LOGISTICS IN THE MANAGEMENT OF MUNICIPAL WASTE

Abstract. The article describes the system of municipal waste management. The logistic processes, collection and disposal of waste have been also presented. Municipal waste was tested on three export routes. Particular attention was paid to the problems encountered in the first link of the municipal waste management logistics chain.

Keywords: logistics, waste management chain, waste management, municipal waste, logistics processes, recycling
1. Introduction

There is a huge amount of rubbish produced in the world. In Poland most of them go to a dump. At present, the Poles produce about a kilo a day, which gives more than 300 kilograms of rubbish per year. Most of the waste is recyclable\(^1\). Unfortunately, still a significant group of waste is the so-called – mixed municipal waste. The waste contains materials and substances that should be segregated.

The problem of disposal and disposal of municipal waste is one of the most important and most difficult to solve the environmental problems of the present day. It is not enough to plan logistical processes like recycling, disposal, and above all, tackle the problem at the source to effectively prevent excessive landfill.

Already at the stage of product design we should think about their later disposal. The increasing amount of waste and the lack of space for their storage are also the effect of placing on the market excessive quantities of disposable packaging, advertising, etc. On the other hand, economic growth has contributed to improving the quality of life. Consumers are more likely to get rid of used things that are not always used\(^2\).

Urban management bodies carry out more and more in-depth analysis of the system in order to make the waste more efficient and effective and to ensure that it is properly transported to disposal sites\(^3\). However, the area of active dumping diminishes but the number of waste does not. Disposing of waste is becoming more and more expensive. Therefore, the efficiency of municipal waste management depends to a great extent on the quality of organizing logistics processes. An important point in the waste chain management is the

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\(^1\) Krzywda D.: Procesy logistyczne w gospodarce stałymi odpadami komunalnymi. „Logistyka – nauka”, nr 2, 2012, s. 830-837; Wota A., Woźniak A.: Logistyczne aspekty składowania odpadów komunalnych w województwie małopolskim. „Infrastruktura i Ekologia Terenów Wiejskich”, Vol. 3, nr 2, Polska Akademia Nauk, Oddział w Krakowie, 2006, s. 135-146; Górski M., Pchalek M., Radecki W., Jerzmański J., Bar M., Urban S., Jendrośka J.: Ustawa Prawo ochrony środowiska. Komentarz. C.H. Beck, Warszawa 2011; Kaca A., Kaca G.: Wskaźniki masy odpadów w Polsce w świetle danych statystycznych. „Problemy Inżynierii Rolniczej”, nr 3(77), 2012, s. 123-134; http://wyborcza.pl/1,97654,13757458,Wielka_segregacja.html, 19.10.2017; Domagała T., Wolniak R.: Odwrócony łańcuch dostaw. „Logistyka”, nr 1, 2014, s. 24-27; Wolniak R., Stachurek I., Binkiewicz P.: Procesy logistyki odwrotnej na przykładzie recyklingu opakowań z tworzyw sztucznych. „Gospodarka Materiałowa i Logistyka”, nr 12, 2014, s. 15-22; Wolniak R., Sędek A.: Wykorzystanie metody QFD do projektowania proekologicznych wyrobów i usług. „Problemy Ekologii”, nr 4, 2008, s. 179-182; Wolniak R., Sędek A.: Using QFD method for the ecological designing of products and services. “Quality and Quantity”, Vol. 43, nr 4, 2009, s. 695-701; Kruczek M.: Model łańcucha logistyki odwrotnej użytkowego sprzętu elektrycznego i elektronicznego. Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie, z. 60, Gliwice 2012, s. 165-178; Kokowska-Pawłowska M.: Sposoby zagospodarowania niektórych odpadów poprodukcyjnych z punktu widzenia strategii firmy w ochronie środowiska. Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie, z. 88, Gliwice 2016, s. 151-164.

\(^2\) Wielik J.: System gospodarki odpadami komunalnymi na terenie Rudy Śląskiej, praca dyplomowa. Wyższa Szkoła Zarządzania Ochroną Pracy w Katowicach, 2010; Wolniak R.: Problemy gospodarki odpadami w gminie Będzin. Zeszyty Naukowe Politechniki Śląskiej, z. 31, 2005, s. 185-202.

\(^3\) Ustawa z dnia 14 grudnia 2012 r. o odpadach (DzU. z 2013 r., poz. 21).
so-called collection at source. Proper planning, but also careful sorting and disposal of waste by the inhabitants, can contribute significantly to reducing the negative impact of waste on the environment. Often solid municipal waste can become a valuable raw material that can be found in various branches of the economy.4

The aim of the paper is to show that the quality of logistical processes in the case of municipal waste management depends on the awareness of the inhabitants of the region and its infrastructure not only of the way the municipal services are provided. The paper presents selected results of mixed municipal waste surveyed in different regions of Ruda Śląska. Selected areas were characterized by different degrees of urbanization.

2. Logistic issues in the management of municipal waste

In the system of municipal waste management, the stages of collection, export, processing and disposal of waste can be distinguished.

Collection of municipal waste includes activities related to the preparation of waste for transport to places of recovery or disposal. At this stage it is possible to distinguish activities related to the placement of waste in containers or bags providing temporary shelter. Among the containers in the system of collection of municipal waste from the inhabitants in the multi-family housing is usually used containers of plastic with a capacity of 110 dm³ to containers with a capacity of over 1m³, "sockets" consisting of a set of three containers of 1.5 m³, e.g. "igloo"and the so-called baskets for PET bottles.5

On the other hand, the collection of municipal waste from residents of a single family building, based on the "source collection" system, mainly uses plastic bags (white – clear glass, green – colored glass, yellow – plastic, blue – waste paper) and 120 l plastic material intended for the collection of biodegradable waste. In addition, the farms are equipped with a 110 l, 120 l or 240 l container (depending on reported needs) intended to collect unsorted

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4 Wota A., Woźniak A.: Logistyczne aspekty składowania odpadów komunalnych w województwie małopolskim. „Infrastruktura i ekologia terenów wiejskich”, Vol. 3, nr 2, Polska Akademia Nauk, Oddział w Krakowie, 2006, s. 135-146; Ustawa z dnia 14 grudnia 2012 r. o odpadach (DzU. z 2013 r., poz. 21); Dyrektywa Parlamentu Europejskiego i Rady 2008/98/WE z dnia 19 listopada 2008 r. w sprawie odpadów; https://www.mos.gov.pl/srodowisko/odpady/odpady-komunalne/zagadnienia-ogolne/pojecie-odpadow-komunalnych-w-przypadku-zrodel-wytwarzania-innych-niz-gospodarstwa-domowe, 19.10.2017; http://www.rudaslaska.pl/theme/ruda-slaska/uploads/poziomy_recyklingu_2016.pdf – dane opracowane przez A. Strzebinczyk-Opilka, 09.09.2017; Wolniak R., Stachurek I., Binkiewicz P.: Execution of logistic function of packaging of plastic materials. „Logistyk”, nr 2, 2015, s. 9-12; http://www.rudaslaska.pl/theme/rudaslaska/uploads/miejsca_zagospodarowania_odpadow_komunalnych_IV_2016.pdf, 10.09.2017; Malindžák D., Pacana A., Pačaiová H.: Effective Model of Environmental and Logistics System Quality Improvements for Cement Factory Vessels. "Przemysł Chemiczny", Vol. 96(9), Wydawnictwo SIGMA-NOT, 2017, s. 1958-1962, DOI 10.15199/62.2017.9.31, Warszawa 2017.
waste. There are also hazardous waste collection points (such as batteries, old paint and lacquers). All these wastes are collected in containers and received by a specialist company selected by tender procedure.

Due to the quality of the processes of subsequent transport and treatment of municipal waste, it is important to collect the municipal waste by the inhabitants themselves. The general state of municipal waste is influenced by the following: segregation, i.e. whether the waste is actually segregated, for example bottles are cleaned, labels are ignited, dangerous substances are passed to the collection points or do the people attach importance to crushing, do they use biodegradable bags for biomass, etc. Waste collection is the first logistic process in the waste management, and therefore its quality is translated into successive stages. The effective and optimal implementation of the waste collection process must take into account factors such as: the size of the area from which the waste is collected, the structural and economic and social determinants. Legal regulations are defined for the site. The method of collection depends also on the available technologies of export and processing in the area and the number of active landfills.

Another logistics process is the removal of waste, i.e. the collection of waste from the place of their collection and the transshipment to vehicles in order to move through the successive stages of the development system. Self-handling can be done manually or mechanically, using appropriate means of transport. When the transport of waste takes place directly from the place of collection to the disposal plant we are talking about a one-stage system. This system can be non-replaceable, replaceable or disposable.

In the unconverted system, the waste is discharged from the containers to the means of transport (garbage trucks) and the containers remain in the collection area. In a removable system, the filled containers are picked up and delivered empty (hooked). Disposable bags (bags and big bags) do not require containers, replacement or cleaning. The disadvantage is that the bags themselves become waste, and the bags are transported to the transport center by hand. Single-stage waste disposal is still the dominant system in Poland6.

In the two-stage transport system, the so-called transshipment stations are use in the places where temporary waste is collected and pre-sorted. According to the literature7, this solution reduces system costs by up to 30%.

The impact on the logistics process at this stage depends on how to prepare the waste for transport (sealed bags, segregation of waste, properly exposed containers in front of property, the distance of containers from the house, the degree of crushing the waste, etc.) – so all the

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5 Wielik J.: System gospodarki odpadami komunalnymi na terenie Rudy Śląskiej, praca dyplomowa. Wyższa Szkoła Zarządzania Ochroną Pracy w Katowicach, 2010.
6 Malinowski M., Woźniak A.: Problem optymalizacji logistycznych parametrów transportu odpadów komunalnych w aspekcie strategii ekofirmy. „Infrastruktura i Ekologia Terenów Wiejskich”, nr 10, PAN, Oddział w Krakowie, 2011, s. 107-119.
7 Ibidem.
activities connected with the collection. In addition, the process of export is influenced by: location and number of places of containers, containers, baskets; the carrying capacity of the transport vehicle, the general condition of the transport equipment, the frequency of exports and the time of the fall of the waste collected, the schedule of exports; organization of the work of the export team, number of available means of transport, roads, days and hours of travel, the distance between the place of collection and the place of segregation of the processing, disposal or storage, as well as routes, types of contracts signed, etc.

Once the waste is delivered to the destination place, it is processed. This includes pre-processing such as sorting, separation and grinding as well as pressing and briquetting. At this stage of waste management, it is also possible to see the impact of the quality of the preceding processes. Proper segregation facilitates the use of processing and recycling methods. Recycling: material (mechanical), raw material (chemical), thermal (energetic) and organic (biological).

The last step of the process is to dispose of waste by subjecting them to biological, physical or chemical transformation to bring them into a state that does not pose a threat to human life or health and the environment. At this stage, the processes of waste disposal, waste incineration, gasification and pyrolysis, solid fuel processing, composting and methane fermentation in chambers can be distinguished.

3. Research methodology

The research was conducted on municipal waste from households and from commercial and service establishments located in the city of Ruda Slaska. The term municipal waste is in accordance with Art. 3 sec. 1 point 7 of the Act of 14 December 2012 on waste\(^8\). This term mean household waste, excluding end-of-life vehicles, as well as non-hazardous waste from other waste generators which by their nature or composition are similar to household waste\(^9\); as well as mixed municipal waste, i.e. municipal waste, which have undergone waste treatment activities which have not significantly altered their properties.

Three trash collection routes were selected (Table 1).

\(^8\) Ustawa z dnia 14 grudnia 2012 r. o odpadach (DzU. z 2013 r., poz. 21).
\(^9\) http://www.rudaslaska.pl/theme/rudaslaska/uploads/miejsca_zagospodarowania_odpadow_komunalnych_IV_2016.pdf, 10.09.2017.
Table 1

| Signification of the route | Characteristics |
|----------------------------|-----------------|
| Route 1  | multifamily housing blocks |
| Route 2  | multi-family housing complex with commercial and service establishments |
| Route 3  | single-family residential buildings and suburban areas |

Based on BN-87/9103-04, indicators for the accumulation of solid urban waste have been identified. The mass and volume of waste collected on a given export route was measured at a certain time and the density of waste was calculated. The formulas (1-2) in Table 2 were used for the calculation.\(^\text{10}\)

Table 2

| Volume indicator of accumulation: | \(b_{s, bj} = \frac{\sum_{i=1}^{n} V_i}{M_d} \cdot 365 \text{ [m}^3/\text{M} \cdot \text{rok]} \) (1) |
|----------------------------------|--------------------------------------|
| Bulk mass index:                 | \(b_m = \frac{\sum_{i=1}^{n} m_i}{M_d} \cdot 365 \text{ [kg/ M} \cdot \text{rok]} \) (2) |

Symbols:
- \(V_i\) – volume of waste collected [m\(^3\)],
- \(n\) – number of containers [pcs],
- \(M\) – the number of residents,
- \(m\) – mass of waste collected on a given measurement day [kg],
- \(d\) – number of days of waste collected.

Source: Urban waste disposal – Methods for determination of aggregate indices BN-87/9103-04.

By quartering, samples were taken according to BN-87/9103-03 "Urban waste disposal, collection, storage, transmission and preparation of test samples"\(^\text{11}\). The studies excluded the fractions indicated in item 20 of the Annex to Commission Decision 2000/532/EC, which are collected separately at source and other waste indicated in item 20 02 of that annex, which are not included in mixed municipal waste.

According to PN-93/Z-15006, the morphological composition of municipal solid waste was determined\(^\text{12}\).

Detailed study and tools and test equipment are described in\(^\text{13}\).

\(^\text{10}\) Unieszkodliwianie odpadów miejskich – Metody oznaczania wskaźników nagromadzenia BN-87/9103-04.
\(^\text{11}\) Unieszkodliwianie odpadów miejskich – Pobieranie, przechowywanie i przesyłanie oraz wstępne przygotowywanie próbek odpadów do badań BN-87/9103-03.
\(^\text{12}\) PN-EN 13965-2:2011 – wersja angielska, Charakteryzowanie odpadów – Terminologia – Część 2: Terminy i definicje odnoszące się do gospodarki; Wielik J.: System gospodarki odpadami komunalnymi na terenie Rudy Śląskiej, praca dyplomowa. Wyższa Szkoła Zarządzania Ochroną Pracy w Katowicach, 2010; PN-Z-15006:1993. Odpady komunalne stałe – Oznaczanie składu morfologicznego.
\(^\text{13}\) PN-EN 13965-2:2011 – wersja angielska, Charakteryzowanie odpadów – Terminologia – Część 2: Terminy i definicje odnoszące się do gospodarki.
4. Results of research

Accumulation rates are calculated using the formulas given in Table 2. The results presented in Table 3 indicate that the highest accumulation rates of waste are characterized by compact housing (Route 2).

Table 3

| Signification:       | Bulk density [kg/m³] | General volume indicator [m³/M per year] | Overall mass index [kg/ M per year] |
|----------------------|----------------------|-----------------------------------------|-------------------------------------|
| Route 1              | 69                   | 2,03                                    | 139                                 |
| Route 2              | 102                  | 6,29                                    | 614                                 |
| Route 3              | 219                  | 0,87                                    | 190                                 |

Source own work.

Fig. 2. Composition of municipal waste according to route
Source: Own work.

The mean values of granulometric measurement of municipal waste are shown in Fig. 1 a-c. Fractions above 100 mm and 100-40 mm are the most common, accounting for 67% of the average annual waste.

The average values of the fuel properties of the fractions are shown in Table 4. The calorific value for the municipal waste collection route was 5.36-8.34 MJ/kg.

Table 4

| Route     | Humidity [%] | Flammable substances [% s.m.] | Biomass [% s.m.] | Heat of combustion MJ/kg s.m. | Calorific value MJ/kg | Chlorine content % s.m. | Sulfur content (bound) |
|-----------|--------------|-------------------------------|------------------|------------------------------|-----------------------|------------------------|------------------------|
| Route 1   | 40,1         | 77,42                         | 63,18            | 15.7                         | 8.34                  | 0.26                   | 0.27                   |
| Route 2   | 39,53        | 66,53                         | 48,43            | 12.42                        | 6.87                  | 0.21                   | 0.34                   |
| Route 3   | 39,74        | 67,67                         | 53,06            | 10.61                        | 5.36                  | 0.24                   | 0.33                   |

Source: Wielik J.: System gospodarki odpadami komunalnymi na terenie Rudy Śląskiej, praca dyplomowa. Wyższa Szkoła Zarządzania Ochroną Pracy w Katowicach, 2010, s. 53.
Comparing the data with the results of the research presented in\textsuperscript{14} it can be stated that the fuel properties of municipal waste of the city of Ruda Śląska are variable depending on the time of the year, and the waste from multi-family block building with central heating is characterized by high calorific value.

The morphological composition determined in accordance with PN-93/Z-15008 01 (Figure 2) confirms that the collected mixed municipal waste contains significant quantities of paper, plastics and glass which are recyclable. Only on Route 3 in the morphological survey hazardous waste was not found. The largest volumes of plastics and textile waste were recorded on Route 2. The results confirm that the residents of single-family homes, to a greater extent, separate waste than residents of multi-family housing. This is related to the level of awareness of the inhabitants of the regions concerned but also to the system of waste collection.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{morphological_composition.png}
\caption{Average morphological composition of municipal waste collected on routes 1-3}
\end{figure}

Source: Own work.

\textsuperscript{14} Kalisz M., Matejczyk M., Nowak B., Sieja L., Szojda G.: Analiza składu morfologicznego odpadów komunalnych na terenie miasta Ruda Śląska. IETU, Katowice 2009.
5. Conclusion

The analysis of the obtained results allows to formulate the following conclusions:

- In the analyzed logistic chain, it is necessary to strengthen the first link, namely selective collection at source, especially in areas characterized by compact multi-family housing, as this region has the highest unregulated waste amount.
- It would be advisable to plan, design and build a waste incineration plant in the area of Ruda Śląska, as confirmed by the results of research on the amount of waste produced. It is recommended to introduce a technology solution to recover energy from municipal waste.

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