EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

WASTE MANAGEMENT

STUDY SUPPORT FOR THE ENVIRONMENTAL TECHNOLOGY PROGRAMME

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OSTRAVA 2021

VŠB TECHNICKÁ UNIVERZITA OSTRAVA | FAKULTA MATERIÁLOVĚ TECHNOLOGICKÁ

Title: WASTE MANAGEMENT

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Page number: 141

Study material for the professionally oriented bachelor study programme Environmental Technology of the Faculty of Materials Science and Technology.

Language correction: not done.

The learning support was created within the project: **Technology for the Future 2.0**

Registration number: **CZ.02.2.69/0.0/0.0/18_058/0010212**

CONTENTS

GUIDELINES FOR THE STUDY

Objective of the course

The aim of the course is to introduce the basic concepts of waste management and waste treatment, and to study waste management issues in terms of legislation and in terms of resources and the possibility of waste recovery or their treatment / processing in accordance with applicable laws and regulations. After studying the module, a student should be able to formulate basic requirements of current legislation in this field, he/she should know waste producers' obligations, production and consumption sphere sources of waste as well as he/she should be able to analyse basic physical and thermochemical properties of samples of waste.

For whom is the course intended?

The module is included in the bachelor study for the subject „Waste Management“ . However, a student of any other subject, if he/she meets required prerequisites, can study this course.

The textbook is divided into parts, chapters, which are in line with logical division of the learning material, but they are not equally comprehensive. Estimated time to study a chapter can vary greatly, so the large chapters are further divided into numbered sub-chapters corresponding to the structure below.

The author of learning material wishes you successful and enjoyable study with this textbook

Jiří Fiedor

1 INTRODUCTION TO THE WASTE MANAGEMENT ISSUE AND THE CZECH AND EU LEGISLATION IN THE FIELD OF WASTE MANAGEMENT

1.1. History of waste management

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe the historical background in disposal methods of waste from industrial spheres, as well as from consumption spheres.

Lecture

History before the Industrial Revolution

There were issues with waste handling since the time of man transition from the hunting and gathering to the settled society. Waste treatment has been always much more developed in the big cities. Issues with waste processing were becoming increasingly difficult in particular with increasing population density. At the same time, waste production per area unit increased and space available for its deposition decreased. History of waste treatment is so largely linked to the history of big cities [1].

With the thriftiness and skills of former population, useful utilization of almost every kind of waste could be found until beginning of the Industrial Revolution. For example, in the 18th and 19th century, the landfill of the capital of Scotland, Edinburgh, was keeping at the same size for hundreds years, because everything being brought to the environment was usually utilised in some way [1].

Man began to deal with waste since they moved from nomadic life to the settled life – to farming, i.e. before about 8,000 to 9,000 years. In that time, they have learned to put waste into waste pits outside the settlement in order to the waste did not bother them with bad smell and insects and did not attract wild animals. By the way, these pits are valuable source of information for today's archaeologists.

In ancient European and Asian civilizations, especially in the palaces of monarchs, there were well-functioning systems of waste disposal, because the monarchs of empires of that time knew about relationship between dirt, lack of hygiene and spreading diseases, such as black death, cholera, or smallpox, from scholars (e.g. from Hippocrates, 400 years BC). E.g. 320 years BC, the Athens' streets were daily cleaned by sweeping. In Rome, in addition to daily disposal of municipal garbage, general cleaning of streets and public spaces was called in certain periods (so-called lustratio urbis). The streets were sprinkling against dustiness on regular basis; cleaning trash in the Coliseum with 100,000 visitors was resolved. However, this work was being carried out by slaves and prisoners of war at that time. For example, during the reign of the Emperor Domitian (81 – 96 AD), insect (bedbugs, lice, etc.) hunt was held in order to improve the hygiene. The Emperor Vespasian (69 – 79 AD) established ground containers for urine; a guard of this facility had to be paid. In ancient cities, attention to public access to drinking water was paid; sometimes very sophisticated water structures were used (for example aqueducts or paved channels) [2].

However, this achieved level significantly dropped down in the Middle Age when ancient empires, namely the Roman Empire, broke up and peoples migrated; knowledge of hygiene and life culture were forgotten for nearly one thousand years. In the Middle Age, there were human and animal excrements on the streets, as well as in the streams and rivers and these often served as a source of drinking water. No wonder that a third of Europe's population, i.e. almost 25 million people, fell a sacrifice to diseases in the period from 6th to 14th century.

The situation has become better since the 15th century. Streets began being paved, excrements and mud were being cleaned from the streets, the remains of people died of infectious diseases were being burned, and waste issues began being solved. Beginning of improvements is found primarily in richer urban areas and cultural areas, for example in Paris of the 12th century or in Renaissance Italian cities of 13th and 14th century. In this region, these measures were being introduced by much-travelled and well-educated aristocrats (e.g. William of Rosenberg in the Český Krumlov Castle) [3].

- **History after the Industrial Revolution**

The Industrial Revolution, which made people to move to big cities first in the Europe and then in the United States, caused troubles for population in great number. Fumes from factory chimneys, pollution of rivers and streams by industrial waste and accumulation of garbage and other kind of waste on uninhabited places, streets and street corners were creating ugly mess. However, higher degree of resulting problems caused that people become aware of the possibility of disease due to presence of waste in their environment. For example, in London in 1954, cholera bacteria from soil contaminated by waste entered the groundwater and the river Thames, from which the water was supplied to households.

In this region, regulations on street cleaning for Prague were issued in 1826, containers pouring ash over were being introduced and treatment of building waste was being regulated. At the same time, water pipeline and sewerage systems began to being built.

When the 19th century turned to 20th century, the first incineration plants, landfills, and composting plants were established. The first incineration plant was built in the Great Britain in 1876, the first controlled landfill was built in the same country in 1900 and the first composting plant was built in the Netherlands also in 1900. These basic methods of waste disposal have being spread throughout the Europe from there. For example, the first incineration plant in the Central Europe was built in Brno in 1905 [3][4].

Legislation development in field of waste management in the Czech Republic

The first law regulated overall waste sector was the Act No. 238/1991 Coll. on waste. Until then, there was no general law on waste and this sector was controlled mainly by local regulations. The first Czech Act on waste showed number of issues and was replaced by the Act No. 125/1997 Coll. as amended by the Act No. 167/1998 Coll., the Act No. 350/1999 Coll., and the Act No. 37/2000 Coll. The text of this law has been accompanied by a series of the issued regulations. The basic regulations were following::

- Decree of the Ministry of Environment of the Czech Republic No. 337/1997 Coll. on promulgating Catalogue of Waste
- Decree of the Ministry of Environment of the Czech Republic No. 338/97 Coll. on details of waste management
- Decree of the Ministry of Environment of the Czech Republic No. 339/97 Coll. on evaluation of hazardous properties of waste.

None of these amendments to the Waste Act and the decrees has not been ideal and did not meet the requirements of practice or requirements of the European Union. Preparation of the Czech Republic for EU membership has required implementation of EU legislation into the Czech legal order of waste management too. To better understand the current legislation on waste it is necessary to become familiar with the EU basic strategic documents and directives. It is very important to know the principles applied in the EU in the field of waste management..

Questions 1.1

1. In which year and in which country was put into operation the first incineration plant?
2. In which year and in which country was put into operation the first incineration plant in the Central Europe?
3. In which year and in which country was put into operation the first controlled landfill and the first composting plant?
4. What was the historical development of basic legislation in the field of waste management in the Czech Republic?

1.2. EU basic strategic documents and directives in the field of waste management

Time to study: 2 hours

Objective: After reading this paragraph, you will be able to

- understand basic strategies of EU member states in the field of waste management
- interpret waste management hierarchy resulting from the European legislation

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Lecture

❑ The Waste Framework Directive 2008/98/EC [5]

The new Waste Framework Directive of June 2008 is much more specific than the original one of 1975. It needs to be understood as a comprehensive document, it has to be read whole and take advantage of its rationality. For example that the waste should be collected separately if technically, environmentally and economically practicable. Or that the waste should be recovered in one of the nearest appropriate installations, by means of the most appropriate technologies regardless of the national borders. Interconnection of technical feasibility, environment access and economic aspects has to be reflected in all activities of waste management. It should always bear in mind that the waste is a source and therefore "Don´t waste waste!"[6].

Some interesting points the new framework directive provides:

a) Waste treatment hierarchy

A new five-stage hierarchy for waste management (see Figure 1) is set and the States are obliged to ensure all waste to pass through the stage of recovery, i.e. material or energy. If the waste cannot be re-used by any of these methods, it should be dispose in a safe manner.

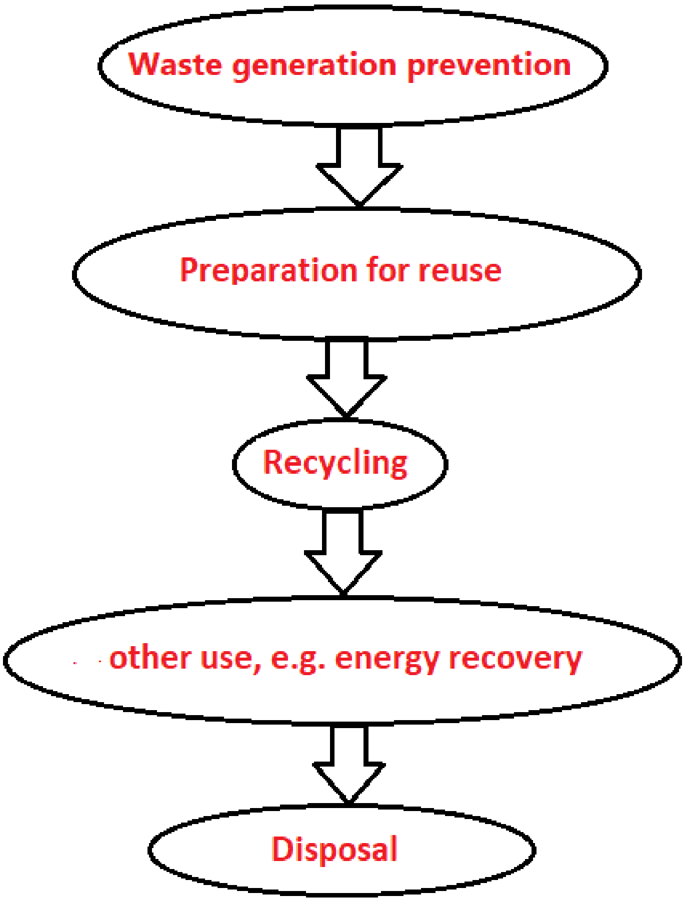


Figure 1: Hierarchy of waste management according to the EU Directive 2008/98/ES [author]

a) Recycling

The new directive aims to contribute to the creation of a "recycling society" in Europe. For the first time, specific recycling targets are set out in the Framework Directive:

- Recycle 50 % of household and similar waste by 2020 and 70 % of construction and demolition waste.
- By 2015, each country must introduce a separation of at least glass, paper, metals and plastics.

b) Principle of self-sufficiency

Member States are obliged to establish an integrated and adequate network of waste disposal installations and of installations for the recovery of mixed municipal waste collected from private households. Where it is necessary or advisable, the network is developed in cooperation with other Member States. Member State may prohibit incoming shipments of waste destined to incinerator plants.

The European Union as a whole must be self-sufficient with the network of these installations and Member States may achieve given objectives independently with regard to their geographical conditions. Waste must be disposed or recovered in one of the nearest installation, using the most appropriate method and technology.

The principle of self-sufficiency does not mean that each Member State must have complete network of installations for recovery and disposal of mixed municipal waste.

c) Ban on the mixing of hazardous waste

Směrnice dále řeší např. zákaz míchání nebezpečných odpadů, odpadní oleje, biologicko-rozložitelný odpad a nutnost stanovení kvalitativních požadavků pro účely výroby kompostu, problematiku povolovacího řízení v odpadovém hospodářství, plány odpadového hospodářství, programy předcházení vzniku odpadů.

b) Reporting

A separate issue is setting the conditions for reporting on Member State's waste management plan implementation and on waste prevention program. These reports will be in the form of a questionnaire and the first one will focus on the implementation of the new Directive in the Member State. Prevention programs, objective and indicator fulfilment, manufacturer's liability for selected types of products, recycling targets and measures, material and energy waste recovery, etc. will be assessed.

The European Parliament adopted an amendment to the Waste Framework Directive in the second reading on June 17, 2008. Developing and discussing this principal standard were in the public gaze. At last, it emerged to be a subject of battle between opponents of incineration plants and the proposer of the Directive – the European Commission; the opponents of incineration plants did not get their way.

The amended Waste Framework Directive also recognising the waste incineration plants with required efficiency of energy recovery as the installations for waste re-utilization was approved by an overwhelming majority.

The Czech Republic acted somewhat strange but not surprisingly in this process. While the Ministry of Environment stood up for negative opinion on incineration plants and energy recovery of waste, the Czech Members of the European Parliament maintained majority rational position that the waste is a source of energy and it should be recovered. The fact that the Member States may prohibit incoming shipments of waste destined to incinerator plants from other Member States thanks to the Czech Republic and Ireland is not important.

The amended Waste Framework Directive is a clear message. Restricting it to waste incineration plants would mean to take problem out of context.

Stavros Dimas, European Commissioner for the Environment. Expressed the essence when said that the Directive represents shift of waste perception from unwanted burden to a valuable resource" [6].

- **Council Directive 2000/53 /EC on end-of life vehicles [7]**

The purpose of the Directive 2000/53/EC is to harmonise legislation on recycling and disposal end-of-life vehicles and their parts. It requires, among other things:

* System for collection of all of the end-of-life vehicles should be developed.
* Measures to ensure the manufacturers of vehicles bear a substantial portion of the costs associated with the collection and processing of end-of-life vehicles should be taken.
* Objectives of re-using or recycling at least 70 - 85% (by weight) of the end-of-life vehicles by 2006 and at least 85 - 95% (by weight) of the end-of-life vehicles by 2015 should be set.
* The use of hazardous substances in vehicle production should be restricted.
* The use of recycled materials should be encouraged and the disassembly and recycling by appropriate measures when designing vehicles should be facilitated.
* Deposition and dismantling of end-of-life vehicles should not damage humane health or environment and the utilization and recycling of vehicle parts should be allowed.
* Information on end-of-life vehicles processing included information on risks associated with uncontrolled vehicle disposal should be provided to consumers.

- **Council Directive 99/31 /EC on landfill of waste [8]**

The aim of the Directive is to prepare measures, procedures and guidance to restrict the negative effects on environment and the risks to human health arising from waste landfill. The Directive requires, among other things:

- National strategy for reduction in content of biologically degradable components of municipal waste leading to fulfilment of specified objectives should be developed and implemented.
- Common landfilling of hazardous and other waste should be prohibited.
- Landfilling of tyres, liquid wastes, infectious hospital waste and certain types of hazardous waste should be prohibited.
- Strict measures to controlling, monitoring and reporting of waste and to closing down of waste disposal sites and landfills should be applied.
- Operators of landfills should be required to prepare plans for measure fulfilment; further possible operation of existing landfills should be decided.

- Landfills and waste disposal sites should be classified according to the type of deposited waste.
- Landfills and waste disposal sites should be placed, built and operated in accordance with the specific standards.

The Council Directive on waste landfill requires the amount of biodegradable municipal waste to be reduced to 75% of total quantity of the biodegradable municipal waste produced in 1995 no later than in 2006, further reduction to 50% has to be done in 2009 and reduction to 35% in 2016. If more than 80% of biodegradable municipal waste was landfilled in 1995 (which is the case of the Czech Republic), fulfilment of the above targets is possible to postpone by 4 years. In the Czech Republic, therefore, the target years of EU Directive requirement fulfilment are 2010, 2013, and 2020.

Other EU directives on waste incineration has been implemented into the Czech legislation on air (89/429/EEC, 89/369/EEC, 94/67/EC, and 2000/76/EC). These directives provide technical conditions of incineration plant operation, obligation of emission measurement and the obligation of announcement of all information. The last of these directives significantly extends the possibility of waste incineration with fuels (co-incineration) out of incineration plants, for example in cement plants, but under strictly defined conditions of air, water and soil protection..

Cross-border shipments of waste (import of waste into the Czech Republic, export of waste from the Czech Republic and transit of waste through the Czech Republic) are governed by directly applicable legislation of the European Communities, which has replaced Regulation (EEC) No 259/93. This directly applicable legislation is Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste.

Questions 1.2.

1. Please list basic strategic documents and directives in the field of waste management applied in the EU Member States.
2. Please describe in short the importance of EU legislation on waste management.

1.3. Basic legislation on waste management in the Czech Republic

Time to study: 5 hours

Objective: After reading this paragraph, you will be able to

- describe basic principles resulting from the Waste Act;
- know obligations of waste producers and licensed persons in relation with applicable implementing regulations;
- classify waste by the Catalogue of Waste;
- evaluate hazardous properties of waste.

Lecture

Current Czech legislation on waste management is compatible with the above EU directives. This includes following acts, regulations and government decrees.

Act:

Act No. 185/2001 Coll. on waste and the amendment to certain other acts

Decrees:

93/2016 Coll.	Decree laying down the Catalogue of Waste
94/2016 Coll.	Decree on the evaluation of hazardous properties of waste
116/2002 Coll.	Decree of the Ministry of Industry and Trade on marking returnable packaging
170/2010 Coll.	Decree on batteries and accumulators and amending Decree No. 383/2001 Coll., On details of waste management, as amended
237/2002 Coll.	Decree of the Ministry of Environment on the details of the manner of take-back procedure of certain products
248/2015 Coll.	Decree on details of implementation of tire take-back
294/2005 Coll.	Decree on the conditions of depositing waste in landfills and its use on the surface of the ground and amendments to Decree No. 383/2001 Coll. on details of waste management
321/2014 Coll.	Decree on the scope and method of ensuring separate collection of municipal waste components
341/2008 Coll.	Decree on details of biodegradable waste management and amendment to Decree No. 294/2005 Coll., on the conditions of depositing waste in landfills and its use on the surface of the ground and amendments to Decree No. 383/2001 Coll. on details of waste management (the Decree on details of biodegradable waste management)

352/2008 Coll.	Decree on particulars of handling waste from car wrecks, selected car wrecks, method of keeping the records and evidence of waste generated in facilities for the collection and processing of car wrecks and information system to monitor flows of selected car wrecks (on details of car wrecks management)
352/2005 Coll.	Decree on particulars of handling electrical and electronic equipment and waste electrical and electronic equipment and on the detailed conditions of financing their handling (the Decree on handling electrical and electronic equipment and waste electric and electronic equipment)
374/2008 Coll.	Decree on waste shipment and amendment to Decree No. 381/2001 Coll. laying down the Catalogue of Waste, List of Hazardous Waste and list of waste and countries for the purposes of export, import and transit of wastes and the procedure in granting consent to the export, import and transit of waste (Catalogue of Waste) as amended
383/2001 Coll.	Decree on details of waste management
384/2001 Coll.	Decree of the Ministry of Environment of the Czech Republic on managing polychlorinated biphenyls, polychlorinated terphenyls, monomethyl-tetrachlorodiphenyl methane, monomethyl-dichlorodiphenyl methane, monomethyl-dibromodiphenyl methane and all mixtures containing any of these substances in concentration higher than 60 mg/kg (on managing PCBs)
437/2016 Coll.	Decree on conditions of use of treated sludge on agricultural land and amendment of Decree No. 383/2001 Coll., On details of waste management and amendment of Decree No. 341/2008 Coll., On details of management of biodegradable waste and amendment of Decree No. 294 / On the conditions of landfilling of waste in landfills and their use on the terrain surface and amending Decree No. 383/2001 Coll., On details of waste management (Decree on Details of Biodegradable Waste Management)
641/2004 Coll.	Decree of the Ministry of Environment of the Czech Republic on the scope and manner of keeping records of packaging and reporting the data from these records

Orders:

111/2002 Coll.	Government Order specifying the amount of the deposit on selected types of returnable packaging
352/2014 Coll.	Government Decree on Waste Management Plan of the Czech Republic for 2015-2024

- **Act No. 185/2001 Coll. on waste [9]**

Σ Summary of terms

Basic concepts, without which it would not possible to understand the following text of the electronic support, are clearly set out in the following paragraph.

a) Waste is any movable thing which the person discards or intends or is required to discard. Waste disposal takes place whenever a person hands over a movable thing for recovery or disposal within the meaning of this Act or when it is handed over to a person authorized to collect or buy waste pursuant to this Act, regardless of whether it is a free transfer or a consideration. Disposal of waste occurs even if the person removes the movable item.

A person is obliged to dispose of a movable item if it is not used for its original purpose and the item endangers the environment or was disposed of on the basis of a special legal regulation (eg Act No. 258/2000 Coll. On public health protection).

A movable thing produced through a production, primary objective of which is not the generation or acquisition of the movable thing does not become a waste but a by-product, if:

- is produced as an integral part of production;
- its further use is provided;
- its further use is possible without further processing in a manner other than the normal production practice; and
- its further use is in accordance with the specific legislation and does not lead to adverse effects on the environment or human health.

Some types of waste cease to be waste if, after the waste has been the subject of one of the uses, meets the following conditions:

- thing is commonly used for specific purposes;
- there is a market or demand for the thing;
- the thing meets the technical requirements for the specific purposes set out by specific legislation or standards applicable to the products; and
- the use of thing is in accordance with the specific legislation and does not lead to adverse effects on the environment or human health.

The Ministry in collaboration with the Ministry of Industry and Trade of the Czech Republic may issue a decree setting criteria that specify when movable thing might be considered as a by-product and not as a waste and when a waste ceases to be waste.

b) **Hazardous waste** - Waste showing one or more of the hazardous properties listed in the Annex to the directly applicable European Union Hazardous Waste Characteristics (Commission Regulation (EU) No 1357/2014 of 18 December 2014 replacing Annex III to Directive 2008/98/EC of the European Parliament and of the Council on waste),

c) **municipal waste** – all waste generated in the territory of a municipality in connection with the activities of natural persons and which is stated to be municipal waste in the Catalogue of Waste with the exception of waste produced by legal entities or natural persons authorized to conduct business,

d) **waste similar to municipal waste** – means all waste generated in the territory of a municipality in connection with activities of legal persons or natural persons authorized to conduct business and which is stated to be municipal waste in the Catalogue of Waste,

e) **waste management** – means activities aimed at preventing the production of waste, waste handling and remedial care for sites where waste has been permanently stored and the supervision of these activities,

f) **waste treatment** – means the gathering, collection, purchase, transport, shipment, storage, treatment, recovery and disposal of waste,

g) **facility** – means technical equipment, a location, a construction or part thereof,

h) **waste gathering** - means the short-term concentration of waste in waste gathering equipment in the location of its generation prior to further management of the waste;

i) **waste storage** – means temporary storage of concentrated waste in a facility designed for such purpose for a period of 3 years prior its recovery or 1 year prior its disposal,

j) **landfill** - a facility established in accordance with a special legal regulation (Building Act No. 183/2006 Coll.) and operated in three immediately following stages of operation, including the facility operated by the waste producer for the purpose of disposal of its own waste and the facility intended for waste storage with the exception of the storage of waste referred to in point (i),

k) **first stage of landfill operation** - operation of the facility pursuant to letter j) for waste disposal by depositing it on or below ground level,

l) **the second phase of landfill operation** - operation of the facility under point j) for the possible use of waste in the closure and reclamation of the landfill,

m) **third phase of landfill operation -** operation of the facility according to letter j) not intended for waste management with the purpose of ensuring after-care of the landfill after its closure,

n) **waste collection** - means the concentration of waste by a legal person or natural person authorized to conduct business from other entities for the purpose of its delivery for further recovery or disposal;

o) **separate collection** - collection where the waste stream is separated according to the type, category and nature of the waste in order to facilitate specific treatment,

p) **purchase of waste** – means the collection of waste in case where the waste is purchased for an agreed price by a legal person or a natural person authorized to conduct business,

q) **waste treatment** – means any activity resulting in a change in the chemical, biological or physical properties of waste (including its sorting) for the purpose of enabling or facilitating the transport, recovery or disposal thereof, or for the purpose of reducing the volume thereof, or reducing the hazardous properties thereof, if appropriate

r) **re-use** – the procedures, in which products or their components that are not a waste are used again for the same purpose, for which they were originally intended,

s) **waste recovery** - an activity resulting in waste serving to a useful purpose by replacing the materials used for a specific purpose, even in a facility not intended for waste utilization, or that the waste is treated for this specific purpose; Annex 3 to the Waste Act lists methods of waste recovery,

t) **preparing for re-use** – the use of waste including the treatment or the repair of used products or their parts and the control carried out by a licensed person according to special regulation consisting in checking that the used product or its part that has been waste, are all capable to be re-used after treatment or repair without further processing,

u) **material recovery of waste** – the use of waste including recycling and other recovery methods as a material for the original or other purposes, except for immediate energy recovery,

v) **waste recycling** – any use of waste, in which the waste is reprocessed into products, materials or substances for original or other purposes of their use, including the reprocessing of organic materials; the energy recovery and the processing into products, materials or substances to be used as fuels or backfills are not waste recycling,

w) **waste disposal** – an activity that is not a use of waste, even if the activity has a secondary consequence of material or energy recovery; Annex 4 to the Waste Act lists methods of waste disposal,

x) **processing of waste** – use or disposal of waste including preparation prior to use or disposal of waste,

y) **primary producer of waste** – any person who produces waste in connection with its activity,

z) **waste producer** – means a legal entity or a natural person authorized to conduct business who produces waste in connection with its activity; or a legal entity or a natural person authorized to conduct business who operates waste treatment or other activities resulting in waste character or composition change; a municipality becomes the waste producer after a private individual deposits waste in a designated location; at the same time the municipality acquires proprietorship of the waste,

aa) **licensed person** – means any person licensed to manage waste pursuant to this Act or pursuant to special legal regulations,

bb) **trader** – means a legal entity or a natural person authorized to conduct business who purchases or sells waste and acts on its own responsibility.

Another interpretation

Classification of waste pursuant to the Catalogue of Waste [9]

The waste producer and the licensed person are obliged to classify waste in accordance with the Catalogue of Waste issued by the Ministry of the Environment (hereinafter referred to as the "Ministry") under an implementing legal regulation (Decree 93/2016 Coll. On Waste Catalogue).

If no unambiguous classification is possible pursuant to the Catalogue of Waste, the Ministry shall classify waste based on a proposal submitted by the competent municipal authority with extended competence.

The Ministry shall issue a decree regulating the following:

a) the Catalogue of Waste;

b) the procedure for classification of waste pursuant to the Catalogue of Waste; and

c) particulars required for a proposal to a municipal authority with extended competence for waste classification according to the Catalogue of Waste.

Classification of waste by categories [9]

For the purposes of waste management, the producer and the authorized person are obliged to classify the waste into the hazardous category, if any

a) exhibits at least one of the hazardous properties listed in the Annex to the directly applicable European Union hazardous waste regulation (EU Commission Regulation No 1357/2014 - see Table 1)

b) is listed in the Waste Catalogue as hazardous waste; or

c) is mixed or contaminated with any of the wastes listed as hazardous in the Waste Catalogue

Mixed municipal waste is not classified in the hazardous waste category and the waste producer and the licensed person are not obliged to manage the waste as hazardous even if it meets the conditions for management of hazardous waste.

Should the waste producer or the licensed person prove by a certificate of elimination of hazardous waste properties that the waste specified does not have any properties pertaining to hazardous waste, they shall not be obliged to comply with the regime stipulated for hazardous waste; however, they shall be obliged to verify whether such properties are actually missing. The method and frequency of such verification shall be determined by the authorized person in a certificate of elimination of the hazardous properties of waste.

The car wreck, from which all dangerous parts were removed and all operational charges removed in the manner stipulated by the implementing legislation, can be categorized as other waste without an assessment of the hazardous properties of waste. The Ministry shall stipulate, by means of an implementing legal regulation, the method of dismantling of dangerous parts of car wrecks and the way of pumping out operational fillings from car wrecks (Decree No. 352/2008 Coll., On details of car wrecks handling).

Table 1 List of characteristics of waste which makes it hazardous [10]

Property code	**Property title**
HP1	Explosive
HP2	Oxidizing
HP3	Flammable
HP4	Irritant - irritating to skin and eyes
HP5	Specific target organ toxicity / Inhalation toxicity
HP6	Acute toxicity
HP7	Carcinogenic
HP8	Corrosive

HP9	Infectious
HP10	Toxic to reproduction
HP11	Mutagenic
HP12	Release of acutely toxic gas
HP13	Sensitizing
HP14	Ecotoxic
HP15	Wastes capable of displaying any of the abovementioned hazardous properties when handled, which they did not possess at the time of production

Evaluation of the hazardous properties of waste [11]

If the waste producer or authorized person believes that the hazardous waste after treatment has no hazardous properties and intends to treat it as other waste, they shall apply to the authorized person or persons pursuant to Section 7 (1) of the Act on evaluation of hazardous properties. If the Czech Environmental Inspectorate (hereinafter referred to as the "Inspection") has reasonable doubt that the waste producer or authorized person correctly classified the waste, the waste producer or authorized person may by decision impose an obligation on the authorized person or persons pursuant to § 7 par. evaluation of hazardous properties of waste.

Hazardous waste characteristics listed in Table 1 under the code HP 1 to HP 3, HP 12, HP 14 and HP 15 shall be evaluated by a legal entity or natural person authorized by the Ministry; other hazardous substances shall be evaluated by a legal entity or natural person authorized by the Ministry of Health).

The waste producer, who believes that the waste produced has no dangerous property after treatment, shall prepare an Application for the Evaluation of Hazardous Properties of Waste, which he shall forward to the authorized person. The authorized person shall ensure the collection of waste samples and analysis of the sample for the required hazardous properties. On the basis of the results of the analyzes, the authorized person shall issue a "Certificate on the elimination of hazardous properties of waste" (hereinafter the "Certificate") if the waste no longer exhibits any hazardous property or "Notification" if it proves that the waste continues to exhibit a hazardous property. These documents shall be handed over to the originator, who shall, in addition to receiving the „Certificate“, dispose of the waste as a cathegory „others“ and, in the case of receiving a „Notification“, dispose of the waste as a cathegory „hazardous“.

Prevention of waste production [9]

Everyone is obliged in connection with his/her activities or within the scope of his/her competence to prevent the production of waste, to reduce the amount of waste and its hazardous properties. Where the production of waste cannot be avoided, it must be recovered or disposed of in a manner which does not endanger human health and the environment and which is in compliance with this Act and with special legal regulations.

A legal entity and a natural person authorized to conduct business producing products is obliged to produce these products in a manner that reduces the generation of unrecoverable waste from these products, particularly of hazardous waste.

A legal entity and a natural person authorized to conduct business and engaged in placing products on the market, are obliged to provide information on the manner of recovery or disposal of the unused product parts in the documentation accompanying the product, on the product packaging in the user guide or by some other suitable form of information.

General obligations in waste management [9]

Everyone is obliged to manage waste and to discard it only in a manner specified by this Act and other legal regulations issued for environmental protection. Hazardous waste management is also regulated by special legal regulations valid for products, substances and preparations with the same hazardous properties, unless otherwise provided for in this Act or in the implementing legal regulations.

Unless otherwise specified below, waste under this Act may only be managed in facilities designed for waste management pursuant to this Act. Waste management must not endanger human health nor endanger or damage the environment and pollution limits set forth in special legal regulations (e.g. limits for air pollution) may not be exceeded.

Only a legal entity or a natural person authorized to conduct business, operating a facility for the recovery or disposal or collection or purchase of a certain type of waste will be entitled to take over waste proprietorship. This shall not apply to the transmission of the necessary quantities of waste samples for analysis, testing, analysis for the purpose of determining true properties and meeting the requirements for the acceptance of waste at the installation, for science and research purposes or other non-waste management purposes.

When transferring waste, everyone is obliged to ascertain whether the person to whom the waste is being transferred is entitled under this Act to accept the waste. If such a person fails to show such competence, the waste may not be transferred to it.

Diluting or mixing waste for the purpose of compliance with criteria for its acceptance in a landfill and mixing hazardous waste with other hazardous waste or other waste is prohibited. In exceptional cases, mixing hazardous waste with other hazardous waste or other waste is allowed, subject to approval by the regional authority with competence for the waste management location. The regional authority will only issue a permit if mixing the hazardous waste does not endanger human health and/or the environment and provided the purpose of mixing the hazardous waste is compliance with the technical requirements for waste recovery or disposal and increasing waste management safety.

The waste manager [9]

A waste producer and licensed person who have, during the previous two years, managed hazardous waste in quantities exceeding 100 tonnes of hazardous waste per year and an operator of a landfill for hazardous waste or for municipal waste are obliged to ensure professional waste management through a qualified person (hereinafter referred to as the "waste manager").

The waste manager is responsible to the waste producer or the licensed person who appointed him/her as waste manager for ensuring professional waste management. The waste manager represents the waste producer or the licensed person in negotiations with the public administration authorities in the area of waste management, in particular when they are carrying out their control activities.

A waste manager may act in this capacity for a maximum of five waste producers or licensed persons or five individual separate operating units.

Only a natural person who has completed university education and has had a minimum of 3 years of experience in the waste management sector within the last 10 years or is a secondary school graduate with a secondary school graduation certificate and has a minimum of 5 years of experience in the waste management sector within the last 10 years may be appointed a waste manager.

Obligations of waste producers [9]

A waste producer shall be obliged to:

a) classify waste by types and categories;

b) ensure priority waste recovery;

c) transfer the proprietorship of waste, which he/she cannot recover or dispose of by himself/herself pursuant to this Act and to the implementing legal regulations, only to a person, entitled to accept waste;

d) verify the hazardous properties of waste and to manage waste according to its actual properties;

e) gather waste sorted by types and categories;

f) safeguard waste and protect it against undesirable deterioration, misappropriation or leakage;

g) keep operating records of waste and waste management methods;

h) enable inspection authorities access to buildings, sites and facilities and, if requested, to submit documentation and to provide accurate and complete information relating to waste management;

i) prepare a waste management plan pursuant to this Act and to the implementing legal regulation and to ensure that it is followed;

j) appoint a waste manager under the conditions laid down in this Act;

k) pay the fees for storing waste in a landfill in the manner and scope stipulated in this Act.

Rights and obligations of municipalities and natural persons managing municipal waste

Municipalities are subject to the obligations of originators, unless the law provides otherwise.

The municipality in its independent competence establishes a generally binding ordinance of the municipality system of collection, collection, transport, sorting, use and disposal of municipal waste generated in its cadastral territory. A generally binding decree may also provide for a system for the management of construction waste produced in its cadastral territory by non-self-employed natural persons.

The municipality is obliged to provide places for the disposal of all municipal waste produced by natural non-entrepreneurs in its cadastral territory. The municipality is obliged to provide places for separate collection of municipal waste components, at least hazardous waste, paper, plastic, glass, metals and biodegradable waste. The Ministry may stipulate in a decree the details of the scope and method of ensuring the separate collection of municipal waste components.

Producers who produce waste similar to municipal waste can, by contract with the municipality, use the system of collection, collection, transport, sorting, recovery and disposal of municipal waste introduced by the municipality. The contract must be in writing and must always contain the agreed price for this service.

Natural persons and producers of waste involved in the system of collection, collection, transport, sorting, recovery and disposal of municipal waste introduced by the municipality are obliged to separate and dispose of municipal waste and municipal waste similar to municipal waste designated in accordance with the generally binding ordinance of the municipality. unless they dispose of the waste or dispose of it in any other manner provided for in this Act.

The municipality may levy remuneration for the collection, collection, transport, sorting, recovery and disposal of municipal waste from natural persons on the basis of a contract. The contract must be concluded in writing and must contain the amount of the payment. If the municipality collects this remuneration, it cannot set a municipal waste fee or a local fee for the operation of the system for collecting, collecting, transporting, sorting, recovering and disposing of municipal waste under the Local Fees Act.

Fee for municipal waste

A municipality may set, in a generally binding municipal Decree and collect a fee (hereinafter referred to as the "fee") for municipal waste produced on its territory. The fee cannot be imposed simultaneously with a local fee for the operation of a system of gathering, collection, transport, sorting, recovery and disposal of municipal waste.

Every natural person producing municipal waste during his/her activity shall be subject to payment of the fee. Any owner of land and buildings where municipal waste is produced shall be liable to pay the fee. In the case of a building in which an associate has been set up, pursuant to a special Act, the association shall be liable to pay the fee. The payer shall then divide the fee among the individual payers. The fee shall be administered by the municipality that introduced it on its territory.

The maximum fee amount shall be set on the basis of the expected justified costs to the municipality arising from the management of municipal waste, apportioned between the various fee payers based on the number and volume of the containers designated for the deposit of waste attributable to individual properties or based on the number of persons occupying an apartment, and depending on the level of sorting of that waste. The fee may also reflect the costs related to the lease of containers designated for waste depositing. The fee constitutes income for the municipality.

Special provisions for waste landfilling [9]

The landfill operator is obliged to:

a) prove, before the operation of the landfill, that it has no debts to the local tax office and to the local customs office;

b) to finance the first phase of the landfill operation

c) to ensure the decontamination, reclamation and after-care of the landfill following the closure of the landfill, and to prevent the negative impact of the landfill on the environment; ensure these activities from their own funds and from financial reserves for at least 30 years,

d) collect fees for the dumping of waste in the landfill, pay them to the beneficiary of the fee and inform the beneficiary of the fees due,

e) to keep records of the deposited waste throughout the operation of the landfill and the subsequent care of the landfill.

Special provisions for waste incineration [9]

Waste can be incinerated only if the conditions set by the legislation on air protection (emission limits) and on energy management are met.

The technical requirements for the management of waste arising from the incineration of hazardous waste in incineration plants are set by the Ministry in a decree.

Waste incineration is considered to be energy recovery only if the incineration process achieves a high degree of energy efficiency. The amount of energy efficiency required and the formula for its calculation are given in Chapter 5.2.1.

Waste incineration plants where the conditions for energy recovery of waste are not met are waste disposal facilities.

Take-back of some products [9]

The take - back obligation shall apply to:

a) lamps and tubes,
b) tires;
c) household electrical appliances

The obligation to ensure the take-back of used products offered for take-back lies with the legal entity or natural person authorized to do business, which manufactures or places the mentioned products on the market in the Czech Republic, regardless of the trade mark.

The liable entity shall ensure, through a legal entity or a natural person authorized to do business, that sells take-back products to the consumer (hereinafter referred to as the "last seller") that the consumer is informed of the way of taking back such used products.

When selling products subject to take-back, the last seller is obliged to inform the consumer about how to take back these used products. If he fails to do so, he is obliged to collect these used products directly in the establishment, without any claim for payment from the consumer, for the whole working time and without tying the collection of used products intended for take-back to purchase goods.

The liable entity may, based on a written agreement with the municipality, use the system of collection and sorting of municipal waste established by the municipality to fulfill its obligation.

The liable entity shall ensure the recovery or disposal of used products reclaimed in accordance with this Act and the implementing legislation by the end of the calendar year following the calendar year in which they were collected.

Waste recording and reporting [9]

Waste producers and licensed persons disposing with waste are obliged to keep records on waste and waste management methods. Records shall be kept for each separate place of business and for each type of waste separately.

If waste producers and licensed persons produce or dispose more than 100 kg of hazardous waste per calendar year or more than 100 tonnes of other waste per calendar year, they are obliged to send truthful and complete report on waste types and quantities and management method to municipal authority with extended competence every year no later than February 15 of subsequent year.

Waste management plans [9]

The waste management plan is prepared by the Ministry, regions and municipalities to the extent stipulated by law. The Waste Management Plan is being elaborated in order to create conditions for the prevention and management of waste pursuant to this Act.

Waste management plans of the Czech Republic and regions can be publicly viewed, extracts, copies or copies from them.

Public administration bodies in the waste management sector [9]

The following bodies provide public administration in the waste management sector:

a) the Ministry;

b) the Ministry of Health;

c) the Ministry of Agriculture;

d) the Inspectorate;

e) the Czech Trade Inspectorate;

f) the Central Institute for Supervising and Testing in Agriculture;

g) customs offices;

h) the Czech police force;

i) public health protection bodies;

j) regional authorities;

k) municipal authorities of municipalities with extended competence;

l) municipal authorities and military domain authorities.

The Ministry is the central public administration authority in the waste management sector, executes supreme state supervision in the waste management sector, except for public health protection in waste management.

The Ministry of Agriculture coordinates the monitoring of compliance with obligations related to the application of treated sludge on agricultural soil.

The Ministry of Health executes supreme state supervision and controls the activities of the state administration in the area of the protection of public health during waste management, authorizes legal entities or natural persons to evaluate the hazardous properties of waste, extends the validity of this authorisation and revokes this authorisation.

The Inspectorate (CEI) verifies compliance by legal entities, natural persons authorized to conduct business and municipalities with the provisions of the legal regulations and the decisions of the Ministry and other administrative authorities in the waste management sector, as well as compliance with the specified procedures for the evaluation of the hazardous properties of waste. It imposes fines on legal entities and natural persons authorized to conduct business for breach of the obligations.

- **Decree 93/2016 Coll. laying down the Catalogue of Waste [12]**

Waste is classified under six-digit catalog numbers of waste types, divided into three pairs of numbers. The first two digits indicate the waste group, the second two digits indicate the subgroup, and the third two digits the waste type.

Hazardous waste is marked with an asterisk (*) after the catalogue number in the list. Wastes without asterisks are classified as "other"; they are not dangerous. The waste catalogue contains 20 waste groups.

The waste producer or authorized person shall classify waste under the six-digit waste type catalog numbers listed in the Waste Catalog, in which the first two digits indicate the waste group, the second two digits the waste sub-group and the third two digits the waste type.

Depending on the industry, industry or technological process in which the waste is generated, the appropriate group is first sought, then within the group the waste subgroup. The name of the waste type with the appropriate catalog number is searched in the sub-group; the choice of waste is as specific as possible.

If the corresponding waste catalog number in groups 01 to 12 and 17 to 20 cannot be found in the Waste Catalogue, the waste catalog number is searched in groups 13, 14 and 15 of the Waste Catalog.

If no suitable catalog number is found even in groups 13, 14 and 15, the catalog number for the waste is sought in group 16.

If no suitable catalog number is found even in group 16, the waste shall be assigned a catalog number ending in the double digit 99 of the waste group, as searched under paragraph 2. The waste name shall include a technical or commonly used name. If the producer or authorized person assigns more than one type of waste under one catalog number ending in the double digit 99, which will therefore differ for the purposes of registration only by the name of the waste and not by the catalog number, such waste must comply with § 16 1 letter e) and § 18 para. 1 letter h) of the Waste Act.

Where waste consists of several components listed under separate catalog numbers in the Waste Catalog, the assignment to the type of waste which is most dangerous in terms of harmful effects on humans and the environment shall take precedence.

- **Decree 94/2016 Coll. on the evaluation of hazardous properties of waste [11]**

This Decree sets out the content of the application for the authorization of hazardous waste assessment and the content of the proposal to extend the validity of this authorization (hereinafter referred to as the "application for authorization"), the hazardous properties of waste and the content of the certificate and communication.

The definitions of hazardous waste characteristics and the criteria on the basis of which the individual hazardous waste characteristics are assessed are set out in a directly applicable EU regulation. [10]

Procedure for evaluation of hazardous properties of waste: waste producer who believes that produced waste has no longer a hazardous property submits an application for revaluation of hazardous properties of given waste to an authorized person. The authorized person shall provide qualified sampling of waste, choose an appropriate laboratory for analysis of hazardous properties and forward the sample to be analysed. Based on the test protocol, if the waste is proven not to contain hazardous property, the authorized person issues Certificate on Elimination of Hazardous Properties of Waste, passes it to the waste producer. The producer is then entitled to handle with the waste as "other waste". Otherwise, the authorized person issue a Communication, passes it to the waste producer and (s)he is obliged to handle waste as hazardous waste.

- **Decree of the Ministry of Environment of the Czech Republic No. 383/2001 Coll. on details of waste management [13]**

This Decree implementing the Waste Act regulates the particulars of an application for consent for the operation of facilities for the use, disposal or collection of waste and the particulars of an application for consent for the management of hazardous waste. The technical requirements for the facility and the list of wastes are stipulated. Technical requirements for waste oil management are set.

- **Decree of the Ministry of Environment of the Czech Republic No. 294/2005 Coll. on the conditions of depositing waste in landfills and its use on the surface of the ground and amendments to Decree No. 383/2001 Coll., on details of waste management [14]**

This Decree implements the relevant regulations of the European Communities1) and, in accordance with them, stipulates:

a) technical requirements for waste landfills (hereinafter referred to as "landfill") and conditions of their operation;

b) a list of waste types that must not be deposited in landfills or that may only be deposited in landfills under certain conditions;

c) the method of assessing waste on the basis of its leachability and miscibility and waste acceptance criteria for facilities that use and dispose of waste products;

d) technical requirements for handling waste produced from incineration of hazardous waste;

e) requirements for depositing asbestos-based waste in landfills;

f) requirements for the temporary storage of metallic mercury

g) requirements for depositing waste as technological material in secured landfills;

h) the method of creating and drawing on financial reserves;

i) the scope of the landfill management plan**.**

Questions 1.3.

1) Please describe basic concepts resulting from the Waste Act.
2) Please try to outline the main importance of the Waste Act.
3) When are the waste producer and the licensed person obliged to classify the waste into the category "hazardous waste" according to the Waste Act?
4) What is the purpose of the Catalogue of Waste? In what legal document can we find it?
5) What products are covered by take-back and what is the meaning of the take-back?
6) Please describe the procedure for evaluation of hazardous properties of waste.
7) Please list the bodies of state administration in the field of waste management.
8) What are the basic legal conditions for landfilling and incineration of waste?
9) How legislation regulates the municipal waste management?

Additional references

[1] Wilson D. G.: Handbook of Solid Waste Management. New York, 1977

[2] Bilitewski B., Härdtke G., Marek K., Weissbach A., Boeddicker H.: Waste Management. Springer - Verlag, Berlin 1997.

[3] Filip J.a kol.: Odpadové hospodářství. ES MZLU Brno, 2002.

[4] Toelgyessy J., Piatrik M.: Odpad - surovina budúcnosti. Obzor, Bratislava, 1984.

[5] Směrnice Evropského parlamentu a Rady 2008/98/ES, ze dne 19. listopadu

2008, o odpadech.

[6] Rámcová směrnice o odpadech/don´t waste waste. Dostupné z http://www.odpadjeenergie.cz/legislativa/ramcova-smernice-o-odpadech-don-t-waste-waste.

[7] Směrnice Evropského parlamentu a Rady 2000/53/ES, o vozidlech s ukončenou životností.

[8] Směrnice Rady 1999/31/ES ze dne 26. dubna 1999 o skládkách odpadů.

[9] Zákon č. 185/2001, o odpadech v platném znění. Sbírka zákonů ČR, částka 71, roč. 2001.

[10] Nařízení komise (EU) č. 1357/2014 ze dne 18. prosince 2014, kterým se nahrazuje příloha III směrnice Evropského parlamentu a Rady 2008/98/ES o odpadech (nebezpečné vlastnosti odpadů).

[11] Vyhláška MŽP a MZ č. 94/2016 Sb., o hodnocení nebezpečných vlastností odpadů.

[12] Vyhláška č. 93/2016 Sb., o Katalogu odpadu.

[13] Vyhláška MŽP č. 383/2001 Sb., o podrobnostech nakládání s odpady.

[14] Vyhláška č. 294/2005 Sb., o podmínkách ukládání odpadů na skládky a jejich využívání na povrchu terénu a změně vyhlášky č. 383/2001 Sb., o podrobnostech nakládání s odpady

2 PRODUCTION AND TREATMENT OF SELECTED TYPES OF WASTE

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- quantify the amount of waste produced in the Czech Republic according to the industries;
- know methods of processing each types of waste;
- interpret waste treatment methods abroad.

Lecture

2.1 Production and treatment of waste in the Czech Republic

In 2017 a total of 34,5 million tonnes of waste were produced. Year-on-year, since 2016, waste production has increased by 0.8%, since 2009 even by 7.0%. The growth of total waste production is mainly due to the development of construction activities, especially in the area of transport infrastructure.

The production of hazardous waste and its changes are mainly influenced by industry and also by the remediation of old environmental burdens. This can also be observed for individual regions. E.g. the high production of hazardous waste in the Moravian-Silesian Region is due to the industrial orientation and ongoing remediation works (mainly in the Ostramo lagoons). In contrast to the above examples, the development of hazardous waste production is positive; between 2009 and 2017, its production decreased by almost a third (30,2%) to 1,5 million tons [15]. Table 2 shows the development of waste production in the Czech Republic.

Table 2 Development of waste production in the Czech Republic **[15]**

Waste group	Year	2009		2013		2017	
	Waste type	Total	of which hazardous	Total	of which hazardous	Total	of which hazardous
1	Wastes from geological prospecting, mining, treatment and other physical and chemical processing of minerals and stone	86 525	255	139 783	2 497	72 525	1 487
2	Wastes from primary production in agriculture, horticulture, hunting, fishing, forestry and from the production and processing of food	698 725	874	309 274	2 299	259 606	2 182
3	Wastes from woodworking and manufacture of boards, furniture, cellulose, paper and paperboard	227 660	1 469	148 915	475	175 475	721
4	Wastes from the leather, fur and textile industries	59 620	441	79 217	497	100 145	478
5	Wastes from petroleum refining, natural gas cleaning and pyrolytic coal processing	175 201	161 037	12 462	12 221	16 881	16 811
6	Wastes from inorganic chemical processes	56 646	53 354	15 664	10 850	18 025	13 683
7	Wastes from organic chemical processes	110 021	54 220	102 547	26 517	150 414	32 264
8	Wastes from the MFSU of paints, varnishes and enamels, adhesives, sealants and printing inks	31 291	24 438	38 023	29 433	49 713	38 877
9	Wastes from the photographic industry	3 293	2 475	1 916	1 493	1 352	1 080
10	Wastes from thermal processes	2 736 186	203 580	2 124 872	120 052	1 755 342	192 611
11	Wastes from chemical surface treatment, surface treatment of metals and other materials and from hydrometallurgy of non-ferrous metals	54 820	49 401	72 549	68 345	103 304	96 404
12	Wastes from forming and from the physical and mechanical treatment of metal and plastic surfaces	586 548	64 906	621 140	83 473	714 668	101 546
13	Oil wastes and liquid fuel wastes (excluding edible oils and wastes specified in groups 05 and 12)	115 945	115 945	141 044	141 044	166 572	166 562
14	Wastes of organic solvents, refrigerants and propellants (except wastes specified in groups 07 and 08)	4 673	4 673	3 953	3 953	3 908	3 908
15	Waste packaging, absorbents, cleaning cloths, filter materials and protective clothing not otherwise specified	1 077 459	44 020	1 007 637	47 916	1 228 846	58 804
16	Wastes not otherwise specified in this catalog	610 839	202 059	686 571	185 628	597 030	224 446
17	Construction and demolition wastes (including excavated soil from contaminated sites)	18 520 614	798 904	17 904 590	412 064	20 742 812	256 560
18	Wastes from and / or related medical or veterinary care (with the exception of catering waste and catering waste not directly related to health care)	33 301	30 499	36 739	31 681	42 417	34 514
19	Wastes from waste treatment, recovery and disposal facilities, wastewater treatment plants for on-site effluent treatment and the production of water for human and industrial use	1 950 231	315 565	2 144 323	224 377	2 771 043	226 628
20	Municipal wastes (household and similar commercial, industrial and office wastes), including components from separate collection	5 125 081	33 217	5 028 289	38 308	5 542 537	38 115
50	Wastes arising from electrical waste	2 607	56	1 106	234	x	x
Celkem		**32 267 286**	**2 161 390**	**30 620 616**	**1 443 358**	**34 512 615**	**1 507 679**

Table 3 shows waste generation in individual regions in 2017.

Table 3 Waste generation in individual regions of the Czech Republic in 2017

Region	Total waste production [t]	Total waste production per person [kg/person]
Capital City of Prague	4 703 471	3 656
Central Bohemian	4 409 302	3 276
South Bohemian	1 863 632	2 916
Pilsen	2 538 192	4 382
Carlsbad	807 946	2 729
Ústí	2 875 375	3 503
Liberec	958 235	2 173
Hradec Králové	1 484 942	2 824
Pardubice	1 460 866	2 824
Vysočina	1 519 019	2 986
South Moravian	4 246 714	3 597
Olomouc	2 246 754	3 549
Zlíns	1 329 205	2 280
Moravia Silesian	4 068 962	3 370
Czech RepublicTotal	34 512 615	3 259

The generation of municipal waste, which is closely related to the place of residence of the originators, is also slightly increasing, amounting to 5 690,6 thous. tones. In terms of per capita, it reached 537 kg/capita. Year-on-year, the production of municipal waste increased by 1,4%, since 2009 by as much as 6,9%. The increase in municipal waste production in the last two years is mainly due to an increase in the production of biodegradable waste. Methods of municipal waste management in selected years are shown in Table 4.

Table 4 Methods of municipal waste management in selected years

Method of treatment	2009		2013		2017	
	t	%	t	%	t	%
Amount of energy recovered municipal waste	319 284	6,0	614 502	11,9	685 277	12,0
Amount of materially recovered municipal waste	1 206 436	22,7	1 561 729	30,2	2 135 660	37,5
Amount of municipal waste disposed of by landfilling	3 409 772	64,0	2 698 737	52,2	2 583 390	45,4
Amount of municipal waste removed by incineration	2 057	0,04	2 837	0,05	3 497	0,06

2.2 Methods of waste management abroad

In 2014, total waste production from all economic activities and households in the EU-28 was 2 503 million tonnes. This was the largest quantity recorded in the EU-28 in the period 2004-2014 [16].

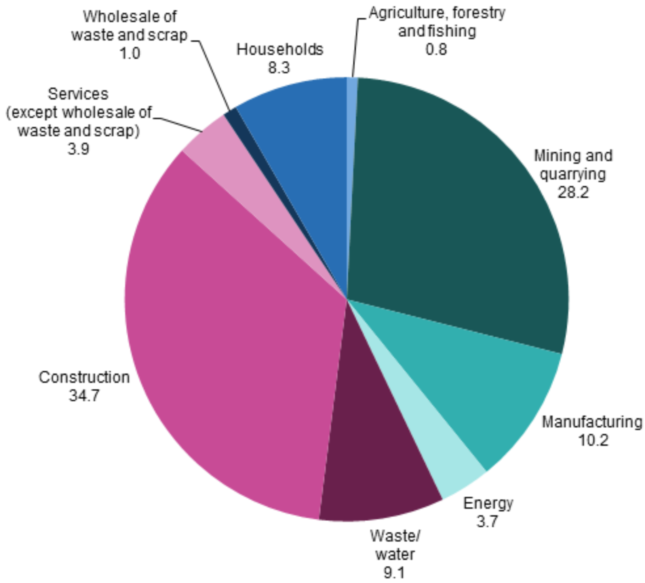
As expected, the total amount of waste generated is to some extent related to the population and size of the country's economy. Table 5 shows that the smallest EU Member States generally reported the lowest level of waste generation, while in the larger countries it was the highest. However, a relatively large amount of waste was produced by Bulgaria and Romania, while relatively small amounts were generated by Italy.

Table 5 Waste generation in EU countries [16]

	Total		Mining and quarrying	Manufacturing	Energy	Construction and demolition	Other economic activities	Households
	(million tonnes)	(kg per inhabitant)	(%)					
EU-28	2 502.9	4 931	28.1	10.2	3.7	34.7	14.9	8.3
Belgium	65.6	5 838	0.1	21.7	2.1	40.2	27.3	8.6
Bulgaria (1)	179.7	24 872	88.6	:	5.1	0.7	4.0	1.5
Czech Republic	23.4	2 223	1.0	18.8	4.3	40.2	21.8	13.9
Denmark	20.1	3 558	0.1	6.4	5.4	52.6	18.5	17.1
Germany	387.5	4 785	1.9	15.8	2.6	53.3	16.9	9.5
Estonia	21.8	16 587	36.3	20.2	32.6	3.1	5.6	2.2
Ireland (1)	15.2	3 285	17.8	:	2.1	12.4	57.6	10.0
Greece	69.8	6 404	67.9	7.0	15.6	0.7	2.3	6.5
Spain	110.5	2 378	16.9	13.4	4.8	18.5	28.3	18.3
France	324.5	4 913	0.7	6.7	0.5	70.2	13.1	8.8
Croatia (1)	3.7	879	0.1	:	3.2	16.6	48.9	31.2
Italy	159.1	2 617	0.6	16.7	2.0	32.5	29.5	18.6
Cyprus (2)	2.1	2 406	:	:	:	31.0	48.9	20.2
Latvia	2.6	1 315	0.2	9.4	27.8	17.3	18.3	27.1
Lithuania	6.2	2 114	0.4	42.1	1.6	7.0	30.1	18.7
Luxembourg	7.1	12 713	1.8	4.0	0.0	84.5	6.1	3.4
Hungary	16.7	1 688	0.5	16.2	13.9	20.7	31.0	17.7
Malta (1)	1.7	3 896	2.2	:	0.2	74.5	13.8	9.3
Netherlands	133.2	7 901	0.1	10.1	1.3	68.1	14.1	6.4
Austria	55.9	6 541	0.1	9.7	0.9	72.1	9.8	7.5
Poland	179.0	4 710	42.3	17.6	12.2	9.5	13.7	4.6
Portugal	14.6	1 402	1.9	17.9	1.2	10.3	36.3	32.3
Romania (1)	175.6	8 820	87.0	:	4.0	0.6	6.2	2.2
Slovenia	4.7	2 273	0.2	28.1	13.5	17.4	28.9	12.0
Slovakia (1)	8.9	1 636	3.2	:	6.1	15.6	55.4	19.6
Finland	96.0	17 572	65.4	10.7	1.5	17.0	3.7	1.7
Sweden	167.0	17 226	83.2	3.4	1.1	5.3	4.5	2.5
United Kingdom	251.0	3 885	10.5	3.2	1.3	48.0	26.0	11.0
Iceland (3)	4.5	1 651	0.0	17.6	0.3	2.1	36.1	44.0
Liechtenstein	0.6	14 919	1.7	2.0	0.1	0.0	0.4	95.9
Norway (1)	11.7	2 283	2.8	:	1.3	23.0	52.7	20.3
Montenegro	1.2	1 872	22.5	5.2	31.7	9.2	15.3	16.1
FYR of Macedonia	2.2	1 058	3.4	67.9	23.3	0.5	4.9	0.0
Serbia	49.1	6 890	84.5	1.8	9.1	0.6	0.7	3.3
Turkey (4)	73.1	947	4.2	:	32.8	:	20.2	42.8
Bosnia and Herzegovina (3)	0.5	1 161	1.6	27.2	71.1	0.0	0.0	0.0
Kosovo (UNSCR 1244)	1.0	574	19.3	7.0	0.0	0.3	26.3	47.0

(1) Other economic activities includes also manufacturing.
(2) Other economic activities includes also mining, quarrying, manufacturing and energy.
(3) 2012.
(4) Other economic activities includes also manufacturing, construction and demolition.
Source: Eurostat (online data code: env_wasgen)

The share of individual economic activities and households in total waste production in 2014 is shown in Figure 2. In the EU-28, 34,7% of all construction waste was generated in 2014, followed by mining and quarrying (28,2%), manufacturing (10,2%), waste and water management (9,1%) and households (8,3%); the remaining 9,5% of waste was generated by other economic activities, in particular services (3,9%) and energy (3,7%).



Source: Eurostat (online data code: env_wasgen)

Figure 2 Share of individual economic activities and households in total waste production in 2014 [16]

In 2014, approximately 2 320 million tonnes were processed in the EU-28. This also includes the treatment of waste imported into the EU, so the reported quantities are not directly comparable with the data on waste generated.

Almost half (47,4 %) of waste treated in the EU-28 in 2014 was disposed of other than incineration. A further 36,2 % of waste processed in the EU-28 in 2014 was sent for non-energy recovery and backfilling (referred to as recycling for simplification). Only slightly more than one tenth (10,2 %) of waste treated in the EU-28 was used for backfilling. The remainder was sent for incineration, either for energy use (4,7 %) or not (1,5 %). There were considerable differences between the EU Member States as regards the use of different processing methods. For example, some Member States had very high recycling rates (Italy and Belgium) and others favored landfill (Bulgaria, Romania, Greece, Sweden and Finland) [16].

In the case of municipal waste, there has been a significant reduction in landfilling of this waste in the last 20 years and, on the contrary, the level of material and energy recovery has significantly increased, as shown in Table 6.

Table 6 Methods of municipal waste management in EU-28 countries [16]

Municipal waste landfilled, incinerated, recycled and composted, EU-28, 1995-2017

	1 995	1 996	1 997	1 998	1 999	2 000	2 001	2 002	2 003	2 004	2 005	2 006	2 007	2 008	2 009	2 010	2 011	2 012	2013	2014	2015	2016	2017	Change 2017/1995 (%)
	million tonnes																							
Landfill	145	143	144	140	140	140	135	131	125	118	110	109	107	101	98	93	86	79	73	68	64	60	58	-60
Incineration	32	32	35	35	36	39	40	41	41	44	48	52	52	54	55	57	60	59	62	64	65	68	70	118
Material Recycling	25	28	32	35	40	40	43	47	48	49	52	54	60	61	62	63	64	66	65	68	71	73	74	195
Composting	14	16	17	18	19	24	24	26	26	28	29	30	32	35	34	34	34	35	36	38	38	41	42	196
Other	10	14	12	12	12	12	12	12	12	13	17	14	11	10	7	6	6	6	6	5	6	6	6	-44
	kg per capita																							
Landfill	302	295	298	289	287	287	277	268	254	239	223	220	214	202	194	185	171	156	145	134	125	117	113	-63
Incineration	67	67	72	73	74	79	81	84	84	90	96	104	105	108	110	114	119	118	122	126	128	134	137	104
Material Recycling	52	58	66	72	82	83	87	95	97	99	105	109	119	121	124	126	128	130	128	133	140	143	144	177
Composting	29	33	36	37	39	48	50	53	53	57	58	61	64	69	68	67	67	70	72	74	75	81	81	179
Other	20	29	24	23	26	24	24	25	25	27	33	27	21	20	15	12	12	12	12	11	12	11	11	-45

Source: Eurostat (online data code: env_wasmun)

eurostat

Due to the constant diversion of the materially unusable part of municipal waste away from landfills, its energy recovery is currently becoming a trend. Energy recovery of waste means the use of thermal energy released during the incineration of waste to produce electricity and heat. Cogeneration plants using waste to generate electricity and heat are generally referred to in the Czech Republic as energy recovery facilities (ERF). According to current data from the European Confederation of European Waste-to-Energy Plants [17], 518 ERF was in operation at the end of 2017 with a total annual capacity of 93,6 million tonnes of waste. These figures do not include hazardous waste incineration plants.

Most ERF is currently in operation in France (126) and Germany (121). ERF has the largest total annual capacity in Germany (26 million t/year), France (14,7 million t/year) and the United Kingdom (9,5 million t/year).

Also interesting is the view of ERF capacity per capita. In this statistic, Denmark (0,62 t/capita) is the number one, followed by Sweden (0.56 t/capita), Switzerland (0.46 t/capita) and the Netherlands (0.44 t/capita).

At the same time, Sweden is the only country in Europe where the per capita ERF capacity exceeds per capita municipal waste production (0,44 t/capita). Moreover, Sweden is very far in the municipal waste recycling rate (52 % in 2014). As a result, the Nordic country imports a large part of the waste incinerated in its ERF from abroad. According to the latest available data, about 2,7 million tonnes of waste were imported into Sweden in 2014. In the same year 5,7 million tonnes were incinerated at ERF, of which 2,1 million tonnes were Swedish municipal waste.

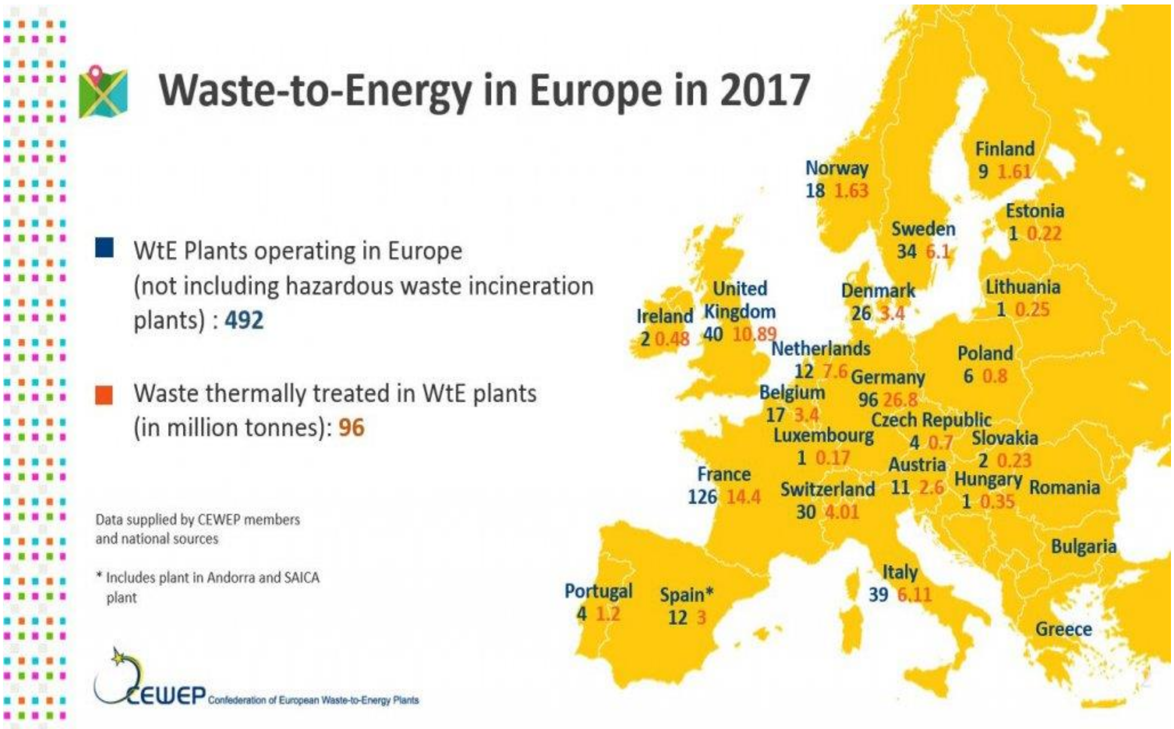


Figure 3 Number of ERF in European countries 2017 [17]

As can be seen from Figure 3, some states are well ahead of the energy recovery of waste. If we look at these countries as a whole, we find that since 2010, both the number and the total annual capacity of European ERF have increased.

While the number of ERF increased by approximately 15 % from 451 to 518 between 2010 and 2017, the total annual capacity of ERF in Europe increased by almost 30 % from 73,3 to 93,6 million tonnes. The figures and graphs in the following figure show the set growth trend in this area.

Questions 2

1. Quantify the amount of waste generated in the Czech Republic according to the individual sectors in which they are generated.
2. Interpret waste management methods abroad.

Additional references

[15] Waste generation in the Czech Republic in 2017. Available from http://www.enviweb.cz/112768.

[16] Waste Management Information System. CENIA, Czech Environmental Information Agency, 5.12.2018 [online], available from https://odpady.cenia.cz/.

[17] Waste statistics. Eurostat - the official European Statistical Office. Available from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics/en#Statistika_odpad.C5.AF

[18] Confederation of European Waste-to-Energy Plants. Evropský svaz pro energetické využití odpadů, dostupný z https://www.cewep.eu/.

3 SOURCES AND PRODUCTION OF WASTE

3.1 Municipal waste

Time to study: 4 hours

Cíl: After reading this paragraph, you will be able to

- describe major sources and production of municipal waste;
- describe basic methods of municipal waste collection;
- explain methods of separate collection of municipal waste;
- explain methods of processing usable/recyclable components of municipal waste;
- explain methods of treatment of mixed municipal waste in the Czech Republic and abroad.

Lecture

The Act No. 185/2001 Coll. on waste defines the municipal waste as all waste produced by activities of natural persons within municipality, excluding waste produced by legal persons. Therefore, it is a household waste and similar waste from stores, crafts, services, various offices and institutions as well as from industry. According to the Catalogue of Waste, it belongs to the Group 20: Municipal waste (waste from households, similar waste from trade and industry, and waste from offices) including components from separate collection which belong to Group 15 01.

Mixed municipal waste is not categorized as hazardous, although it can show hazardous properties. Producer and authorized person are not obliged to treat this waste as hazardous waste. Legal and natural persons qualified to business producing waste similar to municipal waste may be contractually involved in waste management system, which is in accordance with generally binding decree of respective municipality.

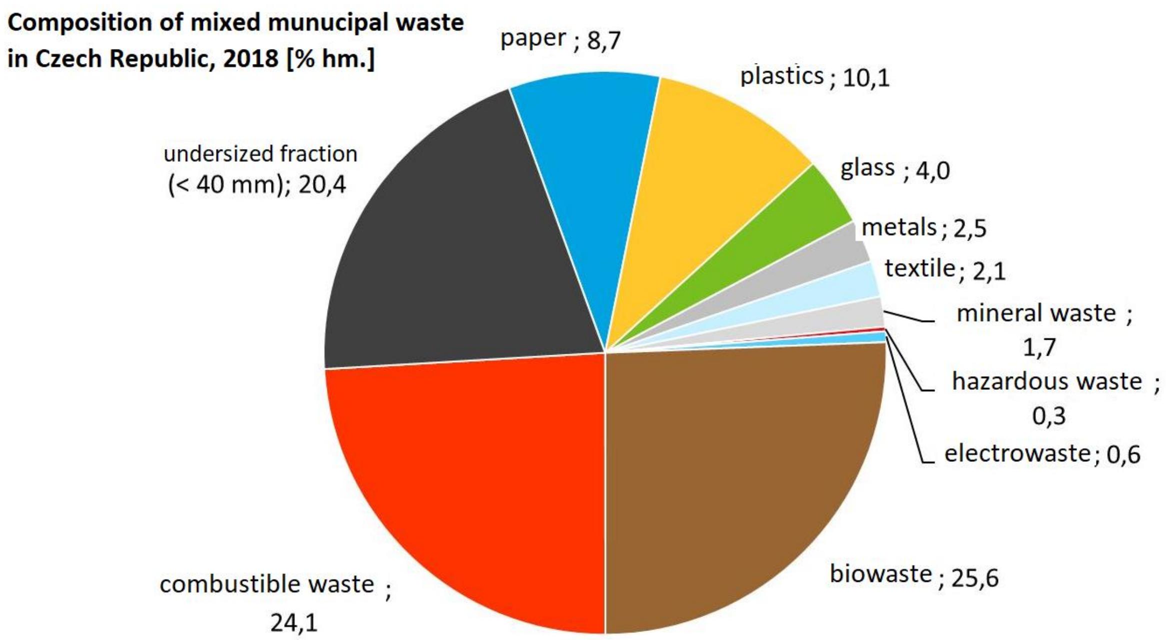
Sources and production of municipal waste

Household operation, housing, technical and civic amenities, schools, offices, crafts, transport, recreation, sport, public green maintenance are the source of municipal waste.

The Table 7 and picture 4 states average composition of municipal waste in the Czech Republic varying according to the waste production area as well as the season.

Table 7 Average composition of municipal waste in the Czech Republic [19]

Municipal Waste	[hm. %]
paper and cardboard	8,7
plastics	10,1
glass	4,0
metals	2,5
textile	2,1
mineral waste	1,7
hazardous waste	0,3
electrowaste	0,6
biowaste	25,6
combustible waste	24,1
underlay fraction <40 mm	20,3
total	100



Picture 4 Average composition of municipal waste in the Czech Republic [19]

Composition of household waste including each material group in the Czech Republic is comparable with the data from other countries. It may occur in the following forms:

Bulky waste – household waste and waste similar to household waste that cannot be collected in collection containers of volume up to 1.1 m3 due to its sizes or weight. The bulky waste can be found in larger quantities after general cleaning, house construction and redevelopment, moving of people and it is composed primarily of the scrap metal (refrigerators and freezers, washing machines, televisions, cookers, car parts, etc.), the construction waste produced in small household repairs and maintenance, the carpets, the floor coverings, the tyres.

Usable/Recyclable components of municipal waste – types of municipal waste obtained through separate collection or sorting that (from the technological point of view) can be used either directly, or after treatment (paper and cardboard, glass, small plastic items, other plastics, small metal items, cans, other metals, wood, organic waste, compostable waste from kitchens including cooking oils and kitchen waste from canteens and restaurants, textile materials, spray containers, electrical waste). For effective utilization, this waste must not contain any harmful substances. Separately collected usable components of municipal waste are sometimes called inaccurately "secondary raw materials". From the technological point of view, the material able to be processed in industry after treatment and cleaning is referred as the usable component of municipal waste. However, it need not be a raw material. It would become a raw material, equivalently to natural raw material, when it will be purchased for this purpose.

Hazardous components of municipal waste – waste oil and greases, paint residues, adhesives and resins, solvents, acids, bases, detergents, degreasers, cosmetics residues, photographic chemicals, drugs, pesticides, batteries and accumulators, oily rags, brake fluid, brake pads, fluorescent tubes and other mercury-containing waste, equipment containing chlorofluorocarbons, televisions, etc.

Street sweepings – dirt collected through public spaces cleaning and garbage discarded to the street and park waste bins (street sweepings, waste from markets, and other non-compostable waste from green areas).

Green waste – waste of biological origin from maintenance of orchards, parks, forest parks, housing estate and street green, grass playing areas owned or administrated by a municipality, from gardens of individuals and cemeteries.

Mixed waste – waste that remains after separation of usable components and hazardous components from municipal waste.

Other waste similar to household waste – waste produced in non-residential buildings owned or administrated by a municipality or produced by the activity of legal entities or natural persons in relation with housing stock management [20].

Gathering and collection of municipal waste

The most common method of municipal waste collection is a container collection with subsequent container emptying (kerbside collection). Containers (waste containers, dustbins, etc.) are placed at the collection points (stations) and regularly emptied and taken away for further use or disposal.

This method is also used for separate collection of recoverable components of municipal waste. The container collection with container exchange (high-volume containers) is used for higher amount of municipal waste in one place or for bulky waste. Another method of collection of municipal waste and its individual components is delivery way – collection containers are placed at collection points (waste centres) and people bring waste to these centres personally.

Separate collection

An optimal method of municipal waste utilization is its sorting in households and storing in special collection containers intended for individual components. In this way, it is possible to obtain highly pure secondary raw materials, which can be further re-used far better. Considering the fact that quality requirements of processing companies for secondary raw material supplies continue to increase – the emphasis is particularly placed on secondary purity and minimum content of impurities, the post-sorting is almost always performed in such a way, so that sorting components meet requirements for subsequent processing. Recently, sorting of hazardous components of municipal waste (oils, solvents, old chemicals, pesticides, drugs, paint residues, old batteries, strip lights, discharge lamps, discarded appliances, refrigerators, etc.) is mainly promoted.

According to the Waste Act, the municipality is obliged to set a place where inhabitants may deposit the hazardous components of municipal waste and where the waste is secured against theft or leakage threatening environment. This obligation may be provided through regular waste collection by an authorized person (e.g. mobile collection). In addition, according to the Waste Act, municipalities are allowed to request a discount for landfilling municipal waste, from which the hazardous component has been removed through sorting.

Waste collection vehicles specially modified are used for mobile collection of hazardous waste. The vehicles must meet the ADR International Standard on carriage of dangerous goods. Hazardous waste containers must be provided with attestation. When liquid waste (solvents, consumer chemicals residues, used mineral oils) is collected, the vehicle must be equipped with a drip pan and equipment for collecting oil (sawdust, vapex). Operators of vehicles must be specially trained to carriage of dangerous goods [3][20].

Utilization and disposal of waste

Municipal waste is a valuable source of secondary raw materials that can be obtained through mechanized sorting or separate collection. The possibility of utilization of materials obtained from the municipal waste depends on the level of their contamination by other components of municipal waste.

The guiding principle in municipal waste management is to reduce the volume of its production. This can be achieved e.g. by establishing returnable packaging, repurchase of newspapers, magazines, paper, textile, white and coloured glass, plastics, ferrous and non-ferrous metals, C/D batteries. Drugs, paints, solvents, oils, chemicals, car batteries and other hazardous waste should be removed from the municipal waste by a special method. Portion of the organic fraction of municipal waste could be used as feedstuffs; the rest can be further composted. In the Czech Republic, the separate collection of each component of municipal waste in the place of its production has being implemented gradually since 1983 [3][20].

Complex treatment of municipal waste

The complex treatment of municipal waste takes place in special treatment (processing) plants where the waste is crushed and screened; glass, metals, plastics, paper, screenings for composts, and fuel are obtained through sorting. The separated components may be used for the production of substitute fuel for cement works or heating plants. The bulky waste is treated through similar process.

Usable and hazardous components of municipal waste must be removed first in order to the municipal waste can be composted. The resulting product must meet all requirements of CSN 465735 that stipulates the maximum permissible concentration of toxic heavy metals in the compostable waste and compost (As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Zn).

Incineration of municipal waste in incineration plants equipped with devices for flue gas cleaning is environmentally friendly, from the economical point of view, however, it is still disadvantageous compared to landfilling. Volume of waste is possible to be reduced to one-tenth of the original volume through the incineration. In addition, pathogens contained in the waste are eliminated the most quickly and the most reliably. Gaseous emissions from an incineration plant are cleaned through bag filters and electrostatic filters with subsequent wet cleaning where acid gaseous components of incineration products (HCl, SO_2, etc.) are removed. In order to remove NO_x, the DENOX filters are used. Emission risk can be reduced by removing hazardous portion of municipal waste before incineration.

Solid incineration products (cinders, ash captured on filters) are classified as hazardous waste according to the Catalogue of Waste. From the chemical point of view, however, they are more stable than the original municipal waste disposed to landfill. Considering the design of landfill intended for their disposal and the prescribed solidification of fine fraction of waste (ash), the leakage risk of leached dangerous pollutants into ground water is negligible. After removing scrap iron, the cinder can be used in road construction, building industry or for road gritting. At present, incineration of municipal waste with subsequent recovery of heat for power and steam generation takes place routinely. In the Czech Republic, approximately 10% of mixed municipal waste are currently used for power generation in municipal waste incineration plants in Brno, Prague and Liberec.

Today's global trend is production of fuel from mixed municipal waste, called as RDF (Refuse Derived Fuel). The production method consists in the removal of non-incinerable components and the treatment of waste grain size. Considering the fact that some components, such as metals, non-incinerable components or biological waste, are removed from the municipal waste during the fuel production, the fuel is combusted optimally resulting in lower amount of ash as well as its composition is different.

Unfortunately, from the economic point of view, the municipal waste landfilling is the most advantageous method of municipal waste disposal in the Czech Republic. However, from the environmental protection point of view, it is the least advantageous. Various dangerous compounds (e.g. heavy metal compounds, polychlorinated hydrocarbons, chlorophenol, chlorobenzene, etc.) are extracted from the landfilled municipal waste in the presence of microorganisms. These compounds may adversely affect ground water quality near the landfill even for several decades after landfill closure [3][21].

Every landfill of municipal waste creates a sort of biological reactor, in which biochemical processes take place. Organic compounds pass through aerobic or anaerobic reactions into various chemical bonds, releasing toxic gases (methane, ammonia, hydrogen sulphide, dioxins, and furans) and other gases that support greenhouse effect or deplete ozone layer.

Municipal waste landfilling itself is affected by Council Directive 1999/31/EC of April 26, 1999 on the landfill, by which EU Member States are obliged to reduce the amount of biodegradable municipal waste disposed on landfills to the following percentage of waste produced in 1995: 75% in 2010, 50% in 2013, and 35% in 2020. In the Czech Republic, approximately 90% of mixed municipal waste is currently disposed in landfills [8].

Otázky 3.1

1. Please describe major sources and production of municipal waste.
2. Please state the basic methods of municipal waste collection.
3. Please explain the methods of separate collection of municipal waste.
4. Please explain the methods of processing usable/recyclable components of municipal waste.

3.2 Construction waste

Time to study: 1 hour

Cíl: Objective: After reading this paragraph, you will be able to

- describe the main construction activities during which the waste is produced;
- describe the basic types of waste produced during these activities;
- state the basic methods of treatment and utilization of this waste

Lecture

Construction waste represents a significant proportion of the total amount of waste. The construction industry is burdening the environment in the production of building materials (energy intensity of production, extraction of natural raw materials), transport intensity (considerable weight of buildings, and thus of transported materials), locally and short-term construction site (noise, dust, construction waste) and energy intensity of heating). At the same time, however, the construction industry is also able to partially relieve the environment mainly by the ability to consume industrial and construction waste as a substitute for natural raw materials. The advantage is that construction waste (per inhabitant in the Czech Republic is 600 - 1000 kg per year) is largely recyclable. There are several dozens of recycling lines working in the Czech Republic at the same time, the unifying element of which is mobility - either in the form of purely mobile - located on wheeled chassis, or semi-mobile equipment placed mostly in container frames.

It is estimated that around 10-12% of construction waste is recycled in the Czech Republic, which is a low value. In large cities, this situation is significantly better (eg 25-30% in Prague and Brno). However, more than 60% (up to 90% in Dresden) are recycled in large European agglomerations.

The quality of recycled materials and the efficiency of the whole process are directly proportional to the quality of the demolition works, especially the sorting of the material from the demolition directly at the place of their origin. From a recycling point of view, it is advantageous to select a demolition process that would also allow the use of entire building elements and components. This is a relatively new trend, especially in EU countries (currently only possible in exceptional cases) - recycling means not only crumbling, sorting and separating rubble and waste, but also processes leading to the direct reuse of whole building elements and components.

The following types of recyclate are currently used:

- ***brick recycled material used*** (possibly as a mixed material) as backfill material, eg for energy distribution or for stabilization of substrates of unbound road layers. However, high-quality sorted recyclates can be used at a much higher level. E.g. for the production of brick concrete for filling masonry in monolithic structures, for the production of prefabricated elements for the preparation of special blocks, for the production of building mixtures as mortar fillers;
- ***recycled concrete*** as a substitute for natural aggregates for the production of structural concrete or as an addition to bituminous mixtures for the construction and repair of bituminous pavements;
- ***asphalt recyclate*** - tests of re-use of old bituminous mixtures from roadways have been carried out in our country so far, which showed that most of the asphalt recyclates cannot be processed by suitable hot methods, or this processing is uneconomical. On the contrary, the use of emulsions, possibly in combination with cement, has been proven to be very suitable, by wrapping environmentally harmful parts and thereby reducing environmental hazards [21] [22].

Wastes from construction activities can be divided according to types of construction and types of materials into:

- building waste,

- wastes from transport and civil engineering works and their operations,

- wastes from the production of building materials.

Construction waste construction is accompanied by any construction, reconstruction and repair of buildings, maintenance of buildings and utilities, maintenance and reconstruction of technological operations, reconstruction and construction of roads, highways, railway lines, their safety systems and stations, waste from water management and pipelines, gas pipelines, steam pipelines, long-distance electro-cable and telephone wiring, water and sewerage systems, area telephony) and the like.

Other wastes that may occur in connection with the construction activity: packaging materials (PET foil, paper, cans, spray cans), paints, adhesives, cardboard, used cleaning textiles, used brushes, sandpaper, abrasive and polishing discs, residues It is mostly inert waste that does not react with the outside environment (surrounding waste in the landfill body).

If construction waste is mixed as it was produced during the demolition of an old construction or as it was collected after construction, it is called mixed construction waste or demolition waste and must be treated as hazardous waste.

The main possibility of using soils and excavation materials is directly on the site for backfilling excavations in earthworks, use for creating noise barriers and roads, leveling terrain unevenness. In a landfill, this material can be advantageously used for overlapping of layered waste or for reclamation.

The treatment of construction debris is economically advantageous only if the waste is competitive products. Brick and concrete pulp can be advantageously reused in concrete. However, this utilization requires prior sorting by type. Road demolition materials, since they contain various components, can be reused as a soundproofing wall construction material without prior screening, into the road body as a substructure of road construction

Construction waste from construction sites, all remnants of materials and raw materials, can be predominantly reused on another construction site, unusable residue (about 10%) can be deposited in landfill. The re-use of residual raw materials is a prerequisite for maintaining their technical quality of primary building materials.

Of the total amount of construction debris, up to 40% can be used as an inert material, the other materials are sorted by about 10% (wood, glass, metals, plastics), the rest is unsuitable for use in the construction process. Sorted 40% of the rubble can be processed on sorting machines. Different bulk weights, rolling behavior and magnetic properties are decisive for sorting. The principles of the function of individual sorting machines are from simple sieving to completely mechanized separation of individual fractions and materials.

Currently, advanced technological equipment is mobile, semi-mobile and stationary with the output of 50 to 400 tons per hour. However, treatment plants with an output of 100 - 150 tons per hour prevail. For crushing debris, jaw crushers, cylindrical, centrifugal and reflective crushers are used. The sorting is carried out either dry or in an aqueous environment.

All recycling and sorting lines operating according to approximately the same scheme: material intake, pre-sifting, pulverizing, magnetic separation of ferrous metals and further sorting of the material according to the customer's request. Mobile treatment plants work at the customer's place of waste generation or where it is necessary to extract and subsequently prepare the building material from the mined rocks.

Benefits of mobile treatment plants:

- minimum space requirements

- easier authorization of operations

- low transport costs for rubble and recycled material

- Possibility of use on site or demolition

- used for direct use on the construction site (eg road and highway construction)

Disadvantages of mobile treatment plants:

- higher operating costs (transport, assembly, possible replacement of personnel)

- limited range of products (fractions) produced due to limited accessories

- more difficult control of the debris supplied

- Problems with emissions of pollutants into the air, excessive noise (no covers, fixed fixation etc.) can arise due to the requirement for the easiest possible assembly and disassembly [24]

Questions 3.2

1. Please describe the main construction activities during which the waste is produced.
2. Please describe the basic types of waste produced during these activities.
3. Please state the basic methods of treatment and utilization of this waste.

3.3 Waste from mining and quarrying

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe the basic types of waste produced during mining and mineral processing;
- describe the negative impact of these wastes on the environment.

Lecture

In the Czech Republic, waste production from mining and quarrying is considerable. The largest source is coal mining, to a lesser extent then mining of limestone, feldspars, kaolin, gypsum, sands, clays, cement raw materials, basalt, bentonite, graphite, fluorite, sandy gravel, building block, brick clays, etc. Waste is produced in various mining operations and finishing plants, during transport, followed by overburdens (a mixture of various rocks – soil, clays, sands), tailings and aggregates contaminated by residues of flotation reagents, coal sludge, but also spoil banks, slag heaps and residual quarries.

From the environment point of view, this waste is burden with its large volume, negligible utilization and difficult disposal. Heavy metals and other pollutants are released as a result of weathering and rainwater leaching. Some waste can be used as a raw material for production of bricks, moulded bricks, porous earthenware (tailings), for reclamation (spoil banks and slag heaps), for fuel production (coal dust and sludge), and in production of fertilizers.

Spoil banks and slag heaps from coal mining are not regarded as excavated soil and consequently, they are not handled as waste. They are used as part of the territory through reclamation to create agricultural land, forest plantations, recreational areas, etc.

Waste mining and quarrying is usually disposed through landfilling or physical and chemical methods. Flotation sludge is deposited on a sludge lagoon. Considering the current run-down of mining and quarrying, production of this waste is expected to reduce.

In the Czech Republic, coal dust and sludge deposited as waste cover considerable part of the territory and may negatively affect the environment. At the present time, the research focused on utilization of eluates from coal scouring and partially on utilization of coal sludge for production of light artificial aggregates [24].

The source of waste is the extraction and treatment of mineral resources (coal, ores and non-mineral resources).

This waste includes overburden, tailings and aggregates, coal dust and sludge. Furthermore, the ore or non-ore concentrates (treatment product) and treatment wastes are produced in the treatment process and can be used as secondary raw materials.

The overburden usually consists of various sedimentary rocks (soil, clays, sands, slate). The tailings and aggregates are a product of mineral processing. This waste is contaminated by residues of flotation agents (phenols, organic acids, xanthates, oils, heavy metal compounds), heavy liquids (organic bromine compounds) or cyanidation (CN) and amalgamation (Hg) agents when flotation and heavy liquid separation is used. .

The non-fired tailings from coal mining have on average 43-52% SiO_2, 19-22% Al_2O_3, 4.5-6% Fe_2O_3, TiO_2, CaO, MgO, Na_2O + K_2O, coal residues, sulphides and water. The tailings of ore mining are of varying composition depending on the type of ores, origin and associated minerals. Coal sludge contains fine particles of coal, tailings, sulfides, etc.

The ecological defect is caused by a large volume of waste that is difficult to dispose of and which is poorly used, which, due to weathering and leaching by rainwater, releases increased amounts of heavy metals, sulphates or phosphates and residues of reagents from the treatment process. The amount of such waste is the highest of all waste.

The largest producer of waste from mining and quarrying in the Czech Republic is coal mining, less mining of mineral resources. In the Czech Republic, black coal, brown coal, lignite, oil and natural gas are mined. In the Czech Republic, uranium ore was also mined to a large extent. Among the non-ore raw materials, the highest production is in limestone, as well as kaolin, sand, cement raw materials, gypsum, feldspar, etc. [25]

Utilization of waste from coal mining

Charcoal tailings is a raw material for the production of bricks, fittings and porous aggregates. Lignite tailings in the USA are used as natural humus for soil conditioning. Burned anthracite tailings are used in the US to scatter highways in winter. Coal dust and sludge are used to a small extent as fuel. Technological tests of artificial lightweight aggregate production were carried out with coal sludge.

In the case of open-cast mining of coal and non-metallic raw materials, the use of accompanying raw materials is possible.

Of these, the following are used to a very limited extent:

- clays (brick, ceramic, earthenware, etc.)

- natural sorbents (eg cypris clays)

- sand and gravel (glass production, construction)

- aggregates

Oxihumolites (rust brown coal, used in the manufacture of paints, mordants and industrial fertilizers)

Use of wastes from ore and non-ore mining

According to the chemical composition of ores:

- ores with pure metal (only precious metals Ag, Au, Pt)

- oxide ores (most common)

- pyrite ores (metal bound to sulfur)

To a lesser extent in the USA and Canada, wastes from the mining and processing of iron ores are used as concrete filler, asphalt aggregate, brick production, as a spreading material.

Waste from mining and ore processing of non-ferrous and precious metals is only used in a small amount for the production of bricks, refractory materials, construction and road construction.

Waste from the production of chromium ores is used as a magnesium-silicate raw material for the production of refractory materials.

Hoppers and dumps from ore mining have relatively high concentrations of heavy metals, so they are not suitable for reclamation purposes [25].

Waste water from ore mining and treatment

During mining, waste water, leachate leaches and mine water are produced. In order to obtain the metal, the ore is separated from the tailings by crushing, gravity or magnetic sorting, floatation, flotation. The tailings contain silicates, alumina, iron oxide and calcium carbonate as impurities.

The pollution of ore water treatment plants is as follows:

- suspended solids, that is mainly waste mash (ground tailings). The concentration of suspended solids is in the range of 20-300 g/l
- dissolved substances which are leached from ore and waste mash (heavy metals, sulphates)
- additives used in flotation

The most widespread method of wastewater treatment from ore treatment is its removal to a tailing pond. Separation of waste mash by sedimentation takes place at the tailings ponds.

Ore is processed by metallurgical processes (pyrometallurgical-heat, hydrometallurgical-wet processes). The hydrometallurgical process makes it possible to process even very poor or polymetallic ores.

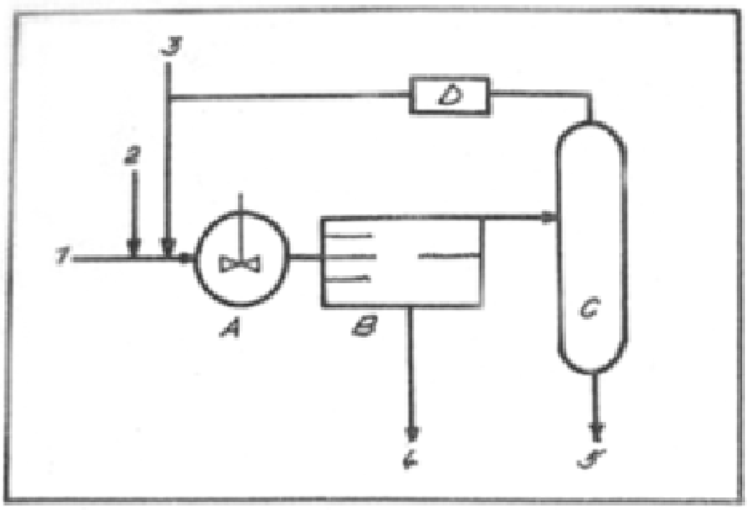
The hydrometallurgical process consists of leaching, separating the leachate from the leach, cleaning the leaches and recovering the metals. Various leaching agents (water, acids, bases, salts, organic solvents) are used for leaching. Leaching takes place at normal temperature and pressure or at higher temperature and pressure. The leachate is separated from the leach by sedimentation or filtration. The leachate cleaning process removes impurities by precipitation, hydrolysis, cementation and extraction. Metals are obtained from the solution by cementation, electrolysis, hydrogen reduction or another reducing agent.

During hydrometallurgical processes waste water is generated. There are dissolved metal compounds, complexing agents and organic solvents in the waste water. Efforts are made to achieve the maximum possible water recirculation from all operations; technologically necessary blowdowns are led back to the water treatment circuits.

Procedures such as precipitation, co-precipitation, ion exchange, electrochemical processes, cementation or extraction of metal complexes with organic solvents are used to trap metals from wastewater.

Hydrometallurgical processes are more advantageous from the point of view of environmental protection compared to heat treatment processes, because the amount of gaseous emissions is lower in order, emissions of solid particles are not.

The scheme for the extraction of metals from wastewater is shown in Figure 5.



Extraction of metals from waste water

A – extraction, B – separation, C – striping, D - trapping the organic solvent

1 – waste water, 2 – salting solution (Cl^-), organic solvent,

4 - purified water, 5 – metal concentrate

Figure 5 Scheme of metal extraction from wastewater

Biometallurgical processes used in biometallurgy can also be applied to recover metals from waste. These procedures are based on the mechanism of leaching of metals by bacteria or on selective separation of metals by biosorption in the cells of microorganisms. Leaching with bacteria or algae yields lead, mercury, copper, zinc, cobalt, uranium and other metals from the diluted solution. By biosorption, a high concentration of metals in the biomass is achieved, for example up to 20% by weight of uranium, up to 30% by weight of silver. (calculated on dry weight basis). Biometallurgical processes make it possible to extract metals also from piles [25].

Questions 3.3

1. Please describe the basic types of waste produced during mining and mineral processing.
2. Please describe the negative impact of these wastes on the environment.

3.4 Waste from the forestry and woodworking industry

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe the basic composition of waste from woodworking plants;
- state the basic types of waste produced in logging, processing in sawmills, joinery and carpentry, and furniture making;
- state the methods of utilization of this waste.

Lecture

The woodworking plants produce significant amount of solid wood waste, composition of which is as follows:

- industrial edgings and grafts (about 40%)
- sawdust and wood shavings (about 30 %)
- other waste (about 30 %)

Currently, waste from woodworking industry is utilized in different ways. The choice depends on the characteristics of wood, its composition and incidence. Energy recovery, feedstuff and biochemistry are the most important areas of utilization of waste produced in wood processing. The areas can mutually overlap. Waste fibrous materials are treated and processed to wood-fibre materials or certain types of pulp, cardboard or paper. Sawdust are suitable raw material for some chemical and biochemical production.

In **logging**, wood waste is produced directly on-site and is represented by treetops, branches and trunks of diameter less than 7 cm, pruning products, stumps, barks, and leaves. If a special machinery is possible to use directly on the site of wood waste production, the wood matter can be treated and processed into chips, which can be further used in different ways (production of pulp, fuel, particleboards, etc.). In addition to wood fraction, the forest chips contain also a portion of bark, assimilation organs (leaves, pine needles), infructescence (of cones), and mechanical impurities. The proportions of these components in the forest chips vary depending on the type of logging, season and other factors.

Therefore, some methods of technological utilization of forest chips require their sorting. For example, extraction of essential oil from tree green requires sorting only this fraction. The green foliage may be used also for production of chlorophyll paste, vitamin feed meal or pellets. If no chipper is available, the wood waste is usually incinerated.

Sawmill production consumes the largest volume of round logs. They are processed into treated and untreated cut timbers, sleepers, dimension timbers, prisms, etc. The products of this industry are the intermediates for further processing or the final products, especially in construction industry, mining, but also in road construction. Woodworking plants and sawmills produce a large amount of bark. It is used mainly in composting as a substitute for peat and a covering substrate.

The waste from sawmills amounts about 35% of processed materials. They include mainly end-cuttings of round logs, splinters, sawdust, and timber cuttings. The sawdust are a specific type of wood waste that is produced in longitudinal and transverse cutting of wood. Their small size is typical – usually from 3 to 7 mm; they contain a high portion of wood dust. Their sorption capacity is high; therefore, they can be used, for example, for local leakage of petroleum products, soaked sawdust are then incinerated. They are also suitable for the production of biological briquettes or pellets.

Shavings, cuttings and boards are usually valuable in terms of energy, if not contaminated with harmful substances (glues, varnishes). Otherwise, they have to be incinerated together with other hazardous waste from wood impregnation in facilities intended for hazardous waste disposal.

The **production of veneers** is also very important field of woodworking industry. The field is characterized mainly by the production of agglomerated products – the common name of particleboards and wood-fibre boards – that can be further classified according to technical parameters. They are used primarily in the production of furniture, in construction industry or joinery/carpentry.

Waste from **joinery and carpentry production** (production of windows, doors, doorframes, roof structures, family houses and cottages, assembly elements) mainly consist of wooden boards, planks, splinters and sawdust. Majority of waste is incinerated directly on-site; chemically preserved and treated wood is transported and processed into, for example, an alternative solid waste (e.g. ASA's production line for alternative fuel in Brno produces alternative fuel under trade name ASAPAL from various types of incinerable waste including wood waste).

Furniture and home accessories making as well as the timber industry have a long tradition in the Czech Republic; these industries use much of domestic raw materials. The field of furniture making includes production of sitting furniture, furniture for offices and shops, furniture for population, kitchen furniture, and production of mattresses [24].

Questions 3.4

1. Please describe the basic composition of waste from woodworking plants.

2. Please state the basic types of waste produced in logging, processing in sawmills, joinery and carpentry, and furniture making.
3. Please state the methods of utilization of this waste.

3.5 Waste from the production, processing and use of paper and cardboard

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- state basic raw materials for paper production and methods of their manufactures;
- describe the types of waste from production and processing of paper and the possibilities of its recovery;
- explain the possible negative effect of waste from production and processing of paper on the environment.

Lecture

Pulp, semi-pulp, waste paper, wood pulp, and textile pulp (sometimes) are the basic raw materials used in paper production. The **paper** is a cohesive layer mainly of plant fibres of areal weight up to 150 $g \cdot m^{-2}$. It is formed by combining individual fibres through secondary bonds. The fibres that are in an aqueous suspension after mechanical treatment are dewatered and dried on a paper machine.

The **pulp** (or cellulose) is a pulp produced chemically from plant raw materials containing incrustation substance residues, in addition to the cellulose. Lignin and other substances accompanying the pulp that are contained in the wood mass dissolve through the application of suitable chemicals in production of pulp.

Various kinds of deciduous and coniferous trees are used for pulp production today. The wood has to be debarked first and chopped into chips of required size (length: 10–30 mm, thickness: 2–5 mm). The chips are poured on piles of high 15–25 mm where they must be stored for six weeks in order to the resins degrade through spontaneous warming. Then the chips are passed to the boiling process. The production of pulp depends on chemicals used for boiling solution: The basic categories are sulphitic (acidic) processes and alkaline processes, both of them can be further categorized. The production of pulp results in waste liquor of calorific value of 5.5 to 8.4 MJ · kg^{-1} that can be recovered by incineration in special boilers. The Table 7 shows the basic characteristics of sulphitic waste liquors [24].

Table 7 Characteristics of sulphite liquor

Parameter	Value
Water content [% by weight]	47.31
Ash content [% by weight]	7.02
Total sulphur [% by weight]	2.87
Calorific value [MJ · kg^{-1}]	8.05

Paperboards and cardboards differ from paper by larger areal weight. The paper with areal weight 150 – 250 (400) g·m^{-2} is referred as a cardboard. The paper with areal weight from 250 g·m^{-2} to thousands g·m^{-2} is referred as paperboard. This range is not exactly follow neither in the Czech Republic nor abroad.

Cardboards and paperboards may contain one or more layers. Single-layered cardboards and paperboards are produced in a single-pulp layer directly on a sieve of paper machine. Multi-layered cardboards and paperboards are produced from multiple layers with the same or different pulp composition, or different colour. They are produced either through combining several layers from individual sieves by compression under wet conditions, or through gluing several layers of finished paper or cardboard outside the paper machine.

Waste from the paper industry includes various paper sludge and bark of tree. When processing paper and cardboard, mainly cuttings, remains and waste from printing are generated. The largest production of waste paper is from the use of paper and paperboard (used packaging, printed materials, waste coloured paper, maculature, paper plates, waste from roof cardboard, photographic paper, paper oil filters, etc.).

Almost all sectors of activity (production and processing of paper and paperboard, chemical industry, filtration processes, printing, photoengraving, bookbinding, production and use of photographic materials, reprographics, trade, production and processing of roofing felt, construction, car repair, administration, municipal sphere, etc.) are a source of this waste.

Waste paper may endanger the environment, if it is contaminated with harmful substance that, when landfilling, may be released through leaching, or may produce excess amount of undesirable emissions during incineration. The presence of these pollutants also reduces possibility of waste paper recycling.

Waste from the paper industry can be composted, energy recovered or landfilled. Waste paper and paperboard is normally processed as secondary raw material in production of newsprint, cardboard, packing paper, insulating materials, wallpaper, furniture, horticultural containers, packaging, and crates. This requires a strict sorting of waste paper in accordance with the standard (CSN 501990) for further potential applications; however, any class may not contain impurities.

Waste containing these impurities or various harmful substance (laminated paper, toilet paper, tarpaper, cardboards, containers with aluminium foil, carbon paper, paper harmful to health from medical facilities, oil filters, etc.), based on the impurity character, are composted, incinerated or landfilled where necessary [26].

Questions 3.5

1. Please state basic raw materials for paper production and methods of their manufactures.
2. Please describe the types of waste from production and processing of paper and the possibilities of its recovery.
3. Please explain the possible negative effect of waste from production and processing of paper on the environment.

3.6 Waste from the leather industry

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe methods of leather and hides working and name the waste materials generated in this process;
- describe negative effects of liquid waste (in particular) from leather processing on the environment;
- name the treatment methods for this waste.

Lecture

A whole range of waste, whose recovery or disposal is problematic and expensive, is generated during initial processing of raw materials in leather and textile industry.

Many mechanical, chemical and combined methods are used for initial **processing of rawhides and hides** (hide/skin is the upper layer of animal bodies) to usable raw material – leather for production of footwear, personal protective equipment and tools, gloves, clothing, belts, sealing bags, haberdashery, etc. Before further processing, rawhides are firstly preserved, and then soaked in lye, dyed, lubricated and further the leather is finally shaped for the above production.

Many waste baths from preservation, leaching, decalcification that contain impurities of many chemicals partially consumed in the process are produced; new chemical compounds are formed in them; they are also contaminated by waste from rawhides; environmental risk of these baths is very significant because of high content of acids, bases, metal salts (Cr, Zn, Al), dyes, tannin pigments, fats, oils etc. The largest amount of such waste materials are concentrated in the wastewater; there are also high concentrations of hardly biodegradable surfactants. Produced waste are mainly hazardous waste.

Tanneries and dry hides processing, production and processing of leathers, production of footwear and other leather goods, discarded footwear and leather goods are the source of waste. Discarded leather goods also become a part of municipal waste. Environment risk of waste from the leather industry and waste of leather and hides is very significant due to their diversity and content of chemicals and chromium.

From the ecological point of view, waste fats from tanneries and waste of pelts and waste of leather non treated by chrome tanning are the least hazardous; other waste from leaching and leather chrome tanning are hazardous because of content of ammonium salts, sulphides, chromium salts, dyes, sulphide lubricants, boron compounds, organic and inorganic acids, oxalate, oils, barium salts, and surfactants, content of pathogenic organisms is problematic too. Presence of chromium salts in waste sludge and wastewater poses a risk of oxidation to toxic and carcinogenic hexavalent chromium during water treatment.

The amount of waste produced by leather industry and its quality depends directly in the technological process of rawhide leaching. Currently, most of tanneries deposit their waste of tanning leathers on landfills; other waste from production is being chemically treated to eliminate hazardous properties and toxicity and to be possible to use in other technological processes or to be disposed in appropriate and no expensive way.

The main problems in the area of waste in the leather industry is the use of landfilled stocks of leather treated by chrome tanning, which can be processed as follows:

- to use small particles as filter material for gas purification;
- to treat by alkaline hydrolysis using calcium hydroxide or magnesium oxide, where the solid tanning waste is converted into water-soluble proteinaceous substrate readily separable from chromite complexes;
- to treat by acidic hydrolysis, which, however, has not too worked; proteinaceous hydrolyzate and chromium complexes cannot be easily separated, as chromium compounds are very soluble in water;
- to treat by enzymatic hydrolysis that is practised in the USA and Denmark; in the Czech Republic, the technological process was being developed in 1994 and 1995 by

grant principal investigators (Langmaier et al., 1995) – the gelatinizable fraction is obtained in the 1st reaction stage; in the next stage, the remains are exposed to the mixture of alkaline agents with addition of proteolytic enzyme and the waste from chrome tanning is subsequently fully degraded. The mixture is hot filtered forming the protein hydrolyzate (can be composted or used as an additive of fodder mixture) and the filter cake (can be re-used to prepare slurries for leather tanning).

Chromic waste (shavings) and ashes from shaving incineration have composition similar to chromic ore and can be leached with success in the solution of 6M H2SO4 at the presence of oxidizing reagent (preferably CrO). Recovery ratio of chromium is 95–98%. The resulting leachate with a high content of heavy metals is neutralized with whitewash or limestone; the solution is purified from the sludge, 6-valent chromium is reduced to 3-valent chromium by addition of wood sawdust in H2SO4 to form alkaline chromium sulphate, which can be dried and re-used for preparation of tanning bathes. Cr(OH)3 is also possible to precipitate from the solution; this compound is suitable for the production of pigments, dyes and other chromium compounds.

Shavings from chrome-tanned hides can be used to produce adhesives for textile and paper industry, or in a mixture with natural rubber and styrene-butadiene rubber latex for production of leather substitutes. The protein hydrolyzate is used as a levelling agent in the production of laundry detergents. Waste leather and leather products can be used to produce durable coatings and films, rubber composites for the production of sports goods or leather imitation after crushing and other treatment.

Pyrolysis of tanned waste is performed at the temperature of 500–600 °C without media containing oxygen (air, water vapour, carbon dioxide). Under these conditions, the tanned waste practically become only carbonized and the organic matter is not incinerated to carbon dioxide. If the pyrolysis forms the first stage of thermal treatment, the volume of combustion gases in the two-stage incineration unit is about half. It will then positively reflect in the size of the equipment needed for the purification of flue gases.

The second stage of thermal processing is performed at the temperature of about 1,200°C under atmospheric oxygen. In this case, the combustion gases as well as carbonaceous ash generated in the first stage are incinerated. At temperatures above 1,200 °C, no more undesirable oxides of nitrogen are formed. The products of incineration are cooled and the heat is usually used to heat water.

The thermal processing of tanned leather waste is often applied in practice. Industrial waste incineration plants are mostly used. Pyrolysis stations processing mainly tanned waste are also operated. The advantage of pyrolysis is the concentration of heavy metals in a solid residue. Leaching of these metals is small compared to the process of incineration [24][25][26].

Questions 3.6

1. Please describe methods of leather and hides working and list the waste materials generated in this process.
2. Please describe negative effects of liquid waste (in particular) from leather processing on the environment.
3. Please state the possible treatment methods for this waste.

3.7 Waste from the production and processing of textile materials

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- name the type of waste generated in the textile industry;
- describe contaminants in the textile industry;
- characterize methods used for treatment of textile waste.

Lecture

Textile is a collective term for industrially processed plant, animal or synthetic fibres into yarn, woven fabrics or products made from them.

Textile waste contains:

- depreciated or damaged textile materials;
- waste of semi-finished and finished products from textile production;
- textiles taken out of operation or consumption as a result of end of life, technology changes, quality requirement and textile quality changes.

Textile waste can be pure, uncontaminated by other impurities or can be contaminated by impurities – then is classified according to the pollutant or the technology, in which it serves.

Textile and clothing industry mainly produce:

- waste uncontaminated by harmful substances such as incoming raw materials, semi-finished products from spinning plants, weaving mills, bad lot batches, cuttings of fabrics, knitted fabrics and yarns;

- collecting textiles – worn clothes and discarded carpets from population, written-off bed clothes and personal clothes from health care, social sphere etc.;
- discarded textile floor coverings and carpets;
- protective textiles – uncontaminated.

These above-mentioned types of textile waste are usually pure, uncontaminated by harmful substances. They can be mostly recycled (reprocessed) to products of equal or lesser aesthetic and other utility value (e.g. reworking of old clothes to geotextiles usable in construction, agriculture, ecology, etc.), or can be incinerated with energy recovery.

The textile waste can also include technical fabric waste contaminated by pollutants according to the technology, in which the technical fabric is installed as wiping cloths, filter materials, protective cloths, etc. The simplest and most reliable method of disposal of this textile waste is its thermal recovery in an incineration plant.

In connection with textile industry decline in the Czech Republic, the production of traditional textile waste from primary production and vice versa production of waste of textile fabric nature used in the production of other technologies have decreased. This determines current change in a ratio of re-processable waste (amount of recyclable waste continues to decrease) and waste amount to be disposed. In addition, the character of waste to be disposed is changing. It tends to have the character of waste that must be disposed by incineration in an incineration plant so at least the energy contained in the waste is recovered (more and more intensive contamination of technical fabrics with contaminants from production technologies of chemical, petroleum and other processing industry).

The amount of textile waste, which are to be disposed, is still increasing. Manufacturing companies of clothing and upholstery industry are not equipped to recycle their waste. In these companies, the foreign costumers supply their fabrics and carry away the finished products, but the waste remain in the Czech Republic.

A significant volume of imported worn-out clothing and subsequent second-hand selling is currently causing an increase in textile collecting waste. In the following years, this problem probably still will deepen. The fact that unsellable part of the second-hand is disposed by incineration outside facilities designed for it or by deposition on non-secure landfills represents the highest environmental risk.

Within a recovery of textile waste, it is possible to be processed or treated using mechanical, thermomechanical and chemical methods. When processing by mechanical methods, the character of waste does not change. After fiberization, the fibres are re-used as a material for the production of non-woven fabrics or rags in the production of paper and paperboard. When thermomechanically or chemically treated, the waste loses its textile character (by chopping, granulating, milling or other non-destructive treatment) or changes substantially (e.g. by hydrolysis or other destructive treatment).

Destructive procedures of disposal or utilization of the textile waste include:

- regranulation and depolymerisation of synthetic fibres waste;
- biochemical utilization (composting, production of fertilisers or feedstuffs) of plant fibre waste – flax, cotton, hemp, etc.;
- other applications, production of ceramics, adhesives and binders, carbonizing to activated carbon.

Uncontaminated textile waste can be re-processed to products, but usually of lower quality. Spinning waste from some operations is returned into production as a part of raw material. After fiberization on tearing machines, the waste of yarns, threads, fabrics, knitted fabrics, etc., is added back as one of the components of processed mixture. Padding, cleaning wool, stuffing and filling materials, polishing and cleaning materials as well as insulating filler of concretes in construction industry are produced from non-spinning material.

Thermal and acoustic insulations for construction industry, base materials, filling materials for the fur, furniture, upholstery and automotive industries, charity and forwarding blankets and pads, insulation pads under carpets and floor coverings, floor coverings can be produced from the regenerated textile waste. Unprocessable residues of the above waste can be landfilled or thermal recovered in incineration plants. Each disposal method has its advantages and disadvantages, pros and cons. Landfilling, seemingly problem-free, has a number of economic and environmental drawbacks:

- is demanding on considerable land take due to the large volume of waste;
- landfill fees continue to rise;
- synthetic fabrics are difficult degradable;
- release of pollutants to air, water and soil.

From an ecological, economic and social point of view, the incineration can be recommended, preferably in small incineration plants directly at the source of waste in textile production, or free capacity of municipal incineration plants of household waste can be used.

Incineration of textile waste has many advantages compared to landfilling:

- significant reduction in waste volume;
- utilization of high calorific value of textile waste (12 to 25 $MJ \cdot kg^{-1}$);
- easier disposal of the incineration solid residue;
- ecological acceptability of the method provided that the incineration plant is equipped with a device for the capture, decomposition or modification of toxic pollutants from incineration (CO, H_2SO_4, SO_2, NH_3, HCl, acetaldehyde, formaldehyde, furans, dioxins, etc.) [23][25].

Questions 3.7

1. Please state the type of waste generated in the textile industry.
2. Please describe contaminants occurring in the textile industry.
3. Please characterize methods used for treatment of textile waste.

3.8 Waste from extraction, processing and utilization of crude oil

Time to study: 2 hours

Objective: After reading this paragraph, you will be able to

- describe processes taking place in crude oil extraction and characterize waste produced in these processes;
- describe the possible waste produced during transport and storage of crude oil and petroleum products;
- describe the negative effects of oil processing operations (petroleum refineries);
- describe types of waste generated by the use of petroleum products, in particular waste oils, and methods of their treatment.

Lecture

Gaseous, liquid and solid waste is generated in any type of handling with oil – from exploratory wells up to petroleum product usage. (It is the waste from drilling and extraction of crude oil, waste from its processing, and waste resulting from the use of petroleum products.)

Oil processing, gas purification and oil refining, transport and storage of crude oil and petroleum products, various industries (e.g. chemical industry, machinery, textile industry, etc.), as well as construction, energy, long-distance transport of oil and gas, petrol gas stations, fuel storage tanks, car repair and fleet maintenance, metalworking, agriculture and municipalities represent source of waste..

Wastes from drilling and oil extraction

Oil pools are opened and extracted using deep drill wells from which the crude oil springs itself to the surface or is drawn. The pumping mainly uses pressure of gases accumulated on the pool top underneath an impermeable layer of rock. Wells drilled for oil extraction pass through various rocks of different hardness and consistency. Drilling is carried out at dry conditions or by so-called drilling fluid. Drilling fluid is a fluid of high density that cools drill instrument and prevents cave in of well parts not cased yet. It is driven into the well from the surface and then is pumped off. Crushed rocks is removed from the bottom and the well is being continuously cleaned in this way. When drilling at dry conditions, crushed stone must be taken up using special vessel with a hinged bottom.

The main contamination sources are as follows:

- contaminated soil from the well and its surrounding (it is rocks drilled out and taken away from the well in oily flushing fluids);
- waste liquid streams from oil extraction;
- additional chemicals and gaseous exhalations of nature gas, hydrocarbons and hydrogen sulphide;
- oil spills at seas as a result of accidents at oil extraction at sea.

Contaminated soil from the well and its surrounding is mostly deposited on leak-proof disposal sites. Waste liquid streams from oil extraction are returned into workout wells at an appropriate place, e.g. through some of exploratory wells, thereby pool pressure is increased.

Waste produced during transport and storage of crude oil and petroleum products

Since the density of marine traffic as the most important form of crude oil transport between continents is increasing, there are fairly often crashes and subsequent environmental damage caused by oil spill. However, flushing sludge and ballast water from tankers, amount of which is significantly higher (80%) represent a far greater problem than the pollution caused by tanker accidents.

Oil pipelines are the most important mode of transport on land. Oil pipelines represent line source of contamination of surface water and groundwater. The contamination is caused mainly by waste sludge on pumping stations and in tanks.

Accidents in road and rail transport can cause a local contamination of groundwater and surface water.

When storage crude oil and petroleum products, they leak from storage reservoirs, tanks and other containers because of the poor condition of storage facilities or improper handling.

Oily sludge generated during transportation and storage of crude oil and petroleum products is granulated or briquetted and then disposed through proper incineration. Oily sludge can be oxidized to form similar products usable for construction and insulation purposes.

In the case of accidents on water surfaces and watercourses, special containment booms or floating barriers that enclose oil spill are used and the petroleum products are mechanically collected in collection containers. Used loose adsorbent materials (sawdust, Vapex, sand, chalk, FIBROIL fabrics) are usually disposed in a hazardous waste incineration plants [23].

Waste produced in crude oil processing

For every million tonnes of crude oil processed in European refineries (capacity of European refineries ranges from 0.5 million tonnes of crude oil per year to more than 20 million tonnes of crude oil per year), the refineries emit and produce:

- 20,000 – 820,000 tonnes of CO_2
- 60 – 700 tonnes of NO_x
- 10 – 3,000 tonnes of dust particles
- 30 – 6,000 tonnes of SO_2
- 50 – 6,000 tonnes of VOC
- 0.1 – 5 million tonnes of wastewater
- 10 – 2,000 tonnes of solid waste

The amount of waste generated by refineries are relatively small compared to the amount of raw materials passing through and the amount of produced products. In particular, the following types of waste are included:

- waste from the petroleum oil refining;
- used filter clays and other filter materials;
- deactivated catalysts;
- coatings and encrustations from storage tanks (rust);
- dust from the air filters;
- contaminated soil;
- other waste;
- various liquid residues and solid or semi-solid waste;
- used refining reagents and chemicals;
- emissions of gases and vapours in oil processing plants, technological processes and storage and handling of crude oil and petroleum products (smoke emissions, dust, soot and mechanical particles, hydrocarbons, oxides of nitrogen and sulphur, etc.);

- refinery sludge (e.g. sludge from treatment of oil-contaminated water, sludge from dewatering and desalting of crude oil, sludge from treatment of cooling and feed water, sludge from raw material and product tanks, etc.).

Refinery sludge can be briquetted or granulated to use in installations for solid fuels or it can be used as secondary liquid fuel. Obtaining of components contained is sludge (sulphuric acid, oil portions, etc.) is a little more difficult. Acid refining wastes can be used in the production of expanded clay (lightweight ceramic sand for adsorption, insulation and decorative purposes).

Decontamination of soil contaminated with petroleum products is performed either on-site by absorption in a suitable absorbent, or by removal of the contaminated layer that is then transported into a secure decontamination area where the petroleum products are degraded by activity of special microorganisms.

The oil contained in a used bleaching clay can be extracted and separated using water vapour or the bleaching clay can be used as filler in rubber processing.

Used catalysts that can no longer be regenerated are processed directly in refinery; if they contain rare metals, they are usually returned to the producer or other specialized companies [26].

Waste produced in using petroleum products

In particular, the waste include heavy organic compounds that are released by the vehicular traffic, the operation of petrol gas stations, the use of solvents and used lubricating oils. The used lubricating oils are a typical example of petroleum products that are returned to the refinery for reprocessing to regenerate their desired properties after exhausting of their utility value. At present day, the complex schema of the used lubricating oils has crystallized into such an effective form that this very effective secondary raw material can be collected, processed and re-distributed to use environmentally friendly, in all stages of the process. However, if the used lubricating oils contain undesirable impurities of other substances or solid contaminants, they have to be incinerated in hazardous waste incineration plant.

Most of this waste contains organic compounds (PCB, tars, etc.), heavy metals and other toxic organic compounds that pose a risk to groundwater and surface water, plants, animals and humans. Motor, compressor and bearing oils, benzine, white spirit and kerosene are the most toxic.

Waste mineral oils are produced by discarding lubricating, hydraulic, transformer and heat transferring oils from operation at the end of their service life due to their contamination with mechanical materials, water, operating liquids or degradation products of original oils and their additives, so that may contain contaminants such as residues fuel and brake fluids, machining fluids, soot, metal particles, dust, paint residues, chlorinated hydrocarbons, PCBs, etc.

Waste oils are toxic to aquatic organisms, as well as to vegetation in high concentrations. Their vapours may also pose a risk to health (they irritate eyes, respiratory tract, skin and alimentary tract). A part of the waste oils is incinerated in cement rotary kilns; a part is exported to foreign countries (540 tonnes were exported in 1997). At present day, small boilers are increasingly used for heating of premises in the Czech Republic, these boilers may use the waste oils as fuel. Current legislation allows such disposal, although environmentalists are concerned about possible air pollution in this way because they are concerned about non-compliance of quality requirements for incinerated oils (they must not contain undesirable impurities, PCBs, etc.).

Waste lubricating greases can be re-used (e.g. to grease the points). If they are heavily contaminated, they are treated through pyrolysis process of thermal decomposition to other useful products or they are incinerated [26].

Questions 3.8

1. Please describe the processes taking place in crude oil extraction and characterize waste produced in these processes.
2. Please describe the possible waste produced during transport and storage of crude oil and petroleum products.
3. Please describe the negative effects of oil processing operations (petroleum refineries).
4. Please describe types of waste generated by the use of petroleum products, in particular waste oils, and methods of their treatment.

3.9 Waste from the chemical industry

Time to study: 2 hours

Objective: After reading this paragraph, you will be able to

- characterize basic inorganic chemical productions and types of (particularly) hazardous wastes produced during their operation;
- know method of reworking and treatment of this waste;
- characterize basic organic technologies and describe types of waste produced from them;
- describe methods of organic waste treatment.

Lecture

3.9.1 Waste from inorganic chemical productions

Inorganic chemicals constitute the most substantial part of the chemical industry products.

The most serious and the most important inorganic chemicals include sulphuric acid, sodium hydroxide, chlorine, phosphoric acid, nitric acid and other chemicals derived from them. They pose a great risk to human health and the environment. Hazardous substances include also some inorganic pigments and their modifications (chrome yellow, zinc and titanium white, etc.).

Waste produced in chemical productions can be divided by state of matter to gaseous, liquid and solid waste.

The gaseous waste may be produced directly in technological production processes (chlorine, hydrogen sulphide, hydrogen chloride, hydrogen fluoride, fluorine, and compounds thereof, etc.) or in power units (sulphur dioxide, sulphur trioxide and nitrogen oxides).

Liquid waste mainly consists of process wastewater. Its contamination depends on type of the production and the technical level of technological process. It is contaminated by organic substances and dissolved and dissolved inorganic substances. It is mainly cooling and process (technology) water. Before discharge into receiving water, they should be always pre-treated on industrial wastewater treatment plant.

The most significant portion in production of chemical represents the production of sulphuric acid. The total annual production in the world is estimated at about 150 million tonnes 0. The sulphuric acid is used the most in production of chemical fertilisers. In addition, it is also used in refining of crude oil, the production of pigments, the pickling of steel, the extraction of non-ferrous metals, the production of explosives, plastics, etc. The sulphuric acid is produced from sulphur dioxide, which is often obtained by the combustion of elementary sulphur. High amounts of sulphur dioxide are generated in the production of non-ferrous metals. When roasting and smelting ores, large quantities of waste gases, in which the concentration of SO3 is so high that they can be used directly for the production of sulphuric acid as a by-product, are generated, Recently, many production facilities for sulphuric acid have been built in metallurgical plant to utilize waste sources of sulphur dioxide, which also have had a positive impact on environmental.

Solid waste from the chemical industry represents also an environmental problem. More than 50% of the total production of solid waste from inorganic chemical productions consist of only a few types of waste: waste gypsum, green vitriol, sodium sulphate, limestone stubs, acid waste from the production of titanium dioxide, waste from the production of soda, carbide lime, clays, sludge from wastewater treatment and purification of brine, etc.

Only a part of waste from inorganic chemical industry is used as a secondary raw material. The remaining part is disposed by landfilling or by incineration with organic matter.

Generally, the procedure of disposal of waste chemicals can be summarized in a few basic steps (as they most often occur in the form of solutions, this basic state of matter is assumed):

a) neutralisation – of acids by bases, of bases by acids, salts are precipitated;

b) sedimentation – settling of sludge, some of the resulting chemical compounds can be subsequently utilized, non-utilizable compounds if they have any toxic properties are incinerated in the hazardous waste incineration plants or deposited on secured landfills [25].

3.9.2 Waste from organic chemical productions

The organic industry includes several basic productions (crude oil refining, petrochemical production, chemical utilization of coal) and the production of special final compounds including intermediates (surfactants, detergents, soaps, paints and varnishes, solvents, flammable monomers for the production of polymer resins, organic dyes and pigments, pharmaceuticals, pesticides, additives for polymers), and the production of pulp and paper.

The organic chemical production is a source of mainly liquid waste, composition of which is often complicated; the waste is also often toxic. Wastewater must be treated especially biologically; however, some types of water are difficult to be degraded by microorganisms. Other typical waste from organic technologies includes finger-like substances and sludge. Their disposal into lagoons has caused enormous problems that are now only very expensive remedied. Current trend is towards incineration of these materials in industrial waste incineration plants with a perfect purification of exhaust gases and slag deposition in landfills of relevant type.

Treatment of different types of the waste from organic production depends on the used technologies. Most of the waste from one production is a raw material for other production. Where the recovery is problematic, the optimal methods of disposal such as incineration in incineration plants (mostly), solidification, cementation, etc. are looking for [26].

3.9.3 Polymer waste

One of the major groups of solid waste are so-called polymer waste. It is a waste from the processing of plastics and a waste from the processing of rubber.

Plastics are polymeric materials (synthetic, semi-synthetic or natural), which are classified as thermoplastics (by heating, they become soft and flexible, when cooled, they again solidify and harden) and thermosets (thermosetting resin). Various admixtures are often added to them in order to achieve specific properties of products (e.g., plasticizers, catalysts, stabilizers, pigments, fillers). The gum elastic is produced by vulcanization of the rubber.

Waste plastics can be generated during the production and processing of plastics (cuttings, rejects), as well as during their usage in various industries (packaging technology, electronics production, mechanical engineering, production of toys, photographic industry, printing, etc.). Waste rubber occurs mainly in the production and use of tyres, footwear, as a part of some discarded devices and equipment (gaskets and seals, belts, cables, hoses, conveyor belts, etc.), floor coverings (carpet, mats, and floor tiles), adhesives, sealants, school aids, protective devices.

The plastic packaging can be classified as hardened plastic waste, which includes a variety of resins, polyesters, foils, polyethylene, hardened moulding materials, polystyrene, toughened paper and fabric, polyurethane, polyamide, hard foam, artificial casings, film and celluloid, PVC, Perspex, polyacrylate, wrappers and containers made of plastic, polyvinyl acetate, polyvinyl alcohol, polyvinyl acetate, epoxide resins, ion exchange resins, polyolefins) and as non-hardened plastic waste (waste softeners, waste from the production and processing of plastics).

The rubber waste includes worn tyres and their scraps, asbestos rubber waste, metal rubber waste, foam latex, rubber granulate waste, waste rubber flour and dust.

The polymeric waste contains various carcinogenic and toxic substances, which may be released into the environment when landfilling or incinerating. It is also characterised by very slow and very difficult biodegradability.

The processing of collected plastic waste depends on several important factors. Individual types of plastics must be sorted and especially they must not be contaminated with harmful substances or impurities of other materials. The polyolefin-based waste (polyethylene, polypropylene) are processed to various consumer goods (parts of electrodevices, tubes, pipes, crates, etc.). The waste of polyvinylchloride bottles can be used to produce drainage pipes, extruded profiles and plates. The mixed waste of PVC and polyolefins are processed to pallets and floor panel for industrial plants. Non-sorted plastic waste are processed as a component of mixture of other materials (dust, wood, aluminium, paper, or paperboard) to partition walls, reels, fence pales, drain pipes, etc.

The plastic waste can be disposed on landfills, but this is not too environmentally friendly because of the difficult and lengthy biodegradation, or in incineration plants, where the energy of waste is recovered, but subsequently the ash has to be disposed and the undesirable emissions have to be captured.

For several years, the research is focused on the production of light-degradable and biodegradable plastics that are degraded by action of different degradation factors (ultraviolet radiation, atmospheric oxygen, microorganisms). These plastics, however, do not meet the functional requirements, which should have.

A reclaim is obtained from the waste soft rubber (V-belts, hoses, conveyor belts, tyres, etc.), which is sorted by possible admixtures (for example textile). At first, the rubber is ground and then is regenerated in different ways (e.g. at the presence of regenerating oils or plasticizers, by action of water vapour, at an elevated temperature and pressure). The reclaim can be used in the production of outsoles and heels, hoses, floorings, gaskets and seals, cable jackets, conveyor belts. Ground waste rubber is also used as a material for surface treatments of sports ground racing tracks. Finely ground waste rubber is used as a filler for rubber mixtures.

Worn tyres are treated by grinding to form ground rubber, polyamide cords and steel. The ground rubber is further regenerated, thereby it become again processable and vulcanizable; however, its mechanical properties are worse compared to the original rubber. This finely ground waste rubber is used as a filler for the normal rubber mixtures, mixtures of thermoplastics and reactoplastics (thermosets), especially of thermoplastic rubbers, further for asphalt materials for road surfaces, concretes and mixtures for the production of bricks [20][24].

3.9.4 Pesticides

Pesticides are chemically or biologically active substances, which are used against harmful animals, weeds and parasitic fungi or mildews that threaten agricultural, garden and forest plants, stocks of agricultural products and foods, industrial materials (wood, leather, and textile), useful animals and man itself.

According to their use, the pesticides are divided:

- insecticides (anti-insect preparations)
- herbicides (anti-weeds preparations)
- rodenticides (anti-rodents preparations)
- fungicides (anti-fungi and anti-mildew preparations)

Pesticide residues from the production include a wide range of liquid or powdered products that cannot be utilized for various reasons. Organic pesticides can be reliably disposed only by incineration at the temperature higher than 1,100 °C, hydrometalurgically or by solidification.

Because waste pesticides constitute a source of risk and environmental hazard, there is a need in the practical management of such waste to develop a systematic collection of these types of waste (e.g. like the collection of pharmaceutical products) in order to avoid their distribution in municipal waste.

3.9.5 Detergents and cosmetic products

This group of waste includes:

- waste detergents (washing powders, cleaners);
- cosmetic products with expired warranty period;

- waste from the cosmetic production;
- remains from the detergent production;
- waste liquid surfactants;
- waste solid surfactants;
- waste softeners and solvents.

Waste detergents, washing powders, cleaners are not regenerated or recycled because the active components are already consumed or so diluted, that regeneration is impossible. The waste from the production or the rest stocks of detergents and cleaners can be used for some less demanding purposes (cleaning and/or degreasing surfaces in the industry etc.).

The waste from the cosmetic production can be used for some less demanding purposes in the chemical industry. This waste can be disposed by physical and chemical methods as well as by thermal disposal with energy recovery.

Phosphates from detergents and cleaners contained in the wastewater (from use of these products) can be precipitated and separated by filtration and decantation; separated sludge can be incinerated or solidified.

Solid waste from the production, distribution and use of detergents, cleaners and cosmetic products, which cannot be utilised for any reason, should be disposed by incineration in an incineration plant. Its landfilling without pre-treatment, for example by solidification, is dangerous for the environment. The organic residues from the production of the above products (plant pomaces) can be successfully composted and the biomass can be returned again into the natural environment.

The effort of activities in the environment and development of detergents, cleaners and cosmetic products is focused on the as high limitation of waste generation as possible, the implementation of environmentally friendly production, the introduction of less harmful, more effective and more easily biodegradable products in accordance with world trends, the establishment of separate collection of discarded products, e.g. like collection of drugs and pharmaceutical products [20][24].

3.9.6 Waste from the production of dyes and paints

The paints are generally materials intended for application to objects for the purpose of their preservation and protection from adverse surroundings effects. They are applied in liquid or powder form with the assistance of diluents (solvents) using various tools; the solvents subsequently volatilize or dry and thus the dye deposit is cured; in some material, it must be cured by so-called baking at high temperatures.

The ecological risk of paints depends on their composition. Each waste generated in the production, shipping, transport, sale and application of paints is a hazardous waste.

The water-soluble paints are the least hazardous for the environment. In addition, the paints soluble in organic solvents are highly flammable, volatile solvents contribute to oxygen effect deepening and sometimes deplete the ozone layer of the Earth's atmosphere.

The importance of the ecological risk of waste from dyes, varnishes and paints is the same. The waste generated directly in the production include waste of individual components, spills of paints, varnishes, pigments and other materials during handling and the matter that is sucked at their disposal, unfit and degraded remains of these materials and containers, tools, equipment and sorbents combinable by them.

Used solutions can be regenerated and recycled, water dilutable paints can be collected, thickened, distilled to remove excess water and subsequently recycled; empty cans contaminated with paints are disposed as scrap metal or incinerated in hazardous waste incineration plant with heat recovery – as well as contaminated brushes and other spraying equipment and textiles [24].

Questions 3.9

1. Please characterize basic inorganic chemical productions and types of (particularly) hazardous wastes produced during their operation.
2. Please state the method of reworking and treatment of this waste.
3. Please characterize basic organic technologies and describe types of waste produced from them.
4. Please describe methods of organic waste treatment.

3.10 Waste from the energy industry

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- characterize types of waste produced in power plants;
- describe the possible procedures of energy waste treatment.

Lecture

The waste from the energy industry includes solid inorganic waste directly related to the process of heat generation and power generation including flue gas treatment.

Characteristic waste of this field includes electrostatic separator fly ash, cinders and slag from coal combustion, energo-gypsum (calcium sulphate), solid reaction products from flue gas treatment, the product of coal combustion in fluidised boiler with desulphurization, product of dry additive desulphurisation method. The waste from the energy industry are important from the view of environmental protection, because they contain various toxic or carcinogenic metals, furans, dioxins and may also be radioactive.

The source of the above waste are combustion chambers and incineration plants for the black and brown coal, lignite, coke, wood (boiler rooms, heating plants, power plants, industrial plants, local combustion chambers).

Most of the waste from the energy industry is disposed by landfilling. The use of ash for other purposes is around 5%. The ash is used throughout in mines for subbases, fillings, remediation, reclamation, etc. The ashes are mainly used in the construction industry in the production of cements (they are added into mortars and plasters), further they are added into concretes, cements, light concretes, concrete light fillings, building elements, tiles, wall tiles, heat-insulating materials, and they are also used in road construction. However, this use is limited by health and hygiene regulations (mainly limit quantities of heavy metals, PCBs, formaldehyde and other toxic substances). From the technical point of view, the most widespread use of the ash is its processing in the production of aerated concrete. The ash and slag can also be used for wastewater treatment where they can help to remove phenols, cyanides, pesticides, mercaptans, etc.

The cinder is used as a construction material in the preparation of concrete mixtures for various types of cinder concrete to produce filling, insulating or supporting concrete elements, in winter road gritting and in off-road and road adjustments. Currently, the most power plants draw the ashes by dry method. The ash and products of flue gas desulphurisation are mixed together, the mixture is moistened in order to the reduction takes place and the handling is improved and the stabilizate is formed. The stabilizate can be used for stabilizing terrain, sealing and closure of municipal waste landfills.

The energo-gypsum is a full substitute of natural gypsum in cement plants, where it is used as an ingredient for cement set granulation. It can be also used in the production of portland cement as a set regulator [20][26].

Questions 3.10

1. Please characterize types of waste produced in power plants.
2. Please describe the possible procedures of energy waste treatment and recovery.

3.11 Waste from mechanical engineering

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- characterize types of waste produced in engineering facilities;
- describe the possible procedures of treatment and recovery of waste from mechanical engineering.

Lecture

In the mechanical engineering, there is many waste metal materials, as well as metallic waste, chemicals and contaminated equipment.

In metalworking, a number of waste is generated: waste of paints, varnishes, solvents, packaging of these products, contaminated textile, paper and metal filters soaked with oil, waste from machining contaminated with cutting and drilling emulsions, waste of these emulsions, degreasers, and packaging of degreasers, etc.

Most of the metallic waste and waste from machining or other working and metal treatment is categorized as hazardous waste due to their hazardous properties (toxicity, carcinogenicity). Since this waste contains non-ferrous metals in different quantities and forms, it is very interesting from the economic point of view. It is a valuable secondary raw material, because it allows recovery of pure metals under far more favourable economic conditions compared to the primary raw materials. The table 8 shows energy consumption for the production of selected metals from ores on the one hand and from the waste on the other hand.

Table 8: Energy consumption for the production of 1 tonne of a metal from the ore and from the waste in kWh.f^{-1}

metal	from the ore	from the waste	Energy saving [%]
Al	65 000	2 000	97
Cu	13 500	1 700	87
Pb	9 500	500	95
Zn	10 000	500	95

The slags can be used as substitute for aggregate provided that they are not leachable and do not become eroded; metal parts of depreciation waste can be re-worked by remelting (scrap iron and other scrap metal); used acidic pickling baths can be neutralized with lime or hydroxides and they are possible to be used in other chemical productions or deposited as sludge on a secure landfill; lead plates extracted during processing of waste lead accumulators can be remelted for the lead; oils, other organic waste and tempering salts (nitrites, nitrates, cyanides, barium compounds) can be further re-processed [20][24].

Questions 3.11

1. Please characterize types of waste produced in engineering facilities.
2. Please describe the possible procedures of treatment and recovery of waste from mechanical engineering.

3.12 Waste from the production, processing and use of glass and glass products

Time to study: 0.5 hour

Objective: After reading this paragraph, you will be able to

- characterize possible waste produced in the glass industry and describe the possibilities of its treatment.

Lecture

Waste from the glass industry mainly include waste materials from demolition of furnaces, blasts of raw materials, glass waste from cutting works, and glass fragments. The wastes from furnaces include ganister bricks and fire-clay bricks, residues of electrically melted refractory materials, remains of magnesite bricks and various sediments.

The glass fragments from the glass industry are added into a batch along with the collecting glass; therefore, they are not the waste under the Waste Act. The glass waste from municipal sphere contains various glass fragments of used glass products, products with the glass components, glass packaging, lighting, etc. Furthermore, they are the fragments of glass products combined with other materials (e.g. metals, plastics, etc.).

The waste from the demolition of the glass furnace is mostly safe; therefore, it is deposited in a landfill. The most frequent and the most efficient utilization of the glass fragments is their re-use in the glass production as a part of the glass batch. The largest amount of waste glass is obtained by separate collection from the population, in which the emphasis is on sorting by colour.

Question 3.12

1. Please characterize possible waste produced in the glass industry and describe the possibilities of its treatment.

3.13 Electrical and electronic waste

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- categorize electrical and electronic waste into groups by product type;
- explain the procedure of electrotechnical scrap processing;
- explain the treatment of plastic and other recoverable parts of electrical and electronic products.

Lecture

This group of waste has various names. Depreciation waste or electronic scrap are often used. It includes:

- heavy electronic scrap;
- office, information and communication technology;
- laboratory devices and medical equipment, cash dispensers;
- household devices: refrigerators, freezers, stoves, washing machines, dryers, microwave ovens, dishwashers, vacuum cleaners, coffee makers, food processors, toasters, irons, hair dryers, power tools, sewing machines, camcorders, hi-fi systems, electric shavers, clocks, etc.;
- televisions, satellite antennas, car radios, tape recorders, radios, tuners, amplifiers, gramofons, CD players, video players, electronic musical instruments;
- non-functional parts and discrete components: television screens, screens of PC monitors, fuses, contacts, contactors, printed circuit boards, etc.;

The electronic scrap contains various pollutants, which negatively influence processability and recycling option. When this waste is landfilled, there is a risk of leaching pollutants by action of acid leachates and landfill wastewater or batteries. When incinerating (as a part of municipal waste), toxic emissions containing heavy metals, dioxins and furans are generated.

The production of electrical and electronic waste can be expected to continue to increase worldwide. The reason is the total development and modernization of engineering, telecommunications (optic cables, digitization), office and computer equipment (computers, printers, copiers, telephones, answering machines, etc.), audiovisual equipment, modernization of households, etc.

The electrical and electronic waste is a valuable source of secondary raw materials, rare metals (Ag, Au, Pt-metal), and energy recoverable components (wood, paper, cardboard, plastics, rubber, sealants etc.). However, the presence of various pollutants adversely affects the possibilities of the waste utilization. Therefore, its sorting by the pollutant content is desirable already in the stage of collection.

When processing electrical and electronic waste, massive structural parts (covers, frames, coolers, etc.) are mechanically removed first, then the discrete components, basic substance components, and components containing pollutants (capacitors with PCBs, asbestos insulations, mercury switches) are dismantled and separated. It is followed by the recycling valuable components and the disposal of unusable portion. Ferrous metals are separated by magnetic separation and are used as blast furnace burden. Copper and aluminium are separated by gravity methods, separation in heavy liquids, melting away and electro-induction separation. Further processing is carried out in metallurgical plants. Rare metals can be obtained after electronic scrap shredding in special shredders through pyrometallurgical, hydrometallurgical, electrochemical and biological processes or a combination thereof [23][25].

The screens are usually crushed; metals are separated by magnetic separation and after luminophor washing out, the mixed glass fraction can be used for example in the production of glazes or the vitrification of toxic and low-level radioactive waste. If the sale of the mixed crushed glass is low, the fraction is deposited on a secure landfill of hazardous waste.

Plastics are used in the production of other materials or are returned to the production of the same plastic or are energy or material recovered (incineration, pyrolysis, chemical processing, depolymerisation, etc.).

Another type of waste from the use of electrical components is waste light sources. Waste light sources include non-functional fluorescent lamps, discharge tubes, and light bulbs. The fluorescent lamps are light source for low voltage. This is a discharge tube filled with a diluted gas and containing a slightly volatile metals (e.g. mercury, cadmium, and sodium), which convert electrical energy into light by means of electrical discharge. The discharge lamps operate at higher voltage with the help of the low-pressure arc discharge (mercury and sodium discharge lamps) or the high-pressure arc discharge (mercury, halide, and xenon discharge lamps). The mercury occurs in a sealed ampoule inside bulb. The bulbs are the light sources, in which the light is produced by heating of tungsten spiral in a vacuum or an inert gas inside glass bulb.

The **fluorescent lamps and discharge tubes** may contain glass, silicon dioxide, tungsten, molybdenum, metals (Al, Ni, Fe, Cu, Mn, nickel-plated iron, stainless steel), luminophor, various pollutants (Hg, Cd, Ba, Sb, Pb, In, Sr, Zh, V, Y). The light bulbs contain glass, putty, copper, tungsten, aluminium, and nickel. Pollutants are here present only in metal form.

Risk of fluorescent lamps and discharge tubes consists in releasing of mercury vapours when they are broken. At the end of its life, waste sources occur most often as a part of municipal waste on the landfills, where not only the mercury may vaporized, but also toxic compounds may be leached.

Recycling of fluorescent lamps is carried out through:

1. Crushing and subsequent sorting of individual components (materials). In this way, up to 95% of yield of secondary raw materials (glass, scrap iron, aluminium, and mercury) can be achieved. The tube crushing is followed by dry sorting (vibrating screens, magnetic and pneumagnetic waste sorting, which is not economically costly, but separated components are below the quality required for their use). Wet sorting (physical and chemical methods) can achieve higher product quality grading, but at significantly higher costs. Unusable components are landfilled after removal of mercury and other pollutants.
2. Disassembling with the subsequent use of the individual components. The aluminium bases are separated from the waste pipes. From the bases, the aluminium is extracted, or they are landfilled; glass after removal of luminophor can be re-used in the production of fluorescent lamp tubes. The yield of secondary raw materials is up to 92%.

The use of discharge lamps is less compared to the fluorescent lamp and thus the production of waste is much smaller. Big differences in sizes and types complicate the treatment and recovery of individual materials as secondary raw materials.

The principle of treatment of **waste bulbs** is similar to the fluorescent lamp tubes. Obtained pure glass and leaded glass are re-used in glass factories; glass containing various additives (tungsten, putty, Al, Ni, Cu, Fe, and Mo) is deposited in landfills.

Waste fluorescent lamps and discharge lamps are classified as hazardous waste; therefore, it can be disposed only on a properly secured landfill of hazardous waste. Only if hazardous properties (toxicity) are eliminated during treatment, it can be deposited on normal waste landfill [23][26].

Questions 3.13

1. How is the electrical and electronic waste categorized into groups by product type?
2. Please explain the procedure of electrotechnical scrap processing.
3. Please explain the treatment of plastic and other recoverable parts of electrical and electronic products.
4. What is the principle of recycling of fluorescent lamps?

3.14 Waste from pharmaceutical productions and health care

Time to study: 1 hour

Cíl: Po prostudování tohoto odstavce budete umět

- categorize waste from health-care facilities into groups by location of occurrence,
- to explain what methods are the most suitable for treatment of pharmaceutical and medical waste.

Lecture

This group of waste includes specific waste, which are generated by activities of therapeutic, diagnostic, hygienic, or research centres. The vast majority of this waste is produced from consumption and application of pharmaceutical products, it is both human and veterinary care in healthcare facilities. Sources of this waste further include laboratories, pharmacies, drug trade and consumers. Very similar group of waste is the waste from the cosmetic production and consumers of cosmetics both therapeutic and decorative.

The waste from the production of pharmaceutical products are represented in less extend. This waste is mostly biologically, chemically and bacterial contaminated; therefore, it is mainly the waste of "N" category.

Healthcare facilities, pharmaceutical production plants, and research institutions produce following waste: waste of photographic material character, discarded packaging paper, glass, metal and plastic, textiles, lamps, electrical waste, metallic waste from discarded equipment, waste from cleaning, waste disinfection and cleaning agents, waste of municipal waste nature, waste from preparing food in hospitals, waste from greenery and the like.

Medical waste differs in composition also within one kind depending on the type and field of activities of the facility in which it was generated. In place of consumption of pharmaceutical products (hospitals, healthcare and veterinary care facilities), packagings of these products, application aids (ampoules, syringes and needles, bottles, spatula, cups, infusion and transfusion sets, bandages), expired drugs, and drugs and pharmaceutical products discarded for other reasons are mostly represented in the waste composition. If the above waste is generated in household, it become one of the hazardous components of the municipal waste (unused pills, unused salves, used bandage material, syringes and needles, e.g. from application of insulin for diabetics, drug and salve packagings, etc.).

In the production plants, laboratories, research and development institutes and similar institutions, there is mostly the waste of production raw materials, solvents, culture media, microbial cultures, laboratory glass, containers of disinfectants, etc. Currently, increasing amount of therapeutic products of foreign manufacture continues to enter on the market of the Czech Republic; their composition, product characteristic and thus characteristic of possible waste are not completely known.

There are many form of drugs (tablets, dragées, drops, injection solutions, capsules, suppositories, salves, etc.) of various composition (galenicals – plant extracts, hormones, vitamins, alkaloids, antibiotics, synthetic drugs, etc.).

From the hygienic and epidemiological point of view, most of the drug components are harmful due to their toxic properties (content of heavy metals, alkaloids, and inorganic and organic compounds) or the possible formation of resistant microorganisms if the unused drugs are discarded into sewer or landfill. Possible contamination of water, soil, uncontrolled source of microorganisms, uncontrolled progress of known and unknown chemical reactions are a serious environmental problem.

In the production, a part of the waste liquid is recovered (solvents, extractants). In some cases and for some products, it is possible so-called reworking – if the product does not meet quality requirements for any reason. "Rejects" from the production can be repeatedly reworked provided that new clinical tests and stability tests are performed, which is time consuming and costly.

With the exception of marcs of medicinal plants and waste of protein character, the best method of disposal of pharmaceutical waste is incineration. Non-recyclable residues of solvents, extractants, chemical residues, sweepings, drug rejects, disposable packagings from incoming raw materials (except glass packagings) are disposed in this way already within the production. Glass containers can be conveniently returned for recycling in glassworks, marcs of medical plants, protein waste and other hygienic biological waste can be composted and returned to soil as active biological material[23][25].

Questions 3.14

1. How is the waste from health-care facilities categorized into groups by location of occurrence?
2. Please explain what methods are the most suitable for treatment of pharmaceutical and medical waste.
3. Please characterize the hazardous properties that pharmaceutical and medical waste show.

3.15 Waste from wastewater treatment plants

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- characterize the types of sludge in process of wastewater treatment;
- list and describe the methods of successive sludge treatment and further processing.

Lecture

Both surface water and groundwater are used as sources of drinking and service water. Untreated wastewater in groundwater and surface water may cause such changes that make treatment of this water difficult. The untreated wastewater has also an impact on river ecosystem. That is why the wastewater has to be treated and purified. The treatment and purification may result in formation of sludge-like waste. Waste is produced in each of technological step of treatment; these steps are mechanical, chemical and biological.

The aim of mechanical treatment is to remove:

- coarse materials on screens and sieves;
- materials lighter than water in grease and oil traps and in settling tanks;
- materials heavier than water in detritus tanks and in settling tanks;
- suspended substances through the filters.

The aim of the biological treatment is to remove organic compounds that are remaining in wastewater after mechanical treatment. The principles are based on the knowledge of water self-purification. Biomass forming as a result of intense reproduction of microorganisms is being removed from the system. Colloidal and dissolved compounds are converted to dissolved compounds that can be separated from water (biocoagulation). Portion of organic compounds is oxidized at the same time; the obtained energy is utilized by microorganisms. Biomass of intensively reproducing organisms forms a biological layer on various carriers (biofilm) or free floating particles.

Biological filters

The device consists of a circular concrete tank with a perforated bottom, under which there are openings for air intake and water drainage. On the bottom, there is a filling material (medium) having a high surface area; wastewater mechanically pre-treated is trickled through this medium. The material is gradually covered by biofilm that is used as cleaning medium. In the trickling biological filters, the biological layer gradually dies and its residues go away from the filter as stabilised humic material.

Activation process

The activation process uses the knowledge that if the sludge is returned to the new batch of wastewater, the process of biological treatment is speeded up. The sludge creates new biomass from the brought organic compounds and its volume increases. The increase of activated sludge is removed from the system and is further processed, for example through methanisation or incineration. It can be also composted or used as fertilizer. Water from the mechanical pretreatment is brought into activated sludge tanks where the activated sludge is returned. This mixture is aerated and mixed. The activated sludge tanks can be mixing or with progressive flow.

Rotary disc reactors

These devices belong to rotary biofilm reactors, in which the layer of biofilm on a rotating carrier is alternately immersed in water. Organic compounds are gradually transported into biofilm that is released into water as a sludge with good sedimentation properties. It is then separated in a secondary sedimentation tank.

Sludges are pretreated in order to change and improve their properties. Two goals are the most important – the sludge stabilization and the excess water elimination.

Sludge from wastewater treatment contains high amount of water – up to 99%. Dewatering during the process is facilitated or even possible only when sludgy changes its structure. Chemical and thermal processes are implemented for this purpose. Chemical preparation of sludge is two-step process consisting of destabilization step and precipitation step.

Generally, sludges from WWTP cannot be further processed and disposed without prior stabilization as present organic compounds begin to degrade resulting in acidic and smelly fermentation right after anaerobic conditions occur. Therefore, the main goal of stabilization (aerobic and anaerobic) is elimination of organic compounds through biochemical transformations, so that unpleasant effects already mentioned are reduced.

Excluding the sludge use for agricultural purposes, water content interferes with other method of utilization. Therefore, the sludge is dewatered prior to subsequent processing. When landfilling, the dewatering is precondition to maintain stability of landfill body.

Raw sludge is first thickened to approximately 5% by weight. This thickening is performed using a thickener (drying beds, ponds, lagoons). Further dewatering (to 25–35% by weight) is performed through so-called machine dewatering. Dewatering equipments include centrifuges, vacuum filter presses, or belt filter presses. Since a mechanical dewatering method can reach maximum 40% by weight of dry matter content, thermal devices (drying) are necessary to use for further treatment. In many cases, mechanical dewatering alone is not sufficient for spontaneous incineration. Water separated from sludge during dewatering contains a high amount of organic compounds, so it must be returned to wastewater treatment plant.

Drying is the evaporation of water remaining in sludge after mechanical dewatering. For endothermic process, the necessary heat must be supplied from outside. Therefore, low-cost operation is decisive criterion for construction of such facility. The required level of drying depends on the purpose for which the sludge will be used. Working temperature of drying ranges usually between 120–170 °C, but odour nuisance is not excluded. Degassing of contained compounds increases with increasing temperature. Compared to coal, sludge shows the ash content up to five times higher and the calorific value significantly lower (9 – 12 MJ/kg) [23][26].

Sewage sludge is most often processed by composting or as an addition to the feed mixture in biogas plants (see Chapter 5.1).

Questions 3.15

1. Please characterize the types of sludge in process of wastewater treatment.
2. Please list and describe the methods of successive sludge treatment and further processing.

3.16 Waste from agriculture

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe activities of animal and crop farming;
- list and characterize types of waste produced in animal and crop farming.

Lecture

Waste from agriculture consists of waste from primary agricultural and horticultural production.

Waste from animal farming

Livestock farming, slaughterhouses, meat processing industry, fish and game processing, and feathers processing are the source of waste. The following barnyard manures are produced in livestock farming (cattle, sheep, pigs, scratching and water poultry):

- ***muck*** – a mixture of litter, solid excrements, urine, water, feedstuff remains and small quantity of substances used in stabling, for example to treat animals, disinfestation and disinfection of stable rooms;
- ***slurry*** – liquid mixture of solid excrements, urine, process water that may contain undesirable impurities of feedstuff remains and substances used in stabling;
- ***manure*** – an organic fertilizer resulting from muck ageing in a manure pit;
- ***liquid manure*** – a mixture of livestock urine and water.

When fermenting correctly, the muck (manure) is valuable fertilizer for agriculture. Controlled fermentation with capturing and use of biogas generated is another utilization of the muck (manure). The slurry produced in operations without bedding materials is used for biogas production at anaerobic stabilization and subsequently as fertiliser in agriculture.

Crop farming

In the crop farming, there is a substantial amount of biomass that is necessary to be further processed or removed after obtaining products. In the Czech Republic, waste mainly consists of straw, residues of various haulms, beet cuttings, maize stems, waste from grain cleaning, etc. The most common way of utilization of vegetable materials is feeding either in fresh state or after ensiling or processing to a feed meal. Waste which are not suitable for feeding are mostly treated by composting (see Chapter 5.1). The straw is a valuable by-product used as an organic fertilizer or feed. In recent years, energy use of straw is coming to the fore. In addition to biomass, other waste may be produced in the crop farming; this waste may have hazardous properties and it must be handled in accordance with this fact.

The main hazardous waste from crop farming is:

- waste from seed dressing (treatment) with mordant residues containing Hg
- plastic and paper packaging contaminated by seed mordant containing Hg
- remaining reserves of inorganic agrochemicals containing heavy metals and toxic elements (Cu, As)
- remains of organic pesticides and other agrochemicals

Methods of treatment of these types of waste are not systematically solved in the Czech Republic; for example methods for incineration of remains of treated seeds and their packaging in an incineration plant specially equipped with device for capturing mercury vapours are known.

Other waste produced in crop farming that can be considered as incinerable is for example: sunflower hulls, cotton hulls, rice hulls, straw dust, molasses, fruit stones, malt draff, etc. [25]

Questions 3.16

1. Please describe activities of animal and crop farming;
2. Please list and characterize types of waste produced in animal and crop farming.
3. What are the methods of processing of selected agricultural waste, both from the crop and animal farming?

3.17 Waste from food industry

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe types of waste from selected food productions (sugar industry, meat processing, dairy production, production of beer, wine and alcohol, etc.);
- suggest suitable methods for processing of wide range of food waste.

Lecture

Most of the waste from the food industry can be used either directly as fodder or as a raw material for production of feedstuff, fodder mixture or fertilizers. A part of waste is wash down into wastewater – that is why food factories operate also wastewater treatment plant.

Problematic waste include some food raw materials containing heavy metals and PCBs over limit (milk and dairy products, animal fats), biotechnological production waste containing residues of antibiotic, and wastewater with high content of nitrates, nitrites and sodium chloride.

3.17.1 Sugar industry

The following by-products are generated in the production of sugar:

- beet roots separated by beet washing are processed to sugar or used as a feedstuff;
- molasses (saturated solution of sucrose containing various organic compounds), which is used as feed or for the production of yeast, alcohol, citric acid, etc.;
- beet pulps (pressed beet pulps) are treated to very valuable fodder;
- carbonation mud (the mixture of water, calcium carbonate, potassium, nitrogen, phosphoric acid, sucrose and organic compounds) is used mainly as a fertiliser for the neutralization of acidic soils, is added to combined fodder, etc.

Due to the wide possibilities of use of the above products, they cannot be considered as waste, but as very valuable raw materials.

3.17.2 Meat processing

Today, the technologies literally waste-free are used for meat processing. The by-products are used as a raw material for other production as follows:

- the hides are processed to leather in tanneries or used in the production of collagen and gelatine;
- the horn (hooves, horns, cloven hooves) are the raw material for the production of protein hydrolyzates, fodder mixtures, hoof oil, etc., bristles and horsehair are used in brush manufacturing plants;
- the greases (pork lard, beef tallow, content of grease traps) are a raw material in meat industry and fat manufacture;
- the offal (kidneys, livers, tongues, head meat, etc.) are processed together with the meat in meat products; as frozen are supplied for sale or used for pharmaceutical purposes;
- the blood is used in meat products, canned food or also to feedstuff;

- the intestines are used as packaging for meat products or in the production of catguts and for sewing leather;
- the content of digestive tract is composted;
- the glands are used in pharmaceutical industry to produce drugs;
- from the bones, gelatine, bone meal, or fertilizers are produced;
- the feathers are used as a filling of bed clothes, to produce nitrogen fodder, or lightweight building materials.

The internal organs, head and meat unfit for normal consumption (unsafe food) are disposed in accordance with the provisions of the Act on veterinary care in rendering plants.

3.17.3 Dairy industry

The by-products from the dairy industry (buttermilk and whey) are also perfectly usable. Only the centrifuge sludge can be called waste; this sludge contains various mechanical impurities (fur, feedstuff, bedding, dust) and may be contaminated by pathogenic germs, and that's why it is disposed in rendering plants or incinerated.

3.17.4 Production of oils and fats

The products are generated by pre-treatment of seeds and fruits (e.g. peeling); after grinding, they are used as fodder or added to building materials. After pressing or extraction of oil, the oil-cakes and extracted groats are used as valuable animal feedstuff. The lecithin is obtained from hydrate slurry. The soap sludge contains soap solution, oil and various impurities. It is used to produce soaps, detergents, biodiesel, etc.

3.17.5 Fruit and vegetable processing

The most important by-products are pomaces and marcs from fruit juice pressing (mainly apple juice); the marces can be used as fodder or in the production of apple pektin and dietary fibre. The fruit stones and kernels are extracted and the resulting oils are used in the pharmaceutical and cosmetic industry; the residue is used as fodder. Shells of kernels can be used as building material filler.

3.17.6 Production of beer, wine and alcohol

The following by-products are generated in the production of malt and beer:

- the malt sprouts are used in the pharmaceutical industry or as an ingredient in feedstuff;
- the malt draff is used as fodder;
- the hops draff cannot be used as fodder because of content of bitter substances; that is why it is used the most often to loosen the soil, for composting or is incinerated;
- the bitter slurries and foam covers are used for composting;

- the brewer's yeast is a raw material for the production of dietitian, in the cosmetic and pharmaceutical industries or in the processing of fodder;

The by-products generated in the production of wine (stems, rapes, seeds, yeast lees and tartar) are re-used through incorporation into soil of vineyards, in the food industry or as ingredients in animal feedstuff.

The molasses spent wash from the alcohol production are used as a raw material in the production of potash (potassium carbonate), stillage coal, yeast, as well as animal feedstuff or fertilizer [23][24].

Questions 3.17

1. Please describe types of waste from selected food productions (sugar industry, meat processing, dairy production, production of beer, wine and alcohol, etc.).
2. Please suggest suitable methods for processing of wide range of food waste.

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4 METHODS OF MATERIAL RECOVERY OF SELECTED TYPES OF WASTE

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- explain the concepts of recycling and recovery of waste;
- characterize both of the processes of waste material recovery.

Lecture

The basic procedures of material recovery of waste include **recycling and regeneration**.

Recycling is a procedure of treatment of waste materials, wherein the waste material is utilized by an appropriate technology for the production of recycled products. Therefore, the waste is used as a secondary raw material. The recycling can be distinguish by several points of view. Primary recycling is a process by which a raw material or a product that has the same or similar characteristics as the original material or product is obtained from the waste. For example, metal waste of cast iron is used in the metallurgical industry as a substitute for the primary raw material.

Secondary recycling is a process by which a material or a product that has significantly different characteristics compared to the original material or product is obtained from the waste (e.g. processing of PET into polyester staple). With respect to the process character, we distinguish physical recycling, where a new material is obtained from the waste only by physical means (recycling of glass fragments). Chemical recycling is characterized by chemical decomposition of the waste into low-molecular compounds, from which a new material is obtained through chemical processes. Polymeric waste is often chemically recycled.

From the organizational point of view, recycling can be performed by:

- a producer of waste
- a purchaser of waste that uses the waste
- waste is partially treated by a waste producer and a purchaser of the waste the processing completes

- recycling technology, which is an independent system of an organization and takes the waste from producers and after its treatment and processing, sells it to a customer as a secondary raw material

Recyclable waste includes waste from productions (cuttings, grinding residues, rejects, remains, etc.) or consumer waste (after use of products).

Regeneration is a process, when the original properties of material that he had have before it has become a waste can be restored through a suitably chosen technological process. For example, the purification of solvents is the regeneration. Used solvents contain impurities (e.g. metal chips, textile fibres, oils, dyes). Regeneration of used solvents is performed as a distillation (mainly steam and vacuum). The obtained distillate has character of the original solvent.

Material and energy resources saving is one of the main conditions of the national economy and is closely related to environmental protection. This policy, however, has not yet been fully respected. Contamination of the environment with emissions, irrational exploitation of natural resources, inefficient use of energies and their dispersion in the environment are caused by the formation of linear production systems failing to respect patterns of closed cycle of substances in natural ecosystems. The need to recycle waste for other human life on this planet has its theoretical justification, based on the laws of thermodynamics and the law of conservation of matter. From these laws, technical and physical limits of the economic and production systems follow. The material can be used without causing some losses. Such losses are necessary to minimize.

The example of paper recycling can make clear that the recycled paper of the same parameters as the paper produced from the primary raw material could have cannot be produced without the addition of primary raw material. This is true for all recycling.

Recycling procedures should be designed so that some components of the waste do not affect negatively properties of new products. The future recycling of products is to be considered already in the design or project preparation. It is necessary to consider the simple removal and possible utilization of the major components of the product.

The economic aspects are important when deciding on recycling importance. Wholesale prices of secondary raw materials are normally set out on the basis of a comparison of utility properties of primary and secondary raw materials. Production costs of recycled raw material are substantially higher than the primary raw materials, so in many cases, the use of primary materials is paid off. The state should supported recycling by other relief for recycled products (lower VAT rate) and at the same time, the use of non-renewable material resources should be burdened by environmental taxes. In the Czech Republic, the material recycling is not currently sufficiently supported. Recycling should be always a measure to improve environmental protection. It should not have higher energy requirements compared to the production from non-recycled raw material and the disposal of waste and should not be a source of excessive emissions. In many cases, the recycling hat to be carried out in cross-industry co-operation. Often, technical standards, which are unnecessarily stringent on control of incoming RAW materials ARE A BRAKE ON DEVELOPMENT OF RECYCLING [20][24].

Questions 4

1. Please explain the concepts of recycling and recovery of waste.
2. Please state briefly the examples of waste material recovery.

4.1 Recycling of glass

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- state basic procedures used in recycling of waste glass;
- state undesirable foreign matter in waste glass;
- state specific selected company and technology used in recycling of glass.

Lecture

In many respects, glass is an ideal material. It is easily recyclable and its quality does not diminish through recycling. In the production, up to 90% of glass fragments can be used. When sorting glass, a great attention must be given to the purity. Mainly porcelain, ceramics, plastics and metals should not be collected together with the glass. It is also important to sort glass to coloured and white. Products of glass industry may consist of sheet and hollow glass. For re-appreciation, it is necessary to separate the coloured glass from white glass. In view of the fact that the most of sheet glass contains colouring metals, it is not possible to be add to containers designated for hollow glass, but only to coloured glass fragments. The production technology of white molten glass differs from the production technology of coloured molten glass. The higher amount of white glass fragments is contained in coloured glass fragments, the smaller amount of glass fragments is possible to be added to the molten glass.

Saving of primary sources of raw materials and energy is the advantage of glass recycling. Quality of glass does not diminish through recycling and up to 90% of glass fragments can be added to the production mixture. Every 10% of glass fragments in the mixture save about 2% of energy. The recycling of disposable glass packaging represents only a second best solution as the glass becomes a waste only when it is damaged or broken. Lifetime of glass enables 30 or more rounds of a bottle.

White sheet glass is the most suitable for recycling. Relatively high purity of material is ensured for it. Such purity cannot be ensured for fragments of white bottles. Although they are carefully sorted before crushing, coloured glass fragment remain among white glass fragments. Then, there will be no choice than, according to the percentage of coloured glass, to decide whether the fragment basis will be used for production of white glass or coloured glass. It is easier for coloured fragments. Bottles are produced in two basic colours (brown and green) and shades. Brown is normally achieved by adding iron sulphide and green by adding chromium compounds. Chromium is very strong colouring component, and therefore the green glass fragments may not be used in large quantities in the production of brown glass (spoiling brown colour by green tinge). A car glass represents a specific field. Although the car glass looks as completely transparent at the first glance, it contains a high percentage of iron and therefore may not be used in the production of white glass.

The bottle crushing must follow strict standard. Only ten grams of ceramic materials, six grams of metal and magnetic waste, one half gram of non-magnetic waste and no infusible material may remain per one hundred kilograms. Prior to crushing, these impurities are removed on the sorting line, equipped with, for example, metal collecting magnets or lightweight materials blower. The glass is then crushed into fragments ranging in size from 3 mm to 2 cm. Crushing of car glass is more complex. The car glass is covered with a protective film that must be removed. Therefore, the glass is pulled through a press, where it is broken and then it is rotated in a threshing drum, until is separated from the bare foil.

Crushed fragments are mixed with other ingredients. This produces the so-called glass batch that is melted down in a furnace at the temperature of approximately 1,460°C. The melt then passes to the production machines where bottles and other packaging are shaped. In the end, the finished products are cooled down in a lehr, pass through the final inspection and are ready to be used.

A piece of non-molten material can remain in the bottle glass. This is the weakest point of the glass packaging, therefore, these defective pieces are rejected by the final inspection and they are returned to the crusher in the beginning of the process. When checking the glasses, shocks occurring on filling lines are simulated. Bottles are then viewed using special cameras that reveal even the slightest impurity in the glass; defective bottles are returned again to the beginning of the production [26].

Questions 4.1

1. Please state basic procedures used in recycling of waste glass.
2. Please state undesirable foreign matter in waste glass.

4.2 Recycling of metals

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- state the location of metal waste production;
- state the possibilities of processing and utilization of scrap metal.

Lecture

The term "metal waste (scrap)" is usually understood as the waste, in which the metal is represented mainly in its pure form, metallic form either alone, or in the form of alloys. The metal waste is useful to further subdivide into steel and cast iron waste and non-ferrous metal waste. This classification is not always possible to do exactly, because metal waste can be quite complex conglomerate of steel, cast iron and various non-ferrous and rare metals with eventual representation of non-metallic fractions. We are talking about complex metal waste in this case.

Metals can be also categorised according to their origin:

- The returnable (production) waste produced in metallurgical production cycle (in steelworks, metallurgical works, foundries, forges, etc.). It also includes slag fractions with high content of metallic metal. Chemical composition of these waste types is usually exactly known and metallurgically, they are more preferred than primary raw materials.
- The manufacturing waste is generated in the actual production of machinery, equipment, tools and other metal goods, i.e. forging, pressing, machining, burning, and further processing of metallurgical semi-finished products. It mainly consists of material residues (cuttings, chips, scales, sawdust, defective parts, etc.) from mechanical engineering in particular.
- The depreciation waste is discarded machinery and their components, liquidated equipment from industrial plants and household, steel structures, car wrecks, electronic and electrical equipment, etc.

Recycling of this waste saves non-renewable resources (metal ores) and energy. The source of such waste is buying up from the populations, separate collection, large scale municipal waste, industrial waste, electrical waste, waste from car wreck disposal, separate collection of metal packaging (beverage cans), municipal waste incineration plants. The collection of consumer metal waste practically does not exist in the Czech Republic, but the magnetic separations of waste treatment facilities provide about 20% utilization of metal waste.

Some production waste has hazardous properties (oiled scales and oiled metal splinters and shaving). Tins and cans must be de-tinned or the tinned metal packaging are processed to reinforcing steel.

The production of 1 tonne of iron from ferrous scrap saves 2 tonnes of coal, 4 tonnes of iron ore and 70 man-hours.

When recycling metal waste, sorting, spraying, pressing, briquetting, cryogenic grinding and other procedures leading to homogenisation and mechanical treatment of metal waste are used. If non-ferrous metals are necessary to be separated from ferrous metals, slitting, burning, melting away, and granulating are used or the hydrometallurgical process (leaching) is used. Non-ferrous metals are non-magnetic [27].

Metal waste is categorized:

- Metal steel waste
- Metal cast iron waste
- Metal waste of non-ferrous metals (mainly cooper, aluminium, lead, zinc and alloys)
- Metal waste containing mercury
- Metal waste of rare metals (mainly with portions of gold, silver, platinum and rhodium) This is particularly the electrical components, rare metal plating, printed circuits and photochemicals (films, bathes of fixer, photographic paper) are also included there.

Questions 4.2

1. Please state the location of metal waste production.
2. Please state the possibilities of processing and utilization of scrap metal.

4.3 Recycling of plastics

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- state the sources of plastic waste;
- list the types of plastic waste materials;
- describe the basic technologies for recycling of selected types of plastics;
- state the specific processing technologies operated in the Czech Republic.

Lecture

Recycling of plastics is generally understood to mean the reuse of plastics on the one hand in production and on the other hand at the end of the useful life of plastic products. The recycling of plastics uses either the material itself or the energy contained therein.

Recycled products are often (but not always) as good and durable as primary raw materials. The point is that thermal, chemical, mechanical and biological processes are degraded during recycling. This can lead to reduced recycled plastic applications. Thus, the properties of recycled plastics may not be the same as those of newly manufactured plastics.

It should also be recalled that the increased use of plastic waste (so-called material recycling) is hampered by the convenience of exporting plastic waste to Asian countries where (logically) labor costs are lower than in the Czech Republic. In addition, Europe is complicating recycling itself with countless regulations. In China, up to 76 % of European plastic waste (approximately 7,3 million tonnes) is reported to have ended up recently. However, the future of exports to China is probably a thing of the past. Theoretically, this could lead either to the near-sighted search for new outlets or to an efficient construction of the recycling infrastructure.

For successful recycling, waste plastics should be sorted as best as possible. So what we throw into the containers goes through further sorting on sorting lines. Whether automated (for example, light reflectance from the surface of materials) or much more often with the help of a human hand. Technologies have advanced, but they can't handle many things yet. The cleaner the waste entering the process, the better the quality of the recycled waste is likely to be. Remember: not everything we throw into a plastic container is recycled. On average only about 30%. Tzv. Single-type waste is crushed and subsequently used to produce new products. Simply said. There are countless possibilities of plastic recycling. Here we look at how PET, Polystyrene and PVC can be recycled.

After throwing your favorite plastic containers into the yellow container, the pickup truck arrives and transports the plastic to the sorting line. Here, teams of relatively qualified employees select on the treadmill everything that does not belong there. In addition, plastics are sorted by type (in the Czech Republic, PET, hollow packaging made of hard plastic, expanded polystyrene and plastic foils are currently most frequently sorted in the Czech Republic). Then everything is sorted, bundled and transported for further processing. What remains can be used for downcycling. This is a method (for example, it is available to Transform a. S. Bohdaneč Spa), when everything is ground and an unsightly secondary plastic is produced. It is usable in the construction industry or for the production of various covers, cable troughs, etc. Downcycling is not very widespread in the Czech Republic and quite often the plastics, which are useless, travel further as TAP (solid alternative fuel) to heating plants or cement plants.

Waste from recycling lines is called discard. It can be 30-50% of the original amount of sorted waste. Incinerators and landfills are not very interested in this material. Further processing is not possible due to the great diversity of these materials. Therefore, it is recommended to sort only those types of plastics that can be processed. By proper sorting we reduce recycling costs.

An important factor is the “purity” of the recycled material. This is important for the cost of the subsequent recycled product. However, it is technically difficult to achieve so-called single species. None of the sorting systems is 100 percent perfect. In addition, the situation is complicated by some manufacturers who still use new, multi-layer, surface-treated and dyed plastics, which have a low recycling capacity. In other words, manufacturers strive to captivate customers with new, even better packaging, whose recyclability is often complicated, if not impossible. A separate chapter of the recycling complications is made of plastics with the addition of a bio component [28].

PET waste is the most demanded plastic commodity. This is generally the greatest interest, and often it is just PET, which is collected from the collected plastic most. It is not a rule, but it is not an exception. Everything depends on the possibilities of the processor. It is said that PET recycling is the driving force of the entire plastic recycling industry.

First, **PET** packaging, transparencies and solid hollow plastics (eg yogurt jars, cosmetics and detergent packaging and other recoverable waste plastics) are removed from the waste pile on the sorting line. The next step is crushing and grinding. The material is crushed into tiny flakes and these are perfectly washed in water. This removes residues of food, beverages, adhesives and other impurities. The washed flakes are melted and a mixture is formed depending on the type, if necessary. This blank is heat treated and pressed into metal molds. Then the recycled material goes to its customer. Some customers are only interested in flakes.

Similarly, for example, plastic films are recycled. They also undergo a milling and crushing martyr to form granules, which are thermally melted and pressed into an endless "sleeve". It is then used to produce bags that you use at home for waste.

PET recycling by spinning

It is a technology that is used in the textile industry. Textile products made of waste plastic are no longer recyclable and when they are exhausted, they are disposed of as normal non-recyclable waste.

The spinning method requires a sorted, chopped, clean and dried PET material as feedstock. This is melted and spinning process. It is the process of converting a liquid substance into a textile fiber.

Bottle-To-Bottle PET recycling

This is a method where new PET bottles are made from used PET bottles. The basic prerequisite (and necessity) is an extremely clean input PET material. It is first carefully sorted, crushed, bathed and dried. This is followed by melting at about 280 ° C. The melt is filtered under high pressure through a ceramic filter to remove impurities. Cooling follows. There is something called the regranulate. A new beautiful PET bottle is blown out of this material again. At present, this method is in decline.

Recycling of PET using microwaves

The idea comes from the soil of the Institute of Chemical Process Fundamentals of the CAS. This technology uses microwave energy to break down PET into individual components. It can be described as follows: it is the principle of depolymerization of polyethylene terephthalate to terephthalic acid and ethylene glycol using microwaves. The process consists in the selective cleavage of the ester bond into the acid and alcohol moieties. The components obtained (terephthalic acid and ethylene glycol) are returned to the process by polycondensation. It is a gradual condensation of monomers and oligomers. Polycondensates are formed. The advantage of microwave PET recycling is that PET does not need to be sorted by color. In addition, not only PET but also polyester fabrics, carpets and PET materials can be recycled in general.

Recycling of expanded polystyrene

The abbreviation for expanded polystyrene is EPS and its average lifetime is around fifty years. The vast majority of expanded polystyrene is air. Only two percent are plastic. For this reason, the transport of polystyrene collected is a challenge. Therefore, briquetting of polystyrene is being used. For recycling to be effective, polystyrene must be well sorted. In principle, stickers, stickers or prints should not interfere. What may matter is colored polystyrene foam. Dyes reduce the quality of the recycled material, which is not of interest. However, it can also be used to lighten concrete, but not all processors can use it.

The expanded polystyrene is crushed and the resulting recycled product is a granulate from which other products are produced. Apparently the best-known is the use in insulating materials.

Polystyrene from construction is problematic. Very often it contains various additives and flame retardants that make normal recycling impossible. The best known retarder is hexabromocyclododecane. And it is said to have carcinogenic effects. Such waste polystyrene is incinerated at temperatures around 900 ° C and it is forbidden by law to throw it into plastic containers. This also applies to polystyrene, which you have, for example, after reconstruction at home in an apartment or house. Currently, methods are emerging that could allow recycling of this problematic material in the future.

PVC recycling

PVC recycling is relatively demanding. That is why much of this plastic ends up in landfills and incinerators. When assessing the possibilities of recycling, additions to the PVC (stabilizers, lubricants, fillers) should be taken into account. Another prerequisite for meaningful recycling is the homogeneity of input waste.

Mechanical recycling of PVC is used, for example, in the processing of plastic windows and similar construction waste. The components are free of other materials (glass, metal). The material is conveyed to a so-called mill, where the waste is crushed to a particle size of about 10 mm. This pulp proceeds to the so-called dedusting device, where the electrostatic separator separates the rubber and PVC particles. The recovered recycled material can be used to reclaim the plastic window frames. It is estimated that up to 40% of plastic windows are made of recycled using the so-called coextrusion method. Recyclate can also be used for the production of technical products by injection or extrusion.

The PVC pipe waste is ground to a particle size of about 5 mm and is used to produce a lightweight middle layer of new pipes. Recycled PVC waste flooring, after treatment with suitable additives, is applied to the middle or bottom layer of flooring.

Chemical recycling cleaves a chain of polymer molecules. The chemical recycling of PVC waste is intended primarily for the recovery of hydrogen chloride and hydrocarbon. The hydrocarbons produced are used either as a chemical raw material or as an energy fuel. This kind of recycling is very demanding [28].

Questions 4.3

1. Please state the sources of plastic waste.
2. Please list the types of plastic waste materials.
3. Please describe the basic technologies for recycling of selected types of plastics.

4.4 Recycling of paper

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- understand the technology of paper production;

- name waste produced in primary paper production;
- describe technology and types of waste produced in recycling of waste paper.

Lecture

The paper is actually a sheet of fibres with a range of added chemicals, affecting the properties and quality of the sheet. The pulp for the production of paper can be made of natural fibre materials by chemical or mechanical methods or may be prepared by pulping of waste paper.

The waste paper is very valuable secondary raw material. From the point of view of waste paper treatment, it is necessary to distinguish easily and difficult processable paper.

- Easily processable paper – normal types of paper containing pulp and fillers and binding agents. The most frequent type are newspapers and magazines, where newsprint contains pulp and pulp trees.
- Difficult processable paper – contains substantial amounts of improving additives, sometimes plastic and metal foils.

In the recycling of paper, it is necessary to take into account quality of the supplied raw material. The raw material include cuttings from printing offices, where colours of known composition, dust, sand, or clips are the only impurities. The raw material includes also paper from collecting centre or even from the container for paper. Anything can be found here. Processing the second raw material is naturally more demanding for a paper mill. Therefore, I will deal with it.

The first step is soaking input raw material and its subsequent pulping. It is carried out in a tank equipped with stirrer. Usually, this is a purely mechanical process. Just occasionally, a small amount of sodium hydroxide ($NaOH$) is added to facilitate pulping (i.e. it reduces retention time of suspension in a tank; thereby it reduces the energy consumption).

The pulping is followed by gross sorting operations. Already in the pulping tank, a rope (called "cop") is usually used to bond spinning impurities during stirring suspension. They include thread, foil, tape, duct tape, etc. The next phase of gross sorting take place at separate devices, which always remove a certain type of impurities.

The sorting uses different densities or sizes of impurities in paper pulp or fibres. Sorters usually work on the principle of straining through sieves with openings (or slits) of such a size that good fibres can (or cannot) come through. Alternatively, the suspension passage through a conical vessel causes a vortex and then impurities of higher density are at the edge of the vortex and the impurities of lower density stay in the centre.

After gross sorting (but also sometimes before it), unpulped fibre rolls are deflaked. This is carried out purely mechanically on deflaking machinery. They are followed by a sorting line where unpulped remains are removed.

After this, there is a removal of very small or soluble impurities (dyes, pigments, fillers etc.) – fine grading operations takes place, commonly called as deinking processes. These usually include flotation or washing. In flotation (usually in the presence of a flotation agent that is a detergent able with one end of the molecule to capture impurities and with the second end to capture air bubbles – i.e. the other end is poorly water-wettable), the suspension of fibres is bubbled with air, which brings the impurities on the surface in the form of a foam that is subsequently removed. The second method is washing fibres. The suspension is diluted with more amount of water and subsequently is concentrated on a filter partition. However, it must be noted that the resulting sludge is very dilute and can be purified just by using a larger amount of energy or chemicals.

Following chemicals are used most often in the deinking processes: NaOH, sodium sulphite (Na2SO3), complexone DTPA, soap, water glass (a mixture of silica and sodium oxides). None of these chemicals does not constitute any environmental threat (when large quantities do not leak, for example at accident – NaOH is a strong alkali, soap and water glass are weak alkalis, sulphite could cause eutrophication of water).

After this sorting, only fine impurities of density close to the density of cellulose remain in the paper pulp suspension. These impurities are usually polymeric materials. If these substances have low melting point (approx. 30–40 1C), they are called stickies. They are ones of the most problematic compounds in paper recycling. They can clog opening of sieve or stick on the drying cylinders (thus reduce heat transfer or cause breakage of paper strip), change the colloidal properties of paper pulp (only soluble stickies), thereby a foam can be formed and fillers in new produced paper may be poorly captured. In addition to the technological problems, insoluble stickies cause formation of spots with glassy aperture in the produced paper. Unfortunately, stickies usually cannot be removed. Only dispersible stickies can be disperse under the visibility limit, thereby the quality of the produced paper is improved.

Dispersion can be performed by chemical processes (but these are not so much used), thermal (heating to the temperature about 150 °C, followed by dispersion), or thermo-mechanical (suspension is heated to the temperature below 100 °C, followed by the mechanical breaking of the particles).

Within the sorting, the suspension itself is separated into fraction of short and long fibres. This separation is still in its infancy and is used hardly anywhere.

After paper pulp purification may (but need not) follow its lightening or bleaching. The lightening consists in masking of the chromophore (color-causing) chemical groups. For this purpose, sodium thiosulphate ($Na_2S_2O_3$) or hydrogen peroxide (H_2O_2) are usually used.

When bleaching the paper pulp, similar procedures as for the bleaching of the pulp produced from fresh wood (i.e. using of chlorine dioxide (ClO2), NaOH, oxygen (O2), ozone (O3), hydrogen peroxide, etc.) are used. From the environmental point of view, thiosulphate is a harmless chemical that may contribute to eutrophication of water at most; however, in the case of accident leakage it can cause one-time water/soil animal kill. It does not have a tendency to accumulate in the environment. Hydrogen peroxide is a very aggressive compound. However, it is very unstable and almost all used amount reacts during normal operation to form water. In the event of an accident, the progress would be similar to thiosulphate (only accident surrounding would not be fertilized). Ozone is a toxic gas even at a low concentration. Chlorine dioxide is the least biodegradable. It is not too hazardous (compared to chlororganic compounds), but I do not know its exact toxicological and biologic characteristics. Oxygen as a strong oxidizing agent may in the case of leakage (i.e. at higher concentrations in the air in the immediate vicinity of the leak) cause burning or burns the respiratory tract (however, compared to the risk of explosion in the plant, this is negligible).

Subsequently, the recycled paper pulp is treated virtually the same as with non-recycled. Various filler, gold sizes, auxiliary paper agents (defoamers, biocides – to prevent slime formation, pH stabilizers or colloidal system stabilizers, etc.), or dyes are added into it. Then it is injected onto a paper machine and the resulting paper then passes through various finishing operations.

The paper is now produced, but the problem of waste remains to solve (only metaphorically – the problem of waste must be resolved before start of operation – as opposed to nuclear power plant) [29].

Questions 4.4

1. Please describe the technology of paper production.
2. Please state waste produced in primary paper production.
3. Please describe technology and types of waste produced in recycling of waste paper.

4.5 Recycling of construction waste

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- name the types of waste generated in various construction operations;
- name the possibility of utilization of construction and demolition waste;

- name the specific technologies for construction waste treatment.

Lecture

Qualification of construction waste is based on the technology of construction, the average age of the demolished buildings and building density. The construction waste from building structure contains rubble and waste materials according to the specific construction. These materials are always in close relation to the construction and may contain topsoil, concrete (possibly with steel reinforcement), brickwork, mortar, gypsum materials, wood, plastics, ferrous and non-ferrous metals, paper, bitumens, and residues of paint and putties. Waste from construction site may include all things falling away in the work place, including waste from remediation of houses and flats.

The construction site waste includes mineral components, wood, steel and non-ferrous metals, plastics, paper, bitumen paperboard, organic residues, backfill waste as well as hazardous waste (paint, varnishes, solvents).

After appropriate treatment, the mineral construction rubble can be used in the following areas: noise walls, backfilling of excavations, base layers of exposed roadways, parking areas and sports facilities, bonded layers of less stressed roads, strengthening of forest and agricultural roads, aggregate for concrete and mortar in limited extend, filler for various construction materials bonded by hydraulic or bituminous binder.

Recycled materials are suitable for backfilling of sewers or gas pipelines, compacted areas, and a number of construction activities. The companies have learned to use the recycled material thanks to mobile devices – recycling on-site – as the recycling economy often depends on transport costs.

Quality of the recyclate depends on technology, on the basis of which the waste being processed, to a large extent. Basically, there are two options on the market: jaw crushers and impact crushers. The jaw crusher press the waste and as the volume decreases, the waste falls down lower and lower until a sort of "ball" is created. On the other hand, in the impact crusher, a drum with blades – knives – rotates against the fixed plate and the material is actually cut. The result is not a ball as in the first case, but sharp-angled recyclate, which is very important for future use. If a certain level of compaction of fill is necessary to achieve, so it is better to use recyclate from the impact crushers. Less amount is consumed and roller and bulldozer are not used so frequent as in the case of recyclate from the jaw crushers. The secret of savings lies in the fact that the sharp-angled grains are locked better as small balls.

Both technologies represent on difference: possibilities of use in different seasons. The jaw crusher working on the principle of pressing material cannot be used in the summer for treatment of, for example, asphalt and concrete bitumen. They can work effectively only when the ambient temperature is at the freezing point. This problem does not occur in the impact crushers, as they do not crush (press), but cut [26].

Questions 4.5

1. Please list the types of waste generated in various construction operations.
2. Please state the possibility of utilization of construction and demolition waste.

4.6 Accumulator recycling

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe technology of electrochemical cell recycling;
- describe technology of Ni-Cd battery recycling.

Lecture

Recycling of electrochemical cell

Basic precondition for recycling of primary electrochemical cells is their separation from the separate household waste or separate collection. Separated batteries are then mostly treated pyrometallurgically (using physical refining processes) in any combination with the hydrometallurgical methods (leaching in acids or other solvents and the obtaining from the solution mainly by electrolysis) and treating processes.

The ***process RECYTEC*** treats unsorted electrochemical cells. Battery mixture is distilled in a continuous pyrolysis furnace at dry conditions at the temperature of 600–650 °C. Volatile components (water, electrolyte and volatile metals, in particular Hg) are distilled out and sublimated. All volatile components are then cooled in the condensation chamber to the temperature of 30 °C. The condensed portion is then divided into three product using a centrifuge. The aqueous phase recirculates back to the condensation column; Hg-fraction is treated as usual and oil and fat fractions are incinerated. The remaining gases are purified in a wet scrubber and by adsorption on active carbon. Heavy metals are removed from wastewater by aluminium cementation (removal of trace Hg); this water is then fed in further stages as a process water or is evaporated. Solid fraction from the dry distillation is cooled and gradually crushed and screened at wet conditions. Fine fraction mainly consists of the manganese dioxide MnO_2 (with traces of graphite, Zn, and Fe), gross class is magnetically separated after dewatering. Non-magnetic fraction is further leached in the solution of tetrafluoroboric acid and the extract is gradually electrolysed to Zn / Cd, Fe / Cr / Ni and Cu / Ag fractions. If sorting is performed at dry conditions, electrodynamic separation may be included, conductive fractions are then treated by leaching, and non-conductive fractions are mixed with fine grain size classes of materials.

The process SUMITOMO is based on a purely thermal treatment of batteries (alkaline, Zn-C and Hg cells). The mixture of cells is continuously dosed into the furnace where it is first dry distillated at temperatures above 500 °C. Volatile metal fractions, especially Hg are eliminated. Subsequently, the batteries in the furnace are exposed to the temperature above 800 °C. Plastics and other organic substances are converted to flammable gases. The solid residue from the thermal treatment in the induction furnace is subjected to a reductive melting at 1350–1500 °C. Metals with low evaporation point passes into a form of metal vapours. Fe and Mn form a slag melt (approximately 35% of Mn and 55% of Fe). Gas from the shaft furnace is burned at temperatures above 950 °C and dusted off. Hg is obtained by condensation. The purified gas is adjusted to a temperature of 40 °C and the residual content of Hg is separated on active carbon.

TNO process for recycling metals from alkaline Zn-Mn and Zn-C batteries is based on purely hydrometallurgical treatment. Batteries are first crushed in a hammer crusher and then sorted on a screen grinder. Oversize product (consisting primarily of steel, copper and plastic components) constitutes about 30-40% by weight and due to Hg content, it is deposited as hazardous waste. Fine fractions are leached in hydrochloric acid and sodium hypochlorite NaClO. The material is then filtered at pH = 3. The filter residue consists mainly of carbon and manganese dioxide. Hg content in the solid portion should not exceed 50 ppm. The filtrate containing Zn and Hg is treated electrolytically and Hg and Zn are removed by precipitation at pH = 10, such as $Zn(OH)_2$.

Such cells that can be re-charged are denoted as secondary electrical cells. When discharging, the chemical energy is converted into electrical energy; when charging, chemical changes occur on the electrodes and in the electrolyte, wherein the electrical energy is accumulated in the form of the Gibbs energy of the reaction products. This group of cells include lead accumulators and nickel - cadmium accumulators [23].

❑ Recycling of Ni-Cd accumulators

In Europe, there are currently three operational technology for complete recycling of Ni-Cd batteries. French technologies SNAM and SAVAM, and Swedish technology SAB-NIFE.

Technology SAB-NIFE A.B. allows to process both open industrial systems and small batteries (button, cylindrical) on two lines. Industrial accumulators are manually dismantled and freed from the electrolyte. Ni plates (containing more than 18% Ni and Fe) are sold directly to the metallurgical works; metallic packaging contaminated with sludge and containing Ni and Cd are rinsed in two stages under sulphuric acid and water, granulated and recycled as scrap iron. The negative electrodes, after rinsing with water, are pyrometallurgical processed in a retort furnace at 850 °C under reducing conditions (to avoid CdO formation). Cd is converted into the gaseous state and is condensed in the condenser. Furthermore, it is refined and sold for the production of Cd plates. Ni-Cd batteries (closed systems) are fed as a whole into a retort furnace and treated at temperatures 400–500 °C in an oxidizing environment that is ensured by slight excess of oxygen. During thermal processing, present plastics are decomposed and resulting fumes are after-burned under oxidizing conditions at the temperature of 900 °C. The combustion products are purified by the wet method. In the second stage, the batteries are distilled under reducing conditions at the temperature of 850 °C and Cd is obtained from the gaseous state through condensation. The solid residue after thermal treatment contains up to 30% of Ni and is further salable. This technology is able to process Ni-Cd batteries as well as sludge and filter dust containing Cd, Ni and Co. Technologies SNAM and SAVAM work on a similar principle [23].

Questions 4.6

1. Please describe technology of electrochemical cell recycling.
2. Please describe technology of Ni-Cd battery recycling.

4.7 Recycling of screens

Time to study: 0,5 hour

Objective: After reading this paragraph, you will be able to

- describe the procedure of dismantling and consequent processing of used TV screens;
- name and characterize specific technology used for processing of TV screens in the Czech Republic.

Lecture

Known recycling technologies for treatment of waste screens are usually based on the diminution and sorting with the eventual inclusion of separation processes. Technology of companies ZUBLIN UMWELTTECHNIK and NOKIA can be a suitable example. After aeration of complete screens and separation of the electronic system in the node of predismantling, the screens are crushed in a hammer crusher. Crushing node is closed and connected to the suction equipment. Magnetic parts are separated from the crushed material on the conveyor belt using a system of overhung magnetic separators. The glass portion is further washed with pressurized water (without added chemicals). The washed glass product passes through the separation node, in which fine-grained sludge fractions, process water, and glass products are separated. Thick-walled screen glass can be separated from thin-walled conical lead glass using a mesh sorter of the Mogensen type. This yields about 90% of low-leaded (unleaded) screen glass and 10% of composite materials.

Process water containing sludge is treated by sedimentation and ecirculated into the process. The settled solid phase is dewatered on a belt filter and can be landfilled as a hazardous waste or further processed. Regarding the granulometric composition, the material is relatively fine-grained (about 98% of the grains – 100 μm, of which about 50% below 20 μm). The material of grain size below 20 μm concentrates a majority of elements contained in the screen surface layers (Eu, Y, and Zn), the cone (Fe) and reflective layer (Al). Suggestion of further processing of the fine-grained fractions is based on this finding. They are processed by gravity methods and through flotation. The material is first intensively wiped in matrix unit for 30 minutes and is hydraulically sorted in a hydrocyclone, whose parameters are set so as the separating size of grain reaches 20μm. Both products of sorting are let to settle and subsequently filtered in disk filters. The resulting products consist of the glass fraction (discharge from the hydrocyclone) that is recyclable without problem in glassworks due to convenient contents of Y and Zn and the fine-grained fraction with concentrated amount of Y, Eu and other elements; this fraction can be deposited or further treated by flotation in order to obtain luminophor concentrate [30].

Question 4.7

1. Please describe the procedure of dismantling and consequent processing of used TV screens.

4.8 Recycling of fluorescent lamps and discharge tubes

Time to study: 0,5 hour

Cíl: Objective: After reading this paragraph, you will be able to

- describe the known treatment processes for waste fluorescent lamps and discharge tubes.

Lecture

Recycling technology can be divided into two large groups: complete crushing followed by separation and gradual (controlled) destruction with continuous separation.

The process KÜHL – intact VSZ (discharge lamps) are manually fed into a shredder and after shredding, they are manually fed into a demercurizing furnace. After filling, the furnace is gas-tight closed and the material is thermally treated at 520 °C. The resulting Hg vapours are condensed in a cooler; the air from the furnace is purified by adsorption on activated carbon and is returned back to the furnace. The line is complemented by three-product sorting. The coarsest product made of large metal and glass particles and the medium-sized product (fine glass and metals) are recyclable or can be deposited on solid household waste landfills. The finest fractions (-0.1 mm) consisting of luminophores and glass dust must be deposited at landfills for hazardous waste (due to the content of Sb). Sorting can be placed just behind a shredder, so only the finest fractions are demercurized.

Processes MRT and OSRAM – in the first stage, discharge lamps are sorted by type and length. In the next node, the end of tubes are cut off and luminophores are blown out by compressed air. Hg-bearing wastes are filled into special containers (120 l) and are distiled in vacuum at the temperature of 400–600 °C and at the vacuum of 10 mbar in an inert atmosphere. The organic fractions are burned in the post combustion chamber at the temperature of 850 °C in an oxidizing atmosphere. Hg in the form of vapour is condensed in the cooler; residual contents of Hg are adsorbed on activated carbon. Purged tubes usually are not completely freed from luminophores and they have to be post-treated after shredding.

System KUSTERS – waste discharge lamps are introduced into the crusher. After the two-stage shredding, the shredded material is magnetically separated on a drum separator. The non-magnetic fraction is sorted in three-product screen sorter to Al-product, glass product and luminophore. The whole operation is performed in a hermetic system. All products with the exception of luminophore can be further utilized. [31].

Question 4.8

1. Please describe the known treatment processes for waste fluorescent lamps and discharge tubes.

4.9 Recycling of car wrecks

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe the procedure of wreck processing environmentally acceptable;
- describe technology of catalytic converter recycling.

Lecture

Recycling of car wrecks

Major part of technologies today introduced and used is based on the car wrecks shredding in shredders and subsequent separation and sorting. These technologies are designed to obtain three basic products: waste steel, non-ferrous metal and inert remains after shredding that contains a mixture of non-metallic materials (plastics, glass, varnishes etc.) and is landfilled.

The technology of processing car wrecks is a combination of three basic treatment operations – shredding, sorting, and grouping. From the system point of view, the whole technology can be divided into several sub-systems. The Subsystem 1 consists of income car wrecks, the Subsystem 2 includes a storage and the Subsystem 3 includes preliminary dismantling and shredding wrecks. The organization of these subsystems is a very important factor for the following technological operations to run smoothly. In addition to the control of hazardous substance content (fuel, lubricants, batteries, etc.) and their removal, the dismantling of usable components is carried out. The dismantled wreck is shredded in a modified hammer crusher (shredder) in the Subsystem 3. The shredder is connected to a suction equipment (cyclone, wet separator), which ensures the dedusting of process air. Shredding node output varies between 4–70 t/h. In the Subsystem 4 (separation), fine and light fractions of waste are separated in pneumatic separators (mostly Zick-Zack separators). Coarse and heavy fractions are magnetically separated to produce steel waste and mixed fraction of non-ferrous metals. Steel fractions are hand re-sorted (the Subsystem 5) to remove possibly present undesirable objects, such as remains of non-ferrous metals, etc. The fraction of non-ferrous metals contains a residual portion of non-metal impurities (glass, rubber), therefore, it is processed in the Subsystem 6. Here it is separated mainly aluminium and its alloys, non-magnetic steel, and mixed fractions of non-ferrous metals, which can be further treated in pyrometallurgical or hydrometallurgical process [32].

Waste catalytic converter recycling

Hydrometallurgical methods include, in particular, acid leaching of whole pellets or selective dissolution of the noble metals. It is followed by refining of leachate and its processing to a metal, typically by a pressure reduction or precipitation. A pilot operation of the modern technology, using two-stage pressure cyanide leaching followed by precipitation of noble metals from cyanide complexes through pressurized thermal decomposition, has been verified for the batch of weight of 45.3 kg and now it is included among processes for granting permission for commercial use. The main advantage of hydrometallurgical technologies is low consumption of reagents and the variability of the leaching process, in which the parameters can be varied so as to achieve maximum efficiency of retrieval of noble metals in the processing of different types of catalytic converters.

In recent years, the pyrometallurgical recycling methods have focused mainly on the melting with copper as the collecting metal, and the technology of plasma melting, that uses mostly iron as the collector. Pyrometallurgical recycling processes are more demanding from the energy point of view. Moreover, they are actually a combined method of recycling, because the obtained alloy containing noble metals must be further processed by hydrometallurgical methods [32].

Questions 4.9

1. Please describe the procedure of wreck processing environmentally acceptable.
2. Please describe technology of catalytic converter recycling.

4.10 Recycling of tyres

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- characterize the basic methods of recycling of worn tyres.

Lecture

The result of currently used technologies is steel separated from bead bundles and cords, textile and rubber granulate. The weight ratio of these components is approximately 25:10:25. Cryogenic technology is based on a mechanical breakage of frozen tyres; however, the costs of freezing media are very high, so the mechanical grinding in special mills is more common. Steel bundles of beads and cords are processed in the steel industry, textile is probably the most problematic product of recycling – it is separated from the other components by blowing, and therefore it contains a large amount of dust, nevertheless the textile can be used, for example, to insulation and damping plates or as a catalyst for combination of bitumen with asphalt. Separated rubber granulate has a number of utilizations depending on fraction size, its purity and basic material, i.e. type and construction of recycled tyres. High-quality granulate is processed into rubber mixture intended for further processing in rubber industry. This saves a considerable part of both synthetic and natural rubber and other ingredients in the production of new products, and also the production of sorption materials for capturing crude oil leakage into the environment. The granulate is also used to produce floor coverings, damping elements, floor tiles, sports grounds, railway passages, and roads. The least quality part is disposed in incineration plants [33].

Question 4.10

Please state the basic methods of recycling of worn tyres.

Additional references

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5 PRINCIPLE OF WASTE TREATMENT TECHNOLOGIES

5.1 Biological methods of waste treatment

Biological waste treatment methods are applied for waste, which are able to biologically degrade under various process conditions. Biological treatment methods include:

- Aerobic degradation (composting)
- Anaerobic fermentation (digestion, methanation)
- Biological detoxification of hazardous waste (biodegradation)

Many wastes can be treated by biological methods to lose their hazard or even become reusable. These microorganism methods involve a wide range of biochemical reactions, which are controlled by biological catalysts - enzymes. In order for these biological processes to be useful for waste treatment, it is necessary that the microorganisms involved in these processes contain certain enzymes or complexes thereof.

Another necessary condition is the composition of the waste, where substances that are toxic to microorganisms or inhibit enzymatic activity cannot be present. If such substances are present in waste at concentrations that will adversely affect biological processes, biological processes cannot be used. This is one of the most common limitations for the use of biological methods. Finally, for the use of biological methods, it is necessary to ensure conditions in the environment of the treated waste which allow microbial activity (suitable pH, moisture content, temperature and concentration of macrobiotic elements in ranges suitable for the operation of microorganisms).

There is no micro-organism or group of micro-organisms that is universally applicable to all wastes for the biological treatment of waste. Therefore, when using biological waste treatment, it is necessary to choose appropriate microorganisms that are capable of achieving the desired objectives. A number of microorganisms (bacteria, yeasts, molds and lower fungi) can be used for biological treatment of waste.

Despite the fact that a number of biological processes have been developed for different types of waste in the laboratory, in practice biological treatment of waste is used only for a limited amount of waste. The main reasons are economic process parameters and feasibility on a large scale, sensitivity of processes to changes in the composition of feedstocks and low efficiency, which results in a disproportionate increase in investment costs (size of tanks and other equipment). However, biological treatments of waste, despite these shortcomings and difficulties, have many favorable technological properties and sometimes are able to solve problems that are not solvable by other technical means. The great advantage of some biological technologies is that they break down unwanted and dangerous organic substances into harmless products or convert toxic compounds or ions into non-toxic. In fact, they work in a waste-free manner, as there is no need for further modifications or other interventions to remove the resulting products.

Practically, biological methods are used mainly for waste composting, treatment of petroleum hydrocarbon-containing waste, anaerobic digestion of waste with the aim of biogas recovery and for mechanical-biological waste pre-treatment [34].

5.1.1 Composting of waste

Time to study: 2 hours

Objective: After reading this paragraph, you will be able to

- express the basic meaning of composting;
- describe the basic principle of composting;
- state the basic conditions for the proper composting process;
- describe each phase of composting process.

Lecture

The purpose of composting is the decomposition of organic compounds contained in waste and their conversion into stable humic substances. The basic principles of the process are as follows:

- Organic substance decomposition using aerobic microorganisms in the presence of O_2.
- The organic substance and the oxygen are used as an energy source for microorganisms.
- A part of microorganism's carbon binds, a part is released as CO_2.
- Following processes gradually take place: hydrolysis of proteins, carbohydrates and fats; ==> formation of amino acids and monosacharides; ==> heat production; ==> conversion to organic acids, carbon dioxide, protein microorganisms, and ammonia.

Advantage of the composting consist in:

- the composting enables to return original materials into natural food cycles;
- harmful substances are disposed or converted into new materials;
- the volume of waste is reduced up by 30 %.

The purpose of composting is to produce humus substances similar to soil humus and obtain plant nutrients. Produced compost is a stabilized, odourless, brown to black homogeneous mass, with crumbly to lumpy structure, rich in humus substances and plant nutrients.

When organic substances are degraded by microorganisms, temperature increases through so-called self-heating, resulting in:

- faster degradation of organic substances
- thermal disinfection of materiál
- only thermophilic microorganisms survive at increased temperature
- pathogenic organisms are degraded if the temperature is kept at required level for sufficient period
- conversion of organic residues

When composting waste, optimal conditions for microorganism development must be ensured. These conditions include:

- the adjustment of ratio of carbon and nitrogen (C: N) through an appropriate ratio of treated waste
- the adjustment of humidity
- ensuring minimum presence of phosphorous
- the adjustment of pH value
- the adjustment of granulation and homogeneity of substrate
- aeration of substrate
- temperature control during composting process.

In order to achieve the value of the ratio C : N in the range of 25-30 : 1 (good stability and agronomic efficiency) for mature compost, the ratio of C : N should be optimized to values in the range of 30-35 : 1 in the fresh compost. During the compost maturing, a part of carbon is released as carbon dioxide and the ratio of C : N narrows. Waste with high ratio of C: N (wood chips, straw, paper) are more resistant to microbiological degradation compared to waste with low ratio of C : N (see Table 9). Excessive high ratio of C : N in the fresh compost extends its maturing; if the compost with high ratio of C : N is applied into soil, the degradation of compost continues in soil environment, for which the soil nitrogen needed for grown plants is consumed. If the ratio of C : N is low in the fresh compost, the nitrogen content exceeds metabolic need of microorganisms, resulting in ammonia nitrogen losses, extension of maturing period and decrease in productivity of formation of humus substances.

Table 9 The ratio of C : N in compostable biological waste

Waste	C : N ratio
young grass (short cur)	22 - 30 : 1
grass of extensive areas	30 - 40 : 1
old vegetation	40 - 60 : 1
leaves	40 - 60 : 1
green chips	70 - 90 : 1
chips from pruning	90 - 120 : 1
chips from trunks	100 - 200 : 1
bark of coniferous trees	100 - 120 : 1
kitchen waste	20 - 30 : 1
paper	150 - 200 : 1
sawdust, shavings	120 - 200 : 1
rabbit droppings	15 : 1
animal excrements, poultry droppings	8 - 10 : 1
horse manure	15 - 25 : 1
straw	100 - 120 : 1
activated sludge from WWTPs	5 - 8 : 1
contents of kitchen grease trap	180 - 200 : 1

Conversion of organic substances in composting takes place at different phases (phase of decomposition, transformations, maturing).

Mesophilic phase (phase of decomposition/degradation) is accompanied by heat releasing and substrate heating to temperature of 50–60 °C. Aerobic microorganisms degrade cellulose, starch, hemicellulose, proteins and fats to lower molecular compounds; they use released nutrients for their metabolism. Thermophilic fungi are used to degrade lignocellulosic tissues. Intensive formation of organic acids increases acidity of substrate (decrease in pH value). In the process, carbon dioxide is formed through respiration of microorganisms. In the case of excess of nitrogen, the ammonia is released in the compost. Volume of substrate is also reduced. The foundation stones of humus substances are formed. This phase of degradation is also referred as hydrolysis, mineralization or hot phase. When intensive aerating, the phase can take 2–3 weeks; for the composts with high portion of wood chips, however, it may take even two months.

The phase of degradation is followed by the ***thermophilic phase*** (phase of conversion): the temperature decreases to 40–45 °C and representation of microorganisms is changed. Appearance of the compost is changing, original waste matter is no longer recognizable. Earthworms and other small animals begin to work and create the crumbly structure. The compost gets an even brown colour and a faint scent of forest soil. In the phase of conversion, aerobic conditions are necessary to be maintained in order the compost not to turn sour, however aeration need not to be as intense as in the beginning of maturing.

In the ***phase of final maturing***, stability of compost increases, new humus substances (mainly humic acid) are formed and molecular weight of humus substances increases, the nutrients are tightly integrated in organic bonds, acidity of substrate decreases (increase in pH value). In this phase, there should not be ammonia or phytotoxic substances in the substrate. The structure should be crumbly, the material should be characterized by strong smell of garden or forest soil. In the phase of final maturing, the temperature of compost gradually decreases to ambient temperature.

Some composting methods recommend to apply microorganisms into the fresh compost through various preparations. In operational conditions, these preparations are usually without demonstrable effect and application of these products makes the production of compost too expensive. The most suitable composition of microorganisms is possible to introduce into the compost using topsoil, hotbed soil or mature compost. A sufficient amount of waste from weeding flower beds ensures proper microflora, especially in home composting. An oversize fraction of less degraded particles of the compost resulting from sieving mature compost is good inoculum when applied into a fresh compost newly created.

Microbiological and enzymatic preparations of Sanitree (a company from South Africa) have been proven to be useful in home composting of grass phytomass without any other addition of structural materials and soil, even in the conditions of insufficient aeration of compost filling. In the Czech Republic, it is possible to obtain this preparation under the name "Oxygenator". 50 g of preparation in suspension with 2 l of lukewarm water are applied on 2 m^3 of compostable materials. The preparation has been tested in composting of short cuts of park grass in fillings of hight of 2,5 m. It ensured heating of these fillings to 70 °C and volume reduction to one-third of the original volume, without odour formation. Using the preparation, the usable grass compost was obtained in two months with only single digging. The preparation can be recommended in the conditions of home composting where appropriate inoculum is missing. In larger composting plants for green waste, the application of the preparation increases costs of composting up by 25% and the preparation is used to compensate deficiencies of extensive technology and poor composition of raw materials of composts and mainly to reduce unpleasant odour of rotting grass [26].

Composting in the Czech Republic has almost the oldest tradition in Europe, as the first composting plant with controlled technology was introduced in the Czech Republic in 1912. Since then, the composting has continued to develop until 1987, when almost 2,5 millon tons of compost were produced in the Czech Republic, mainly from municipal and industrial bio-waste and sewage sludge. After 1989, composting has lost subsidy support and compost production has been minimized to 200-400 thousands tons per year. In order for composts produced from municipal waste to be usable in agriculture, they must meet their maximum permissible quantity of harmful substances according to ČSN 465735. Composts are also used for reclamation and for establishing and maintaining greenery.

In the past, composting was considered important in terms of maintaining the fertility of agricultural land with a view to achieving state sovereignty in food production. In terms of agricultural restructuring and current agrarian policy, there is no interest of the agricultural sector in promoting composting. However, composting remains an important tool in waste management and its importance will increase in the application of the new waste legislation. Composts and growing substrates are put into circulation by sale under the Fertilizers Act No. 308/2000 Coll.

From the organizational point of view, composting of green and other biowaste can be carried out at the following levels:

- domestic composting (in family gardens);
- community composting (in housing estates, gardening colonies);
- central composting (industrial composting).

The basic equipment for composting is crushers and wood chippers for treatment of vegetable waste, compost shredders and screeners (most often sieves). Composting biofermentors ensure maturing of fresh compost under controlled conditions of intensive aeration while maintaining reliable hygienic temperatures of 65-75 ° C [20].

Questions 5.1.1

1. Please express the basic meaning of composting.
2. Please describe the basic principle of composting.
3. Please state the basic conditions for the proper composting process.
4. Please describe each phase of composting process.

5.1.2 Anaerobic digestion

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe the principle of anaerobic degradation of organic matter;
- describe products of anaerobic digestion;
- state the possibilities of utilization of anaerobic digestion products.

Lecture

The greatest advantage of anaerobic digestion (biological gasification) is the reduction of greenhouse gases production. The amount of emissions produced in combustion of the biogas (approximately 60 kg CO_2 per GJ) is lower than that of coal (100 kg CO_2 per GJ); the emissions do not increase the anthropogenic greenhouse effect, since the produced carbon dioxide was bound by plants during photosynthesis (formation of biodegradable waste matter is linked to the process of photosynthesis). In addition, another portion of CO_2 remains in a digestate or in a stable digestate-based compost. The combustion of biogas does not produce harmful emissions (SO_2, heavy metals) compared to other fuels.

The anaerobic digestion process is considered as one of the technologies that contribute to sustainable development of human society on the planet. The EU's intention is to ensure biogas production with a total annual energy wattage 630 PJ by 2010. The biogas would enable substitution of 15 Mt of fossil fuels in production of heat and electricity. Biodegradable waste of animal and plant origin as well as targeted grown phytomass of energy plants can be treated through the anaerobic digestion. The biogas plants can processed not only animal excrements, but also waste from crop farming, from production and processing of fruits and vegetables, waste from slaughterhouse, dairy industry, waste fats, waste from tanneries and pharmaceutical industry, waste from production of biodiesel and bioethanol, waste from green maintenance and biological waste from separate collection of solid municipal waste. The biogas is advantageous to obtain during anaerobic stabilization of activated sludge.

Biological production of biogas (mainly methane) takes place in natural anaerobic environments forming in sediments, wet soils, rice fields, digestive systems, etc. Microorganisms responsible for the production of methane belong to unique genealogical group that is believed to have been created a long time ago, before the oxygen appeared in the Earth's atmosphere. Microbial production of methane has four stages and is caused by four main groups of microorganisms:

(a) **hydrolytic** bacteria that decompose organic macromolecular polymers (polysaccharides, lipids, proteins) to low molecular weight compounds soluble in water. The process takes place outside the cell using so-called extracellular hydrolytic enzymes.

(b) **acidogenic** microorganisms that decompose products of hydrolysis within the cell to simpler organic compounds (in particular acids; alcohols, CO_2, and H_2 are further formed).

(c) syntrophic **acetogenic** microorganisms producing hydrogen, which may ferment organic acid higher than acetic acid and alcohols higher than methanol to acetic acid, H_2, CO_2; they are very important representatives of organisms involved in the process of acetogenesis.

(d) **methanogens** that may produce methane from acetate, H_2, CO_2, and some other single carbonaceous organic substances.

Specific biogas production per 1 kg of degraded substance is the highest for fats (1.12–1.51 m^3 with methane content 62–67%). 1 kg of degraded carbohydrates produce 0,79–0,88 m^3 of biogas with 50%-portion of methane. 1 kg of degraded proteins produce 0,56–0,75 m^3 of biogas with 71–84%-portion of methane. Composition of biogas produced in well working reactors is 65–75% of methane, 25–35% of carbon dioxide and smaller quantity of hydrogen, nitrogen, hydrogen sulphide and ammonia.

The actual potentials of biogas production from different substrates are shown in the table 10.

Table 10 Production potential of biogas [26]

Substrate	**litres of biogas/kg of dry matter**	**m^3 of biogas/t of wet waste**
cattle slurry	250	25
pig slurry	420	36
poultry droppings	470	141
cattle straw manure	300	75
horse manure	260	73
cereal straw	250	200
young grass	710	95
grass in flower	410	105
corn straw	310	260
distiller's solubles	420	44
sugar beet tops	450	112
dried activated sludge	540	55
municipal biological waste	700	210
waste from fat treatment	1200	750
grease from trap	1330	800
vegetable waste	600	90
household biological waste	330	100
kitchen biological waste	450	138

The anaerobic digestion process can be divided into 4 main phases:

1. ***Hydrolysis*** is the first stage of degradation, macromolecular dissolved and undissolved organic substances such as polysaccharides, lipids or proteins are decomposed into low-molecular substances that are soluble in water. Decomposition takes place by extracellular hydrolytic enzymes, which are produced exclusively by fermenting bacteria. At this stage, low molecular weight substances are formed which, unlike high molecular weight, are capable of being transported within the cell.
2. During the second phase, called ***acidogenesis***, the hydrolysis products are further broken down into simpler organic substances, which are alcohols, acids, CO_2 and H_2. These substances ferment and produce a number of final reduced products, depending on the initial substrate and also on environmental conditions. When hydrogen produces a low partial pressure, acetic acid, H_2 and CO_2 are formed, and higher hydrogen partial pressures produce higher organic acids such as lactic acid, ethanol, and the like.
3. The third phase is ***acetogenesis***, the process of oxidation of H_2 and CO_2 and acetic acid. Hydrogen-producing microorganisms called syntrophilic acetogenic microorganisms break down organic acids higher than acetic acid, alcohols, as well as aromatic compounds. Their presence, along with other micro-organisms that consume their hydrogen, is more than important. Excess hydrogen throughout the system initiates the activity of acetogenic microorganisms.
4. The last phase is ***methanogenesis***. Methanogenic microorganisms are capable of decomposing substrates, monohydric substances such as methanol, methylamines, formic acid, CO_2, CO and H_2. Of the polycarbonate, only acetic acid can decompose due to methanogenic organisms. Methane and carbon dioxide are decomposition products [26].

The basic products of the anaerobic digestion are the ***biogas*** rich in methane and the ***biologically stabilised substrate*** - so-called digestate that keeps its fertilising effect after anaerobic degradation.

In practice, produced ***biogas*** is used mainly for the following:

- direct combustion and heating of heat transfer medium (heating)
- production of electricity and heat (co-generation) - BG combustion engine drives a generator of elektricity
- production of electricity, heat and cooling (trigeneration) - cogeneration unit is accompanied by an absorption heat converter for cold production
- non-energy use (chemical production of secondary products from BG)

The ***digestate*** is typically used as follows:

a) Direct application to the agricultural land

- substrate is stabilized and homogenised
- higher utilization of nutrients
- lower content of pathogens and weed seeds

b) Separation of solid fraction from substrate by pressing (filter press)

- solid fraction is used for composting
- or after drying and pressing, production of briquettes or pellets with addition of wood chips or straw as biofuel
- the remaining fluid fraction with nutrient content is applied as a fertilizer or as wastewater is treated at the waste treatment plant [2].

Questions 5.1.2

1. Please describe the principle of anaerobic degradation of organic matter.
2. Please describe characteristics of anaerobic digestion products.
3. Please state the possibilities of utilization of anaerobic digestion products.

5.1.3 Biological degradation

Time to study: 0.5 hour

Objective: After reading this paragraph, you will be able to

- briefly explain the basic principle and application of biodegradation.

Lecture

The biodegradation is a method of waste treatment, which is used to reduce contamination of petroleum substances and polyaromatic hydrocarbons. Polluted soils, concretes and rubble, oil sludge from dishwashers, traps and treatment plants are mainly treated in this way. After determining the level of contamination, the waste is spread on a secure decontamination surface and its physical, chemical and biological environment is treated, if necessary. A biopreparation is applied on the prepared waste – this biopreparation provides the decontamination. Based on the continuous monitoring the process, the conditions in biodegrading waste are adjusted. Decontaminated materials are subsequently used depending on their quality [26].

Advantages of biodegradation:

- possibility of waste treatment on the site of its production, transport costs are eliminated
- minimum distortion of the locality, where the waste occurs
- lower costs than that of other methods

Disadvantages of biodegradation:

- limited activity of microorganisms at the temperature under 19 °C
- not all of contaminants are biologically degradable

Questions 5.1.3

1. Please describe the principle and utilization of biodegradation process.
2. What are the advantages and disadvantages of biodegradation?

5.2 Thermal methods of waste treatment

Lecture

Thermal methods of waste processing waste are generally technologies, where the waste is exposed to a temperature higher than limits of its chemical stability, or it is exposed to a temperature and oxygen in the environment with controlled oxygen content. These procedures of thermal decomposition include incineration, pyrolysis, and gasification.

By these procedures, originally hazardous compounds contained in flammable waste are converted into relatively harmless products. However, it should be noted that the thermal methods are not the final method of waste disposal, as by-products – ash and gaseous substances – are formed and they contain harmful gaseous and solid particles.

5.2.1 Incineration of waste

Time to study: 2 hours

Objective: After reading this paragraph, you will be able to

- define the process of waste incineration;
- describe basic principles of waste incineration;
- characterize structural designs of waste incinerators that are the most

commonly used;

- characterize products formed during the waste incineration process, methods of their elimination from the combustion product flow and method of their treatment.

Lecture

The waste incineration is controlled exothermic combining of combustible components of waste with the oxygen under stoichiometric or nonstoichiometric conditions.

The incineration can be also defined as controlled waste burning at high temperatures and stoichiometric or higher content of oxygen in a facility intended for the efficient and complete incineration. The complete incineration involves the conversion of total carbon to carbon dioxide (CO2), hydrogen to water (H2O) and sulphur to sulphur dioxide (SO2). The waste incineration generates other products: ash, combustion products and released heat energy.

Incineration of waste has many advantages, for example:

- reduction in the volume to 10–15% of the original volume
- reduction in the weight to 20–40% of the original weight
- destruction of toxic chemicals contained in waste
- destruction of pathogens
- sterility of combustion residues
- recovery of energy contained in waste

The disadvantage of incineration is the production of gaseous emissions (NO_x, CO, SO_2, SO_3, HCl, and H) and solid pollutants (ash), which increases the cost to build an effective system for combustion product treatment. Other disadvantages of waste incineration compared to other processing methods mainly include high investment costs for the construction of incineration plants, high operational costs or problems with the use of the heat produced.

Advantageousness of the incineration is given by the concentration of population and the lack of large tracts of land for other landfills. The public opinion should be tilted to the incineration process that mus be performed with released energy recovery. The challenge for professionals is to reduce the price for waste incineration.

- **Principles of incineration**

Waste incineration is the most radical and the most effective method of hygienic disposal of waste. The process of solids incineration is very complex and is the sum of multiple reactions. Effective incineration requires a sufficiently high incineration temperature, sufficient retention time of the waste in the combustion chamber and the continuous movement of waste bed. Solid waste incineration is conditioned by waste drying and heating to ignition temperature, which is achieved by firstly, heat radiation of hot combustion products and hot wall of the furnace, and secondly, convection of combustion products or preheated air. In the first stage, the waste is dried at the temperature of 50 °C to 150 °C. At higher temperatures, the volatile compounds are formed as a result of complex degradation processes. These compounds are flammable and after their ignition, the flame is formed. The remaining solid material is further gradually degassed and, after achieving an ignition temperature, is gradually incinerated without heat intake from the outside.

The ignition temperature is the minimum temperature at which he waste spontaneously burns as a result of releasing of high amount of heat to compensate losses to the surroundings. In order to further incineration takes place as required, forming a basically harmless gaseous substances, it is necessary to provide some basic conditions, which include:

- sufficient amount of combustion air that should be supplied with an excess of 1.5 to 2.0 to the stoichiometry of the combustion reactions;
- a sufficient amount of heat generation to heat the waste to ignition temperature,
- ensure the retention of combustion products in the post-combustion chamber or space at the temperature of 850 °C or 1100 °C for waste with a content of more than 1% (wt.) of halogenated organic substances (expressed as chlorine) for at least two seconds, with a content of at least 6% of oxygen.

If waste contains elements such as Cl, F, S, and N within its flammable components, it can be expected the formation of HCl, HF, SO_2 + SO_3, and NO + NO_2 during incineration. It is clear that the waste combustion gases consist primarily of nitrogen N_2, carbon dioxide CO_2, H_2O vapour and excess oxygen. Others gaseous substances can be regarded as trace contaminants and they are not usually taken into account in the calculations to determine the consumption of combustion air and the quantity of produced flue gas. However, the requirements on technical security of incineration plant for flue gas purification depend on the content of these trace contaminants.

The combustion chamber is supplied by combustion air, wherein the inlet side of the combustion air is dependent on the design of the furnace. Combustion air is supplied in over-stoichiometric quantities to the content of individual burnable elements (C, H, and S) in a flammable substance so that there is a complete incineration and thus oxidation of the carbon present in the waste flammable into harmless CO_2 (see reaction 5.1). The amount of combustion air spupplied into the combustion furnace is characterized by the ***excess air coefficient n.***

$$C + O_2 \Rightarrow CO_2 + \text{heat} \quad (5.1)$$

In the opposite case, i.e. when there is inadequate oxygenation of flammable waste elements, incomplete combustion takes place, accompanied by the formation of toxic carbon monoxide CO (see reaction 5.2).

$$C + 1/2O_2 \Rightarrow CO + \text{heat} \quad (5.2)$$

The value of the excess air therefore mainly depends on the fuel type and the furnace construction, i.e. on mixing of the waste with the input air. In practice, it is necessary to seek a compromise solution of input combustion air amount. In order to conduct a complete combustion, it is desirable to supply a higher amount of the combustion air. However, higher amount of supplied combustion air increases demands on consumption supporting as well as additional fuels needed to heat the flue gas to a desired temperature and it also influences the formation of NOx. The literature recommends amount of combustion air expressed as the excess air coefficient n to be from 1.5 to 2.0.

Effective waste incineration is often provided by moving grates, designed so that the waste could passing through the furnace combustion chamber. There are a number of grate design type, such as belt, drum, shaking or sliding. The design of rotary furnaces allows the burned ash falls through the grate holes into a tank, from where it is passed to a container for further processing. The advantage of movable grates consists in the possibility to control the speed at which the material moves through the combustion chamber of the furnace, and also good mixing of waste required for complete combustion.

For optimum oxidation of the flammable components of the waste, the combustion air is usually supplied in two stages (primary and secondary). The primary air, which is necessary for the process of waste burning and also cools the grate structure is supplied below the waste bed and passes through the waste layer from the grate bottom. The flow rate of combustion air should not be too high since then the ash flies away instead of falling down to a collection system located under the grate. The secondary air is supplied into the reaction chamber above surface of the waste bed in order to unburnt components of flammable gases better burn out.

Another frequently used method of waste incineration is the incineration in a rotary kiln. Waste incineration in the rotary kiln is significantly different from the incineration process on the grate; individual stages of the process are similar to those in the grate furnace. The movement of burned waste is ensured by slow rotation of the kiln supported by a slight slope of the kiln (about 7 degrees). When incinerating waste in the rotary kiln, the heat is transferred also by conduction of the hot lining to the waste bed located on it. This happens due to slow rotation of the drum rotary kiln resulting in continuous waste mixing and also heating of uncovered part of lining, which at some point creates a crown and accumulates heat; after partial turn, the heated part of the lining goes under the waste bed and the heat is transferred to the waste by conduction (see Figure 6). As a result of the continuous movement of waste in the rotary kiln, there is a good contact of flammable material with the oxidant. The combustion products are usually conducted in parallel flow with the direction of waste movement into the chamber of auxiliary combustion where the unburnt fractions are after-burned The advantage of the drum rotary kiln is the possibility to incinerate pastelike materials and more intensive heat transfer from heated kiln lining to the waste bed.

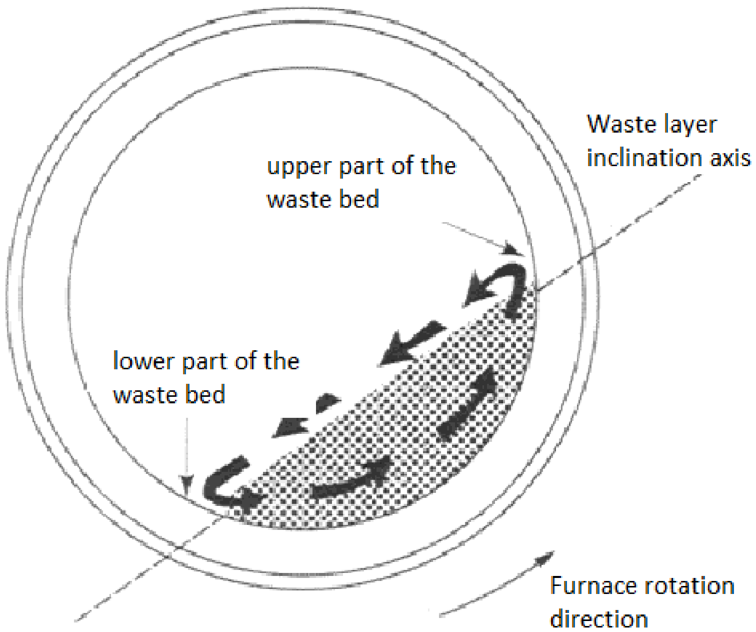

Figure 6 Illustration of the waste movement in the cross section of the rotary kiln

Currently, various designs of waste incineration fluid furnaces are operated and developed. The fluidized bed combustion process depends on ensuring oh appropriate (uniform) grain size of waste batches. Core of the process is based on the combustion air injection from the bottom at high speed into a layer of granulate waste, thereby the individual grains begin to float (formation of fluidized bed), the reaction surface is enlarged and the combustion process is very intensive through the whole waste bed [35].

❑ Products of waste incineration

Although the waste incineration can be considered as an effective method of waste disposal, however, in various stages of the incineration process (see Figure 7) secondary products are formed – these products need to be treated in accordance with applicable laws and regulations.

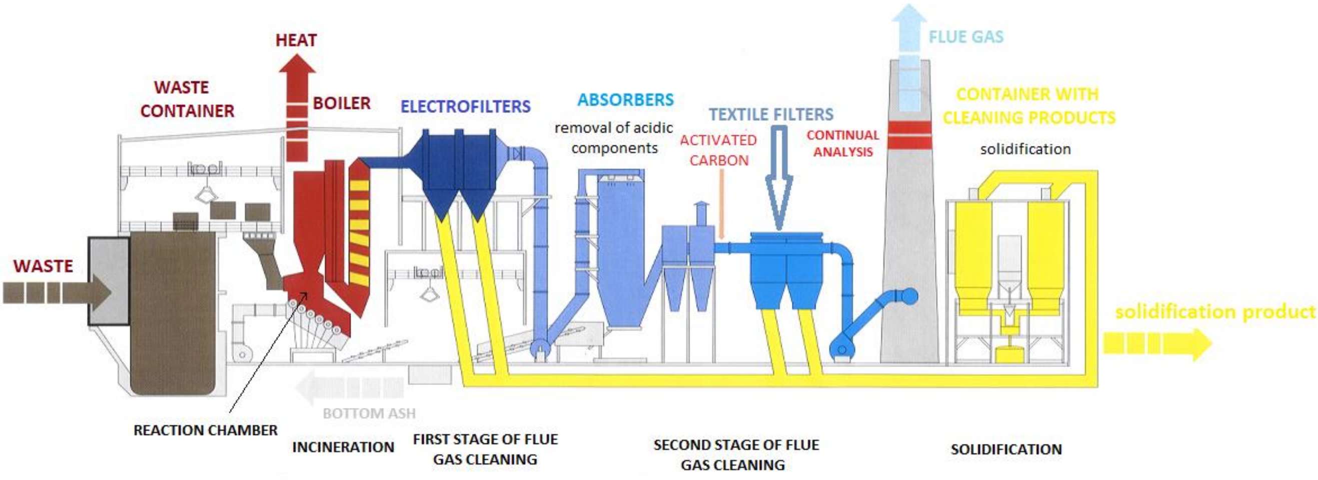

Figure 7 Diagram of the municipal waste incineration plant SAKO, a.s. Brno before redevelopment

Ash and cinder

One of the products of waste incineration is the main solid residue or ash (burned out cinder). Because of relatively high content of oxides of heavy metals in the ash, it is necessary to ensure thorough analysis of aqueous extracts and based on its results suitable type of landfill for safe deposition is chosen. Most of incineration plants is equipped with a magnetic separator to obtain unburnt ferrous metal components of the ash and cinder that are further utilised in the production of crude iron in the metallurgical industry.

American Society of Mechanical Engineers in cooperation with the US Bureau of Mines carried out research of vitrification of solid residues from waste incineration. For experimental needs, the ash samples were taken from five municipal waste incineration plants and more than two hundred experiments of their vitrification have been carried out. The vitrification process took place in electric arc furnaces in a continuous manner. The resulting products are characterized by favourable properties with regard to the degree of immobilization (fixation) especially of heavy metals in the vitrified matrix.

Fly ash

Another solid remain from waste incineration is the fly ash or dust particles removed from the combustion products. Risk of the fly ash lies in the fact that the large quantities of polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCPFs), and heavy metals, particularly mercury are adsorbed on the particles. The fly ash is removed from the combustion products usually using electrostatic precipitators or textile filters (see Figure 7). The electrostatic precipitators are working on the principle of attractive forces between oppositely charged particles of the fly ash (charging electrode) and oppositely charged collecting electrode of a large surface, wherein the collecting electrode periodically removes ash layer by shaking off into a container. The textile filters are made of appropriate fabrics, with sufficient mechanical and thermal resistance.

The fly ash from combustion product is classified as hazardous waste in the Catalogue of Waste and it must be further treated as follows. The fly ash is usually disposed/removed by deposition on a secure landfill of hazardous waste. Before landfilling, it is often processed (treated) by solidification, in most cases by cementation, when leachable particles harmful to the environment are partially immobilized in the formed (solid) mixture of fly ash, cement, water, and sand. This mixture of fly ash, cement, sand, and water is most often deposited on appropriate secured landfill according to the class of leachability.

Acid gas products of waste incineration

Acid components produced in waste incineration most often include SO_2, SO_3, HCl, and HF depending on the composition of the incinerated waste. These components are characterized by ability of sorption on sorption agent. Hence, for their removal from the combustion products, the absorption method in an alkaline reagent is used in the process that takes place in absorbers (see Figure 7); at the same time, these acidic components are neutralized.

Depending on the physical state of the sorption agent and the resulting product, the processes of acidic components removal are divided:

– dry processes

– semi-dry processes

– wet processes

The principle of the dry process is the dosage of alkaline sorbent in powder form either directly into the waste or into the hot combustion products, which reacts with the acidic components to form neutral dust particles. The particles are removed from the combustion products through a filter or electrostatic precipitator and further processed, for example, by solidification. The efficiency of such a purification process is 30-50% (at excess reagent).

At semi-dry method of acidic components removal, the liquid alkaline additive (aerosol of whitewash of $Ca(OH)_2$ or NaOH) is fed into the combustion products in such amount that the water is evaporated by the heat of the combustion products and the resulting neutral product is in the dry state. This product is further processed in a similar manner as the product of dry methods of acidic components removal. The efficiency of the process is about 85 %.

The efficacy of acidic components removal using the wet process is the highest, reaching values up to 98 %, but on the other hand, there is a problem with further processing of neutral product. The combustion products are sprayed by circulating water to neutralize HCl and HF that are soluble in water. Acidic components such as SO_2 and SO_3, which are not soluble in water, but have the ability of sorption, are washed out from the combustion products using circulating water with addition of whitewash. HCl and HF can be removed following the same procedure. The dewatered product is often processed by solidification before it is deposited on a secure landfill. A disadvantage of this wet process is that after neutral product dewatering, residual wastewater has to be further treated.

Nitrogen oxides

In waste incineration plants where exceeding of emission limit for nitrogen oxides is expected devices for removal of these harmful substances are installed. Their function is based on the denitrification reactions and we are talking about DENOX (DeNOx) filtres. The necessity for removing NOx from combustion products is a denitrification reaction (5.3). The reaction can be ensured using a non-catalytic process, where ammonia or its aqueous solution is injected into the hot space at the temperature range of about 870–970 °C, in which the denitrification reactions take place, or using a catalytic process where the used catalyst enables the reaction takes place at lower temperatures (at about 250–400 °C).

$$4\ NO_2 + 4NH_3 \dashrightarrow 4\ N_2 + 6\ H_2O + O_2 \qquad (5.3)$$

Trace components of the flue gas

The remaining pollutants, especially PCDD, PCDF, Hg, are removed either by passing the combustion products through a stable filter with activated carbon, where these components are adsorbed, or by dosage powdered activated carbon (e.g. sorbalit) into the flow of combustion products. The adsorption takes place at a temperature 150-200 °C with contact time approximately 2 seconds.

Wastewater

Wastewater are generated in the waste incineration plants both when cooling the main solid residue and also when removing acidic components of the combustion products by wet method. Wastewater from the removal of acidic components from the combustion products usually has a high content of heavy metal salts and other trace elements (As, Pb, Hg, and Ni). For this reason, it is necessary to purify wastewater in wastewater treatment plant of a given waste incineration plant.

For example, the technology of wastewater treatment in industrial waste incineration plant SPOVO, s.r.o. Ostrava is based on the two-stage treatment of wastewater generated in the process of acidic components removal from the combustion products. In the first stage, wastewater is neutralized using whitewash $Ca(OH)_2$ and the excess sulphate is eliminated as gypsum. In the second stage, heavy metals salts are precipitated using precipitation reagents ($FeCl_3$, polyelectrolyte). Subsequently, heavy metal sludge is dewatered on semi-automatic filter presses and the filter cake is deposited on a secure landfill. Treated wastewater is pumped to the neutralization station and then into the tank of BorsodChem MCHZ, a.s. Ostrava's A–block for use for technological purposes.

Thermal energy

The thermal energy released during waste incineration is collected from the combustion products in a heat exchanger and it is used mostly for the production of steam, which is usually supplied to the heating system, thereby the simultaneous generation of electricity and thermal energy is enabled. In some incineration plants, a part of the heat is used to re-heat the combustion products before entering DENOX filter or to pre-heat the combustion air supplied into the reaction chambre [35].

The legislation currently in force requires that waste incineration plants be operated under the energy recovery regime, if technically and economically feasible. Energy recovery is defined in the Waste Act as such waste management, where the waste, after ignition to the ignition temperature, burns independently without the addition of heat from outside and the energy generated is demonstrably used. By law, such an incineration plant must operate with an energy efficiency of at least 65% [9].

Formula for calculating energy efficiency [9]

Energy efficiency = $(E_p - (E_f + E_i)) / (0{,}97 \times (E_w + E_f))$

where:

- E_p means the annual amount of energy produced in the form of heat or electricity. It is calculated by multiplying the energy in the form of electricity by 2,6 and the heat produced for commercial use by 1,1 (GJ/year).
- E_f means the annual energy input to the system from fuels contributing to the production of steam (GJ/year).
- E_w means the annual amount of energy contained in the waste treated, calculated using the lower net calorific value of the waste (GJ/year).
- E_i means the annual energy supplied without E_w and E_f (GJ/year).
- 0,97 is a factor of energy losses due to ash and radiation.

This formula shall be used in accordance with the reference document on best available techniques for waste incineration. The minimum energy efficiency level required for the recovery of waste by the R1 (energy recovery) method for installations that have received an installation approval before 1 January 2009 is set at 60 %, and for installations that have received an installation approval after 31 December 2009 is set to 65 %.

Questions 5.2.1

1. Please define the process of waste incineration.

2. Please describe basic principles of waste incineration.
3. Please characterize structural designs of waste incinerators that are the most commonly used.
4. Please characterize products formed during the waste incineration process, methods of their elimination from the combustion product flow and method of their treatment.

5.2.2. Pyrolysis of waste

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- characterize the basic principle of the waste pyrolysis process;
- describe the core of the pyrolysis process;
- characterize products of pyrolysis and possibilities of their use.

Lecture

The standard CSN 06 3090 [36] defines the waste pyrolysis as a thermal decomposition of organic waste in the absence of oxidizing media in the reaction chamber, wherein higher molecular organic materials decompose to simple volatile products and coke at temperatures usually in the range of 500 °C to 1000 °C.

Waste pyrolysis (degassing) can be also defined as a thermal decomposition of organic materials without access of oxidizing atmosphere (air, carbon dioxide, water vapour), which leads to the formation of discrete solid, gaseous and liquid fractions. In the industry, the pyrolysis has being used to produce charcoal, methanol, turpentine, and coke for many years. In the seventies, some companies carried out experiments on pyrolytic decomposition of municipal solid waste, but none of the proposed technology for pyrolysis of municipal solid waste was suitable, especially from economic aspects. The pyrolysis seems to be most suitable for processing of organic materials with a high net calorific value.

Pyrolysis processes can be generally characterized by the equation:

$$C_aH_bO_c + \text{heat} \Rightarrow H_2O + CO_2 + H_2 + CO + CH_4 + C_2H_6 + CH_2O + \text{tar} + \text{coke} \quad (5.4)$$

Core of the pyrolysis consists in the fact that the organic compounds are less stable at higher temperatures, high molecular compounds decompose to low molecular compounds, leading to their decomposition to volatile (gaseous) products, viscous liquid residues (tar) and carbon-rich coke. The whole process is endothermic; therefore, the system must be supplied by heat.

In most cases, the pyrolysis process starts at about 200 °C and proceeds until temperatures reaches value above 1000 °C. The pyrolysis is preceded by a drying process, which takes place at temperatures around 100 °C at normal atmospheric pressure. When heated, the organic material bonds become unstable and the volatile components are released. Only coke will left on the end of the process. During the temperature increase, organic components cleaved from larger portions of the molecules are cracked first. A lot of different long-chain connections are created. This phase is not dependent on the type of decomposed material.

Pyrolysis reaction reaches its peak at about 500 °C, when the greatest amount of pyrolysis products is formed. The chemical reaction depend on the composition of the input material and the chemical composition as well as water content in a batch become more important.

The composition and quality of the pyrolysis products may vary and are dependent on the management of operational parameters such as pressure, temperature, time, batch size, the use of catalysts and auxiliary fuel. At high temperatures exceeding 760 °C, gaseous products, such as hydrogen, methane, carbon monoxide, and carbon dioxide, are formed. At lower temperatures of 450–730 °C, tar, charcoal, and liquid residues, such as oils, acetic acid, acetone, and methanol, are formed. The calorific value of resulting oils and gases increases with the increase in hydrogen presence in the pyrolysis chamber, and at higher presence of water, carbon monoxide and hydrogen can be produced; they can be used as substitute for natural gas.

Currently, extensive researches are carried out on technology development in order to obtain energy and valuable products from waste materials. Thermochemical decomposition in anaerobic conditions or thermal degradation also leads to the formation of usable liquid, solid and gaseous products. Thermochemical decomposition involves gasification, liquefaction and pyrolysis. The liquid product has a high concentration of benzene, xylene, and toluene. The solid product contains a considerable amount of black (fixed) carbon and can be used as a modification of asphalt in the construction of roads. The gaseous product is primarily composed of methane and can be used for heating in reactors [2][35].

Questions 5.2.2

1. Please characterize the basic principle of the waste pyrolysis process.
2. Please describe the core of the pyrolysis process.
3. Please characterize products of pyrolysis and possibilities of their use.

5.2.3 Gasification of waste

Time to study: 1 hour

Objective: After reading this paragraph, you will be able to

- describe the basic principle of gasification process;
- characterize the products of gasification and state methods of their use.

Lecture

Gasification of waste is a controlled thermal decomposition of waste materials at temperatures above 800 °C at a substoichiometric oxygen content in the reaction space, resulting in the conversion of carbonaceous materials to gaseous combustible material of desired composition.

From the chemical point of view, the gasification is a conversion of carbon-containing solids, liquids, and gases at partial oxidation with oxygen, H2O or CO2. Depending on gasification conditions, gases of different compositions, which differ in calorific value, are formed. Gasification can be of great importance for thermal waste treatment processes, the chemical energy contained in waste is only partially converted into unusable heat during conversion.

Most of the contained energy is converted into new chemical compounds, in particular CO and hydrogen, which are then usable in various sectors. Therefore, the significant portion of waste is converted into new compounds, in this case into gases that have defined the energy content. [36].

The process is highly endothermic and proceeds according to the following scheme:

- Carbon in the coke residue is gasified using carbon dioxide:

$$C + CO_2 \rightarrow 2\,CO \quad -155\ \text{MJ} \qquad (5.5)$$

- Water vapour reacts similarly:

$$C + H_2O \rightarrow CO + H_2 \quad -118\ \text{MJ} \qquad (5.6)$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2 \quad -90\ \text{MJ} \qquad (5.7)$$

- Released hydrogen reacts to form methane:

$$C + 2H_2 \rightarrow CH_4 \quad - 88\ MJ \qquad (5.8)$$

The advantage of this process is that due to high temperatures, there are no problems with the formation of highly toxic dioxins, furans and polycyclic aromatic hydrocarbons. Reducing environment also prevents the formation of the nitrogen oxides. This method of waste disposal is still in the stage of laboratory or pilot plant verification and there are not sufficient practical experience with him yet; however, its use can be assumed as promising [35].

Questions 5.2.3

1. Please describe the basic principle of gasification process.
2. Please characterize the products of gasification and state methods of their use.

5.3 Deposition of waste on landfills

Time to study: 2 hours

Objective: After reading this paragraph, you will be able to

- categorize landfills in basic groups;
- know parameters determining on which landfill category the waste may be deposited;
- characterize sealing system of each type of landfills;
- characterize drainage system of landfills;
- describe principle of landfill reclamation;
- state financial background of waste landfilling.

Summary of terms

In the following text, basic terms and concepts are listed, without which it would not possible to understand the following text.

a) **inert waste** – waste having no hazardous properties and which undergoes no significant physical, chemical or biological changes under normal climatic conditions. Inert waste is not easily soluble in water, is neither combustive nor physically or chemically reactive, is not biodegradable and does not cause the breakdown of other substances, with which it comes into contact, in any manner that might result in damage to the environment or pose a threat to human life.

b) **biodegradable waste** – any waste that is able to decompose anaerobically or aerobically (e.g. food, green waste, paper).

c) **water leachate** – a solution that was prepared from a waste sample according to the standard CSN EN 12 457-4 on leaching waste in water

d) **waste stabilization** – a waste modification technology consisting of the use of physical, chemical and biological processes leading to the continuous (controlled) release of harmful substances from the waste into individual environmental media.

e) **leachate class** – a class of waste leachability in water, i.e. a set of the highest allowable concentration values for selected harmful substances released in the first water leachate of waste.

f) **reclamation (re-cultivation**) – bringing a place that had been affected by human activities into harmony with its surroundings and renewing the function of the terrain surface in relation to its original use or newly designed use.

g) **barrier** – a natural or artificial barrier, effectively preventing contamination of the environment

h) **landfill base** – geological bedrock, which is located under foundation bottom

i) **foundation bottom** – an area with which the landfill structure meets with subsoil

j) **landfill body** – structural layers including deposited waste

k) **leachate** – water leaking from the landfill body

l) **leachate sump** – a drainless impermeable reservoir into which the drainage system flows to remove leachate from the landfill

m) **the highest groundwater level** – the highest water level, which may occur during the construction or operation of a landfill.

n) **foil** – a plastic membrane used as an areal sealing element

o) **degassing system** – a system of vertical, horizontal or inclined collection drains and drainage pipes

p) **coefficient of filtration** – a degree of permeability of porous media

q) **drainage system** – a system of line and drainage elements, ensuring collection and drainage of leachate

r) **collecting drain** – a drainpipe in the landfill body partially perforated, providing collection and drainage of leachate

s) **conducting drain** – drain pipe discharging leachate from the landfill into the sump; collecting drains are connected and discharged into this drain[37]

Lecture

In the Czech Republic, the waste landfilling is governed by the Decree of the Ministry of Environment of the Czech Republic No. 294/2005 Coll. on the conditions of depositing waste in landfills. According to the Decree, landfills are divided into three groups. Waste is accepted to the landfills of each group according to the type and category pursuant to the Catalogue of Waste and Hazardous Waste List, their actual properties, the classes of leachability by wastewater (see Appendix 2 of the above Decree), and the pollutant content in the dry matter.

The landfills are divided on the basis of their technical safety systems:

a) Group S – inert waste – designates for inert waste.

This group is marked as S-IO for the purposes of records and reporting waste and facilities. Waste categorized as "other waste", water leachate of which must not exceed the maximum allowed values for the leachate class No. I in any indicators, may be deposited on this group of landfills.

b) Group S – other waste – designates for waste in the "other waste" category; the group is marked as S-OO for the purposes of records and reporting waste and facilities. This group is further divided into sub-groups:

Sub-group S-OO1 – designates for waste in the "other waste" category containing low levels of biodegradable compounds. The following waste may be deposited on landfills of this subgroup:

- waste, water leachate of which must not exceed the maximum allowed values for the leachate class No. IIa in any indicators;
- content of TOC in the dry matter shall not exceed 5%; in the case of exceeding, the DOC content must be DOC $\leq$ 80 mg/l.

Sub-group S-OO2 – designates for waste in the "other waste" category containing low levels of biodegradable compounds. The following waste may be deposited on landfills of this subgroup:

- waste, water leachate of which must not exceed the maximum allowed values for the leachate class No. IIb in any indicators;
- content of TOC in the dry matter shall not exceed 5%; in the case of exceeding, the DOC content must be DOC ≤ 80 mg/l.

Sub-group S-OO3 – designates for waste in the "other waste" category containing high levels of organic biodegradable compounds and waste that cannot be evaluated on the basis of their water leachate. Also other waste, water leachate of which does not exceed the maximum allowed values for the leachate class No. IIa may be deposited on landfills of this group.

c) Group S – hazardous waste – designates for hazardous waste. This group is marked as S-NO for the purposes of records and reporting waste and facilities. The following waste may be deposited on landfills of this subgroup:

- waste, water leachate of which must not exceed the maximum allowed values for the leachate class No. III in any indicators;
- Waste that exhibits loss on ignition higher than 10% of dry matter or the TOC content is higher than 5%; when exceeding, DOC content has to be DOC ≤ 100 mg/l.

The technical requirements for waste landfills, including conditions governing their location, technical conditions for their operation, sealing, monitoring and conditions governing their closure and reclamation shall be deemed to be met if they comply with relevant technical standards:

- CSN 83 8030: Landfilling of waste – Basic conditions for designing and construction of landfills
- CSN 83 8032: Landfilling of waste – Sealing of landfills
- CSN 83 8033: Landfilling of waste – Handling of seepage waters from landfills
- CSN 83 8034: Landfilling of waste – Degasification of landfills
- CSN 83 8035: Landfilling of waste – Closure and reclaiming of landfills
- CSN 83 8036: Landfilling of waste – Monitoring of landfills

❑ Sealing of landfills

The sealing system of a landfill is proposed with regard to the type of waste being landfilled, the class of leachability and the natural conditions of landfill site.

The sealing system of a landfill must be designed with such materials to avoid compromising their integrity as a result of the landfill subsidence or the effect of surface water and weathering.

For multiple sealing, it is recommended to use different sealing materials whose favourable properties are complementary and those adverse are excluded.

Properties of sealing materials:

- sufficiently low permeability
- the ability to withstand deformation of sealing system foundation without breaking
- chemical resistance to leaches released from deposited waste
- the ability to restrict diffusion of contamination into the surrounding environment
- the thickness of the foil for the materials with limit value of Class II of leachability and for the waste that cannot be evaluated on the basis of water leach must not be less than 1.5 mm
- the thickness of the foil for the waste corresponding to Class II of leachability must not be less than 2 mm
- soils used into ground sealing after compaction must not show the coefficient of filtration higher than $k = 1 \cdot 10^{-9}$ m/s

Dewatering of landfills

Rainwater that flows through the landfill body is drained through a drainage system. The system must meet the following conditions and requirements:

- No surface water can flow to the landfill, otherwise retention ditches designed for 100-year water
- All types of landfills must be equipped with internal drainage system for draining leachate waters
- Landfills in the group S-IO must be provided with areal drainage element made of material of k = 1 · 10-4 m/s and with layer of thickness of at least 0.3 m
- Landfills in the group S-OO and S-NO must be provided with areal drainage element made of material of k = 1 · 10-4 m/s and with layer of thickness of at least 0.3 m supplemented by collection drain pipes
- It is necessary to collect leachate into a sump without drain and subsequently to dispose them.
- The drainage system must be designed so that its design and functionality could not be affected by landfill settling, action of water leachate and mechanical clogging or fouling of tube drains.
- Arrangement of collection drains should be design so as to ensure that it is possible to carry out the revision and their cleaning in time of landfill operation.
- The drain must be designed so as to ensure its impermeability in view of the surrounding environment (in particular passage through sealing).

- The sump of water leachate is to be located outside the landfill.

❑ Closure and reclaiming of landfills

After the closure of landfill, it is necessary to perform the adjustment of the landfill body shape, the cover and the reclamation of surface, and to carry out follow-up treatment of the site for at least 30 years. The purpose of the cover is to prevent damage the environment in the area of landfill. The purpose of reclamation is to create conditions for the subsequent land use for other purposes.

The surface of the landfills S-IO does not need to be impermeably closed.

The surface of the landfills S-OO (single layer) and S-NO (multi-layer) must be secured with a waterproof cover protecting against penetration surface and rainwater.

❑ Obligations of landfill operators

According to the Waste Act [9], the landfill operator is obliged to meet the following requirements:

a) during operation of the landfill, to create and maintain a financial reserve for reclamation, to maintain the landfill and remediation after termination of the landfill's operation within the scope set forth in this Act and in implementing legal regulations;

b) ensure, after termination of the landfill's operations, its remediation, recultivation and follow-up care and to restrict the negative impact of the landfill on the environment; these activities must be funded from the operator's own resources and from the financial reserve over a period of at least 30 years;

c) collect fees for disposing of waste in the landfill, to transfer the money to the fee recipient and to inform the fee recipient of any outstanding fees;

d) archive records of waste deposited over the entire period of the landfill's operation and the period of follow-up care of the landfill.

e) creation of financial reserve shall be included in the operator's costs;

f) funds of the reserve are stored on a special escrow account in a bank and must be included in the bankruptcy landfill operator;

g) drawing from the financial reserve may be made only with the approval of the regional office for work related to reclamation.

Producer is obliged to pay a fee for landfilling its waste; the fee also applies to the producer, which is itself a landfill operator and this landfill is on his own land. The fee for landfill consists of two components. The ***basic component*** of the fee payable for waste deposition, for the deposition of hazardous waste, it is also paid the ***risk component***. To the extent provided by law, the fee is an income of the municipality in whose cadastral the landfill is located, and the State Environmental Fund of the Czech Republic.

The basic component of the fee is the income of the municipality in whose cadastral area the landfill is located. In the event that the landfill is located on cadastral areas of several municipalities, the income is divided proportionally according to the size of the part of the landfill located in the cadastral area of these municipalities. The risk component is the income of the State Environmental Fund.

Questions 5.3

1. Please state the basic categories of landfills.
2. Please state the parameters determining on which landfill category the waste may be deposited.
3. Please characterize sealing system of each type of landfills.
4. Please characterize drainage system of landfills.
5. Please describe principle of landfill reclamation.
6. Please state financial background of waste landfilling.

Další zdroje

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