appearance is every 2 months.

Radio is recommended for short agitation messages (5-10 sec.), which can appear on radio stations 2-3 times a week at "prime time" or just before news broadcasting.

For the agitation it is also recommended to use the internet, which allows accessing to any databases (text, audio or visual information), using them, interchanging by data, communicating with unlimited number of people. It is recommended for each municipality to create an information portal of household waste management, where can be placed any information about the main problems of environmentally friendly household waste management.

The agitation of environmentally friendly household waste management among people at places of their residence is recommended to carry out by producing the agitation leaflets of different content and their distribution in mailboxes. The leaflets are recommended to distribute once a month.

For the purpose of diversified teaching kids in kindergartens, pupils in schools, their parents and teachers and formation of ecological culture in the sphere of waste management, the local governmental and business organizations dealing with household waste management are recommended to contact with educational organizations to carry out a complex educational agitation.

In kindergartens at the first stage it is recommended to talk with teachers and explain the purpose and objectives of environmentally friendly household waste management, determine the agitation activities, as well as time and conditions for their carrying out.

At the second stage it is recommended to talk with parents in order to inform them about the household waste management in the municipality and encourage the interest to take part together with children in the events on environmentally friendly household waste management proposed to conduct in every house, courtyard or region.

At the third stage the direct contact with children is recommended. As the purpose and content of the work for a specific age group is different, these lessons are recommended to conduct with different age group of kids separately.

To teach the pupils in schools for understanding the importance and relevance of environmentally friendly household waste management, the following events are recommended:

- lectures and seminars for pupils about environmentally friendly household waste management according to the educational level;
- workshops for forming the skills of separate household waste collection;
- environmental actions and events aimed at promoting of environmentally friendly household waste management;
- creative and research contests dedicated to environmentally friendly household waste management;
- environmental conferences and roundtables for highlighting the information about environmentally friendly household waste management.

The higher education institutions are recommended to complement the environmental education courses by lectures on environmentally friendly household waste management.

Agitation materials placing

The posters with agitation information on environmentally friendly household waste management are recommended to place on outdoor advertising boards along roads with high traffic and in crowded places (town/village centre). In such places at least 3-5 posters are recommended to place.

The agitation materials in public transport can be placed every 2-3 months (recommended duration is 1 month).

The packagings with agitation materials are recommended to use by shops and give to participants of environmental events.

The placing of agitation materials can be continuous during all the time of carrying out the agitation on public opinion formation.

Methods of studying the public opinion on environmentally friendly household waste management

To determine the effectiveness of measures to form a public opinion the studying a public opinion is recommended.

For studying a public opinion the following most efficient methods are recommended:

- personal contacts;
- work with focus groups;
- "hot" phone lines;
- analysis of mail;
- polls;
- phone interviews.

Personal contact as free communication with people is recommended to use for effective identification and assessment of trends of people’s treats the household waste problem. One of the types of personal contact is conversation with key informants, in another words the selection and interviewing well-informed leaders and experts in the sphere of household waste management. Interview should be conducted in the form of free and not time-limited debate, when selected persons invited to discuss the issue.

Focus groups are recommended to use for determining the reaction of people on the processes taking place in the sphere of household waste management, as well as for collecting the information used by other methods of studying a public opinion on environmentally friendly household waste management. Focus group should be formed by 6 to 10 people. Lessons in focus groups are recommended to conduct with moderator experienced in environmentally friendly household waste management.

In order to get immediate feedback and track issues which are of particular concern and interest for different social groups, it is recommended to use "hot" phone lines.

In order to collect the information on household waste management, it is recommended to conduct periodic mail (e-mail) review, considering that:

- letter writers are more disposed to critical approach, but not a constructive one;

- letters inform about local household waste problems, which writers are directly faced with, but which are not a public opinion.

In order to get simple and clear answers to questions about environmentally friendly household waste management, which require certain time for considering and response, it is recommended to use polls.

The advantages of questionnaires sent by mail (e-mail) are significant saving of time and money, convenience to respondents, the guarantee of anonymity, absence of interviewer impact. The disadvantage of many polls is low rate of answers. This means that the final results can not be representative.

For quick collection of information on household waste management, as well as for possibility to explain questions and get answers from the greater number of people, it is recommended to use a phone interview.

CHAPTER 4
HOUSEHOLD WASTE LANDFILLING

4.1 The impact of landfills and waste dump sites on environment

A large area is needed for waste landfilling. It is difficult to find "free" area not only in suburban territories but even far from the settlements. Due to the length increasing of waste transportation routes to the places of disposal, the costs for waste management are increased.

Landfills are significant source of pathogenic microorganisms formation. Due to birds, animals, and insects they are spread to the settlements, creating a danger of epidemic diseases and infection of people.

Research and regular monitoring show that the majority of landfills and waste dump sites are in primitive state.

The main negative environmental impact of waste landfilling is connected to generation of landfill gas and leachate.

Landfilling leads to scattering solid waste in the atmosphere in the form of fine particles and requires waste compacting with subsequent covering it by soil layers. There is constantly self-burning of waste at the landfills and especially at waste dump sites due to the waste is not covered by such soil layers. As a result, the atmosphere of municipalities nearby contains products of incomplete waste burning, which are very harmful substances, including chlorides (household waste contains plastic, including chlorinated polymers) and others.

According to the investigations, the following harmful gases are emitted at landfills:

- PVC (concentration up to 48 mg/m^3);
- dichloromethane (concentration 106 mg/m^3);
- toluene (concentration up to 236 mg/m^3);
- ethylbenzene (concentration 20 mg/m^3);
- xylene (concentration up to 20 mg/m^3);
- cyclohexane (concentration up to 43 mg/m^3);
- hydrogen sulfide (concentration up to 633 mg/m^3).
- more than 20 other harmful components (concentration 3-14 mg/m^3).

Due to biological, physical and chemical transformations of waste components the landfill gas (biogas) is generated, consisting of methane, carbon dioxide, hydrogen sulphide and other hydrocarbon substances (see Table 4.1), which cause waste self-burning and unpleasant odours. These contaminants affect air quality, human health, and create conditions for landfill burning. It is not only carbon dioxide, but methane is "greenhouse gas" as well, responsible for global warming on the Earth. Moreover, methane is 20 times more harmful than CO_2 by this characteristic. CH_4 emissions from all the world's landfills are about 40 million tons per year and can not be ignored.

Table 4.1. Atmosphere composition at landfills (height 1 m), Donetsk region, Ukraine, mg/m^3 (2004 year)

Substance	Concentration in the air	Limit value
Dust	0.3-0.8	0.15
H_2S	0.003-0.053	0.005
NH_3	0.013-0.04	0.04
NO_2	0.05-0.09	0.04
SO_2	0.012-0.14	0.05
CO	0.7-6.1	3

Complex organic substances, containing in household waste, are decomposed at landfills during certain time, but these processes are very slow. Initially (1-2 months), aerobic processes occur under the influence of microorganisms using oxygen for the organic matter oxidation. After 1-2 months the temperature inside the landfill (at the deep of 2 metres) rises to 20-40°C. The products of aerobic decomposition of household waste are mostly carbon dioxide, nitrates and water. Gradually the activity of aerobic processes is decreased. When the oxygen inside the landfill is depleted (about 0.7 litres of air per 1 kg of waste), the anaerobic processes begin to dominate. They are very slow occurring mainly in the food waste. Anaerobic bacteria do not use molecular oxygen for the oxidation of organic substances, but obtain the necessary energy from organic substances decomposition. 1 ton of household waste can release (in natural way) up to 200 m^3 of landfill gas during 20-30 years, corresponding to approximately 5-6 m^3 per hour. In the case of complete landfill gas removal from waste, this figure will double to 400 m^3 per 1 ton of waste (but because the process is technologically intensified, the period of active gas generation is reduced to 10 years).

When passing through the landfill the water contacts with waste and dissolves waste components, forming highly toxic waste leachate. The leachate with BOD5 about 500-5000 mg/l is always generated inside landfills at a depth of 1.5-2.5 m and more. It is very toxic liquid which continuously flows out from waste. The leachate volume, generating in the landfill depends on the amount of annual precipitation in the region, water evaporation and water absorption by the waste inside landfill.

Leachate usually contains toxic microbiological components, a lot of toxic organic compounds, heavy metals, ammonium and sulphate ions and others (see Tables 4.2 and 4.3).

The leachate also pollutes groundwater near landfills (see Table 4.4). Unfortunately, leachate is collected and processed at very few landfills in Ukraine. It is one of the reasons why these landfills are actually waste dump sites.

Table 4.2. Average characteristics of landfill leachate

Constituent	Average value
Leachate volume, m^3/ha per year	3000-6000
pH	7.6
COD, mg/l	2320
BOD5, mg/l	795
Chlorides, mg/l	1678
Sulphates, mg/l	1266
Ammonium, mg/l	236
Nitrites, mg/l	0.1
Nitrates, mg/l	7.7
Nitrogen, mg/l	104
Phosphorus, mg/l	2.9
Fluorides, mg/l	6
Cyanides, mg/l	0.2
Hydrocarbons, mg/l	1.1
Phenol	5.2
Arsenic, mg/l	34
Lead, mg/l	68
Cadmium, mg/l	11.5
Mercury, mg/l	2
Zinc, mg/l	510
Halogenated organic substances, mg/l	0.8

Table 4.3. Typical data on the composition of leachate from new and old landfills in the USA

Constituent	Value, mg/l		
	New landfills (less than 2 years)		Old landfills (greater than 10 years)
	Range	Typical	
BOD5	2000-30000	10000	100-200
TOC	1500-20000	6000	80-160
COD	3000-60000	18000	100-500
Total suspended solids	200-2000	500	100-400
Organic nitrogen	10-800	200	80-120
Ammonia nitrogen	10-800	200	20-40
Nitrates	5-40	25	5-10
Total phosphorus	5-100	30	5-10
Orthophosphorus	4-80	20	4-8
Alkalinity as $CaCO_3$	1000-10000	3000	200-1000
pH	4.5-7.5	6	6.6-7.5
Total hardness as $CaCO_3$	300-10000	3500	200-500
Calcium	200-3000	1000	100-400
Magnesium	50-1500	250	50-200
Potassium	200-1000	300	50-400
Sodium	200-2500	500	100-200
Chloride	200-3000	500	100-400
Sulphate	50-1000	300	20-50
Total iron	50-1200	60	20-200

Table 4.4. Concentrations of heavy metals and some anions in groundwater near landfills, Donetsk region, Ukraine, mg/l (2004 year)

Ion	**Cd**	**Fe**	**Mn**	**Co**	**Ni**	**Zn**	**Pb**	**SO_4**	**NH_4**	**NO_3**
Groundwater concentration	0.001-0.002	0.4-2.9	0.1-0.2	0.06-0.5	0.1-0.3	0.4-2.2	0.01-0.15	590-894	1.8-4.8	18.6-81.5
Limit value	0.001	0.3	0.1	0.1	0.1	1	0.03	500	2	45

If leachate passes through the soil to underground water level, then it contaminates this water, which can lead to environmental disaster.

The presence of highly toxic heavy metals in household waste is a great danger to the environment. According to the investigations, one kilogram of household waste contains:

up to 6 mg of arsenic,
up to 3000 mg of lead,
up to 50 mg of cadmium,
up to 2810 mg of chromium,
up to 1000 mg of copper,
up to 200 mg of manganese,
up to 189 mg of nickel,
up to 15 mg of mercury,
up to 4000 mg of zinc.

Therefore, one kilogram of household waste can contain from 285 to 11260 mg of different heavy metals. They are leached in the soil and underground water due to the influence of waste humidity and precipitation. Most of heavy metals can cause toxic effects (e.g., poisoning by mercury causes Minamoto illness). There are number of toxic effects caused by salts of zinc, cadmium or chromium. Besides, heavy metals compounds cause mutagenic effects on the human. It happens in two ways. On the one hand, such compounds disturb the chromosome apparatus of somatic cells, which can results in malignant tumours. On the other hand, if these compounds impact on reproductive system, they can cause persistent genetic mutations, which cause different forms of illness and mental disability of children.

Scientific studies have shown that the soil under landfills still remains contaminated for a long time after the landfill closure (about 2-2.5 times longer in comparison to the time being under the landfill).

It is clear that landfills are significant sources of environment pollution, including soil and water contamination and impact on residents of surrounding settlements. Therefore, there is an urgent need to attract public attention and mass media on the dangers posed by landfills.

Only companies providing complete waste neutralization and recycling can exclude the danger of pollution by waste and eliminate harmful effects of landfills.

Currently, there is a tendency not only to expand existing landfills, but also to open new landfills, which are considered as the cheapest way of household waste management. One who can not see the problem of municipal landfills, who considers the landfilling as the easiest and cheapest way of waste management, conduces to environmental degradation.

Unfortunately, the problem of waste management was ignored until nowadays. Ukraine is few decades behind such countries as Germany, Japan, France, USA, Italy and others in solving the waste problem. This situation must be changed as soon as possible.

4.2. Requirements for new landfills

Modern landfill is a complex and expensive technical construction with area of several dozen hectares and depth of few tens of meters. The bottom of the landfill is not just a ground layer but multilayered construction with mandatory collection and neutralization of leachate. The landfill gas collection is mandatory as well. Collected leachate has to be treated. Vertical gas wells are mounted of perforated ferrous-beton rings with diameter of 0.7 m. The distance from the road should not be more than 500 meters. The landfill bottom must have such soils as clay or loam. A groundwater should be at depth of more than 2 m, ground water springs should not exist. The possibility of at least 10 m height (or depth) waste disposal should be provided (for large landfills at least 20 m). The land area for the landfill is selected accounting the time of its exploitation (15-20 years). At the selected area the following works are performed: topographical research, geological research to determine soil filtration factor, hydrogeological research of precipitation. Landfills have to ensure environmental safety by six indicators: organoleptic, sanitary, phytoaccumulative, water-migratory, air-migratory and toxicological. The waste is disposed at landfills by layers. Compacted waste layer is covered the isolating layer of inert material with height not less 0.25 m. This layer protects the neighbour land users from blowing out the light fractions of household waste and decreases landfill gas generation and thus number of fires. The isolating layer should be compacted as much as possible. For this purpose it is advisable to provide waste transportation on this layer. The best materials for the isolating layer are well compacted loams and sandy loams with humidity 30- 50%. The use of construction waste and some types of inert industrial waste is also possible. Sand is not recommended to use. The clay layer of 0.5 m with a filtration factor less than 5-10 cm/s is a reliable measure for groundwater protection from the harmful effects of household waste leachate.

Landfill should have environmental technical facilities providing collecting of water and gas emissions generated in the landfill body.

These facilities are as follows:

- antifiltration membrane at the landfill bottom;
- drainage system for leachate collection;
- drainage system for directing the surface runoff from surrounding areas;
- system of pumping off and treatment of landfill leachate;
- drainage system for landfill gas collection;
- system of pumping off and treatment of landfill gas;
- system of impenetrable surface recultivative membrane.

The waste disposal process at landfills should be conducted by work areas, which allow fast and stage-by-stage carrying out the environmental measures, without waiting for the landfill operation finishing.

Monitoring of landfill influence on the environment includes four main stages:

- monitoring during construction;
- monitoring during waste disposal;
- monitoring during recultivation;
- monitoring after recultivation.

Depending on a landfill size the duration of each stage can be different. However after recultivation time period is determined, basically, by waste composition and properties. Actually it is ended when all basic processes of waste stabilization have been finished and landfill body has transformed from an alien body to a neutral component of the environment. For unprocessed household waste this period lasts 10-20 years.

Monitoring of landfill impact on the environment at all stages of its operation is one of the most important principles of waste disposal. In this regard, monitoring should be conducted not only during the landfill operation, but also during 10-15 years after its closure.

It is important to have conditions which obligate the landfill owner to eliminate the environment pollution by own efforts, even if such pollution is found few years after the landfill closure.

Nowadays, all the EU member states build landfills compliant with the legislation (but to different extension). On the other hand, there are significant quantity of old landfills which are not compatible with new legislation, and it will be difficult to close them in near future.

Majority of the EU member states have started composting and separate biowaste collection.

But the amount of accumulated household waste is still great. There are some measures in the form of separate waste collection introducing and use of processing plants. But in many cases, landfilling is the cheapest and easiest way. There are also problems of old landfills recultivation. Fee for household waste landfilling in the EU is relatively low (up to 60 euros/ton). It does not allow efficient household waste managing.

Modern landfills in the EU are equipped with processing facilities (sorting and restoring certain components, energy recovery, biogas plants).

4.3 Decomposition of waste at landfill

The analysis shows that household waste consists mainly (70-80%) of organic components which are disposed to decomposition in the conditions of landfills due to natural chemical and biological processes.

It should be noted that food waste is decreased in household waste and content of packaging materials (paper, cardboard, plastic, PET bottles) is increased.

The geological environment and especially the aeration zone at landfills are exposed to impact (development of ravines, landslides and areas of complex pollution). This confirms complex landfill affecting on all environment components near the nearby areas, which creates environmental risk of polluters penetration in a food chain and human body.

Precipitation, solar heat and warming of the landfilled waste contribute to unexpected physicochemical and biochemical processes inside the landfill. There are toxic chemicals in liquid, solid and gaseous state among the resulting products. During the storage at landfills waste is able to transform to other substances with other physic-chemical and toxic properties. This leads to appearance of new environmentally hazardous substances at waste disposal sites, which can be a serious threat to the biosphere and human existence. Ways and mechanisms of such influence are complex and poorly researched.

The low-molecular organic compounds are formed as a result of hydrolysis. During few weeks they pass the oxygen-nitrate oxidation stage and decompose under aerobic conditions to water, carbon dioxide and nitrogen. The temperature inside a landfill is increased when these processes occur.

Under anaerobic conditions the decomposition of hydrolysis products occurs. The duration of this stage is from 1 to 6 months. Organic compounds are destroyed to low-molecular acids as a result of fermentation and sulphates recovery processes (e.g., acetic acid is formed). Also carbon dioxide and hydrogen sulphide are formed and small amount of methane is released. The intermediate products (carbon acids and alcohols) are formed during this process.

When the landfill gas emission is decreased, the last stage of organic waste decomposition (humus formation stage) starts. The duration of this stage is up to 40 years. Different stages of organic waste decomposition processes are shown in Fig. 4.1 (without specifying stages time-scale).

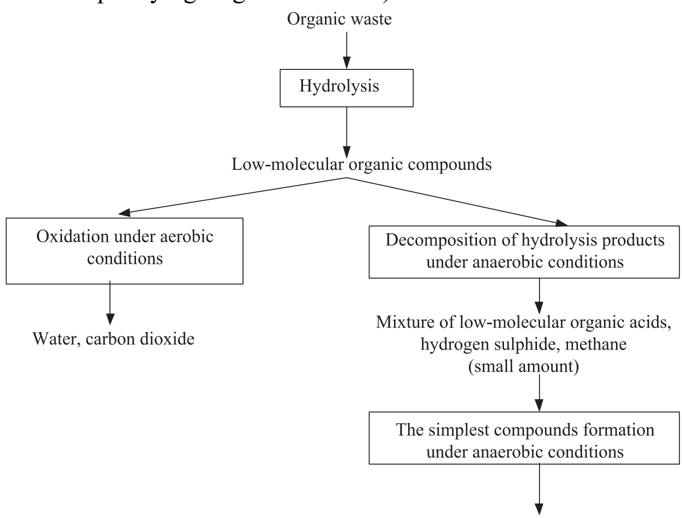


Figure 4.1. Processes of organic waste decomposition

Biochemical degradation of organic compounds in landfill body corresponding to stages of organic waste decomposition (Fig. 4.2) can be understood by the following theoretical explanations.

The formed compounds can be used by methane bacteria to produce methane. The stage of anaerobic decomposition of organic compounds lasts for 8-40 years. Methane formation occurs steadily in first three years.

The waste covering by layers of inert soil both protects the atmosphere from pollution and terminates the oxygen access to waste inside the landfill body. However, household waste is a porous material, so air reserves in the pores are enough for aerobic processes in landfill body for a first time (3 months). The warming of landfill body to temperature of 20-40°C is observed. The main products of aerobic processes are carbon dioxide and water. Gradually, oxygen reserves in the pores of waste is decreased and aerobic processes activity slows down. The anaerobic processes caused by the activity of anaerobic microorganisms begin to dominate in landfill body. These processes are slow and occur mainly in food waste and other organic compounds. Anaerobic bacteria do not use molecular oxygen of air for organic compounds oxidation, but obtain the necessary for life energy from organic compounds decomposition.

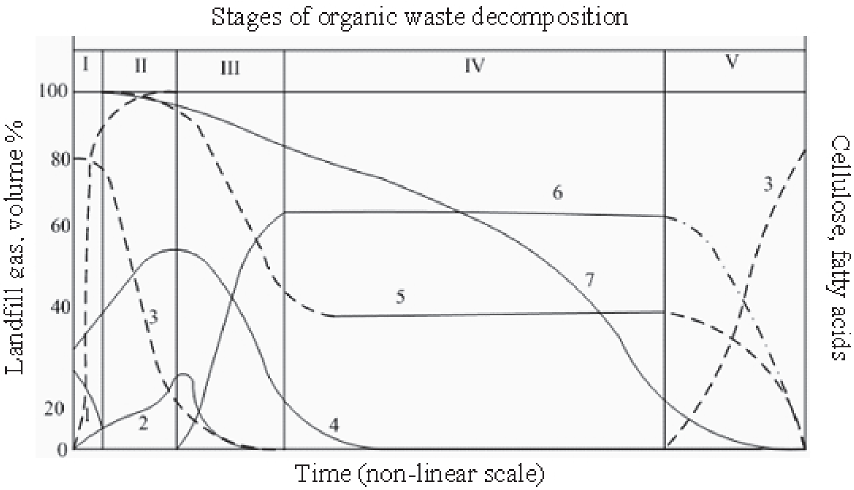


Figure 4.2. Stages of organic waste decomposition:
I − stage of oxidation under aerobic conditions, II − stage of decomposition of hydrolysis products under anaerobic conditions, III − stage of unstable methane formation, IV − stage of methane formation, V − stage of humus formation;
1 − oxygen, 2 − hydrogen, 3 − nitrogen, 4 − fatty acids, 5 − carbon dioxide, 6 − methane, 7 − cellulose.

These processes are called anaerobic fermentation. Anaerobic fermentation is a complex of biochemical processes transforming organic compounds of waste to stable products. As a biochemical process it is limited by microbial populations and environmental factors and can be conditionally divided into several stages.

Theoretically, anaerobic biochemical reactions occurring in landfill body without oxygen access can be presented as follows:

first stage

$$\underset{cellulose}{(C_6H_{10}O_5)n} + nH_2O \xrightarrow{microorganisms} \underset{glucose}{n(C_6H_{12}O_6)}$$

At the first stage high-molecular compounds are decomposed to low-molecular compounds by biochemical decomposition (hydrolysis).

second stage

$$\underset{glucose}{n(C_6H_{10}O_6)} \xrightarrow{microorganisms} 2\underset{ethanol}{n(CH_3CH_2OH)} + 2n(CO_2) + 57kcal.$$

The fermentation without oxygen access leads to the formation of ethanol, carbon dioxide and the releasing of small heat amount (12 times less in comparison to aerobic process). Therefore, unlike the rapid decomposition under aerobic conditions, the decompositions process under anaerobic conditions is rather slow and lasts for a long time.

third stage

$$2\underset{ethanol}{n(CH_3CH_2OH)} + nCO_2 \xrightarrow{microorganisms} 2\underset{acetic\ acid}{n(CH_3COOH)} + \underset{methane}{n(CH_4)}$$

At the third stage further decomposition of organic compounds by microorganisms occurs. Organic acids and their salts and small volumes of methane are formed. In the real conditions of household waste decomposition the following compounds of small volumes are also formed: hydrogen sulfide, ammonia, hydrogen and other gases.

fourth stage

$$2\underset{acetic\ acid}{n(CH_3COOH)} \xrightarrow{microorganisms} 2\underset{methane}{n(CH_4)} + 2n(CO_2).$$

The fourth stage called methane fermentation includes organic compounds transformation to methane and carbon dioxide, as well as methane producing from a free carbon dioxide and hydrogen. Methane bacteria can exist only under anaerobic conditions. For their reproduction more time is needed in comparison to acid-forming bacteria. Speed of anaerobic fermentation depends on the metabolic activity of methane bacteria, which in turn depends on:

- temperature (optimal is 33-54°C);
- C / N ratio (optimal in the range of 10-16);
- pH value (optimal is 6.5)

- other external conditions, such as the presence of heavy metals, ammonia, nitrates, sulphates, antibiotics and others in household waste.

In the case of deviation from the above mentioned optimal conditions, the formation of volatile acids is increased and methane generation is decreased.

4.4 Collection, treatment and neutralisation of leachate

According to researches, majority of landfills in Ukraine do not have leachate treatment and it flows to nearby water bodies. Leachate is collected in specially designed storage ponds at some landfills. The bottom of such ponds often has close contact with aquifers. In such cases the "leachate pond" is very dangerous due to leachate infiltration to underground water through the bottom.

For protection the groundwater and surface water from contamination by leachate, the following measures take place when new landfills are constructed in Europe:

- pumping off the leachate from a landfill body, followed by its transportation to wastewater treatment facilities;
- use of multilayer covering for the bottom and slopes of the landfill bowl.

According to the European Union regulations, multilayer anti-filtration coverage must contain the following layers:

- lower layer of coverage is compacted clay layer with thickness of at least 0.5 m; the thickness of lower layer, quantity of inter-layers and the degree of each layer humidification are determined by the calculation depending on the physical and mechanical properties of clay available in the area of landfill construction, as well as on the weight of construction facilities. In the absence of clay it can be replaced by artificial anti-filtration materials (defined by project organization);
- lower intermediate drainage is made of sand-gravel mixture and it is intended for collecting and transferring of leachate leaked through the main film coverage when it is damaged;
- central layer of coverage is made of stabilized polyethylene film with thickness of 2 mm;
- upper drainage layer above a polyethylene film is made of sand-gravel mixture and it is intended for collecting and transferring of leachate. The upper drainage layer includes perforated drainage pipe network for draining the leachate to the pits, where pumps are installed for pumping off the leachate outside the landfill body. The whole system of the lower intermediate drainage and leachate pumping has a duplicate function and operates only in emergency situations when central film coverage is damaged. The fractional composition of sand-gravel mixture is defined by project organization calculation based on the original material;
- upper transition layer laid on upper drainage to protect it from silting. This layer is made of artificial porous tissues, lets liquids flowing through and holds suspensions.

The multilayer coverage construction complying with the European Union regulations and leachate pumping scheme are shown in Fig. 4.3.

Analysis of leachate contamination indicators shows that the range of chemical compounds concentrations making up the leachate is quite wide. High salinity and high concentration of chlorides are characteristic leachate features of landfills that are under long-term operation.

The chlorides content can be used as indicator of natural water bodies pollution to determine the effect of waste disposal sites.

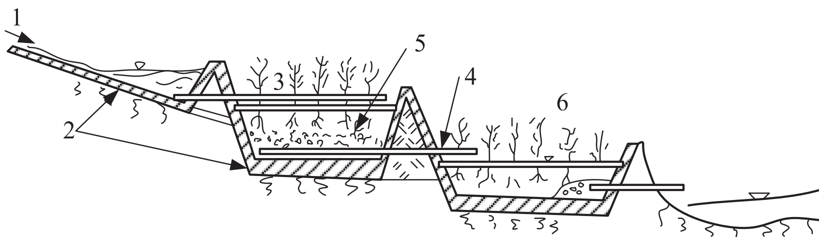


Figure 4.3. Scheme of wastewater treatment facility of "Bioplateau" type:
1 − surface flow input for treatment; 2 − coverage for groundwater protection from pollution;
3 − perforated pipe of wastewater supply in section of infiltrative bioplateau; 4 − perforated pipe for reception of wastewater passing through biofilter, and flowing to the next section;
5 − biofilter; 6 − aquatic plants.

Heavily contaminated landfill leachate is not a favourable environment for bacteria. At the same time, values of COD and BOD indicate on high level of leachate contamination by organic compounds, which in favourable conditions can act as a nutritional medium for pathogenic microorganisms and leads to its reproduction. Therefore, the treatment of landfill leachate is very important. Taking into account that leachate is contaminated both by organic compounds and by salts, there is no the only method of leachate treatment.

Nowadays, leachate transporting by special vehicles from landfills to wastewater treatment plants is widely spread in Eastern Europe. According to calculations, daily leachate input of 20 m^3 to the treatment facilities with capacity over 200000 m^3 per day does not cause much change in the concentration of pollutants in the wastewater and it does not affect the operation of treatment facilities.

In the European Union and the United States landfill leachate is treated at local wastewater treatment facilities located near landfills.

The scheme of biological leachate treatment by Bayer−Turmbiologie method is shown in Fig. 4.4. Such a scheme is used for leachate treatment on facility with capacity 600 m^3/day at the landfill near Cologne (Germany). Earlier, before the construction of such facility, the leachate was transported by special vehicles to city Cologne wastewater treatment plant.

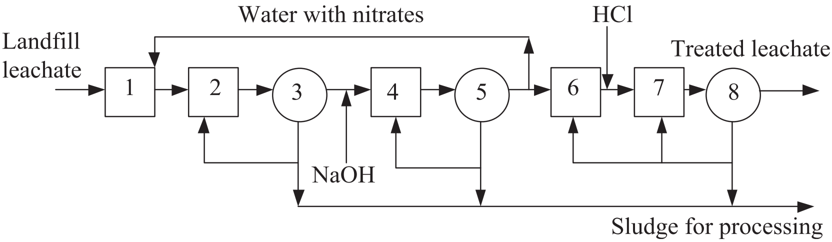


Figure 4.4. Scheme of biological leachate treatment by Bayer−Turmbiologie method: 1 − receiving reservoir, 2, 4 − tower tanks of initial denitrification, 3, 5, 8 − decanters, 6, 7 − tanks of final denitrification.

More perfect scheme of leachate treatment is biological treatment scheme, similar to the above mentioned one, but with additional treatment by methods of ultrafiltration and absorption by activated carbon (see Fig. 4.5).

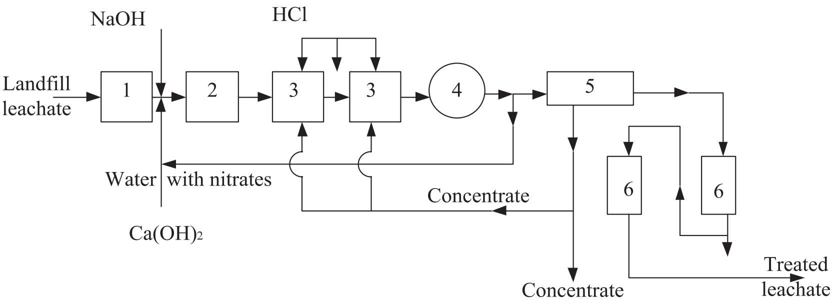


Figure 4.5. Scheme of biological leachate treatment with additional treatment by methods of ultrafiltration and absorption: 1 − receiving reservoir, 2 − denitrification tank, 3 − nitrification tank, 4 − decanter, 5 − ultrafiltration, 6 − filters with activated carbon.

Table 4.5. Basic parameters of leachate treatment facilities operation

Parameter	Concentration	
	Input	output
BOD5, mg/l	60	10
COD, mg/l	600	100
NH_4-N, mg/l	420	10
NO_3-N, mg/l	20	35
NO_2-N, mg/l	20	5
Cl^-, mg/l	20000	Data not available
SO_4^{2-}, mg/l	1300	Data not available

There are facilities in Western Europe for leachate treatment by the scheme presented in Fig. 4.6.

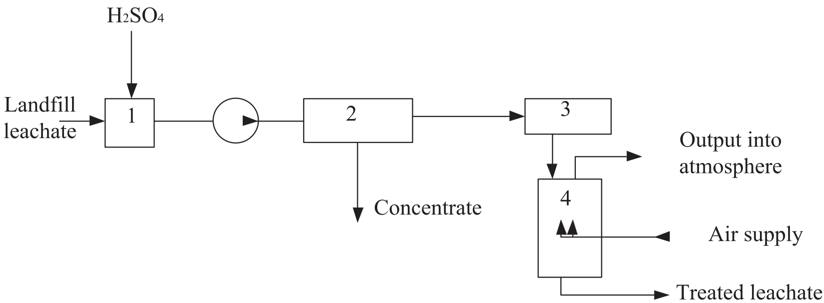


Figure 4.6. Scheme of landfill leachate treatment by reverse osmosis method: 1 − receiving reservoir, 2 − reverse osmosis installation, 3 − treated leachate collector, 4 − degasser.

The degree of leachate treatment are as follows:
BOD − from 2100 to 5 mg O_2/l;
COD − from 7300 to 15 mg O_2/l;
Cl^- − from 3010 to 20 mg/l;
NH_4^- − from 1300 to 10 mg/l.

4.5 Collection and utilization of biogas

Landfill gas (or biogas) is generated as a result of anaerobic decomposition of organic waste. In the total volume of methane emitted into the atmosphere every year, about 40-70% is formed as a result of human activity, including more than 20% connected to waste disposal sites.

It is estimated that one ton of household waste can generate 200-300 m^3 of biogas.

The main components of biogas are as follows: methane − 40-75% (usually 50-60%), carbon dioxide − 30-40%, nitrogen − 5-15%, oxygen − 0-2%, hydrogen sulphide and other toxic compounds (small volumes).

Biogas contains gases having properties harmful to human health. Depending on the level of biogas emissions into atmosphere and degree of its dilution by air, landfill gas can cause toxic effects in all live organisms.

The root systems of plants at the landfill surface are exposed to the same harmful effects of landfill gas, which can lead to delays of their growth and even death.

The hollows in a landfill body formed due to unequal waste decomposition can accumulate biogas. In this case there is a real danger of explosion (7-15% methane mixture with air is explosive).

Methane and carbon dioxide are greenhouse gases. This requires the measures to limit their emissions to the atmosphere.

Taking into account the above mentioned, for air and human health protection and for preventing the explosions, the landfill gas must be collected preventing its getting into the atmosphere.

One ton of household waste containing about 50% of organic compounds during period of decomposition under anaerobic conditions can generate from 175 to 300 m^3 of biogas depending on external conditions. Knowing the waste volume at landfill one can predict the biogas volume formed by the waste decomposition. For example, the landfill with 20 million tons of accumulated household waste can be a source of $3.5 \cdot 10^9$ to $6 \cdot 10^9$ cubic meters of biogas emission. The industrial biogas collection can be started not earlier than two years after waste disposal and biogas should be burned as a torch during these two years. The industrial biogas collection is increased while waste is disposed and reaches a maximum at the last year of active landfill operation. During passive landfill operation (after the end of waste disposal) biogas generation is gradually declined and reaches the minimum in 12-15 years after the landfill closure. Since then, the flaring of residual biogas should be used.

Landfill gas is a low-energy fuel, because beside methane there is a large amount of carbon dioxide in the gas composition (50%).

Depending on the methane content, biogas has heating value from 15 to 20 MJ/m^3, corresponding to half of the natural gas heating value.

Biogas also influence on climate change and countries are obligated to minimize emissions of greenhouse gases such as methane, which is equivalent to 25 m^3 of carbon dioxide by environmental consequences for the climate change. In this regard, reduction of biogas emissions into the atmosphere provides not only improvement of environmental situation near the landfill, but it also helps to fulfil the international obligations.

Biogas also has negative impact on plants, depressing them at areas adjacent to a landfill (mechanism of impact is connected to saturation of the soil pores by biogas and the displacement of oxygen).

The negative impact of biogas on the environment in most developed countries has led to legislative forcing the landfill's owners to prevent spontaneous distribution of biogas.

The technologies of biogas collection and utilization became widespread in the last few decades. For example, about 35 million m^3 of biogas per year was generated in Germany at landfills. This allowed producing 140 million KWh of electricity annually and saving 14000 tons of oil per year. On the Ukrainian landfills biogas is mainly not collected.

Many countries have developed different technologies for production of "pure" methane (e.g., for motor oil) and "pure" carbon dioxide from biogas.

Vertical wells, pipelines and compressor stations are used for biogas collection. They provide gas supplying to the motor-generator (when using the biogas for electricity generation). The compressor creates the necessary dilution to collect biogas and transport it by pipelines (see Fig. 4.7).

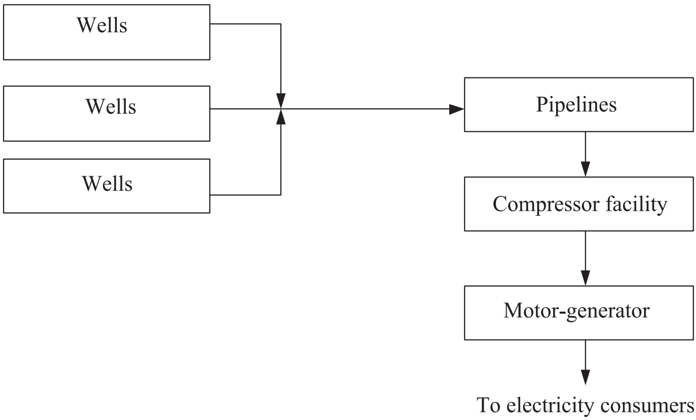


Figure 4.7. Scheme of biogas production and utilization

According to experience, drilling of wells with diameter of 250-300 mm is the most advisable (for comparison the wells with diameter of 150-200 mm are drilled in Sweden).

According to European data, the average biogas output from well with depth of 10 m is 10-20 m^3 per hour. The stable well operation is provided if volume of pumped biogas does not exceed the volume of generated biogas. It is calculated that 15-20 wells drilled in the landfill body are required to provide 1 MW of power. The biogas output control is done by speed control of compressor.

The distance between gas wells at landfill site is typically 50-60 m. If quantity of gas wells at waste disposal site is optimal and landfill slopes are compacted, the collected biogas volume is up to 80% of total generation. If biogas is collected on so called bio-areas with uniform waste (European requirements), then level of biogas collection rises to 90%.

Fig. 4.8 shows a general view of wells for biogas collection.

The biogas well operation includes several stages. At the first stage the perforated steel or plastic pipe is moved down in the well. This pipe is closed from a down side and provided by flanged connection in the wellhead part.

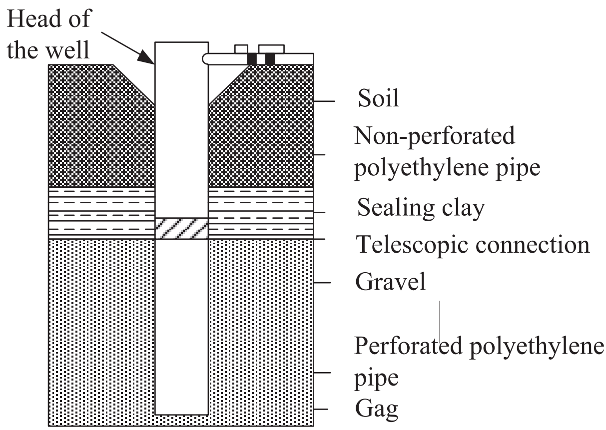


Figure 4.8. General view of well for biogas collection

Then the space between pipes is filled by porous material (e.g., gravel) with layer-by-layer compacting to a depth of 3-4 m from the wellhead. 3-4 metres of clay lock is constructed at the next stage to avoid air coming to the well. Then the wellhead is installed. The wellhead is a metal cylinder provided by gas-inrush facility for regulation the well production rate and controlling the biogas composition, as ell as by pipe for well connection to the pipeline.

The casing pipes are used in Sweden for wells mounting (Fig. 4.9). After installing the perforated plastic filter these pipes are partly removed from the landfill body. The 3 metres-length lower section of the casing pipe remains at 1,5-4,5 m below ground level and the isolating coverage with height of 4.5 m is constructed above the upper part of the filter. It creates a relatively high dilution around the well and increases the efficiency of biogas collection. According to Swedish practice, there are some operational difficulties during biogas collection at existing landfills. During the first ten years some of gas wells and filters have to be updated (pipes destruction under the influence of waste subsidence, filter pipes corking). The scheme of wells arrangement at high-filled landfill in Sweden is shown in Fig. 4.10.

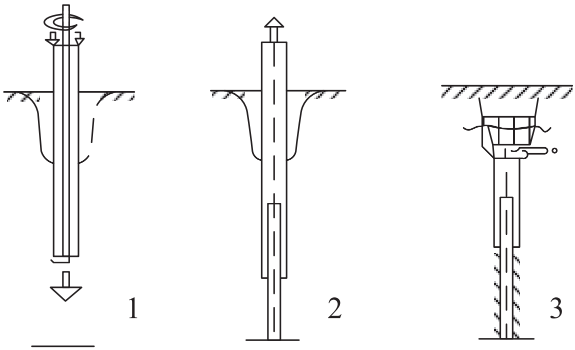


Figure 4.9. Construction of gas wells (The European practice)

The temperature of generated biogas corresponds to the landfill body temperature, which is increased to 25-40°C under anaerobic decomposition of organic compounds. Since household waste is characterized by high humidity, biogas is saturated with water vapour. When temperature of biogas is decreased to 10°C, then up to 20 g/m^3 of condensate is produced in the gas pipelines system. There are 100 litres of condensate generating daily in 1 MW installation. This condensate must be removed from the biogas collection system and sent to treatment, since it is very similar to leachate by chemical composition. The incline of gas pipes at landfill should ensure the condensate collection (according to European practice, the incline of pipes is at least 20%). For humidity removal from the system the facility for drawing out of condensate are set (steel tanks with hydro gates).

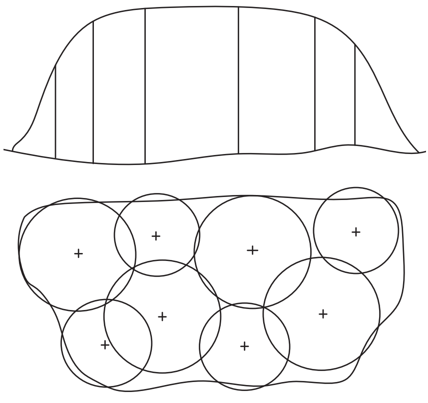


Figure 4.10. Scheme of gas wells arrangement on high-filled landfill

Biogas generated at landfills is mainly used to produce electricity. From 1 m^3 of biogas it is possible to produce 1.5 kWh of electricity. Unfortunately, the big energy potential of landfills is currently not used. At the same time, in developed countries the electricity producing from biogas is stimulated by the state through special laws. For example, there are laws in the US and the EU obligating the energy companies to use alternative energy sources. These laws also obligate the consumers to buy alternative energy. The cost for alternative energy is typically 2-2.5 times higher in comparison to the cost of energy produced from traditional energy resources (gas, oil). In some cases, the electricity produced from biogas is partly or fully used for the needs of the company operating the landfill.

The traditional form of biogas utilization in Sweden is its combustion in gas boilers for heat producing. Gas boilers are often connected to the local heating system. Sweden also has the experience of biogas utilization for combined production of electricity and heat in stationary gas engines.

In cases of difficulties with biogas utilization (e.g., due to long distances to the consumer), collected biogas is burned in special gas burners. Biogas flaring should be considered as an emergence and temporary measure, which reduces biogas emission into the atmosphere and reduces the probability waste self-burning at landfills.

4.6 Landfill closure

Landfill has to be closed for waste disposal after reaching the level specified in the project. At large landfills with operation time not less than 5 years it is allowed 10% exceeding of projected level.

The last layer of waste before landfill closure is covered with a layer of soil for further recultivation.

Protection coverage arranged above upper layer of soil at landfill is the basic element providing environmental safety. Protection coverage is a combination of isolation and filter elements for the collection and taking out of leaked surface water, precipitation and biogas.

The protection coverage is built according to following order. First, some roughness on the landfill surface is carefully flattened. Then the overall planning of the entire surface is performed with a slight slope to the edges of the landfill. Then the levelling layer of mineral soil or purified construction waste with thickness of at least 0.5 m and diameter 4-32 mm is sprinkled.

If gas is still generated in the landfill body, then the layer of gas-pervious material (e.g., sand) with thickness not less than 0.3 m is laid above the levelling layer.

Then the anti-filtration layer is installed above the gas-pervious layer. It consists of two layers of clay (each with thickness of 0.25 m) and layer of artificial rolled isolation with thickness not less than 2.5 mm. For the construction of anti-filtration coverage the clay with filtration index at least $5 \cdot 10^{-10}$ m/s is used. The final construction of the landfill isolation layer depends on the direction of recultivation.

The outer slopes of landfill are strengthened from the beginning of landfill operation with increasing the waste disposal height. The material for the outer slopes strengthening is the soil removed from the landfill bottom and other fertile soils.

For outer slopes protection from erosion they are planted by plants: at first stage by grass sowing immediately after laying the fertile soil layers.

Recultivation of closed landfills is a complex of operations aimed at restoration of productivity and economic value of restoring areas and at improving the environment.

Recultivation takes place after the end of closed landfill stabilization, that is after strengthening and reaching the constant, stable state of landfill soils. The time of such processes are specified in the Table 4.6.

Table 4.6. Time of closed landfills stabilisation for different climate zones, years

Type of recultivation	**Climate zone**		
	southern latitudes	**middle latitudes**	**northern latitudes**
Sowing of perennial grasses, creation of pasturages, haymaking, lawns	1	2	3
Planting of bushes and trees	2	2	3
Creation of gardens	10	10	15

The direction of recultivation defines further targeted use of restored territory. The most suitable for closed landfills are agricultural, forestry, recreational and constructional directions of recultivation.

Agricultural direction of closed landfills recultivation is used if the landfill is situated in the zone of land using or agricultural company. The purpose is to create arable lands, haymakings, pasturages or gardens on the areas disturbed in the process of landfilling. When using the agricultural direction of recultivation, the vegetables and fruits growing, as well as gardening are allowed 10-15 years after the landfill closure. Creating of pasturages and haymakings is allowed 1-3 years after the landfill closure.

Forestry direction of recultivation is creation of forest plantations of different types on the areas disturbed by landfills. Afforestation involves the creation and growing of trees for meliorative, anti-erosion, field protective, and landscape using 2-3 years after the landfill closure.

The thickness of the upper isolating layer at closed landfills, which can be used in the future for some non-productive open-air buildings, should be not less than 1.5m.

Recreational direction of closed landfills recultivation is possible after the landfill soil covering by the coverage consisting of: levelling layer of inert material, gas- and water-proof layers, drainage layer, protective layer of potentially fertile soil, fertile soil, and installation of gas wells for biological stage of recultivation.

Constructional direction of closed landfills recultivation is possible only after removal of all landfill soil. Construction of residential buildings at the territory of closed landfill is not allowed without landfill soil removal. When landfill soil is removed, construction of residential buildings can be allowed only after appropriate sanitary-bacteriological research.

Landfill recultivation is performed in two stages: technical and biological recultivation.

Technical recultivation stage involves research of landfill soil and its impact on the environment, as well as preparing the landfill site to further usage.

Biological recultivation stage includes measures for restoring the landfill areas for their further usage. These include a complex of agronomic and phytomeliorative measures for disturbed areas restoring. The technical stage is followed by of biological stage of recultivation.

The project and cost calculation documents are developed for the recultivation. The next documentation is obligated:

1. Topographical plan of landfill at the beginning of the recultivation; the landfill plan after recultivation; vertical planning.
2. Scheme of landfill soil movement in case of its removal; the technology of recultivation.
3. Explanatory note including characteristics of the landfill soil, materials and technical facilities used in the degasation system.
4. Qualitative and quantitative characteristics of plants and fertilizers.
5. Cost calculations.

The main input data for the recultivation project are as follows: year of landfill operation start; year of landfill closure; type of waste accepted (household, industrial, construction); the distance from the landfill to the nearest objects; total area of alienated land; area occupied by waste; the total waste volume; height of waste layer (including height above ground level); the type of top layer of isolating material (soil, slag, construction waste, etc.); the thickness of the upper isolation layer; characteristic of the territory where landfill is situated (forest, swamp, field, ravine, pit, residential area, etc.); affiliation of adjacent areas; predicted use of the area; the distance from the soil disposal site to closed landfill; self-overgrowing of landfill; plants species; bushes species; trees species; grass density; age of trees.

During the recultivation slopes are aligned and taken out, and potentially fertile soil is transported to the closed landfill. This soil is laid on the landfill surface layer by layer, creating recultivation layer and technical stage of recultivation is ended.

The thickness of potentially fertile soil is chosen depending on the further use of closed landfill: arable land – 0.7 m; haymaking – 0.6 m; shelterbelts – 1-2 m. The thickness of fertile soil is as follows: arable land – 0.3-0.4 m; haymaking – 0.2-0.3 m; shelterbelts – 0 m.

Technical stage of recultivation involves the processes of stabilization, aligning and terracing, construction of degasation system, creating multifunctional recultivation coverage, transferring the area for biological recultivation stage.

If the landfill rises above ground level more than 1.5 m, then its outer slopes are aligned, for high landfills the terraces are constructed on the slopes.

The outer slopes of landfill are aligned by moving the landfill soil from the top landfill edge toward the bottom edge by consecutive steps. During the high landfill recultivation the combination of terracing and aligning of outer slopes surface is used. Terraces are arranged every 10 meters on landfill height. The width of terrace should be at least 3 m.

The characteristics of outer slopes are defined depending on the further use of the area formed after the landfill closure. The inclines of slopes are as follows: for crops growing – 2-3º, for meadows and pastures – 5-7º, for gardens – 11º, for forests planting – up to 18º. The inclines of outer slopes used for organization of recreation areas, ski hills, etc., should be up to 25-30º.

The top recultivation layer of closed landfills consists of potentially fertile soil and layer of fertile soil. The light, medium or heavy loam without gravel-stone inclusions and other non-toxic rocks are used as artificial underlying layer.

The fertile and potentially fertile soils at closed landfills are taken from places of their temporary storage or other places of their possible formation. These soils are transported by vehicles and in some cases by scrapers.

After the end of technical stage the biological recultivation stage begins. The duration of biological recultivation stage is approximately 4 years and includes the following operations: selection of perennial grasses, soil preparation, planting and care for plants.

When sowing the grass mixture of two components, the seeding norm is reduced by 35%, while sowing grass mixture of three components – by 50% of each herb species.

In the first year of biological recultivation stage the soil preparation includes disking to a depth of 0.1 m, introducing the main fertilizer and before-seeding soil compacting. Then separate-row sowing of prepared grass mixture consisting of two, three or more species is carried out. The grass mixtures are chosen by condition of good area sodding of recultivated landfill, taking into account their resistance to frost and drought, longlife, quick growth after cutting.

During the sowing small seeds are putted on a depth of 1-1.25 cm, and big seeds – 3-4 cm. The distance between the rows of the same name is 45 cm, and between the general rows – 22.5 cm.

The care of crops at the first year includes periodic irrigation to soil humidity up to 35-40%, mowing to a height of 10-15 cm, and introducing the mineral fertilizers with subsequent harrowing to a depth of 3-5 cm.

In the next (second, third and fourth) years the care of perennial grasses growing includes the following operations: in the spring: introducing the nitrogen fertilizers and harrowing to a depth of 3-5 cm; in the summer: grass mowing to a height of 5-6 cm and introducing the mineral fertilizers (140-200 kg/ha) followed by harrowing to a depth of 3-5 cm and a one-time irrigation (200 m^3/ha).

4 years after grass sowing the area of recultivated landfill is transmitted to a relevant organization for further land use. The scheme of park forming during the landfill recultivation is shown in Fig. 4.11.

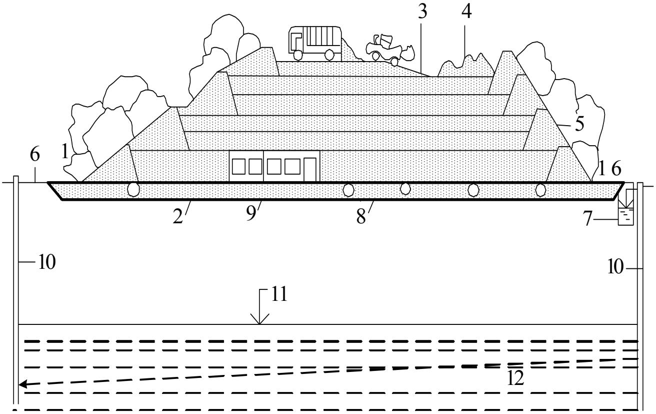


Figure 4.11. Scheme of park creating on the landfill near Gelsenkirchen (Germany) during the recultivation:
1 – ditch for leaked water draining, 2 – basic coverage (mineral material),
3 – construction of "mountain" layer-by-layer, 4 – soil for filling, 5 – decorative “green” protective wall, 6 – ring road, 7 – filtration mine for leaked water, 8 – surface drainage (30 cm of gravel), 9 – entrance control and weight, 10 – wells for groundwater monitoring,
11 – groundwater level, 12 – groundwater flow direction.

The possibility of plants growing on contaminated or gradually contaminating soil depends on the following factors: first, when recultivating such objects, one should choose the plants the most resistant to a specific type of pollution, which grow well in extreme conditions of air and soil pollution and thus fulfil the phyto-hygienic role; second, when growing plants, it is important not only to chose plant species resistant to contamination, but these plants are also required to have a possibly to clean a soil from pollutants (phytomelioration function).

In practice, eliminating sources of further soil contamination, restoring the area and growing the plants resistant to pollutants, it is possible to reduce gradually the content of contaminants in the soil due to the natural processes of self-cleaning. Some contaminants are taken out the soil by the plants, and some of them are washed out.

Growing the plants resistant to contaminants is recommended at areas of landfills influence, which are intended to plant the parks or shelterbelts.

The biological stage of disturbed areas recultivation is used mainly in the final phase of the land restoration after putting a layer of relatively clean soil or after introducing chemical meliorants.

Annual and perennial grasses mixtures with non-deep root system are intended for planting alleys, but they are limited to use as haymaking requiring the preliminary soil restoration to a depth of at least 40 cm.

When restoring the land to a depth of 60 cm, these areas can be used for afforestation and shelterbelts planting. During forestry recultivation it is advisable to plant forests having economic, defensive, sanitary-hygiene, and recreational functions.

Phytomelioration is carried out as follows:

1. The fertile layer is created.

2. The agro-technical operations are conducted (soil processing, fertilizers preparation and their introducing into the soil with subsequent harrowing by two traces, pre-seeding compacting, preparing grass mixtures and sawing of landfill surface).

3. Sawing the phytomeliotants in four stages:

- first: plowing, disking and cultivating the soil before test sowing;
- second: test grass sawing to assess the residual soil phytotoxicity;
- third: the level of seed rising in the soil is checked (it is repeated if negative result is obtained);
- fourth: grass sowing 1.5-2.5 years after the landfill closure, if the test grass sowing is successful on at least 75% of the area.

4. Sod-forming grasses are sowed after pre-seeding soil processing using separate-row sowing of prepared mixture consisting of two, three or more components (seeds for grass mixture are selected taking into account the condition of good sodding of recultivated landfill area).

5. The grasses assortment, tree and shrub species able to grow on contaminated soils is selected. The soil bio-suitability and the location of the recultivated area, biological properties of plants, planting purpose, and features of previous restoration operations are taken into account.

6. The assortment of tree and shrub species for parks is selected. They should be resistant to environmental pollution under urban conditions. The possibility of restoring areas usage as a park, location of areas, biological properties of plants, and plantation purpose are taken into account.

7. The mixed park plants are formed and planted.

8. The dividing zones consisting of shrub-grassy plants and having a width of 10 meters are created (at the same time they serve as fire protection zones).

9. The dividing zones can involve small water bodies required for amphibians settlement.

10. At the watersides the water-regulating and soil-protecting plants are arranged. At the borders of dividing zones the fruits and berries shrubs are planted to accelerate the settlement by useful animals.

The duration of biological recultivation stage is 2-5 years or more, depending on soil and climate conditions, the level of initial contamination and pre-treatment of the area. The plants used for recultivation should be of tested local populations. The plants should quickly acclimate, be resistant to adverse climate conditions (or adverse physical and chemical properties of the soil), have a strongly developed root system, have the ability to symbiosis with microorganisms.

To form environmentally stable plants, the parks of mixed plants are created: up to 60% – main species, 20% – associated species, up to 20% – shrubs. Every 200-300 metres the dividing zones of shrub-grassy plants (10 m width) are created.

It is prohibited to use the plant products grown on contaminated soil as food or feed before recultivation is completed.

4.7 Decreasing of landfills negative impact

When developing the treatment methods of area contaminated by waste, the scientific research aimed at implementing new ideas is needed. The variety and complexity of the tasks do not allow producing general recommendations. Each case requires its own specific strategy. However, there are several fundamental treatment technologies based on hydraulic, biological, physical, physic-chemical and other methods, which can be combined in two directions.

First. Contaminants removal by landfill soil replacing. The technology of soil replacement requires its removal and transportation to specially prepared landfills for re-disposal or to the place of processing. Due to a lack of suitable areas the landfill soil is re-disposed extremely uncommon and it is not planned to do in the future.

Second. Localization and prevention of spreading the pollution from a landfill. To do this, different technological methods are used: different methods of toxic substances dissolution and extraction, washing out, heat treatment, ozonation, filtration, vitrification and other physic-chemical methods.

The landfill soil is neutralized using mobile installations at the place of disposal or stationary at specialized companies.

One of the methods of old landfill neutralization without removing the landfill soil is harmful substances removal using the transport medium (gas or water) by air sucking through landfill soil or by hydraulic method. When sucking the air through landfill soil, the easy-volatile compounds are removed. The application of this method is limited in weakly bound and sandy low water-saturated soils, which requires the protection coverage construction on the entire landfill surface. The air sucked through the vacuum well is cleaned by filter with activated carbon before emitting into the atmosphere.

Let us consider the example. When neutralizing the landfill, where soil was contaminated with polychlorinated biphenyls, easy-volatile chlorine hydrocarbons contained in plant oils, the air sucking is the first stage. The second stage is microbiological treatment. At the initial contamination by 175 mg of chlorine hydrocarbons per 1 kg of soil, the concentration has decreased to 1 mg per 1 kg of soil after neutralization. The content of chlorine hydrocarbons in the sucked air passed through activated carbon filter has decreased to 0.01 mg per 1 m^3.

The hydraulic method is used when the substances polluting a landfill soil are dissolved in water or groundwater contamination takes place. Further spread of harmful substances is localized by creating a going down funnel and pumped water is cleaned from impurities. To do this, pump and water intake wells are created in the direction of groundwater flow. Pumped groundwater after the treatment (activated carbon, biological method or extraction) is used for irrigation the landfill area.

For the use of this technology, the hydro-mechanical characteristics of pollutants, water and air in the landfill body must be known. Chlorine hydrocarbons are removed from groundwater in this case by two-stage installation for light fractions distillation.

If the soil contains microbiologically soluble substances (aromatic, aliphatic and other hydrocarbons contained in plant oils), then after pumping and cleaning of groundwater and leachate the landfill soil is treated by microbiological method.

The presence of mixed pollutants in landfill soil (both organic and inorganic) requires the use of physic-chemical methods of treatment. The mobile installations with a capacity of 30 m^3 per hour used in this case are able to neutralize soils contaminated with heavy metals, polycyclic and aromatic hydrocarbons.

The physical method of neutralization is the technology of contaminants washing out using organic solvents, surfactants or steam.

The technologies of biological treatment of landfill soil are based on the possibility of hazardous substances destroying. There are many types of bacteria, actinomycetes and fungi able to destroy organic compounds. The main influence on the destruction rate are provided by temperature and humidity of environment or landfill body, the presence of oxygen, carbon, nitrogen and phosphorus (essential elements for microorganisms), and their ratio. Since bacteria as a source of nutrients can use only liquid biodegradable compounds, the landfill soil should have enough humidity. In practice, the biological neutralization is carried out by increasing the activity of microorganisms available in the landfill body.

If it is impossible, the soil is put in special containers after previous processing. The efficiency and reducing the duration of microbiological decomposition are influenced by (along with the availability of sufficient amount of microorganisms) selection of process parameters: supply by nutritional solution, oxygen and trace elements, temperature and other physical characteristics.

It should be noted that both biological methods of landfill soil treatment require considerable time and costs.

The most promising is the technology of contaminated soil burning and roasting or thermal processing. This method is used when soil is contaminated by harmful organic substances including oils and resins. The mobile installations of rotary tube furnaces are used for thermal processing in Germany and the Netherlands. First, contaminants are previously burned at 400-450°C, and then they are roasted at higher temperature (thermal decomposition and neutralization of contaminants occur). The installations are equipped with the necessary gas cleaning facilities.

The current difficulties in the use of thermal processing technology are associated with high energy consumption and high costs. For efficiency increasing of this method, the used fuel type, methods of gas cleaning and energy recovery are important.

The immobilization technology is based on consolidation, fixation or chemical bounding of pollutants in landfill soils in order to prevent further dissemination in the biosphere. For this purpose landfill soil is removed and processed by special reagents in special automatic mixer. Special dosing system ensures uniform wetting and spontaneous chemical reaction even at a low content of chemicals. During processing, a chemical transformation of pollutants to water-insoluble non-toxic compounds takes place.

The basic method of localization and preventing the spread of contamination, often called as capsulation, allows eliminating such landfill hazards as groundwater pollution, atmosphere contamination, surface soil erosion. The capsulation includes the creation of horizontal hermetic bases, installation of vertical hermetic walls and compact covering of landfill surface. As hermetic bases, the natural geological barriers in the form of impermeable layers of clay or loam are often used. Vertical hermetic walls are usually constructed by the technology "wall in the ground" filling them by bentonite and cement mixture. The use of hermetic mass based on calcium bentonite, slug-cement and special additives allows producing almost waterproof sections of water-isolating walls.

For the capsulation of landfill soil is also used technology (tested in the US) of "wall in the ground" with the use of single-ladle type excavator. The depth of the walls is about 10 metres. The special multi-layer coverage is made on the landfill surface providing landfill soil isolation, minimizing the surface water infiltration and eliminating the uncontrolled biogas and harmful dusted substances emissions in the environment. The following scheme of capsulation can be considered as an example (layers from the bottom): fibrous coverage; isolating layer of mineral soil (35 cm), laid in two levels (20 and 15 cm); drainage layer (feldspar barrier) of 20 cm thickness with integrated drainage channels; potentially clean soil layer (60 cm); potentially fertile soil layer (30 cm); fertile soil layer (15-20 cm).

For isolating layer construction, a mixture of mineral substances and bentonite additive is used. For the sealant manufacture, the stationary mixer with process controlling system, accurate components dosing and mixing is used. The resulting sealant can be used in almost any weather conditions. It allows reducing the isolating layer thickness to 35 cm.

CHAPTER 5
INDUSTRIAL METHODS OF WASTE PROCESSING. EUROPEAN EXPERIENCE

There are many waste processing methods developed.

Household waste collection and transportation are very expensive operations. Their cost is currently up to 80% of the total cost of landfilling.

Industrial waste processing allows minimizing costs for transportation and other operations. Waste processing must be done taking into account the possibility of maximal profit obtaining to compensate the investments in industrial processing. It should be noted, when sorting and processing the household waste, its amount intended to be incinerated or landfilled is significantly reduced.

The technological solutions, industrial methods and equipment for preparation and processing of household waste allow choosing the most efficient (environmentally and economically) individual complex solution of the household waste problem for each municipality or region considering its conditions and needs.

Correctly selected methods of household waste preparation and processing are cost-effective and environmentally friendly.

5.1 Methods of waste preparation and processing

The methods of waste processing are implemented using dozens of technologies.

Industrial processing should be considered as the final stage in the scheme of household waste management.

The most widespread are the following methods of waste preparation and processing (Fig. 5.1):

- shredding;
- amalgamation;
- classification and sorting;
- enrichment;
- heat treatment;
- leaching;
- dehydration.

5.1.1 Shredding of waste

Waste shredding is a process of size reducing of the material pieces by destruction under the influence of external forces.

Shredding is one of the accessory operations used in the waste processing.

The expediency of including shredding operations in the technological scheme of waste processing is determined mainly by size requirements for appropriate directions of material processing: enrichment, thermal and other types of processing.

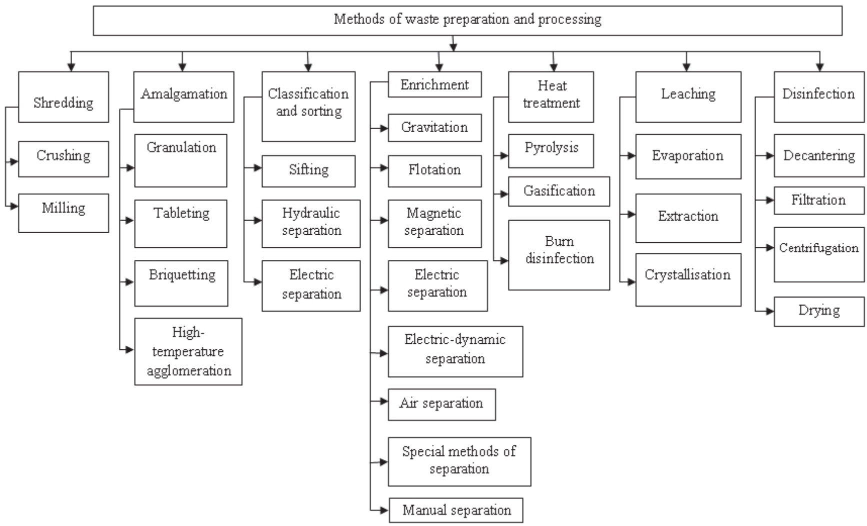


Figure 5.1. Methods of waste preparation and processing

Solid household waste (both organic and inorganic) could be shredded to necessary size by crushing, splitting, breaking, cutting, sawing, rubbing and by various combinations of these methods (Fig. 5.2).

Reducing the size of solid waste pieces is achieved by crushing or shredding. The process of small pieces shredding is called milling.

Jaw, cone, roll, and rotary crushers of different types are used for crushing. The size of the pieces before crushing is 20-1000 mm, and after crushing − 1-250 mm.

The milling of pieces with size of 1-5 mm is carried out by wet and dry methods by using various types of mills.

Shredding is called large if processed waste pieces have size 200-1000 mm, medium and intermediate − 50-250 mm, small − 20-50 mm and thin − 3-20 mm, and in some cases − 0.1-0,001 mm.

For crushing and milling great amount of mechanical energy is consumed. So it is important to make right selection of the shredding way.

One of the indicators characterizing the crushing process is the crushing (shredding) degree, which refers to the ratio of the greatest pieces size *D* before crushing to greatest pieces size *d* after crushing (shredding):

$$i = \frac{D}{d}. \tag{5.1}$$

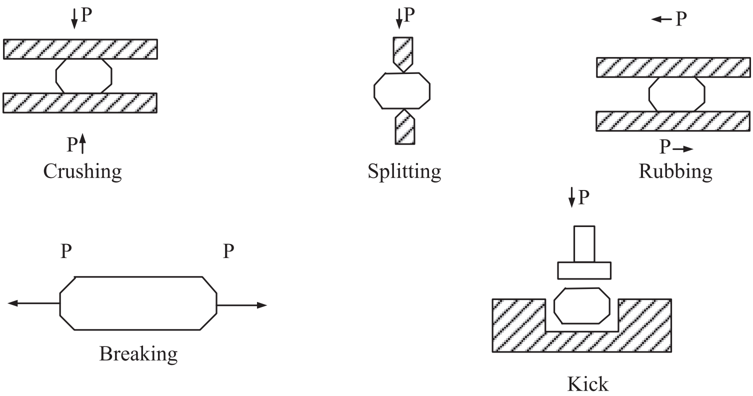


Figure 5.2. Methods of waste shredding

The total degree of shredding is the multiplication of degrees of crushing performed in several stages:

$$i_{заг.} = i_1 \times i_2 \times i_3 ... i_n. \quad (5.2)$$

The shredding degrees of waste at one stage are as follows:

- large and of high hardness − 2-6;
- medium − 5-10;
- small − 10-50;
- the smallest − 50 and more.

For large crushing two types of crushers − jaw and cone − are mainly used. Jaw crushers are used only for crushing metals and other hard materials. In jaw crusher (Fig. 5.3) shredding is carried out by pieces crushing between vertical stationary plane and mobile inclined plane (jaws). An important characteristic of jaw crusher is the angle φ between the jaws (planes), which is called the angle of capture (Fig. 5.4). If this angle is too large, the waste pieces can be pushed out from crusher. If it is too small, then the shredding degree is low.

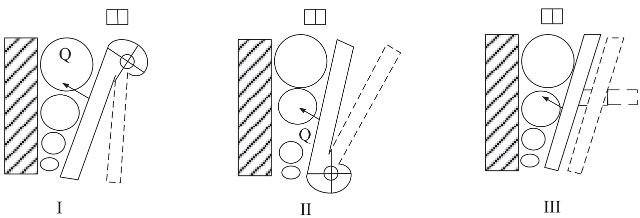


Figure 5.3. Scheme of crusher jaws movement

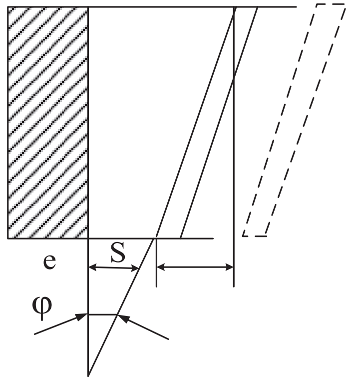


Figure 5.4. Capture angle of jaw crusher

To avoid waste pushing out from the crusher, the angle of capture φ is needed to be less than double angle of friction. Average friction angle is 17°. The angle of capture is in average within 17-25°.

Shredding of polymer film waste and waste of packaging and PET bottles is carried out in washing-cutting installations or shredders (crushers) of rotary type.

5.1.2 Amalgamation of household waste

Amalgamation of waste is used for recycling of plastics, producing building materials from appropriate waste and in other cases. Amalgamation of the small size materials is performed by methods of granulation, tableting, briquetting, and high temperature agglomeration.

Granulation is carried out by running and pressing in granulators of different types. The capacity and characteristics of the granulators depends on the properties of input waste and applied constructions.

Waste tableting is carried out by use of different types of tablet machines, based on dozed waste pressing in matrix channels. Tablets are produced in the form of cylinders, spheres, disks, rings, etc.

Briquetting is used for making the waste more compact, reducing waste volume, improving of transportation and storage conditions. Briquetting is carried out by use of different press types. For example, wood waste briquetting increases heating value of sawdust and shaving. The compact briquettes can be used as solid fuel. Pressing of metal shaving results in lower metal losses in furnaces.

High-temperature agglomeration is carried out by use of agglomeration installations for amalgamation of dispersed metal waste. The amalgamation of shredded polymer waste for density increasing is carried out in special installations − agglomerators. The density of agglomerated polymer waste can achieve 450-1000 kg/m^3, which significantly facilitates the operation of worm press of extruder-granulator. As a result, it allows obtaining granulated polymer material with density of 850 kg/m^3.

5.1.3 Classification and sorting of household waste

Waste classification and sorting by fractions is conducted by sieving using different types of sieves, grids, sifters; by hydraulic and air separation using hydrocyclones and spiral classifiers.

Sifting is used for shredded solid waste separating by fractions with granules of equal size.

The process of sifting can be of self-importance − for the preparation of certain products types or it can be supplement, for example, when preparing the material for any subsequent operations. In the first case sifting is called sorting, and in the second case it is classification.

Sifting is carried out using sieves or sifters (devices, the main part of which are flat cylindrical or conical sieves. When sifting, small pieces of size smaller than sieve holes pass through them, and large pieces remain in the sieve separated from small pieces.

Household waste can be processed in the same way as multi-component natural raw (ores, mining and chemical raw materials, coal, etc,). When involving household waste in industrial processing as raw material, concentrating processes are very important as preparing operations allowing to extract valuable components for re-use, remove hazardous components and optimize the waste composition for next stages of processing. It is proved by international conferences on minerals concentrating, where great attention was paid to issues of household waste concentrating.

Household waste separation (by the analogy of other raw materials, e.g., minerals, includes processes of primary raw processing for valuable components obtaining, hazardous and ballast components removal, extracting of waste fractions optimized by composition for processing by any method.

Unlike minerals concentrating (always connected with environment pollution), household waste separation has direct environmental effect, because the remains amount is always less than amount of input material and waste composition for next processing is optimized: waste is homogenized, burning ability of waste is lower, content of hazardous and ballast components is decreased. These increase the environment safety of industrial processing of household waste.

Household waste separation and concentrating are efficient operations before thermal and biological waste processing. According to published data, previous household waste separation, as well as removal of metal components, used batteries, accumulators, and some types of synthetic materials allow decreasing of mercury and arsenic emissions by 70-75% and lead emission by 40% during waste incineration. At the same time, the efficiency of household waste incineration and fermentation is increased and the composition of products and waste of processing is improved.

There are 3 possible inter-complementary directions of household waste separation:

- selective household waste component collection in the places of generation followed by using special sorting installations (mainly by manual sorting, for metal removing the mechanized separation is sometimes used);

- selective household waste fractions collection in the places of commercial waste generation (waste of markets, shops, schools and other organizations) followed by removal of valuable components by combined methods of manual and mechanized sorting (on special installations);

- separation on the plants (mainly mechanized sorting, because manual sorting of household waste on slow-moving conveyer is low-efficient; in many cases the technological scheme can include manual sorting of large household waste fractions).

The most technically complicated is the operation of solid materials sifting (the process of household waste separation by size). The sifting is widespread and unique. It can be used for every solid material.

When processing solid materials, 2 types of sifters are used − drum and vibratory. Grate sifters are used less.

Drum sifter is the most common installation used for household waste separation. They are often used for argillaceous ores washing, sorting of sand, gravel, broken stones, as well as for asbestos, graphite and other ores concentrating.

Drum sifters have sifting cylindrical surface, and some times they have polyhedral form.

Drum sifter is set on supporting rollers at a slight angle to the horizon (typically 5-7°).

The material is loaded into rotating drum and falls on sifting surface (Fig. 5.5), pieces of material are grabbed to the inner surface of the rotating drum under the influence of friction force. Then the pieces rise to a height *H*. Once the surface *AB* takes the position of natural incline, pieces roll on this surface and simultaneously move on the *AC* due to drum incline, moving down to the unloading end of the sifter.

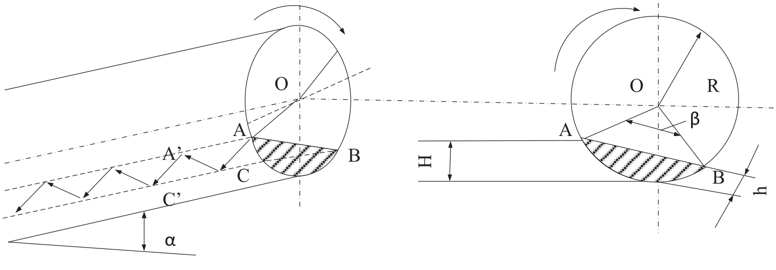


Figure 5.5. Principal scheme of the sifting process

After termination of the movement, pieces are grabbed again by the drum and the cycle repeats. As a result, the trajectory of the piece movement is a zigzag line *ACA'C '*.

Moving along the inner surface of the drum, the waste is sieved to two products – under-grate and above-grate. If several size fractions are needed to obtain, then sieving grids are constructed of several sections with holes of different sizes increasing to the unload end.

The thickness h of the material segment lay contained in the sifter drum should not exceed double size of the largest pieces of fractions d_{max}.

The abruption angle β (the largest central angle corresponding to loading segment) should not exceed 90° ($\beta \leq 90°$).

According to practice data, the diameter D of drum during household waste sifting must exceed the size of the largest piece at least 8 times.

The optimal speed of drum rotation is 30-45% of the crucial speed (typically 10-15 RPM).

At constant capacity, the efficiency of sifting is increased with decreasing of the layer of household waste loaded on sieving surface or with increasing the drum diameter.

The capacity of sifter is increased with increasing the angle of drum incline *a,* but it reduces the efficiency of sifting. The real capacity of drum sifters for household waste is 20-25 tons per hour.

The following products are derived from sifting:

- screenings consisting of particles passed through the sieve holes;
- waste consisting of particles not passed through the sieve holes (moves to another end of sifter).

On the practice, not all particles, smaller than sieve holes, pass through the holes due to the imperfection of sifting process. Some of them leave the sifter together with the waste. That is why there are always more sifted particles than screenings.

The process of sifting is the more perfect, the closer are the quantities of screenings and sift. The ratio of screenings amount to sift amount is the sifter efficiency characterizing the quality of sifting. It can be expressed by the formula:

$$E = \frac{G_1 \times 100}{\frac{G_a}{100}} \% \tag{5.3}$$

Or

$$F = 10000 \frac{G_1}{G_a} \%. \tag{5.4}$$

where G – total weight of input waste, kg;

a – sift content in the input waste, %;

G_1 – weight of screenings derived from sifting, kg.

The efficiency of sifter ranged from 60 to 75% (max. 90%) depends on its type and construction. There are also several influencing factors:

- shape and size of sieve holes;
- shape of waste pieces;
- thickness of waste layer on sifter;
- humidity of sorted waste;
- speed and character of waste movement on sifter.

The shape and size of the sieve holes are decisive factors and must be selected in each case depending on the shape of waste particles. The sieves with round holes are used for sieving the waste with particles of relatively round form. In other cases the sieves with oblong, rectangular and square holes are used.

The pieces of round form pass through sieve holes much easier than pieces of elongated shape.

The holes size is usually selected slightly larger than particle size needed to obtain among screenings. For example, for obtaining the particles with size from 5 to 25 mm, the sieve holes size must be 3 mm larger.

If sifting is carried out in drum sifters made of perforated sheets, it must be accounted that the actual holes diameter is smaller then nominal one due to bending.

The thickness of waste layer on the sifter affects the sifting quality. When waste layer is thick, small pieces at the top can get in waste without contact with the sieve. Therefore, the thinner the waste layer is, the more effective sifter operates.

Sifters should be evenly provided by material. If sifter is loaded unevenly and the sieve is periodically loaded by large portions of sorted waste, then sifting conditions significantly deteriorates.

Selection of waste movement speed in sifter is crucial. The lower the speed is, the more particles fall into the holes and the higher the sifter efficiency is. Therefore, the speed should be selected in each case taking into account both sifter efficiency and its capacity.

For particles having a shape close to round, it is recommended to define the maximal speed of waste movement on sifter by the expression:

$$v \le \sqrt{\frac{rg}{2}}, м/с, \tag{5.5}$$

where r – radius of screenings pieces, meters.

The movement nature and way length of the waste on the sieve also is of great importance. The longer the way, the higher the quality of sifting.

Increasing the length of waste way on the sifter allows sifting with low speed and small thickness of the layer increasing the sifting quality.

Free sliding of waste on the sieve surface ensures that small particles remain in the top layers without contacting with the sieve holes and go out from sifter together with waste. Therefore, it is more profitable to shake off the waste on the sieve, as is adopted for majority of modern sifters.

The conditions of small pieces sieving deteriorate with increasing the humidity of sorted waste, since pieces stick together, combine in clumps, and therefore they are retained on the sieve.

Main features of typical sifter for household waste separation:

- holes diameter – 250 mm;
- drum diameter – 3000 mm;
- length of sieving surface – 6000 mm;
- weight – 15 tons.

Main features of typical sifter for compost separation:

- holes diameter – 45-60 mm;
- drum diameter – 2500 mm;
- length of sieving surface – 4000 mm;
- weight – 20 tons.

Sifters are classified by various criteria as follows:

- depending on the modes of operation: stationary and mobile sifters;
- depending on the shape of sieving grates: flat and drum sifters;
- depending on the type of sieving grates: grid and grate sifters.

In turn, each of above sifter types includes number of sifter constructions.

5.1.4 Enrichment of waste using flotation

Waste enrichment is carried out by extracting of one or more components from the whole waste mass. The most common methods of waste preparation by enriching are flotation, gravity, magnetic separation, electrodynamic separation, air separation, special methods of separation, manual sorting and other.

Flotation methods are based on different wettability of particles surface by water. Finely shredded waste is processed by water with added flotation reagents, which increase the difference between wettabilities of the valuable component and other waste. As reagents oils, fatty acids and their salts, mercaptans, amines and others are used.

The effect of flotation separation depends on the saturation of water with air bubbles stuck to the poorly wetted waste particles. Becoming lighter, they are taken to the surface, separating from the well wettable particles. Depending on the nature of water saturation, there are pressure, bubble (foam), electrical, biological and chemical flotation.

Method of bubble flotation is based on the properties of some particles to adhere to air bubbles and move with them in a foam layer (concentrate), and other particles remain suspended in water (flotation "tails").

The separation of household thermoplastic waste by type is conducted using the following methods: flotation, separation in heavy media, air separation, electric separation, chemical methods of deep cooling. The most common is the flotation method allowing to separate a mixture of such thermoplastics as polyethylene (PE), polystyrene (PS), polypropylene (PP) and polyvinyl chloride (PVC). Separation of shredded plastic waste is conducted in flotation bath. The installation for flotation separation of plastic waste is shown in Fig. 5.6.

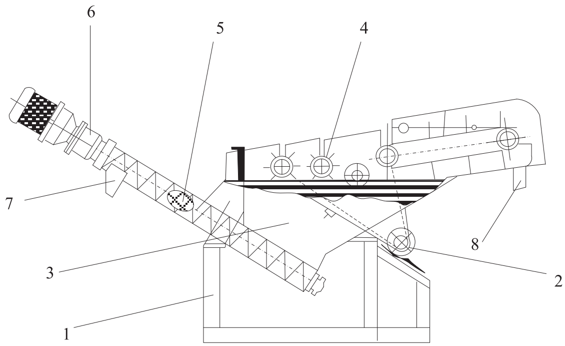


Figure 5.6. Flotation bath:
1 – base, 2 – electric engine, 3 – bath of fractions separation, 4 – blades, 5 – shnek conveyor, 6 – reducer, 7 – tray of heavy fraction unloading, 8 – tray of light fraction unloading

Methods of flotation and separation are the most effective and economically viable.

Economically viable is using mixed plastic waste without separation. According to research data, mixed plastic waste has the following composition: high-density polyethylene (HDPE) – 9.5%, low-density polyethylene (LDPE) – 20.2%, polypropylene (PP) – 7.4%, polyvinyl chloride (PVC) – 16.5 %, polystyrene (PS) – 18.3%. Flotation method is based on the difference between the unit weights of plastic waste components.

Important operation of waste preparation (especially if it is heavily polluted) is a washing with hot or cold water with or without the use of detergents. Existing technologies of plastic waste processing also use washing-cutting devices. However, in the case of large contamination of plastic waste (over 5%), the washing is inefficient and low-productive. In practice, the multi-stage washing is used with the addition of detergents if necessary.

There are also produced installations having devices both for washing and drying with capacity of up to 350-500 kg per hour. In such an installation shredded waste is loaded into the bath filled with washing solution. The film is stirred by blade mixer, while the dirt moves to the bottom and washed film emerges.

An important operation when preparing plastic waste for processing is shredded polymer drying after washing-cutting device and flotation (separation). Different types of dryers are used for that: shelf, chamber, conveyors, etc. In most cases, film dehydration and drying is carried out on vibrating sieves and in whirling separator. The residual film humidity is 0.1%.

Waste identification involves determining the specific type of polymer (e.g., when separating mixed waste) and is conducted by various methods (by defining the density, melting temperature, smell of burning material, flame colour, etc.).

For waste pieces shredding the rotary knife shredder with capacity from 100 to 1000 kg per hour. Film and fibrous waste is shredded in a shredder of another type with devices for preliminary and final waste shredding. When processing film waste, water is pumped in the shredding chamber.

Shredder capacity is determined by its structure, quantity and length of knives, rotor speed, type of waste. The lowest capacity is observed when processing styrofoam waste, which is difficult to load compactly. Higher capacity is achieved when processing films, fibrous waste, and blown products.

The degree of shredding determined by sieve holes size, which protects the bottom or side of milling chamber, ranging from 2-3 to 25-30 mm.

Shredding is very important stage of waste preparation for processing, since degree of shredding determines density, pourity and size of resulting product particles. Regulating the degree of shredding allows processing mechanizing, improving the material quality due to averaging its technological characteristics, reducing the duration of other manufacturing operations, simplifying the construction of processing equipment.

A promising way of shredding is the cryogenic method, allowing to obtain fine fractions of plastic waste with the dispersion degree from 0.5 to 2 mm.

Among the common methods of fine polymeric fractions obtaining, the most appropriate is the method of mechanical shredding.

5.1.5 Mechanical dehydration

Sometimes household waste should be dehydrated. Sometimes there are suspensions hardly separated. To improve the process, the previous processing by reagent and non-reagent methods is carried out. Lime, iron salts, aluminium are used as reagents. The main disadvantages of reagent method are the high cost and corrosive effect of reagents on the equipment.

Non-reagent waste processing involves freezing and thawing, thermal processing, sawdust introduction in the waste.

When freezing and thawing, bounded water is transformed to the free water separating from the solid phase. The thermal processing is waste heating to a temperature of 170-200°C. At this time, some organic compounds are decomposed, sediment is compacted and dehydration occurs better.

The main methods of mechanical waste dehydration are filtration, centrifugation and passing the pulp through a hydro-cyclone.

When filtering the waste, vacuum filters and filter-presses are usually used. The filtering medium is filter tissue and layer of sediment, which adheres to the tissue forming extra filter layer during filtration, which stops all fine particles of suspension.

The most widespread are drum vacuum filters. Also conveyor, disc vacuum filters and filter presses, vibrating filters are used.

The process of filtering is based on the capturing of solid suspended particles by simple barriers, which let liquids to pass and capture solids. As a result of direct contact of the suspension and the surface of porous barrier and due to different pressure before and after barrier, the liquid passes through pores and solids are trapped on the surface of barrier, forming sediment layer, which is then removed (see Fig. 5.7).

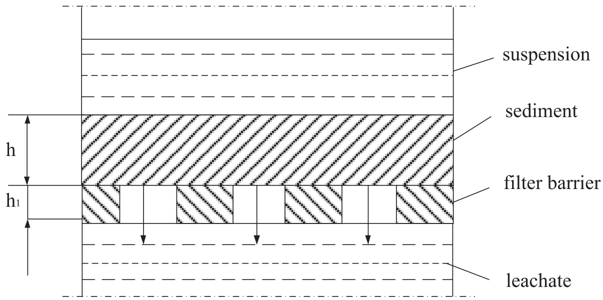


Figure 5.7. Scheme of filtration process

The degree of separation completeness largely depends on the pressure of filtration process. The leachate is obtained more clean if filtration starts at low pressure and then pressure increases with sediment formation increase.

In quantitative terms, the filter capacity is characterized by rate, i.e. by the amount of leachate passing through the 1 m^2 of filtering barrier surface per time unit.

Filtration rate can be expressed by the equation:

$$C = \frac{dV}{F_0 \cdot \tau}, \tag{5.6}$$

where V – volume of leachate, m^3;

F_0 – filtration surface, m^2;

τ – duration of the filtration process, sec.

It has been empirically found that the filtration rate is proportional to the pressure due compression of sediment channels under the influence of high pressure.

Next researches have confirmed that during all the time of filtration, for any filtering material, the leachate flow rate is proportional to the pressure. However, the liquid movement through the pores of sediment during the filtering is so complicated by side factors that above mentioned proportionality can not be noted. These side factors are, first of all, compressibility and heterogeneity of sediments.

5.1.6 Magnetic separation

Magnetic methods are based on separation of materials by the magnetic properties. They are widely used in the case if household waste contains metallic components.

Magnetic separation is the process of solid materials separation in a magnetic field, which is based on the difference between their magnetic properties (mainly magnetic susceptibility).

The particles with size from 0.1 to 200 mm are usually exposed to magnetic separation. A great importance for magnetic separation has an ability of separating components to magnetization, which is characterized by magnetic susceptibility.

By magnetic properties (the ability to magnetize in external magnetic field) all substances are divided on diamagnetic, paramagnetic and ferromagnetic. Relating of the substance to a certain group is determined by processes in atoms, molecules and crystals.

Diamagnetic substances (bismuth, silver, gold) have negative magnetic susceptibility. Electrons of atoms acquire additional angular velocity under the influence of magnetic forces. As a result, additional magnetic moment appears in every atom, and it is directed against external field creating this moment.

Paramagnetic substances (chromium, manganese, tin, platinum, rare earth elements) have positive magnetic susceptibility. Atomic magnetic moments are oriented in the direction of the field under the influence of magnetic forces. As a result, paramagnetic substances are magnetized in external magnetic field in the direction of the field.

Diamagnetic and paramagnetic substances have very small magnetic susceptibility that is almost independent from field intensity.

Ferromagnetic substances (iron, nickel, cobalt, cadmium) are characterized by the ability to spontaneous magnetization even in the absence of external magnetic field. When the intensity of external magnetic field increases, then magnetization of the ferromagnetic substance also increases at given temperature until full saturation (all atomic magnetic moments become parallel and oriented on the field direction).

Ferromagnetic components acquire energy during magnetizing for magnetic field creating inside and outside the component. The magnetic force acting on the ferromagnetic component in magnetic field is determined by the potential energy acquired by volume unit of component during its magnetization:

$$F = -\frac{\mu_0 \cdot \chi \cdot H^2}{2}, \qquad (5.7)$$

where χ – magnetic susceptibility, $(\chi = 1/H)$;

H – intensity of magnetic field.

For magnetic components attraction to a magnet, the magnetic force of gravity acting on these components should exceed the force of gravity, medium resistance to particles movement and other mechanical forces.

The more the difference between the magnetic susceptibility of the components is, the easier they are separated in magnetic field. The higher magnetic susceptibility is, the less field intensity is required to separate the components.

Ferromagnetic components of most of solid waste (including household waste) has unit magnetic susceptibility at least $3{\cdot}10^{-3}$ cm^3/g. They are efficiently extracted using magnetic separators with a relatively weak magnetic field of intensity up to 120 kA/m (typically separators with the magnetic field of 90-200 kA/m are used). These are all products of black metals, which were used and became the waste, as well as packaging cans and others.

For magnetic components isolating from the household waste, the most suitable are hanging electromagnetic ferrous separators with automatic unloading and pulley separators. In the working area of these separators the magnetic field is created by a system of electromagnets with coil powered by direct current.

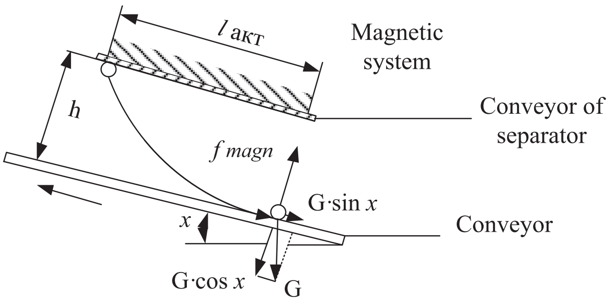


Figure 5.10. Scheme of forces acting on ferromagnetic body in magnetic field of hanging separator

Fig. 5.10 shows the scheme of forces acting on ferromagnetic component, which is transported by inclined conveyor and gets into the influence zone of magnetic system of hanging separator installed at a distance *h* from the conveyor. After the ferromagnetic components shifting to the conveyor of separator removing it from the working zone of separation, magnetic force needs to overcome the force of gravity *G* or its normal component $G{\cdot}\cos x$.

The minimal unit magnetic force f_{magn}, which is required to extract ferromagnetic components at monolayer waste supply in separation zone of hanging electromagnetic separator, can be calculated by the formula:

$$f_{magn} = \frac{2hv^2}{l^2_{act}} + g, \qquad (5.8)$$

where h − height of separation zone, m;

v – speed of conveyor, m/sec;

l_{act} – length of the active separation zone, m;

g – acceleration of gravity, m/sec^2.

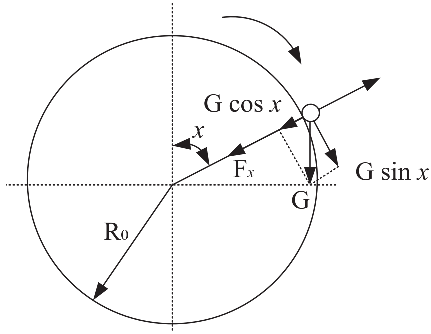


Figure 5.11. Scheme of forces acting on a ferromagnetic body in magnetic field of pulley separator

Fig. 5.11 shows the forces acting on the ferromagnetic component in separation zone using magnetic pulley. The unit magnetic force f_{magn} required to extract ferromagnetic components of household waste, is as follows:

$$f_{magn} = \frac{2v^2}{R_d} - g \cdot \cos x, \tag{5.9}$$

where v – speed of conveyor, m/sec;

R_d – radius of the drum, m;

g – acceleration of gravity, m/sec^2;

x – angle determining the position of ferromagnetic component on the drum surface, degrees.

When separating large particles of household waste, if the ratio of particle size d to drum radius R_d ($d/R_d > 0.05$), the unit magnetic force is defined by formula:

$$f_{magn} = \frac{v^2 \cdot (R_6 + 0{,}5d)}{R^2_{\ 6}} - g \cdot \cos x, \tag{5.10}$$

According to calculations, the unit magnetic force rising during magnetic separation is 10-12 N.

Removal of black metals from the household waste flow is directly dependent on the intensity of ferromagnetic components interactions with magnetic field. It is sharply decreased with increasing the distance between poles of magnetic device and transported waste. Limiting height of hanging separator above the conveyor is 600 mm (mostly no more than 300-350 mm). In any case, this height has to provide free passing of transported waste under the separator (minimal height of hanging separator above the conveyor with waste should be at least double height of the largest waste particles).

The final component removal depends on the separation duration. The time of black metal being in a magnetic field of separator depends on the transportation speed of waste (the conveyor speed). The magnetic induction on the surface of conveyor transporting household waste, which is required for black metals removal, slightly depends on the flow rate, but is more dependent on the intensity of non-ferromagnetic components flow.

Hanging magnetic separators are installed above conveyor transporting waste: most frequently anywhere between drive and tail drums of conveyor perpendicular to the direction of conveyor movement, or in the place of material unloading from conveyor in the direction of conveyor movement.

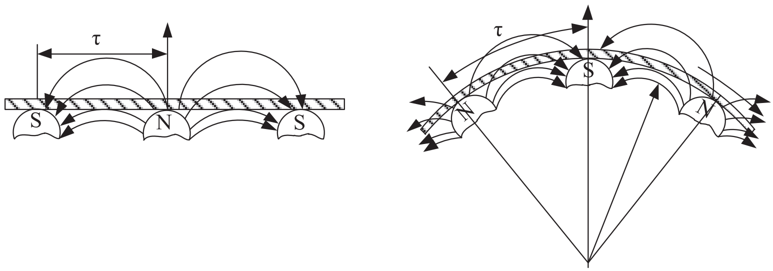
Electrodynamic separation is combined process of magnetic separation based on the use of the difference between magnetic susceptibilities separated waste components (extracting of ferromagnetic components) or between their electrical conductivities (extracting of diamagnetic and paramagnetic components).

The main applications of electrodynamic separation are extraction of nonferrous metals from the household waste flow, as well as separation of nonferrous metals by types. The size of separated components is 40-50 mm.

Nonferrous metals contained in household waste are of the main valuable components. Nonferrous metals in household waste are mainly represented by different types of used packaging and aluminium dishes (cans for drinks, tubes, plates, spoons, forks, pots, lids, etc.) and much less by sanitary products made on copper base (bronze, brass). The content of nonferrous metals in household waste is about 0.7%.

Nonferrous metals relate to non-ferromagnetic conductive substances by their physical properties. Therefore, by changing the magnetic flux passing through such substances, the eddy currents are raised, which are inductive and increase with the rate of magnetic flux change. Unlike electric current in the wires, eddy currents are locked directly in conductive mass, forming whirl-type contours. The interaction of the magnetic field and eddy currents induced in conductors is used in electrodynamic separation.

For nonferrous metals removal from household waste, the most widely used is electrodynamic separation in moving or rotating magnetic field, which like the magnetic field of rotating asynchronous machine can be created by winding of three-phase current (linear asynchronous engines) or during relative movement of the drum (or conveyor) and the multi-polar system (Fig. 5.12).



a) b)

Figure 5.12. Location scheme of poles of open multipolar magnetic system in the plane (*a*) and on the cylindrical surface (*b*)

Moving magnetic field is generated by electric field (current of shifting. Electromagnetic system with winding of three-phase current creates sinusoidal moving field when three sinusoidal fields are imposed and shifted at angle $2/3\pi$ compared to each other. At each point of electromagnetic system of three-phase current, the moving field is created due to winding phase shifting.

The characteristic of magnetic field on the surface of the linear engine inductor and at different distances from its surface are described in Fig. 5.13.

Magnetic induction B_z at different distances from the inductor surface is calculated by the formula:

$$B_z = B_0 \cdot e^{\frac{\pi z}{\tau}}, \qquad (5.11)$$

where B_0 – magnetic induction on the inductor surface, T;

z – distance from the inductor surface, m;

τ – pole step of the inductor, m;

Fig. 5.13 shows that with increase of distance (by height) from the separator surface, the magnetic induction decreases sharply (from 0.19 T to 0.12 T at 10 mm height above the separator of industrial type). Therefore, significant impact on the separation results have correct selection of the conveyor thickness and providing (if possible) of single-layer household waste supply in the work zone of inductor. The figure also shows that magnetic induction is significantly reduced in the peripheral zone of the separator ("edge effect"). According to studies, magnetic induction depends also on linear engine power (10 times reduction of engine power causes doubled reducing of magnetic induction on the engine surface).

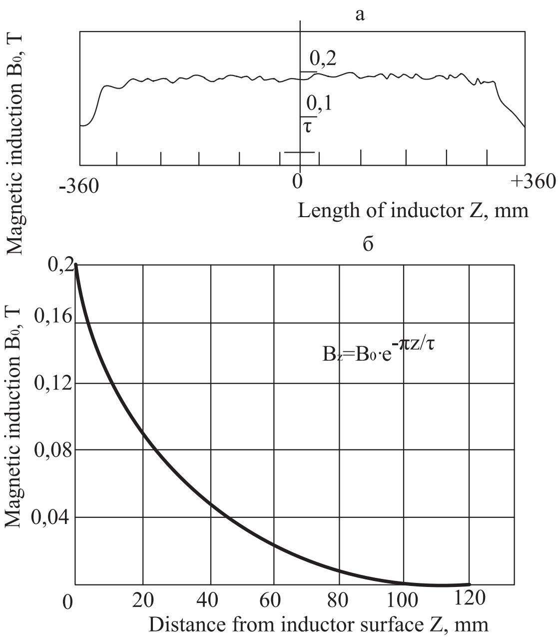


Figure 5.13. Characteristic of the magnetic field on the inductor surface of linear engine (*a*) and at different distances (*b*) from its surface

The power of currents induced in the conductor depends on both the parameters of primary magnetic field and the physical properties of the conductor, its size and shape.

By the ability to expose to electrodynamic separation, nonferrous metals are characterized by parameter *j/ρ* – the ratio of electrical conductivity to density (electrical conductivity *j* quantitatively characterizes the ability of metal to conduct electric current). The higher this ratio is, the easier (if other conditions are equal) metal is extracted by electrodynamic separation (see Table 5.1).

Table 5.1. Value of parameter *j/ρ* for different metals (at room temperature)

Metal	**j, 10^6 Ohm^{-1}·m^{-1}**	**ρ, 10^3 kg/m^3**	**j/ρ, 10^2 m^2·Ohm^{-1}·kg^{-1}**
Aluminum	35,4	2,70	130
Magnesium	23,0	1,74	130
Copper	59,1	8,93	66
Silver	68,1	10,49	65
Zinc	17,4	6,92	25
Brass	15,6	8,47	18
Tin	8,8	7,29	12
Lead	5,0	11,34	4,5
Stainless steel	1,4	7,9	1,8

Flat particles are easily exposed to deflecting forces and therefore are easily separated from non-metallic components. However, there are many metal particles of spherical or cylindrical forms in household waste, which are hardly exposed to deflecting forces due to rotational movement they make by the influence of eddy currents. The smaller the size of separated particles is, the more difficult is carried out the separation based on the use of eddy currents.

The result of the interaction of magnetic field and eddy currents induced in the nonferrous metal particles is generating of pushing-out electrodynamic force acting on nonferrous metal.

Fig. 5.14 illustrates the behaviour of nonferrous metal particle in the moving magnetic field created by winding of three-phase current. Fig. 5.14 shows the inductor with six slots for pole division (industrial type separator) and distribution of the magnetic flux along its surface at time moment *t*. If a sample in the form of disc *2* from diamagnetic or paramagnetic material (aluminium, copper) is placed in magnetic field of linear engine *1* (Fig. 5.14, b, c), then electromotive force (EMF induction) E is induced in the sample. Also, eddy currents i are generated, which interact with a primary magnetic flux changing its induction. As a result, the force F_r is raised, which has direction defined by the rule of left hand and it is perpendicular to the flow and current and causes the disc movement.

EMF of induction in the sample at the moment of being crossed by magnetic lines is proportional to the magnetic field induction, velocity of moving field and to the sample size:

$$E = B \cdot V \cdot l, \tag{5.12}$$

where B – magnetic induction, T;

V – velocity of the moving magnetic field, m/sec;

l – active length of the sample, m.

The velocity of the moving magnetic field corresponding to the wave motion of magnetic induction B is as follows:

$$V = 2\tau \cdot v, \tag{5.13}$$

where τ – pole step of the inductor, m;

v – current frequency, Hz.

With the increase of current frequency and therefore the rate of magnetic flux change, the absolute value of pushing-out electrodynamic force increases. Therefore:

$$E = B \cdot 2\tau \cdot v \cdot l. \tag{5.14}$$

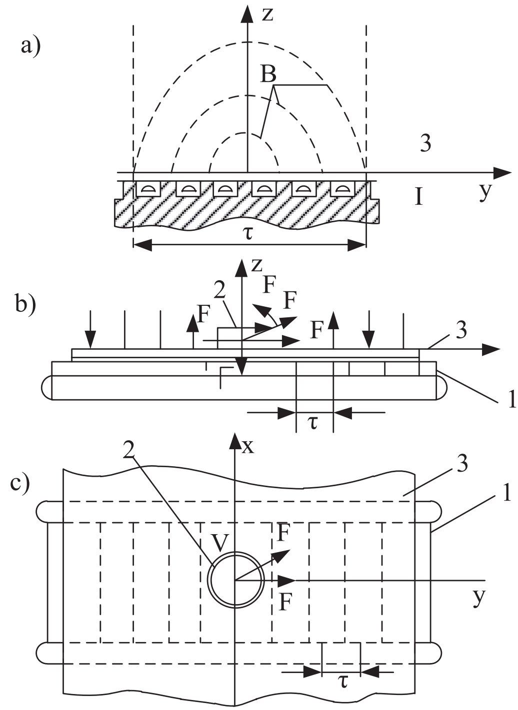


Figure 5.14. Interaction of nonferrous metal particle with the moving magnetic field: a – distribution of the magnetic flux along the inductor, b – forces raising during particle moving along the separator surface, c – movement of nonferrous metal particle of disc form on the separator surface; 1 – linear engine, 2 – sample of nonferrous metal, 3 – conveyor

The EMF value is proportional to the magnetic induction of that area of magnetic field, which is currently crosses the sample. The current i in the conductor is late by phase at angle φ compared to EMF causing it. In the moment when the magnetic flux has a maximal value and EMF induced in the conductor is maximal as well, the current does not reach a maximum value and continues to increase. Thus, the strength of interaction between the current in the sample and the magnetic field is very difficult to calculate. In general case, this force is proportional to the current and magnetic induction, and also depends on the size and shape of the sample:

$$F = i \cdot B \cdot l, H. \tag{5.15}$$

One can also argue that the force F is proportional to the magnetic moment M of substance and to the magnetic field gradient *gradB* (in inhomogeneous magnetic field, the sample with induced current is introduced into the area of stronger field):

$$F = M \cdot gradB. \tag{5.16}$$

For electrodynamic separation it is necessary to take out nonferromagnetic conductive body (disc) from the separation zone, i.e. electroconductive body must be given an acceleration *a*.

In general, the equation of non-ferromagnetic conductive body movement in the moving magnetic field is as follows:

$$ma = F - F_{res} - mg, \tag{5.17}$$

where *m* – mass of non-ferromagnetic conductive body, kg;

a – acceleration given to non-ferromagnetic conductive body, m/sec^2;

F_{res} – force of resistance, N;

g – acceleration of gravity, m/sec^2;

F – pushing-out electrodynamic force raising during the interaction of conductive body with the moving magnetic field, N.

The strength of resistance during electrodynamic separation is mainly determined by friction between the sample and surface (or conveyor). The force of friction preventing the sample removal from the separation zone is applied to the conductor sample along its touch surface and it is always directed in the direction opposite to its movement.

Electrodynamic separation is carried out if the pushing-out electrodynamic force overcomes the force of friction and the force of gravity and moves the sample. Force of friction is not dependent on the conductor area, but depends on the quality of the sample surface processing and inductor coverage.

The resulting force *F* acting on the sample consists of two forces: the force, which acts in the direction of the moving magnetic field and determines the pushing-out of non-ferromagnetic conductive material from the separation zone, and the force, which produce the rotating moment (directed counterclockwise).

The theoretical calculations of force *F*, as was noted, is difficult. Thus, when studying the process of electrodynamic separation, it is advisable to determine experimentally the force, acting on nonferrous metal samples placed in the moving magnetic field.

According to practice, for ensuring the completeness of nonferrous metals extraction, the electrodynamic separation should be carried out in several stages (the main and control operations). Separators must be installed on different conveyors with different speed (e.g., 0.8-1.0 m/sec for main operation, and 1.0-1.2 m/sec for the control operations). Flow layer will be compacted during overloading. Nonferrous metal components take another (more favourable) place on other conveyor. This increases the likelihood of additional extracting of components during the control operation.

5.1.7 Air separation

Air separation is the process of separation in moving gas (air) medium based on the use of the difference between densities of components and their movement speeds.

Air separation can be used for separation household waste including non-metallic waste components of shredded luminescent lamps, in which mercury was extracted. Air separation is effective for waste dedusting, as well as for small particles separation during dry shredding of construction waste (air separator operates in a closed loop with shredder).

Air separation in household waste separation is used for dividing of the waste stream on light and heavy fraction (it is especially necessary by conditions of metals extracting technology), as well as for the extracting of combustible components for subsequent thermal processing. But not only energy recovering is possible for light fraction processing. Besides, air separation is used for the removal of impurities in compost obtained from household waste.

During air separation of household waste, paper, polymeric film, some textile components (mostly synthetic), and garden waste are separated as light fraction. The typical size of particles after air separation is 250 mm.

The behaviour of light components of household waste during air separation is mainly influenced by ascensional aerodynamic force − the resultant of all forces (normal and tangential) distributed over the surface of particle located in the air flow. Aerodynamic force depends on both the parameters of particles (shape, size, surface condition, position in the flow) and the parameters of air flow and pneumatic separating system (air speed and its direction, degree of turbulence, uniform of flow, width of flow).

Calculation of the required air speed, providing household waste separation on two fractions – light and heavy, can be approximately done by the speed of light fraction components calculated using graphic-analytical method.

A single particle moving in the air is exposed to the force of gravity directed downward and determined by volume V and density p_p of the particle:

$$F_g = m \cdot g = V \cdot p_p \cdot g, \tag{5.18}$$

There is also another acting force (Archimedes force directed upwards).

Taking into account the small value of this force, it can be neglected. It is important for separation in a liquid medium. The force of aerodynamic medium resistance F_r is expressed by quadratic Newton's law:

$$F_r = W_p^2 \cdot C_A \cdot p_A \cdot l_P^2, \tag{5.19}$$

where V – volume of particle (component), m^3;

p_A – density of air, kg/m^3;

C_A – coefficient of frontal resistance (coefficient of aerodynamic air resistance to particle movement);

W_p – speed of particle movement, m/sec;

l_p – linear size of particle, m.

Speed of the particle movement is a final speed of the particle (component) during free falling, when forces of gravity and resistance are balanced.

If forces F_r and F_g are equalled, then:

$$V \cdot p_p \cdot g = W_p^{\ 2} \cdot C_A \cdot p_A \cdot l_p^{\ 2}, \tag{5.20}$$

$$W_p^{\ 2} = \frac{V \cdot p_p \cdot g}{C_A \cdot p_A \cdot l_p^{\ 2}}, \tag{5.21}$$

$$W_A = \sqrt{\frac{\delta_p \cdot p_p \cdot g}{C_A \cdot p_A}}, \tag{5.22}$$

where δ_p – thickness of the film material (such as paper, plastic film), m.

For defining the speed of movement, it is needed to calculate the coefficient of frontal resistance C_A characterizing the ability of particles to resist to air flow. In general, it depends on the criterion of pressure mode R_e, the factor K accounting the influence of particle shape ($\delta_{p,}$ l_p), particles concentration β and on geometric characteristics of device L and ratios $L/\ \delta_p$ and L/l_p.

The coefficient of resistance C_A depends on the position of component in air flow (on its orientation compared to movement direction). But mostly, the value of C_A is determined by criterion of movement mode and it is a function of dimensionless Reynolds number R_e.

Reynolds number characterizes the mode of body movement in liquid medium (turbulent or laminar) and accordingly the prevalence of a particular type of resistance (dynamic resistance of the medium or resistance of medium viscosity). Reynolds number is a dimensionless value defined as ratio of inertial forces to forces of viscosity:

$$\mathrm{R_e} = \frac{p_l \cdot v \cdot l}{\mu_l}, \tag{5.23}$$

where p_l – density of liquid;

v – flow rate;

l – linear size (e.g., diameter);

μ_l – viscosity of liquid.

Taking into account the similarity of physical phenomena in moving liquid and gas and their impact on bodies streamlined by them, the coefficient of resistance C_A can be expressed in the form of depending on the Reynolds number:

$$R_e = \frac{W_A \cdot p_A \cdot l_p}{\mu_A}, \tag{5.24}$$

$$C_A = \frac{F_r}{W_A^{\,2} \cdot p_A \cdot l_p^{\,2}}, \tag{5.25}$$

where μ_A − coefficient of air viscosity.

The speed of movement can be determined using the Reynolds number from diagram of dependence (Fig. 5.15).

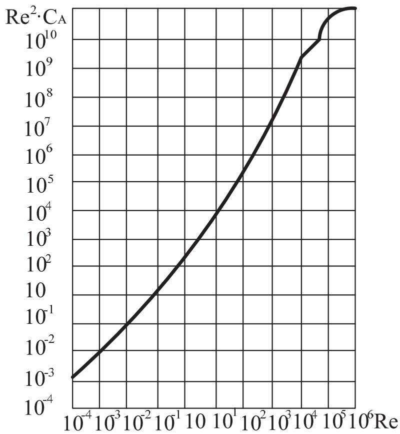


Figure 5.15. Diagram of dependence $R_e^2 \cdot C_A = f(R_e)$

The value $\mathrm{Re}^2 \cdot C_A$ can be found by mathematical transformation excluding W and l_p from the equation of Reynolds number and coefficient of resistance:

$$R_e = \frac{W_A \cdot p_A \cdot l_p}{\mu_A}, \qquad W_A^{\,2} \cdot l_p^{\,2} = \frac{R_e^2 \cdot \mu_A}{p_A},$$

$$C_A = \frac{F_r}{W_A^{\,2} \cdot p_A \cdot l_p^{\,2}}, \qquad W_A^{\,2} \cdot l_p^{\,2} = \frac{F_r}{C_A \cdot p_A},$$

$$\frac{R_e^2 \cdot \mu_A}{p_A} = \frac{F_r}{C_A \cdot p_A}, \qquad R_e^2 \cdot C_A = \frac{F_r \cdot p_A}{\mu_A^{\ 2}}. \tag{5.26}$$

Replacing F_r by F_g results in the following equation:

$$R_e^2 \cdot C_A = \frac{F_r \cdot p_A}{\mu_A^{\ 2}} = \frac{F_g \cdot p_A}{\mu_A^{\ 2}} = \frac{m \cdot g \cdot p_A}{\mu_A^{\ 2}} = \frac{V \cdot p_p \cdot g \cdot p_A}{\mu_A^{\ 2}}. \tag{5.27}$$

The parameter $R_e^2 \cdot C_A = f(R_e)$ is calculated using above dependencies and Reynolds number is defined by the diagram, then speed of movement can be calculated as follows:

$$W_A = \frac{R_e \cdot \mu_A}{p_A \cdot l_p}. \tag{5.28}$$

There are two main methods of components separation in air separation: in horizontal air flow (air flow direction is perpendicular to the direction of gravity force acting on components) and in vertical air flow (air flow direction is opposite to the direction of gravity force acting on components). Accordingly, components of light fraction are transported by air in a horizontal or vertical direction in air separator.

There are equations for determining the theoretical operating speed of air in the process of air separation:

in vertical air flow:

$$W_A^{\ V} = (1,2 \div 1,5) W_{A,} \tag{5.29}$$

in horizontal air flow:

$$W_A^{\ H} = W_A \cdot l / h, \tag{5.30}$$

where l − particles shifting in horizontal air flow, it equals to about $20l_p$;
h − height of the operating area of separation, m.

The theoretical operating air speed calculated by last equations for separation of household waste in vertical flow is 5 m/sec, in horizontal flow − 2.5 m/sec. On the practice, to ensure the efficiency of household waste separation on two fractions (light and heavy), the air speed should be increased at 1.5-2 times.

The laboratory air separator installation with vertical air flow (Fig. 5.16) includes the following main elements: fan, valve regulating air flow speed in range from 0 to 6.5 m/sec, vertical chamber of division consisting of lower cylindrical tube and upper part formed by two elements of truncated cone shape, loading device, sedimentation chamber of cyclone type, unloading devices for light and heavy fractions. To measure air speed in the operating area of air separator the holes are made.

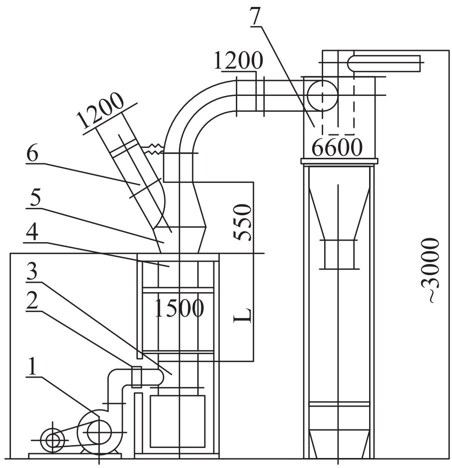


Figure 5.16. Laboratory air separator for household waste separation in vertical air flow: 1 − fan, 2 − valve regulating air flow speed in range from 0 to 6.5 m/sec, 3 − vertical chamber of distribution consisting of lower cylindrical tube and upper part formed by two elements of truncated cone shape, 4 − loading device, 5 − sedimentation chamber of cyclone type, 6, 7 − unloading devices for light and heavy fractions respectively.

According to the minimal diameter of air separator operating area, the maximal particles size in the experiments is 160-180 mm. The capacity of both vertical and horizontal separator is limited by loading device (it is about 5 kg/min).

Air separator operates as follows. The air is supplied by fan 1 through the valve 2 and device of air supply 3 into a cylindrical distribution chamber 4 and it moves up forming a vertical flow. The separated waste is loaded by the device 6 in the area of minimal speed (distribution chamber 5) formed by elements bases of truncated conical shape. The vertical air flow blows low density components from the waste (mainly waste paper, polymeric film, textiles). The heavy fraction is taken off from the bottom of cylindrical part of distribution chamber (through the unloading device 7). Some components of the light fraction, which were not separated from the heavy fraction in the upper part of distribution chamber 5, move with heavy fraction downward, enter the lower part of distribution chamber 4 in the area of higher air speed and, finally, come to sedimentation chamber 7. In other words, the separator structure provides the increase of vertical air flow speed upward and downward from the area of distribution (near the loading waste), provides efficient waste separation and completeness components removal. The ratio of diameters of elements bases with truncated cone shape in operating area of separation is 1.2:1.5 and the ratio of their heights is 2:1 (downward).

The main factors affecting the technological indicators of air separation are air speed, size and humidity of the material. All three factors mainly affect the removal of cardboard, laminated paper and textiles from natural fibres.

During air separation of mixed household waste in horizontal air flow (air-dry state), mainly newspapers, laminated paper and polymeric film are extracted as light fraction. Optimal air speed is about 5 m/sec. The paper content in light fraction reaches 75% (it is double increased compared to content in the input waste). All components removal as light fraction monotonically decreases with increasing the humidity (at speed 5 m/sec). With increasing the humidity, selectivity of air separation slightly increases and paper content in light fraction increases to 80% (in the case of dry mixtures separation − 75%) at humidity 40-50%. The composition of heavy fraction of air separation slightly changes with increasing the household waste humidity due to great removal of textiles and cardboards.

Air separation of household waste in vertical air flow, compared to horizontal flow, allows obtaining the cleaner product by the paper content, but at lower removal. When separating the wet household waste, mainly one type of paper (newspapers) is extracted in light fraction. Removal of paper is reduced from 55% (air-dry state) to 43% (60% humidity). Therefore, the selectivity of air separation in vertical air flow is higher in comparison to horizontal air flow.

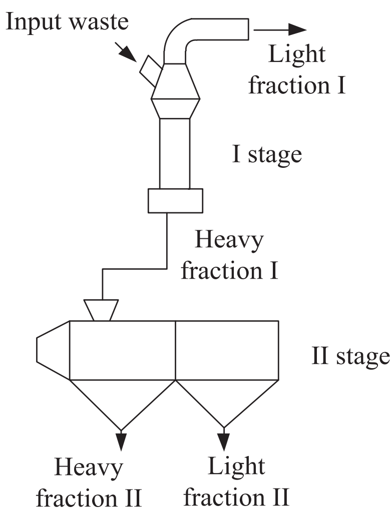


Figure 5.17. Scheme of two-stage air separation

The natural properties of household waste as an object of separation are better used in consecutive air separation in vertical and horizontal air flow when the input of horizontal air separator is heavy fraction of vertical air separator. During wet household waste air separation, already after the first stage of the process the material drying takes place (humidity content reduces by 10-20%, heated air can be used if necessary), which conduces additional removal of dense types of paper (cardboard, laminated paper) at the second stage. However, the practical implementation of the two-stage household waste air separation considerably complicates the construction of sorting plant, so it can be included in the technological scheme of household waste separation only in cases, when it is necessary, for example, to maximally remove paper for recycling. If the light fraction is sent to incineration, then one-stage air separation is technologically acceptable.

It should be noted that air separation depending on the separated material composition and technological tasks can be regulated by the formation of the air flows with appropriate speed. When separating light fraction obtained in vertical air separator, significantly increase of polymer film content in the final product can be achieved by selecting appropriate speed of horizontal air flow. The most efficient air separation is at speed of horizontal air flow 0.9 m/sec in upper part of the separation chamber, and 1.25 m/sec − at the lower part, and for intensification of separation process of materials, which are similar by density and aerodynamic characteristics, physical properties of the light fraction components are regulated by humidifying of material (optimal humidity of material is 40%).

The most typical constructions of air separators used for household waste separation are considered below.

For municipal waste separation in a horizontal air flow, the separators patented in the US and Germany (Fig. 5.18 and 5.19) and intended for shredded waste separation can be used.

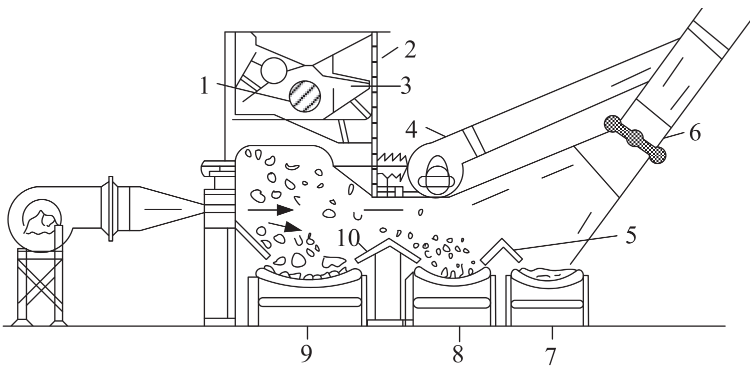


Figure 5.18. Air separator for household waste separation in horizontal air flow (USA): 1 − axle, 2 − receiving funnel, 3 − shredder, 4 − fan, 5 − tube, 6 and 10 − directed inserts, 7, 8, 9 − conveyors

In this separator waste is loaded in receiving funnel 2 and processed in shredder 3 with impeller rotating on axle 1. The shredded waste is picked up by horizontal air flow. The heaviest components (metal cans, rubber, stones, etc.) get to the conveyor 9, light components (wet wood, non-metallic items) get to the conveyor 8, items made of aluminium and similar materials − to the conveyor 7. The paper, textiles, etc., are picked up by air flow and flowed in the tube 5, to which additionally air is flowed by fan 4, then it get into the furnace. To avoid mixing of waste the separating directed inserts 6 and 10 are installed between conveyors.

The installation patented in Germany (Fig. 5.19) is provided by the air circulation system 4 and chamber made as a pipe with a loading bunker 2, in which the shredded waste is supplied by vibratory feeder 3. The material picked up by horizontal air flow from the fan 1, is divided on three fractions and removed to the collectors 8, 10 and 11, and the lightest components are flowed in the cyclone 5. Inside the chamber between unloading holes the moving barriers 6 and 9 are mounted for regulation of separation. Removal of fine particles in the cyclone 5 is regulated by height changing of barrier 7.

Typical construction of air separator of vertical type is shown in Fig. 5.19.

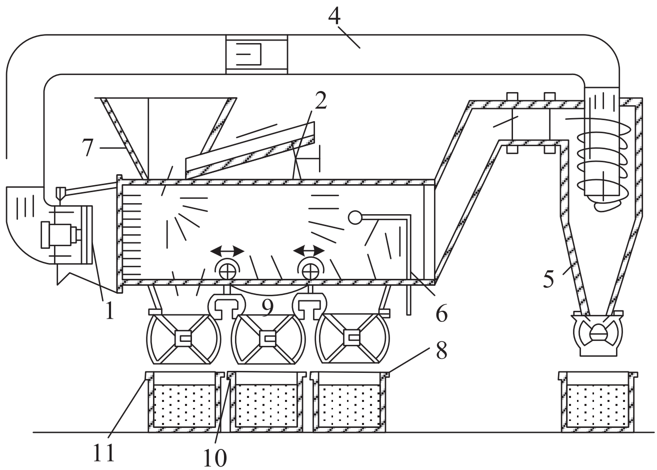


Figure 5.19. Air separator for household waste separation in horizontal air flow (Germany):
1 − fan, 2 − receiving funnel, 3 − vibratory feeder, 4 − air recirculation system, 5 − cyclone, 6 and 9 − moving barrier, 7 − barrier, 8, 10 and 11 − collectors of materials

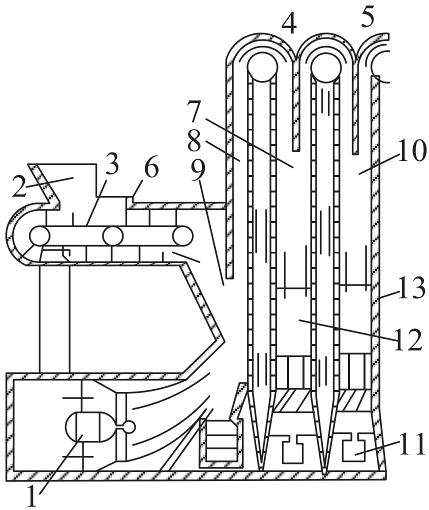


Figure 5.20. Multisectional vertical air separator (USA):
1 and 13 − fans, 2 − receiving bunker, 3 − conveyer, 4 − blades, 5 − chamber of separation, 6 − channel, 7, 10 − sorting columns, 8, 9 − throats, 11 and 12 − inclined grates

The multisectional vertical air separator for shredded household waste is patented in the USA. Waste is supplied in bunker 2 and moved to the separating chamber 5 by conveyor 3 with blades 4. The material coming into the camera moves upwards by air flow from the fan 1 in the narrowing channel 6. Waste from a narrow throat 5 come into the first sorting column 7, where the air flow moving upward from the fan 13 performs the first cleaning. Light fraction of material is moved upward by air flow through the narrowing throat 9 in the second sorting column 10. The heavy fraction is removed by inclined grates 11 and 12 on the conveyor. The number of sorting columns is determined depending on required purity of the material. Installation is provided with air circulation system.

One of the air separation types is vibratory-air separation. Air that is supplied through a perforated vibrating deck and deck vibrations provide material loosening and its separating by density and simultaneous transporting of light and heavy components in opposite directions to the unloading ends of the deck (Fig. 5.21). For increase of the separation efficiency, deck is set inclined, the incline angle must ensure unhindered lifting of heavy components (at given amplitude and direction of the deck oscillations).

For the first time vibratory-air separation for dry fine-shredded fractions of household waste was used in Switzerland. Two types of products were obtained. One of them concentrated heavy inert components (a mixture of glass, ceramics and stones), another − light components (a mixture of plastic, rubber and wood). The heavy fraction is recommended to use at landfills or in road construction, light fraction − in steel and coverage for floor production.

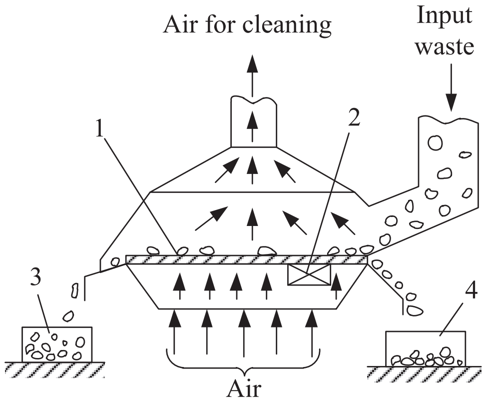


Figure 5.21. Scheme of vibratory-air separator:
1 − perforated deck, 2 − vibrator, 3 and 4 − tanks (for light and heavy fractions)

5.1.8 Manual sorting of household waste

There are a lot of valuable components in household waste, which are potentially acceptable for recycling.

Products obtained by mechanized sorting of the entire mass of household waste are characterized (except metals) by low quality, that causes difficulties when selling them.

The most efficient way is to recycle waste on the base of selective component collection in the places of its generation, preventing the getting of valuable components to the mixed waste. In this case, uncontaminated components can be involved for processing. Selectively collected waste does not contain any impurities of other components, but it requires some processing.

In the developed countries obtaining of valuable raw materials from household waste is mainly done by extensive organization of separate waste collection at the places of generation. The final separation of collected selectively collected waste is carried out at special sorting plants, mostly by manual sorting. There are direct sorting (extraction of valuable components) and reverse sorting (removal of polluting components including hazardous), which are carried out at such plants. Usually paper (including by different types), plastics, glass and metals (metals are often extracted automatically by using air-dynamic and magnetic separation) extraction is used.

The technology of sorting of selectively collected waste in most cases is the same. It is manual selection of different components from the low-speed conveyor (width is no more than 1200 mm, speed − less than 0.5 m/sec, mainly 0.1-0.2 m/sec) and mechanized sorting of metals. In some cases, manual sorting follows by the sifting of input waste for fine particles removal and loosening waste mass. The technological scheme can include shredding operations (packaging opening) if necessary. Equipment for mechanized sorting is installed on a certain height from a floor in a special room equipped with active ventilation system and disinfecting device.

The remains of sorting are usually compacted (container compaction). A lot of separated components (metals, paper, plastics, textiles) are also compacted, but the method of packaging is used. The paper, plastic and textile are always packaged by use of strapping wire or rope. These processes are fully automated. The packing increases the efficiency of products accumulation, storage and delivery to the customer. Accommodation of packages in the warehouse and loading them into vehicles are conducted by use of the autoloader (the use of magnetic pucks is possible to move packages of black metals). Compacting and removing of sorting remains in compressed form reduce transportation costs.

Garbage trucks delivering waste for sorting pass radiometric control, they are weighed and unloaded on a flat beton area (minimal size 30x30 m). Waste is supplied into a tail part of deepened conveyor or into tabular feeder of light type by frontal loader (optimal option is the use of advanced horizontal-inclined feeder, where rubber tape preventing material loss is attached to the plates). The upper branch of feeder-conveyor delivering material on the sorting conveyor is deepened by 0.4 m. The capacity of a sorting line ranges from 3 to 10 tons per hour depending on the waste composition. The components separated as recyclables are dumped in the holes and fall in lower-situated containers (bunkers) (under the sorting room). The horizontal conveyor can serve as bottom of the containers. This makes it easier to supply paper, plastic and textiles for packing (automatic supply of materials on the horizontal-inclined conveyor feeding packaging press).

It should be noted that for the staff working at the places of manual separation (places are equipped on both sides of the horizontal sorting conveyor) the conditions of increased comfort are provided. Typically, sorting lines are placed in special closed glazed rooms with local intensified lighting, dust capturing and air conditioning. Sorting rooms are situated in the building, where all the complex of waste receiving and processing and products storage is placed.

Table 5.2 provides information about the capacity of manual household waste sorting by the final product.

Table 5.2. Information on the capacity of household waste manual sorting by the final product (data of ISWA − International Solid Waste Association)

Separated component	**Capacity, kg per hour on 1 worker**	**% of removal**
Newspapers	700-4500	60-95
Corrugated cardboard	700-4500	60-95
Glass (without separating by colour)	400-800	70-95
Plastic packaging (mainly polyethylene)	140-280	80-95
Aluminium cans	45-55	80-95

The leading European companies on press and conveyor equipment manufacturing for sorting plants and recyclables processing are Presona (Sweden), UTG (Germany), Macpresse (Italy), Imabe Iberica (Spain).

In the nearest future in Ukraine it is difficult to organize full-efficient selective waste collection, while a lot of pilot projects are organized and recyclables collection is introduced in many municipalities. For household waste involvement in sorting to obtain valuable products and minimize the waste amount sent for processing and disposal, not a component, but a fraction collection of household waste is advisable in Ukraine. The European technologies for sorting those waste fractions containing uncontaminated valuable components can be adopted as well. The optimal composition of household waste involved in processing to obtain valuable products should be selected on the base of dividing waste streams of residual and commercial waste. Sorting at special facilities should be conducted mainly for non-residual waste (waste of markets, shops, institutions, schools, etc.) containing a lot of paper and characterizing by low content of food and other organic waste. Manual sorting efficiency largely depends on the work organization on the stage of household waste collection and transportation.

It should be noted that the elements of manual sorting are included in technological scheme of complex processing of household waste in developed countries. As a rule, manual sorting is used for large size material (200-300 mm). It is explained by the fact that large material does not contain food waste, besides, small particles are poorly sorted manually.

5.2 Technological scheme of household waste separation

As was mentioned above, household waste is a heterogeneous mixture of organic and inorganic components of complex morphological composition (ferrous and nonferrous metals, paper, textile components, glass, ceramics, plastics, food waste, stones, bones, leather, rubber, wood, garden waste, etc.). A lot of them, in particular metals, become a waste after single use.

Separation of household waste has its own specificity when selecting both processes and installations. Even processes, which are identical for other objects of separation, in the case of household waste are characterized by another regime and have specific details and features. At the same time, some installations and processing methods used for household waste separation can be also used for the enrichment of fossil raw materials.

The quantity of separation operations their features and order in the technological scheme depend on morphological composition, particles size, humidity, waste sorting tasks in each case.

According to industrial practice of household waste sorting, quality of products obtained by mechanized sorting (except metals) is lower compared to manual sorting. As a result, paper (as part of the light fraction), glass and other components are difficult to sell. Taking into account the above mentioned and real value of the materials and market conditions, mainly ferrous and nonferrous metals are considered as key waste components during mechanized sorting, since their content in household waste is continuously growing.

Metals should be removed also for the reason that they must not get in the incineration and fermentation processes.

Therefore, in general, efficient scheme of mechanized household waste sorting should include:

- extracting of ferrous and nonferrous metals;
- separation of the waste stream on two fractions − combustible and biodegradable (for thermal processing and biological processing or landfilling respectively);
- removal of dangerous and ballast components.

Comparison and selection of technological schemes of household waste sorting by criterion assessment are difficult, since not all schemes have the same purpose and take into account regularities of waste separation in the same way. For example, shredding of all household waste worsens further separation efficiency and increases costs without any obvious advantage).

According to world practice, household waste sorting typically begins from sifting. Different size particles are separated by appropriate methods providing certain technological effect (increased extracting and cleanliness of separation). At the same time, according to experience, use of drum sifter at the beginning of the process is not needed, because sifter holes are easily clogged by wet and textile components.

Taking into account the specificity of Ukrainian household waste, simple transferring of European sorting technologies to Ukrainian conditions is not an optimal solution. Any European technology must be adopted to Ukrainian conditions, taking into account above mentioned technological properties of household waste.

Analysis of modern foreign technologies of household waste separation shows that they are not universal and it is not advisable to use them for processing of Ukrainian household waste, which has more complex composition. In most cases foreign technologies are intended to solve certain task of extracting various valuable components (or mixtures of components), but they are not intended to solve the complex task of waste preparing for further processing by any method.

According to practice, there is low efficiency of fine particles sifting. Thus, technological schemes including such operation are not optimal.

The analysis shows that almost all foreign technologies involve the regulating of separated waste stream by the use of sifting. Efficiency of separation is higher, if not only sifting methods are used for regulating of separated waste stream (household waste separation by small particles is difficult), but also air separation dividing waste stream on light and heavy fractions can be used. Air separation of main waste stream is also an operation improving sanitary-hygiene conditions of work, drying the waste, increasing the completeness of metals extraction, separating of inert components.

Therefore, the actual task when designing appropriate plants is the use of workable and tested technology of household waste separation, which fully takes into account its specific composition, as well as international experience.

5.3 Thermal processing of household waste

5.3.1 Overview of waste incineration

Incineration is the most adjusted method of household waste processing. The possibility to use this method is based on morphological composition of household waste containing 70-80% of organic (combustible) fraction.

Incineration has become the first technical method of waste management used in practice by mankind: first incineration facility was built in 1878 near London. Naturally, first such installations were built in countries with a relatively small area and high population density. Currently, incineration is most widely used in Japan, Switzerland, Denmark, Sweden, Netherlands and France.

In the 1980s the quantity of incinerated waste per capita was as follows (in kg/person per day): Norway and Spain – 0.05; UK, Italy, USA, Canada and Finland – 0.05-0.15; France, Japan, Austria, Germany, Belgium and Netherlands – 0.25-0.4; Sweden, Switzerland, Denmark, Luxembourg and Monaco – more than 0.5. Currently, European countries use thermal methods for processing 25-30% of household waste, in Japan – 65-70%, in the US – 15-20%.

Since incineration is exothermic process, the heat generated can be utilized.

When the energy crisis happened in the 1970s, waste was considered as energy source. It was estimated that incinerating of 1 ton of household waste can produce 1300-1700 kWh of thermal energy or 300-500 kWh of electricity. A very intensive construction of incineration plants with heat recovery of emitted gases took place during this period. Also great work has been carried out on obtaining of household waste combustible fraction in the form of fuel pellets mixed with charcoal (waste part is 20%) for using at power plants. This fuel from a waste has different names in different countries: "RDF" in the US, "BRAM" in Germany, "Brini Fuel" in Scandinavian countries. Currently, the production of fuel pellets from household waste for next sale to external consumers is low cost-effective and rarely used. The better variant is energy production at the incineration plant for energy needs of this plant and for transferring of excess energy to consumers.

There are over 400 incineration plants in the world. It is estimated that in Western Europe the household waste incineration could cover 5% of heat energy consuming by households. For example, in Sweden this figure reaches 13%.

Most European incineration plants have the capacity from 170 to 800 tons per day and mainly use boilers of small or medium capacity (5-15 tons per hour).

The technology of household waste incineration is continuously improved.

In the 1930s, the furnaces were designed for continuous layer incineration of household waste on the grates installed at the furnace bottom.

The boilers with pseudo-liquefied layer furnaces (system "solid-gas") appeared in the early 1980s. In the late 1980s, the furnaces with circulating boiling layer appeared, which met environmental requirements and did not require compulsory waste preparing to incineration. In the early 1990s, there was the research of household waste incineration in the layer of bubbling slag melt at a temperature of 1350-1500°C using oxygen enriched blowing, which allows reducing the amount of gases emitted and receiving the uncontaminated slag. Finally, new methods of combined thermal processing of household waste were developed and tested in recent years, including processes "pyrolysis-incineration" and "pyrolysis-gasification".

Modern thermal processes are environmentally friendly when processing the prepared household waste, complying with the technological standards and using the modern methods of gas cleaning (in turn, gas cleaning efficiency largely depends on the implementation of so-called primary measures in thermal process). In this case, according to German practice, industrial emissions are well below the limits regulated by environmental legislation.

The volume and composition of gases emitted during thermal processing of household waste depends on the waste composition, used equipment and regime of the process. During the layer incineration of 1 ton of household waste there are 4500-6000 m^3 of gases produced. When using the waste gasification or its incineration with oxygen blowing, the amount of emitted gases is reduced to 600-1000 m^3 per 1 ton of waste.

There are also 700-1100 m^3 of water vapour, 200-400 kg of slag and 20-50 kg of volatile ash, which are produced from 1 ton of household waste during the incineration.

The efficiency of thermal processing of household waste is determined by the composition of waste, technology of the process, the preparedness of waste to incineration and the stabilization of its composition, regime of the process (process temperature, time of waste gases being in the combustion chamber, temperature of waste gases, volume and distribution of blowing air), and by technology of the process automation.

The air consumption for incineration in modern boilers can be maintained at the lowest possible level (oxygen concentration in the waste gases is less than 3%, while CO content is no more than 10 mg/m^3). Blowing air performs several functions: supplies the oxygen for the combustion of organic waste components, regulates the process of inhomogeneous waste incineration, mixes waste gases, and cools boiler components and waste gases.

Due to the fact that the expensive gas cleaning decreases the economic performance of incinerating plants, there is an increased importance of direct waste components recycling, waste separation, and implementing of primary measures facilitating the gas cleaning: reduction of incinerated waste stream (using selective collection and sorting), stabilization of waste composition, extraction not only valuable but also dangerous components before incineration.

In Germany until recently dominated thermal methods of household waste processing and technological development in this field has been connected with improving the thermal technology. But now, waste problems are solved mainly by organization of selective waste collection in the places of waste generation. Selective collection does not cover only main valuable components (glass, metal, paper, etc.). For example, such hazardous waste as used batteries are mostly absent in household waste. A similar situation exists in Japan and several other developed countries.

Selective collection of household waste is practically absent in Ukraine. Therefore, when selecting the technology solutions, it is necessary to take into account differences in the composition of waste exposed to thermal processing. Besides, household waste in developed countries has increased heat value in comparison to Ukrainian household waste.

Since household waste incineration is an effective way of waste neutralization, it is necessary to determine the optimal place of waste incineration in the system of complex household waste processing. Obviously, incineration should be used for not all the waste generated, but preferably for its combustible fraction, which significantly reduces the harmful effect of gas emissions on the environment, reduces the required furnaces capacity, and allows extracting the valuable components of household waste for recycling.

The main trend in waste incineration is the replacing of direct household waste incineration by the optimized incineration of combustible fraction extracted from household waste, as well as replacing of incineration as a process of household waste elimination to incineration as a process providing both waste neutralization and heat and electricity producing.

The main advantages of modern methods of thermal processing are as follows:

- reducing the volume of waste by 10 times;
- efficient waste neutralization;
- use of the energy potential of organic waste.

Waste can be considered as alternative fuel. At the same time, incineration should be primarily assessed as a recycling method, but not a way to produce energy. This means that priority conditions must be optimal for reducing the environmental hazards of technology rather than for achieving maximal energy production.

The experience of household waste incineration in majority of countries, including Ukraine, shows that the highest efficiency of incineration can be achieved by the use of combined method: layer (basic) and chamber (for afterburning the products of thermal decomposition). Incineration of high-humidity multicomponent household waste, which has many specific properties, on the grates using layer method (see fig. 5.22) has several important advantages:

- high-humidity household waste incineration without prior drying;
- high stability of the incineration process in desired and required ranges;
- possibility of household waste incineration without any prior processing (sorting, shredding, except large objects, metal separation, etc.);
- computer managing of incinerator mechanisms for achieving the maximal possible completeness of waste incineration.

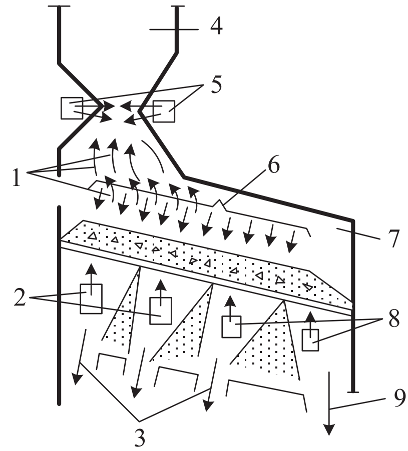


Figure 5.22 – Scheme of layer process of household waste incineration: 1 – volatile components, 2, 8 – primary air, 3 – remains and slag, 4 – afterburning chamber, 5 – secondary air, 6 – household waste, 7 – incineration chamber, 9 – slag.

These benefits correspond to the entire range of incinerators capacities for the waste of all Ukrainian municipalities. The intensity of the waste burning process in the layer tends to increase, while the torch process is very close to limit by these characteristics. A substantial increase of the intensity can be achieved by increasing the primary air temperature, which conduces to very active drying of high-humidity waste in the first zone of grates and to a significant increase of volatile components volume in the second zone. The high-temperature air supply in these zones dramatically reduces above parameters at the output of zones compared to fuel preparation in conventional layer furnaces. This is due to the fact that waste drying process and emission of volatile components are carried out by both convective heat exchange and due to the heat received by layer from furnace space. Process intensification is also facilitated by high concentration of combustible waste part, waste porosity, and therefore multiple waste washing by high-temperature oxidant. A significant impact has regulating of hot air supplying of each zone of grates, including zones of coke incineration and slag burning out.

Increase of waste incineration process intensity causes an increase of primary high-temperature air speed in the layer and therefore leads to removal of many large particles by the stream of gases emitted away from a layer. In order to reduce the mechanical underburning above the grates, a narrowed section is arranged at the bottom of afterburning chamber, where dense layer with mechanical and chemical afterburning) is permeated by the gases mixed with secondary air (oxidant). This conduces to active gases afterburning in the chamber above this section.

The increased rate of air filtration through waste layer while process intensification and very active removal of small fuel particles could form holes in the layer (craters), where main air volume would be directed, while the main part of layer would be without air. However, it is not true if blowing air pressure does not exceed 1500-2000 Pa and waste layer on the grates has a thickness of 380-420 mm. With these limitations air filtration rate can be determined by the formula

$$W_f = \sqrt{\frac{2g \cdot P}{p_A}} \tag{5.31}$$

where p_a – air density at its temperature, kg/m^3;

P – static air pressure under the grates, kg/m^2.

Therefore, the scheme of organization of household waste layer incineration is countercurrent, when fuel is supplied to grates from above and air enters from below and permeates the waste layer. The unit thermal stresses of grates should not exceed

$$q_R = (0,7 \div 1,2) \cdot 10^6 \text{ W/m}^2. \tag{5.32}$$

Taking into account the relatively small heat value of unsorted and unprepared household waste (5.7 MJ/kg in average), its combustion is stabilized by: in a layer –primary high-temperature air supply (400-450°C), in afterburning chamber – hot secondary air supply (230-250°C) and some amount of additional fossil fuel (gas, oil).

5.3.2 Potentially harmful gas emissions in thermal processing of household waste

For projecting the incineration plant meeting the environmental and economic requirements, one must have fundamental knowledge about potentially hazardous ingredients contained in household waste and formed during incineration, as well as their behaviour during combustion.

Household waste is a heterogeneous mixture containing almost all the chemical elements in the form of different compounds. The most common elements are carbon (about 30% by weight) and hydrogen (4% by weight), which contain in organic compounds. In some cases, heat value of household waste is developed countries reaches 3300 kcal/kg. The further increasing of household waste heat value will affect the construction features of thermal equipment.

Incineration of household waste is usually oxidation process and oxidation reactions dominate in the combustion chamber. The main products of carbon and hydrogen combustion are CO_2 and H_2O respectively. N the case of incomplete combustion unwanted products are formed: carbon monoxide CO, low-molecular organic compounds, polycyclic aromatic hydrocarbons, ash, etc. Similar compounds can be products of the reactions occurring in the zone of colder equipment elements (for example, at the output of the furnace, at the stage of gas cleaning, etc.).

It has to be taken into account that household waste contains potentially dangerous element characterized by high toxicity and volatility (see Table 5.3): different compounds of halogens (fluorine, chlorine, bromine), nitrogen, sulphur, heavy metals (copper, zinc, lead, cadmium, tin, mercury, etc.).

Table 5.3. Content of dangerous elements in the Earth crust and household waste

Element	**Content, grams per ton**	
	Household waste	**Earth crust**
Chlorine	5000-8000	150
Bromine	30-200	2.4
Sulphur	1000-3000	500
Copper	200-1000	60
Zinc	600-2000	70
Lead	400-1000	14
Mercury	0.5-5	0.1
Cadmium	5-15	0.15

The table shows that the content of halogens, sulphur and heavy nonferrous metals in household waste is much higher compared to Earth crust.

During the incineration of household waste, halogens are preferably in the form of their compounds with hydrogen (HCl, HBr, HF), which are the most stable products of combustion.

Sulphur mainly (70%) transforms to the non-volatile sulphates left in slag and volatile sulphur dioxide SO_2.

All volatile products of reactions form waste gases. In untreated gas emissions compound concentrations are as follows (mg/m^3):

HCl − 300-1000, HBr − 100-500, HF − 2-10, SO_2 − 100-500.

Dry household waste contains about 1% of nitrogen (by weight). The main product of nitrogen oxidation is nitrogen monoxide NO, its usual concentration in the untreated gas is 200-400 mg/m^3.

Some heavy metals contained in household waste (iron, chromium, nickel) do not form volatile products during incineration and basically get in the slag.

Lead and cadmium form chlorides emitting with other gases. When cooling waste gases to 200°C, these chlorides are condensed and captured with ash at the stage of gas cleaning. At the same time, one of the most toxic metals, mercury, and its compounds stay primarily in the gas phase even at lower temperatures.

The heavy metals content in household waste has increased dramatically over the last decades due to batteries, accumulators, luminescent lamps, synthetic materials (dyestuffs, stabilizers), etc. According to German practice, 1 ton of household waste contains in average 300 grams of batteries. Household waste of a city with population of 0.5 million people about 50 tons of used batteries are generated annually. Mercury content in this amount ranges from 1 to 25%. There is about 15% of cadmium in nickel-cadmium batteries waste. The total cadmium content in German household waste is 10-15 mg/kg (the main sources of cadmium are batteries and synthetic materials).

According to US data, the main sources of lead in household waste (and therefore in gas emissions during waste incinerating) are as follows: 65% − lead-acid batteries (mainly from vehicles), 27% − electronic devices, 4% − glass and ceramics, 2% − plastics (temperature stabilizers and dyestuffs); main sources of cadmium are as follows: 54% − batteries, 28% − plastics, 9% − electronic devices, 5% − other household devices (washing machines, etc.), 4% − dyestuffs; the main source of mercury are batteries.

When incinerating household waste, 90% of cadmium gets to waste gases and sediments mainly on small (less than 2 microns) particles of volatile ash. Therefore, the main task in gas cleaning is complete capturing of volatile ash characterizing not only by high cadmium content, but also high content of lead and other metals.

According to practice, the concentration of metals in the waste gases during household waste incineration is 10-100 times more compared to concentration of metals in the waste gases of power plants using coal. Therefore, heavy metals are specific contaminants of incineration plants.

When incinerating household waste, especially with oxygen lack, very toxic compounds are formed: dioxins and furans.

Use of very high temperatures and the creation of any additional zones of additional combustion do not solve completely the problem of reducing the dioxins concentration in the waste gases, since dioxins have the ability to a new synthesis at lower temperatures. At the same time, with increasing the temperature, the volume of volatile metals and their content in volatile ash increases (especially with increasing the content of chlorinated organic compounds in incinerated waste).

Theoretically, there are two ways to avoid dioxins formation:

- binding of HCl formed during household waste incineration using soda, lime, potassium hydroxide;
- transforming the copper and iron ions to inactive form, such as copper binding to complexes using amines.

5.3.3 Selecting a temperature of thermal process

Thermal processing of household waste is high-temperature oxidation of organic components. The temperature of thermal process can not be any, it is determined by specific environmental and technological requirements.

1. For minimization of slag and toxic volatile organic compounds generation it is necessary to provide the most complete thermal decomposition of organic components of household waste (carbon monoxide and ash are formed during underburning, as well as optimal conditions are created for formation of dioxins and furans − very toxic and dangerous compounds).

According to practice, when using the technology of incineration in circulating boiling layer, which provides the most intense mixing of prepared (shredded) waste, and in the case of good contact of waste with the heat carrier, the minimum required temperature of the process is 850°C. The content of unburned components in the slag at this regime is about 1% (typical temperature is 850-950°C).

When using the technology of layer incineration of unprepared (unshredded) household waste, the intense waste mixing is not possible, and required temperature of the process is 900-1000°C. The content of unburned components in such conditions at properly organized process does not exceed 2-3%.

For the process of household waste gasification in a dense layer using vapour-air mixture as the gasification agent, the required temperature, according to experiments, is at least 1200°C. For comparison, classic non-catalytic gasification of coal actively occurs at temperatures above 900ºC).

2. For ensuring the decomposition of organic compounds formed during the incineration (primarily dibenzodioxins and dibenzofurans) to harmless and non-toxic substances, the minimum required temperature during combustion in boiling layer, according to EPA research, is 850°C (time of staying of gases emitted in incineration chamber must be at least two seconds). In fact, environmental requirements for the temperature of the process coincide with technological requirements. In real conditions for ensuring the dangerous compounds decomposition, expected time of waste gases staying in combustion chamber is at least 3 seconds.

3. For slag neutralization (obtaining of slag melt and its further vitrification during the thermal processing of household waste), the temperature of process must be above the melting point of slag (1300°C).

The approximate slag composition for European plants is as follows (g/kg): Si − 500; Ca − 150; Fe − 30-50 (100); Al − 100; Na, K − 60; Mg − 25; C − 15; S − 5-10; Zn − 2-8; Cu − 1-4; Pb − 1-3.5; Ni − 0.1-0.4; Cr − 0.15-0.6; Cd − 0.003-0.3; Hg − $3 \cdot 10^{-4}$; Cl − 3; F − 0.3. Common size of the slag particles is 25 ± 4 mm. Heavy metals in the slag are in the form of oxides (common particles size is 1 mm).

In real processes the temperature of 1350-1500°C is usually maintained:

- required temperature for slag melt obtaining in the Vanyukov process is 1350-1400°C;
- temperature for electric-slag melt obtaining is 1400-1500°C;
- sufficient temperature for slag melt obtaining in the "semicocking-incineration" process (co-combustion of pyrolysis gas and solid carbon organic residue separated from the mineral fraction), according to practice, is 1300°C;
- when gasificating the solid pyrolysis residue of household waste (carbon residue separated from the mineral fraction or together with it) and implementing the combined technologies "pyrolysis-gasification" with liquid slag removing and using oxygen as the gasification agent, high oxygen content during the blowing ensures high temperature of the process − up to 2000°C.

5.3.4. Classification of thermal processing methods

There are dozens of thermal technologies variants for practical use. It is very important to determine the optimal field of each method use and its real practical value.

The critical analysis and comparison of the thermal technologies are impossible without their clear classification.

Depending on the temperature of the process, all methods of household waste thermal processing, which have industrial use or were tested, can be divided into two major groups: processes with temperatures below the melting point of the slag and processes with temperatures above the melting point of the slag. In turn, by the principal character of the process, these groups can be divided into three sub-groups, which are classified in details by the type of technology applied (see Table 5.4).

Table 5.4. Classification of methods of household waste thermal processing

Group	Sub-group	Type (the technology applied)
Thermal processes with temperatures below the melting point of slag	1. Layer incineration with forced mixing and moving of waste	a) on pushing grates; b) on rolling grates; c) in drum rotating furnaces
	2. Incineration in the boiling layer	a) in stationary boiling layer; b) in whirling boiling layer; c) in circulating boiling layer
	3. Incineration-gasification in the dense layer without forced mixing and moving of waste	a) vapour-air process
Thermal processes with temperatures above the melting point of slag	1. Incineration in the layer of slag melt	a) using oxygen enriched blowing (Vanyukov process); b) using earth gas for blowing (fuming-process); c) using electric-slag melt
	2. Incineration in the dense layer and slag melt without forced mixing and moving of waste	a) blast furnace process (using air heated to 1000°C)
	3. Combined processes	a) pyrolysis-combustion of pyrolysis gas and separated hydrocarbon residue using non-enriched blowing (Siemens process); b) pyrolysis-gasification (synthesis gas obtaining using a combined heat treatment of pyrolysis gas, hydrocarbon residue separated from metals and mineral components) using oxygen enriched blowing (Noell process); c) pyrolysis-gasification (synthesis gas obtaining using a combined heat treatment of pyrolysis gas, hydrocarbon residue and mineral components) using oxygen enriched blowing (Thermoselect process)

The main factors influencing the selection of thermal technology are the level of process preparedness for industrial use, limited equipment capacity, environmental and economic criteria (environmental impact, capital and operating costs), exploitative criteria (duration of equipment use between repairing or updating, applicability to repair, work reliability, automating possibility).

Fig. 5.23 shows the example of technological implementation of household waste thermal processing on a stationary installation designed for processing the household waste of variable composition and variable humidity. Such incinerators are made as mobile installations with furnace chamber (on railway platform or vehicle) with capacity from 50 to 300 kg per hour (0.25-1.5 m^3 per hour) and stationary installations with capacity up to 6 tons per hour (30 m^3 per hour) equipped with rotating furnace.

Currently such two mobile installations with capacity of 150 kg per hour are used in Ukraine.

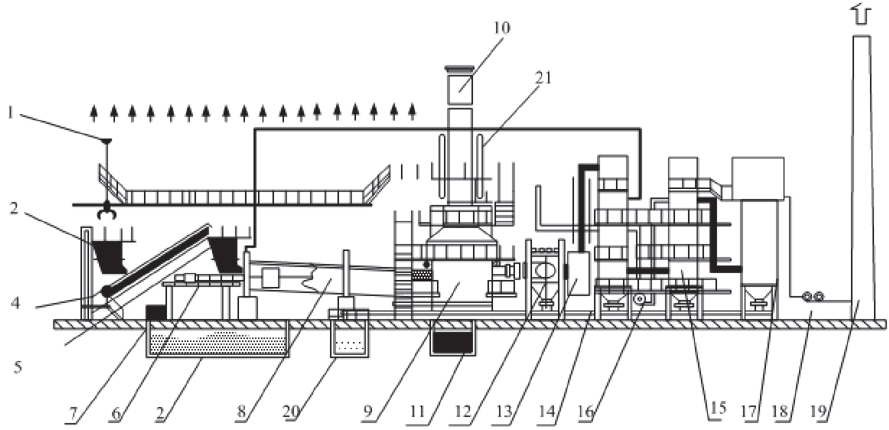


Figure 5.23. Structure of stationary incineration installation:
1 – crane-girder with grab, 2 – compartment for waste receiving, 3 – intermediate bunker, 4 – conveyor, 5 – loading bunker, 6 – loading device, 7 – shredder for sorted plastic waste, 8 – rotating furnace, 9 – afterburning chamber, 10 – lid of the chimney of direct dump with pneumatic drive, 11 – bath for slag receiving, 12 – inertia-whirling coaxial dust collector, 13 – catalytic device, 14 – scraper conveyor, 15 – recuperator, 16 – fan of high pressure, 17 – bag filter, 18 – smoke exhauster, 19 – chimney, 20 – bunker for slag, 21 – recovery boiler.

The process of waste incineration in the installation of any type includes the following operations:

- waste receiving;
- waste loading into the furnace;
- waste incineration in the rotating furnace;
- collection and utilization of ash and slag;
- cooling, cleaning and emission of incineration products.

The ash corresponds to substances of 4th class of danger by the composition and can be used for road construction, as well as filler in beton products manufacturing (such as paving tile), facing tile, etc.

Multistage system of gas cleaning provides complex cleaning of incineration products with accordance with European standards. The technology of cleaning is as follows:

- afterburning of heavy hydrocarbons and carbon monoxide takes place in afterburning chamber at a temperature of 950-1050°C;
- for increasing the degree of high-toxic organic compounds neutralization, incineration products pass through a catalytic reactor. The hardly oxidative organic compounds not burned in afterburning chamber of furnace (including benzo(a)pyrene, dioxins and others) are neutralized at catalyst;
- cleaning of incineration products from acid inorganic compounds is performed by injection of alkaline solution;
- mechanical polluters, including heavy metals compounds and trace amounts of ash, are deposited in the inertia-whirling and cassette fabric filters.

Cooling of incineration products is carried out in heat recovering devices with air heating to 400°C in the installations of any type, as well as with obtaining of heat and (or) electricity in stationary installations (3.5-4.5 GJ per ton of waste).

All types of installation provide almost complete mechanization of the process and automation of operations management.

5.3.5 Analysis of combustion and gasification of household waste

Based on the knowledge about physical and chemical conditions and nature of the household waste incineration in the layer, as well as taking into account multicomponent waste composition and peculiarities of most components combustion, the kinetics of basic chemical transformations can be derived.

It is known from the theory of fossil solid fuels burning that the main process during any solid fuel burning is burning out and gasification of coke carbon. This is also applied to household waste incineration. However, waste contains certain original components (metals, including heavy, chlorine- and fluoride-containing components, etc.) behaving slightly differently during the combustion. An important impact during waste burning and cooling of the combustion products has the formation of two zones – oxidative zone (mainly, lower part of layer in zone of volatile components flying out and zone of coke burning and afterburning chamber) and reductive zone (mostly places of convective heating surface). Below are the initial temperatures, at which the volatile components in some types of fossil fuels and household waste start to form:

wood – 160°C;

brown coal – 130-170°C;

peat – 100-110°C;

household waste – 90-108°C.

The main reactions after waste preparation on the grates and releasing the volatile substances are as follows:

$$C + O_2 = CO_2;$$
$$CO_2 + C = 2CO;$$

$$2C + O_2 = 2CO;$$
$$2CO + O_2 = 2CO_2.$$

The first, third and fourth reactions characterize oxidative (oxygen) burning zone and the second reaction characterizes renewable zone. The oxygen amount need to be supplied under the layer is defined by the formula

$$L = \alpha_e \cdot 22,4 \cdot B_C / 12, \quad (5.33)$$

where α_e – coefficient of air excess at the output of layer;

B_C – coke carbon amount entering to the layer surface, kg/m^2·hour, it is defined from the ratio B_C/R;

R – area of the grates, m^2.

The oxygen amount used by the fuel layer located on the grates is as follows:

$$V_O = a \cdot \alpha_m \overline{c} \cdot \frac{6}{d_e} \cdot (1-m) \cdot h_w, \quad (5.34)$$

where a – coefficient of fuel particles streamlining;

α_m – coefficient of mass exchange, defined as follows:

$$\alpha_m = M \cdot W_f. \quad (5.35)$$

M – coefficient of proportionality depending on the height and structure of the fuel layer;

W_f – air filtration rate through the layer, m/sec.

$$M_f = \sqrt{\frac{2g \cdot P}{p_A}}, \quad (5.36)$$

$\overline{c}$ – average oxygen concentration in the layer, m^3/m;

d_e – equivalent diameter, m;

h_w – height of the waste layer on the grates, mm;

m – layer porosity, defined as follows:

$$m = \frac{V_p}{V} = \frac{V - V_C}{V}, \quad (5.37)$$

where V_p – volume of porous in the layer volume V;

V_c – volume of coke in the layer volume V.

For layer countercurrent furnaces with mechanical fuel loading on a layer, the porosity is practically constant over the entire height.

A significant impact on the kinetics of the household waste combustion has ballast part of waste, primarily metal components (cans, ferrous and nonferrous metals, metal parts of household items and so on). Besides, waste contains a lot of construction waste. All of these components are involved in chemical interaction between themselves and with other compounds during the incineration process. For example, iron oxide FeO in the oxidative zone transforms to iron oxide Fe_2O_3, and the oxidation of iron pyrites FeS_2 transforms a significant part of air oxygen to solid residue by the reaction:

$$2FeS_2 + 11O_2 = 2Fe_2O_3 + 8SO_2.$$

Sulphur dioxide can react with calcium carbonate:

$$2CaCO_3 + 2SO_2 + O_2 = 2CaSO_4 + 2CO_2.$$

The behaviour of iron inclusions in different zones of waste incineration influences the characteristics of slag melting. In the oxidative zone iron exists in the form of Fe_2O_3, and in the reductive zone – in the form of FeO and can even be reduced to Fe. Since divalent iron easily reacts with silicon forming relatively low-melting compounds, the slag melting can be reduced. In general, in the oxidation and reductive zones melting characteristics are approximately constant.

The melting temperatures of some compounds are listed in Table 5.5.

The presence of compounds similar to other metals (including non-ferrous) and significant amount of silicon salts in household waste listed in Table 5.5 changes earlier point of view that the increasing of primary air temperature over 200°C can not be allowed due to relatively low melting point of above compounds and sticking them on tubes. The long operation of incineration plants did not confirmed this opinion.

Table 5.5. Melting temperature of some compounds

Compound	**Melting temperature, °C**
SiO_2	1710
$3Al_2O_3{\cdot}2SiO_2$	1850
$2FeO{\cdot}SiO_2$	1065
$CaO{\cdot}FeO{\cdot}SiO_2$	1100
$CaO{\cdot}SiO_2$	1540
$CaO{\cdot}Al_2O_3$	1500

The presence of metal objects in household waste, as well as iron compounds generated during combustion, has a positive effect on the processes taking place in the same layer, as follows:

- accelerating of waste preparation (drying) in the first zone of grates due to intense heat transfer from metal objects with high heat value to the input waste;

- uniform stabilization of thermal mode along the grates;

- accelerated oxidative processes, since metal compounds act as a catalysts between combustible components and oxidant.

The second ballast component is the waste humidity. Its value is significant – 56-60%, varied by seasons. Accepting the distribution uniformity of external humidity throughout the waste mass, one can assume that water evaporation at the initial stages of waste incineration conduces to volatile components release. At the same time, for this evaporation the heat is spent, which is required for stabilizing the incineration process in the layer. But this negative phenomenon is easily neglected by hot primary air supplying from the bottom of grates through the household waste layer.

5.3.6 Technological scheme of household waste incineration

Technological scheme of household waste incineration is shown in Fig. 5.24. It is intended for the solution of following tasks:

- providing absolutely complete incineration of all household waste, including large (refrigerators, washing machines, beds, including metal, etc.) without any previous preparation (drying, sorting, etc.);

- ensuring the environmental safety of the process of waste neutralization;

- complete use of valuable waste components (ash, slag, waste of gas cleaning, etc.);

- elimination of municipal landfills;

- providing the profitability in order to achieve the payback of capital and operating costs.

Solving these tasks is provided by the following technical solutions. There is part of landfilled waste sending for neutralization. Also toxic industrial waste similar to household waste by the characteristics (wood, textile and light industry waste, etc.) can be accepted, as well as sediments of sewage. Large waste is shredded in special device before incineration, and then it is mixed with the rest of household waste. The waste mixed by the grab in receiving bunker is transferred to the unloading bunker of incinerator, from where waste is taken to the combustion chamber using feeder and it is burned in a layer (1st stage of incineration), through which the primary hot air is supplied. Volatile waste components emitted during drying and warming in the first two zones on the grates, as well as the products of complete and incomplete waste combustion and formed coke are sent in vertical afterburning chamber (2nd stage of incineration) through the narrowed section at the top of the combustion chamber, in which the hot secondary air comes. The formed gases, which wash next heating surfaces including water economizer located in the last boiler chimney, are cooled to a temperature of 220-230°C at which gases get out of boiler and come to the two-stage gas cleaning device. At the first stage of this device (cyclone) gases are cleaned from large mechanical suspensions (ash and dust), and at the second stage (rotary filter, in which the dry lime is blown) − from small particles dust, HF, HCl and SO_2. The gases cleaned in this way come in a cyclonic chamber of recovery boiler (3rd stage of incineration), where they are burn out (for afterburning the products of incomplete combustion) using additional fossil fuels at 1100°C. Then they come to the afterburning chamber (4th stage of afterburning), where products of incomplete combustion are burned out.

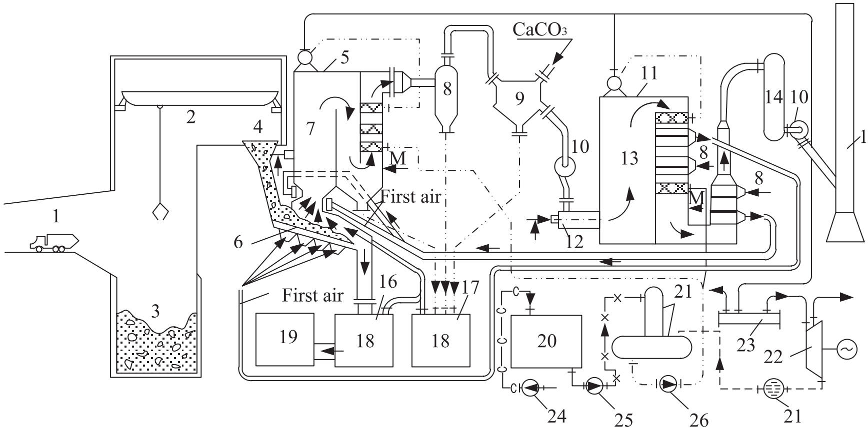


Figure 5.25. Technological scheme of waste incineration plant:
1 – receiving section, 2 − grab crane, 3 − receiving bunker, 4 − bunker of boiler, 5 − incinerator, 6 − 1st stage of incineration, 7 − 2nd stage of incineration, 8 − cyclone, 9 − rotary filter, 10 − smoke exhauster, 11 − recovery boiler, 12 − 3rd stage of incineration (afterburning), 13 − 4th stage of incineration (afterburning), 14 − filter for mercury capturing, 15 − chimney, 16 − section of slag melting, 17 − section of ash melting, 18 − 5th stage of incineration (afterburning), 19 − section of metal ingots and construction materials manufacturing, 20 − chemical water treatment, 21 − deaerator, 22 − steam turbine with generator, 23 − steam collector, 24 − input water pump, 25 − chemically treated water pump, 26 − feeding pump, 27 − capacitor.

$\xleftarrow{B}$ air from fan; $\xleftarrow{м}$ injection of ammonium solution; ⟶ device for additional fuel burning; - overheated vapour; - c – input water; - x – chemically treated water; -··- feeding water; - - - condensate; -·- ash.

In one of the recovery boiler chimneys with the required temperature level the spraying device is set for thorough mixing of ammonium solution and waste gases for reacting with nitrogen oxides and neutralizing them (third stage of gas cleaning). Two air heaters are installed in the last chimney of the boiler: in the first air heater (according to the gas direction) primary air is heated for waste incinerator, and in the second air heater – secondary air is heated. Waste gases are cooled to 110-120°C. At this temperature they enter the fourth stage of cleaning – filter, where gases are cleaned from mercury using activated coke (or coal).

Household waste of different quality is supplied in the furnace of waste incinerator, including waste with heating value not providing stable and reliable combustion. Therefore, waste incineration is usually accompanied by a simultaneous burning a certain amount of additional (fossil) fuel in the same furnace. Such co-incineration is used if the heating value of the waste is less than 1550 kcal/kg (6.5 MJ/kg). Additional (fossil) fuel must provide the total heating value of the fuel mixture at above mentioned value, ensuring the stabilization of incineration process. The amount of required fossil fuel (the nominal fuel with heating value of 7000 kcal/kg is used for calculations to simplify it), which provides the stabilization of incineration process while burning the required amount of household waste, can be determined according to the following expressions:

heating value of the fuels mixture

$$Q_f = Q_f^n \cdot g + Q_w \cdot (1-g), \tag{5.38}$$

where Q_f^n – heating value of nominal fuel (7000 kcal/kg or 29.3 MJ/kg);

Q_w – heating value of household waste, defined by samples measuring, kcal/kg (MJ/kg);

g – mass fraction of one of the fuels in the mixture, in this case it is the fraction of nominal fuel;

After appropriate transformations of above formula:

$$g = \frac{Q_f - Q_w}{Q_f^n - Q_w}. \tag{5.39}$$

The amount of nominal fuel (tons per hour) required for stabilizing the combustion process in waste incinerator is as follows:

$$B_{nf}^{st} = g \cdot \frac{B_w}{\eta_I}, \tag{5.40}$$

where B_w – required amount of household, tons per hour or tons per year;

η_I – efficiency of incinerator.

The waste gases, which are generated in the incinerator due to co-incineration of household waste and certain amount of fossil (nominal) fuel, come in cyclonic furnace of recovery boiler for re-burnout at 1100°C using additional amount of the same fossil (nominal) fuel. Its amount can be determined based on the equation:

$$V_w \cdot B_w \cdot I_w'' + V_{nf} \cdot B_{nf}^{st} \cdot I_{nf}'' - (V_w \cdot B_w \cdot I_w' + V_{nf} \cdot B_{nf} \cdot I_{nf}') = V_{nf}^g \cdot B_{nf}^c \cdot I_{nf}''' \cdot \eta_{rb}, \tag{5.41}$$

where V_w – unit volume of waste gases (m[3]/kg) forming during the household waste incineration and entering in recovery boiler for burn out (the coefficient of air excess before recovery boiler). It is determined on the basis of the following expressions:

$$V^O = 0{,}089 \cdot C^P + 0{,}255 \cdot H^P + 0{,}033(S^P - O^P), \quad (5.42)$$

$$V_{RO_2} = 0{,}0187 \cdot (C^P + 0{,}375 S^P), \quad (5.43)$$

$$V^O_{H_2O} = 0{,}0124(9H^P + W^P) + 0{,}0161 \cdot V^O, \quad (5.44)$$

$$V^O_{N_2} = 0{,}79 \cdot V^O + 0{,}8 \cdot N^P / 100, \quad (5.45)$$

$$V^O_g = V_{RO_2} + V^O_{N_2}, \quad (5.46)$$

$$V_{H_2O} = V^O_{H_2O} + 0{,}0161(\alpha_1 - 1) \cdot V^O, \quad (5.47)$$

$$V_g = V^O_g + (\alpha_1 - 1) \cdot V^O, \quad (5.48)$$

where α_1 – coefficient of air excess before recovery boiler, which is determined during the calculation of waste incinerator and gas cleaning devices;

$$V_w = V_g + V_{H_2O}. \quad (5.49)$$

$C^P, H^P, S^P, O^P, N^P, W^P, A^P$ are defined by the results of household waste analysis or according to the appropriate tables.

B_w – amount of household waste, kg per hour;

I_w – heating value of waste gases formed during household waste incineration in waste incinerator (at the temperature and coefficient of air excess equal to those before the recovery boiler), kJ/m[3]. It is defined by the formula:

$$T_w = I^O_g + (\alpha_1 - 1) I^O_A = V'_{RO_2}(cV)_{CO_2} + V^O_{N_2}(cV)_{N_2} + V^O_{H_2O}(cV)_{H_2O} + (\alpha_1 - 1) V^O (cV)_A, \quad (5.50)$$

where $(cV)_{CO_2}$, $(cV)_{N_2}$, $(cV)_{H_2O}$, $(cV)_B$ – enthalpy of each component of waste gases and humid air (kJ/m[3]) and of 1 kg of ash (kJ/kg). They are listed in the Table 5.6.

V_{nf} – unit volume of waste gases formed by nominal (additional) fuel burning, which is used to stabilize the process of household waste combustion in waste incinerator (with a coefficient of air excess equal to that before recovery boiler), m[3]/kg. It is determined by formulas (5.42) – (5.49), but using $C^P, H^P, S^P, O^P, N^P, W^P$ related to nominal fuel;

I_{nf} – heating value of waste gases formed by nominal fuel burning, which is used to stabilize the process of household waste combustion in waste incinerator at the temperature and coefficient of air excess equal to those before the recovery boiler kJ/m[3]. It is calculated by the formula (5.50).

Table 5.6. Enthalpies of waste gases components

v, °C	$(cV)_{CO_2}$, kJ/m³	$(cV)_{N_2}$, kJ/m³	$(cV)_{O_2}$, kJ/m³	$(cV)_{H_2O}$, kJ/m³	$(cV)_B$, kJ/m³	$(cV)_3$, kJ/m³
100	169	130	132	151	132	80.8
200	357	260	267	304	266	169.1
300	559	392	407	463	403	263.7
400	772	527	552	626	542	360
500	996	664	699	794	684	458.5
600	1222	804	850	967	830	560.6
700	1461	946	1005	1147	979	662.9
800	1704	1093	1160	1335	1130	767.6
900	1951	1246	1319	1524	1281	874
1000	2202	1394	1478	1725	1436	984
1100	2457	1545	1637	1926	1595	1090
1200	2717	1695	1800	2131	1754	1206
1300	2976	1850	1963	2344	1913	
1400	3240	2009	2127	2558	2076	
1500	3504	2164	2294	2779	2239	
1600	3767	2323	2461	3001	2403	
1700	4035	2482	2629	3227	2566	
1800	4303	2642	2796	3458	2729	
1900	4571	2805	2968	3688	2897	
2000	4843	2964	3139	3926	3064	
2100	5115	3127	3307	4161	3232	
2200	5387	3290	3483	4399	3399	

Notes: 1. Enthalpies of waste gases and humid air $(cV)_A$ are specified for the air humidity 10 g/m³. 2. Converting the tabular values in kcal/m³ can be done by dividing into 4.186.

B_{nf}^{st} – nominal fuel consumption for stabilizing the combustion in the waste incinerator, kg/h;

$I_w^{''}$ – heat resulting from waste gases (formed by household waste burning in incinerator) re-burnout in recovery boiler at a temperature of 1100°C and the coefficient of air excess equal to that before the recovery boiler, kJ/m³;

$I_{nf}^{''}$ – heat resulting from waste gases (formed during nominal fuel burning for stabilizing the combustion in the waste incinerator) re-burnout in recovery boiler at a temperature of 1100°C and the coefficient of air excess equal to that before the recovery boiler, kJ/m³;

V_{nf}^{g} – unit volume of waste gases formed by nominal fuel burning, which is used for re-burnout of waste gases coming from waste incinerator to recovery boiler, m³/kg. It is determined by formulas (5.42) – (5.49), but using $C^P, H^P, S^P, O^P, N^P, W^P$ related to nominal fuel and coefficient of air excess $\alpha_2 = 1.05$;

B_{nf}^{c} – nominal fuel consumption for re-burnout of waste gases coming from waste incinerator, kg/h;

I''_{nf} – heating value of waste gases formed during nominal fuel burning for their re-burnout at the coefficient of air excess in the furnace α_2 = 1.05 and at a temperature equal to theoretical burning temperature, kJ/m^3. It is defined as follows:

$$I'''_{nf} = I^O_r + (\alpha^T_2 - 1)I^O_A = V'_{RO_2}(cV)_{CO_2} + V^O_{N_2}(cV)_{N_2} + V^O_{H_2O}(cV)_{H_2O} + (\alpha^T_2 - 1)V^O(cV)_A, \quad (5.51)$$

where $(cV)_{CO_2}$, $(cV)_{N_2}$, $(cV)_{H_2O}$, $(cV)_A$ – enthalpies of each component of waste gases and humid air (kJ/m^3) and 1 kg of ash (kJ/kg).

η_{rb} – efficiency of the furnace of recovery boiler, it is assumed as η_{rb} = 0,95-0,97.

Therefore, total consumption of additional fossil (nominal) fuel can be defined by the equation:

$$B^{add}_{nf} = B^{st}_{nf} + B^c_{nf}. \quad (5.52)$$

To convert the nominal fuel consumption to amount of certain fossil fuel (gaseous or liquid) the following expressions can be used:

$$E_f = \frac{Q_f}{6830 \div 7000};\ B^{add}_f = E \cdot B^{add}_{nf}, \quad (5.53)$$

where Q_f – heating value of certain fossil fuel, kcal/kg.

The total amount of thermal energy obtained from the incineration of household waste and additional nominal fuel is defined as follows:

$$\sum Q = (B_w \cdot Q_w + B^{st}_{nf} \cdot Q_{nf} \cdot \eta_f + B^c_{nf} \cdot Q_{nf} \cdot \eta_{rb}), \quad (5.54)$$

where Q_f – heating value of certain household waste over certain time or average heating value if the annual amount has to be determined, kcal/kg, kJ/kg.

The above mentioned amount of heat energy is used in the form of overheated steam, the amount of which is determined by the expression:

$$D = \frac{\Sigma Q}{(i_{steam} - i_{wat}) \cdot 10^3}, \quad (5.55)$$

where i_{steam} – heating value of steam obtained, kcal/kg

i_{wat} – heating value of the feeding water entering into the waste incinerator.

The heat energy produced by household waste burning in waste incinerator and afterburning in the recovery boiler is expected to partly use for own needs in the form of overheated steam. Rest of heat energy is sent to steam turbine generators for electricity production and to external heat consumers (if required). It should be noted that the technological scheme allows (if necessary) increasing the production of heat and electricity over the amount produced only during household waste combustion and afterburning. This can be done by increasing fossil fuel consumption in recovery boiler without changing of fossil fuel consumption for providing the combustion process stabilization in waste incinerator. For this purpose, a special synchronization of two boilers operation in interconnected mode is provided in order to maintain the amount of overheated steam produced, their similar settings, as well as required aerodynamic conditions of general gas path.

Organization of department is expected, where all the slag remaining after waste incineration is converted to the liquid-melting state (5th stage of incineration) using special electric furnaces at a temperature of 1600-1650°C in order to separate the liquid metal from liquid slag and drain them to different containers through separate gutters. The produced metal bars (containing different metals available in input household waste) of certain size are the products for selling. The slag without liquid metals and the waste of gas cleaning systems are used for the construction products and materials manufacturing.

Studies, which were conducted for the definition of captured ash and dust quality and composition, have shown that heavy metals, dioxins and furans are absorbed on the surface of ash and dust. This proves that the mineral part can be harmless after thermal waste processing.

The captured ash and dust are converted to liquid-melting state in electric furnaces in the presence of additives at a temperature of 1650-1700°C. Liquid ash and dust can be used for construction products manufacturing.

Therefore, as a result of household waste incineration using above mentioned technological scheme, the products for selling are produced (heat and electricity, metal bars, construction products and materials), which allows covering the capital and operating costs. These are zero waste technologies.

Table 5.7 shows Amounts of products produced by household waste incineration per one tonne of household waste burned.

Table 5.7. Amounts of products produced by household waste incineration

Characteristic	Unit	Value
Amount of heat	Gcal/t	2.8-3
Amount of electricity	kW·h/t	1230-1250
Amount of additional nominal fuel	t/t	0.2-0.25
Amount of metal extracted from the slag	t/t	0.065-0.075
Amount of glass tiles	m^2/t	2.1-2.2
Amount of gravel	t/t	0.21-0.23

5.3.7 Kinetics of dioxins and furans generation and neutralization during household waste incineration

Many researches in different countries, including Ukraine, have proven that dioxins and furans are generated at temperatures up to 450°C during heating or combustion of any materials consisting of chlorine- or fluorine-containing components, heavy hydrocarbons, paper. They are present in volatile evaporating substances at landfills. Besides, they are present in compost (fertilizer) prepared by household waste composting.

Dioxins (polychlorinated dibenzodioxins, $Cl_2H_4Cl_4O_2$) and furans (polychlorinated dibenzofurans, $Cl_2H_4Cl_4O$) are dangerous and harmful substances with maximal limit concentration in the air $0.5 \cdot 10^{-9}$ mg/m^3. They affect internal organs and contribute to the very serious diseases.

Dioxins and furans can not be destroyed. Therefore, their generation should be excluded by using appropriate technology of heating or burning of chlorine- and fluorine-containing materials. They can be only partly captured by absorption no small- and large-size mineral impurities followed by neutralization.

One kilogram of household waste with 5.5-6.5% of chlorine- and fluorine-containing components and other dioxin compounds has maximal dioxins and furans content of $50 \cdot 10^{-9}$ g. The conditions of their generation and releasing are as follows:

- low temperatures of material heating or burning, when the products of incomplete combustion are generated;
- lack of oxygen (less than 8%), during thermal processing of the waste;
- presence of chlorine- and fluorine-containing and other dioxin-forming components in the incinerated waste;
- short time (less than 2 seconds) of thermal impact on the molecular connections of these substances at a temperature over 850°C for their destruction.

During the incineration according to existing technologies, all these conditions are met when household waste comes in the incinerator, despite the temperature at least 820°C inside the furnace. At this time, there are gradual heating of waste layer on the grates, continued waste mixing with primary air coming through grates and waste layer and the required time and temperature parameters of influence on the toxic compounds are absent. Therefore, dioxins and furans amount depends on the intensity and speed of waste layer heating to a temperature above 450-500°C (for this purpose, 80% of the required primary air with a temperature below 400°C is supplied), thorough waste mixing with sufficient oxygen amount (for this purpose, the narrowed section is arranged in upper part of the grate chamber, through which the flow of combustion products, which is mixed with 20% of the required secondary air heated to 250°C, is directed to the afterburning chamber).

Since conditions of dioxins and furans generation are created at the initial stage of waste incineration process of limited time, the amount of dioxins and furans generated in this period is up to 32% of the maximal possible. However, due to the temperature in afterburning chamber (above 850°C) and the duration of combustion process (above 2 sec), the most of dioxins and furans (98-99%) are destroyed by breaking their molecular connections and by transformation of some molecules to neutral ones. 1-2% of contaminators remain in waste gases. The remaining chlorine- and fluorine-containing components and some molecules of chlorine and fluorine actively react with hydrogen during the waste incineration forming stable HCl and HF, which together with sulphur dioxide are then captured: HCl, HF and SO_2 reacting with lime in gas cleaning devices are transformed to calcium carbide used for construction materials production.

The combustion chamber, where the grates are situated and the preparation for incineration and waste combustion process take place (1st stage of incineration), as well as afterburning chamber, where the process of waste burning and afterburning of incomplete combustion products take place (2nd stage of incineration), form the oxidative zone of waste incinerator, where active reacting of combustible waste components and oxidant (oxygen) takes place. All chemical reactions of combustion occurring in this zone are exothermic, so the temperature level is high. The oxygen amount is at least 8-11.5%. Therefore, there are no conditions for dioxins and furans generation in this zone except the initial stage of preparation to the process of waste incineration.

Directly after oxidative zone, there is reductive zone. There is almost no oxygen in this zone. All chemical reactions occurring mainly between compounds formed in oxidative zone are endothermic and similar to next reaction:

$$CO_2 + C = 2CO.$$

Since all reactions in this zone take place with the absorption of heat energy, the temperature is dramatically reduced. In other words, there are conditions created in reductive zone for secondary dioxins and furans generation. Much larger size of this zone (2-3 times) in comparison with oxidative zone conduces this. According to research and calculations, the amount of secondary dioxins and furans in this zone with those passed through the oxidative zone (1-2%), is up to 15% of maximal value. They are generated mainly from products of incomplete combustion of chlorine- and fluorine-containing components of household waste, which are unburned at first two stages of combustion, as well as from a very small amount of free chlorine and fluorine molecules, which have not reacted during HCl and HF generation in oxidative zone. 2% of this amount is absorbed on the surfaces of dust particles and volatile ash collected in "bags" of waste incinerator chimneys. Another amount (near 14%, or $1.785 \cdot 10^{-6}$ mg/m^3) as a part of the waste gases flow comes to high efficient gas cleaning system, where dioxins and furans absorbed on the surface of volatile ash and dust are deposited in the bunkers of these devices. Here is also collected calcium carbide formed in reactions of lime with sulphur oxides, hydrogen chloride and fluoride. Heavy metals containing in waste gases in the vapour state are absorbed on the surface of dust and ash.

Therefore, there are secondary dioxins and furans (2% or $1.216 \cdot 10^{-11}$ mg/m3), as well as products of incomplete waste combustion are still containing in waste gases after the gas cleaning devices. Scheme of dioxins and furans generation and neutralization during the waste incineration is shown in Fig. 5.26.

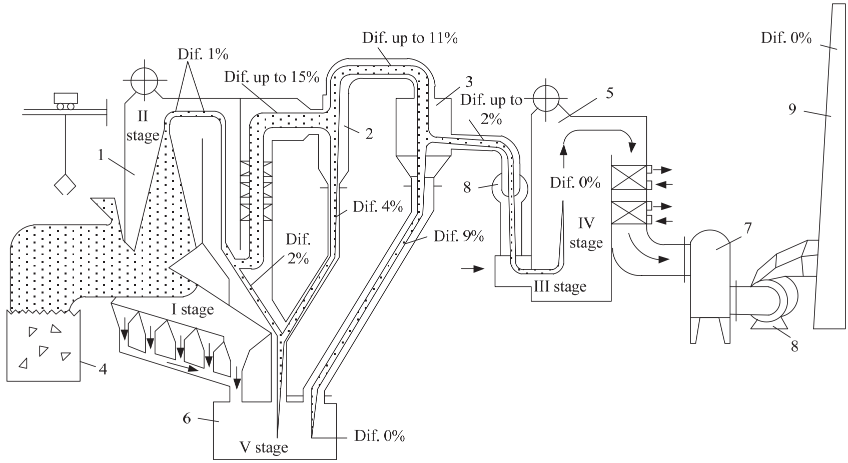


Figure 5.26. Scheme of dioxins and furans generation and neutralization:
1 – incinerator, 2 – cyclone, 3 – rotary filter (or scrubber), 4 – receiving bunker,
5 – recovery boiler, 6 – section of thermal processing (at 1700°C) of ash and slag, 7 – filter with activated coke, 8 – smoke exhauster, 9 – chimney.

For the final and complete destruction of dioxins and furans not captured in highly efficient gas cleaning systems, in the absence of solid phase in undusted products of combustion and dioxin- and furan-forming components, as well as to achieve absolute completeness of waste gases combustion, two stages of afterburning united in recovery boiler are additionally installed. Third stage of afterburning is presented by cyclone incinerator, where cleaned gases after the gas cleaning system come in. After re-heating to a temperature of 1100-1200°C using additional (fossil) fuel, when the products of incomplete combustion are finally afterburned, waste gases enter in the afterburning chamber (4th stage), where the same conditions as at 2nd stage of incineration (temperature above 850°C and duration over 2 seconds) are created, which provide the final destruction of the molecular bonds of residual dioxins and furans and exclude the possibility of additional secondary polluters formation, since there are no conditions for their generation. Therefore, there are mostly no dioxins and furans in waste gases after 4th stage of afterburning,

5.4 Waste composting

Composting is a form of organic waste processing. Composting is a biological method of household waste neutralization. The essence of the process is as follows. Various microorganisms, mostly thermophilic, actively grow and reproduce themselves in the waste mass, resulting in waste self-heating to 60°C. Disease-causing and pathogenic microorganisms die at this temperature. The decomposition of organic contaminants in household waste continues until relatively stable material similar to humus is obtained. The mechanism of the main composting reactions is the same as during the decomposition of any organic substances. When composting, more complicated compounds decompose and transform to more simple. The main chemical indicators, which characterize the waste as the material for composting, biofuel and organic fertilizers obtaining, are organic matter content, ash content, content of total nitrogen, calcium, carbon.

Table 5.9 includes types of waste which can be composted.

The following methods are used for industrial composting:

- composting in pits without forced aeration;
- composting in pits with forced aeration;
- composting in the installations with controlled conditions (rotating barrels, horizontal or vertical silage towers, etc.);
- combined system.

The cost of composting grows with the use of specialized devices and can be significant.

The selection of composting methods is determined by the criterion of optimal combination of cost and effect achieved by waste composting.

Table 5.9. Waste that can be composted

Types of waste which can be composted	Waste
The best	Plants, food waste, paper, sanitary materials
Normal	Animal waste, wood, silt
Moderate	Recyclables, inert components
Unsuitable	Metals, hazardous waste, medical waste

The economic efficiency of composting depends on the availability of markets for composting products.

The cycle of household waste processing at composting installations consists of three stages:

- receiving and previous preparation of the waste;
- biothermal neutralization and composting;
- compost processing.

Installation for receiving and previous preparation of the waste includes receiving bunker, feeders, conveyors, magnetic separators. Biothermal neutralization and composting take place in horizontal rotating drums. Installation for compost processing consists of control sifter, magnetic separator and device for ballast shredding. Besides, a warehouse of ready product (i.e. compost maturation place), and device for waste and compost weighing, as well as washing installation for garbage trucks are needed. Mainly typical installations are used, which are refined and upgraded taking into account the household waste properties of appropriate municipality and according to optimal conditions for waste neutralization.

Waste processing must necessarily be conducted with obtaining of products safe for environment and human health. Waste neutralization is primarily provided by high temperature of aerobic fermentation. Most of the pathogens die during the biothermal process. However, compost derived from biothermal household waste neutralization at waste treatment plants can not be used in agriculture and forestry, since it contains impurities of heavy metals, which can get into organic waste with grass, berries, vegetables or milk. For the same reason, it is advisable to use the compost in urban gardens and parks non-systematically.

The disadvantage of composting is the need for storage and processing of non-composting waste, which amount is a significant part of the total waste volume. This task can be resolved by incineration, pyrolysis or landfilling of the waste.

5.5 Biological decomposition of organic waste

It is known that the methods of biological decomposition of organic contaminants are the most environmentally friendly and cost-effective. This is evidenced by the parameters of various waste processing methods, which are shown in the Table 5.10.

Table 5.10. Parameters of waste processing methods

Method of waste processing	Unit capital costs, eur/t	Operating costs, eur/t	Income, eur/t
Incineration of shredded waste	6000-8000	5-8	3
Incineration in recovery boilers	8000-13000	7-12	3-5
Pyrolysis	14000-32000	5-15	4.4-13.1
Biological processing	22000	9.4	8.2

Currently, large amount of diluted industrial waste are treated by biological methods. Usually oxidation carried out in aeration tanks, biofilters and biological ponds are used.

The major shortcomings of aerobic technologies are energy consumption for aeration and problems associated with the processing and utilization of large amount of produced excess silt (up to 1-1.5 kg of microorganisms biomass per each kilogram of organic substances extracted). To exclude these shortcomings, the anaerobic treatment using methane fermentation is used. There is no necessity of additional electric power for aeration, which is important taking into account energy crisis. This decreases the amount of sediment and forms useful organic fuel – methane.

Anaerobic processes of microbiological conversion of organic matter are very complex group of phenomena. A lot of their fundamental aspects became clear only recently. However, industrial technologies of anaerobic treatment reached very high level already in 1980s and they are widely used now.

Intensive anaerobic technologies are not widely used in Ukraine. This causes considerable damage to the environment because genetic engineering methods allow obtaining the microorganisms able to neutralize environmentally hazardous organic compounds and other substances.

Fig. 5.27 shows the classification of anaerobic reactors constructions, which are widely used in different countries.

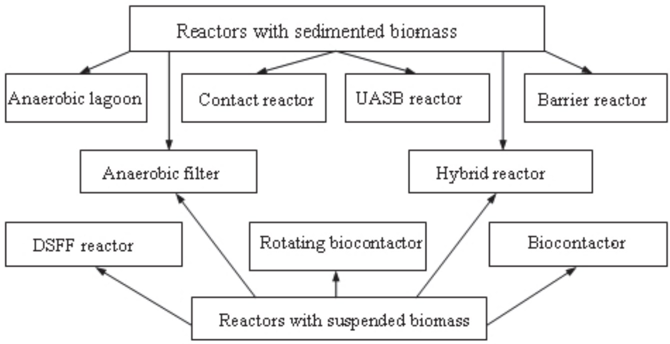


Figure 5.27. Classification of anaerobic reactors constructions

It should be noted that microorganisms respond differently to various substances in the waste. It is therefore necessary to check the ability of waste to biological decomposition by anaerobic microorganisms and determine the optimal processing conditions. The most suitable test in this case is the biochemical methane potential (BMP). The waste sample is mixed with anaerobic culture in a certain environment under anaerobic conditions (closed container) and periodically the volume of formed gas is measured. The volume of methane produced in control period, which is divided by the carbon amount in the waste estimated as chemical oxygen demand (COD), shows bio-processability of tested waste sample. Methane fermentation process takes place at constant overall COD amount divided during the cleaning process on COD of methane (usually more than 90%) and COD of formed biomass. A variant of test COD determining (or waste convertibility) is assessment of waste toxicity, i.e. measuring the relative speed of simple organic substrate (sucrose) transforming to biogas in the presence of the test waste sample and without it. This test is useful for the waste processability determination and for assessment of methanogenesis conditions.

Many tests can be conducted in a short time and with a small sample amount. This allows to define the strategy of biological processing of waste, options of including the stages of previous and joint processing in the technology, as well as selection of microorganisms and conditions of their optimal acclimatization.

The list of substances, which are biodegradable by anaerobic method, includes different classes of organic compounds: alcohols, aldehydes, aliphatic and aromatic acids. At the same time, according to studies, some organic compounds incompletely decompose under anaerobic conditions. Therefore, the processability of waste under anaerobic conditions depends on the ability of certain microorganisms to decompose the compounds containing in the waste, as well as on the resistance of microorganisms to toxic organic and inorganic compounds. It should be noted that waste bio-processability under anaerobic conditions above mentioned organic compounds has been identified by many investigations.

Consecutive multi-stage destroying of organic substances molecules is possible due to the unique properties of certain microorganisms groups to carry out catabolic process (decomposing of complex molecules to simple ones) and exist using the energy of complex molecules destruction without access to neither oxygen, nor other electron acceptors (nitrates, sulphates, sulphur, etc.), which are better by energy features. Microorganisms use carbon of organic compounds for this purpose.

Therefore, complex organic molecules are destroyed to methane and carbon dioxide in the process of reductive decomposition.

The scheme of methanogenesis demonstrating carbon flows during the degradation of complex organic substances is shown in Fig. 5.28.

Stage of hydrolysis is a decomposition of complex biopolymer molecules (proteins, lipids, polysaccharides and other organic molecules) to simpler oligomers and monomers (amino acids, carbohydrates, fatty acids).

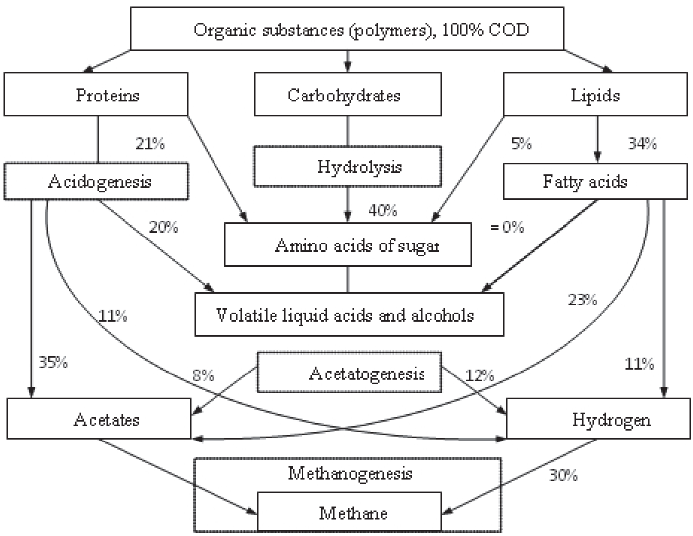


Figure 5.28. General scheme of methanogenesis

Stage of fermentation is a process of formed monomers decomposition to more simple substances (lower acids and alcohols), while carbonic acid and hydrogen also forms.

The methane precursors (acetates, hydrogen, carbon dioxide) are formed during acetatogenesis stage.

Methanogenic stage results in the final product of complex organic substances decomposition – methane. There are many types of microorganisms (several hundreds), mostly bacteria, involved in a complex process of transformations. When decomposing the persistent toxicants such as polychlorinated phenols, Rhodo coccus and Mycobacterius, which are widespread in a nature, play an important role.

The mechanism of decomposition includes parahydroxylation and subsequent dechlorination of parachlorinated phenols. For example, tetrachloro-hydroquinone is first formed from pentachlorophenol, then trichloro-hydroxybenzoyl, and then 1,2,4- trihydroxybenzoyl. The process is completed by destruction of the aromatic ring (see Table 5.11).

Table 5.11. Mechanism of anaerobic decomposition

Organic compounds	**Result of anaerobic decomposition**
2,4-dinitrophenol bis (2-ethylhexyl) phthalate 2,4-dimethylphenol 4-chloro-m-cresol 4,6-dinitro-o-cresol	Methane volume is 10% of the theoretical level at concentration of 20 mg/l
tetrachlorethylene 1,1,1-trichloroethane chloroform carbon tetrachloride	Decomposition is slowly and occurs only in the presence of other metabolite, which can support the growth of microorganisms as a carbon source
aldrin α-hexachlorocyclohexane γ- hexachlorocyclohexane	Transformation to dieldrin Dechlorinatation to pentachlor-cyclohexene + HC1 Transformation to 1,3,4,5,6-pentachlor-cyclohexene
DDT	Partly dechlorination
toxaphene	Reduction and dechlorinatation
1,1- dichloroethane 1,2-dichloroethane	Biodegradation
carbamates (N-methyl)	Destroying depends on the monomethylamin destruction
halogenated benzoates (iodine-, chlorine-, bromine-)	Decompossition of only 3-2, 3-, 4-substituted compounds to CO_2 and CH_4
benzene izopropilbenzen ethylbenzene toluene	Destroying to CO_2 i CH_4. Anaerobic microorganisms also catalyze the hydroxylation, demethylation, decarboxylation and demethoxylation
3,4-, 2,5-, 3,5-dichlorobenzoate (2,4,5-trichlorophenoxy)acetate 5-bromo-2-chlorobenzoate 4-amino-3,5-dichlorobenzoate	Anaerobic microorganisms cause dehalogenation

In methane biocenose the hydrolytic, fermentative, syntrophic and methane groups of microorganisms are main. They provide all stages of anaerobic destruction of substances in close and complex interrelations between themselves and other microorganisms. The main factors influencing the anaerobic reactors capacity are as follows: reaction ability, phase and chemical composition, size of loading waste, duration of processing, microorganisms concentration inside the reactor, efficiency of mass exchange in reactive environment, speed of reactor loading, temperature, pH, presence of feeding and toxic substances.

Reactors with suspended biomass are biofilters with ascending and descending flows and fixed biofilm (DSFF reactor). Reactor with expanded and suspended particles layer is rotating biocontactors. There is no big difference between different reactor constructions. This is proven by last research, according to which, for example, CASBER-reactor has peculiarities of both contacting reactor and reactor with pseudo liquid layer.

The list of used industrial technologies of anaerobic treatment is shown in Table 5.12.

Table 5.12. Technologies of anaerobic treatment

Type of reactor	Technologies of anaerobic treatment	Company-developer
Contacting with sedimentation and ultra-filtration	ANAMET BIOENERGY IRIS MARS	AC. Biotecnics AB (Sweden) Biomethanics Ltd (USA) Institut de Recherches de I'industrie sucrerie (France), Dorr-Oliver Inc. (USA)
Anaerobic biofilter	CTLROBIC ANDXAL BIOFAR BIOMASS	Badger (USA) L'air liquide (France) Degremont (Франція) Biomass International
With descending flow	DSFF Bacardi FIJM FJXE	National Rechearch Council (Canada) Bacardi Corp. (USA) Societe Generals pour les Techniques Nouvelles (France)
UASB	LARAN BIOPAG BIOTHANE TAMAN BIOTIM	Linde AG (Germany) Paques BV (Netherlands) CSM (Netherlands) Tampella Ltd (Finland) ESMIL (Belgium) Biotim N.V. (Belgium)
With pseudo liquid layer	ANITRON HYFLO GIST-BROCADES	Dorr-Oliver Inc. (USA) Ecotrol Inc. (USA) Gist-Brocades N.Y. (Netherlands)
Rotating biocontactor	AnRBS	Autotral (USA)
Anaerobic lagoon	ADI-BVF	ADI International Ltd. (Canada)

As a rule, biological methods are recommended to use together with chemical and physical methods of waste processing. High efficiency can be achieved at relatively low costs.

It should be noted, that features of first stage of microbiological anaerobic decomposition of solid organic waste are studied in laboratory conditions. At this stage, wet waste in reactor is exposed to fermentative hydrolysis with formation of light fatty acids, which at second stage are transformed to methane and carbon dioxide using other bacteria in separate reactor, where light fatty acids are flowed in by circulating liquid stream. It is proven that for maximal utilization of household waste organic fraction during anaerobic processing, when obtaining the energy and fertilizers for agriculture, the water should not be added to processed waste. The volume of produced gas is 500 litres per 1 kilogramme of dry organic material. This gas contains about 60% of methane.

There are continued investigations of efficient ways of polymeric waste biodegradation. For accelerating the development in this direction, it is necessary to increase the manufacturing of biodegradable polymers and simultaneously develop the efficient systems of collection and sorting of such waste.

Recently, there is increased interest to biotechnologies use, especially for the most toxic and dangerous waste processing. It is applied to biodegradation of pesticides, oil, phenols for waste neutralization.

Genetically modified organisms can also be used for treatment the waste in soils.

For proving the environmental safety of biotechnologies of different waste treatment, including dangerous, the environmental control of bacteria contamination and treated substrates must be always carried out.

CHAPTER 6
WASTE MANAGEMENT COMPENDIUM: FROM THE PRACTICE FOR THE PRACTICE. THE EUROPEAN EXPERIENCE

by Franz Stalder

6.1 Introduction

A few years ago waste has been a dirty word and who had something to do with waste, he was a third-class person. This has changed lately. Everything which is produced even becoming trash. So waste has become a brother of the production. However, the disposal has not yet become part of the production. Often products are produced, which in the disposal of toxic substances due to then leads to problems. Examples are the fluorescent bulbs, which have been highly praised because of electricity savings, but then led for the mercury to major problems and environmental pollution. The same is now observed with sun voltaic panel. As once treated with rare toxic-substances panel should be disposed of, today this is not discussed. But, every one who manufactures a product is partly responsible for their subsequent disposal.

Also concerning the training are observed serious deficiencies. While production needs engineers with 4-5 years employing university degree in mechanical engineering, electrical engineering, chemistry, physics. Generally opinion is that the waste management no special know how required, although detailed knowledge is required in all areas. In any disposal operation carried out chemical and physical processes or requires mechanical devices that need engineering studies. In addition, a technical implementation is often problematic due to different priority of the requirements in the individual states, economic conditions often make it impossible to dispose of the prior art or required investments are not possible because no benefit result.

It should also be clearly noted that no procedures or systems can be transferred from one country to another country. In any case, the boundary conditions, the political situation, the legal loading regulations to clarify the financial situation and considered.

The following comments are intended to demonstrate this problem.

6.2 Waste Management

The term waste management includes all activities and measures in connection with waste, i.e. with materials and material that someone is no longer needed. In particular, this includes:

- collection, storage, store;
- the collection;
- sorting and separation;
- additional use and recycling;

- handling, processing as detoxify, strengthen, integrate, convert, burn, thermal and biological processes;

- landfilling.

Waste management follows the generally applicable management rules. First it must be clarified, who takes which substances by what specifications. The second question has to be clarified in which form and quality which wastes are available. How has to be collected these wastes? The third question has to be clarified: what is necessary to do in order to obtain the required product from the available input. And finally, it is to clarify the financial and technical feasibility, and calculate all necessary treatments and investments. The following diagram is intended to show this relationship:

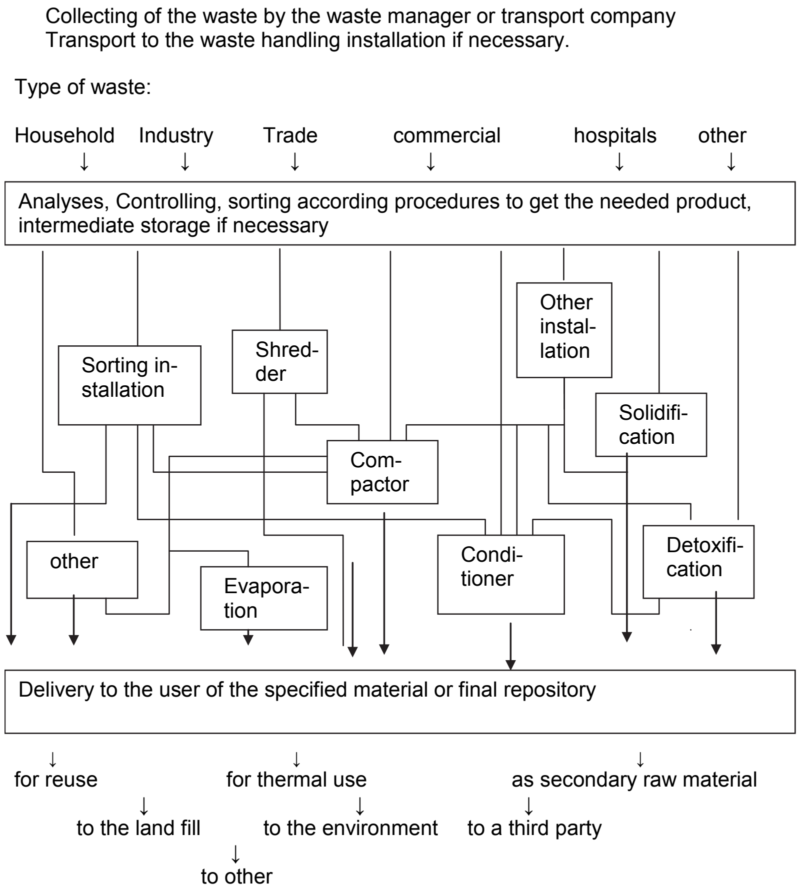


Figure 6.1. Waste handling scheme

6.3 Type, quantities and composition of waste

6.3.1 Household waste

Quantitatively, the bulk of the waste is mixed household waste. Quantitatively, is expected for the Central European urban population with a seizure of 280 kg /E•year. The composition varies depending on the collection system, for example when organic waste, glass, newsprint, etc. are collected separately. This aspect will be discussed later. Thus, the composition must be determined for each project. As an average guideline it can be assumed, according to a survey by BDE (Germany) for household waste in Germany following composition:

Paper / crumpled paper 37.5 kg/E•a
glass 20.0 kg/E•a
Packaging paper ½ Paper ½ Plastic 27.5 kg/E•a
Biowaste, leftovers 92.0 kg/E•a
textiles 7.5 kg/E•a
Metal tins 2.0 kg/E•a
Mineralized material (ashes) 2.0 kg/E•a
Mineral Shards 3.0 kg/E•a
Others 88.5 kg/E•a
Total: 280.0 kg/E•a

The calorific value is specified with 8500 kJ/kg, which is very deep. In Switzerland with 12000 kJ/kg expected. The density of slightly pressed household waste is approximately 120 kg/m^3.The compression in the garbage truck is 4-5 compartments, thus 500-600 kg/m^3.The density of bio-waste is 800 kg/m^3.

Household-type waste from the commercial have a much higher proportion of paper and plastic., The amount is given as 120 kg/E•a. The household waste from the hotel industry has a greater share of biological waste.

6.3.2 Hospital waste

A special category are the hospital waste This can be divided into:

• pathogenic waste, so body parts of patients. Here are considered ethical principles. They are disposed of in crematoria. It is no longer occurred.

• Household-type waste, kitchen waste. These are distinguished from waste from households or the hospitality industry.

• Infectious waste. This category is explained in detail below.

The amount of special attack to be treated infectious waste is in the Central European area 120 to 180 g/d•bed. Larger quantities indicate an un-economical logistics system and inexact separation. Per 1000 inhabitants is a need of 3 beds is based on a load factor of 2.7 or otherwise defined: from 1000 residents to be admitted each year an average of 125 people with a stay of 10 days.

The composition varies depending on the activity of the hospital heavyweight (Medicine / Surgery):

• wound dressing;
• gauze;
• swabs;
• syringes;
• gloves;
• clothing;
• infusion material;
• operation material.

The PVC content is with a 12-20% compared to domestic waste, 3-5% very high. The humidity is variable about 30%.

The collection takes place in special plastic containers of 30 and 60 l (see Fig. 6.2), tightly fitting and not possible to reopen when closed, or stable cardboard boxes with plastic fabric inserts. The still practiced in certain countries only collection in plastic bags should be rejected, even for internal transport. The waste is stored internally in the hospital refrigerated cells to final disposal

Disposal must be by incineration. An earlier practiced autoclaving, that is sterilization with steam by 120° C, is insufficient. After this process a shreddering is necessary.

Figure 6.2. Special plastic waste containers

Combustion requires no pretreatment. At combustion temperatures to 900 ° C all the germs are destroyed for sure. The topics of combustion will be discussed later.

Many hospitals have their own, small incinerator. A small muffle furnace is usually used. However, hospital waste contains higher content of PVC. So a corresponding choice of material and an exhaust gas treatment is necessary. The ash is defaced and inert. By combustion in external systems transportation is required. The often mentioned "transportation risk" traffic accident with bursting of containers is hypothetical and irrelevant. If the wastes are packed in tight containers, this transport is no problem in closed vehicles.

Hospital waste can be dropped directly into the combustion chamber of a household waste incineration plant. The relatively small amounts of hospital waste together the household waste the PVC content is insignificant

6.3.3 Hazardous waste

In the category of hazardous waste, substances that require special handling because of their toxicity. In the legal provisions than 800 substances and mixtures are listed.

With regard to the treatment there are the following main groups:

- liquid, aqueous inorganic contaminated waste;
- organically contaminated liquids;
- sludge;
- solid waste;
- equipment and supplies.

The amounts and types depend on the size and nature of the industry. There are detailed surveys required. The treatment options will be discussed later

6.3.4 Rubble and excavated soil

The amount construction waste and excavated earth is highly dependent on the local construction. In Germany, one expects a waste of 80 Miot/a (80 million inhabitants) or 1 t/E•a. Even this amount must be checked each site-specific. Rubble and excavated earth only needs to be specially treated if contamination is present, for example, from past industrial operation.

Most possible contamination:

- phenols, mercury, tar, oils, PCBs, CFCs;
- bath liquids from the electroplating;
- solvents, asbestos;

In most cases the contamination can be reduced to 98 to 99 % only by washing.

6.3.5 Organic waste

In household-waste and of the maintenance of green areas, there is a considerable portion of organic waste.

Biogenic wastes are mostly wet, smell distressing and rather low caloric content. According to the chosen waste management concept, it is therefore advantageous means of separate collection this fraction in the amount of about 30% $_{G}$ and approximately 150 kg / inhabitant and year with the ordinary household waste to escape. Composting allows beside the gain of high-quality energy, the good usable product to get potting soil.

However, it must be very clearly indicated that the biogenic groupware must be pure species. An unclean input leads to uncorrectable hardly usable product. In separate collection systems for about 2% impurities are detected.

Biowaste is standardized separated collected directly in the kitchen (Fig. 6.3).

Figure 6.3. Example of biowaste collection

The treatment options will be discussed later.

6.4 Collecting systems

The collecting systems are organized differently according to requirements. For home-garbage distinction is made between a bag fee, whereby the waste in bags of 35 l. 60 l or 110 l must be provided by means of revenue stamps. (Swiss system) or pure container emptying (Germany) charged by weight. The collection is done by garbage trucks with tipping container (see Fig. 6.4). Press-Waste trucks have a capacity of 20 m^3 or 10 tons at a press force of 320 kN. With this information, the daily truckloads and discharge times can now be calculated.

Figure 6.4. Waste collecting track

Bio-waste is provided in "green container" and collected separately (Fig. 6.5) with the usual garbage truck.

Figure 6.5. Collecting of biowaste in green container and household waste in bag with special (red) tag.

In Germany all packaging material is collected in "yellow bag" for special sorting and partly recycling

But also other material is collected separately like:

- Pet bottles by the shops in separate big plastic bags
- Glass by container
- Clean news papers and carton bounded in packages

In every case a user of this separate collected material is necessary.

In Switzerland every village has special collecting centers for toxic and special waste as battery, old oil, fluorescent lamps, electronic devices. Periodically the waste is transmitted to the relevant processing centers. Industries deliver their hazardous waste directly to the appropriate waste-processing companies.

Figure 6.6. Modern collecting center for separate collection of paper, waste oil, cardboard, inert material, glass, metals, construction waste, hazardous waste, electronics.

6.5 Treatment plants and processes

6.5.1 The aim of the treatment

The treatment of waste in particular the following objectives:

- obtain usable secondary raw material;
- further use permit;
- energy gain;
- transfer them into an inert state;
- detoxify chemically or physically;
- immobilize polluting substances or embed secure.

In a first step it is to clarify the requirements and specifications for the chosen disposal.

The second step is to determine which waste is delivered in which form and quantity.

In the third step it is to clarify, what is necessary to do with the input to get the specified product. As an example: for Incineration and for simply land fill no process is necessary.

Finally, there is the feasibility in technical and financial terms.

6.5.2 Treatment of domestic waste

6.5.2.1 Landfill

Household waste is deposited in many countries untreated in landfills. This is a very cost-effective method, but much more harmful to the environment. The leach rate of a landfill (through put of rain water) makes groundwater unfit for human consumption.

In the Table 6.1 the concentration range is represented by some landfill leach rate-content materials

Table 6.1. Leachate content

Parameter	Dimension	Concentration range
CSB	mg/l	100 to 10'000
BSB_5	mg/l	20 to 5'000
NH_4^+-N	mg/l	50 to 2'500
AOX	mg/l	0,1 to 5
GF	mg/l	2 to 100
Cr	mg/l	n. n. to 330
Pb	mg/l	n. n. to 200
Cu	mg/l	n. n. to 200
Ni	mg/l	n. n. to 200
Zn	mg/l	n. n. to 600
Hg	mg/l	n. n. to 20
Cd	mg/l	n. n. to 50
Conductifity	mS/cm	2'000 to 25'000
Abdampfrückstand	mg/l	1'000 to 15'000
Residuen ignition	mg/l	800 to 10'000

However, the gas formation results in uncontrolled incineration or explosion by concentration of more than 5 %. In addition, the dumping of toxic substances can not be excluded.

There are detailed EU prescriptions for the construction of new landfills. This concerns especially the verifiable foil seal downwards, leach rate collection systems, gas collection systems and operation with documentation of delivery and deliverer. The amount of TOC is limited to 5 %.

For recultivating of land fill covering with earth is necessary and plants with deep roots and surface roots have to be planted. For redevelop of old land fill especially the following checks .are necessary:

- water throughput and quality;

- geological situation;
- time period of filling;
- gas production;
- type of deposited waste material and deliverer.

The result of these verifications will give the requirement measures

6.5.2.2 Municipal incinerator

In Switzerland, all domestic waste is burned since the 70's for Electricity and hot water production purposes. The household waste undergoes no treatment. The utilization factor can be calculated from the heating value of the refuse. The thermal efficiency is about 85%, and the electrical efficiency over the turbine 35%. The standard size of an incinerator is at a throughput of 150000 to 200000 t/a. The combustion temperature is 850-900°C. The off gas cleaning system is usually by 3 steps. Acid pH 1 for the elimination of HCl, HF, heavy metal and dust, alkaline with NaOH and pH 8 elimination of SO_2 and then neutral. In the dry cleaning systemis used Ca and Coke for the elimination of Hg, Dioxins, Furans and CH combinations. De NO_x is done by NH_3. Exhaust gas is monitored by continuous measurement of CO, SO_2, NO_x, O_2, HCl, dust, and in addition physical parameter. Volume stream, pressure (under pressure in the burning chamber), temperature.

The operation of a municipal waste incineration requires know-how. With the setting of λ and the setting of regulation of pressure, flow, temperature, the combustion of the process is controlled. λ influence the burning process:

$\lambda < 1$ under stechiometric: too little air, CO production,
$\lambda = 1$ stechiometric: theoretical amount
$\lambda > 1$ overstechiometric: too much air.

If the own use deducted, remain approximately 0.5 MWh/t waste. This energy covers about 10% of the demand of households that can dispose of their waste in the system.

Relative to a conventional waste incineration plant can be assumed that:

- design size 120000 t/a household and commercial waste from 260000 E;
- with 8400 kJ/kg (very low) and 7000 full-load operational hours the throughput is 17.14 t/h;
- the thermal performance is therefore 143 GJ/h or 40 MW;
- at a firing efficiency of 85% are 35 MWh/t available;
- for this approximately 50t/h produced superheated steam at 40 bar and 400° C;
- for pure electricity production with a turbine efficiency of 35% 11 MW of electricity are generated;
- by λ 1.5-2 recalculated generated at 11% O_2 approximately 86000 m^3 of gas produced. The dimensioning of the induced draft fan depends on λ, the waste material and the cooling system (Quench). 1 t household waste corresponds to 250 kg of fuel oil or 250 m^3 of natural gas or 2,500 kWh/t. The produced steam is

about 2.5 t by 40 bar and 400°C and the produced electric power approximately 0.7 MWh.

The volume reduction by incineration is about 90 to 95%, the weight reduction 75 to 85 %. The ash and slag is inert, deactivated.

The production of dioxins depends on the temperature of the combustion (see Fig. 6.7). So, the temperature regulation is one important parameter.

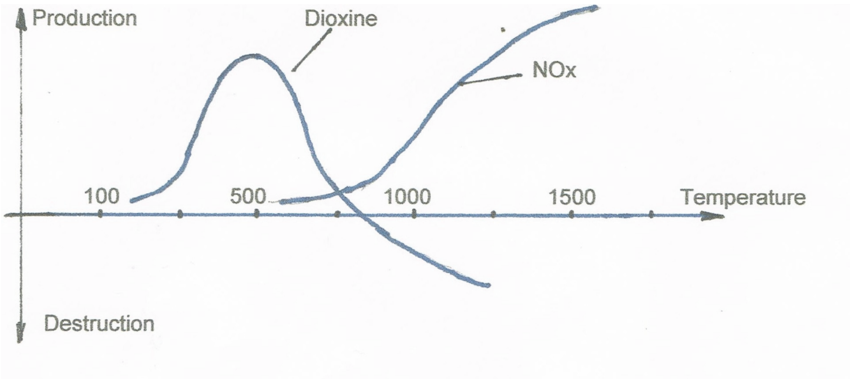


Figure 6.7. Production of Dioxins and NO_x in relating of the temperature

Figure 6.8. Control center of waste incinerator

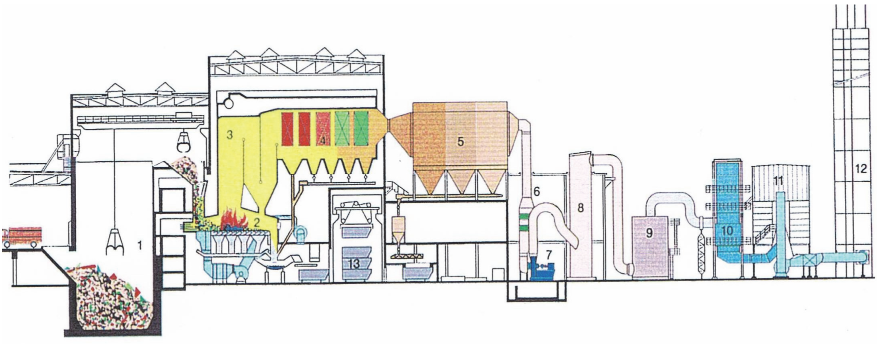


Figure 6.9. Schema of standard household waste incinerator:

1 – waste bunker,
2 – combustion chamber with grate
3 – afterburner chamber
4 – boiler, heat exchanger
5 – electrostatic dust precipitator
6 – economizer
7 – induced draught fan
8 – flue gas scrubber
9 – wet electrostatic precipitator
10 – NO_x reduction
11 – dioxin removal
12 – chimney
13 – slag and ash removal

There are also other types of incinerators as Muffle furnace, shaft or pit furnace, chamber furnace, fluid bed incinerator. All this types are used only for special cases.

6.5.2.3 Sorting of household waste

First is to clarify the purpose of sorting and the quality of the sorted product. There are different possibilities and installations.

Sorting belt: After automatic opening of the bags the waste is put on a belt. Special parts of the waste as Pet bottles or glass bottles or aluminum cans can taken out by hand.. If the packaging material is collected separately like Germany this sorting system is feasible. The over flow (not usable part of the waste) is more than 50 %.

The through put of the belt is about 5 t/h with 6 discharge points.

To separate the light fraction (paper and plastic) there is used another separate system:

The waste is also put on a belt which transports the material with specified speed about 4 m high. At the end of the belt the waste is falling down and separate automatically by the weight and falling speed, supported by a fan.

Another system is to separate by a rotating drum separator screen of 15 cm size.

This light fraction is used as alternative fuel instead of coal in heating centers and cement factories. In Cement factories there is needed high energy. In the clinker zone the temperature has to bee at least 1450°C. There are two possibilities to feed the alternative fuel, either as small particles (3 cm) in the front plate or as compressed material in the cold end. The burning time of the feed alternative fuel has to be calculated in consideration of the clinker zone. It is possible to replace about 50 % of the coal.

6.5.3 Hospital waste

The closed drums or packages have to be incinerated either by small incinerator of the hospital or in household waste incinerators.

The sterilization by 120°C with steam in closed containers is also practiced in some countries but in Switzerland it is not allowed because the complete disinfection is not guaranteed.

6.5.4. Hazardous waste

6.5.4.1 General aspects

The needed installations are depended of the type of the toxicity and the composition and compound of the material. The aim of handling is the detoxification or the stabilization either by chemical process or by mixing with special stabilization material.

The treatment and processing depends of the type of waste. Aqueous liquids are processed in chemical/physical (C/P)-plants, solid hazardous waste and solvents are incinerated by high temperature. Devices and equipments have to be dismantled and separate the toxic parts.

6.5.4.2 Solid hazardous waste

Instead the grate firing as used for household waste there is a rotating kiln incinerator chamber. The rotations mix the waste while burning and guarantee the complete oxidation. The temperature should be about 1200°C by 3 seconds to split all toxic compounds. The ashes are melted and drain at the end of the askance kiln. The ashes and slag are in the form of insoluble black glass. The incinerator design size is normally about 5t/h. Hazardous sludge and solvents are pumped in the kiln through the front plate. The off gas cleaning is equal the incinerator for house hold waste. Special attention needs the NOx generating.

6.5.4.3 Aqueous liquids

In C/P-plants (see Fig. 6.10-6.12) the detoxification inorganic liquids is done by reduction, oxidation and neutralization, and by controlled and analyzed precipitation, flocculation, filtering. According the liquids different procedures and the addition of different chemicals are necessary. All delivery of liquids has to be analyzed and stored separately in tanks.

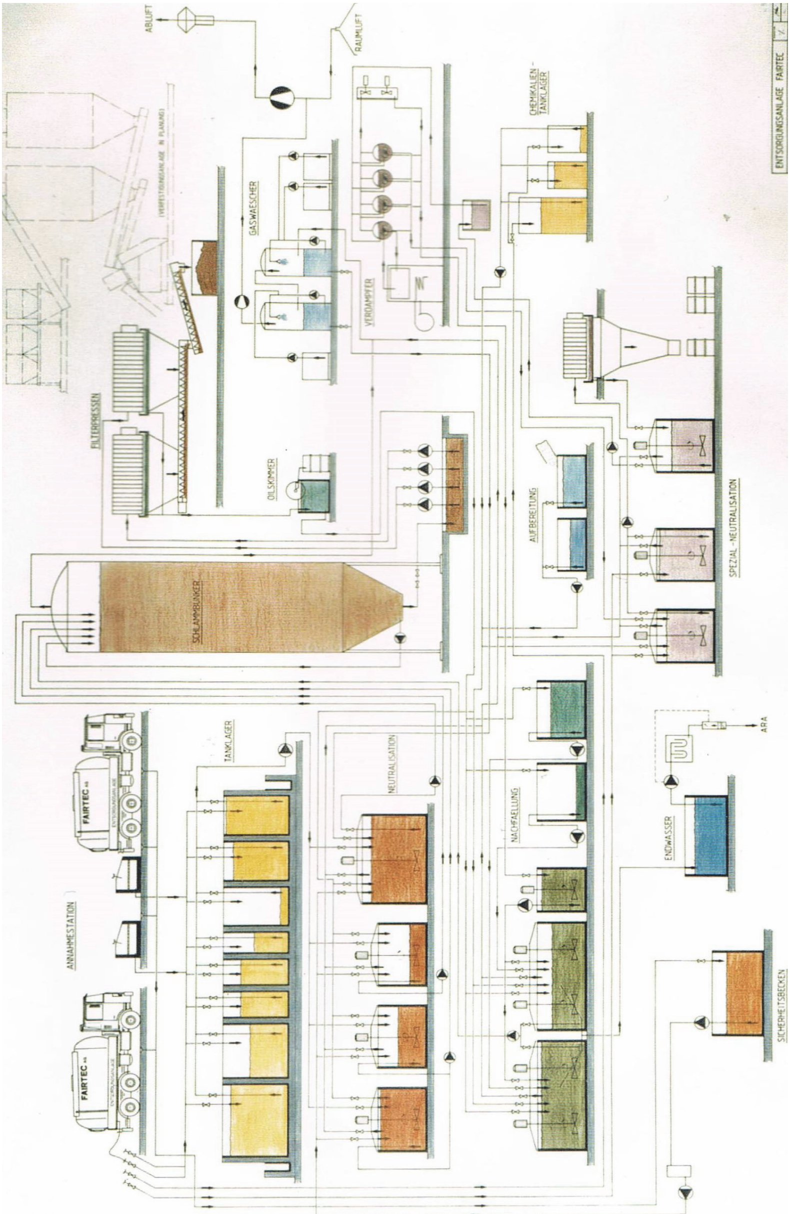


Figure 6.10. Schema of a tank storage and C/P plant

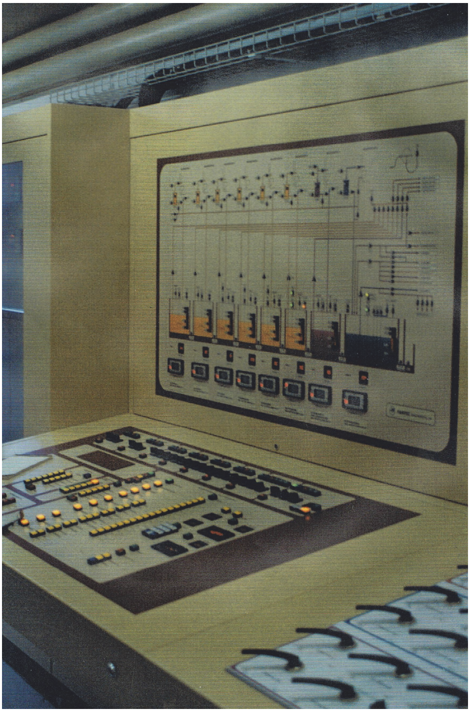


Figure 6.11. Switching panel for the tank storage

Procedure for the detoxification of liquids (see also Table 6.2):

<u>Cyanide:</u>
Oxidation with sodium hypochlorat by pH 10 ((hydrocyanic acids)
Precipitation with Fe II or Fe III result Hexacyanoferrat by pH 8.5

<u>Nitrite</u>
Oxidation with Hypochlorite or Peroxide
Reduction with urea (pH 3-5) or sulfamin acids

<u>Hg</u>
Transfer from Hg I to Hg II with sodium hypochlorid, precipitation with Hydroxide and second with sodium sulfide.
Hg steaming by 600°C.

<u>Chromate</u>
Reduction Cr VI to Cr III with Fe_2 salt or sodium sulfite.
Hydroxide precipitation together wit other heavy metals.

Figure 6.12. C/P plant

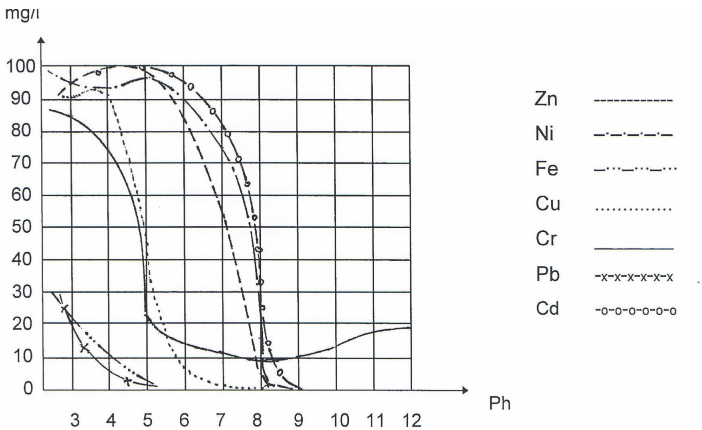


Figure 6.13. Different precipitation reaction of heavy metals in relation to pH

Table 6.2. Conditions for precipitation

Metal	precipitation from pH	to pH	End solubility	Re solubility as of pH	Precipitation with
Cu	5.8 5.5	7.5 7.0	1 ppm 1 ppm		K, N S
Zn	7.5 7.0 7.2	8.8 8.5 9.5	2 ppm 1 ppm 1 ppm	10.5 10.5	N K S
Ni	7.8	9.5	2 ppm		N, K, (S)
Cd	9.0 7.0	10.5 8.0	2 ppm 0.5 ppm		N, K S
Pb	6.5 5.5	10.0 6.3	1 ppm 1 ppm		N, K S
Fe (III)	3.0	4.0	0.1 ppm		N, K, S
Fe (II)	5.5	9.0	1 ppm		N, K, S
AI	4.5	5.5	1 ppm	8.5	N, K, S
Cr (III)	6.0 6.5 6.0	7.0 7.5 6.8	1 ppm 1 ppm 10 ppm	8.8 7.3	N K S

** N = sodium hydroxide, K = lime milk, S = sodium carbonate.*

After flocculation and filtering with the chamber filter press the product has a humidity of 50 % and can solidify with cement.

Oil separation of Emulsions is done by pH 1-2 and skimmering or overflow. If reduction of CSB is necessary, it is possible by adsorption or oxidation with H_2O_2 or stripping.

6.5.5 Rubble and excavated earth

For contaminated material in most of the cases a wash process will decontaminate. The wash water has to be processed as show above in C/P plant.

6.5.6 Organic waste

6.5.6.1 Aerobic composting

If there are low requirements in energy utilization, smell, space and time the aerobe composting is very simple and cheap. Biological waste as green cutting, sludge from communal waste water systems, catering waste has to be mixed and shredder to the size of 5-10 cm. The material is stacked in clamp of 3m high, 6-8 m basis. While 8 weeks the material is 4 times to mix and restack. The material is to cover against rain water.

The composting process is finished after 1 year and the material can used as fertilized earth by farmer.

6.5.6.2 Anaerobic process and composting

The shredded waste is put in closed reactor container (fermentor). The liquid part of the waste is about 50-60 %. With exclusion of air, the fermentation takes place by anaerobe microorganisms (Fig. 6.13). Only wood is not fermented because of the Lignin.

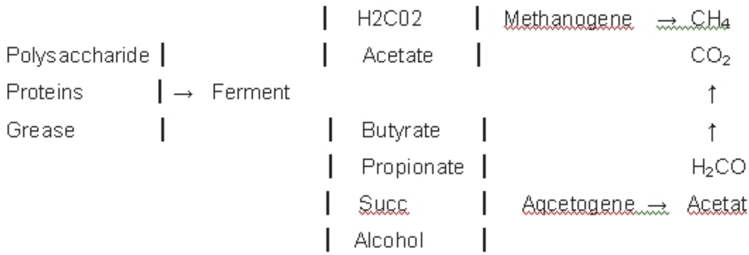


Figure 6.13. Biomass gaseous process

The reaction Temperature is about 50-60°C. The degree of degradation after 2 weeks is 40-50 %. The gas production is about 150 m^3 biogas/t wastes with about 60% Methane gas equal 58 l heat oil. Comparison natural earth gas CH_4 9,86 kW/Nm^{3,} biogas 6.27 kW/Nm^3. In the fermentor there is a slow rotating screw feeder which feed the material to the output and separate the liquid part. After the anaerobic process the product is to aerobe composting at least 6 month. For some purposes a screening is necessary and also controlling of plastic parts. The final products are: 40 % compost earth, 40% liquid fertilizer. The limits for heavy metal in the compost are given by the legal regulations of the country.

Figure 6.14. Aerobic composting plant

6.6 Radioactive waste

6.6.1 General information

Radioactivity is the spontaneously splitting of nuclides. The result is α (neutron), β (electron), γ (energy)–radiation. Without any radioactivity no evolution is possible.

There exist terrestrial radiation from the ground (as Granit) and cosmic radiation. Also radioactive waste emits radiation. Type, energy level, time and splitting specification are shown in the nuclides table (Fig. 6.15, 6.16). All nuclides have a specified half live time. In this time the half of the amount of the nuclides are transferred in other nuclides or stable material, so it is no more radioactive. This is an exponential reduction of the radioactivity

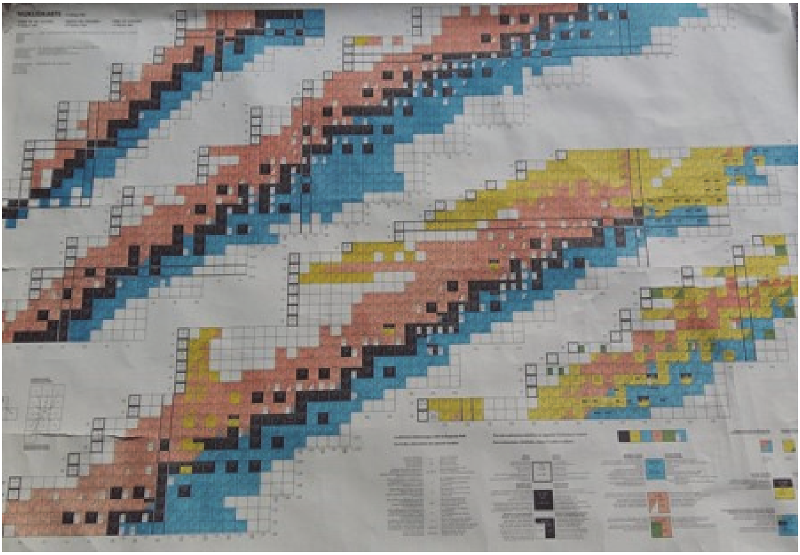


Figure 6.15. Nuclide table

The radioactive waste is produced in research center, in the industry, in hospitals and in nuclear power plants. The amount is very small. In Switzerland are 5 nuclear power plants in operation two nuclear research center and some hospitals and have produced in 40 years only about 5000 m^3 waste in conditioned form and stored. For all drums there are documentations with all necessary information.

The conditioning of radioactive waste has to guarantee the save storage about the time to achieve the natural radiation level by the exponential reduction of the radiation in fact of half live time.

Figure 6.15. Details of the Nuclide table

Radioactive waste is material contaminated with different nuclides.

Figure 6.16. Storage room for medium and low level radioactive waste.

The radioactive waste is subdivided in the 3 group’s high level, medium level and low level radioactive. The toxicity is dependent of their nuclides. So all waste has to be controlled and the nuclides analyzed. Then it is possible to calculate the time, the radioactive waste will be only normal waste.

6.6.2 High level wastes

High level waste is used fuel from nuclear power plants, sources from industry and medicine. Used fuel is stored in the plant it selves in boric acid water basin until save transport to recycling center or geological storage in stable formations is possible by the radiation level. But there are also technical researches to use this fuel again in the new generation of nuclear power plants as fuel which operate with high energy neutrons.

Sources are shielded normally with the absorber Pb and stable packed in drums.

6.6.3 Medium level wastes

The medium level wastes are filter from the cleaning of the primary water recirculation system in nuclear power plants. Ashes and slag from the radioactive waste incineration have also higher level radioactivity and some sources have only moderate radioactivity. This waste is shielded and then packed with cement or bitumen in 200 l drums.

6.6.4 Low level waste

The type of low level waste are contaminated clothes, cleaning material, contaminated material and parts from revision of installations in the primary area of the nuclear plant, air filter of the primary air recirculation system and so on.

This material is incinerated in a special closed incinerator. In Switzerland there is a electric arc flash incinerator in operation. The temperature is about 11000°C and all material is melted. This black glass and the filter dust are handled as waste according their level.

6.7 Recycling

6.7.1 General aspects

To save the earth recourses it is necessary to check the possibilities of recycling or reuse.

In lot of cases recycling is only a expensive illusion. Very often the recycled material can not fulfill the same and necessary specification as new raw material. In some cases the separate collecting is done by the toxicity and not as fact of recycling. Or no body takes the achievable, reachable product. In this situation the first task and duty is to look for customer for the product of the recycling. And then it is possible to check, how it is possible to get this product wit the existing input. The financial calculation shows who has to pay contributions. There exist different models:

- Prepayment system. The customer pays in the moment who buy a product some amount for waste handling and recycling.
- Paying in the moment of delivering the waste to the collecting center.
- Depot. Customer pay depot and get back in the moment of give back.
- Subsidy payment of the government.

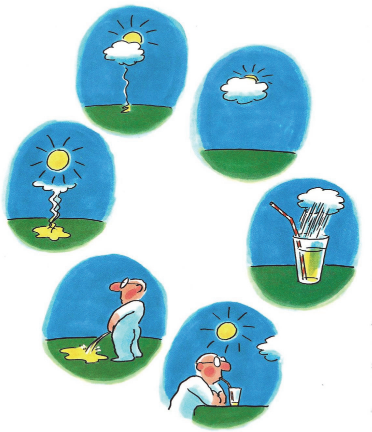


Figure 6.17. Recycling

The following schema shows the different payment.

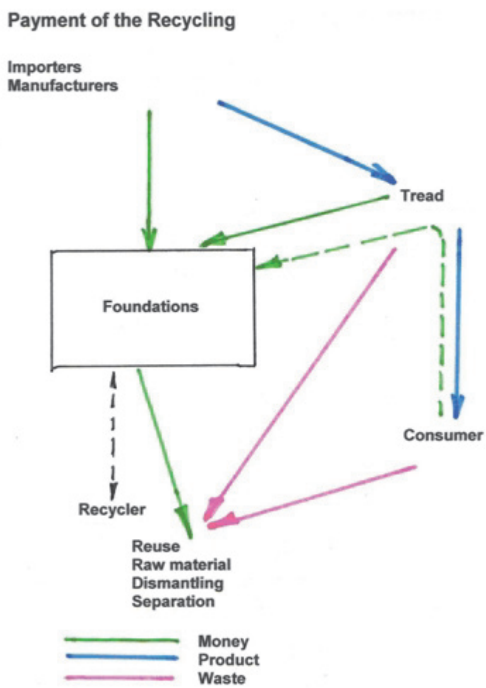


Figure 6.18. different payment for the recycling

6.7.2 Recycling Material and Products

For the following materials the recycling is established:

Glass: Glass bricks, glass wool for insulation
Att. Different melting points

PET bottles: different parts from plastic. Parts for cars
Att. Caps with different plastic, etiquette, adhesive
Lot of different type of PET

Plastic bottles: alternative fuel
Att. Mixed plastic PE, PU, PET, PVC a.o.

Batteries: Hg-recycling, metal recycling
Att. Toxicity

Paper: cardboard, paper, packaging material
Att. Bleaching agents, printing ink

Biological : Gas production, fertilizer earth/liquid
Att. impurities, foreign substances

Old oil: fuel in cement plants and incineration plants
Att. Mixed solvents

Tire: New profile, alternative fuel in cement plants
Att. New profile not allowed in all country

Wood: chipboard panels
Att. No color or coating

Mixed waste: incineration and produce electricity and hot water

Metal: sorting and melting for reuse

6.8. Future

Until recently waste was never discussed. There was also no possibility to get know how in this field. Today the people know, waste is the brother of the production and every product will be waste once. Lot of know how is necessary to handle waste in the right way. But much more commitment and effort are necessary. Waste management needs know how in standard regulation of management, in chemistry, physics, mechanics and electric. If waste management is a accepted faculty, the save of recourses of the earth is possible.

But it is also necessary to change the mentality in some countries. For this it needs motivation, either by low or by money, benefit.

For the waste management too much regulations will kill the interest and effort in this field. Not everything what is possible is necessary. It is much more efficient for the environment to do every where only 80 % instead 99.9999 % only on one point. **Too many rules lead to the death!**

I hope, this information will help to find the right way to save the resource and the future.

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HOUSEHOLD WASTE MANAGEMENT. THE EUROPEAN EXPERIENCE

Монографія

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