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Ondřej Procházka

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Pro autory

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The deadline of the next issue is on July 8, 2021, more on October 8, 2021.

Challenges of Covid-19 Medical Waste Management in Indonesia: A Multi-stakeholder Perspective

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Abstract

The increase in the number of positive Covid-19 patients in Indonesia shows that the Indonesian government has not been fully prepared to face this outbreak. Recently, most of patients have been treated in several hospitals and emergency hospitals designated for Covid-19 patients. As a consequence, there has been an increase in Covid-19 medical waste. This study aims to explain how the management of Covid-19 medical waste is carried out by several stakeholders who are responsible for managing this hazardous waste.

This study used qualitative research methods. The process of collecting primary data is carried out by interviewing stakeholders such as the Director of the Hospital, the Ministry of Environment, the Ministry of Health, environmental NGOs, and private parties managing hazardous and toxic waste (B3). Meanwhile, secondary data sources are processed from legislation, literature, and data related to Covid-19 waste management, such as the capacity for treating B3 waste, Increasing Medical Waste, Managing Hazardous Waste Elimination, etc.

The results of this study indicate that the government has planned the development of medical waste treatment. However, it is hampered because the policy will only be implemented in 2020 – 2024. Meanwhile, from the private sector, the main problem faced is that not all private waste management companies still do not have an incinerator permit. Moreover, in the perspective of hospital managers, apart from having limited incinerators, some of the challenges faced in managing covid-19 waste are low supervision in waste management so that many parties recycle the waste.

Keywords: *Covid-19, Waste Management, Indonesia, Multi-stakeholders*

Introduction

The covid-19 pandemic is currently developing rapidly around the world. One of the environmental impacts caused by this pandemic is an increase in the demand for and use of health-protective products to protect the general public, patients, health workers, and other workers. The increasing trend towards the use of health products is expected to be in line with the global pandemic curve for various plastic products as personal protective equipment (PPE) such as gloves and masks for health workers, disposable plastic components for life support equipment, respirators, and general plastic supplies including syringes[1]. This condition has resulted in an increase in the amount of medical waste, especially Covid-19[2]. For example, the amount of medical waste in Wuhan has quadrupled to more than 200 tons of waste on February 24, while this amount exceeds the capacity of medical waste management in Wuhan, which is only able to manage 50 tons of medical waste per day[3].

Medical waste has become an important problem because it has the potential to cause health problems and environmental damage[4,5]. The issue of medical waste has become a crucial issue in various countries. In developing countries, medical waste is placed together with non-medical waste, which can pose a risk of unavoidable health problems[67]. For example, the problem of medical waste in the form of sharp objects that are not handled properly has the potential to be contaminated with twenty pathogens, which resulted in the emergence of the hepatitis B virus (HBV), hepatitis C virus (HCV), and HIV virus in 2010[8]. The explanation above shows that medical waste management is a serious problem that can cause serious health problems.

Many health facility services in Indonesia ignore medical waste management by not implementing proper waste management[9]. According to data from the Ministry of Health, 2,820 hospitals and 9,884 community health centers produce 290 tons of medical waste every day. Meanwhile, there are only ten licensed waste processing plants in Indonesia with a combined capacity of 170 tons per day, and only 87 hospitals have incinerators to treat waste on-site with a combined capacity of up to 60 tons[10]. In addition, transportation and waste treatment processes are already problematic. Among them, PT Putra Restu Ibu Abadi (PRIA) was accused of hoarding or dumping B3 waste, including medical waste near residential areas in Mojokerto, which resulted in a decrease in the quality of residents' well water and cases of medical waste scattered in mangrove forest areas in Karawang in 2018 and banks of the Ciherang river, West Java[11]. These conditions indicate that medical waste treatment in Indonesia has not been resolved optimally.

The increase in the number of Covid-19 patients in Indonesia shows that the Indonesian government has not been fully prepared to face this outbreak. As a consequence, there has been an increase in Covid-19 medical waste. Based on a case study in China, the average patient infected with Covid-19 contributed 14.3 kilograms of medical waste per day[12]. If this is multiplied by the number of positive patients in Indonesia to date, the resulting waste reaches 243,457.5 kilograms of medical waste. This amount cannot be estimated because it does not include the amount of medical waste mixed with domestic waste produced by the patient under surveillance or people under surveillance, which carries out self-quarantine. Therefore, this condition worsened the management of medical waste management in Indonesia before the pandemic was still not optimally resolved.

The occurrence of the Covid-19 pandemic gave birth to a governance crisis and policies for handling pandemics in various countries. Indonesia also faces similar challenges, even exacerbated by the nuances of the politicization of the pandemic, ignorance of science at the beginning of the crisis, limited economic capacity, and a minimal health service system[13]. This study aims to explain how the management of Covid-19 medical waste from various multi-stakeholder perspectives. Through this perspective, researchers will get comprehensive results on the complexity[14,15] of the Covid-19 medical waste problem. As a study model, this article will aim to enrich the discussion and debate on the management of Covid-19 medical waste in Indonesia.

Methods

This research was conducted in June - October 2020 in Indonesia. This research uses qualitative methods. The data collection process was carried out in several stages. First, the research team conducted semi-structure interviewed to participants/informants who have an interest in managing B3 and Medical Covid-19 waste, such as the Ministry of Health, Ministry of Environment and Forestry (KLHK), Private B3 Waste Management Companies, Hospitals, Indonesian Hospital Association, and environmental NGOs. Several points were asked in the interview process including laws or regulations that govern waste management, breakthrough rules, regulations, and policies to regulate Covid-19 medical waste, implementation of Covid-19 waste management policies, obstacles faced in managing Covid-19 medical waste and so on.

In addition, the data collection process was also carried out through the participation of the research team in a webinar that discussed the issue of medical or other B3 waste in Indonesia. Furthermore, this research is also complemented with secondary data such as data on hazardous waste processing capacity, data on increased medical waste, and related laws and regulations about waste management.

The data analysis in this study used thematic analysis. This analysis was carried out in several stages [16]. First, reviewing the interview transcripts. Then, coding the results of the interview transcript from several quotes and classifying the results of the interview based on the topics discussed. And the last one is interpreting the findings from predetermined ideas, namely the multi-stakeholder challenges in managing covid-19 medical waste.

Results and discussion

Government Efforts in Handling Covid-19 Medical Waste

Based on *Worldometer* data as of November 21, 2020, Indonesia is in the 21st position with the total COVID-19 cases in the world with a case record of 488,310[17]. As a consequence, there has been an increase in the amount of B3 infectious COVID-19 waste. According to the Minister of Environment and Forestry Siti Nurbaya Bakar, the volume of infectious medical waste throughout Indonesia as of June 8, 2020, reached more than 1.100 tons[18]. The piles of B3 COVID-19 waste have an impact on the environmental conditions of the community. This indicates the need for action in proper waste management. Meanwhile, based on a study conducted by the government, the capacity for B3 medical waste management in 6 regions in Indonesia is only able to manage a total of 314.29 tons/day[19].

Table 1: The Number of B3 (Hazardous and Toxic) Waste Management Services in Indonesia[19]

REGION	SUMATERA	JAWA	BALI NUSRA	KALIMANTAN	SULAWESI	MALUKU PAPUA	TOTAL
Health Service Facility Capability	8.58	41.72	2.40	8.00	9.51	0.00	70.21
Ability of B3 waste management services	5.40	225.48	0.00	10.80	2.40	0.00	242.08
TOTAL	**13.58**	**267.20**	**2.40**	**18.80**	**11.91**	**0.00**	**314.29**

The low capacity for managing B3 medical waste in 6 regions in Indonesia is a new problem in the management of B3 medical waste management. Based on the results of the capacity gap analysis carried out by the Ministry of Environment and Forestry on April 28, 2020, it shows that the ability to manage medical, hazardous limbs in 6 regions in Indonesia during the pandemic has increased to 877.26 tons/day[19]. From the six regions, the Java region is the largest contributor to the largest amount of Covid-19 medical waste in Indonesia because almost a third of the population in Indonesia is in the Java region.

This waste management capacity is supported by the destruction of cement kilns or other required destruction installations. Optimization of hazardous waste treatment capacity Health service facilities and licensed B3 waste management services are also carried out by allocating the entire capacity to manage infectious B3 waste.

As a guide in dealing with the impact of a pandemic, there are several efforts made by the government in dealing with B3 COVID-19 waste management. First, savings and reallocation of the K/L APBN 2020 budget to be converted into funds for handling COVID-19. Second, forming the COVID-19 Task Force Unit within the scope of the Ministry of BAPPENAS (National Development Planning Agency) to formulate national development planning policies in the context of handling COVID-19, one of which is compiling a study of hazardous waste management in Indonesia. The B3 and B3 Waste Management Policy have become a priority agenda in the 2020-2024 RPJMN (National Medium-Term Development Plan), namely the construction of an integrated hazardous medical and hazardous waste treatment facility. The construction of B3 medical waste processing facilities in 32 provinces and integrated B3 waste processing facilities in 4 regions (Sumatra, Sulawesi, East Java, and Kalimantan) are detailed in the following table.

Table 2: KLHK Project Support[20]

List of Ministry/Institution Project	TARGET	Ministry/Institution
Construction of Integrated Hazardous Waste Treatment Centers in Sumatra and Papua	2 unit	Cooperation between government and business entities
Construction of Integrated Hazardous Waste Treatment Centers in Kalimantan	1 unit	Cooperation between government and business entities
Construction of Integrated Hazardous Waste Treatment Centers in East Java	1 unit	Private Sector
B3 waste treatment facilities from Health Service Facilities	32 province	Ministry of Environment and Forestry (KLHK)
Management of medical waste in health care facilities according to standards	8.800 Health Service Facility Capability	Ministry of Health

The construction of B3 medical waste processing facilities, and integrated B3 waste processing facilities is one of the strategic priority projects (major projects) in building the environment, increasing disaster resilience and climate change. B3 medical waste processing facilities in 32 provinces and integrated B3 waste processing facilities will be built in 4 regions (Sumatra, Sulawesi, East Java, and Kalimantan) with the aim of increasing the capacity of B3 medical waste management in Indonesia. In addition, the benefits of the construction of B3 waste processing facilities are an increase in the capacity of the amount of B3 waste treated to 26,880 tons/year and reduce transportation costs for B3 waste management[3]. Simultaneously an Early Warning System (EWS) was also built for priority non-natural disasters, especially for epidemics and disease outbreaks in the 2021 Government Work Plan (RKP), including those related to B3 medical waste management.

Management of B3 medical waste from Health Service Facilities before the pandemic is regulated in the Minister of Environment and Forestry Regulation 56/2015 Procedures and Technical Requirements for Management of Hazardous and Toxic Waste from Health Service Facilities (Data from the Ministry of National Development Planning/ and IATL ITB, 2020). The regulation describes the stages of waste management, starting from reduction and sorting, container and storage, transportation, processing, burial, and landfilling. In 2018 the Directorate of Performance Assessment of Hazardous and Non-B3 Waste Management of the Ministry of Environment and Forestry also issued a roadmap related to waste management from Health Service Facilities from 2019 to 2028. This is also regulated in the Ministry of Health Regulation Number 7/2019 concerning the Health Hospital Environment. The following is an overview of the flow of medical waste management for Health Service Facilities.

Referring to the Circular of the Minister of Environment for 2020 SE.2 / MENLHK / PLB.3 / 3/2020, the tools used for handling B3 / Medical waste are Incinerators and Autoclaves. However, it is not necessarily when the Incinerator and Autoclave tools listed in the Ministerial Regulation can be used just like that, but there are strict regulations in the use of these tools. Management of B3 COVID-19 waste in the scope of the hospital, personal protective equipment waste, test equipment, and laboratory equipment are classified as dangerous infectious B3 medical waste so that the processing is carried out using an autoclave equipped with a counter. Meanwhile, waste originating from the homes of Patients under Monitoring (PDP) and People under Monitoring (ODP) such as masks, tissues, medicine bottles, and other household waste is processed using an incinerator. Broadly speaking, crisis management in facing a pandemic includes at least the aspects of risk, impact, and mitigation[21].

The obstacle faced by Hospitals

The incidence of B3 medical COVID-19 health facilities has increased by up to 30%, which is 328 tons per day (KLHK, 2020). Based on data from the Ministry of Health, as of March 2020, as many as 4,500 B3 medical COVID-19 waste has been processed using hospital incinerators. Of the 132 referral hospitals, 110 of them already have licensed incinerators[22].The data on the generation of medical waste from Health Service Facilities does not include the development of the number of COVID-19 referral hospitals, which has reached 506 hospitals throughout Indonesia[23]. This is a gap when all hospitals can produce waste, which is increasing in quantity during the COVID-19 pandemic. However, the amount of utilization of medical waste processing equipment is still insufficient or even inadequate.

The low capacity for managing B3 medical COVID-19 waste in hospitals creates new problems. This arises as a result of the unpreparedness of hospitals and related agencies in dealing with the COVID-19 pandemic. In addition, this problem is caused by the structuring of B3 medical COVID-19 waste handling procedures that have not been right on target, a low level of supervision at the container, transportation and storage stages by the hospital, and illegal use of waste by hospital staff[23]. There is a need for cross-sector coordination on the ease of managing hospital medical waste in the era of the COVID-19 pandemic, considering that hospitals and medical personnel currently need high concentration in patient care.

Supervision in the management of B3 and Medical Covid-19 waste in Indonesia, which is mostly generated by the use of masks for the community, creates a risk of recycling activities carried out illegally against used disposable masks. The risk that arises is the possibility of transmission of the virus caused by a recycling process that is wrong or does not follow the correct procedure and is carried out without official permission from the relevant agency. This also creates an increased risk of infected patients, which in turn can result in increased medical waste for hospitals or health agencies. However, if the PPE waste is recycled with an appropriate method such as the recrystallization method. This method includes cutting plastics, dissolving plastics, mixing with anti-solvents, depositing on anti-solvents, and separating solvents and anti-solvents, so that a pure plastic without degradation will be obtained which has benefits and functions as a plastic with similar quality[24].

Outside Java Island, the number of licensed transporters is difficult; on-site facilities are very few, the number of licensed managers is felt to be very insufficient so that the handling of Covid-19 is more focused on handling infected patients. On the other hand, there is a problem of medical waste processing which is no less important to take seriously. Transporter and Managers who understand the dangers of Covid-19 medical waste are deemed minimal so that implementation in the field is in accordance with predetermined regulations (Timely waste collection & avoiding illegal use) In addition, it is equally important to have the compliance and vigilance of all medical personnel regarding the precautionary protocol against the risk of infection through the use of PPE (Personal Protective Equipment). Increased medical waste management costs have increased, in difficult times such as now hospital cash-flow is disrupted, thus adding to the hassle of hospital management, so it is necessary to have a standardized price / special price for hospitals for the medical waste management process in the Covid-19 era. The handling of medical waste by the hospital, of course, needs to apply a special price so that waste management can be carried out properly according to existing procedures and can be carried out optimally.

The Private Sector Roles

The dangers contained in medical waste must be considered, given the risk of poison and can infect someone if misused. Covid-19 medical waste comes from PPE (Personal Protective Equipment) and masks produced by hospitals, health centers, clinics, laboratories, and households that are aware of PHBS (Clean and Healthy Living Behavior) in the midst of a pandemic. The risk posed by B3 Covid waste is caused by medical waste that is not sterilized due to a lack of qualified knowledge. There is a need for further medical waste treatment so that the risks can be overcome. If the processing is not correct, it can spread the disease to other patients, the public, and health workers because it contains microorganisms or germs. Moreover, the agency to sort or double-check medical waste that has not been cut by residents so that later it is not misused by the community so that the dangers arising from covid-19 medical waste can be overcome[2].

The role of medical waste management companies in handling the Covid-19 outbreak was conveyed by Dr. Eng. Candra Nugraha[25] as the President Commissioner of PT. Jasa Medivest said that there are several stages in integrated waste management, namely:

1. ***Training***
   We are providing training to producers of medical waste in both hospitals, laboratories, and households in handling medical waste.
2. ***Fetching Loading***
   Carry out the collection and loading of medical waste from waste generators. Before taking the load, it is necessary to spray disinfectant against the wrapped waste.
3. ***Transport***
   Transport the evacuated waste to the disposal site
4. ***Extermination***
   Exterminate medical waste by burning it using an incinerator. Before carrying out the combustion process, it must go through a disinfection process first.
5. ***Residue Handling***
   Handling bottom ash and fly ash to PPLI

To carry out the handling process of Covid-19 medical waste, it is also necessary to have a security system for workers in the form of wearing PPE (Personal Protective Equipment) and collaborating with other parties who handle waste, environmental control, or related agencies. In this case, PT. Jasa Medivest collaborated with the Center for Environmental Health and Disease Control Engineering to transport 594 kilograms of medical waste in the activity of returning the Diamond Princess crew from the Kertajati Class II Port Health Office to the *Dawuan* plant. In a period of four months, starting from January to April 2020, there was an increase in the amount of medical waste generated by several hospitals such as Dr. Hasan Sadikin Bandung, RS. Dr. Lung HA. Rotinsulu Bandung, Al-Ihsan Regional Hospital Bandung, Syamsudin Sukabumi Regional Hospital, PPSDM Prov. West Java Cimahi, etc. The following is a diagram of the rate of increase in medical waste, which is quoted from PT. Java Medivest:

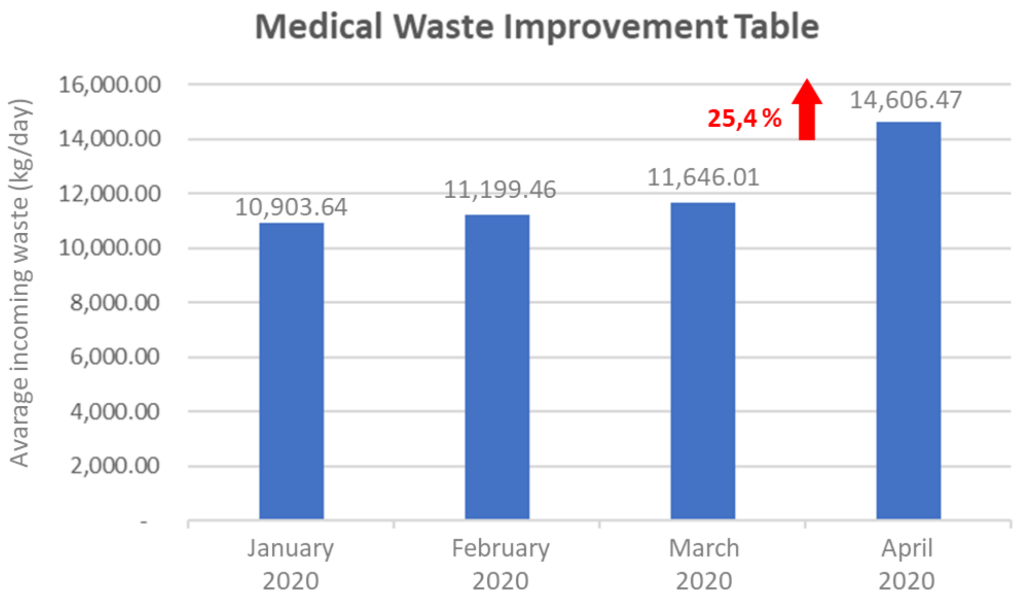

Figure 1: Medical Waste Improvement Table[25]

From the Figure 1, it can be clearly seen that from January to April, there was an increase in the amount of medical waste from 10,903.64 kg to 11,199.46 kg in February and increased again in March with a total of 11,646.01 kg. From March to April, to be precise, on April 21, there was a significant increase in the amount of waste by 25.4%, with a total of 14,606.47 kg. The type of medical waste Covid-19 consists of disposable PPE (Personal Protective Equipment) waste made from plastic, which is not easy to get wet, is not easily destroyed, and is not completely flammable. The increase in the amount of Covid-19 Medical waste has also emerged due to the use of disposable masks by the public, which is still frequently used.

The Covid-19 Medical waste management system in Indonesia, in principle, avoids misuse of society, undertakes efforts to reduce medical waste through recycling or reuse, recovering, and processing it first before landfilling or destroying waste. The challenge in waste management arises when there is a significant increase in medical waste, given the increase in infected patients and the use of disposable medical devices by hospitals in handling Covid-19 cases in Indonesia.

The accumulation of Covid-19 medical waste in the waste disposal site at Health Service Facilities is an impact caused by the limited final processing of B3 waste. In addition, an increase in the number of patients infected with Covid-19 also produces infectious waste that needs to be sterilized before processing waste before it is destroyed. A good management process in treating Covid-19 medical waste in accordance with procedures ranging from reducing the amount of waste, sterilizing to culling waste through incineration using an incinerator by a company that already has a license can certainly be an alternative to facing challenges in managing Covid-19 medical waste in Indonesia.

Conclusions

The covid-19 pandemic has become an outbreak that cannot be avoided by the global community. All governments in the world are not prepared for this pandemic—no exception to developed countries. In Indonesia, the trend of patients infected with Covid-19 shows a sufficient number of increases every day. One of the most significant consequences of the rise in the number of Covid-19 patients is the increase in Covid-19 medical waste in Indonesia.

As one of the countries that are not ready to face this pandemic, the Indonesian government is very overwhelmed in handling this waste because of its unpreparedness with legal rules to manage this hazardous waste. However, with all its limitations, the Indonesian government is making responsive efforts in dealing with the waste problem, including by increasing the number of B3 waste management centers in almost all parts of Indonesia. In addition to government efforts, various sectors support and provide roles in covid-19 medical waste management, namely the private sector and hospitals.

However, this sector is also experiencing several problems in overcoming this Covid-19 medical waste, including the limited incinerator and weak waste control from the government, especially the involvement of individuals who want to recycle the hazardous waste. Therefore, it is necessary to have synergy from stakeholders who have the authority and interest in managing the covid-19 medical waste.

Acknowledgment

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Výzvy nakládání s lékařským odpadem Covid-19 v Indonésii: Perspektiva mnoha zúčastněných stran

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Souhrn

Nárůst počtu pozitivních pacientů s Covid-19 v Indonésii, kteří byli léčeni v nemocnicích a pohotovostních nemocnicích, způsobil, že došlo ke zvýšení produkce zdravotnického odpadu. Studie si kladla za cíl vysvětlit, jak správně nakládat se zdravotnickým odpadem při zapojení několika zúčastněných stran, které jsou odpovědné za nakládání s tímto nebezpečným odpadem.

V práci byly využity kvalitativní výzkumné metody. Proces sběru primárních údajů byl proveden na základě rozhovorů se zúčastněnými stranami, jako jsou ředitelé nemocnic, ministerstvo životního prostředí, ministerstvo zdravotnictví, nevládní organizace v oblasti životního prostředí a soukromé subjekty, které nakládají s nebezpečným odpadem (B3).

Také byla zpracována data a údaje související s nakládáním s odpady v souvislosti s onemocněním Covid-19, jako je např. potřebná kapacita pro zpracování odpadu, zvyšování množství odpadu ze zdravotnictví, minimalizace nebezpečného odpadu atd. Údaje byly převzaty z legislativních a literárních zdrojů.

Klíčová slova: *Covid-19, odpadové hospodářství, Indonésie, zdravotnický odpad, nebezpečný odpad*

Assessment of municipal waste management systems using performance indicators to analyze recycling capacity The case study of Corumbataí basin, São Paulo state, Brazil

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Abstract

The analysis of waste management practices is a multidimensional challenge faced by authorities, especially in developing countries, where actions are needed to reduce, reuse and increase recycling. Performance indicators are often used to assess the quality of municipal solid waste management systems. However, some studies suggest that different realities require different indicators to evaluate the quality of management systems. Moreover, effective data on the reality of municipalities are scarce, especially on the work carried out by the informal sector within the waste management systems. The purpose of this study was to investigate a set of indicators in order to examine the recycling modes and capacity of six municipalities in the interior of São Paulo estate in Brazil. Focus was placed on how the collection of the material for recycling is carried out. The analysis revealed that the municipalities have selective collection being carried out in urban areas, but in different ways and not always with the support of the public power. The reality found in this study points to a great participation of the informal collection in the recycling capacity of the cities surveyed.This study estimates approximately 8% of refuse are collected by the informal recycling of the total amount estimated for generation every year in the investigated cities. The average recycling rate in selected cities is 10.8%.

Keywords: *Municipal waste management; waste indicators; informal sector; recycling.*

1. Introduction

Management of solid waste is one of the most important functions in cities administration, it is a key service on which public health and the external image of the city depend[1,2]. As a result, waste management is a challenge for cities around the world, due to several factors such as growing generation, high management costs and lack of understanding of the diversity of factors affecting functions and interactions of the stages of waste management systems[3,4,5]. It is worldwide recognized that the integrated approach of waste leads the system to greater sustainability, for which the first step consists of knowing all the elements that compose the system[6]. It has been reported by authors that one of the factors affecting waste treatment is the lack of access to information on waste management systems by the authorities[7,8]. Few studies report quantitative information on management systems, especially in low and middle income countries where informal services can reach high level of participation in recycling rates[9,10,11,12].

Appropriate waste management actions involve increasing recycling and reducing the amount of waste landfilled and incinerated[22]. Recycling occurs in different income countries as an importantwaste management strategy, also called the circular economy is applied by governments mainly in the European Union[23,24,25]. In low and middle income countries recycling occurs as a form of revenue for thousands of people[26,27]. In these countries, it is a matter of urgency to implement inclusive policies so that the role of the informal sector in clearing cities and recovering materials is recognized[1,15,28,29].

It is remarkable that municipalities with less than 30,000 inhabitants represent 80% of the municipalities in Brazil[30], therefore, solutions for these municipalities are important. These municipalities also present higher rates than the national averages for recovered mass and percentage of recovery of dry recyclables[30].

The aim of this study was to analyze and suggest indicators for city-level decision-making. The researchers purpose of this study was to investigate a set of indicators in order to examine the recycling modes and capacity of six municipalities in the interior of São Paulo estate in Brazil. Focus was placed on how the collection of the material for recycling is carried out.

In six municipalities (five with less than 30,000 inhabitants and one with 199,000) that make up the Corumbataí river basin in the state of São Paulo, Brazil. Data were collected with focus on recycling dynamics performed by formal and informal sectors. These dynamics represent important actions and should be taken into account when analyzing processes in waste management by the authorities in Brazil.

1.1. Overview of current knowledge

To reach the sustainability in waste management (i.e. treatment of waste in proper way and production of secondary raw materials and energy resources), following waste hierarchy should be applied:

1. Prevention,
2. Preparation for re-use,
3. Recycling,
4. Other recovery, e.g. energy recovery; and
5. Disposal[31].

Performance indicators are indispensable tools for decision-making processes and, when used correctly, can lead to innovative policies and new technologies[31,32]. The indicators offer an understanding of the conditions of systems and provide support for the decision making process. The actions related to waste management can be directed based on appropriate indicators to evaluate the real needs of the municipalities[33].

The most commonly used indicator to measure the environmental effectiveness of waste management systems is the recycling rate[34]. This is because it is complicated to measure waste reduction, so recycling is the option that can be measured[32]. However, other authors suggest that only the recycling rate is not sufficient to evaluate the sustainability of management systems, since this indicator does not assess the impacts caused by non-recyclable materials[35,34,32].

Therefore, to carry out an analysis that perceives reality effectively, several indicators are needed to evaluate the different aspects of the waste management system. Recycling fully participates in any sustainable waste management system and can be a waste recovery activity carried out by the formal or informal sector[36,37,13,5]. However, this work depends on source segregation, selective collection, sorting, mechanical processing and marketing[26].

In developing countries, waste recovery activities are often carried out by the informal sector[39,11,12,40]. That is, those activities that are not recognized by municipal waste management, so they are not accounted for the system. This is because, in developing countries, generators are not always recognized and often send their waste to recycling for revenue without be counted by the formal system[6,18,42]. Studies suggest that informal sector contributes to increasing recycling rates and decreasing the costs associated with waste management[43,6,1,26]. Informal sector is clearly a key ally in cities, if cities were to deal with such waste quantities the costs would be higher[1,44]. It has been reported by many authors the recycling activities performed by informal sector in China[45,8,5,38].

Studies about waste flows are important to support authorities on how to deal with different stakeholders in order to recover material and actors activities. Public acceptance and awareness of waste facilities are important for effective waste strategies. Garnett et al.[52] produced an empirical framework for negotiating the mode and level of public involvement in waste management decision-making, and suggest a need for greater inclusivity and awareness of stakeholders. Berg et al.[62] analyzed transformations occurred after changes in waste management legislation in Poland and have described that legal context of selective waste collection as one of the most effective ways to reduce the amount of waste sent to landfills. Aparcana[58] reviewed barriers and success factors for formalization of the informal waste sector, and concluded that the empowerment of informal workers is confirmed as a further key success factor for the formalization.

Ibáñez-Forés et al.[65] analyzed the evolution of the municipal solid-waste management system of João Pessoa (Brazil), which is one of the pioneering Brazilian cities to implement door-to-door selective collection programs; the authors concluded that the implementation of awareness-raising campaigns should priority in policies on solid waste. Davis and Garb[64] describes the informal work in the Israeli-Palestinian context and show how synergic solutions of partnership between formal and informal sectors can improve livelihoods of informal recyclers while reducing health risks and environmental impacts.

In this way, the study performed by UNEP[60], Global Waste Management Outlook, declares it is necessary to integrate the informal sector to work alongside the formal sector and thus incorporate it to the system. That is a challenge for authorities all over the world.

2. Materials and methods

This study was conducted in six municipalities in order to map waste flows and waste management practices. The methodology used for the development of this research involved a review of the literature on performance indicators for residues, definition of objectives, elaboration of research planning and questionnaires, implementation of field research and application of questionnaires directly with social actors, data collected in the field, analysis and evaluation of the data found, and finally, preparation of the final report. Data collection was carried out from July to December 2017 with the purpose of understanding the household solid waste streams of the municipalities investigated.

2.1. Study area

The municipalities make up the Corumbataí river basin in the interior of the state of São Paulo (Figure 1), which are five with less than 30,000 inhabitants (Analândia, Charqueada, Corumbataí, Ipeúna and Santa Gertrudes) and Rio Claro with 199,000 inhabitants. The total population of these municipalities is 256,819. Brazilian legislation provides that solutions for waste management must be taken from river basins, because this way the natural resources can be respected.

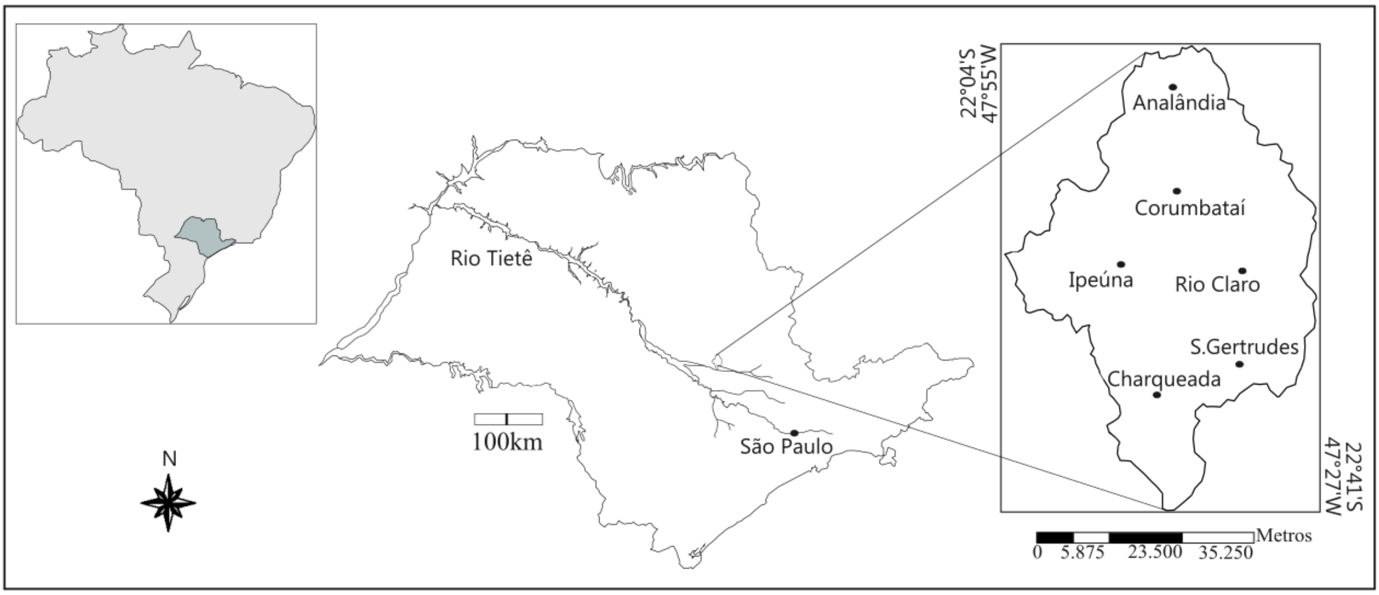


Figure 1: Location of study area. *Source: Own creation*

2.2. Construction of indicators

With the purpose of reveal the flows of the commercial and public solid waste management system of the six municipalities a set of performance indicators were selected. These were chosen in order to analyze all the different stages of the waste management system in the municipalities. With this, the chosen indicators contemplate quantitative and qualitative values of generation, of regular, selective and informal collections, as well as financial and administrative aspects of the practices adopted in the cities studied.

This step consisted in selecting and elaborating the set of indicators based on the survey of the main aspects related to the management of solid urban waste. For this, a bibliographic survey was carried out on the subject, followed by consultations with articles from periodicals, theses and dissertations whose themes involve indicators of solid waste management.

During this phase, a great number of indicators were found, applied in different ways, with several objectives[46,47,48,2]. In this work, we sought to group and select indicators related to the technological and financial issues of waste management in the studied municipalities. On the definition of solid waste, Wilson et al.[48] state that there are different ways around the world to define municipal solid waste. The values investigated in this study are on solid waste generated in households and businesses and do not include health service waste, construction waste or industrial waste.

2.3. Data collection

At the beginning of field work, a survey was carried out to recognize the organizations included in the household solid waste management system, especially those involved with regular, selective collections and informal collection routes conducted by private companies that buy and sell recyclable material. Three different structured questionnaires were developed, tested previously and modified to collect information with city hall employees, recyclable material cooperatives workers and recyclable trade establishments where informal collectors sell material. The organizations were visited and whenever possible, interviews were conducted directly with the actors. Also, data were obtained from public databases in Brazil. The primary data of this research were collected directly with the institutions that manage the various materials. At that stage, prefectures, cooperatives and establishments of commercialization of recyclable material were visited. The data collected refer to the amount of material accounted for by public bodies and published as values for generation and also declared values of collection by formal and informal street scavengers.

Secondary data was investigated to compose the set of performance indicators. Databases provided by the specialized public agencies were searched. Most of the data surveyed are available from the National System of Information on Sanitation - SNIS and the National System of Information on the Management of Solid Waste – SNIR [67], however, also the databases of the Brazilian Institute of Geography and Statistics - IBGE and the Environmental Sanitation Technology Company of the State of São Paulo. Also, values were consulted in the National Treasury Secretariat (STN) to compose the expenditure indicators.

Primary and secondary data refer to the years 2015, 2016 and 2017. Whenever possible, data from the same year were crossed and interviews were conducted directly with the responsible for the information investigated. Although effort was made to obtain all the information in the six municipalities investigated, not all prefectures provided all the information, this fact occurred both in the investigation of primary data and in the investigation of secondary data.

All set of indicators selected were calculated for each of the six municipalities studied, when data existed. The indicators were grouped by stage of the waste management system and over expenditure. At the end a process flow diagram was elaborated to map the results.

3. Results

The findings from the research provides a framework of waste flows, which allow for greater comprehension of waste management practices carried out in the investigated cities. Important outcomes show information for waste generation, selective collection, informal collection, recycling rate and expenditure indicators.

3.1. Waste generation

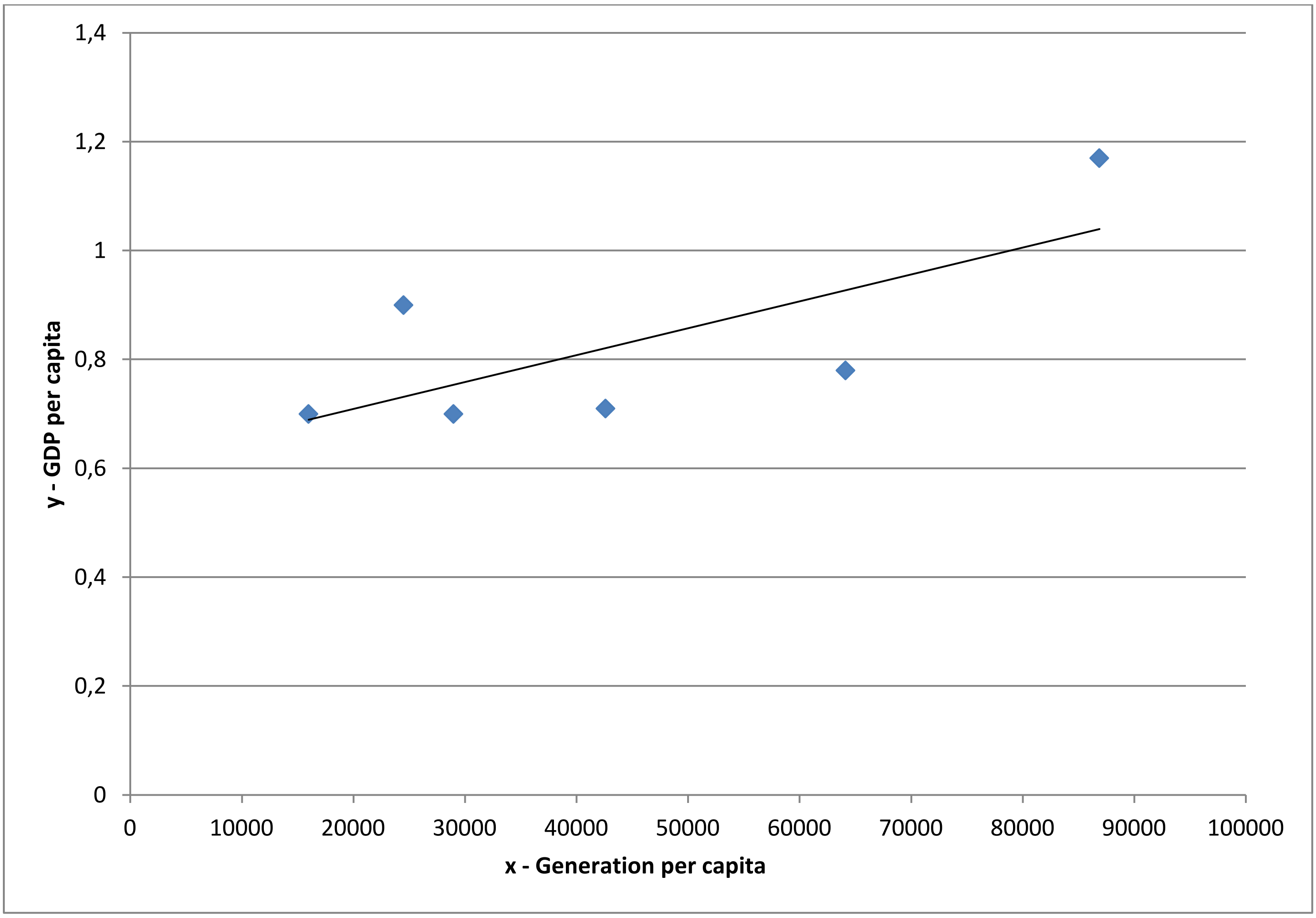
According to Sujauddin et al. [66], the generation of waste is influenced by the size of the families, the level of education of people and economic level, the last was also pointed out by other authors as being a factor that affects the generation of waste[49,42]. However, in Brazil, it was reported by the SNIS [67] in 2015, that the northern and northeastern regions, although they are regions with the lowest GDP per capita (18,358.59 and 15,002.31 R$ / hab. year) had the highest rates of generation per inhabitant (1.13 and 1.22 kg / inhab. day respectively). The same report points the possible causes such as greater control in waste landfills in the south and southeast (0.84 and 0.96 kg / hab. day respectively) or the diversion of recyclables by informal collection and, consequently, non-accounting inside the system.

On average, per capita waste generation was 0.8 kg / inhab. day (Table 1) in the investigated municipalities. Ipeúna presented higher generationthan the national average (1 kg / hab. day). The other cities presented generation lower than the national and regional averages (0.96 kg / hab. day), at this point it should be taken into consideration that there are recycling works being carried out in almost all the municipalities and the official values of per capita generation are calculated from the values of regular collection. These results can be due to informal work that collect recyclable material and divert it from regular collection.

Table 1: Population, GDP per capita and per capita generation rate

City	Total population(1)	Urban population(1)	GDP per capita(2) (R$/hab.year)	Generation per capita(3) (Kg/hab.year)	Regular collection in % on Inhabitants(3)	Rural collection in % on rural Inhabitants(4)
Corumbataí	4,054	2,191	24,506.35	0.90	54	20
Analândia	4,845	3,847	28,983.51	0.70	ad	0
Ipeúna	7,177	6,177	86,883.95	1,17	86	ND
Charqueada	16,772	15,216	15,988.52	0.70	91	ND
S. Gertrudes	25,637	25,364	64,130.83	0.78	95	0
Rio Claro	202,952	198,012	42,613.74	0.71	97	100

ND – No data provided on this aspect.
Fonte: (1) IBGE, 2017; (2) IBGE, 2014; (3) SINIS, 2015; (4) Dados de campo.
Source: Research data.



Graph 1: The relationship between GDP per capita and generation per capita *Source: Own creation*

Coverage data of regular collection show that not all the population has access to the regular collection service, especially the rural population. For example, Corumbataí has large part of its population living in the rural area and only part of that population has access to the regular collection service. Regular collection of rural area is a difficult situation faced specially by cities where rural population is large.

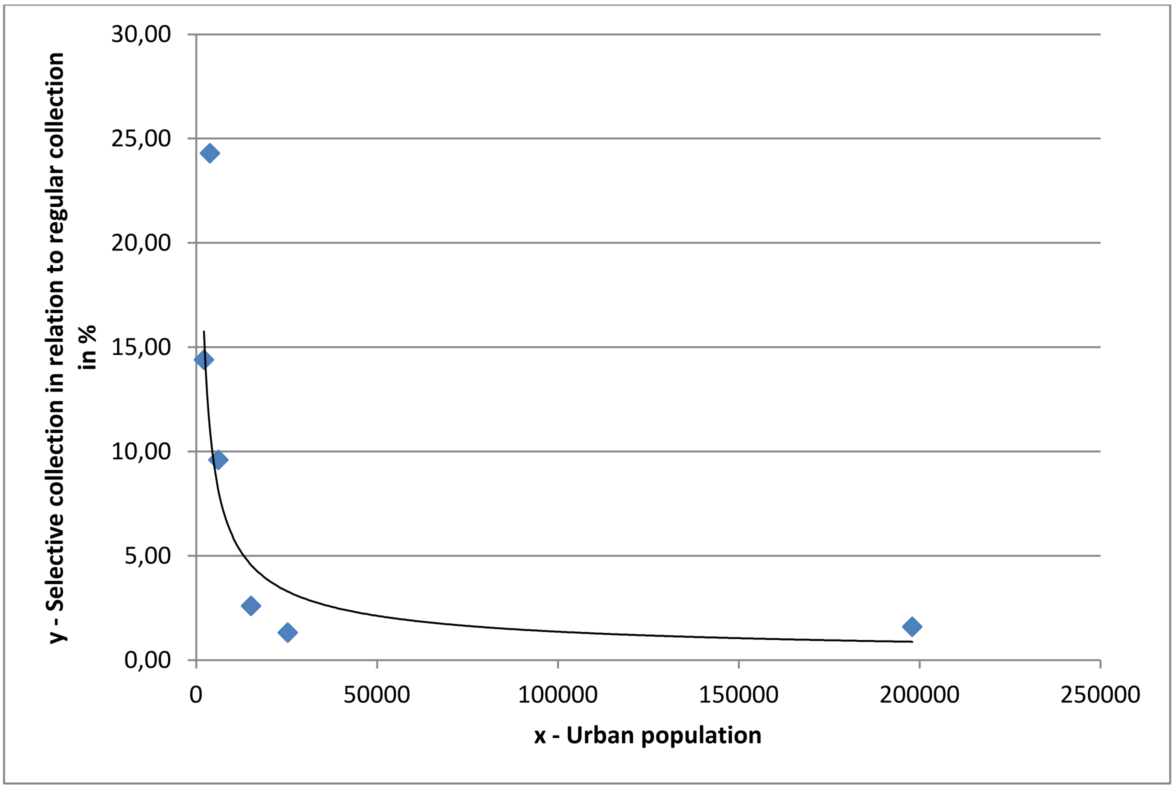
3.2. Selective collection of recyclables

For this study, it was defined selective collection as collection of recyclables offeredfrequently in urban zones, with or without public support. Table 2 shows field data for selective collection.

Table 2: Selective collection structure

City	Selective collection in relation to regular collection in %	Selective collection waste in %	Efficiency of workers (kg/person month)	Revenue per worker (R$/person. month)	Average revenue per recyclable (R$/kg)
Corumba- taí	14.4	12	1,222.20	738.88	0.60
Analândia	24.3	12	4,250.00	2,080.00	0.49
Ipeúna	9.6	3	2,550.00	1,765.00	0.69
Charquea-da	2.6	ND	ND	ND	ND
S. Gertrudes	1.32	17	890.08	1,397.91	0.80
Rio Claro	1.6	10	1,042.20	733.20	0.70

ND – No data provided on this aspect.
Source: Research data.



Graph 2: The relationship between urban population and selective collection in relation to regular collection in %. *Source: Own creation*

Informal collectors in Analândia and in Ipeúna offer urban selective collection. Many studies pointed informal sector as important part of SWM in low and middle-income countries[50,6,1,26]. In Analândia, a family company provides a service that covers the entire urban area and provides packaging for recyclable waste. This family company reaches the highest worker efficiency and revenue. In Ipeúna, informal collectors collect in their own vehicles and have a shed of the city hall to carry out the sorting of the material. In Charqueada, Santa Gertrudes and Rio Claro there are low-income collectors associations (cooperatives) that offer the service in the urban area with help from city hall. Analândia, Corumbataí and Ipeúna achieve considerable values of selective collection in relation to regular collection. Rio Claro, Charqueada and Santa Gertrudes presented selective collection incidence around the Brazilian average of 2.2% [30].

In Corumbataí, the city hall offers the service through a program started 20 years ago. The incidence of selective collection on regular collection signals to the success of the selective collection program of the city council of Corumbataí that obtains 14.42% of recycling on the total collected by the regular collection. The success of a waste management system depends on the segregation at source, which is the result of the active participation of the generators. However, in developing countries, generators are not always known and often refer their waste to recycling without being accounted for by the system[6,42].

3.3. Informal collection

This study focused in identify a waste stream that is not accounted for by the formal management system, in this case the material purchased by recycling depots from generators and from informal collectors that go through urban area looking for recyclable materials. The recycling depots are commercial establishments that deal with population in general to buy recyclable material. For this studied it was investigated the recyclable material bought from people or commercial establishments as supermarkets, stores, bakeries, restaurants, etc, not from industries. The numbers found in this survey were investigated directly with people who buy the recyclable material in small private companies. These companies buy the recyclable material from informal collectors, who run through the surrounding streets of these companies collecting material left for the regular and selective collections or directly with the generating households. Depots also buy material from larger generators that market their waste and, therefore, send waste for recycling in an informal way that is not accounted for by the waste management system. These entrepreneurs are usually a family small company with few employees. The work of these business is responsible for divert tons of material from landfill every year in five of the six studied cities. Table 3 shows the investigated infrastructure of informal recycling.

Table 2: Infrastructure for collecting recyclable material via recyclable deposits

City	Recycling depots	Inhabitants perdepot	Informal recyclable recovery (t/hab.)	Incidence of informal recyclable recovery (%)	Recovered material through depots in relation to regular collection (%)
Corumbataí	0	-	-	-	-
Analândia	1	3,847	17.00	100	21.0
Ipeúna	1	6,177	20.40	100	10.0
Charqueada	1	15,216	2.10	20	0.66
S. Gertrudes	3	8,455	45.50	83	6.76
Rio Claro	14	14,144	511.40	88	12.27

Source: Research data.

In Rio Claro, the largest municipality investigated, the incidence of recycling through recyclable deposits corresponds to 88.45% of recycling capacity. High values for the participation of informal sector in the recycling process of the municipalities studied can be explained by large generators sending their waste for commercialization via the establishments that were investigated once it represents a recipe for their business.

The same was pointed out by Scheinberg et al. [26], who investigated informal recycling in cities in middle- and low-income countries and found that this work is carried out by families and family micro-enterprises that seek to recycle discarded material, a form of income. Informal recyclers rely entirely on recycling revenue and do not receive financial or social recognition of their work to recover materials that would otherwise go to landfill with waste management costs[1].

3.4. Recycling rate

The recycling rate indicated in this study take into consideration informal collection. Corumbataí generate the highest recycling rate per urban inhabitant (Table 4), this city has a large rural population that doesn´t have selective collection. Rural areas are usually the most difficult for city councils to attend with regular and selective collection. Analândia generates second high recycling rate, also has a large rural population that doesn´t have access to selective collection, but where the informal small family company acts in the urban area numbers for recycling rate show similar results from Corumbataí. Actually selective collections of both municipalities are similar, in Corumbataí city council distributes packages for recyclable materials and in Analândia informal collectors also distribute packages for recyclable material. Small municipalities in Brazil (up to 30,000 inhabitants) had a higher recycling rate per inhabitant (23.9 kg/hab. year) than other population groups and the national average (8.0 kg/hab. year)[30]. This fact can be explained by the greater participation of the informal collection in larger municipalities or even greater participation of generators in selective collection programs, which are common in the Brazilian municipalities.

Table 4: Recycling indicators

City	Recycling rate formal + informal (kg/person year)	Selective collection (kg/hab. year)	Total recovered for recycling (t/year)
Corumbataí	60.25	60.25	132.0
Analândia	53.03	53.03	204.0
Ipeúna	39.63	39.63	244.8
Charqueada	6.68	6.55	124.8
S. Gertrudes	26.65	4.21	652.8
Rio Claro	35.56	4.04	6,937.2
Average	42.73	27.95	Total 8,295,6

Source: Research data.

Source segregation is a fundamental step in the operation of an integrated solid waste system[42]. Attitudes of population to separate recyclable materials are affected by active support and real investments of management system, besides the existence of committees of public participation[52], or the existence of taxes and systems of collection by the waste management system[26].

3.5. Expenditure indicators

Analândia did not present data for the expenditure indicators. The numbers presented were reported by prefectures about public cleaning expenses. The values account for expenditures on selective waste collection in municipalities that offer formal selective waste collection, such as Corumbataí, Charqueada, Santa Gertrudes and Rio Claro. However, municipalities did not provide data on specific expenses with selective waste collection. Corumbataí presented the highest expenditure per kilogram (Table 4) and per inhabitant, but the lowest percentage of expenses with regular collection. Ipeúna obtained the lowest values of expenses per kilogram, but Charqueada presented the lowest values for expenses per inhabitant.

In low and middle-income countries, data are rare and little is known about informal sector participation in recycling[26], however, studies by UN-Habitat [1] suggest that recycling via the sector in developing countries can reach 15 – 35% of the waste generated in cities. Wilson et al. [12], however, found informal participation from 20 – 50%. These values can vary greatly from city to city, because in each place the waste system behaves in a way. Organization of informal sector and promotion of micro-enterprises is a way to increase recycling rates and also to reduce material sent to landfills[43,6]. Informal sector, in low and middle-income countries, increases recycling rates at the level of high income countries. Informal recycling is supported by revenues from trading recyclable materials only, with no aid from waste managers. This fact strongly differs from high-income countries, where levels of recycling rate has come at high costs[12].

Table 5: Expenditure indicators

City	Regular collection cost (R$/kg)	MSWM costs in relation to the total city hall costs (%)	Despesas por habitante (R$/hab year)	Despesas com a coleta regular (%)
Corumbataí	0,84	2,80	241,51	29,21
Analândia	ND	ND	ND	ND
Ipeúna	0,31	3,12	134,19	46,40
Charquea- das	0,26	2,45	67,05	ND
Gertrudes	0,55	4,96	180,60	62,60
Rio Claro	0,35	2,55	90,04	41,90
Average	0,46	3,18	133,20	45,01

ND – No data provided on this aspect.
Source: Research data.

3.6. Process flow diagram

Process flow diagram (Figure 2) synthesizes information obtained in investigated municipalities. Data on waste management systems in municipalities in a country with continental dimensions, such as Brazil, are scarce and difficult to collect due to the high degree of complexity generated by several factors that act concomitantly. In Brazil, legislation favors the creation of inter-municipal consortia to increase efficiency of waste management. Six Investigated municipalities comprise a river basin and have the potential to unite in order to face the challenge of properly managing their waste. Informal sector presented itself with anassembled structure able to contribute to increase recycling rates and consequent decrease of the costs and still increase useful life of landfills.

This study estimates approximately 8% of refuse are collected by the informal recycling of the total amount estimated for generation every year in the investigated cities. This value represents the amount of material that are diverged from landfill by waste pickers and generators that sell material to recycling depots.

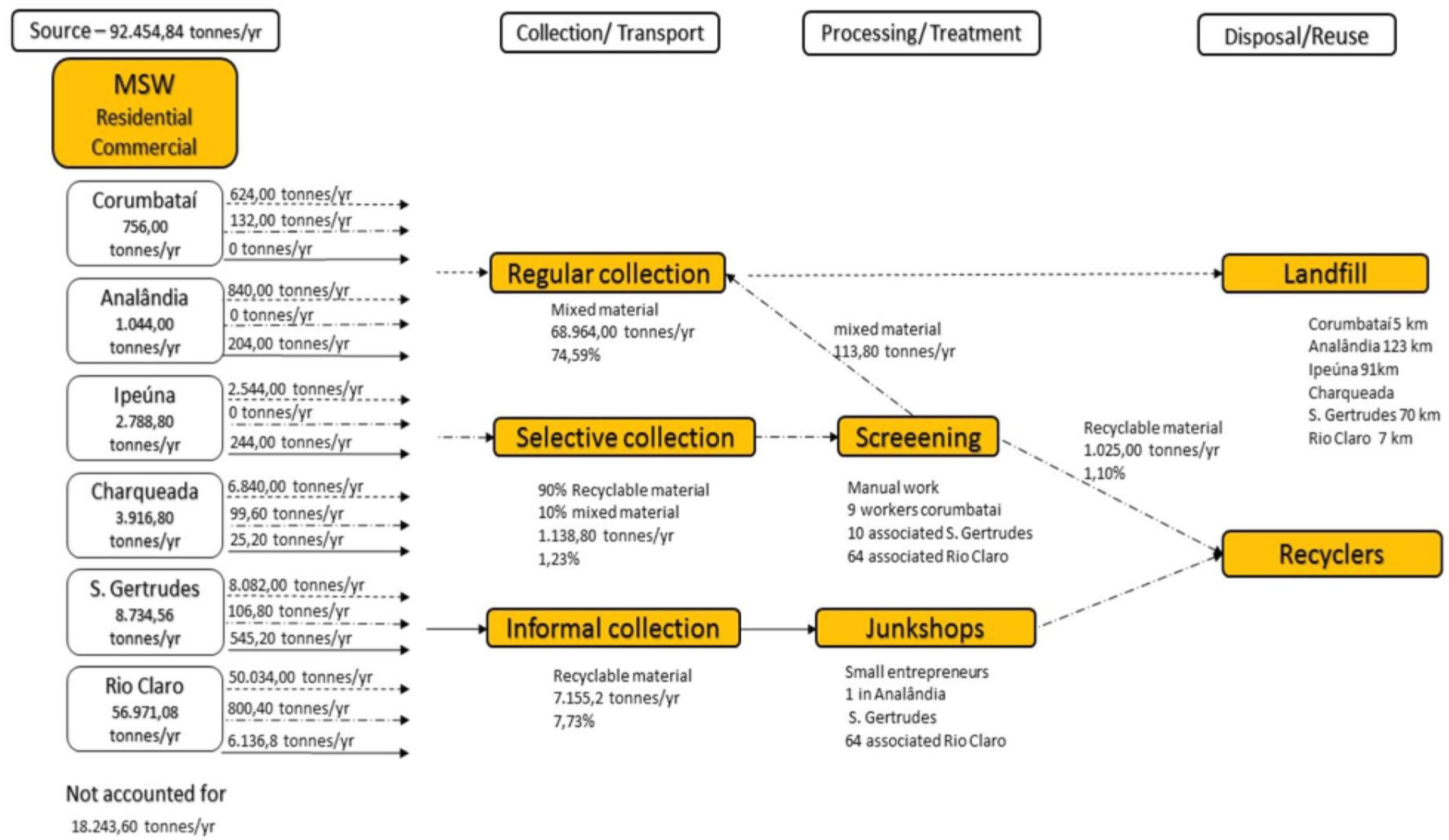


Figure 2: Process flow diagram. *Source: Own creation*

4. Discussion

Chung and Lo [7] highlight that municipal authorities are important actors once they formulate and implement local rules, decide waste management technologies and approaches. For that reason, they deserve more attention from researchers. In the studied cities local authorities must know that they have big infrastructure that supports many workers in different levels, also that these services are responsible for diverging tons of material from landfill. Greater effort is needed to enhance perceptions of complex issues and create a stronger foundation for decisions, in that way it is necessary to combine analysis and deliberation to improve social participation in waste management[53]. Source sorting and separation of waste is a fundamental step and determines the treatment and quality products of further steps[54,42,55].

Regular and selective collection don´t attend all rural population. Small cities studied with large rural population cannot attend all its population with simple regular collection. Corumbataí at the same time presents a successful selective collection program in urban area and part of inhabitants in rural areas do not have access even to regular collection. That is a challenge for low and middle income countries to offer regular collection service for all rural areas. Baran [63] investigated waste management practices in rural areas in Poland in the European context and identified some problems, including aversion of residents to waste sorting, helplessness of municipalities in battling illegal waste landfill sites, lack of infrastructure and ineffectiveness of educational campaigns. Zeng et al. [57] investigated rural household´s behaviors and perceptions of rural population in China and verified that most respondents are aware of the importance of source separation and are willing to participate to separation programs. The comparison of these studies suggest that different contexts demand different approaches, in one hand high income countries face more advanced issues, while in the other hand, low and middle income countries face simple question as to offer regular collection for all the population. In the studied cities, all urban areas are attended by selective collection. Informal sector offers organized selective collection service in two of the six investigated cities. The others cities presented high participation of informal collection through recyclable trading depots (junkshops). Informal sector is responsible for most of recycling in low and middle income countries, by definition this sector is left out of formal statistics[26].

Selective collection is efficient where the service is offered systematically with the distribution of recyclable packages to households and direct contact with generators is real. This fact reflects the action of the service with people through years of working on improve awareness of population about the organization of the selective collection. Many authors emphasize the education and optimize understanding about recycling methods as a form to improve source segregation and population participation[52,56,54,57].

The informal sector has large infrastructure and offers regular and reliable service to households end commercial establishments in at least three of six studied cities. Jaligot et al. [21] found that in the informal value chain-enterprises operating down-stream generate more revenue and are less vulnerable to market fluctuations, than the workers of upstream that deals with less quantities of material. In this context, authorities together with public and private sectors are frequently confronted with the dilemma of finding workable situations to encompass all the stake-holders involved[59]. Additionally, informal recyclers are exposed to a wide variety of hazards, due especially to poor working conditions and the lack of recognition for their profession by the system so the conditions can´t be improved[39,36,60]. In Brazil, the legislation already allows the formation of cooperatives for waste workers, that is an important initiative for integrating informal workers into the formal sector[61]. Not with standing, not all the scavengers get to be inside a cooperative and still go through the cities´ streets collecting recyclable material and selling it in recycling depots, this study sought to bring light to the work of informal workers and generators who sell selective material to recycling.

Specific charge policies can improve the performance of generators separation behavior[62]. It is important to highlight that improving efficiency in waste selective collection may lead to decrease the access to waste by scavengers[36,27]. Thereby municipalities must work on inclusive programs so that these people can at least be recognized by the system, these programs are related to integrate the recyclers that are willing to join the formal system, such as professional training, tax deduction, information, equipment and, about everything recognition[5]. Waste workers as scavengers and small family companies offer an important service for society and are not seen by formal system. The small fact of understanding it can provide better conditions for all the stakeholders involved.

The average recycling rate in selected cities is 10.8%. When aligning with recycling rates in European countries in the group of states favoring landfilling, it reaches 18.9% and achieves on average 44.4% [23]. Waste management strategy is one of the most important environmental policy strategies and it can be expected that the recycling rate will converge in the future between developing and developed countries.

5. Conclusion

The data collected in this study indicate significant contribution of informal sector in recycling activities of municipal solid waste. Despite some uncertainties in these assessments, it can be concluded, that informal paths collect a significant share of recyclables in the studied cities. This fact indicates that authorities can find a whole system with great infrastructure for recycling enhancement in the studied cities if take into consideration informal work when stablish waste management.

For this reason, more research is required to describe real participation of informal workers. Studies, which enable the impact of informal services to be assessed and predict the potential for introducing new inclusive policies, are necessary. To understand how informal workers really contribute to waste management in the studied municipalities and other cities in Brazil can reduce costs and support decision makers.

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Hodnocení systémů nakládání s komunálním odpadem pomocí indikátorů výkonnosti k analýze recyklační kapacity. Případová studie povodí Corumbataí ve státě São Paulo v Brazílii

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Souhrn

Analýza postupů nakládání s odpady je vícerozměrná výzva, které čelí orgány, zejména v rozvojových zemích, kde jsou zapotřebí opatření ke snížení množství odpadu, jeho opětovnému využití a zvýšení míry recyklace. Ukazatele výkonnosti se často používají k hodnocení kvality systémů nakládání s tuhým komunálním odpadem. Některé studie však naznačují, že různé případy vyžadují pro hodnocení kvality systémů řízení rozdílné ukazatele. Využitelných reálných údajů a dat od obcí je navíc nedostatek, zejména pokud jde o práci prováděnou neformálním sektorem, v rámci systémů nakládání s odpady.

Účelem této studie bylo analyzovat soubor indikátorů pro zkoumání recyklační kapacity šesti obcí ve vnitrozemí brazilského státu São Paulo. Důraz byl kladen na to, jak probíhá sběr materiálu k recyklaci. Analýza odhalila, že obce mají sice selektivní sběr prováděný v městských oblastech, který je prováděn různými způsoby, ale ne vždy s podporou veřejné moci. Provedená reálná studie ukazuje na velkou roli neformálního sběru na recyklační kapacitě zkoumaných měst. Tato studie odhaduje, že přibližně 8 % odpadu se shromažďuje neformální recyklací celkového množství odhadovaného na generaci a každý rok ve zkoumaných městech. Průměrná míra recyklace ve vybraných městech je 10,8 %.

Klíčová slova: *Nakládání s komunálním odpadem; ukazatele odpadu; neformální sektor; recyklace.*

Reducing the content of zinc in metallurgical waste in a rotary kiln

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Summary

Based on literature analysis, the design and subsequent implementation of the unique and experimental "Laboratory developed thermal equipment for treating metallurgical waste" was carried out. This experimental equipment is used for researching the heat treatment of metallurgical waste, especially in reducing the proportion of non-ferrous metals. This research work aids in the removal of harmful impurities in sludge and their possible reuse as charges in smelters or raw materials for other industries. Described here is the research work carried out on experimental equipment designed to reduce the content of zinc from sludge generated during steel production. Two methods for heat treating steelmaking sludge are described, the first without the addition of graphite and the second with the addition of graphite. Both thermal treatments show a high level of zinc removal, but in the case of adding graphite, the removal of zinc is several times higher compared to thermal treatment without graphite. The work was carried out as part of the project "Research on the processing of metallurgical waste, materials and by-products from metallurgical plants and related operations, number CZ.02.1.01/0.0/0.0/17_049/0008426".

Keywords: *waste, slag, sludge, lead, zinc, thermal treatment*

Introduction

This work provides information on the removal of hazardous impurities from sludge. Hazardous impurities include Zn and Pb, which accumulate in the dust that occurs during the smelting of scrap metal, e.g. in an electric arc furnace. The dust contains a large proportion of iron oxides, from which iron is obtained in an electric arc furnace (EAF) by reduction processes. However, there is also an accumulation of the so-called circulating elements, namely Zn and Pb, because these evaporate from the charge material during melting and accumulate in the trapped dust, which is returned to the EAF as a charge. Zinc and lead also accumulate in the lining and in the furnace components that are in contact with the exhaust gases, such as the electrode contact components.

Hazardous waste is also generated during the production of liquid steel in oxygen converters (referred to as BOF), on average about 20 kg of dust and sludge per ton of liquid steel. Much of this dust is easily recycled by agglomeration or in blast furnaces, but dust with a high zinc content is usually put in landfills. Hydrometallurgical techniques like alkaline leaching, which are often used to remove zinc from the dust of electric arc furnaces, are unsuitable for recovering material from BOF dust because of the lower concentration of zinc present in it and the other actions for reprocessing the separated iron product. Pyrometallurgical treatment using a rotary hearth furnace (RHF), in processes such as FASTMET®, can be viewed as a commercially viable option for the processing and regeneration of iron and zinc if they are used as part of an integrated steelworks. The raw zinc oxide produced can be sold as a raw material containing zinc, and the reduced iron can be used in blast furnaces and to increase productivity.[1]

According to the authors [2] this residue zinc oxide, consisting mainly of iron oxide contaminated with other metal oxides (including zinc and lead), is usually put in landfills at great economic and environmental cost. The author has come up with an alternative based on the principles of industrial ecology, which involves incorporating Waelz slag into clay ceramic building bricks. Using slag is advantageous and ecological, because the bricks produced in this fashion are basically ordinary waste after use and are not hazardous.

At present rotary kilns are widely used to remove Zn and Pb. Rotary kilns are very efficient, but place high demands on flue gas cleaning technology, because in most cases, the material is also heavily contaminated with organic and inorganic components. Dioxins and furans are released during the process and an additional flue gas cleaning system needs to be installed.[3]

Rotary kilns

The principle of RHF equipment, which is used mainly for drying, sintering, roasting, producing metal, etc., is used to research the processing of waste from metallurgical operations. The rotary kiln is only one part of a large unit, which is much larger than the kiln itself, because it also contains charge preparation, equipment for gas blowing, for cleaning flue gas, for the processing of the product from the furnace, see Figure 1.[3]

Industrial rotary kilns are heated by natural gas. According to the contact of the gas with the heated material, we devide rotary furnaces into two basic types. The first type is a furnace with indirect heating, where the gas and its products are not in contact with the heated material, see Figure 2. The second type is a furnace with direct heating, where the gas and its products are in contact with the heated material, see Figure 3.

The linings in the rotary kiln are made of refractory material, whether brick or cast.[2] When the material is heated directly by gas, the heat is transferred directly from the flame to the material. The temperature of the flame and its flue gases reaches 2100 °C.[4] The material is further heated by the radiation of the furnace itself and by heat conduction from the refractory material of the furnace, see Figure 4. When the material is indirectly heated, the heat is transferred to the material only by radiation from the inner shell of the furnace and by the conduction of heat from the inner part of the refractory lining of the furnace.

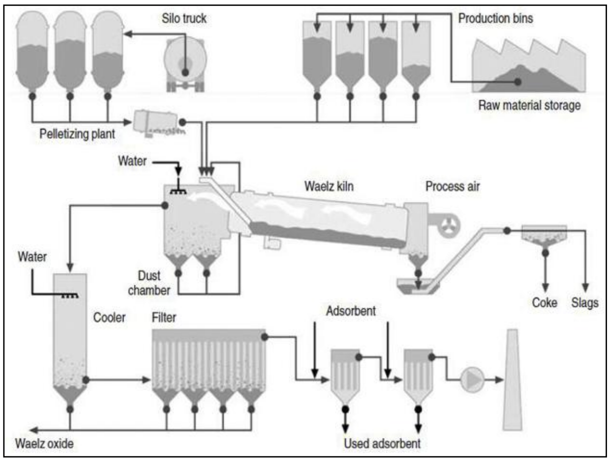

Figure 1: Flow chart of Waelz kiln process[3]

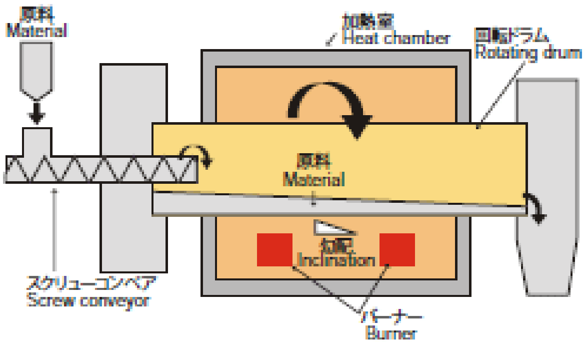

Figure 2: Rotary flame furnace with indirect heating[6]

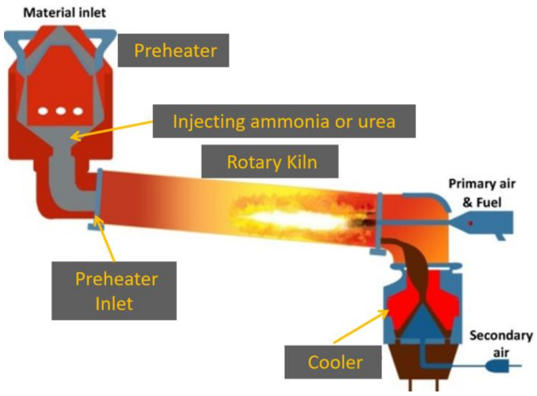

Figure 3: Rotary flame furnace with direct heating[5]

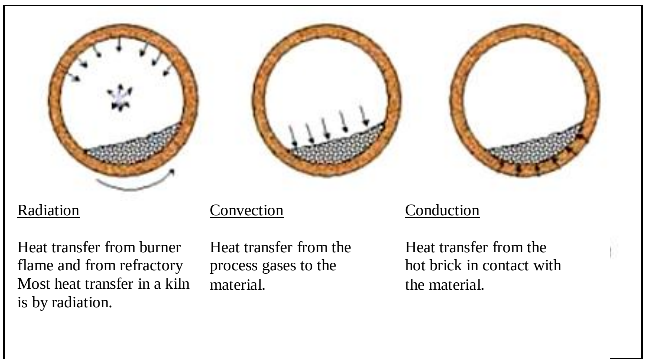

Figure 4: Heat transfer to the material in the furnace[8]

Current knowledge of removing Zn from dust

First the method of removing Zn using CO and O_2 is described, with the basic reaction in a rotary kiln presented in Figure 5. Due to the low boiling point, Zn evaporates at 907°C. The description of chemical reactions between Zn gas and oxygen is described by equations (1), (2) and (3) and in the charge by equations (4) to (9). [7]

The author [7] also mentions the removal of zinc from liquid slag in the furnace for producing lead with excess air and coal or coke. The reactions taking place in the furnace are clearly presented in Figure 6, and are occurring at a temperature of 1300-1500°C. When removing Zn in rotary kilns, the flame heats the atmosphere in the kiln up to a temperature of 2000°C and the material is heated from gas heated up to a temperature of 1500°C, see Figure 7[9]

Reaction in the gas phase (oxidizing):

$\{Zn\} + ½ \{O_2\} \rightarrow ZnO$ (1)

$\{CO\} + ½ \{O_2\} \rightarrow \{CO2\}$ (2)

$\{Zn\} + \{CO\} + \{O_2\} \rightarrow ZnO + \{CO_2\}$ (3)

Reaction in the charge (reducing):

$(ZnO) + \{CO\} \rightarrow \{Zn\} + \{CO_2\}$ (4)

$\{CO_2\} + C \rightarrow 2\{CO\}$ (5)

$(ZnO) + C \rightarrow \{Zn\} + \{CO\}$ (6)

$(FeO) + \{CO\} \rightarrow Fe + \{CO_2\}$ (7)

$\{CO_2\} + C \rightarrow 2\{CO\}$ (8)

$(FeO) + C \rightarrow Fe + \{CO\}$ (9)

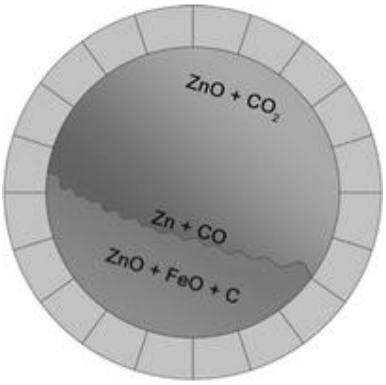

Figure 5: Main reactions in the Waelz kiln, reduction Zn[7]

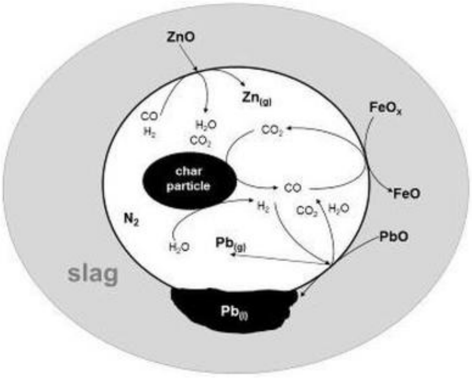

Figure 6: Reaction system occurring in the slag fuming process[7]

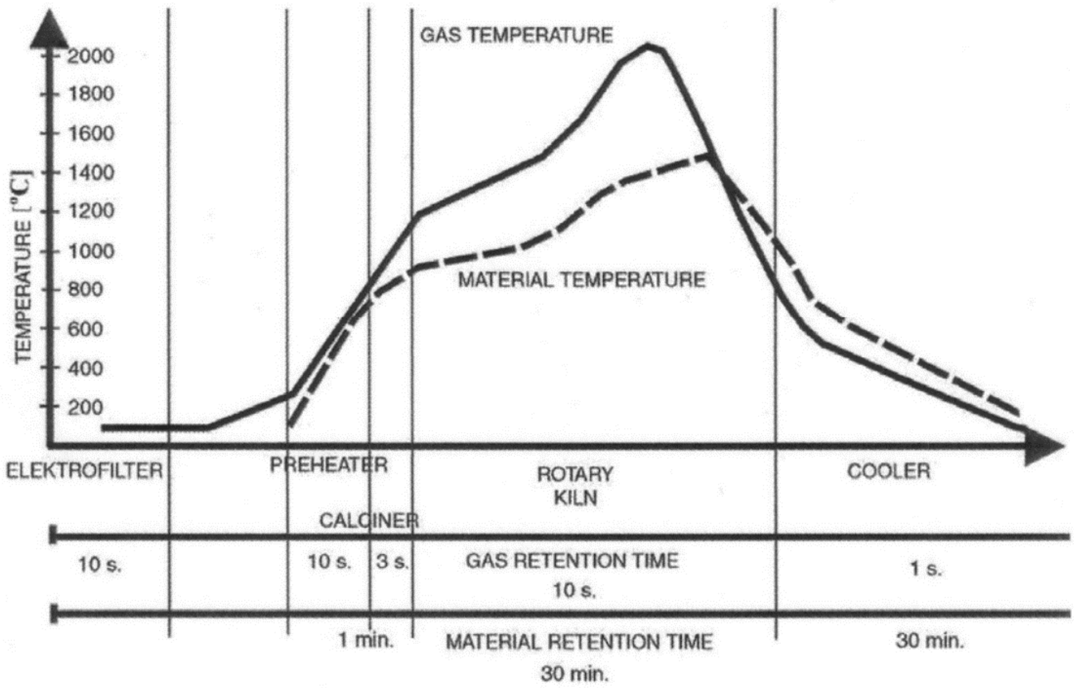

Figure 7: Diagram showing entrance points of AFR in the cement plant as well as temperature profile and retention time of gas and solids[9]

The second way to remove Zn is to use Cl at high temperatures. When removing Zn, the author [10] recommends using chlorides together with high temperature. Where Zn can be completely removed at temperatures in the range of 650 – 900 °C with the addition of 10 wt.% Cl, preferably at 1000 °C, the Zn is left in the form of $ZnCl_2$. The author also points out the negative effect of H_2O in the flue gas during the removal of Zn and, conversely, the positive effect of Si in the input raw material. The average composition of the atmosphere during the experiments was 3.0% CO_2, 18% O_2, 74% N_2 and 5% H_2O with an average gas flow of 12.7 $Nm^3.h^{-1}$ of CH_4 and 19.0 $Nm^3.h^{-1}$ of O_2.

According to the author [10], another very harmful element, Pb, is released in the form of the oxide PbO at above 850°C and without chlorination. When Cl is used, all lead components in the form of $PbCl_2$ are captured. If we increase the temperature to 1000 °C, up to 100% of Pb can be removed using only temperature control. The effect of temperature, the addition of Cl and other additives to remove undesirable elements have been grouped together by the author [9] in Table 1.

Table 1: Relevant parameters influencing the removal of heavy metals from sewage sludge ash by chlorination[10]

Heavy metals	Temperature	Cl addition	Cl availability	Major elements in the ash				Gas composition	
				Al	Ca	Fe	Si	H_2O	O_2
Cd	+	0	0	0	(+)	0	-	++	0
Cr	+	++	++	0	(-)	0	++	-	++
Cu	++	+	+	(+)	0	-	++	0	0
Ni	++	++	++	0	0	-	(-)	-	(-)
Pb	+	(+)	0	0	+	0	+	0	0
Zn	++	++	++	(-)	+	(-)	+	-	0

Note: ++ strongly positive influence; + positive influence; (+) low positive influence; 0 no influence; (-) low negative influence; - negative influence; -- strongly negative influence.

Design and implementation of the experimental equipment

The classic rotary kiln places high demands on temperature control in the kiln, on content control and flue gas cleaning, on the size of the furnace, reaction possibilities (oxidation and reduction), and especially on additional equipment for fuel gas preparation, extraction, etc. From the point of view of the experimental equipment, control and monitoring and accurate evaluations, better results are achievable using rotation using electricity and electricity as heat sources. Such a furnace makes it possible to very precisely control the temperature in the furnace, to control the composition of the gases entering the process, and to evaluate and monitor the output composition of the gases and their contents.

Based on the facts above and analyses of the processes taking place in rotary kilns, a design was made and a tender and subsequent production of the research equipment were carried out. The new equipment is officially called “Laboratory developed thermal equipment for treating metallurgical waste” (referred to as the rotary kiln) and it is shown in Figure 8. The rotary kiln is lined with fibrous ceramics with excellent thermal insulation properties and low heat accumulation. The inner space of the furnace is used for the placement of a sample of up to 400 mm long. The furnace is equipped with a removable corundum or quartz tube. The working environment of the furnace (tube) permits the choice of different types of atmospheres, including creating a vacuum inside it. The machine is equipped with a rotating mechanism driving the inserted tube with the option of setting the speed. The research samples can be inserted into a special ceramic cartridge, see Figure 9, which is then placed inside the tube and the tube itself inserted completely into the furnace. The furnace contains mass flow meters for the input agent with the possibility of switching and mixing gases. The furnace is equipped with an automatic control system to program increases and decreases in temperature, in vacuum, filling the furnace with gases and purging it with inert gas.

Figure 8: *Laboratory refining equipment for the thermal treatment of metallurgical waste*

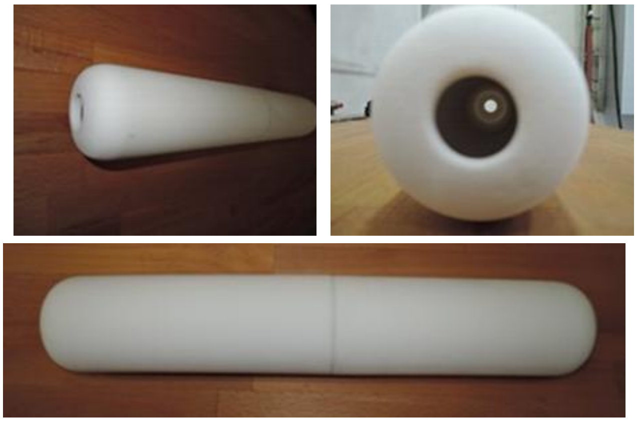

Figure 9: Special ceramic tube

The basic technical parameters of the rotary kiln are as follows:

- The internal diameter of the corundum tube is ϕ 80 mm and the length is 1200 mm,
- Indirect electric heating of the charge,
- Operating temperature range 400-1650°C, with the heating rate 50 – 200 $°C \cdot h^{-1}$,
- The weight of the charge based on granulate, briquettes, pellets ϕ 0.1 – 25 mm is 0.1 – 0.6 kg,
- The obtainable vacuum, more precisely the suction of the atmosphere, is below 50 Pa,
- The rotation of the tube varies continuously in the speed range of 0.1 – 20 min^{-1}, or samples can be heated without rotation,
- Gases are used that can be mixed in different proportions and blown into the furnace: CO, CO_2, O_2, air, N_2, Ar with a flow rate of 10 – 500 $ml \cdot min^{-1}$.

Experimental part

In the rotary kiln at MATERIAL AND METALLURGICAL RESEARCH Ltd., experiments were performed to reduce the content of undesirable impurities in steelmaking sludge generated during the production of steel in oxygen converters. The focus of the experiments was on the removal of Zn from sludge using a thermal process. The experiments were divided into two parts, where in the first series of experiments the samples of steel sludge were only thermally treated, and in the second series of experiments the samples were treated both thermally and at the same time graphite was added as a reduction element. The graphite was in the form of extra pure fine powder with a granulometry of 50 µm. In order to ensure a full reduction environment, a charge to graphite ratio of 1:1 was chosen for the first step.

Both series of experiments were performed with the same 100 g weight of steel sludge and a heating rate of the metal sample of 170°C.h^{-1}, holding at that temperature for 60 min, and a cooling rate of 170°C.h^{-1}. In order to maintain the same starting conditions for all experiments and the heating of the charge, the entire interior of the furnace was evacuated to 50 Pa after inserting the charge into the furnace and closing it. The entire interior of the furnace was then filled with an inert atmosphere composed only of nitrogen.

The steelmaking sludge was subjected to chemical analysis according to QI-ISO-LAB1-10-09 and according to QI-ISO-LAB1-10-04 on LECO CS 230, ARL X-ray and ADVANT´X devices.: 4.3% C, 0.11% S, 48.17% Fe overall, 1.12% MnO, 0.23% Cr_2O_3, 1.8% CaO, 2.20% SiO_2, 1,65% MgO, 3.33% Na_2O, 13.9% ZnO. The experiments showed there was a significant reduction in the content of C and ZnO, see Table 2. Table 2 shows the values of ZnO for 100 g of the charge, i.e. without the graphite reducing element. Table 2 also shows that during the thermal treatment of steelmaking sludge, the ZnO content decreases both without the addition of graphite and with the addition of graphite. In the first series of experiments without the addition of graphite, carbon is consumed in the reduction of ZnO and is subsequently evaporated. In the second series of experiments with the addition of graphite, the reduction in the ZnO content is more drastic even at low temperatures compared to the experiments where graphite was not added. At 700°C, the reduction in ZnO is almost twofold.

Table 2: Chemical composition of steel sludge samples after experiments

	Content C [wt.%]			ZnO content [wt.%]		
Temperature [°C]	700	1000	1100	700	1000	1100
1st series without graphite	3.9	1.5	0.04	13.66	9.11	0.99
2nd series with graphite	-	-	-	6.78	1.33	0.09

Results and discussion

The experimental work shows that the reduction of the content of ZnO can be achieved already during thermal treatment, at a temperature of 1100 °C. From an energy point of view, and therefore also from an economic point of view, the final ZnO content depends on the requirements that the company wants to establish in steelmaking sludge. At a temperature of 1000 °C, the addition of graphite makes it possible to remove seven times more ZnO than without the addition of graphite. The addition of graphite significantly increases the process of removing ZnO from steelmaking sludge, and a certain level of ZnO content can be obtained by using a control element together with temperature control. In a rotary flame furnace, graphite can be replaced by imperfect combustion, or by the addition of graphite or another suitable carbon-containing charge.

Conclusions

This work presents a literature analysis of the issue of reducing undesirable impurities in metallurgical waste, especially the reduction of Zn and Pb. Also presented is the project within which this work and investment have been carried out, the investment being called "Laboratory thermal equipment for treating metallurgical waste" (referred to as rotary kiln). The experimental work described in this work was focused on the reduction of ZnO content in steelmaking sludge in the production of steel in oxygen converters. Based on two experimental series of thermally treating sludge, the first without the addition of graphite and the second with the addition of graphite, it was found that with increasing temperature the effect of removing ZnO from sludge increases and this effect is significantly supported by the addition of graphite, which increases the effect at 1000 °C by up to 7 times.

Acknowledgements

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Možnosti snížení obsahu zinku v metalurgických odpadech v rotační peci

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Souhrn

Na základě literárního rozboru byl proveden návrh a následně realizace jedinečného experimentálního zařízení „Laboratorní termické zařízení pro hutní zpracování odpadů“. Experimentální zařízení slouží pro výzkum tepelného zpracování metalurgického odpadu, zejména při snižování podílu neželezných kovů. Výzkumné práce vedou k odstranění škodlivých příměsových prvků v kalech, aby bylo možné jejich následné využití jednak opětovně v hutích jakožto vsázky, nebo jako vstupní suroviny pro jiné průmyslové odvětví.

Jsou popsány výzkumné práce realizované na experimentálním zařízení, které vedly ke snížení obsahu zinku z ocelárenských kalů vzniklých při výrobě oceli. Popsány jsou dva způsoby termického zpracování ocelárenského kalu, první bez přídavku grafitu a druhý s přídavkem grafitu. Oba termické způsoby zpracování vykazují vysoký stupeň odstranění zinku, ale v případě přídavku grafitu je odstranění zinku několikanásobně vyšší oproti termickému zpracování bez grafitu. Práce byly realizovány v rámci projektového záměru s názvem „Výzkum zpracování hutního odpadu, materiálů a vedlejších produktů z metalurgických a souvisejících provozů číslo CZ.02.1.01/0.0/0.0/17_049/0008426“.

Klíčová slova: *odpad, struska, kaly, olovo, zinek, tepelné zpracování.*

A magnetic hydrophobic sorbent for removal of oil products from water surface

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Abstract

In this article, a development of a hydrophobized sorbent with a silica gel matrix and incorporated magnetite particles is described, porosities and surface areas are measured by nitrogen sorption and desorption isotherms both at pure silica gels and sorbents with incorporated magnetite particles. For a precipitation of silica gel from potassium water glass, four different diluted acids were used (sulphuric, nitric, hydrochloric and acetic). Nitric and sulphuric acids showed the best results, because silica gels from both these acids contained about 1 cm^3 of pores per 1 g with a size in the mesopore range. Moreover, the precipitation of silica gel with nitric acid provided the silica gel with surface area above 900 m^2/g, which is almost 1¾ times more than in the case of the silica gel prepared from sulphuric acid. Silica gels prepared from all four acids were formed by extrusion with 10, 20 and 30 g of magnetite per 100 g of silica gel dry matter. All silica gel extrudates with magnetite particles were also measured by nitrogen sorption and desorption isotherms to determine their surface area and porosity data. A correlation between magnetite contents and porosities was not obvious. Anyway, for needed magnetic properties to collect the sorbent from water surfaces, 10 g of magnetite per 100 g of silica gel dry matter were sufficient. Silica gel extrudates were hydrophobized by silanization with hexadecyltrimethoxysilane and then tested for a sorption of Diesel fuel spills from water surfaces. The extrudates caught roughly 1.3 g of Diesel fuel per 1 g of the sorbent with a sorption efficiency 90%.

Keywords: *hydrophobic magnetic sorbent, silica gel, Diesel fuel*

Introduction

Oil spills on water surfaces belong to serious ecological disasters involving immediate and cheap solutions with regard to large volumes of oil products penetrating to waters from damaged tankers, ships and other accidents. Among various methods of ecological disposal of such contaminations, mechanical methods by using special devices take place[1], various barriers such as booms made of fences and other fire resistant tools[2] can help very effectively, too. In the case of large contaminated areas, burning can be the cheapest method. Anyway, not always such combustion processes are proper or even possible. Chemical treatment of oil spills by various dispersants is utilized as well, but this method is not very cheap[3], especially when synthetic polymers are applied[4]. Moreover, these polymers are not very useful for larger and thicker spills. For oil removal, many sorbents of various natures have been utilized for many years. For sorption of fuels and oil products, both organic and inorganic materials are used[5-7]. Inorganic sorbents are based on natural zeolites, clays and similar materials, silica, alumina etc.[8] Synthetic polymers based on polypropylene or polystyrene foams are advantageous for their natural hydrophobicity and higher sorption capacity than inorganic sorption materials have[6]. Anyway, their drawback lies in prices, non-biodegradability and incompatibility with environment[9].

Nowadays, various cheaper natural materials as cellulose, keratin, agricultural waste, and similar materials become topical and promising sorbents for oil and fuel contaminations[10, 11]. These biopolymeric sorbents interact with oil and fuels by several mechanisms including van der Waals forces, interaction with hydrogen atoms, polar interactions and also chemical bonds. Both adsorption on surfaces of sorbents and absorption into their pores take place[12-14]. Firstly, the contaminant reaches the surface of the sorbent and then it penetrates into its pores, where hydrophobicity and lipophilicity of the sorbent play a very important role[15, 16].

Among biopolymers, cellulose with glucose as its main structural element, usually organized into fibrous matrix with hemicellulose and lignin[17], became popular probably for its availability due to its large production in the world. Wastepaper, fibres from Kapok tree, banana tree, cotton and various agricultural waste can be promising available sources of cellulose sorbents[18-23]. On the other hand, these materials involve further modification to become oleophilic and hydrophobic[24]. Anyway, low hydrophobicity of cellulose remains its main drawback for sorption of oil and fuel contaminants. To overcome this problem, porous cellulose aerogels were developed. Their advantage lies in low density and low price. For sorption processes, also keratins with collagen, contained in animal bodies and available as waste from poultry farms and industrial plants for a treatment of animal residues, can be utilized as natural biopolymers[25-27].

To assume advantages and drawbacks of various sorption materials, comparative tests are needed. When several biomass sorbents (kapok and cattail fibre, rice and coconut husk and bagasse) were tested in comparison with commercial synthetic polyester fibre in bench-scale experiments, polyester provided lower sorption capacities for oil than most biomass sorbents and released more oil than all biomass sorbents[28].

Sorption properties of not only biological sorption materials are also influenced by their particle size as a main factor of their external surface. Goat hairs and coconut husk were utilized for capture of oil and fuel spills with a contact time 90 min. Besides particle size, molecular weight (chain length) and activation were investigated, too. Activation and small particle size had a big importance in sorption features. Oil and fuel contaminants were sorbed in the order crude oil > diesel > kerosene > petrol. Activated keratine coming from goat hairs sorbed more contaminants than coir[29].

Furthermore, other natural polymers provide also promising capability of oil capture, if they are hydrophobic and porous enough. Very good results were reached with porous rubber gel, based on liquid natural rubber[30].

To compare various natural, organic and non-conventional, but cheap inorganic materials for capture of various contaminants, a study with peat, wood chips, cement mixtures, road gritting materials, lime, and limestone crumbling was done. Investigated contaminants included diesel, gasoline, alkali hydroxide, ammonia and acids. Among studied sorbents, every material found its application for some of the wide series of contaminants[31].

Today's trend turns from synthetic sorption materials (e.g. Corexit and similar dispersants) for oil removal to eco-friendly sorbents based on biomass, various sponges and aerogels etc.[32]. Among natural, non-toxic, cheap and biodegradable sorbents, a porous dendrimer structured sorbent (HF-D) from orange peels belongs to noticeable[33], despite it is not suggested for oil removal. Another example is a modified chitosan with oleoyl-carboxymethyl groups which bring about amphiphilic features[34]. Besides bioorganic substances, also hydroxylapatite as an utterly non-toxic and biocompatible inorganic material can be beneficial as a sorbent of toxic organic substances from water (e.g. parabens) for its naturally porous structured agglomerates consisting of nanocrystals. Hydroxylapatite can be modified by γ-Fe_2O_3 for easy magnetic separations[35]. Hydrophobized aquatic plants (eichhornia crassipes) with magnetic nanoparticles were also prepared as a promising sorbent for removal of oil spills[36]. Plant waste (e.g. sawdust) were also utilized for a manufacture of hydrophobic carbon foam with a honeycomb structure with applications in oil capture from water[37]. Anyway, for cleaning environment from oil spills, propoxylated glycerol as a lipophilic gel is efficient and reusable[38], too. Altogether, various materials have assorted sorption capacities for oil spills: hollow carbon spheres 10 g/g, lignin modified aerogel 20 – 40 g/g, polylactic acid 14 – 34, and some sophisticated sorbents can catch even about 100 g/g[36].

In this article, a preparation method of a magnetic hydrophobic sorbent with silica gel as an active component is described and sorption properties for capture of Diesel fuel are tested. This sorbent is suggested for a capture of oil spills from water surfaces.

Experimental

Note: In this chapter, % always stands for weight percent.

Chemicals

Potassium water glass containing 26.5% of SiO_2 and 24.0% of K_2O made in Vodni sklo, jsc, Czech Republic

Acids for precipitation (all made in Lach-Ner, ltd., Czech Republic):
sulphuric acid p.a. (96% of H_2SO_4)
hydrochloric acid p.a. (35% of HCl)
nitric acid p.a. (65% of HNO_3)
acetic acid p.a. (99.8% of CH_3COOH)

Magnetite Fe_3O_4 FEPREN B630 by Precheza, jsc, Czech Republic

Preparation of silica gel

Silica gel was prepared by precipitation of potassium water glass with several acids (all made in Lach-Ner, ltd., Czech Republic): sulphuric acid (96% of H_2SO_4), hydrochloric acid (35% of HCl), nitric acid (65% HNO_3), and pure anhydrous acetic acid. Before use, the acids for precipitation were diluted with water as it is given in the Table 1.

Table 1: Dilution of acids for potassium water glass precipitation to silica gel

Silica gel	Precipitating acid, its final concentration	Weights of acid and water to mix
2V	24% H_2SO_4	25 g of 96% H_2SO_4 + 75 g of water
3V	23.33% HCl	200 g of 35% HCl + 100 g of water
4V	21.67% HNO_3	100 g of 65% HNO_3 + 200 g of water
5V	50% CH_3COOH	501 g of 99.8% CH_3COOH + 499 g of water

Precipitation of silica gel

Potassium water glass (200 g) was diluted with distilled water (1000 g), a pH electrode was immersed and a solution of one of the precipitating acid, prepared according to Table 1, was added dropwise down to pH 5 while stirring. Arisen silica gel was separated on a filter, rinsed with water to neutral pH and let on the filter overnight. Then the cake was saved in a waterproof bag and a content of dry matter (given in the Table 2) was determined in a small sample by drying at 105 °C overnight and then 2 hours at 135 °C. In this dry sample, physical sorption and desorption isotherms of nitrogen were measured to determine surface area, a total volume of pores and a volume of mesopores. In this way, four types of silica gel were prepared from potassium water glass precipitated by four different acids. Surface areas of silica gels were calculated by BET method, total volumes of pores and volumes of mesopores by NLDTF analysis. It is appropriate to note, that the content of dry matter in wet silica gel, determined by drying in two steps as above described, was also assumed equal to the content of SiO_2 in the wet silica gel, as other impurities were present only in negligible trace amounts after thorough washing.

Preparation of silica gel extrudates with magnetite

From silica gels precipitated by various acids, extrudates with various magnetite doses (10, 20, and 30 g per 100 g of silica gel dry matter) were prepared (see Table 2). Silica gel wet cake amounts containing 100 g of dry matter (dry matter contents are given in the Table 2) were blended in a liquidiser with magnetite Fe_3O_4 (made in the Czech Republic, Precheza company, under a trade mark FEPREN B630) in amounts given in the Table 2. Then this mixture was dried at 60 °C in a laboratory dryer to evaporate 65 – 70 g to make the paste thicker. After that the paste was cooled, 2 g of 25% tetramethylammonium hydroxide solution (TMAOH) were added and after blending this paste was pushed in a snail extruder through a matrix with circular slots of 2.5 mm diameter. Arisen extrudates were dried overnight at 90 °C and then at 135 °C for 2 hours. After drying the diameter of extrudates decreased to 2.2 mm, their average length was in the range 0.6-1.2 cm. All these extrudates were collected by a magnetic bar to test their magnetic properties.

***Table 2:** Doses of magnetite to silica gels with various dry matter contents*

Silica gel	% of dry matter	Fe_3O_4/silica	added Fe_3O_4
2V	9.5	0.10	0.95 g
		0.20	1.90 g
		0.30	2.85 g
3V	8.8	0.10	0.88 g
		0.20	1.76 g
		0.30	2.64 g
4V	8.8	0.10	0.88 g
		0.20	1.76 g
		0.30	2.64 g
5V	11.2	0.10	1.12 g
		0.20	2.24 g
		0.30	3.36 g

Hydrophobization of magnetic silica gel extrudates by silanization

Silica gel magnetic extrudates were silanized in a round bottom flask under reflux. Inside the flask, a stainless steel perforated basket with extrudates was stirred in a solution of hexadecyltrimethoxysilane (1.0 g) in methanol (100 mL) by a magnetic stirrer (500 rpm). The flask was immersed in oil bath and heated. After reaching 72 °C in oil bath and 65 °C in the flask, silanization ran 4 hours. After that silanized extrudates were let dry in the air and saved in a plastic bag.

Sorption tests of Diesel fuel spills

Silanized magnetic sorbent containing 10 g of Fe_3O_4 per 100 g of silica (2.0 g) was dried at 60 °C for 2 hours to evaporate residual methanol from its preparation. Meantime, beakers of 50 mL volume with 25.0 g of distilled water and Diesel fuel spills on water surface were prepared. In three pairs of experiments, 2, 3, and 4 g of Diesel fuel were added to create spills. Then the whole dose of dry sorbent (2 g) was thrown on the surface of liquid inside every beaker, the beaker was covered with parafilm to prevent its content from evaporation and let for 24 hours (sorption time) at laboratory temperature. For the whole time the sorbent was on the surface and no particle dropped down, so silanization was fully successful. After the sorption time all magnetic sorbent was collected by a magnetic rod and immersed into a vial with 10 mL of acetone, the vial was closed and thoroughly agitated. Then the liquid was poured away through a filtration funnel into a 100 mL volumetric flask, new acetone (10 mL) was added to the sorbent remaining still in the vial, after capping the vial was agitated again and the liquid poured into the same 100 mL flask. The whole process was repeated once more to extract all captured Diesel fuel in the sorbent. Finally, all the sorbent was poured on the funnel, washed with acetone into the 100 mL flask, the flask was filled with acetone and agitated. Diesel fuel in acetone solution in the flask was analysed by gas chromatography to determine sorption capacity and efficiency of the magnetic silica gel sorbent. Besides that, a full sorption capacity of the sorbent was determined. The sorbent of a precise weight was immersed in Diesel fuel overnight, then it was separated by magnetic rod, let free of redundant fuel on a frit for 15 min without vacuum and weighed again.

Besides that, a full sorption capacity was determined. Silanized magnetic sorbent containing 10 g of Fe_3O_4 per 100 g of silica (2.0 g) was dried at 60 °C for 2 hours to evaporate residual methanol from its preparation. Then the dry sorbent was transferred into a beaker with 10 g of Diesel fuel, covered with parafilm and let overnight at laboratory temperature. After that, the sorbent was collected by a magnetic rod and transferred into a vial with 10 mL of acetone. After short shaking, all the content of the vial was poured on a frit and the liquid was taken into a 100 mL volumetric flask. The sorbent on a frit was washed with acetone and finally the flask was filled with acetone.

Results and Discussion

Results of surface areas and porosity data for all pure silica gels are in the Table 3. Both total pore volume and volume of mesopores reach the highest values for silica gels precipitated from sulphuric (2V) and nitric acid (4V). Anyway, the silica gel from nitric acid has significantly higher surface area and therefore is the best.

Table 3: Surface areas, total pore volumes and volumes of mesopores in silica gels

Precipitating acid, its concentration	Silica gel	Surface area, m^2/g	Total pore volume, cm^3/g	Volume of mesopores, cm^3/g
24% H_2SO_4	2V	539.9	1.117	1.069
23.33% HCl	3V	476.1	0.675	0.674
21.67% HNO_3	4V	935.7	1.015	0.995
50% CH_3COOH	5V	755.9	0.875	0.680

In the Figures 1 – 3 (bellow) dependences of surface areas, total volumes of pores, and volumes of mesopores of all silica gels on magnetite concentrations are given. Incorporation of magnetite into silica gel causes a significant decrease in surface area to very similar values. All the differences in surface area among individual silica gels diminish even with 10 g of Fe_3O_4 per 100 g of SiO_2 and remain very similar also with 20 and 30 g of Fe_3O_4 per 100 g of SiO_2. Porosity data provide slightly bigger differences. In the case of two silica gels (4V from nitric acid and 5V from acetic acid), total volumes of pores and also volumes of mesopores are higher with 20 g of magnetite per 100 g of silica than with a half of magnetite (in relative values about 15% higher) and rather close to corresponding values of pure silica gels.

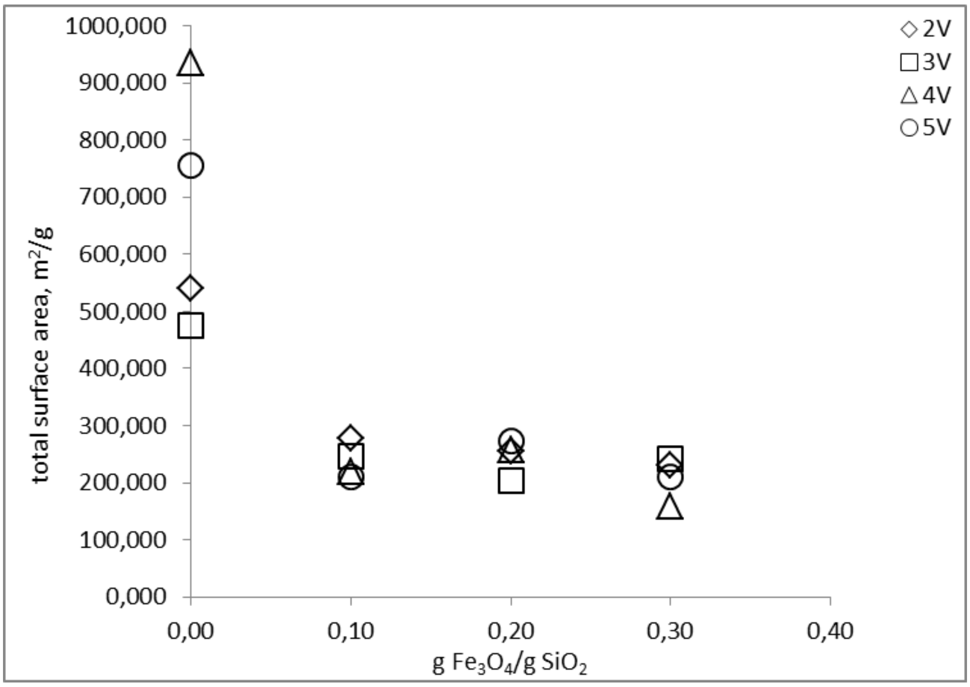

Figure 1: Dependence of surface area of all silica gels on magnetite concentration

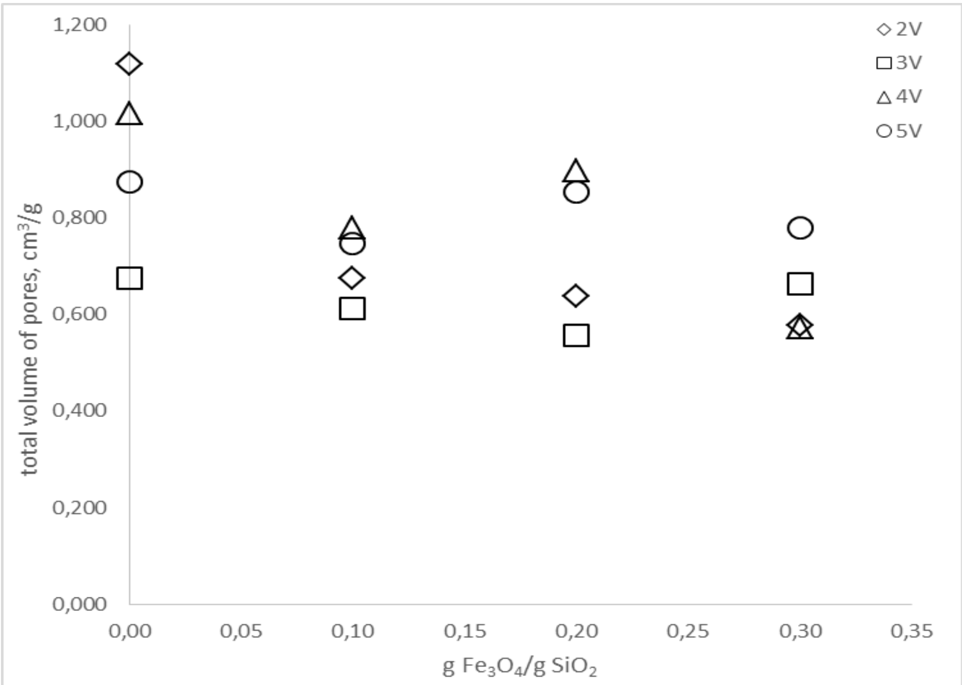

Figure 2: Dependence of total volume of pores of all silica gels on magnetite concentration

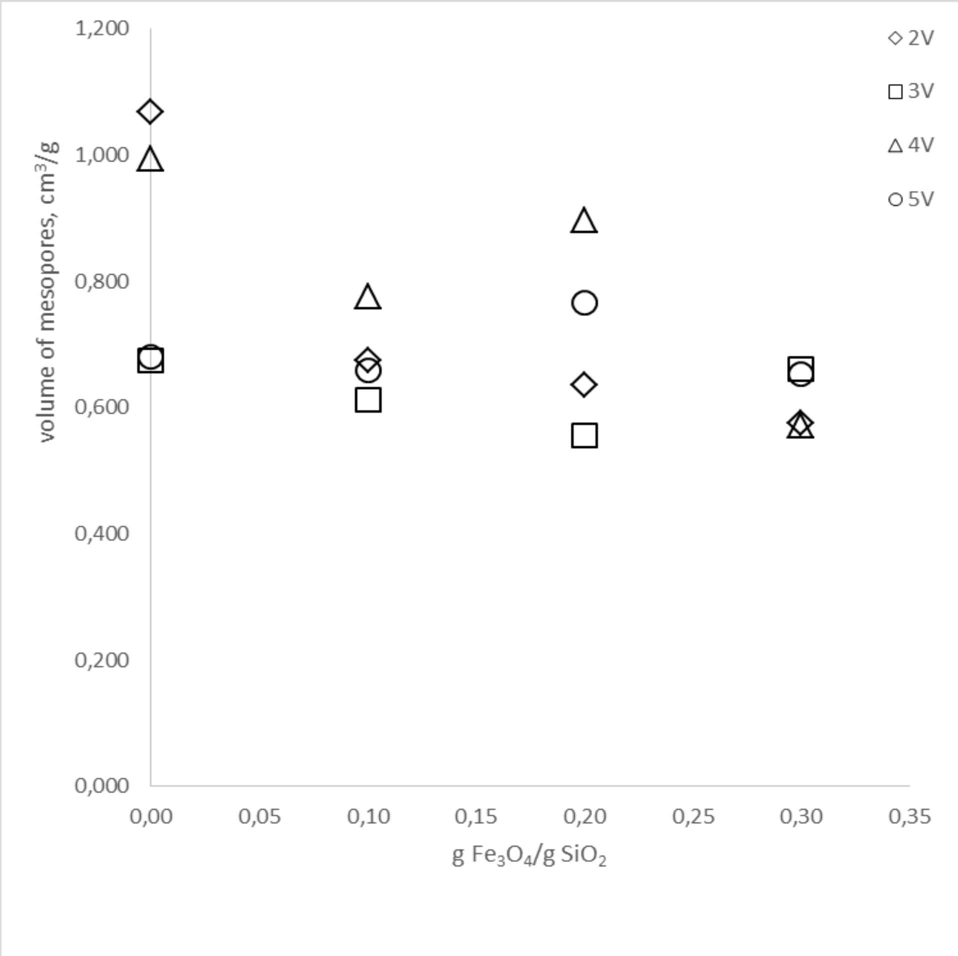

Figure 3: Dependence of volume of mesopores of all silica gels on magnetite concentration

With respect to all results, extrudates prepared from silica gel precipitated by nitric acid with 10% of magnetite were chosen for silanization and capture of Diesel fuel spills. The results given in the Table 4 were achieved with this sorbent, containing silica gel precipitated by nitric acid, extruded with 10% of magnetite and silanized.

Capacity and efficiency of silanized magnetic silica gel for sorption of Diesel fuel spills from water surface

A full sorption capacity of the sorbent for Diesel fuel was 1.435 g/g of the sorbent. In the Table 4, results of sorption experiments are given. Each of three pairs of sorption tests, with 2, 3 and 4 g of the fuel and 2 g of the sorbent, was done with a different saturation of the sorbent with respect to its capacity. From these pairs, average values and relative deviations of individual values from them (%) were calculated. Average values, given under each pair of tests, show, that when the amount of the fuel corresponds to 70% of the sorbent capacity, about 97% of all the fuel is caught. If the quantity of the fuel exceeds 100% of the sorbent capacity only a bit (104%), still nearly 90% is sorbed. Only when the fuel amount exceeds the sorbent capacity significantly, (about 140%), less than 60% of the fuel spill from water surface can be removed. To conclude, if 90% of Diesel fuel spill shall be sorbed, at least 1 g of the sorbent per 1.5 g of the fuel is needed. This dependence is illustrated in the Figure 4 and the experimental points are interpolated by a polynomic curve of the 2nd degree.

Table 4: Weights of sorbents and added Diesel fuel, sorbed amounts per 1 g of the sorbent and sorption efficiency

$m_{sorbent}$ g	m_{fuel}, g	% of capacity	m_{sorbed}/g of sorbent	% of sorption	rel. deviation, %
2.013	2.025	70.1	0.974	96.8	0.16
2.014	2.020	69.9	0.968	96.5	- 0.16
average % of capacity		**70.0**	**average % of sorption**	**96.65**	
2.011	3.006	104.2	1.353	90.5	1.44
2.056	3.014	102.2	1.289	87.9	- 1.44
average % of capacity		**103.2**	**average % of sorption**	**89.2**	
2.002	4.003	139.3	2.270	56.7	1.11
2.028	4.040	138.8	2.342	58.0	- 1.11
average % of capacity		**139.1**	**average % of sorption**	**57.3**	

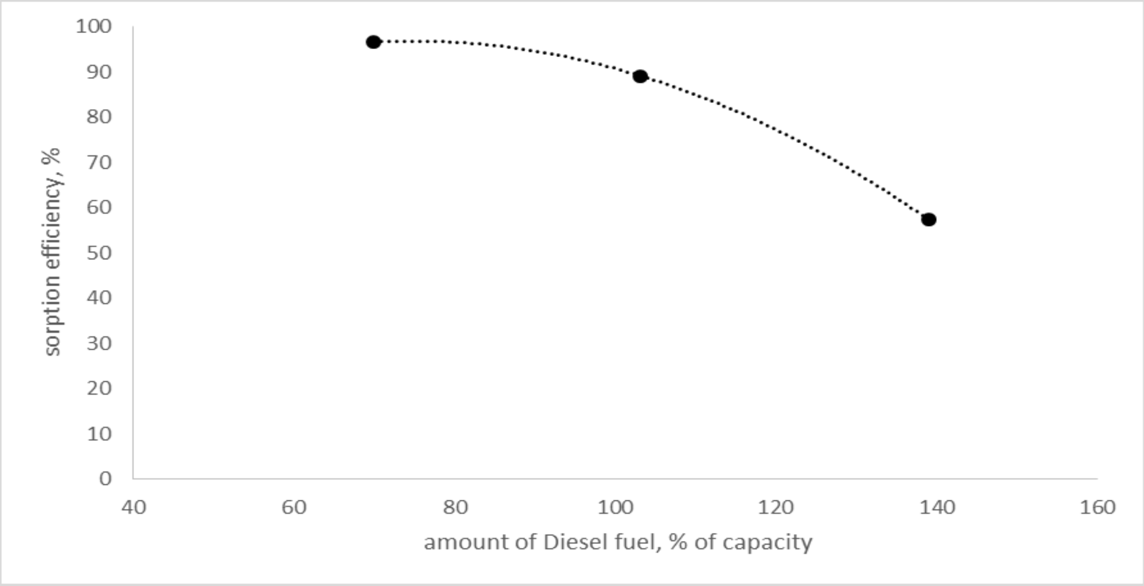

Figure 4: Dependence of Diesel fuel sorption efficiency by magnetic hydrophobic silica gel sorbent on amounts of Diesel fuel, expressed as % of the sorbent capacity

Conclusions

A new hydrophobic magnetic sorbent, for capture of oil or fuel spills from water surfaces, was developed. Its sorption active component is a highly porous silica gel, incorporation of magnetite provides magnetic properties and silanization enables floating on a water surface without immersing even a part of the sorbent. The sorbent was tested in Diesel fuel spill capture from water surface with efficiency in fuel sorption about 90%. Nevertheless, if roughly 90% of Diesel fuel spill shall be sorbed, at least 1 g of the sorbent per 1.5 g of the fuel is needed. Such a sorption capacity is not very high, especially in comparison with published materials mentioned in the penultimate paragraph of Introduction. On the other hand, this sorbent is made from non-toxic materials, environmentally friendly, and can be made rather simply from cheap raw materials, so its drawback can be overcome.

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Magnetický hydrofóbní sorbent pro odstraňování ropných produktů z vodní hladiny

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Souhrn

Je popsán vývoj hydrofobizovaného sorbentu se silikagelovou matricí a zabudovaným magnetitem, byly proměřeny porozimetrické údaje i měrný povrch metodou izoterem fyzikální sorpce a desorpce dusíku, a to jak u připravených silikagelů, tak i s přídavkem různých množství magnetitu. Pro srážení silikagelu z draselného vodního skla byly použity čtyři různé naředěné kyseliny (sírová, dusičná, chlorovodíková a octová), z nichž se nejlépe osvědčily kyselina dusičná a sírová, neboť silikagel z nich připravený v obou případech obsahoval zhruba 1 ml pórů/g téměř výhradně o velikosti mezopórů. Srážení kyselinou dusičnou nadto poskytlo silikagel s měrným povrchem nad 900 m^2/g, tedy téměř 1¾ násobek povrchu silikagelu připraveného z kyseliny sírové.

Silikagely připravené ze všech čtyř kyselin byly tvarovány extrudací s přídavkem 10, 20 a 30 g magnetitu na 100 g sušiny silikagelu, u vzniklých extrudátů s magnetitem byly rovněž proměřeny porozimetrické údaje a měrný povrch. Závislost na množství přidaného magnetitu nebyla jasně patrná, nicméně pro dosažení potřebných magnetických vlastností pro sběr sorbentu z vodní hladiny postačoval přídavek 10 g magnetitu na 100 g sušiny silikagelu. Silikagelové extrudáty s magnetitem byly hydrofobizovány silanizací hexadecyltrimethoxysilanem a poté vyzkoušeny k sorpci motorové nafty pro Dieselovy motory z vodní hladiny. Sorbent zachytil zhruba 1,3 g nafty na 1 g sorbentu s účinností sorpce 90 %.

Klíčová slova: *hydrofóbní magnetický sorbent, silikagel, nafta do Dieselových motorů*

Využití minerální izolace v obvodovém plášti budovy s ohledem na jeho následnou recyklaci

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Souhrn

Článek prezentuje výsledky výzkumu zaměřeného na vývoj obvodových plášťů budov z recyklovaných surovin a s potenciálem opakovatelné recyklace. Důraz je kladen na maximální využití stavebního a demoličního odpadu a úsporu nerostných surovin, zejména při realizaci nosných konstrukcí a exteriérových zateplovacích systémů. Navržený obvodový plášť sestává ze zdicích bloků a tepelné izolace z minerálních vláken. Bloky byly vyrobeny z recyklovaného jemně mletého betonu. Skladba zateplení byla navržena ve dvou variantách s ohledem na její následnou recyklaci.

V Experimentálním centru energeticky efektivních budov (UCEEB) ČVUT v Praze byl v říjnu 2020 realizován obvodový plášť o ploše 10 m², který je exponován reálným podmínkám vnějšího prostředí. V současné době probíhá jeho dlouhodobý monitoring, který se soustřeďuje na analýzu teplotně-vlhkostního chování a s tím související materiálovou degradaci. Průběžná data ukazují, že obě navržené skladby kopírují chování v současnosti běžně používaných stavebních materiálů. Celá konstrukce tak vykazuje potenciál vícenásobné recyklace, včetně kontaktního zateplovacího systému. Na podzim tohoto roku dojde k její demolici a následné kompletní recyklaci. K těmto účelům bude použita nově vyvinutá linka na recyklaci tepelné izolace z minerálních vláken.

***Klíčová slova:** Stavební a demoliční odpad, Recyklace, Obvodový plášť, Zdicí bloky, Cementový kompozit, Zateplovací systémy, Tepelně-vlhkostní chování.*

Úvod

Snahy o materiálové úspory a šetrný přístup k životnímu prostředí se znatelně dotýkají všech průmyslových odvětví. Významnou oblast zájmu v tomto ohledu tvoří stavebnictví, které je extrémně závislé na těžbě a využití nerostných surovin. Dle odhadů se jich v ČR spotřebuje zhruba takové množství, jaké odpovídá všem dalším průmyslovým sektorům dohromady. Kritickou surovinou se tak staly stavební kámen a štěrkopísek, které jsou zařazeny do kategorie neobnovitelných zdrojů. Situaci navíc zhoršuje nevole veřejnosti k zakládání nových a rozšiřování stávajících lomů. Není tedy překvapením, že se v ČR za posledních třicet let neotevřel žádný nový kamenolom i přes to, že ložisek vhodných k těžbě je stále dostatek[1].

Ohroženým výrobkem se tak mohou stát tepelné izolace z minerálních (nejčastěji skleněných a čedičových) vláken. Na trhu s tepelně izolačními materiály zastupují cca 60 % veškeré produkce[2]. Dle databáze Eurostat, která je organizační složkou Evropské komise, se v ČR v roce 2020 vyrobilo vysoce přes 200 tisíc tun vlny ze struskových a minerálních vláken[3]. Zmíněnou informaci lze dohledat pod “Prodcom” kódem 23.99.19.10. Je však nutné upozornit, že do této skupiny nepatří skleněné vlny. Těm náleží kód 13.20.46.00, který ale započítává i vlákna pro textilní účely. Získat informaci o vyrobeném množství tohoto materiálu je tedy velmi komplikované. Někteří odborníci odhadují, že produkce skleněné vlny tvoří přibližně 30 % té čedičové[4].

Dle údajů aplikace VISOH (Veřejné informace o produkci a nakládání s odpady), spravované Ministerstvem životního prostředí ČR v rámci systému ISOH (Informační systém oběhového hospodářství) se v letech 2015 – 2019 izolační materiály skupiny 17 06 03 – 04, do nichž se minerální

Patronem tohoto čísla je Týden výzkumu a inovací pro praxi a životní prostředí TVIP 2020/21 (19. – 21. 10. 2021, Hustopeče)

izolační vata řadí[5], podílely na produkci stavebního a demoličního odpadu (SDO) v průměru jen několika desetinami procent[6]. V tomto ohledu tedy žádný zásadní problém nenastává. Situaci ovšem znatelně komplikuje velmi obtížná recyklace vat ze zateplovacích systémů. Zejména těch, které jsou kontaminovány stavebními lepidly, omítkami a dalšími nežádoucími hmotami[4,7]. Běžnou praxí tak bylo tyto odpady skládkovat. Proti zavedeným zvyklostem ale stojí ekologicky motivované snahy omezit skládkování SDO. Zastřešeny jsou cílem Evropského parlamentu, který požaduje od roku 2020 recyklovat minimálně 70 % veškerého SDO[8]. Pro představu zmiňme, že uložení jedné tuny minerální vaty na skládku stojí cca 1750 Kč[9]. Celá situace tak dává vzniknout novým výzvám v oblasti recyklace minerálních vat, které sloužily v kontaktních zateplovacích systémech budov, tzn., vykazují značnou míru kontaminace nežádoucími stavebními hmotami.

V souvislosti s krizí nerostných surovin nelze nezmínit beton, který nadále zůstává suverénně nejrozšířenějším stavebním materiálem[10]. Pozornost se tedy již několik desetiletí obrací na jeho recyklaci. Dle již zmíněné aplikace VISOH se jedná o odpad skupiny 17 01 01, který v letech 2015 – 2019 (aktuálnější data zatím nejsou k dispozici) představoval v průměru více než 10% podíl na celkovém množství SDO. V absolutních číslech hovoříme o bezmála 10 milionech tun[6].

Podrobnější analýza českých statistických dat dále odhaluje, že recyklace kameniva z odpadního betonu v čase vytrvale stoupá a v posledních letech atakuje 15% hranici v poměru k panenskému kamenivu[1]. Stranou zájmu ovšem stojí jemné frakce (0 – 1 mm) recyklovaného plniva a stejně tak hydratovaná cementová matrice. Přitom v betonu zastupují 15 a v některých specifických případech dokonce 50 % hmotnosti. Oba materiály jsou charakteristické značně heterogenními povrchovými i objemovými vlastnostmi, což jejich aplikační potenciál značně limituje[11]. Některé studie dokonce poukazují na skutečnost, že mohou obsahovat nezanedbatelné množství (až několik jednotek procent) tzv. zbytkových cementových slínků, tedy slínků, které zpravidla kvůli nedostatku záměsové vody nebyly podrobeny hydrataci[12–14]. Jejich dodatečné využití s sebou přináší další potenciál v úspoře cementu. Jedná se nejen o ekonomický, ale rovněž ekologický benefit, zejména vezmeme-li v potaz, že výroba cementu souvisí s produkcí zhruba 5 – 7 % antropogenních emisí CO_2 (cit.[15]).

Jak již bylo naznačeno, využití stavebních materiálů se dostává pod drobnohled odborné i laické veřejnosti. Kladen je důraz na jejich opravdu efektivní využití zohledňující principy udržitelného rozvoje. Na zmíněnou situaci reaguje výzkum prezentovaný v tomto článku. Navržen byl nový typ lehčených bloků pro obvodový plášť s vysokým obsahem recyklovaných surovin, který je koncipován jako nosná vrstva s výrazně lepšími tepelně-technickými vlastnostmi oproti prostému betonu. Bloky jsou z vnější strany zatepleny dvěma variantami tepelné izolace na bázi minerálních vln. Celá skladba již při tloušťce 375 mm vykazuje součinitel prostupu tepla 0,16 $Wm^{-2}K^{-1}$. Maximální možný důraz byl kladen na co největší zastoupení recyklovaných surovin a současně na vysoký potenciál následné opakovatelné recyklace, který bude v pokračujícím výzkumu experimentálně ověřen. Celá koncepce vychází z několikaletých poznatků získaných během experimentálního výzkumu na Fakultě stavební a Centru energeticky efektivních budov (UCEEB) ČVUT v Praze.

Obvodový plášť budov navržený s ohledem na úsporu nerostných surovin

Základní požadavky

Naším cílem je přispět k řešení výše uvedených problémů a navrhnout obvodový plášť budov, který je šetrný k zásobám nerostných surovin a zároveň splňuje současné tepelně-technické standardy. Jeho šetrnost k těmto surovinám spočívá jednak v aplikaci vysokého množství recyklovaných surovin a dále v optimalizaci návrhu, který zajistí jeho opakovanou 100% recyklovatelnost. Důraz je kladen na realizaci experimentu v reálných podmínkách, které ověří vyvíjená laboratorních řešení v praxi.

Z tohoto důvodu byl realizován segment obvodového pláště o ploše 10 m^2, který je exponován vnějšímu prostředí. Samotný plášť sestává ze dvou základních vrstev: (i) nosná část z lehčených zdicích bloků a (ii) zateplení z desek z minerálních vláken. Celá konstrukce je dlouhodobě monitorována. Sledovány jsou následující parametry: průběh teplot, relativní vlhkosti a tepelný tok. Součástí realizovaného experimentu je i demolice a následná recyklace konstrukce, která proběhne v říjnu 2021.

Zdicí bloky

V rámci výzkumu realizovaného v předchozích letech na Fakultě stavební ČVUT v Praze (projekt MPO Trend FV20503) byl vyvinut zdicí systém s vysokým obsahem recyklátu ve formě upravených jemných frakcí betonového recyklátu. Jedná se o komplexní řešení, které je tvořeno lehčenými bloky, speciální zdicí maltou pro tenké spáry a tenkovrstvou omítkou. Celý systém byl popsán ve čtvrtém vydání časopisu Waste forum v roce 2019[16]. Připomeňme, že směs pro výrobu zdicích bloků kompletně postrádá panenské plnivo. Aby bloky splnily náročné a protichůdné požadavky na mechanické (pevnost v tlaku, modul pružnosti) a tepelně-izolační vlastnosti (tepelná vodivost, měrná tepelná kapacita), jejich směs byla vylehčena pomocí napěněné struktury a ztužena mikrovlákny. Vlákna dodala firma Trevos, s. r. o. a byla vyrobena z kompletně recyklovaného polypropylenu (PP). Dosahovala délky 4 mm a průměru 12 µm. Úkolem vláken bylo nejen ztužit matrici kompozitního materiálu, ale zároveň se podílet i na stabilizaci napěněné struktury matrice během tuhnutí a tvrdnutí, čímž dochází k eliminaci sesedání směsi[17,18].

Jak již bylo řečeno, jemné frakce recyklovaného plniva a cementové pasty lze využít jako tzv. aktivní mikroplnivo (plnivo s částečnou pojivovou schopností)[14,19]. Předcházet ale musí vhodná mechanická úprava – vysokorychlostní mletí, které velikost zrn recyklátu přiblíží velikosti zrn standardního cementu. Úpravu zajistila firma Lavaris, s.r.o. Benefitem této technologie je jednak sjednocení frakce odpadu a dále obnažení (odhalení) zbytkových nezhydratovaných slínků. Vzniká tak aktivní mikroplnivo, které je schopné nejen plnohodnotně nahradit jemné frakce panenského kameniva, ale částečně i pojiva[12]. Opomíjená frakce odpadního betonu tak nachází velmi efektivní uplatnění při výrobě nových stavebních materiálů[20]. Původní receptura pro výrobu zdicích bloků byla lehce modifikována s důrazem na zvýšení použitého množství aktivního mikroplniva (frakce 0 – 0,25 mm). Shrnuta je v tabulce 1.

Tabulka 1: Složení lehčeného zdicího bloku.

Složka	Množství (kg/m^3)	Poznámka
CEM I 42,5R	300,45	38 hm. %
Mikromletý betonový recyklát	510,68	59 hm. %
Napěňovací přísada	7,29	0,9 hm. %
Plastifikátor	9,39	1,1 hm. %
Recyklovaná mikrovlákna	8,10	1 hm. %
Voda	200	w/c = 0,5

Výroba bloků pro experimentální plášť probíhala v poloprovozním režimu v betonárně. Aplikován byl standardní postup: příprava směsi v míchacím centru a její následná doprava na místo určení pomocí automobilového domíchávače. Celý proces výroby byl rozdělen do šesti záměsí (po 0,5 m^3) s celkovým objemem 3 m^3. Homogenizace směsi byla provedena na planetární míchačce s vířivým bubnem. Nejprve byly míseny suché složky, do nichž byla přidána voda. Následovalo vmíchání pěny, která byla vyrobena pomocí pěnogenerátoru. Směs byla dále transportována a ukládána do forem, jak ukazuje obrázek 1.

Takto vyrobený zdicí blok dosahoval rozměrů 500×250×175 mm. Výsledná experimentálně stanovená pevnost v tlaku byla 7,2±1,1 MPa. Další materiálové vlastnosti jsou uvedeny v tabulce 2. Z bloků byla běžným způsobem vyzděna experimentální stěna o ploše 3×3,3 m^2, která byla následně opatřena zateplovacím systémem.

Obrázek 1: Proces nakládání čerstvé směsi do domíchávače (vlevo). Poloprovozní plnění forem (vpravo).

Zateplovací systém

Vyzděná stěna byla z vnější strany následně opatřena zateplovacím systémem tak, aby splňovala současné tepelně-technické nároky odpovídající středoevropskému klimatu. Návrh zateplení odrážel požadavky normy ČSN 73 0540-2[21]. Konkrétně bylo cíleno na dosažení součinitele prostupu tepla doporučeného pro pasivní domy $U_{pas,2} = 0,18\ Wm^{-2}K^{-1}$.

Pro vnější zateplení byly zvoleny dvě varianty: (i) zateplení měkkou izolací v lehkém kovovém roštu Knauf Insulation Diagonal 2H o celkové tloušťce 460 mm, značeno jako S1 a (ii) kontaktní zateplení o celkové tloušťce 375 mm, značeno jako S2. V prvním případě je izolace zaklopena z vnější strany difúzně otevřenou fólií. Na ni navazuje větraná dutina a fasádní obklad z desek Heraklith C. Druhá varianta se opírá o klasické systémové řešení kontaktního zateplovacího systému (KZS). Návrh zateplovacích systému zohledňoval požadavky na plánovanou demolici a recyklaci (10/2021). Ve spolupráci se společností Lavaris, s.r.o. a Knauf Insulation, s.r.o. je vyvíjena speciální linka, která bude k těmto účelům určena. Linka bude mobilní, čímž umožní recyklaci přímo na staveništi. Navržena bude tak, aby zvládla zpracovat odpad v podobě čistých i kontaminovaných desek z minerální vlny. Skladby obou variant následují (od exteriéru):

S1	S2
- deska Heraklith tl. 25 mm	- tenkovrstvá omítka tl. 5 mm
- vzduchová mezera tl. 60 mm	- tepelně-izolační deska tl. 200 mm
- tepelná izolace z minerální vlny tl. 200 mm	- stěrka tl. 5 mm
- lehčený blok s obsahem betonového recyklátu tl. 175 mm	- lehčený blok s obsahem betonového recyklátu tl. 175 mm
- vnitřní omítka z recyklátu tl. 3 mm	- vnitřní omítka z recyklátu tl. 3 mm

U obou skladeb bylo dosaženo součinitele prostupu tepla 0,16 $Wm^{-2}K^{-1}$. Vytyčený cíl tak byl lehce překonán a ukazuje potenciál pláště konkurovat běžně využívaným systémům. Materiálové vlastnosti použité tepelné izolace jsou shrnuty v tabulce 2.

Tabulka 2: Materiálové vlastnosti výrobků použitých v obvodovém plášti.

Materiál	**Objemová hmotnost (kg/m^3)**	**Součinitel tepelné vodivosti ($Wm^{-1}K^{-1}$)**	**Faktor difuzního odporu vodní páry (-)**
Lehčený zdicí blok	1000±80	0,31±0,03	4,2±0,1
Cementová stěrka/malta	1500±60	0,55±0,07	7,5±0,2
Tepelná izolace – skladba S1	60±1	0,035±0,003	1,1±0,05
Tepelná izolace – skladba S2	75±2	0,035±0,002	1,2±0,04

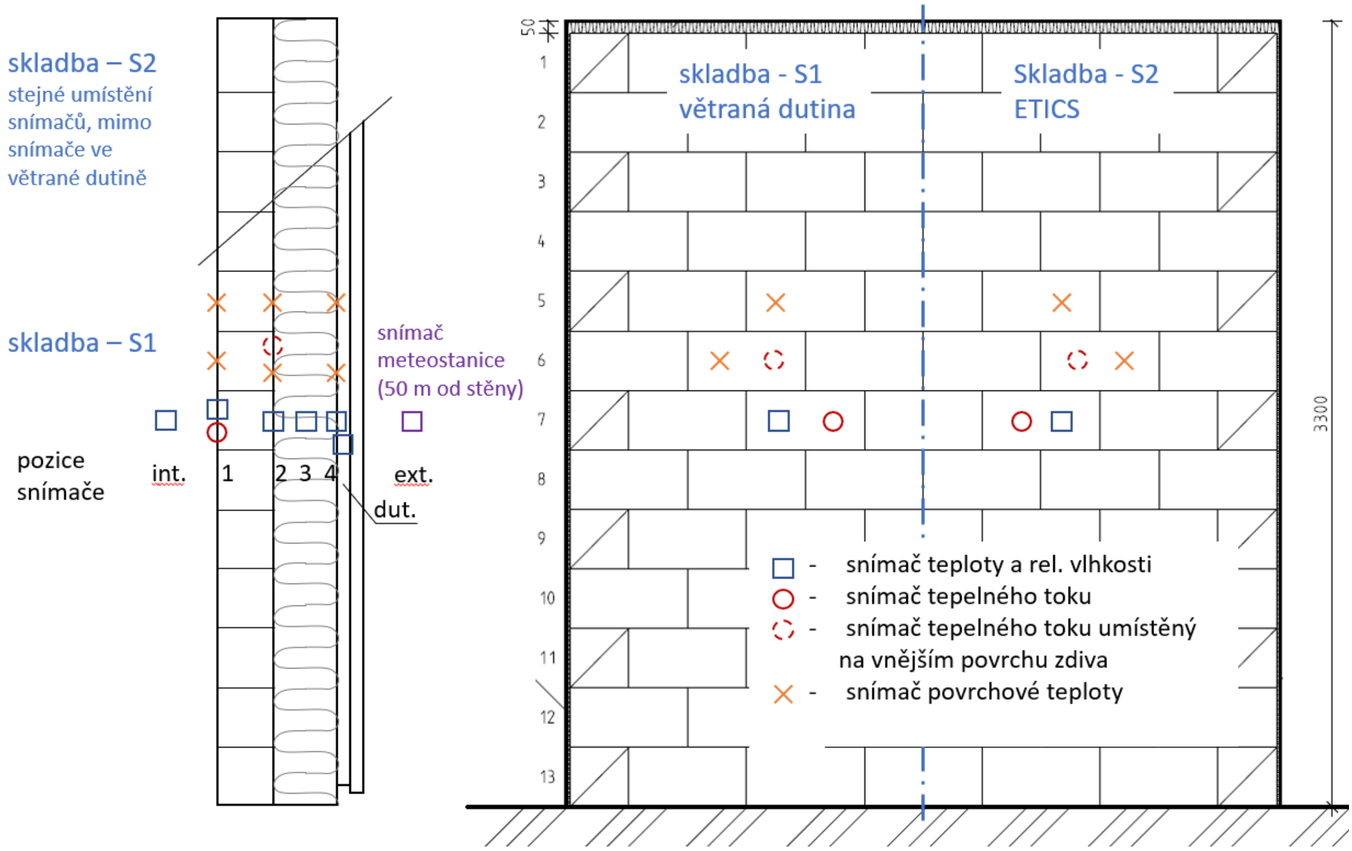
Realizace konstrukce obvodového pláště

Dlouhodobý monitoring tepelně-vlhkostního chování obou skladeb obvodových plášťů je prováděn na experimentální fasádě v Univerzitním centru energeticky efektivních budov ČVUT v Buštěhradu. Osazen byl jeden ze šesti experimentálních otvorů v obvodovém plášti o rozměru 3×3,3 metry. Obrázek 2 ukazuje pohled na plášť z exteriéru. V jeho pravé části je umístěn plášť s větranou dutinou (skladba S1), zatímco v levé části je systém KZS (skladba S2). Vnější povrch obou konstrukcí je exponován exteriérovým podmínkám jihozápadní fasády. Vnitřní povrch navazuje na klimatickou místnost s definovatelnými tepelně-vlhkostní podmínkami. Na začátku experimentu byly podmínky vzduchu v místnosti nastaveny na teplotu 20±1 °C a relativní vlhkost 55±2 %. Jedná se o parametry odpovídající zimním návrhovým podmínkám vnitřního prostředí v obývacích místnostech podle ČSN 73 0540-3[22], včetně bezpečnostní přirážky vlhkosti 5 % vlhkostních.

Jedná se o první realizaci vyvinutého pláště v reálných podmínkách. Mimo níže popisovaný monitoring tepelně-vlhkostního chování proto byly sledovány i technologické aspekty. Ukázalo se, že manipulace s bloky se nikterak nevymyká běžným zdicím materiálům (např. pórobetonu). Při zdění byly použity standardní technologické postupy. Bloky bylo možné řezat běžnými nástroji. Bezproblémově se jevila i interakce se zdicím, omítkovým či zateplovacím systémem.

Pro sledování tepelně-vlhkostního chování obou variant obvodových plášťů byly do každé ze skladeb osazeny tepelně-vlhkostní snímače Rotronic Instruments HC2, snímače povrchové teploty Pt1000 firmy Sensit a snímače tepelného toku. Snímače povrchových teplot a kombinované snímače byly umístěny na vnitřním a vnějším povrchu konstrukcí a na všech rozhraních jednotlivých vrstev. Snímače tak dokumentují tři lineární profily po tloušťce každé z konstrukcí. Jeden kombinovaný snímač byl dále umístěn do poloviny tloušťky tepelné izolace. Snímače tepelného toku byly osazeny na vnitřním a vnějším líci zdiva (viz obrázek 3). Kombinované snímače byly chráněny před mokrými procesy (přestěrkování atp.) kapsičkou z difuzně otevřené podstřešní folie (viz obrázek 4). Vlastní monitoring byl zahájen dne 18. prosince 2020. Skladby budou monitorovány po dobu 10 měsíců, tedy přibližně do října 2021.

Obrázek 2: Segment obvodového pláště na fasádě budovy UCEEB v Buštěhradu. Dokončená část fasády s KZS a rozpracovaná část provětrávané fasády (vlevo) a finální podoba experimentální fasády (vpravo).



Obrázek 3: Schéma umístění snímačů v testovaných skladbách obvodového pláště; vlevo: řez; vpravo: pohled z interiéru.

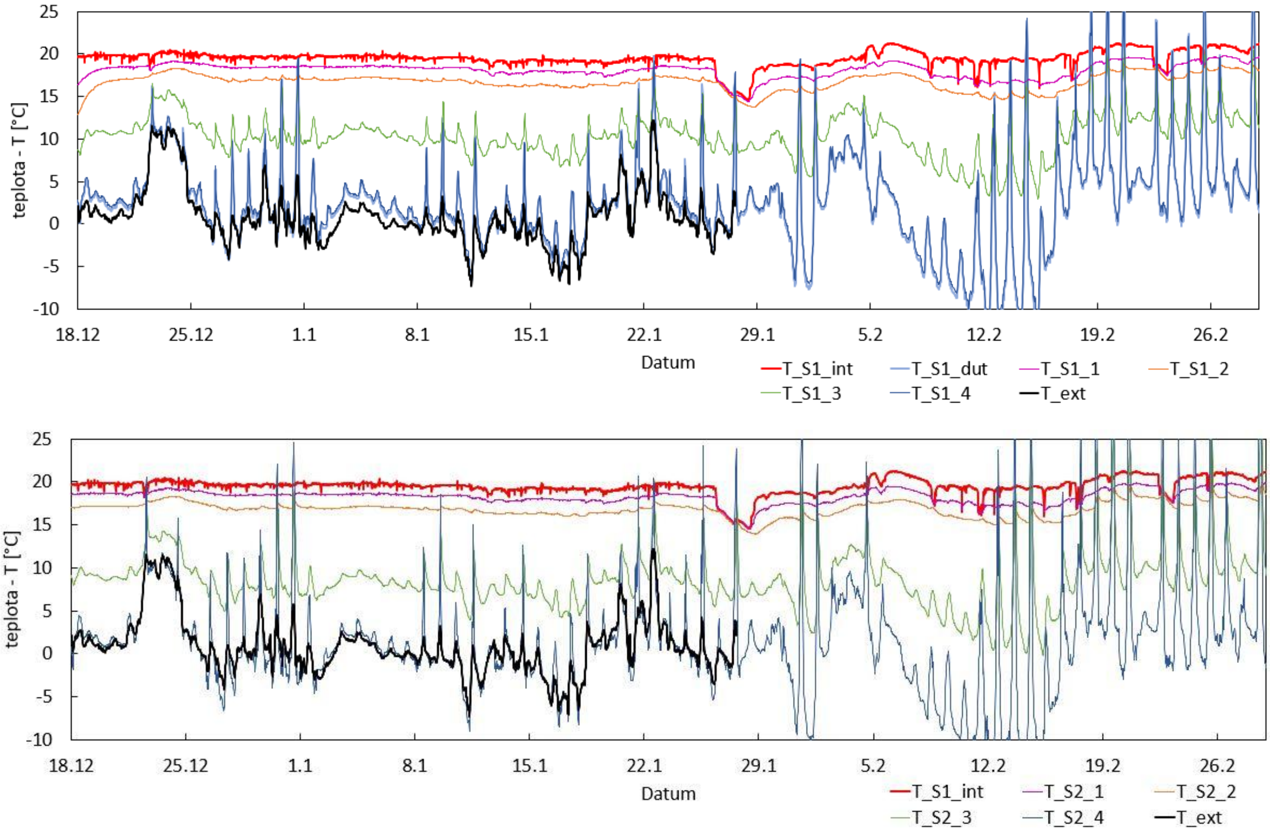
Obrázek 4: Osazení snímačů na vnitřní straně zdicích bloků (vlevo) a snímače na povrchu tepelné izolace souvrství KZS (vpravo)

Výsledky a diskuse

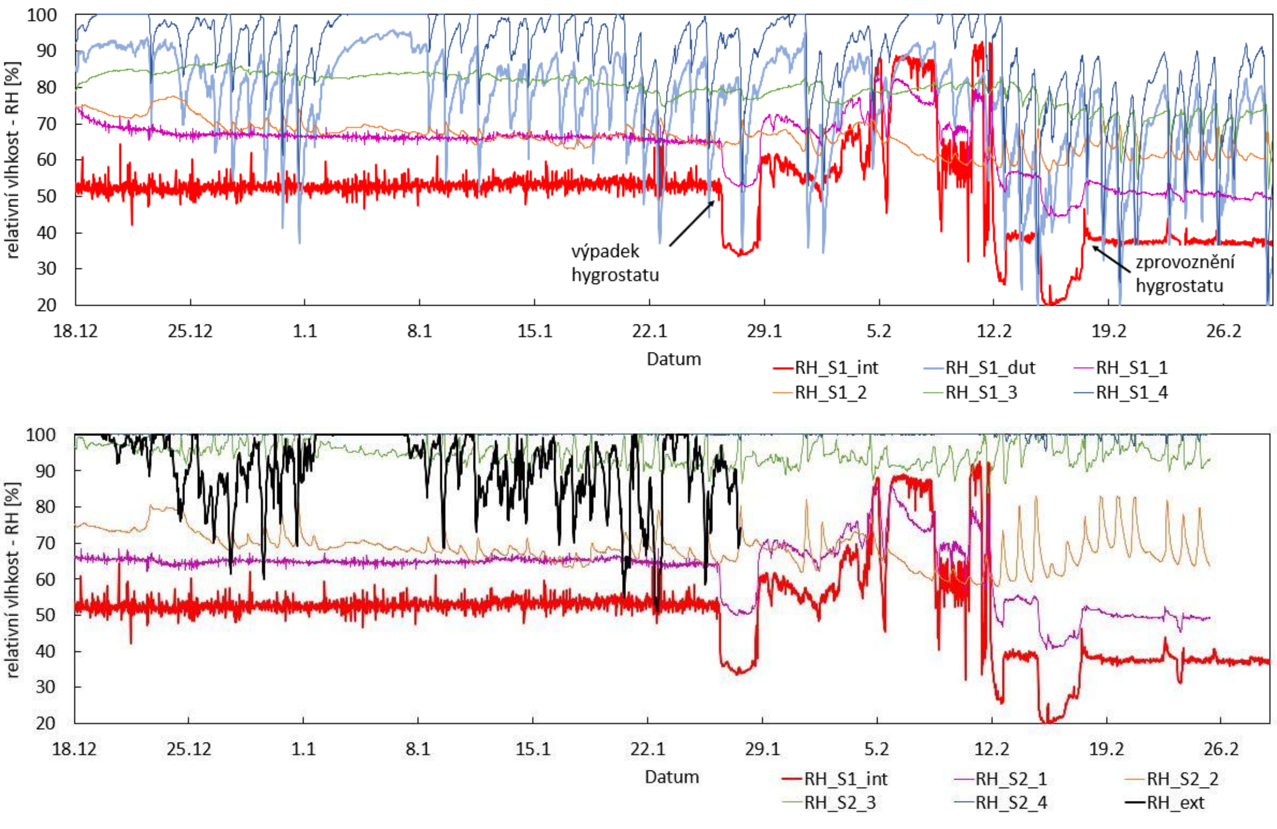
Výsledky ukazují záznam z měření probíhajícího nepřetržitě přes 2 měsíce (od 18. prosince 2020 do 26. února 2021). Obrázek 5 zachycuje průběh teplot ve skladbách jako funkci času. Pro obě varianty společně (S1 a S2) platí, že nejvyšších a velmi stabilních hodnot dosahuje teplota v interiéru (T_S1_int). Její průběh věrně kopíruje teplota na vnitřním a vnějším povrchu bloků (T_S1_1, resp. T_S1_2). Teplotní spád přes zdicí bloky je cca 4 – 5 °C navzdory velmi malé tloušťce. Dokazuje tak jejich slušné tepelně-izolační vlastnosti. Dle očekávání lze největší oscilace hodnot zachytit čidlem v provětrávané dutině (T_S1_dut či T_S1_4), která je ohřívaná slunečním zářením. Naměřená teplota dokonce několikrát přesáhla teplotu interiéru navzdory zimnímu období. Zachycené rozdíly přesahují 35 °C, což je zhruba o 15 – 20 °C větší rozptyl, než jakého dosahovaly teploty vzduchu v exteriéru (T_ext).

Co se týká průběhů relativní vlhkosti, na obrázku 6 je vidět, že od konce ledna nebyla po dobu několika týdnů v interiéru udržována relativní vlhkost na konstantní úrovni 55 % (RH_S1_int). Jednalo se o následek výpadku hygrostatu v klimatické místnosti. Je zřejmé, že v tomto období byla vlhkost v místnosti významně ovlivněna vlhkostmi okolních prostředí. Uvedená skutečnost však měření ani budoucí srovnání dat s numerickou simulací neohrozí, protože okrajové podmínky působící na konstrukci, ačkoliv se výrazně mění, jsou v tomto období zaznamenány. Vzhledem k závislosti relativní vlhkosti na teplotě nejsou její průběhy po tloušťce konstrukce rovnoměrně rozloženy jako v případě teplot. Za pozornost stojí klesající tendence průběhu vlhkosti bloků (RH_S1_1 a 2), která dokumentuje jejich postupné vysychání.

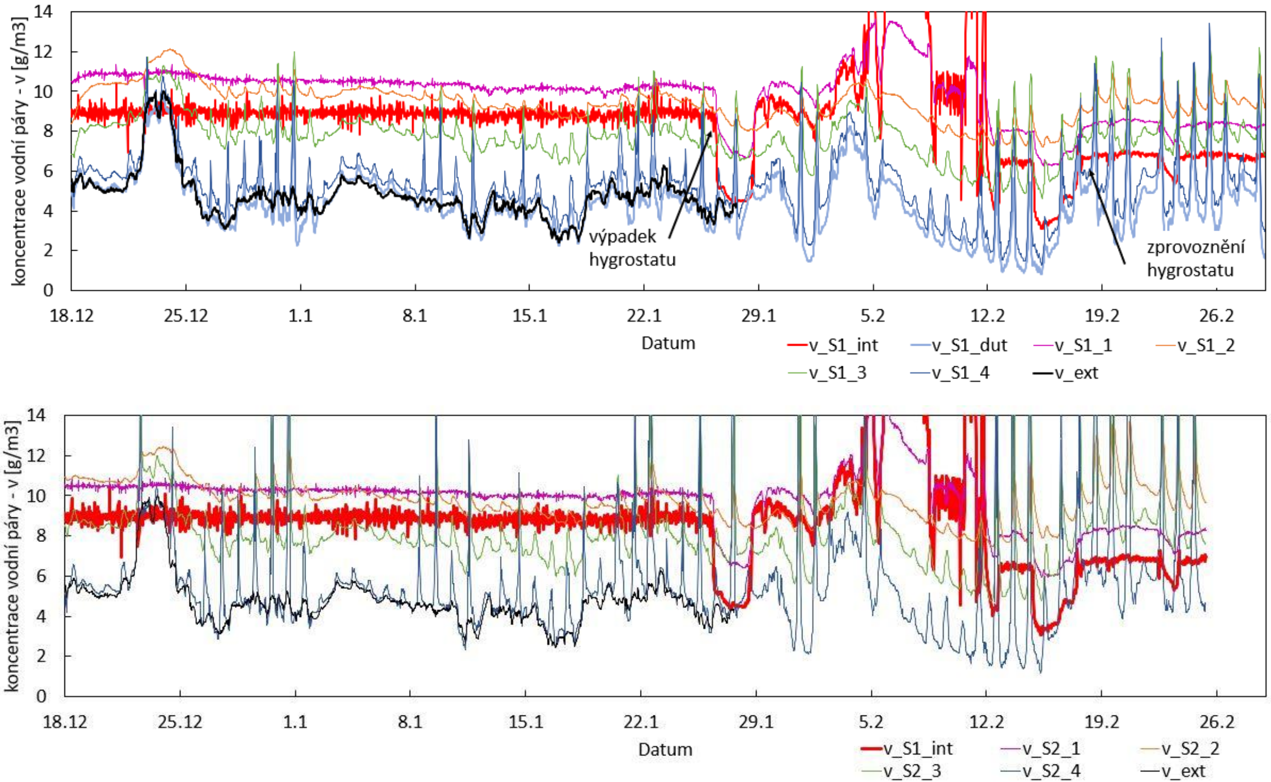
Rozvrstvení hodnot by však mělo být patrné z průběhu koncentrací vodní páry (absolutních vlhkostí), viz obrázek 7. Ani tam ale k takovému rozložení nedošlo. Důvodem je s největší pravděpodobností kapalná voda zadržovaná ve vrstvě zdiva, která postupně vysychá. To potvrzuje i rozdíl hodnot tepelného toku na interiérové a exteriérové straně zdiva (obrázek 8). Původ této vody bude dále analyzován. Rozdíl v dodané a odcházející energii (cca 4,5 Wm^{-2}) je tedy s největší pravděpodobností využit na přeměnu skupenství vody z kapalného na plynné. Z hodnot tepelných toků bylo dále možné stanovit aktuální hodnotu tepelné vodivosti silikátových tvárnic, jejíž průměr se shoduje s předběžnou hodnotou stanovenou laboratorně – 0,31 $Wm^{-1}K^{-1}$. Lze ale předpokládat, že po vyschnutí zdiva se tato hodnota sníží.



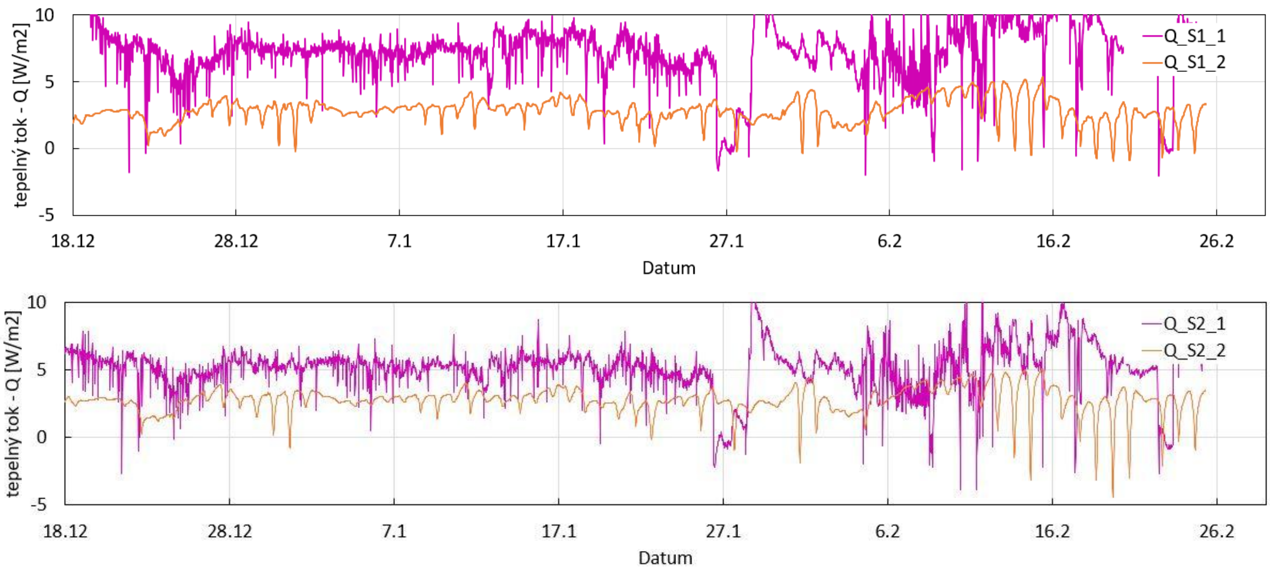
Obrázek 5: Průběhy teplot v konstrukci – skladba S1 (nahoře) a S2 (dole).



Obrázek 6: Průběhy relativních vlhkostí v konstrukci – skladba S1 (nahoře) a S2 (dole).



Obrázek. 7: Průběhy koncentrací vodní páry v konstrukci – skladba S1 (nahoře) a S2 (dole).



Obrázek. 8: Průběhy tepelných toků na vnitřním a vnějším líci zdiva – skladba S1 (nahoře) a S2 (dole).

Závěry

Na Univerzitním centru energeticky efektivních budov ČVUT byl realizován experimentální obvodový plášť sestávající z nosné a tepelně-izolační vrstvy. Nosná vrstva byla vyrobena z bloků z recyklovaného jemně mletého betonu, zatímco tepelně-izolační tvořily desky z minerálních vláken. Účel tohoto experimentu byl dvojí: (i) ověřit aplikační potenciál dříve vyvinutých zdicích bloků a (ii) navrhnout a připravit konstrukci na následnou demolici a opakovatelnou recyklaci.

Během realizace konstrukce bylo potvrzeno, že dříve vyvinuté zdicí bloky dosahují stejných funkčních vlastností jako standardní materiály. Během realizace nebyly odhaleny žádné technologické problémy či nedostatky. Navržené řešení tak může přispět k redukci problémů s nedostatkem nerostných surovin ve stavebnictví.

Plánovaná recyklace se soustředí na zpracování zateplovacího systému, které je v současné době stále limitované zejména kvůli kontaminaci vláken stavebními lepidly, omítkami a dalšími hmotami. Recyklaci musí předcházet podrobný popis dlouhodobé materiálové degradace konstrukce vystavené reálným podmínkám. Z toho důvodu je již několik měsíců sledováno tepelně-technické chování skladeb. Dosavadní data neodhalila žádné nežádoucí změny ve sledovaných materiálech, takže lze předpokládat, že při aplikaci vhodné recyklační technologie může být jejich funkční potenciál využíván opakovaně.

Poděkování

Tento příspěvek byl připraven díky podpoře projektu TA ČR Zéta TJ04000208 "Mobilní recyklační linka na zpracování stavebního odpadu z minerálních tepelně-izolačních materiálů a využití recykláž, včetně možnosti přímé aplikace na stavbách" a v rámci implementace výsledků projektu MPO Trend FV20503 „Lehčené zdicí materiály na bázi mikromletých minerálních vedlejších produktů s řízenými užitnými vlastnostmi".

Poděkování dále patří společnostem Knauf Insulation, s.r.o., Lavaris, s.r.o., Visco, s.r.o., Českomoravský cement, a.s., Sika CZ, s.r.o., Destro, s.r.o., Trevos Koštálov, s.r.o., Uniq Development, s.r.o., díky kterým bylo možné segment obvodového pláště v této podobě realizovat.

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Use of mineral wool in building envelopes with regards to their future recycling

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Summary

The paper presents research results that are focused on development building envelopes based on recycled materials. The main aim is to utilize construction and demolition waste and to save mineral resources. Moreover, it is also targeted to design such constructions which are suitable for further and multiple recycling. The designed envelope is made from building blocks and rock wool heat insulation. The blocks were made of recycled finely ground concrete. The insulation was designed in two variants regarding its further recycling. In the University Centre for Energy Efficient Buildings, CTU in Prague, the building envelope having 10 square meters was made during 10/2020 which is now exposed to real conditions of exterior. Currently, a long-term monitoring is in progress, focusing on temperature-humidity measurement and material degradation. Ongoing data show that both constructions follow the behavior of standard materials. The constructions thus exhibit potential for repeatable recycling, that will be done using the newly developed machine for rock wools recycling in 10/2021.

***Keywords**: Construction and Demolition Waste, Recycling, Building Envelope, Masonry Blocks, Cement Composite, Heat Insulation system, Heat-moisture Behavior*

Verification of the effectiveness of municipal waste prevention (case study)

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Abstract

The basis of our experiment were 4 different model families, living in different conditions and in different parts of the Slovak Republic (district Trnava – city Trnava) and district Ružomberok – city Ružomberok and the village Likavka). In particular, the members of these households had different habits and behaviours in relation to waste and the environment. In 4 model families in the individual months in 2019 (from January 1 to December 31 2019) we tracked the amount of their produced municipal waste. At the same time, if the household separated selected components of municipal waste, their weight was determined (e.g., plastics, metals, multilayer composite materials, paper, glass, biowaste). The aim of our case study is to point out the obvious and fundamental differences in the behaviour of 4 different Slovak model families, which we had the opportunity to monitor not only in terms of the total production of mixed municipal waste (MMW) but also in terms of the number of selected types of sorted components throughout 2019. The results of individual members of the model families were compared with the average amount of waste produced per capita in 2019 in the Slovak Republic (435 kg) and in the EU (450 kg). Despite the fact that members of the Model family 4 separated a considerable amount of waste (143.11 kg), in 2019 they produced the largest amount of MMW (471.48 kg) because used disposable baby diapers were also disposed of within it. The Model family 1, in which members are not involved in waste sorting, produced MMW (388.63 kg) and all this was disposed of by collection and subsequent landfilling. MMW in the Model family 2 accounted for a smaller amount (138.00 kg) due to the sorting of waste in this household. By involving members of the Model family 3 not only in waste separation but also in waste prevention, the smallest amount of MMW was produced in this household - only 2.39 kg. By comparing 4 model families in terms of their year-round production of municipal waste, separated components, or waste prevention, we point out that different behaviour in waste management also brings different results.

Keywords: *municipal solid waste, waste separation, waste prevention, zero-waste*

Introduction

The exponential growth of population, urbanization, industrialization, the development of the social economy[1] and particularly the rapid growth of the urban population the growth of production and consumption, the high demand for new products, and improved living standards[2,3,4] have resulted in an increase in the amount of municipal solid waste (MSW) generation throughout the world. Recent estimates suggest that the global MSW exceeds 2 billion tons per year, which is a potential threat to environmental dilapidation[1,5]. The problem of waste has become an increasingly serious issue in the 21st century due to a growing global population, consumerism, and a linear approach to industrialization[3,6,7]. Waste production increases in proportion to the income of the population and consequently increases the economic and environmental costs associated with waste disposal[8]. The volume of MSW is increasing due to the increased living standards of inhabitants, and households present a rather dominant subject that creates MSW[9].

Recycling is the most suitable way of dealing with waste products. Worldwide the recycling activities are being encouraged and consumers are motivated to participate in these activities through different schemes[10]. One of these options is the proper separation of municipal waste in households. Improving the recycling performance in order to recover qualitative materials, save resources and keep waste out of landfills belongs to the pressing challenges of our time[11].

Our current culture is based on ownership and also on buying and producing everything we desire, not what we really need[12]. People have fallen under the spell of consumer life, in which even durable products are slowly becoming consumer products. With the increasing production of waste, problems also come around – some no longer solvable by recycling.

The growth of waste production, the high rate of landfilling, and the low rate of waste minimization require more efficient waste management than ever before[4].

In 2019, the average Slovak produced 435 kg of waste, i.e., each inhabitant of the Slovak Republic produced approximately 1.2 kg of municipal solid waste (MSW) per day. From 1995 to 2007, the amount of MSW produced per capita in the Slovak Republic per year was maintained at around 300 kg (302 kg in 1995, 309 kg in 2007), since 2008 there has been a gradual increase in the annual production of MSW per capita (331 kg in 2008, 333 kg in 2010, 339 kg in 2014, 393 kg in 2017) and in 2018 for the first time, we exceeded the limit of 400 kg of MSW production per year (427 kg). In the years 2007 – 2019, the total production of MSW in the Slovak Republic increased by approximately 42%. Although in comparison with the production of municipal waste in EU countries, the Slovak Republic is one of the countries with the lowest amount of municipal waste per capita, we are still among the countries with the highest share of landfilling (landfill rate in 2017 – 61%, in 2018 – 55%, in 2019 – 50.6%) and a relatively low rate of municipal waste recycling (year 2017 – 29%, year 2018 – 36%, year 2019 – 39%)[13,14]. In 2019, the average EU citizen produced around 450 kg of waste. The EU average was 45% in 2019, while in Slovakia only 39%[15].

Individuals are becoming more aware that the age of undisturbed consumerism is coming to an end and that their individual behaviours have a direct impact on the surrounding environment and on the lives of future generations[16]. Nowadays, the concepts of waste prevention and zero-waste are beginning to spread. In both cases, it is a change in the lifestyle of the consumer or household. Their main goal is to prevent the production of total waste.

Zero-waste is a visionary concept for confronting waste problems in our society and has been presented as an alternative solution for waste problems in recent decades[17,18]. Household waste minimisation has earlier been studied as a part of voluntary simplicity (a way of life practised by individuals whose ideology calls for minimizing consumption and maximizing reduction) [19,20]. The principles behind zero-waste living are, by the followers of the zero-waste movement, formulated as the five Rs: Refuse, Reduce, Reuse, Recycle, Rot – in that order. Refuse what you do not need. Reduce what you do need. Reuse by using reusables. Recycle what you cannot refuse, reduce, or reuse. Rot (compost) the rest. The goal is to send no waste to landfill or incineration[21,22,23].

Zero-waste and waste prevention have been addressed by several authors in their books[12,24,25,26], who state that is a philosophy based on a set of practices aimed at preventing as much waste as possible. The waste-free approach is based on the individual's decision to reduce the amount of waste they produce every day with the help of small solutions and then apply them to their daily life. This is not just about better waste sorting and recycling, but also thinking about our consumer habits so that the problem is solved at the source because everything will become waste eventually. The best waste is considered to be the one that is never produced; therefore, this philosophy involves the consumer to act responsibly.

The aim of our case study is to point out the obvious and fundamental differences in the behavior of 4 different Slovak model families, which we had the opportunity to monitor not only in terms of the total production of mixed municipal waste, but also in terms of the number of selected types of sorted components throughout all months 2019.

Methodology

The basis of our experiment were 4 model families with different behaviour in relation to waste and the environment:

1. Model family 1 without waste separation and without waste prevention
2. Model family 2 with waste separation and without waste prevention
3. Model family 3 with waste separation and with waste prevention
4. Model family 4 with waste separation and with partial waste prevention and with the exception of disposable baby diapers

We selected model families in 2 parts of the Slovak Republic, in the districts of Trnava (city of Trnava) and Ružomberok (city of Ružomberok and the village of Likavka), with different types of settlement (complex housing construction – flat, individual housing construction – family house), with different gender structure and with different age representation of participants (child – 4 and 18 months, woman – 25, 29, 35, 50 and 83 years, man – 27, 31, 38 and 60 years), with different attitudes to waste separation and with different household equipment (e.g. car, pet). The age categories of the survey participants were registered as of 1 January 2019. In the survey, it was not important for individual families to have the same number of people in the household, as the resulting measurements, which we compared, were converted to the amount of waste produced per person. We compared the obtained data with Slovak (the year 2019 – 435 kg per capita) and European statistics (the year 2018 – 492 kg per capita) on waste and we also compared them between model families.

In the examined model families in the individual months of 2019, we obtained the amount of their produced municipal waste. We were also interested in the number of sorted units, of course, if the model family sorted the waste. The first group of sorted units were plastics, metals, multilayer composite materials (PMMCM), which were weighed as 1 commodity as they were collected together, the second group was glass, the third group was paper, the fourth group was the residual mixed waste and if the model family sorted biowaste, we included this in the fifth group. The monitored families recorded all data on the quantities of waste produced in prepared sheets (weight in grams, respectively in kilograms) during the whole year 2019 (from 1 January 2019 to 31 December 2019). In the case of the lower weight of waste produced in a given month, the amount was weighed using the kitchen or hanging scales, and if the waste was heavier, we used personal digital scales.

Model family 1 consisted of 3 members with an age structure: 60 years (male), 50 years (female), and 27 years (male). All 3 members were economically active. They lived in a three-room apartment in Ružomberok. There was only 1 garbage bin in the household, into which they threw all kinds of waste. Family members were not very interested in the prevention of waste and their subsequent disposal, they did not separate the produced waste at all. They took care of 1 cat in the household. They had 2 motor vehicles at their disposal, which they used mainly for commuting to work, for shopping, and occasionally for travel outside the city. Since all members of the household were employed, the diet of each of them was the same, i.e., breakfast and dinner at the place of residence and lunch outside the place of residence (at work).

Model family 2 consisted of a young couple aged 29 (female) and 31 (male) living in a larger two-room apartment in Trnava. They were partly interested in waste separation. There were 3 bags in the household for waste separation: one for mixed waste, the other for plastics, metals, and multilayer composite materials, and the third for paper. They took care of 1 dog at home. They owned 1 personal motor vehicle, also used mainly for business trips, shopping, and occasionally for trips outside the city to visit the family. Both spouses are employed, so they have regular breakfast and dinner at the place of residence and lunch outside the place of residence (at work).

Model family 3 consisted of 2 members (2 women). They lived in a family house in the Ružomberok district. An older pensioner at the age of 83 and her caregiver at the age of 25. The younger woman, who took care of the whole household, such as grocery shopping, cleaning, cooking, was very interested in how much waste she produced and how it was necessary to sort the produced waste. Subsequent purchases were also based on her interest and opinion. They had a few buckets set aside for waste sorting, or other storage items into which they sorted waste (e.g., paper boxes). They did not have any pets. They did not own any motor vehicles, so they used public transport to travel to the city. They prepared breakfast, lunch, and dinner at home.

Model family 4 consisted of 4 members, spouses aged 35 (female) and 38 years (male), and 2 children aged 4 months and 18 months. Due to the fact that there were 2 children in the household, we asked the partners to use disposable baby diapers for changing children during the year 2019 (3 – 5 pieces a day – an older child only to sleep). The family lived in a three-room apartment in the city of Trnava. The man was working, and the woman was on maternity leave. The family sorted the waste into separate and marked containers and was very interested in actively reducing the waste produced. The only exception in the waste prevention process was the use of disposable diapers. There were no pets in the household and the family-owned 1 motor vehicle used mainly for commuting and shopping. Breakfast, lunch, and dinner were prepared at home (Table 1).

Table 1: Conditions of 4 model families in a case study

Model family	Flat	Family house	Car	PMMCM separation	Paper and glass separation	Biowaste separation	Pet (animal)	Waste prevention
1	yes	--	2	--	--	--	yes	--
2	yes	--	1	yes	yes	--	yes	--
3	--	yes	--	yes	yes	yes	--	yes
4	yes	--	1	yes	yes	yes	--	yes*

*Legend: PMMCM – plastic, metals, multilayer composite materials; * partially waste prevention and with the exception of disposable baby diapers*

The monitored families recorded data on the waste produced during one year from January 2019 to December 2019, while the records were checked continuously during the year (once a month). Based on year-round data, we evaluated the results of measuring the amount of waste produced by model families, compared, and calculated the data of the degree of separation of each family according to the general formula. We used the following formula to obtain the separation rate value[27]:

$$LS_{MSW} = \frac{m_{\text{component }1} + m_{\text{component }2} + m_{\text{component }3} + m_{\text{component }n}}{m_{MSW}} \times 100\ [\%]$$

where: the level of municipal waste sorting (**LS_{MSW}**) is the value of separated municipal waste per year expressed in %; m component is the weight of the sorted municipal waste component; **m_{MSW}** is the total weight of municipal waste; **m component 1** represents in our case plastics, metals, multilayer composite materials; **m component 2** represents paper; **m component 3** represents glass and **m component n** other separated commodities such as biowaste and etc. We compared the average results of the weight share of individual components of mixed municipal waste in individual model families with the analyses of mixed municipal waste for individual (34 municipalities in the Slovak Republic) and complex (16 municipalities in the Slovak Republic) housing construction. These analyses were carried out by the non-profit civic association Friends of the Earth Slovakia (SPZ) and the Institute of Circular Economics[28] (Figure 1).

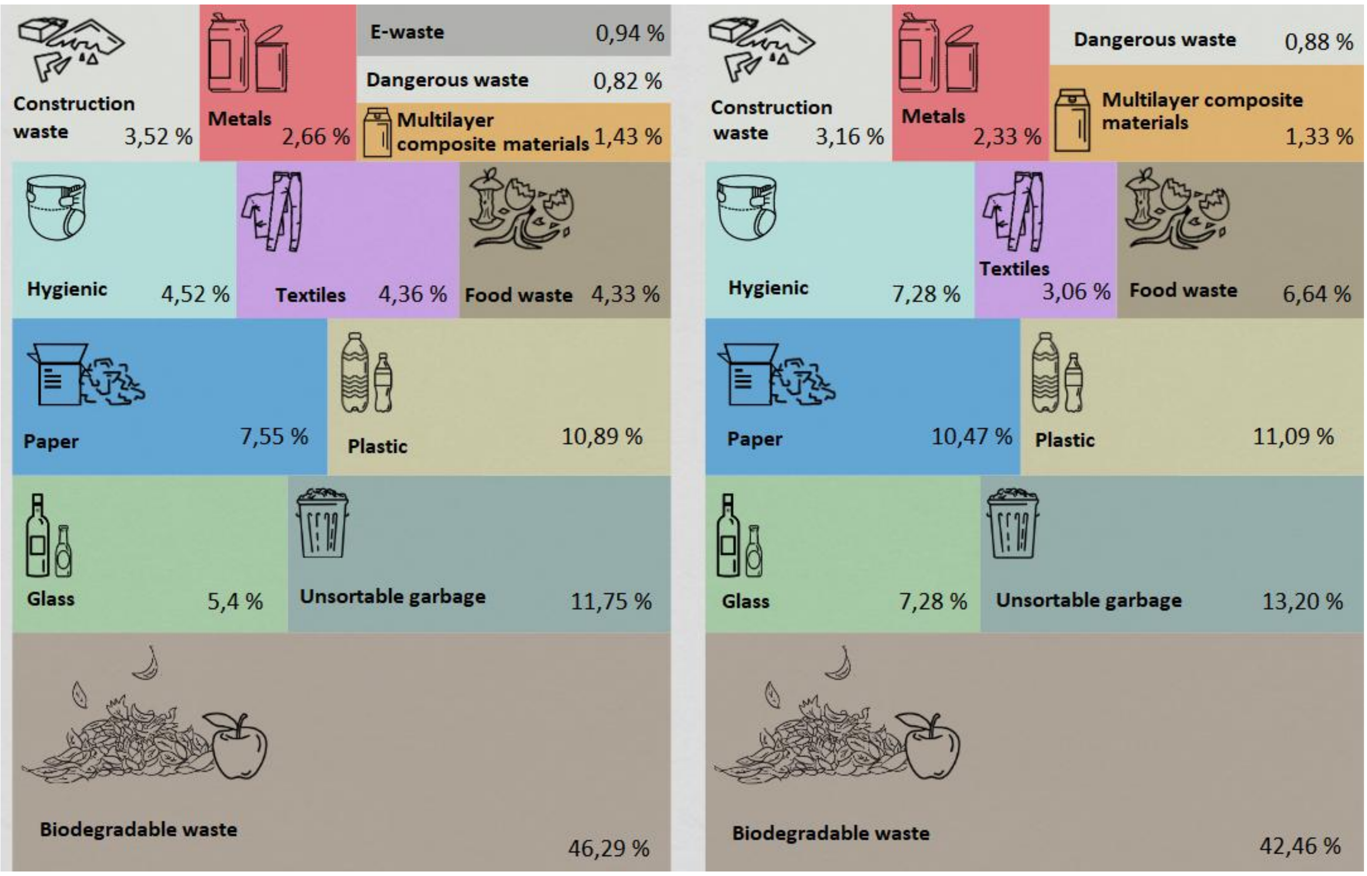


Figure 1: The weight fraction of individual components of mixed municipal waste, individual housing construction (left) and complex housing construction (right).
Source: Madajová, Belicová, Maleš, 2018

Results and Discussion

Model family 1 without waste separation and without waste prevention

During the observed period, Model family 1 produced a total of 388.63 kg of municipal waste (Table 2), which equals to 129.54 kg of municipal waste per member of this household. This number is significantly smaller than the national average and lower than the European average per capita. In the case of the national average, 1 member of the Model family 1 produced 70.22% less municipal waste and in the case of the European average, 1 member produced 73.67% less municipal waste. The average weight of municipal waste produced in 1 month in this household was 32.39 kg.

The members of Model family 1 described themselves as people who did not care how the produced waste was further treated. They stated the waste disposal fees being too high as a reason for this lack of interest. Therefore, the family made no effort to reduce its waste production. They bought food in default packaging materials and when choosing food, they did not look at its packaging, but rather at the price of the product. They did not separate their waste. All generated municipal waste ended up in a mixed container and subsequently at the Biela Púť solid municipal waste landfill in Ružomberok without the possibility of further use. As for the free storage of oversized waste (furniture) or chemicals (paints) in the collection yard, the family used this option. However, they threw out ordinary hazardous waste such as old medicines or non-functional disposable batteries into the rubbish bin for mixed municipal waste in their household.

Table 2: Waste weight results of Model family 1 in 2019

Model family 1 without waste prevention and waste separation (in kilograms)	
Month	**Total waste**
January	37.60
February	38.65
March	30.86
April	33.85
May	24.81
June	30.85
July	23.20
August	30.10
September	28.25
October	38.58
November	33.06
December	38.82
Total	388.63

Table 2 shows that the months of January, February, October, and December are the months with the largest waste production (approximately 38 kg). Since they take care of 1 cat in the household, it was necessary to clean the cat toilet at least twice a year (February, October) by changing the bedding. With this exchange, the waste in the given months increased mixed municipal waste by 10 kg. In December, the increased production of waste was related to the Christmas holidays, and in February they found that flour worms had multiplied in 10 kg of flour, so it had to be discarded. They had the lowest waste production in May and July. In May, the family spent most of their free time in a garden outside the city, eating their vegetables. In July, 2 members of the household were on a two-week holiday. The third member was thus alone at home for half a month, so he produced significantly less waste than a family of three.

Although the family produces a significantly lower amount of waste compared to national and European statistics, despite this being a household that does not separate the basic components of municipal waste and all the waste generated is only landfilled without any other recovery.

Model family 2 with waste separation and without waste prevention

During 2019, Model family 2 produced a total of 258.09 kg of municipal waste (Table 3), which represented 129.05 kg of municipal waste per 1 household member. As the family did not make a significant effort to avoid waste, this amount is almost the same as for the first family. Compared to the national average, they produced 70.33% less waste per person and, compared to the European average, they produced 73.77% less waste per person. The average weight of generated waste in 1 month was 21.5 kg of waste. Unlike Model family 1, however, members of this household separate municipal waste in 5 basic components: plastics, metals, multilayer composite materials, paper, and glass. The amount of separated waste components was a total of 120.09 kg, which equals to 60.05 kg of separated waste per member of the household.

Table 3: Waste weight results of Model family 2 in 2019

Model family 2 with waste separation (in kilograms)					
Month	**PMMCM**	**MMW**	**Paper**	**Glass**	**Total waste**
January	4.20	9.60	3.20	1.50	18.50
February	3.90	8.20	2.30	1.30	15.70
March	5.00	15.10	3.09	2.30	25.49
April	4.25	9.40	1.75	0.90	16.30
May	3.00	14.40	2.70	1.00	21.10
June	5.70	14.00	5.80	1.80	27.30
July	3.10	10.90	6.40	1.00	21.40
August	4.90	16.00	4.90	4.70	30.50
September	5.10	12.50	6.00	1.00	24.60
October	4.60	9.20	1.60	1.20	16.60
November	3.00	10.40	4.30	3.40	21.10
December	2.90	8.30	4.00	4.30	19.50
Total	49.65	138.00	46.04	24.40	258.09
Share (%)	19.24%	53.47%	17.84%	9.45%	100.00%

Legend: PMMCM – plastic, metals, multilayer composite materials;
MMW – mixed municipal waste

Table 3 shows that the largest amount of waste was generated in this household in March, June, and August. In March, higher waste production was related to repainting and cleaning the whole apartment, in June the amount of waste increased due to larger purchases of household goods and appliances, and in August the household organized a larger celebration with friends and family. On the contrary, the months of February, April, and October had the lowest amount of waste produced due to a 1-week business trip of 1 household member. For this family, we must also consider a certain amount of waste generated, which is related to the care of the dog. These were metal and plastic packaging that was properly separated in this household.

Model family 2 also did not significantly try to reduce the generation of waste, but it cared about the environment, so they honestly separated their waste. They bought most of the food in common packaging materials. In part, to reduce waste, especially plastic waste, they did not benefit from not buying more plastic bottles because they owned a water filter kettle. They also had an appliance for making yogurts at home, so they did not produce unnecessary disposable plastic packaging. They did not use a single application that could help them decide how to separate the waste or help reduce their waste. In the management of oversized waste (furniture, carpet, refrigerator) or hazardous waste such as used cooking oil, the family used the possibility of free delivery to the collection yard. Hazardous waste, such as discharged disposable batteries, was thrown into the trash for mixed municipal waste, but the old medicines were handed over to the pharmacy after expiration. Compared to Model family 1, they produced almost the same amount of waste, but it should be noted that almost half of this waste returned to circulation due to separation for further processing.

Comparing the average results of the weight share of individual components of mixed municipal waste prepared by the Institute of Circular Economics[28], we found that in the case of complex housing construction (Figure 1) the share of plastic, metal, and tetra pack (PMMCM) components is 14.75%, paper 10.47% and glass content 7.28%. From the data of Model family 2, whose members live in a flat, in 2019 these shares were found higher in PMMCM by 4.49%, in a paper by 7.37%, and in the commodity glass by 2.17% (Table 3). Since mixed municipal solid waste in this household formed not only the remainder, i.e. unsorted components but also biodegradable waste, we counted these two commodities together. According to the results of INCIEN (2018)[28], the average results in housing conditions show a share of 3 components (food waste, biodegradable waste, and unsortable garbage) of a total of 62.30%, and in Model family 2 we found a share of unsortable garbage of 53.47%, a share lower by 8.83%, as stated in the analysis for complex housing construction prepared on the basis of 16 municipalities in the Slovak Republic.

Model family 3 with waste separation and with waste prevention

Two members of Model family 3, living in a family house, produced a total of 236.84 kg of municipal waste in 2019 (Table 4), which represented 118.42 kg of municipal waste per 1 household member. The average amount of waste generated in 1 month was 19.74 kg of waste. This family tried to significantly reduce the production of their waste and of the total amount they produced, 50.05 kg was returnable glass, which was returned to circulation by proper separation, and 83.15 kg of biodegradable and food waste, which was composted in their own composter in their garden. If we deduct the amount of waste in the form of biowaste and returnable glass from the total amount of waste generated in this household, the total amount of waste produced by this household in 2019 was only 103.64 kg, which represented only 51.82 kg of waste per member. Compared to the national average, 1 member of this household produced 88.09% less municipal waste and compared to the European average 89.47% less waste. The average weight of waste generated in 1 month in this household reached the value of only 8.64 kg of waste.

Table 4: Waste weight results of Model family 3 in 2019

Model family 3 with waste separation and with waste prevention (in kilograms)								
Month	**PMMCM**	**MMW**	**Paper**	**Backed up glass**	**Non-returnable glass**	**Biowaste**	**Total waste 1**	**Total waste 2**
January	2.55	0.20	2.35	3.80	1.60	5.70	16.20	6.70
February	1.65	0.12	4.00	5.20	4.10	4.50	19.57	9.87
March	1.73	0.14	2.73	5.45	4.35	7.35	21.75	8.95
April	2.5	0.15	3.04	4.00	1.80	8.40	19.89	7.49
May	2.7	0.25	2.09	3.80	3.30	7.90	20.04	8.34
June	2.2	0,20	3.10	3.25	2.50	9.50	20.75	8.00
July	1.55	0.18	3.80	4.80	4.15	8.35	22.83	9.68
August	2.65	0.25	2.45	3.15	2.85	6.50	17.85	8.20
September	2.00	0.22	3.10	4.00	3.55	7.65	20.52	8.87
October	2.90	0.25	2.25	3.65	3.18	4.55	16.78	8.58
November	1.64	0.15	2.19	4.55	3.05	7.25	18.83	7.03
December	2.85	0.28	4.15	4.40	4.65	5.50	21.83	11.93
Total 1	26.92	2.39	35.25	50.05	39.08	83.15	236.84	-
Share 1 (%)	11.37%	1.01%	14.88%	21.13%	16.50%	35.11%	100.00%	
Total 2	26.92	2.39	35.25	-	39.08	-	-	103.64
Share 2 (%)	25.97%	2.31%	34.01%	-	37.71%	-	-	100.00%

Legend: PMMCM – plastic, metals, multilayer composite materials; MMW – mixed municipal waste; Total 1 – the amount of waste produced in 2019, including returnable glass and biowaste; Total 2 – the amount of waste produced in 2019 without returnable glass and biowaste; Total waste 1 – summary of all waste commodities for individual months of 2019; Total waste 2 – summary of commodities without returnable glass and biowaste for individual months of 2019

Members of Model family 3 tried to prevent the production of waste in several ways and were also interested in what happens to the generated waste. They bought food, as well as other products, exclusively without packaging and, if this was not possible, they preferred products that were not wrapped in plastic, despite the higher price of the product. They carried exclusively their own textile bags, glass containers or nets for non-packaged purchases. They did not use any disposable products such as plastic cutlery or straws. They did not buy bottled water in PET bottles; they used their own stainless steel and reusable glass bottles for the water. Food scraps were packaged in decomposable textile wipes with beeswax, that are reused. They mainly bought loose tea, which they leached in a metal sieve. They replaced the classic shampoo with its solid version. Plastic toothbrushes were replaced by bamboo brushes, which can be composted, and toothpaste was replaced by tooth-tablets. They stopped using disposable make-up removers and instead bought reusable and washable ones. A significant reduction in waste was also ensured by a domestic composter, in which they disposed of all types of biodegradable waste and kitchen waste that is suitable for the composter. Overall, they tried to eat "without waste". The Model family 3 also dealt with the lifestyle of minimalism in general, so they tried to buy only the necessary and needed things. When it came to buying textiles, family members tried to shop mainly in second hands. They did not use any app for responsible waste management, as they searched all the information on the Internet. In 2019, they did not produce any oversized waste or chemicals. In other years, they used the possibility of bringing such types of waste free of charge to the nearest collection yard. Expired medicine was handed over at the pharmacy, the batteries were thrown into designated boxes (electrical stores) and the used cooking oil was handed over at the nearest gas station.

Both values of Total waste 1 and Total waste 2 in Table 4 show that the month in which the most waste was generated was December. The heavier weight of waste during this month was mainly related to the preparations for the Christmas holidays. The least waste was produced in January, when 1 member of the household travelled for a week's stay.

In comparison with the average results of the weight share of individual components of mixed municipal waste according to analyses in individual housing construction in 36 municipalities (Figure 1) (INCIEN, 2018), we found that the share of plastic, metal and multilayer composite materials (PMMCM) was lower by 3.61% in the Model family 3 for Total waste 1 (including returnable glass and biowaste), where in our measured values the figure was 11.37% and in the average results in individual housing construction the figure was 14.98% (INCIEN, 2018)[28]. However, if we compared these values only after subtracting the amount of returnable glass and biowaste (Total waste 2) with INCIEN analyses (2018), we got higher values for the commodities plastics, metals, and multilayer composite materials (PMMCM) by 10.99%. However, it is necessary to mention that in this household in 2019 no e-waste, construction waste or hazardous waste were produced, which in the analysis according to INCIEN (2018)[28] have a certain representation in the production of waste in family houses. The share of unsortable mixed waste in the average data of family houses according to INCIEN (2018)[28] (Figure 1) was 11.75% and in Model family 3 we observed much lower values not only in Total waste 1 (lower share by 10.74%), but also in Total waste 2 (lower share by 9.44%). For the paper component, the Model family 3 had a 7.33% (Total waste 1) and 26.46% (Total waste 2) higher share of this component compared to the average results in the analysis for single-family homes (7.55%). We compared the share of glass and biowaste in the Model family 3 with the average values only in the value of Total waste 2 (i.e., after subtracting returnable glass and biowaste, which the members composted in their own composter). According to INCIEN (2018)[28], the average proportion of glass was 5.40% and for the Model family 3 it was 37.71%, which is 32.31% more.

However, it should be noted that these higher values of the share of non-returnable glass also arose from the fact that family members often preferred glass to plastic as the packaging of certain foods when shopping. Part of this non-returnable glass was used repeatedly in the household, especially in the summer months at the time of fruit and vegetable canning. Biodegradable waste in the Model family 3 had a share of 35.11% and in average results it had a share of 50.62% (Food waste 4.33% and Biodegradable waste 46.29%) (Figure 1). In this household, the share in the commodity biowaste was 15.51% lower than the average analyses in family houses according to INCIEN (2018)[28]. The lower share of bio-waste in this household reflects not only a more reasonable purchase of food products and produce, but also the preparation of food and meals for household members with the smallest possible production of food waste and biodegradable waste.

Model family 4 with waste separation and with partial waste prevention and with the exception of disposable baby diapers

In 2019, Model family 4 produced municipal waste in the total amount of 614.59 kg (Table 5), which equals to 153.65 kg per member of the household and the average weight of generated municipal waste in 1 month was 51.22 kg. However, we can deduct from this total produced amount of municipal waste the amount of biowaste and kitchen waste (fruit peelings, vegetables, and food scraps) that were composted in the household in the home composter. After deducting the amount of biowaste generated (100.39 kg), this household produced a total of 514.20 kg of waste in 2019. That was 128.55 kg per 1 household member and the average amount of waste generated in this household was 42.85 kg. Due to the fact that there were 2 children in the household, the spouses were willing to use disposable baby diapers for both children during 2019 for the purposes of this study. It turned out that a considerable amount of unsortable waste was produced by the use of disposable baby diapers (52.82% and 63.14%, respectively) (Table 5). In the course of 2019, waste weighing 324.65 kg was generated in this household from disposable baby diapers, which were thrown into a container of unsortable MSW. If instead of disposable diapers, reusable textile baby diapers were used, the amounts of unsortable mixed waste would be considerably lower in this household. Nevertheless, each member of the Model family 4 produced 70.45% less waste per person compared to the national average and 73.87% less waste compared to the European average.

Table 5: Waste weight results of Model family 4 in 2019

Model family 4 with waste separation and with partial waste prevention and with the exception of disposable baby diapers (in kilograms)								
Month	**PMMCM**	**MMW**	**DBD**	**Paper**	**Glass**	**Biowaste**	**Total waste 1**	**Total waste 2**
January	0.58	8.90	30.78	5.45	1.30	7.81	54.82	47.01
February	0.58	5.28	25.22	2.22	0.94	9.16	43.40	34.24
March	1.10	4.20	30.56	1.10	0.85	10.05	47.86	37.81
April	0.44	23.55	31.33	1.78	0.34	7.50	64.94	57.44
May	0.36	16.20	33.68	0.50	1.21	6.90	58.85	51.95
June	0.55	15.13	29.74	0.47	0.34	8.81	55.04	46.23
July	4.25	21.65	28.65	2.40	0.94	8.79	66.68	57.89
August	0.21	12.89	14.25	0.58	0.73	7.42	36.08	28.66
September	2.50	10.48	25.67	1.81	1.12	9.16	50.74	41.58
October	0.35	13.07	28.13	0.91	0.74	7.79	50.99	43.20
November	0.30	6.06	23.75	0.79	0.96	8.10	39.96	31.86
December	1.50	9.42	22.89	1.40	1.12	8.90	45.23	36.33
Total 1	12.72	146.83	324.65	19.41	10.59	100.39	614.59	-
Share 1 (%)	2.07%	23.89%	52.82%	3.16%	1.72%	16.33%	100.00%	-
Total 2	12.72	146.83	324.65	19.41	10.59	-	-	514.20
Share 2 (%)	2.47%	28.56%	63.14%	3.77%	2.06%	-	-	100.00%

Legend: PMMCM – plastic, metals, multilayer composite materials; MMW – mixed municipal waste; DBD – disposable baby diapers; Total 1 – the amount of waste produced in 2019, including biowaste; Total 2 – amount of waste produced in 2019 without biowaste; Total waste 1 – summary of all waste commodities for individual months of 2019; Total waste 2 – summary of commodities without biowaste for individual months of 2019

Table 5 shows that the months in which the most waste was produced were April and July. During these months, the apartment of this household was reconstructed and for this reason the amount of unsortable mixed waste increased. The least waste was produced in August, when the whole family was on a 2-week holiday abroad.

Members of this household have long been trying to prevent waste. Even considering that they have 2 infant children, they are bothered by the state in which we leave the environment for future generations. Through their conscious behaviour, they try to prevent the generation of waste. During 2019, members of this household tried to buy food as much as possible in their own textile and net bags and containers. Instead of plastic bottles, they used metal bottles, which they supplemented with drinking water from the public water supply if necessary. They used bee-wax napkins for food scraps for multiple uses. They composted their kitchen waste and biowaste in a home composter. Most shifts occurred in the bathroom, where they have introduced several changes in previous years, e.g. replacement of classic disposable razor blades with 1 metal razor with replaceable razor blades, disposable make-up remover pads replaced with acceptable textile ones, stopped using shampoo and shower gel in plastic packaging, but bought solid shampoo and solid soap, instead of classic toothbrushes they used composable ones, toothpaste in plastic was swapped for dental tablets, they bought deodorants in glass or made them at home, they did not use classic plastic-wrapped washing gels for washing clothes, but they made their own washing gel from soap at home. The family uses the possibility of free disposal of, for example, oversized waste at the collection yard. The family did not use apps for information on how to dispose of individual waste commodities but searched for them on the Internet. After expiration, the drugs are returned to the pharmacy and the discharged batteries are taken to electronics stores. During 2019, they began using several rechargeable batteries in the home.

Comparing the average results of the weight fraction of individual components of mixed municipal waste for complex housing construction (INCIEN, 2018)[28] (Figure 1), we found that the share of plastic, metal, and tetra pack components (PMMCM) was lower in the Model family 4 at Total waste 1 (biowaste included) by 12.68%, wherein our measured values the figure was 2.07% and in average results, the figure was 14.75%. And also, for Total waste 2 (after deducting biowaste) this share was lower by 12.28%. For paper, the Model family 4 had a share of this component of 3.16% (Total waste 1 with biowaste) and 3.77% (Total waste 2 after deducting biowaste) and the average results according to analyses in complex housing (INCIEN, 2018)[28] were 10.47%, i.e., in both cases, it was a lower share by 7.31%, resp. 6.70%. Another component was glass, where the average results of the analyses in complex housing construction (INCIEN, 2018)[28] the share of glass was 7.28% and in the Model family 4 this share was in both cases (Total waste 1 and Total waste 2) by 5.56%, respectively by 5.22% lower. Biodegradable waste and kitchen waste accounted for 49.10% on average. In the Model family 4, this type of waste had a share of 16.33%, i.e., it was 32.77% lower. The share of unsortable mixed waste in the average data is 13.20% and in the results of the Model family 4 was 23.89% (Total waste 1), resp. 28.56% (Total waste 2). Both of these data were higher by 10.69%, respectively 15.36%.

Our findings are consistent with those from other previous studies. One of the examples of evaluating the waste behaviour of the population (number of samples 682) is an exploratory study z city of Mexicali, capital of the state of Baja California located in the Northwest part of Mexico bordering to the North with the city of Calexico, California in the United States. The objective of selected research was to know the composition and quantity of residential solid waste generated by family typology and socioeconomic strata (low, medium, high) on example 125 families. Residential solid waste samples were characterized and identified by collection and analysis as field data in five categories: Organics, Non-organic, Containers, Inerts and Other types of waste. The results showed that the per capita and the average family waste generation varies according to the family typology and to the socioeconomic stratum where the family belongs. Per capita waste generation of the complete sample is 0.981 kg daily, not considering typology and strata variables, when socioeconomic strata was included in the analysis per capita waste generation varies, in the low-income strata is 0.886 kg, in the medium is 1.04 kg and in the higher is 1.058 kg. In contrast waste composition did not show any difference, except for some of the categories such as garden waste, newspaper, textiles and disposable diapers, these wastes explain the lifestyles of the generators. The largest share of generated residential solid waste was accounted for by organic waste, especially food waste (35.05%) and garden waste (16.27%), followed by sanitation wastes (8.54%), plastic waste (6.60%) and disposable diapers (4.15%). On the contrary, the smallest share fell on Polystyrene (0.02%), Plasticized paper (0.01%), Cellophane paper (0.01%) and Waxed paper (0.03%). The results of the study confirm the resulting variability within the observed families. Environmental problems associated with the generation of waste are part of societal changes where family units play an important role[29].

The quantification the amount and composition of waste generated by households and household waste management behaviourism the city of Buenos Aires (Argentina) assesses next study. A total was evaluated of 525 households classified and weighed their waste during a week and completed a questionnaire on current and potential pro-environmental behaviours. Average daily waste generation was 430 g on person, but total amount of waste varied widely among households. Every household complete one protocol consisted of weighing and recording all household waste produced throughout a week. The protocol was classified into five categories: (1) paper and cardboard (all types of paper and cardboard including Tetra Pak® containers); (2) plastic (all types of plastic); (3) other recyclable waste (metal, glass, fabric); (4) organic waste (food and garden waste) and (5) non-recyclable (e.g. disposable napkins, diapers, pet excrement, cat litter, dirty unwastable containers). Within households currently sorting waste, 68% sorted between 5 and 9 different materials (categories) and a minor fraction of participants (5%) sorted only between 1 and 2 categories. Half the household (50%) separated organic waste, 29% corresponded to recyclable materials and the rest to non-recyclables (21%). Over half the householders sorted e-waste whereas fabric, cooking oil and yard trimmings were sorted by less than 30% of households. Most participants (57%) belonged to households with one or two members; an intermediate portion (35%) was formed by three to four members and only a minor fraction (8%) by five to nine members. Among the household characteristics which could indirectly affect waste generation and composition, only 5% of the households had at least one child under 3 years old (using diapers) and 42% cohabited with at least one pet, mostly cats and/or dogs. Food cooking and eating habits showed that 95% of the participants had at least one home-cooked meal (lunch or dinner) while only 5% declared to have both meals from out- of-home sources. In turn, 93% had at least one meal at home whereas only 7% stated to have eaten both meals outdoors, irrespectively of the source (home or out-of-home). Household composition modified waste generation as people having babies or pets generated more waste per capita than the rest of participants. Likewise, participants cooking at least one meal at home generated more organic waste than the rest. Most participants cooked and had at least one meal at home, thus we conclude that kitchen waste during cooking accounted for their larger amount of organics[30].

An anthropological case study in 5 apartment buildings (residents between 11 and 81 years of age, from 112 households) in the Copenhagen area, Denmark was analysed the relationship between the local municipal waste system and its users. The residents performed waste separation with different intensification and the majority of households (93%) has a yet unrealized potential to separate more waste. The residents stretching to separate as-much-as-possible-waste (7%) expressed strong sustainable values, or they had a daily life with sufficient available time (e.g., retired, unemployed, had a part-time job) to engage in waste separation. The critical barriers identified were cultural perceptions of household order, challenges regarding interim storage in the household, (bio)waste was perceived as disgusting, challenges regarding hygiene and potential extra cleaning, mistrust to the system, convenience of residents, etc. Eight households (7%) expressed strong commitment (sorting all waste possible), 88% separated what was convenient, and six persons (5%) did not sort waste (non-separators) [31]. Next study found to reveal how recycling programmes in Sweden and Bulgaria influenced inhabitants' participation in separation of household waste. The waste separation behaviour of 111 university students from Kalmar, Sweden and 112 students from Plovdiv, Bulgaria. The results showed that a lack of proper conditions for waste separation can prevent individuals from participating in this process, regardless of their positive attitudes. When respondents were satisfied with the local conditions for waste separation their behaviour instead depended on their personal attitudes towards waste separation and recycling.[3] Next study estimate solid waste generation and its composition from 424 households in Medan City (Sumatera island, Indonesia), in 8 sub-districts to ascertain their statistical relationship with geographic location and level of income of household. The average waste generation was 0.222 kg per person daily. Of the total weight, organic waste formed the largest fraction at 61.35%, followed by plastic waste at 17.55%, paper at 8.20%, and rest represented other materials. The amount of household waste generated in each geographic location was different, but it no significant difference within the different income level[32].

Degree of separation in model families

Waste separation is a necessary prerequisite for effective waste management, and it is the most effective means to promote the recycling of domestic waste. It is a key link to realize the harmlessness, reduction and resource utilization of waste. Therefore, it is considered as the top priority in domestic waste management[33]. Pro-environmental behaviour is influenced by internal factors (for example, knowledge, values and attitudes, emotions, motivation and locus of control) and external factors (for example, infrastructure, social and cultural factors, and the economic situation) [34].

To determine the degree of separation in model families 2 – 4, we used the formula given in Methodology. We did not calculate this figure for the Model family 1 because the members of the family do not sort waste. After adding the individual data into the formula, the value of the separation rate for the Model family 2 was 46.53%. The result of the separation rate in the Model family 3 was 98.99%, while this high figure reflects the lifestyle of the members of this model family with significant prevention of mixed municipal waste. The resulting value of the separation rate in the Model family 4 was 23.28%. This extremely low number, despite efforts to prevent waste, is due to the use of many disposable diapers. If we compare these data with the average data of the Slovak Republic, then model families 2 and 3 had a higher degree of separation than the national average in 2019 (by 7.53% and by 59.99%). The Model family 4 had a separation rate lower by 15.72%. If we compare the results of the separation rate of these 3 model families with the average EU data, then Model family 3 achieved a significantly higher separation rate (by 53.99%) and also Model family 2 achieved a higher separation rate, but only by 1.53%. Model family 4 achieved a lower value from the EU average (by 21.72%) due to its degree of separation.

By separating waste, we can primarily reduce the amount of waste deposited in landfills, increase the preparation of still usable waste for reuse in the recycling process and thus save primary resources. The stimulating factor for Slovak towns and municipalities is the differentiation of fees for landfilling waste depending on the achieved percentage of separate waste collection, i.e., the level of municipal waste sorting. This means that if a city or municipality achieves a low level of municipal waste sorting, it pays a higher fee for depositing waste in a landfill. The fee rate is set in the Regulation of the Government of the Slovak Republic no. 330/2018 Coll.[35], which establishes the rates of fees for waste disposal and details related to the redistribution of income from fees for waste disposal. Increasing the efficiency of separate waste collection as well as the overall production of municipal waste depends mainly on the environmental awareness of citizens.

Recycling is a plausible path to reduce the amount of waste generated in the country in a sustainable way[36]. Even if the best recycling strategy is adopted, it will only be successful if it is managed well[37]. Waste sorting is the least that each of us should do for our planet, because the growth of waste generation is a serious problem. Only properly sorted waste into individual components can be further recycled – i.e., returned to circulation. Of course, in addition to sorting waste for recycling itself, we should also prevent the production of waste.

Conclusion

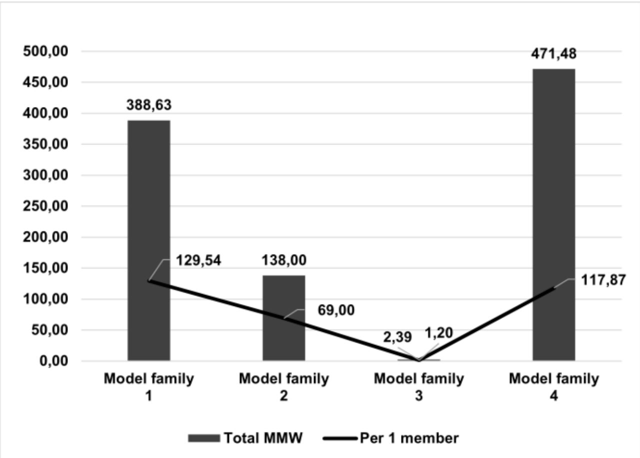
From January 1 to December 31, 2019, we monitored and subsequently evaluated the amounts of municipal waste in 4 different model families in Slovakia. The model families differed from each other in the total amount of municipal waste produced, in the amount of waste per 1 family member, in the involvement in sorting, and in the prevention of waste production.

Members of the Model family 1 not only do not make any effort to reduce the amount of waste but also do not sort their generated waste. This family of three produced a total of 388.63 kg of municipal waste in 2019, which represents 129.54 kg per member (Graph 1, 2). The amount of waste generated per 1 member of this household is incomparably lower compared to the average amount per 1 inhabitant of the Slovak Republic (435 kg). Unfortunately, the entire amount of mixed municipal waste, in this case, was disposed of in the most common way in the Slovak Republic so far – landfilling. Several steps have been recommended to members of this household on how to behave more responsibly in relation to the environment, including reducing the amount of waste generated in this household and the need to sort the basic components of municipal waste, of course in accordance with current legislation.

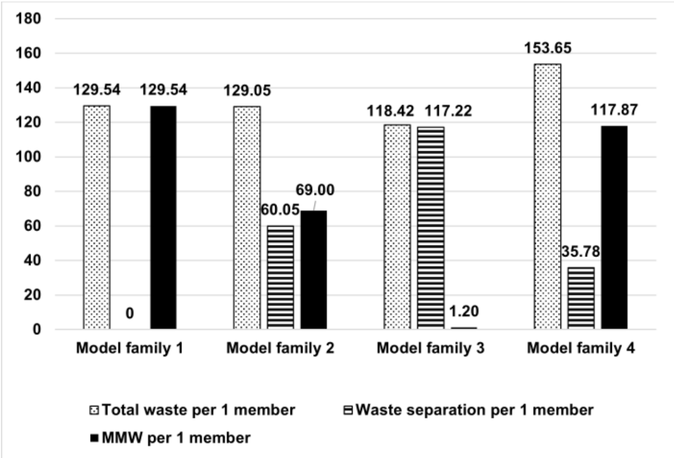
The two-member Model family 2 produced a total of 258.09 kg (129.05 kg per 1 member) in the evaluated period, but mixed municipal waste accounted for a smaller amount due to waste sorting in this household – 138.00 kg (53.47%) (Graph 1, 2). 69.00 kg of mixed municipal waste was produced per 1 member (Graph 2). The remainder was sorted components, plastics, metals, multilayer composite materials (49.65 kg, 19.24%), paper (46.04 kg, 17.84%), and glass (24.40 kg, 9.45%). The separation rate in 2019 in this model family reached 46.53% (120.09 kg, 60.05 kg of separated components per member) (Graph 2). To further reduce the production of waste, we recommended members of this household to establish their own composter for the recovery of biodegradable waste, to start shopping in their own containers, preferably in non-packaging stores, or to try to replace plastic packaging with other, better recyclable alternatives, such as glass, paper, etc.

Two members of the Model family 3 strive to prevent waste and are interested in the zero-waste lifestyle. In 2019, they produced a total amount of waste 236.84 kg – an amount approximately the same as the Model family 2, 118.42 kg per member (Graph 2). Of this total amount, up to 234.45 kg (98.99%) accounted for the separated waste components; plastics, metals, and multilayer composite materials (26.92 kg), paper (35.25 kg), glass (returnable and non-returnable together 89.13 kg), and biowaste (83.15 kg), which they disposed of in their own composter in the garden. They sorted 117.22 kg of various types of waste per 1 household member (Graph 2). Mixed municipal waste accounted for the smallest amount of all evaluated model families in 2019, i.e., 2.39 kg per the whole household (1.20 kg per 1 member) (Graph 1, 2). Due to the zero-waste lifestyle, we recommended to the members of this household the search for other alternatives for products where they still produce waste, especially plastics, metals, and multilayer materials.

Graph 1: Total generated quantities of waste and recalculation per 1 household member in model families 1 – 4 in 2019



Graph 2: The total amount of waste generated, amount of separated components, and amount of mixed municipal waste in terms of 1 household member in model families 1 – 4 in 2019



Model family 4 belongs to a group of young people who try to live in accordance with the zero-waste lifestyle. In the future, they want to follow this lifestyle more and they know that they are only at the beginning of it. In 2019, this young family consisted of 2 adults and 2 children aged 4 months and 18 months who needed diapers (an older child only 3-5 pieces a day to sleep). We asked the couple to use disposable baby diapers during the year 2019. In total, they produced 614.59 kg of all types of waste in this household, which equals to 153.65 kg per member (Graph 2). With this amount, they reached higher values than the Model family 1, whose members do not sort waste at all (by 24.11 kg). Compared to other model families, the weight of their mixed municipal waste was the highest (471.48 kg, per member 117.87 kg) (Graph 1, 2). Of the total amount of mixed municipal waste, disposable baby diapers accounted for 324.65 kg (68.86%). After deducting disposable baby diapers, the value of mixed waste would be 146.83 kg (36.71 kg per member). By separation, they sorted a total of 143.11 kg of waste (35.78 kg per member) (Graph 2). The share of separated components was 23.28%, of which the highest share was biowaste (100.39 kg), which the couple composted in a home composter. In addition, 12.72 kg of plastics, metals, and multilayer composite materials, 19.41 kg of paper, and 10.59 kg of glass were sorted. Even in this model family, other more sustainable alternatives may be tried in areas where they still produce waste.

To increase the level of municipal waste sorting, in which the Slovak Republic lags behind the most developed countries and the European average, it is necessary to increase the motivation of citizens in the area, introduce effective municipal waste management systems that would motivate citizens to produce less mixed municipal waste and a higher level of sorting[38]. Each of us should be interested in how the waste we produce is treated. Instead of fast consumer life, we should slow down and buy only the products that we absolutely need. The basis for minimizing the production and harmfulness of waste is gentle and lower consumption. In order to produce less waste, it is necessary to reduce consumption in particular. We can start by resisting the temptation to buy what we do not need. By not buying too many products, we not only reduce the amount of waste and save natural resources, but also our finances.

Households can minimize residual waste and increase the volume of materials recycled by improving waste separation and changing purchasing behaviour. Changes in household purchase behaviour can contribute to the reduction and improved sorting of solid waste as well. Households may purchase reusable products or decrease their consumption altogether[39].

Waste volume is influenced by the decisions of individuals, connected with their lifestyles. Therefore, it is necessary to increase public awareness of waste economy principles and to increase the ecological behaviour of the general public. Ecological behaviour is based on recycling, as well as the preventive behaviour of individuals[9]. We should all realize that waste does not simply disappear, just because we no longer see it after being thrown in the trash. Waste is not just something we loathe and smell. It is a raw material that we can further process and enhance. The solution to reducing waste production should also be the transition to a circular economy, where each waste is considered a raw material. Recycling is no longer enough for the waste problem alone. We, as individuals, should act responsibly and, at least in small incremental steps, begin to reduce the production of our waste. Although some people honestly separate their waste, in the best case they also recover it by composting and generally prevent its production, there are still very few of these people. People with a consumer type of behaviour, insufficient waste recovery, and insufficient information on the state of waste management are more prevalent. As Anne Marie Bonneau, a well-known blogger and representative of zero-waste in California, says: “We don't need a handful of people doing zero-waste perfectly. We need millions of people doing it imperfectly.”

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Preverenie efektívnosti predchádzania vzniku komunálneho odpadu (prípadová štúdia)

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Súhrn

Základom nášho experimentu boli 4 rozdielne modelové rodiny, žijúce v rôznych podmienkach a v rôznych častiach SR (okres Trnava – mesto Trnava) a okres Ružomberok – mesto Ružomberok a dedina Likavka). Členovia týchto domácností mali predovšetkým rozdielne návyky a správanie vo vzťahu k odpadom a k životnému prostrediu. V 4 modelových rodinách sme v jednotlivých mesiacoch v roku 2019 (od 1.1.2019 do 31.12.2019) získavali množstvo ich vyprodukovaného komunálneho odpadu. Zároveň, ak domácnosť separovala vybrané zložky komunálneho odpadu, ich hmotnosť bola zisťovaná (napr. plasty, kovy, viacvrstvové kombinované materiály, papier, sklo, bioodpad).

Cieľom našej prípadovej štúdie je poukázať na evidentné a zásadné rozdiely v správaní sa 4 rôznych slovenských modelových rodín, ktoré sme mali možnosť sledovať nielen z hľadiska celkovej produkcie zmesového komunálneho odpadu, ale aj z hľadiska množstva vybraných druhov vytriedených zložiek v priebehu celého roka 2019. Zistené výsledky jednotlivých členov modelových rodín boli porovnané s priemerným množstvom vyprodukovaného odpadu na 1 obyvateľa v roku 2019 v SR (435 kg) a v EÚ (450 kg).

Aj napriek tomu, že členovia modelovej rodiny 4 vyseparovali značné množstvo odpadu (143.11 kg), v roku 2019 vyprodukovali najväčšie množstvo zmesového komunálneho odpadu (471.48 kg), pretože v rámci neho boli likvidované aj použité jednorazové detské plienky. Modelová rodina 1, ktorej členovia nie sú zapojení do triedenia odpadu, vyprodukovala zmesový komunálny odpad (388.63 kg) a celé toto množstvo bolo likvidované zberom a následným skládkovaním. Na zmesový komunálny odpad v modelovej rodine 2 pripadalo z dôvodu triedenia odpadu v tejto domácnosti menšie množstvo (138 kg). Zapojením členov modelovej rodiny 3 nielen do separácie odpadu, ale aj do predchádzania vzniku odpadu sa v tejto domácnosti vyprodukovalo najmenšie množstvo zmesového komunálneho odpadu, iba 2.39 kg.

Porovnávaním 4 modelových rodín z hľadiska ich celoročnej produkcie komunálnych odpadov, vyseparovaných zložiek, príp. predchádzaniu vzniku odpadov, poukazujeme na to, že odlišné správanie v nakladaní s odpadmi prináša aj odlišné výsledky.

Kľúčové slová*: tuhý komunálny odpad, separácia odpadu, predchádzanie vzniku odpadu, nulový odpad*

Phytomass as a renewable energy source in conditions of the Czech Republic

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Abstract

A new research carried out in 2018 – 2020 addressed the use of grasses as catch crops in order to determine the production of dry matter and energy in selected grass species and their mixtures. Mixtures of Lolium perenne 'Kentaur', Festuca rubra 'Zulu' and Festuca arundinacea 'Kora' were included in the research. Grasses were established during the business year in three terms as summer, stubble and winter catch crops. In 2019, the dry matter yield of selected grass mixtures ranged between 5.5 $t.ha^{-1}$ and 12.7 $t.ha^{-1}$. The stated yields correspond to a tonne of coal equivalent of 3.33 $t.ha^{-1}$ to 7.6 $t.ha^{-1}$. Dry matter yield in 2020 for selected grass mixtures ranges between 5 $t.ha^{-1}$ and 12.3 $t.ha^{-1}$. The stated yields correspond to a tonne of coal equivalent of 3.03 $t.ha^{-1}$ to 7.36 $t.ha^{-1}$. At the same time, dry matter production was monitored in 2018 – 2020 on an uncultivated land, former meadows and an arable land at one site. Dry matter production ranged between 1.08 and 1.53 $t.ha^{-1}$. This also corresponds to the energy production of 0.62-0.92 $t.ha^{-1}$ equivalent tonne of coal equivalent. The total production of dry matter and energy is 6–8 times lower compared to the monitored grass mixtures usable as catch crops. The occurrence of weeds dangerous in sowing procedures of agricultural production such as Elymus repens, Cirsium sp., Rumex sp. has been reported on an uncultivated land. From an agricultural and landscape perspective such negative phenomena in the form of spontaneous fallow land must be eliminated. Intercrops increase the stability of the landscape agroecosystem, especially in relation to soil, and based on this research grasses grown as intercrops can be recommended and used in agricultural sowing practices. The resulting biomass of catch crops can be used for bioenergy purposes.

Keywords: *Grass, catch crops, dry matter, tonne of coal equivalent, spontaneous fallow*

Introduction

Grasses are a large and diverse family of *Poaceae*, which is represented in the Czech Republic by 64 genera (including important cereals) and more than 200 species[1]. The occurrence of grasses is linked to grassland ecosystems, the most important of which are communities of different types of natural and semi-natural meadows (Figure 1). In the plant system, grasses are monocotyledonous plants that are characterized by the presence of only a single uterine petal and other features such as the type of root system, the structure of the flowers, and the parallel veins of the leaves. They include annual, bi-annual and perennial, non-pollinated and self-pollinated, winter and spring species. Morphologically, they form a relatively unified group[2].

Cagaš[3] states in the Methodology for Agricultural Practice[3]: Grasses as well as their mixtures with various types of clover meet the basic requirements for permanent soil cover, reduce the risk of erosion and the growth of secondary weeds. They also improve physical and chemical condition of the soil, promote the biological life in the soil and, last but not least, offer the immediate readiness to transfer these areas to normal agricultural production. To a greater or lesser extent, grasses and clover can contribute to short-term fallow (1 – 3 years), long-term grassing and produce biomass as an important source of renewable energy. The potential of grass biomass is mainly represented by permanent grasslands (meadows and pastures), lawns, technical areas and purposefully grown grasses for seed harvesting with the use of threshed straw for energy purposes[4, 5].

Grasses can be used to generate heat or electricity in special boilers[6]. Heat or electricity is generated by biogas production. In addition, grass biomass is used to produce briquettes or pellets as a fuel for heating[7, 8].

Further research has been also carried out on the use of grass to produce second generation bioethanol and biodiesel from lignocellulose. Bioethanol is produced by a biotechnological method (anaerobic fermentation by yeast or bacteria), while biodiesel is produced by a thermochemical method using synthesis gas, which can then be chemically converted, for example, by the Fischer-Tropsch method[6]. Grass biomass can also be processed by torrefaction, i.e. thermochemical decomposition without air access. Grass biomass acquires higher calorific value, lower humidity and hydrophobic character[9].

The possibilities of using the potential of grass biomass are very topical. Research into the use of grasses for energy purposes was carried out in three stages. In the first stage of the research, the most suitable grasses for energy purposes were selected and monitored from the group of grass species in terms of green matter yield, dry matter and dry mass, gross calorific value and net calorific value. These included the selection of the best grasses for energy purposes suitable for the conditions in the Czech Republic, such as *Agrostis gigantea* (redtop) 'Rožnovský', *Festuca arundinacea* (tall fescue) 'Kora' and *Arrhenatherum elatius* (tall oatgrass) 'Rožnovský'. At the same time, several varieties of *Phalaris arundinacea* (reed Canary grass) were also verified. This grass species is also very suitable for use in phyto energetics. *Phalaris arundinacea* 'Chrastava' variety was cultivated for the conditions in the Czech Republic by OSEVA Development and Research Ltd. in Zubří. At the same time, an uncultivated land, so-called spontaneous fallow has been also assessed, including botanical evaluation thereof. The dry matter yield of spontaneous fallow grasslands was low (up to 2 $t.ha^{-1}$).

In the second stage of the research, the yield parameters of grasses were verified. These include the yield of green matter, dry matter, dry mass and its content. These parameters were determined for grass species and meadow mixtures that were included in the research in the period of one to two months before the harvest maturity of grasses for seed and in the period within two months after the harvest maturity of grasses for seed. The aim was to determine the most suitable date for the highest dry matter yield harvest. At the same time, combustion tests of grass biomass in small (heat output up to 50 kW) and large boilers (500 kW–2 MW of heat) took place. Thus, a suitable energy producing device (boiler) was determined, in which grass biomass can be burned[10].

The third stage of energy grass research focused on monitoring biogas production. The research of grass biomass combustion and biogas production was carried out by OSEVA Development and Research Ltd. in Zubří in cooperation with the University of Mining and Technology in Ostrava and the Research Institute of Agricultural Technology in Prague[10].

During the period 2018 – 2020, the production of selected grass species and their mixtures grown as catch crops was the subject of a new research in order to determine the dry matter yield and energy production. The production of dry matter and energy of grass mixtures grown as catch crops was compared with the production of spontaneous fallow established on an uncultivated land.

Figure 1: Phytomass in Beskydy in the area of the OSEVA Development and Research Zubří

Material and methods

The 2018 – 2020 research project was divided into two parts. In the first part of the research project, grass mixtures were established at three terms during the year as summer, stubble and winter catch crops. The first results showed that the inclusion of catch crops in sowing procedures prolongs the time of soil cover and thus affects a number of factors, especially in terms of soil protection and by increasing its fertility. Intercrops increase the long-term stability of the agroecosystem, especially in relation to the soil in the landscape. In the case of the grass mixtures, dry matter yield and energy production were monitored. In the second part of the research project, spontaneous fallow on an uncultivated land were selected. Dry matter yield and energy production were determined for these fallow lands. The resulting production of grass mixtures was compared with the production of dry matter and energy on the uncultivated land.

Characteristics of grass species included in the research

***Lolium perenne* L.** (perennial ryegrass) – the variety 'Kentaur' is tetraploid ryegrass with medium to late heading time, intended for pasture use, which was registered in the State Variety Book of the Czech Republic in 2002. The variety is resistant to snow mould infestation, less resistant to leaf spots and moderately resistant to rust infestation (ÚKZÚZ, 2020). The variety was bred by crossing and subsequent selection of late types of foreign tetraploid varieties.

***Festuca rubra* L.** (red fescue) 'Zulu' variety starts growth very early in the spring and early production of green matter, significantly earlier than other permitted varieties, is bushy and of perennial character. Due to the favourable spring overgrowth it is also suitable for ordinary, less demanding grass-plots even in drier conditions. The variety was registered in the State Variety Book of the Czech Republic in 1974 under the name 'Valaška' and was bred from ecotypes found in permanent grasslands in Wallachia[11]. *Festuca rubra* is also suitable for phytostabilization of soil[12].

***Festuca arundinacea* Schreb.** (tall fescue) – is suitable for pastures, for the production of hay and silage, but also for storing the soil at rest[13]. *Festuca arundinacea* 'Kora' is an early to medium early variety, suitable for meadow and pasture use. Spring growth is very fast, grows densely after mowing. Resistant to snow fungus. Tolerates summer droughts and wetting well. The variety was registered in the State Variety Book of the Czech Republic in 1989 and was bred by crossing foreign varieties with Northern Moravia ecotype (Bílovec). The variety has a very good durability[11].

Grasses and grass mixtures were sown in 2018 and 2019 during experiments in various ways and at different times in a small field plot establishment with a plot size of 10 m^2 and rows spacing of 21 cm. At the same time, three sowings of grass mixtures were tested in June, September and in October in 2018 and 2019.

The experimental plots of herbage were fertilized with NPK nitrogen fertilizer with a dose of 40 kg $N.ha^{-1}$ before sowing. Further fertilization was carried out in the spring of the following year by a dose of 55 kg $N.ha^{-1}$ of ammonium nitrate with limestone. In 2018 and 2019, *Lolium perenne* 'Kentaur', *Festuca rubra* 'Zulu' and *Festuca arundinacea* 'Kora' were included in the research. Two two-component mixtures were created, the first with *Lolium perenne* 'Kentaur' a *Festuca arundinacea* 'Kora', sowing 10 kg and 20 $kg.ha^{-1}$. The second mixture contained *Lolium perenne* 'Kentaur' and *Festuca rubra* 'Zulu'. It was also established with a sowing rate of 10 kg and 20 $kg.ha^{-1}$. These mixtures were established in June, September and October in 2018 and 2019. In June of 2019 and 2020 harvesting of the grass mixtures of the first crop established in 2018 and 2019 was carried out (Figure 2). The dry matter yield was then determined and the dry matter yield of selected grass mixtures was converted to a ton of coal equivalent, which will be replaced by the stated amount of biomass harvested in the established mixtures. The values of gross calorific value and net calorific value were also determined.

Figure 2: Grass mixtures in 2020

Habitat characteristics

The catch crops experiments were based on OSEVA Development and Research Ltd. habitat. The habitat lies in Zubří at an altitude of 345 m. The long-term average annual temperature is 7.5 °C and the long-term annual rainfall is 864.5 mm. The long-term average temperature for the growing season is 14.3 °C and the long-term total rainfall for the growing season is 546.8 mm. The land on the station is located in climate region 7 — moderately warm. The experiments were based on medium sandy soil in the years tested. Spontaneous fallow were assessed in Hustopeče nad Bečvou, which is at an altitude of 275 m. They are also in climate region 7. Fallow were predominantly on light sandy and medium sandy-brown soil in the Hustopeče nad Bečvou in the village Velká Lhota at an altitude of 540 m. They were assessed in a former hay and hay-harvesting meadow.

Biomass samples from an uncultivated land with an area of four times one metre were harvested. Dry matter yield, gross calorific value and net calorific value were determined according to CSN EN ISO 18125 on IKA C6000. In 2018 – 2020 an evaluation of fallow land in the area of Hustopeče nad Bečvou and in 2018 another evaluation of one fallow land in the area of Velká Lhota were carried out. The fallow land harvest time during the experimental years took place at the turn of October and November.

Results and discussion

I. part of the research project in 2018–2020

The result of this first part of the research are the yields of dry matter and production of energy of the proposed grass mixtures as intercrops. Table 1 lists parameters for the mixture of *Lolium perenne* with *Festuca arundinacea*, and Table 2 for the mixture of *Lolium perenne* with *Festuce rubra.*

Table 1: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca arundinacea in 2019

Evaluation	***Lolium perenne + Festuca arundinacea***				
Seed rate (kg.ha^{-1})	20	10	20	10	20
Sowing dates	June		September		October
Dry matter yield (t.ha^{-1})	12.7	11.5	11.7	10.9	5.7
Gross calorific value of dry matter (GJ.t^{-1})	17.96				
Energy production (GJ.ha^{-1})	224.00	203.00	207.00	195.00	106.00
Standard deviation	0.11	0.16	0.12	0.09	0.10
Range	0.30	0.56	0.33	0.25	0.27
Tons of coal equivalent (t.ha^{-1})	7.60	6.89	7.01	6.59	3.41

Table 2: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca rubra in 2019

Evaluation	***Lolium perenne + Festuca rubra***					
Seed rate (kg.ha^{-1})	20	10	20	10	20	20
Sowing dates	June		September			October
Dry matter yield (t.ha^{-1})	11.8	11.0	11.4	10.5	10.0	5.5
Gross calorific value of dry matter (GJ.t^{-1})	18.45					
Energy production (GJ.ha^{-1})	207.00	193.00	200.00	184.00	179.00	98.00
Standard deviation	0.20	0.20	0.24	0.20	0.21	0.18
Range	0.57	0.64	0.72	0.60	0.64	0.56
Tons of coal equivalent (t.ha^{-1})	7.02	6.54	6.78	6.24	6.05	3.33

Dry matter yield in 2019 of selected grass mixtures ranges between 5.5 t.ha^{-1} and 12.7 t.ha^{-1}. The stated yields also correspond to the equivalent of a tonne of coal equivalent between 3.3 t.ha^{-1} and 7.6 t.ha^{-1} (Table 1 and 2). The lowest yields of dry matter and energy production are noted in the variant of the experiment established in October 2019.

Dry matter yields of the same mixtures for 2020 are shown in Table 3 and 4.

Table 3: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca arundinacea in 2020

Evaluation	***Lolium perenne + Festuca arundinacea***				
Seed rate (kg.ha^{-1})	20	10	20	10	20
Sowing dates	June		September		October
Dry matter yield (t.ha^{-1})	12.3	11.3	10.6	10.3	5.3
Gross calorific value of dry matter (GJ.t^{-1})	17.96				
Energy production (GJ.ha^{-1})	217.00	200.00	187.00	182.00	94.00
Standard deviation	0.22	0.21	0.14	0.17	0.10
Range	0.57	0.60	0.40	0.48	0.28
Tons of coal equivalent (t.ha^{-1})	7.36	6.76	6.35	6.17	3.17

Table 4: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca rubra in 2020

Evaluation	***Lolium perenne + Festuca rubra***					
Seed rate (kg.ha^{-1})	20	10	20	10	20	20
Sowing dates	June		September			October
Dry matter yield (t.ha^{-1})	11.4	10.7	10.2	9.7	8.9	5.0
Gross calorific value of dry matter (GJ.t^{-1})	18.45					
Energy production (GJ.ha^{-1})	200.00	188.00	179.00	170.00	159.00	89.00
Standard deviation	0.12	0.17	0.07	0.16	0.14	0.16
Range	0.27	0.47	0.19	0.45	0.34	0.44
Tons of coal equivalent (t.ha^{-1})	6.78	6.36	6.06	5.77	5.39	3.03

A tonne of coal equivalent is a fuel derived from black coal. Its net calorific value is 7 000 kcal.kg^{-1} (i.e. 29.3076 GJ.t^{-1}). It is used as large volumes of fuel. The values of gross calorific value and net calorific value, listed in Table 5, were determined in the Research Institute of Agricultural Engineering, p.r.i. in Prague.

Table 5: Average values of gross calorific value and net calorific value for grasses and grass mixtures included in the research in 2018–2020 in 100 percent dry matter

Grass species and mixtures	Gross calorific value kJ.kg^{-1}			Net calorific value kJ.kg^{-1}
	Average	Standard deviation	Range	
Lolium perenne	18 155.0	5.8	62.0	17 862
Lolium perenne + *Festuca arundinacea* mixture	17 959.0	4.3	57.0	17 666
Festuca rubra	18 450.0	4.4	56.0	17 220
Lolium perenne + *Festuca rubra* mixture	18 303.0	7.2	85.0	17 541

Dry matter yield in 2020 of selected grass mixtures ranges between 5.0 t.ha^{-1} and 12.3 t.ha^{-1}. The stated yields also correspond to the equivalent of a tonne of coal equivalent between 3.03 t.ha^{-1} and 7.36 t.ha^{-1} (Table 3 and 4). The lowest yields of dry matter and the energy output is noted in variants of the experiment established in October 2020. Frydrych[14] discloses energy production of selected grass species in the first stage of research as 0.50 – 6.09 t.ha^{-1} of the coal equivalent per hectare. The highest yield of dry matter (9.72 t.ha^{-1}) and energy production of 6.09 t.ha^{-1} was achieved by *Agrostis gigantea* 'Rožnovský'.

Frydrych[15] states that in the first stage of the research, the proposed grasses were assessed in terms of yield of green matter, dry matter and dry mass. They were analyzed for gross calorific value and net calorific value. Based on the results, three species of grasses most suitable for energy use were determined as follows (*Agrostis gigantea* 'Rožnovský', *Festuca arundinacea* 'Kora' and *Arrhenatherum elatius* 'Rožnovský'). The yield of these three grass species ranged on average between 8 and 10 t.ha^{-1} of dry matter in the conditions of Zubří in the fertilized variant. The grasses were tested in the variant without fertilization and with the variant fertilized with 50 kg N.ha^{-1} per year.

Grasses and meadow mixtures included in the second stage of the research were harvested as whole plants at the monthly intervals between May and September. The highest dry matter yields in all three harvest years were achieved in the third cropping year by *Phalaris arundinacea* 'Palaton' 11.89 t.ha^{-1}, *P. arundinacea* 'Chrastava' 11.76 t.ha^{-1}, *P. arundinacea* 'Chrifton' 11.20 t.ha^{-1}, *Agrostis gigantea* 'Rožnovský' 11.12 t.ha^{-1} and *Festuca arundinacea* 'Kora' 10.69 t.ha^{-1}. All these yields were achieved in the fertilized variant of 50 kg N.ha^{-1} in the month of August in three harvest years. The highest dry matter yield was achieved by grasses during the harvest of whole plants in the period from July to August, i.e. during the period of harvest maturity for seed and one month after this harvest maturity for seed.

Strašil[16] mentions one of the alternative crops, *Festuca arundinacea*, the widespread cultivation of which is being considered for energy or industrial use. From an energy point of view, *Festuca* can be used for direct combustion or cogeneration (electricity and heat production). In our conditions, the yields of phytomass dry matter range between 5 and 13 t.ha^{-1}.

It is the speed of development after sowing that is important when utilising grasses as intermediate crops. The speed of development as well as the degree of duration is governed not only by the biological properties of individual grass species, but also by habitat conditions and by the applied agricultural engineering. With the right agronomical practices and rational use, it is possible to significantly increase the durability of grasses through growing technologies. Rapid growth exhibiting *Lolium perenne* and moderately fast growing *Festuca rubra* and *Festuca arundinacea*[17] were selected for the research.

Grasses and their mixtures are useful as catch crops. Grasses can be established as summer, stubble and winter catch crops. The highest dry matter yield and energy production was achieved by a mixture of *Lolium perenne* and *Festuca arundinacea* in sowing 20 kg.ha^{-1} in the first and second sowing dates in June and September in both experimental years. (Table 1 and 3). *Festuca arundinacea* 'Kora' is characterized by considerable adaptability to different habitat conditions and is one of the grasses with the widest habitat amplitude. *Festuca arundinacea* tolerates well both short-term drought and wetlands.

Lolium perenne showed a rapid initial development compared to *Festuca arundinacea* and *Festuca rubra*. *Lolium* and their mixtures can be recommended as intermediate crops in spring, late summer and early autumn with good biomass yield potential. *Lolium multiflorum* var. *italicum* (Italian ryegrass) and *Lolium multiflorum* var. *westerwoldicum* (annual ryegrass) can also be used as intermediate crops. Cagaš[2] characterizes *Lolium multiflorum* var. *italicum* as the most important grass species for intensive forage production on arable land, which is also grown as a fast-growing intercrop.

Based on the research results, it is possible to unambiguously recommend sowing rates for mixtures of *Lolium perenne* with *Festuca arundinacea* and *Festuca rubra* of 20 kg.ha^{-1} (representing a 50% share in cases of individual types of two-component mixtures) and *Lolium perenne* 20 kg.ha^{-1} (cit.[17]).

II. part of a research project in 2018 – 2020

The result of this II. part of the research include dry matter yields and energy production of spontaneous fallows on an uncultivated land.

Research of spontaneous fallows on uncultivated land

The production of proposed grasses and their mixtures for use as intermediate crops, when this material is suitable for energy purposes, was jointly monitored with the biomass production on an uncultivated land in the area of Beskydy Mountains in Hustopeče nad Bečvou locality in 2018 – 2020 and 2018 in Velká Lhota (Table 6 – 8). Low production of dry matter at individual sites was proven by the evaluation of these meadows, the harvest materials and the arable land used already in the past for hay and silage. Negative outcomes of these in the past assessed spontaneous fallow lands in the area of Beskydy (Zubří and the Prostřední Bečva) were noted from the agricultural, soil and landscape point of view in the area where they occur. In terms of agricultural concerns the largest weed population found at all fallow lands comprised of the most dangerous species, namely *Elymus repens* (quackgrass), *Cirsium arvense* (Canada thistle), *Rumex crispus* (curly dock) *R. obtusifolius* (bitter dock) and *R. conglomeratus* (clustered dock). The highest costs in agricultural production in the area of plant protection are incurred by protecting plants against these weeds. Moreover, soil fertility is reduced by the depletion of nutrients by these weeds. The fallow lands that are the source of these weeds are almost always adjacent to the agricultural sites. The probability of weeds spreading from these "foci" even over a distance of several kilometres is high. In addition to this negative phenomenon, there is also a high likelihood of a certain accumulation of diseases and pests on these spontaneous fallow lands. It is a well-known fact that weeds are carriers of numerous diseases and pests harmful to cultivated plants, besides the fact that they also allow their development and further spread of such diseases and plant pests. Dry matter yield on spontaneous fallow lands is very low[14].

Table 6: Dry matter yield and energy value of spontaneous fallow lands in the area of Hustopeče nad Bečvou and Great Lhota in 2018

Fallow land name	Culture	Dry matter yield t.ha^{-1}	Energy production			
			Average GJ.ha^{-1}	Standard deviation	Range	Tons of coal equivalent per hectare
Štěrk	Arable land	1.36	23.77	0.49	0.14	0.74
Velká Lhota*	Meadow	1.14	20.94	0.06	0.16	0.68
U Obory	Meadow	1.28	23.81	0.07	0.20	0.75

**in 2018, a sample of the fallow land was taken at the Velká Lhota site*

Table 7: Dry matter yield and energy value of spontaneous fallow lands in Hustopeče nad Bečvou in 2019

Fallow land name	Culture	Dry matter yield t.ha^{-1}	Energy production			
			Average GJ.ha^{-1}	Standard deviation	Range	Tons of coal equivalent per hectare
Štěrk	Arable land	1.40	26.32	0.06	0.16	0.83
Bečviska	Meadow	1.12	21.00	0.06	0.18	0.66
U Obory	Meadow	1.31	24.29	0.06	0.16	0.77
Poruba	Meadow	1.25	23.28	0.04	0.12	0.73

Table 8: Dry matter yield and energy value of spontaneous fallow lands in Hustopeče nad Bečvou in 2020

Fallow land name	Culture	Dry matter yield t.ha^{-1}	Energy production			
			Average GJ.ha^{-1}	Standard deviation	Range	Tons of coal equivalent per hectare
Štěrk	Arable land	1.53	27.22	0.09	0.24	0.92
Bečviska	Meadow	1.29	21.45	0.06	0.16	0.72
U Obory	Meadow	1.17	19.76	0.12	0.32	0.67
Poruba	Meadow	1.08	18.38	0.06	0.16	0.62

The values of gross calorific value and net calorific value, given in Table 9, were also determined in the Research Institute of Agricultural Engineering, p.r.i. in Prague.

Table 9: The average of gross calorific value and net calorific values in dry matter, spontaneous fallows on arable land in 2018–2020

Fallow land name	Culture	Gross calorific value, kJ.kg^{-1}			Net calorific value kJ.kg^{-1}
		Average	Standard deviation	Range	
Velká Lhota	Meadow	18 370.0	4.3	52.0	17 616
Štěrk	Arable land	18 463.0	4.3	53.0	17 217
Bečviska	Meadow	18 345.0	4.3	51.0	17 060
U Obory	Meadow	18 440.0	5.8	83.0	17 140
Poruba	Meadow	18 475.0	5.8	87.0	17 162

In the first stage of research and possible replacement of an uncultivated land with cultural grass in the past, large tracts of land in the order of 1 – 5 ha were monitored in the Zubří and the Prostřední Bečva areas. In 2018 – 2020 in the area of Hustopeče nad Bečvou and in 2018 in the area of Velká Lhota, these consisted of enclaves up to the size of 0.2 – 0.5 ha. Spontaneous fallow land with meadows for hay harvesting predominated. In terms of the botanical composition species *Elymus repens*, *Calamagrostis arundinacea* (bunch grass in the family *Poaceae*), *Phalaris arundinacea*, *Deschampsia cespitosta* (tufted hairgrass), *Cirsium* sp., *Rumex* sp., *Urtica dioica* (stinging nettle) and *Convolvulus* sp. (bindweed) prevailed on these fallow lands. Species *Elymus repens*, *Dactylis glomerata* (orchard grass), *Holcus lanatus* (velvet grass), *Calamagrostis arundinacea*, *Cirsium* sp., *Urtica dioica, Rumex* sp. and *Aegopodium podagraria* (bishop’s goutweed) occured in the area of Velká Lhota. The yield from dry matter and energy production on spontaneous fallow lands during the monitored years of 2018 – 2020 was very low; it ranged between 1.08 and 1.53 t.ha^{-1} (Table 6, 7, 8). This corresponds with the energy production between 0.62 and 0.92 t.ha^{-1} of coal equivalent from a hectare. Total dry matter production and energy is 6 – 8 times lower than the monitored compositions usable as grass crops. At the same time, we can consider the weeds on these fallow lands to be undesirable from an agricultural point of view, especially by the occurrence of couch grass, plum thistle and sorrels. The solution is to use this uncultivated land for harvesting biomass, grass the former meadows and the arable land, harvest hay for livestock or use it for energy generation purposes. In 2020 harvest began at the former fallow at U Obory, which is used for hay and haylage by a horse breeding farmer. It is not recommended to leave the land uncultivated as spontaneous fallow land due to negative phenomena from an agricultural and landscape point of view. Frydrych[14] indicates the dry matter yield at 0.78 $t.ha^{-1}$ to 1.34 $t.ha^{-1}$ for fallow land on former pastures and arable land in the Zubří and the Prostřední Bečva areas) in the first stage of energy grass research. This corresponds to the equivalent of a tonne of coal equivalent of 0.48 – 0.78 $t.ha^{-1}$ from this uncultivated land.

Conclusion

Phytomass is an important part of the renewable energy sources in the Czech Republic. During 2018–2020, a new research was undertaken, including the use of grasses as intermediate crops established in three terms of the business year as summer, stubble and winter. The production of dry matter in selected grass mixtures and the production of energy, which represents the equivalent of a tonne of coal equivalent , were established (dry matter production from 1 ha will replace the stated amount of black coal in tonnes). The research includes the mixture of ryegrass with tall fescue and ryegrass with creeping fescue. In these variants, the grasses can be used as catch crops. In 2019, the dry matter yield of selected grass mixtures reached was between 5.5 $t.ha^{-1}$ and 12 $t.ha^{-1}$. The stated yields also correspond to the equivalent of a tonne of coal equivalent between 3.33 $t.ha^{-1}$ and 7.6 $t.ha^{-1}$. Dry matter yield in 2020 for selected grass mixtures ranges between 5 $t.ha^{-1}$ and 12.3 $t.ha^{-1}$. These yields also correspond to the equivalent of a tonne of coal equivalent between 3.03 $t.ha^{-1}$ and 7.36 $t.ha^{-1}$. The highest dry matter yield and energy production was achieved by a mixture of *Lolium perenne* and *Festuca arundinacea* in sowing of 20 $kg.ha^{-1}$ in the first and second sowing period in June and September in both experimental years. Based on the results, it is therefore possible to clearly recommend sowing rates for mixtures of *Lolium perenne* with *Festuca arundinacea* and *Festuca rubra* of 20 $kg.ha^{-1}$ (they represent a 50% share for individual types of two-component mixtures). The lowest yield of dry matter and energy was reached by the mixture during the autumn sowing in October as a winter intermediate crop in 2018 and 2019.

At the same time, during the years 2018–2020, the production of dry matter on the uncultivated land of former meadows and one locality of former arable land was monitored. It ranged between 1.08 and 1.53 $t.ha^{-1}$. This also corresponds to the energy production between 0.62 and 0.92 $t.ha^{-1}$ of coal equivalent. The total production of dry matter and energy is 6 – 8 times lower compared to the monitored grass mixtures usable as intermediate crops.

During the same time the occurrence of dangerous weeds in agricultural production was recorded on this uncultivated land, such as *Elymus repens*, *Cirsium* sp. and *Rumex* sp. Negative phenomena, which spontaneous fallow land represent, must be eliminated from both an agricultural and a landscape point of view. By grassing and properly managing former spontaneous fallow lands these areas can be used for the production of biomass usable for livestock and energy production. Intercrops increase the stability of the landscape agroecosystem, especially in relation to soil, and grasses grown as intercrops can be recommended and used in agricultural sowing practices on the basis of this research.

Possibilities for establishing grasses as catch crops at three establishment dates have been verified. Grasses and their mixtures are usable as intermediate crops. The mixtures of *Lolium perenne* in particular with *Festuca arundinacea* and *Lolium perenne* with *Festuca rubra* can be recommended for the sowing of an intermediate/catch crops established in late spring and early summer. *Festuca arundinacea* is characterised by considerable adaptability to different habitat conditions and is among the grasses with the widest habitat amplitude. This is particularly true of wet claims. *Festuca arundinacea* tolerates both dried and wetter habitats well. *Lolium* sp. and their mixtures can be recommended as catch crops in spring, late summer and early autumn. *Lolium multiflorum* subsp. *italicum* and *Lolium multiflorum* var. *westerwoldicum* can also be used as intermediate crops. Harvested biomass is usable on the basis of research results for energy purposes.

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Travní biomasa jako obnovitelný zdroj energie v podmínkách České republiky

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Souhrn

Nový výzkum v letech 2018 – 2020 řešil využití trav jako meziplodin s cílem zjistit produkci sušiny a energie u vybraných travních druhů a jejich směsí. Do výzkumu byly zařazeny směsi Lolium perenne 'Kentaur', Festuca rubra 'Zulu' a Festuca arundinacea 'Kora'. Trávy byly založeny v průběhu hospodářského roku ve třech termínech jako letní, strniskové a ozimé meziplodiny. V roce 2019 bylo u vybraných travních směsí dosaženo výnosu sušiny od 5,5 t.ha^{-1} do 12,7 t.ha^{-1}. Uvedeným výnosům odpovídá ekvivalent tuna měrného paliva 3,33 t.ha^{-1}do 7,6 t.ha^{-1}. Výnos sušiny v roce 2020 u vybraných travních směsí se pohybuje od 5 t.ha^{-1} do 12,3 t.ha^{-1}. Uvedeným výnosům odpovídá ekvivalent tuna měrného paliva 3,03 t.ha^{-1}do 7,36 t.ha^{-1}.

Současně byla v letech 2018 – 2020 sledována produkce sušiny na ladem ležící půdě na bývalých loukách a na orné půdě u jednoho stanoviště. Produkce sušiny se pohybovala od 1,08 do 1,53 t.ha^{-1}. Tomu odpovídá produkce energie 0,62 – 0,92 t.ha^{-1} ekvivalentu tuny měrného paliva. Celková produkce sušiny a energie je 6 – 8krát nižší oproti sledovaným travním směsím využitelným jako meziplodiny. Byl zaznamenán výskyt plevelů nebezpečných v zemědělské výrobě v osevních postupech, jako jsou Elymus repens, Cirsium sp., Rumex sp. na ladem ležící půdě.

Negativní jevy, které představují spontánní úhory, je třeba eliminovat z hlediska zemědělského i krajinářského. Meziplodiny zvyšují stabilitu krajinného agroekosystému, zejména ve vztahu k půdě, a trávy pěstované jako meziplodiny lze do zemědělských osevních postupů na základě tohoto výzkumu doporučit a využít. Výslednou biomasu meziplodin je možné použít pro energetické účely.

Klíčová slova: *Tráva, meziplodiny, sušina, tuna měrného paliva, spontánní úhory*

Hodnocení nakládání s odpady hl. m. Prahy na základě sledování tříděných složek komunálního odpadu a analýzy složení směsného komunálního odpadu

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Souhrn

Vzhledem k vysoké hustotě obyvatel hlavního města Prahy a různorodosti zástavby je efektivní systém sběru, zpracování a likvidace komunálního odpadu zásadní. S pokračujícím ekonomickým rozvojem a stoupajícím počtem obyvatel je pro udržitelné uspokojení potřeb hl. m. Prahy v oblasti nakládání s odpady nutný holistický a integrovaný model řízení odpadového hospodářství. K nastavení modelu je nezbytné znát detailní data o produkci a nakládání s komunálním odpadem. K získání vstupních dat se využívají rozbory směsného komunálního odpadu. Dosud používané metodiky rozborů nejsou jednotné a dle našeho názoru i nedostačující. V článku bychom chtěli představit výsledky dvouletého projektu a použitou metodiku k získávání komplexnějších dat pro nastavení nakládání s komunálními odpady.

Klíčová slova: *odpad; směsný komunální odpad; rozbor; monitoring; metodika*

Úvod

Nakládání s pevným odpadem je jedním z hlavních problémů v otázkách životního prostředí. To platí zejména pro městské oblasti, kde počet obyvatel rychle roste, stejně jako množství vyprodukovaného odpadu. Produkce odpadu se zvyšuje úměrně s růstem životní úrovně obyvatel.[1] Urbanizace a industrializace vede k novým životním stylům a způsobům chování, které ovlivňují složení odpadu. Vzniká potřeba efektivního řízení odpadového hospodářství. Cílem je minimalizovat skládkování odpadů a maximalizovat jeho materiálové využití.

Pro reálné nastavení limitů materiálového využití odpadů a zavedení dostatečné finanční a posléze technické podpory je vhodné mít představu o potenciálu komunálního odpadu (KO), který lze materiálově využít. Aby bylo možné docílit reálného nastavení limitů pro materiálové využití odpadů, je třeba disponovat kvalitními daty o množství, složení a podmínkách vzniku KO, respektive jeho zbytkové složky – směsného komunálního odpadu (SKO).

V současné době není stanoven jednotný Evropský standard pro analýzu složení SKO. Existují pouze nezávazná doporučení některých organizací, např. Evropské komise. V rámci České republiky, Evropy [2–6] i celého světa [7–11] je používáno mnoho odlišných metod. Například v ČR je SKO analyzován společnostmi EKO-KOM, a.s., respektive Green Solution, s.r.o. [12, 13], Incien, z.ú. [14], Odpadová poradenská, s.r.o., [15] nebo platforma Moje odpadky [16] a jejich metodiky rozboru vychází z projektu SP/2f1/132/08 – Výzkum vlastností komunálních odpadů a optimalizace jejich využívání [17].

Řešení projektu CZ.07.1.02/0.0/0.0/16_040/0000379 *Odpady a předcházení jejich vzniku – praktické postupy a činnosti při realizaci závazků Krajského Plánu odpadového hospodářství hlavního města Prahy*, jehož výsledky budou dále prezentovány, také vycházelo z projektu SP/2f1/132/08, ale na rozdíl od ostatních metodik byly v rámci projektu navíc sledovány faktory ovlivňující nakládání s KO tj. sociodemografické údaje, typy a využívání kapacit kontejnerů, čistota tříděných složek KO.

Patronem tohoto čísla je Týden výzkumu a inovací pro praxi a životní prostředí TVIP 2020/21 (19. – 21. 10. 2021, Hustopeče)

Experimentální část

Po dohodě s hlavním příjemcem výsledků projektu byli stanoveni zástupci tří typů městské zástavby, ve kterých byl průzkum prováděn. Konkrétně se jednalo o typy:

- Sídlištní zástavba – byla sledována sídliště Modřany (P12 sídliště) a sídliště Horní Měcholupy (P15). Jednalo se o bytové domy s dálkovým zásobováním teplem. Kalorické frakce komunálního odpadu zde nejsou spalovány. Síť hnízd kontejnerů (HK) zde je ze tří sledovaných typů zástaveb nejhustší. Donáškové vzdálenosti jednotlivých HK jsou do 100 metrů a často se vzájemně překrývají.

- Venkovská zástavba – byly sledovány původně samostatné obce Modřany (P12 vily) a Újezd nad Lesy (P 21). Jedná se o zástavbu tvořenou rodinnými domy obklopenými zahradami a s nimi spojenou zvýšenou produkcí biologicky rozložitelných odpadů, které většinou nejsou zkrmovány. Obyvatelé jsou motivováni ke kompostování. Díky plynofikaci ani v této zástavbě nedochází ke spalování kalorické frakce komunálního odpadu. Síť hnízd kontejnerů je zde ze tří typů zástaveb nejřidší. Donášková vzdálenost je větší než 100 metrů a k překryvu nedochází.

- Centrální zástavba – byla sledována starší bytová zástavbu v lokalitách na Praze 1 a Praze 6. V této lokalitě je produkce KO nejvíce ovlivněna subjekty poskytujícími zejména ubytovací a občerstvovací služby. V centru Prahy 1 jsou kontejnery pro tříděnou složku KO umisťovány i do vnitrobloků. V rámci projektu byly sledovány pouze veřejně přístupná HK.

Hodnocení bylo prováděno ve dvou souběžných činnostech. V první byl prováděn měsíční monitoring všech vytypovaných městských částí. Před terénním výjezdem byla provedena studie obsahující sociodemografické údaje dané oblasti, počet, typ a kapacity sběrných nádob. Monitoring představoval fyzickou kontrolu čistoty tříděných složek KO a využívání kapacit kontejnerů. Monitoring probíhal v den vývozu nejčastěji vyvážených tříděných složek KO, tj. plastů a papíru. Z jednotlivých monitorovacích akcí byl pořizován tabulkový, fotografický a písemný záznam. V písemném záznamu byly podchyceny i aspekty (např. omezená dostupnost HK z důvodu prací na příjezdové komunikaci, poškozený vhozový otvor kontejneru apod.), které mohly hodnocené ukazatele ovlivnit. Ke konkretizaci místních podmínek každé oblasti byla vytvořena v prostředí ArcGIS geoprostorová bodová vrstva (shapefile) v souřadném systému JTSK. Bodová vrstva obsahovala atributy s informacemi o souřadnicích jednotlivých HK a jejich adresou.

Druhou činností hodnocení byl fyzický rozbor směsného komunálního odpadu (SKO), který z kapacitních a finančních důvodů byl prováděn pouze ze tří sledovaných městských částí (Praha 1, sídliště Horní Měcholupy a Újezd nad Lesy). Rozbor SKO byl prováděn každý druhý měsíc po dobu dvou let v areálu ZEVO Malešice. Termíny rozboru byly voleny tak, aby se zabránilo ovlivnění například vánočními a velikonočními svátky. Z logistických důvodů a pro zabránění nechtěného smísení nebo záměny jednotlivých vzorků byl pro rozbor SKO z každé oblasti vyhrazen jeden den.

SKO pouze z jedné sledované městské části byl dovezen svozovým vozem před vhozový otvor ZEVO Malešice. Zde byl odsypán hlavní vzorek o hmotnosti cca 1000 kg. Z hlavního vzorku bylo odebráno minimálně 100 kg podvzorku (sub-sample), a to ve směru z vnějšího okraje hromady k vnitřnímu. Případný výskyt abnormalit nebyl do podvzorku zahrnut. Podvzorek byl tříděn pomocí sady tří na sebe poskládaných sít. Síta s velikostí ok 40 x 40 mm, 20 x 20 mm a 8 x 8 mm byly v tomto pořadí poskládány na sebe. Pod spodním sítem s oky 8 x 8 mm byla upevněna plachta usměrňující spad podsítné frakce do sběrné nádoby.

Podvzorek byl manuálně tříděn na 12 hlavních látkových frakcí (papír, plast, sklo, kov, biologicky rozložitelný komunální odpad (BRKO), nápojový obal, textil, minerální odpad, nebezpečný odpad, spalitelný odpad, elektro, jemná/podsítná frakce) a 15 látkových podfrakcí (karton, tiskoviny, ostatní papír, plastové obaly měkké, plastové obaly tvrdé, PET, sklo světlé, sklo tmavé, hliník, ostatní kovy, kuchyňský odpad, zahradní odpad, podsítné 20-40 mm, podsítné 8-20 mm a podsítné pod 8 mm). Podsítné frakce nebyly látkově dotřiďovány.

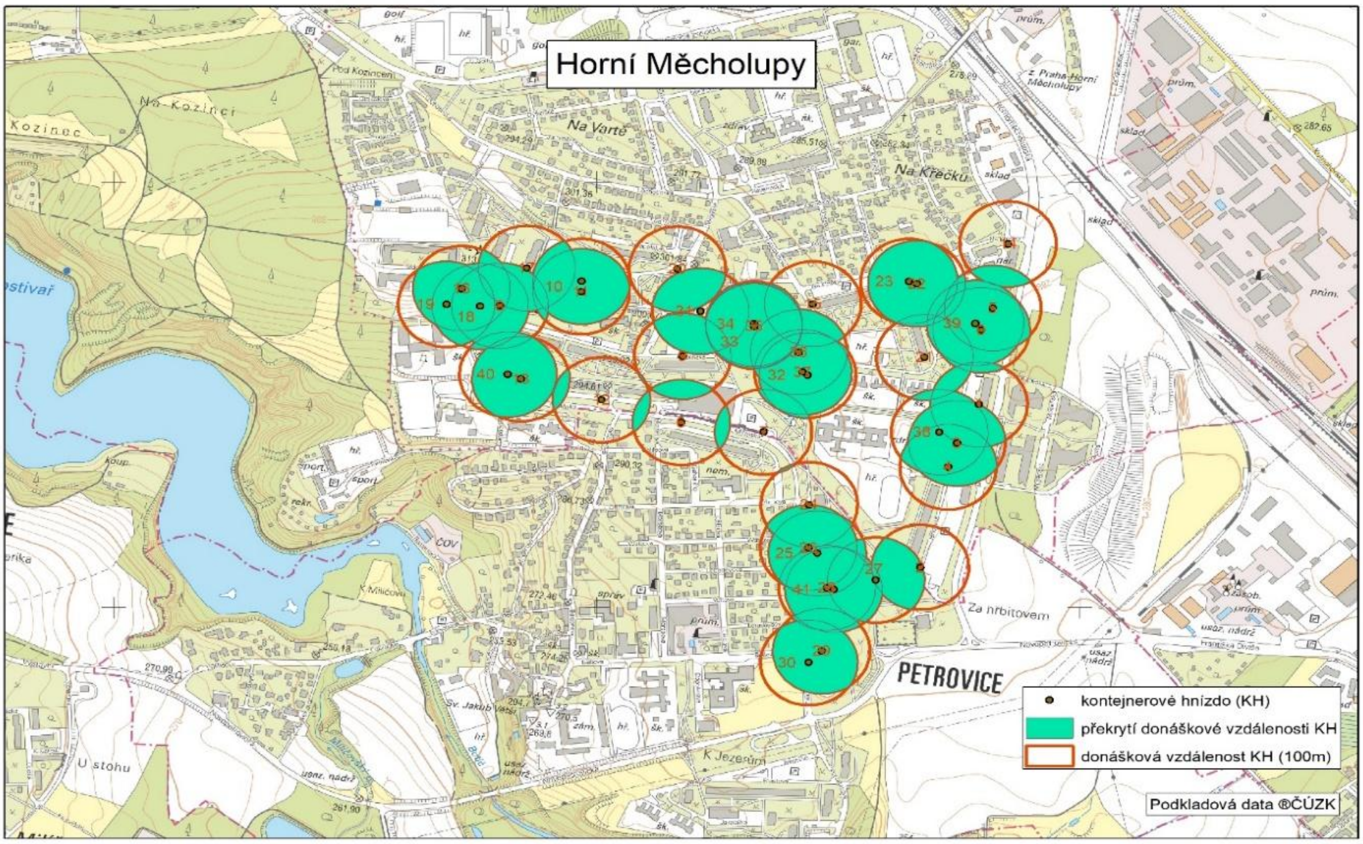
Všechny frakce byly shromažďovány v plastových pytlích a váženy. Pro fyzikální a chemické analýzy byly odebírány dvoukilové vzorky. Z rozboru byl pořízen tabulkový záznam a fotodokumentace.

Po ukončení rozboru SKO byla síta a použité nářadí očištěno, plocha zametena a připravena na další den pro rozbor SKO z další sledované oblasti.

Výsledky a diskuse

Monitoring oblastí

Vybrané sociodemografické faktory neprokázaly významné rozdíly mezi jednotlivými typy zástaveb. Síť HK byla nejhustší na sídlištích. Často zde docházelo k překrytí stometrových donáškových zón (obrázek 1).



Obrázek 1: Lokalizace HK s vyznačenou donáškovou vzdáleností 100 metrů (překryv je zvýrazněn zeleně)

V průběhu dvouletého sledování došlo u většiny HK k navýšení kapacit, a to zejména navýšením počtu svozů (tabulka 1).

Nejčastěji opakujícím se problémem, zejména anonymních sídlišť a odlehlých míst, byl littering a volné ukládání objemného odpadu. Ve všech typech zástavby byl odpad nedostatečně sešlapáván (papír, plast) a nejhorší kvalita třídění byla u nápojových kartonů. Z nepřiměřeně velkých rozdílů mezi naplněností jednotlivých HK, které byly vyváženy ve stejných intervalech, a také podle typu odpadu lze usuzovat, že někteří drobní podnikatelé jsou zapojeni do systému obce vývozem nádob s neodpovídající kapacitou a pro svou nadprodukci odpadu využívají kontejnery pro rezidenty.

Tabulka 1: Počet monitorovaných HK a jejich kapacity

Druh odpadu	**Kapacity kontejnerů v m³ (na konci monitoringu, tj. 31. 1. 2020)**						**Průměrný procentní rozdíl ve srovnání se začátkem monitorování [%]**
	P1	**P6**	**P12 sídliště**	**P15**	**P12 vily**	**P21**	
Papír a karton	1041,8	554,4	345,6	344,2	281,6	490,6	9,0
Plast	732,8	524,0	268,4	419,0	233,2	649,0	2,4
Sklo světlé	91,4	33,4	8,6	15,0	14,0	45,2	-1,7
Sklo barevné	109,2	33,4	8,6	15,0	12,3	45,2	-4,1
Sklo směs	8,8	16,3	12,5	24,9	3,3	0	-1,3
Nápojový karton	44,2	54,8	33,1	86,2	21,3	11,7	35,4
Kov	26,3	6,0	2,9	15,8	2,6	39,6	142,9
Počet HK	29	20	19	32	13	27	

Sběr bioodpadu byl monitorován na sídlišti P15, kde probíhal v prvním roce monitoringu pilotní projekt sběru BRO do hnědých kontejnerů. Nastavená četnost vyvážení byla optimální. Problematické bylo ponechávání bioodpadů v plastových sáčcích/prodejních obalech. Znečištění kontejnerů po vyprázdnění a výskyt hmyzu v teplých ročních obdobích byl negativním faktorem sběru bioodpadů. V druhém roce monitoringu byl pilotní sběr BRO ukončen.

Umístění kontejnerů pro textil u školních a předškolních zařízení, v blízkosti domu s pečovatelskou službou, u obchodního centra nebo u parkoviště byl efektivní a nikdy nebyl v jejich okolí nalezen nepořádek.

V oblastech, kde nebyly kontejnery pro separaci kovu, případně jejich množství bylo nízké, byla znatelná jejich potřeba, a to zejména v letním období, kdy byl zvýšený prodej nápojů v hliníkových obalech. Trend poslední doby distribuovat krmiva pro domácí mazlíčky v hliníkových a kovových nádobách potřebu zvýšení sběrných kapacit jen umocňuje. Zvýšený prodej nápojů v tomto druhu obalu byl na obsahu kontejnerů a i pouličních odpadkových košů znatelný. V případě jejich separace občany a nepřítomnosti kontejneru pro kov byly tyto odpady vhazovány do kontejneru pro nápojové kartony. Nejvyšší čistota třídění byla u skla, ať čirého, tak barevného. Příměs porcelánového nádobí, žárovek a zářivek v kontejneru pro sklo byla málo častým problémem. Na sídlištích byly často u HK, ale i u SKO vně kontejnerů ponechávány potraviny, oděvy nebo ještě použitelné objemné „odpady“. To naznačuje potřebu re-use center.

Po celou dobu monitoringu byl ve všech sledovaných oblastech zaznamenán úklid HK i míst s kontejnery pro SKO pracovníky Pražských služeb, a.s. Úklidové vozidlo neskreslilo námi monitorovaná místa, neboť úklid okolí kontejnerů nezasahoval do separovaného odpadu.

Rozbor SKO

Výsledky dvouletého rozboru SKO tří typů zástaveb jsou uvedeny v tabulce 2.

Tabulka 2 : Podíl skupin látek v SKO ze sledovaných oblastí (v hmotnostních %)

Látková skupina	**Lokalita**			
	P1	**P15**	**P21**	**ČR***
Papír a karton	7,49	8,10	7,31	7,8
Plast	13,32	11,93	10,02	10,1
Sklo	6,66	8,60	5,81	4,0
Nápojový obal (Tetra pack)	1,65	1,53	0,94	n. a.
Bioodpad	21,32	19,05	21,44	25,6
Textil	1,70	4,54	4,29	2,1
Spalitelný odpad	24,52	22,56	24,38	24,1
Kov	2,49	3,03	3,02	2,5
Nebezpečný odpad	0,64	1,66	1,63	0,3
Inert	2,54	2,41	1,51	1,7
Podsítná frakce pod 40 mm	17,69	16,59	19,66	20,4

**Poznámka: Zdroj EKO-KOM a.s.[18]*

Praha 1

Průměrné podíly hlavních složek SKO tvořily plasty (13,32 hm. %), papír (7,49 hm. %), sklo (6,66 hm. %), nápojový karton (1,65 hm. %), kov (2,49 hm. %), BRKO (21,32 hm. %), textil (1,7 hm. %) a spalitelný odpad (24,52 hm. %). V BRKO převažoval vyhnutelný potravinový odpad[1] (VPO), průměr 13,02 hm. %) pocházející z restaurací a fastfoodů (celé pytle s kusy pizzy, noky, omáčky, mouka, syrové těsto, maso), zahradní bioodpad s nevyhnutelným potravinovým odpadem[2] (NPO) se zde vyskytoval v menším množství (průměr 8,3 hm. %). Při srovnání mezi obdobími u VPO převažuje letní období v průměru 19,39 hm. % (maximum srpen 2018 – 37,2 hm. % a minimum srpen 2019 – 7,57 hm. %). Mezi nebezpečnými odpady (průměr 0,64 hm. %) byly nejčastěji odpady z provozoven kadeřnických, kosmetických a jím podobných salónů (obaly se zbytky vlasové a jiné kosmetiky). Spalitelný odpad (maximum 33,42 hm. % a minimum 10,82 hm. %) je v tomto typu zástavby tvořen papírovými ubrousky z veřejných toalet, papírovými účtenkami, odstřiženými visačkami z textilií. Při srovnání se sídlištní a venkovskou zástavbou bylo v SKO významně menší množství jednorázových plen, vyšší množství (průměr 0,63 %) jednorázových polystyrenových přenosek potravin a tištěného papíru (průměr 3,84 %), jako jsou reklamní letáky, turistické průvodce a kancelářský papír. Ze skladby SKO lze usuzovat, že ze sledovaných oblastí mají největší podíl na produkci SKO poskytovatelé služeb se sníženou ochotou třídit.

Praha 15

Průměrné podíly hlavních složek SKO tvořily plasty (11,93 hm. %), papír (8,10 hm. %), sklo (8,6 hm. %), nápojový karton (1,53 hm. %), kov (3,03 hm. %), BRKO (19,05 hm. %), textil (4,54 hm. %) a spalitelný odpad (22,56 hm. %). Oproti ostatním oblastem je v SKO jednoznačně nejvíce objemného odpadu (nábytek, elektroodpad) a obalového materiálu z elektrospotřebičů a nábytku. V porovnání

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[1] Vyhnutelným potravinovým odpadem se rozumí vyhozené poživatelné jídlo a nápoje, tj. potraviny, které byly v určité době před odstraněním, poživatelné (např. mléko, hlávkový salát, ovocný džus, maso, pečivo, suroviny pro výrobu potravin atd.). Pojem není v odpadové legislativě vymezen, byl použit pro řešení projektu.

[2] Nevyhnutelný potravinový odpad jsou potraviny za normálních okolností nepoživatelné (např. kosti, skořápky od vajec, čajové sáčky, slupky od ananasů). Pojem není v odpadové legislativě vymezen, byl použit pro řešení projektu.

s ostatními oblastmi byly materiálové skupiny textil, kartonový papír (průměr 4,89 hm. %) a sklo nejvíce zastoupeny v SKO z P15. V obsahu BRKO je tato oblast nejlepší, a to i přesto, že v druhé polovině monitoringu již nebyl bioodpad separován. V roce 2018, kdy probíhal pilotní projekt sběru bioodpadu, bylo v SKO průměrně 17,97 hm. % této složky a v roce 2019 bez separace se její obsah zvýšil v průměru o 2,43 hm. %. Oproti SKO z P1 a P21 je VPO (v průměru 9,22 hm. %) tvořen zejména pečivem. Ve skladbě bioodpadu je také znát sezónnost ovoce a zeleniny, jejíž NPO tvoří v průměru 9,83 hm. %. Zahradní bioodpad se vyskytuje v malém množství pouze z předzahrádek panelových domů (větve, tráva, listí atd.). Přestože byla oblast v kapacitě kontejnerů pro tříděný kov po P1 druhá nejlépe obsloužená, byl výskyt kovových obalů od nápojů značný. V průběhu projektu se situace s postupným navyšováním kapacit kontejnerů pro kov na sídlišti zlepšovala. Od dubna 2018 (9,49 hm. %) klesl jeho obsah v SKO až na 2,50 hm. % (prosinec 2019). V látkové skupině spalitelný odpad váhově převažovaly dětské plenky a inkontinenční podložky, množstevně to byly papírové a vlhčené ubrousky. Na rozdíl od oblastí P1 a P 21 bylo v SKO velké množství hraček a školních pomůcek.

Praha 21

Průměrné podíly hlavních složek SKO tvořily plasty (10,02 hm. %), papír (7,31 hm. %), sklo (5,81 hm. %), nápojový karton (0,94 hm. %), kov (3,02 hm. %), BRKO (21,44 hm. %), textil (4,29 hm. %) a spalitelný odpad (24,38 hm. %). Významné zastoupení mělo velké množství zahradního bioodpadu, jehož složení se měnilo v závislosti na ročním období – vysypané truhlíky s muškáty a ostatními truhlíkovými květinami, posekaná tráva, listí, větve. Gastroodpadu bylo méně, převažovalo pečivo a slupky od zeleniny. U plastů byl, oproti zbývajícím sledovaným oblastem, malý výskyt PET lahví, převládaly obalové fólie. Ve spalitelné látkové frakci byly zejména vlhčené ubrousky, kapesníky, plenky, kombinované obaly C/XX nebo obaly, na nichž není vyznačen způsob recyklace. Z elektroodpadu se v SKO nacházelo malé množství elektrobaterií, žárovek a zářivek. Objemný odpad nebyl téměř žádný. Z kovu převažovaly množstevně hliníkové obaly od nápojů, ale váhově to byly plechovky od sterilovaných potravin.

Při porovnání s průměrným složením SKO v České republice (tabulka 2), které uvádí autorizovaná obalová společnost EKO-KOM, a.s., vyplývá, že sledované městské části Prahy dosahují nižšího obsahu u složek bioodpad, textil, kov, spalitelný odpad a podsítná frakce pod 40 mm. Nejvýraznější rozdíl 6,55 % je u obsahu bioodpadu v P15, což je způsobeno tím, že v této městské části polovinu sledovaného období probíhal pilotní projekt sběru bioodpadu a zahradní bioodpad a odpady vzniklé při sekání trávy a údržbě městské zeleně téměř není v zástavbě sídlištního typu produkován. Je odvážen zpracovatelskými firmami a je s nimi nakládáno mimo systém sběru SKO. Naopak větší procentní obsah, než je průměrný republikový, je u složek papír, plast, sklo a nebezpečný odpad, a to zejména opět v části P15, přičemž u skla je rozdíl až dvojnásobný.

Pro separované složky je zde příčin několik. Jednak namátkové průzkumy hnízd kontejnerů provedených v rámci projektu poukázaly na časté přeplnění kontejnerů na tříděné složky odpadu, takže v mnoha případech jsou pak vytříděné složky z domácností vhazovány do kontejnerů na SKO. V přeplněných kontejnerech na tříděný odpad se nacházejí velmi často odpady, u nichž lze jednoduchým způsobem zmenšit jejich objem, ale přesto se tak ze strany občanů neděje (papírové/kartonové nerozložené krabice, nesešlápnuté PET láhve a jim podobné obaly atd.). Svou váhu zde má rovněž někdy nepochopená propagace způsobů separace a sběru odpadů (např. neochota třídit v mylné představě, že se následně všechny odpady odstraňují společně ve spalovně/na skládce nebo nepochopení informací o poměrech recyklování plastů). Svůj význam zde má také anonymita sídlištní zástavby a pocit, že dotyčného za záměrně špatné chování stejně nepostihne žádný trest. Trend přeplněných kontejnerů na vytříděný plastový odpad pak může být způsobován také klesajícím zájmem o odpadní plasty na světových trzích. U textilních odpadů se ve velkém množství vyskytují v SKO ložní prádlo, peřiny nebo módní doplňky, přičemž tyto odpady je možné ukládat do kontejnerů na textil (roli zde tedy hraje zejména neznalost občanů). Nebezpečný odpad tvoří z velké části drobné elektroodpady a použitý zdravotnický či hygienický materiál (opět důsledek anonymity prostředí a neochota třídit).

Laboratorní analýzy spalitelné látkové frakce

Fyzikálně chemickým analýzám byla podrobena frakce spalitelné, která obsahovala hygienicky závadné, znečištěné, nerecyklovatelné nebo dosud netříděné složky komunálního odpadu. Výsledky analýz uvádí tabulka 3.

Tabulka 3: Vlastnosti spalitelné frakce (v sušině)

Parametr	P1	P15	P21	BREF
Sušina [%]	47,72	51,09	49,59	60 – 85
Výhřevnost [MJ/kg]	5,22	4,75	5,27	7 – 15
As [mg/kg]	2,02	2,15	4,16	2 – 5
Cd [mg/kg]	1,67	1,53	3,83	1 – 15
Cr [mg/kg]	22,96	37,48	28,46	40 – 200
Mn [mg/kg]	235,50	191,87	249,52	250
Ni [mg/kg]	13,84	21,00	14,65	30 – 50
Pb [mg/kg]	15,07	10,19	14,18	100 – 2000
Tl [mg/kg]	0,50	0,50	0,50	<0,1
Hg [mg/kg]	0,20	0,22	0,24	1 – 5
Zn [mg/kg]	195,58	156,25	212,04	400 – 1400
F [hm. %]	0,01	0,01	0,01	0,01 – 0,04
Cl [hm. %]	0,29	0,20	0,26	0,1 – 1

Obsah manganu, niklu a rtuti v pěti a arsenu ve čtyřech vzorcích přesáhl limity BREF. Vzhledem k tomu, že všechny sledované městské oblasti jsou vytápěny dálkově, nelze výskyt těchto kovů přičíst obsahu popela z místních topenišť. Vědecké zdroje [20, 21] uvádějí jako zdroj těchto těžkých kovů elektrické baterie a léky. Při ideální separaci použitelných složek by v průměrných hodnotách nebyla výhřevnost 10 MJ / kg dosažena ani jednou. V jednotlivých analýzách byla požadovaná výhřevnost spalitelné složky SKO dosažena v P1 2x (prosinec 2018 a únor 2019) a v P15 4x (říjen 2018, červen, srpen a prosinec 2019). Spalitelný odpad z P21 dosáhl výhřevnosti 10 MJ / kg nejčastěji. V roce 2018 to bylo v říjnu a v roce 2019 v únoru, červnu, srpnu a prosinci. Významný vliv na výhřevnost měla i vysoká vlhkost materiálu způsobená vysokým zastoupením bioodpadu v SKO a použitých dětských plen v látkové frakci spalitelné. Případnou intenzifikací třídění a rozšířením prvků primárního a následného strojového třídění komunálního odpadu je zřejmé, že se výrazně změní i kvalita zbývajícího tzv. zbytkového směsného odpadu. Pokud je možné efektivně třídit papír, plasty a biologicky rozložitelný odpad, tj. frakce, které jsou nositeli energetického obsahu v SKO, bude mít tento zbytkový odpad nižší výhřevnost než nyní.

Závěry

Hnízda kontejnerů pro tříděné složky KO je problematické zřizovat zejména z důvodu nedostatku vhodných a pro obslužnou techniku dostupných ploch. Na sídlištích HK zabírají parkovací plochy a v centru Prahy je umístění HK kompromisem odpadové obslužnosti místních residentů a požadavků odboru památkové péče MHP. Většina HK je umístěna efektivně, pro rezidenty na dostupných místech.

Lze konstatovat, že technologie odděleného sběru využitelných složek komunálního odpadu je dobře nastavená. Jako hlavní důvod znečištění tříděných složek je nedisciplinovanost nebo částečná neznalost obyvatel, stejně jako častá (a zbytečná) přeplněnost kontejnerů na separovaný odpad v důsledku neprováděného zmenšení objemu odpadů. Pro snížení množství SKO z každého typu zástavby je potřeba jiné strategie. V centrální Praze by se osvěta měla zaměřit na restaurace, právnické osoby zajišťující služby turistům. Ve venkovské zástavbě by měli být obyvatelé motivováni k prevenci vzniku zejména bioodpadu. Na sídlištích by materiálové využití SKO mohlo být zvýšeno zjednodušením třídění například formou sloučeného sběru nápojových obalů (plastových, kovových a tetrapaků) do jednoho typu kontejneru nebo rozšířením množství tříděných složek KO o bioodpad. Obojí v pilotních projektech na území hl. m. Prahy již probíhá.

K těmto závěrům jsme mohli dospět pouze díky společnému monitoringu oblastí a rozboru SKO. Pro hodnocení a následné nastavení odpadové obslužnosti je tento sloučený postup nezbytný. Poskytuje přesnější nástroje zefektivnění motivace obyvatel k třídění KO. Samotná data získaná pouze rozborem SKO jsou nedostačující.

Poděkování

Příspěvek byl podpořen z projektu CZ.07.1.02/0.0/0.0/16_040/0000379 Odpady a předcházení jejich vzniku – praktické postupy a činnosti při realizaci závazků Krajského Plánu odpadového hospodářství hlavního města Prahy.

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Assessment of waste management of the City of Prague based on monitoring of sorted components of municipal waste and analysis of the composition of mixed municipal waste

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Summary

Due to the high population density of the capital city of Prague and the diversity of development, an efficient system of collection, processing and disposal of municipal waste is essential. With the continuing economic growth and the growing number of inhabitants, the sustainable satisfaction of the capital needs. The City of Prague requires a holistic and integrated waste management model in the field of waste management. To set up the model, it is necessary to know detailed data on the production and management of municipal waste. Analyzes of mixed municipal waste are used to obtain input data. The analysis methodologies used so far are not uniform and, in our opinion, insufficient. In the article, we would like to present the results of a two-year project and the methodology used to obtain more comprehensive data for setting up municipal waste management.

***Keywords**: waste; mixed municipal waste; analysis; monitoring; methodology.*

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Původně vyhlášený program poté, co ani v náhradním listopadovém, či březnovém termínu se nemohl konat, **zůstává v naprosté většině v platnosti a až do 31. 8. 2021 je možné jej doplnit o nově přihlášené příspěvky** *(později až po dohodě).* Průběžně aktualizovaný je ke zhlédnutí ZDE.
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- Kvalita ovzduší a zdravotní rizika

Věda a výzkum pro oběhové hospodářství:
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- Nové zdroje surovin a energie
- Inovativní technologické postupy a inovativní technologie
- Nové materiály a jejich aplikace (bio- a nanomateriály)

je letos ve spolupráci s Centrem výzkumu Řež opět zařazeno téma **Radioaktivní odpady**.

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Přihlášky příspěvků lze zasílat do naplnění kapacity – přihlašovací formulář naleznete ZDE**.** Úspěšné odeslání přihlášky je automaticky potvrzeno. Zhruba měsíc před konáním konference bude na www.tvip.cz zveřejněn aktualizovaný program. Autoři příspěvků budou požádáni, aby zkontrolovali správnost informací uvedených v programu.

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Plné texty přednášek – autory všech příspěvků, **tj. přednášek i vývěsek**, žádáme o včasné předání graficky upraveného plného textu příspěvku v **elektronické podobě** (MS Word) **nejpozději do 30. 9. 2021**. Po tomto termínu nemůžeme garantovat jejich zařazení do sborníku na CD-ROM, který obdrží účastníci konference při registraci.

Grafická úprava textu – příspěvky před zařazením do sborníku konference neprocházejí redakční a ani grafickou úpravou, při jejich psaní můžete s výhodou využít šablonu, kterou spolu s detailním popisem formátování najdete na www.tvip.cz v sekci Informace pro autory.

Prezentace – je nutné předat přítomné obsluze nejpozději 5 minut před začátkem sekce, do které je zařazena přednáška. Pokud prezentaci obdržíme do 30. 9. 2021, bude rovněž zařazena do sborníku na CD-ROM.

Pro vlastní prezentaci přednášky mají přednášející (pokud není uvedeno jinak) k dispozici **15 minut a 5 minut je vyhrazeno pro diskusi**. Ve spolupráci s předsedajícími sekcí se snažíme o maximální dodržování vyhlášeného časového rozvrhu.

Přednáškové místnosti budou vybaveny **dataprojektory**, včetně **notebooků**. Použití vlastního notebooku je možné, funkčnost propojení je třeba na místě předem ověřit ve spolupráci s technikem a současně je nezbytné poskytnout prezentaci obsluze pro další zpracování na DVD.

Vývěsky – formátu **A0** (na výšku) budou přichyceny lepicí páskou na tvrdý podklad (sklo, dřevěné obklady). Vystaveny budou po celou dobu konference v chodbě před hlavním sálem nebo přímo v sále. V programu bude vymezen časový prostor („Autorská prezentace vývěsek“), kdy by autoři měli být přítomni u své vývěsky.

Účast autorů: Autoři se rovněž přihlašují k účasti, na konferenci musí být přihlášen a **osobně přítomen alespoň jeden z autorů** příspěvku, anebo jím pověřená osoba. Jednacím jazykem je **čeština** a **slovenština**. **Zahraniční hosté** jsou srdečně zváni, tlumočení však organizátor nezajišťuje, prezentace příspěvků v angličtině je možná. **Za neodpřednášenou přednášku nebo nevystavený poster bude dodatečně autorovi fakturován poplatek 1000 Kč** (bez DPH) za zařazení příspěvku do programu a jeho uveřejnění ve sborníku.

Recenze: Organizátor konference nemá námitek, aby autoři nabídli svůj příspěvek z konference k uveřejnění v některém recenzovaném časopise, včetně časopisu WASTE FORUM, který je indexován v databázi **SCOPUS**.

Komerční přednášky či krátká sdělení jsou za úplatu možné. Rozsah možností firemní prezentace je široký, stejně jako cenové rozpětí *(více ZDE)*. Rozhodně **není možné komerční sdělení prezentovat jako odbornou přednášku či vývěsku**. V případě porušení této zásady bude dodatečně fakturována příslušná částka podle výše zmíněného ceníku.

INFORMACE PRO ÚČASTNÍKY

Hotel Amande, kde se TVIP 2021 koná, se nalézá na adrese Husova 8, Hustopeče.

Vložné na **TVIP** zahrnuje vstup na obě akce (APROCHEM i ODPADOVÉ FÓRUM), brožuru s programem a souhrny všech příspěvků a CD-ROM či flashdisk s plnými texty příspěvků a předem včas dodanými prezentacemi. Vybírat je možné ze tří typů vložného:

Plné vložné (4 450 Kč bez DPH)

Dvoudenní vložné (3 950 Kč bez DPH)

Jednodenní vložné (3 450 Kč bez DPH)

Přihlášky účasti je možné zasílat **do 15. 9. 2021** (dále možné po dohodě s pořadatelem) prostřednictvím připraveného internetového formuláře. V přihlášce specifikujte také veškeré požadavky na stravu a ubytování.

Ubytování a stravování zajišťuje pořadatel. Vzhledem k omezené ubytovací kapacitě **hotelu Amande Hustopeče** nabízíme ubytování také v těsně sousedícím **hotelu Rustikal a v Penzionu pod Radnicí**. Ubytování je možné v jednolůžkových anebo dvojlůžkových pokojích. V případě dvojlůžkového pokoje je nutné v přihlášce účasti specifikovat jméno spolubydlícího.

Stravování během konference pro ty, kteří je mají objednáno, je zajištěno v hotelu Amande, výjimkou jsou snídaně, ty má každý účastník v tom hotelu, kde je ubytován.

Podrobnější informace, včetně cen ubytování a stravování najdete na www.tvip.cz v sekci Informace pro účastníky.

Open Innovation Matchmaking in Ecology (Waste Management)

Cílem symposia je mj. napomoci setkávání a propojování účastníků za účelem navazování nových příležitostí ke spolupráci. Abychom tento aspekt podpořili, připravili jsme **ve spolupráci s WASTen, z.s.,** tzv. **„Open Innovation Matchmaking in Ecology (Waste Management)“**. Každý, kdo bude mít zájem o asistované propojení s jiným účastníkem, může tak učinit předem prostřednictvím připraveného formuláře nebo na místě na registraci TVIP.

Exkurze

Exkurze je plánována do **Vetropack Moravia Glass**, jednoho z největších výrobců obalového skla a současně jednoho ze dvou zpracovatelů odpadového skla v ČR, nebo bude možné zavítat do areálu společnosti **HANTÁLY, a.s.** navštívit provoz skládky, dotřiďovací linky, kompostárny, Exkurze, včetně dopravy na místo, jsou zdarma. **Zájem o účast je nutné uvést v přihlášce účasti nebo dodatečně emailem na** cemc@cemc.cz**.**

DŮLEŽITÉ TERMÍNY na závěr:

Termín konání: 19. – 21. 10. 2021, z toho

Odpadové fórum: 19. – 21. 10. 2021

Aprochem: 20. – 21. 10. 2021

Přihlášky příspěvků**: 31. 8. 2021** (dále po dohodě s pořadateli)

Zaslání plných textů: 30. 9. 2021

Přihlášky účasti**: 15. 9. 2021**