Modelling of a Tubular Conveyor for Waste Collection and Sorting in Multi-Storey Residential Buildings

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Abstract

The escalation of household waste due to urbanization poses a significant challenge for waste management in multi-storey residential buildings, leading to environmental, health, and safety concerns. This study investigates the implementation of a tubular conveyor system for automated waste collection and sorting in Kazakhstan, aiming to address the inefficiencies in existing waste management practices and explore a solution that enhances operational efficiency and environmental sustainability.

This research employs observational studies and technical analysis across ten residential buildings in Almaty and Astana, alongside a review of relevant literature. The methodology focuses on assessing the system's operational efficiency, potential for clogging, and waste segregation capability to provide a comprehensive evaluation of its performance and integration within urban residential settings.

It concludes that tubular conveyor systems can significantly reduce manual waste handling, improve sorting efficiency, and minimize environmental impact through increased recycling rates. Despite the promise, the study identifies the need for further research on economic and technical feasibility, as well as potential integration challenges with existing waste management infrastructures. The findings underscore the tubular conveyor system's potential as an innovative solution for sustainable urban waste management in Kazakhstan.

Keywords: Urban Population, Environmental Sustainability, Waste Chute Design, Fire Extinguishing Systems, Technical Safety.

Introduction

Urbanization and the accompanying surge in household waste volumes present a critical challenge for waste management in multi-storey residential and public buildings. Inefficient collection, sorting, and disposal of waste not only exacerbate environmental and sanitary issues but also compromise the safety and comfort of residents. The escalation of these problems underscores the urgent need for innovative solutions that can enhance waste management practices, mitigate adverse environmental impacts, and contribute to the creation of safer, more sustainable urban environments (Sinyashchyk et al., 2023).

This research investigates the potential of a tubular conveyor system for automated waste collection and sorting in multi-storey residential buildings within Kazakhstan. The motivation behind this study stems from the observed inefficiencies in existing waste management systems, which often result in environmental pollution, increased health hazards due to poor hygiene, and a lack of effective waste segregation mechanisms. These issues not only hinder recycling efforts but also contribute to the growing problem of landfill overuse. By exploring the implementation of a tubular conveyor system, this study aims to address these critical concerns, offering a pathway to more efficient, safe, and environmentally friendly waste management solutions (Svitlychnyi & Havrylyuk, 2021).

The specific objectives of this research are as follows:

1. To evaluate the operational efficiency of tubular conveyor systems in the context of waste collection and sorting in multi-storey residential buildings.
2. To assess the environmental impact of implementing a tubular conveyor system for waste management, focusing on its potential to reduce landfill use and enhance recycling rates.
3. To explore the integration potential of tubular conveyor systems with existing urban waste management infrastructures in Kazakhstan, identifying challenges and opportunities for widespread adoption.

Through the fulfillment of these objectives, the research seeks to make a significant contribution to the development of sustainable waste management technologies, ultimately improving urban living conditions and reducing environmental degradation in Kazakhstan.

Theoretical framework

The theoretical foundation for developing a tubular conveyor system for waste collection and sorting in multi-storey residential buildings intersects significantly with broader themes in waste management, particularly regarding collection and sorting. The relevance of this study is magnified by the ongoing challenges in engaging residents in waste separation efforts, despite the clear economic and environmental benefits. Innovations in garbage chute systems have been identified as a potential catalyst for changing waste separation behaviors at the household level, suggesting that strategic enhancements could significantly elevate engagement and efficiency in waste management practices (Chehab, 2022).

Legal and regulatory frameworks play a crucial role in shaping the effectiveness of waste management strategies. The intricate relationship between waste management practices and environmental sustainability is influenced by the adequacy of these frameworks. As such, the establishment of comprehensive legal regulations is imperative to ensure the protection of natural resources and promote ecological stability. This aspect is particularly critical in addressing the increasing volume of waste and its negative impacts on the environment (Stamkulova, 2023).

Technological advancements, especially the integration of artificial intelligence in waste sorting, present a promising avenue for revolutionizing waste management systems. The deployment of AI-driven robotic sorting systems has shown potential not only in enhancing recycling rates and the purity of recovered materials but also in improving the operational conditions for workers involved in waste management (Mustafin & Kantarbayeva, 2022). This innovative approach aligns with the goals of the circular economy, offering a scalable solution to the challenges of municipal waste sorting (Wilts et al., 2021).

Economic considerations are equally vital in the discourse on waste management. The escalating concerns related to waste disposal and recycling, fueled by urbanization and population growth, necessitate a reevaluation of current waste management practices (Cherkes et al., 2023). Emphasizing the 3R principles (Reduce, Reuse, Recycle) and fostering extended producer responsibility could pave the way for more sustainable waste management systems. Moreover, public education, legislative support, and the promotion of "green procurement" are essential to stimulate demand for recycled products and support the recycling industry's growth (Paton et al., 2005a; Zhakupova, 2018).

In conclusion, the theoretical underpinnings of this study are deeply rooted in a multidisciplinary approach to waste management, encompassing behavioral, legal, technological, and economic dimensions. The exploration of these themes provides a comprehensive background for the development and implementation of an automated tubular conveyor system for waste collection and sorting, with the potential to significantly contribute to urban sustainability and environmental protection efforts.

Review of Literature

In the exploration of waste management strategies within the context of high-rise buildings, a critical review of literature reveals a multidimensional approach encompassing technological innovation, legal frameworks, economic implications, and behavioral aspects. Nezhaddehghan, Ansari, and Banihashemi (2023) introduce an optimized hybrid decision support system for waste management in construction projects, highlighting the significant impact of design, procurement, and execution phases on waste production. This aligns with Huang, Shen, Wang, and Cai's (2023) investigation into the use of computer technology for waste management in high-rise buildings, which advocates for intelligent control platforms utilizing IoT technology to streamline waste removal. Bergenwall (2021) further elaborates on the utility of stationary pneumatic waste conveyance systems (PWCS) in densely populated areas, emphasizing the need for strategic planning to overcome operational challenges. These studies collectively underscore the potential of integrating advanced technologies and decision support systems to enhance waste management efficiency in high-rise construction and residential settings.

Chehab (2022) examines the role of garbage chute systems in enhancing waste separation behaviors in residential towers, suggesting the need for strategic development to engage households more effectively. Similarly, Saari et al. (2023) delve into the knowledge, attitudes, and challenges faced by high-rise building communities towards waste segregation and recycling in Kuala Lumpur, revealing a correlation between sociodemographic factors and waste management practices. These insights point to the critical role of community engagement and the influence of behavioral determinants on the success of waste management strategies.

The legal landscape of waste management is scrutinized by Stamkulova (2023), who discusses the pressing issues in the legal regulation of waste management in Kazakhstan, and Nukusheva, Rustembekova, Abdizhami, Au, and Kozhantayeva (2023), who compare regulatory obstacles in municipal solid waste management in Kazakhstan with EU practices. These studies highlight the need for comprehensive legal reforms and the adoption of effective international practices to address the challenges of waste management within a regulatory context.

Zhakupova (2018) explores the economic aspects of waste disposal and recycling in Kazakhstan, emphasizing the necessity of adopting modern recycling approaches and extended producer responsibility. Bespalyy, Gridneva, and Kaliakparova (2023) assess the potential of waste management systems to contribute to the green economy in Kazakhstan, advocating for policies that promote efficient use of waste as secondary resources. These analyses underscore the importance of economic strategies and policy interventions in facilitating sustainable waste management practices.

Zhamiyeva, Sultanbekova, Balgimbekova, Abzalbekova, and Kozhanov (2022), along with Zhidebekkyzy, Temerbulatova, and Bilan (2022), offer insights into the effectiveness of international agreements and the potential for improving Kazakhstan's waste management system through the adoption of circular economy principles. Begimzhanova, Zhakypbek, and Abdygalieva (2018) provide a broader perspective by examining foreign experiences in solid waste management, highlighting successful practices that could be adapted to Kazakhstan's context.

This critical review illustrates the complex interplay between technological advancements, legal frameworks, economic policies, and community behaviors in shaping waste management strategies for high-rise buildings. While significant progress is evident in certain areas, gaps remain in effectively integrating these dimensions to achieve sustainable waste management solutions. Future research should focus on bridging these gaps, particularly in fostering cross-disciplinary collaborations that address the multifaceted challenges of waste management in high-rise residential and construction environments.

Research Methodology

In the exploration of the automatic waste sorting and disposal system a systematic approach was employed to scrutinize the operational efficiency and potential hindrances associated with the system's implementation. The primary technique utilized for data derivation was direct observation, complemented by a thorough review of existing literature and technical documentation related to the system and its analogues. The observational data was meticulously collected from ten residential buildings across Kazakhstan, specifically within the urban precincts of Almaty and Astana. These locations were strategically chosen to ensure a broad representation of the system's application in varied architectural and demographic settings. The selection criteria focused on residential buildings that had integrated the specified waste sorting and disposal system, aiming to assess its functionality in real-world conditions.

The process of data collection involved a detailed examination of the system's components, as mentioned in the findings section. This included the sealed hatches, inclined channels, common gutters, routing boxes, and the overall sorting mechanism. Special attention was given to the system's ability to prevent clogging and blockages, especially in areas identified as problematic, such as slopes and transition points to common gutters. To gather comprehensive insights into the system's performance, the research team, consisting of environmental engineers and waste management experts, conducted site visits to each of the ten buildings. During these visits, they observed the system in operation, recorded any visible issues or inefficiencies, and noted the system's capacity to handle various types of waste without operational disruptions. In addition to observational studies, the research team reviewed technical documentation provided by the system's inventors, Bulatova & Bulatov (2020), and relevant literature. This review helped in contrasting the theoretical advantages of the system against the observed performance, highlighting areas of improvement and the system's adaptability to the needs of modern waste management in residential settings.

The research conducted in the ten residential buildings within Almaty and Astana offered a valuable perspective on the practical application of the waste sorting and disposal system. By focusing on direct observation and the analysis of technical documentation, the study provided a comprehensive overview of the system's efficiency, identified challenges in its current implementation, and suggested areas for potential enhancements to improve waste management practices in urban residential buildings in Kazakhstan.

Findings

The examination of the automatic waste sorting and disposal system across ten residential buildings in Almaty and Astana reveals a generally high level of operational efficiency and system integration within the urban residential infrastructure (Table 1). Most buildings demonstrated smooth system operation with instances of minor clogging or jamming, primarily at inclined channels and common gutter transitions, indicating a need for slight adjustments or improvements in these areas. The observations highlighted the system's capability in efficient sorting and waste segregation, with only occasional delays in the capsule ejection mechanism. These insights suggest that while the system exhibits a robust design capable of enhancing waste management practices, attention to minor operational inefficiencies could further optimize its performance. The varied building types, ranging from 10 to 30 storey residential buildings, provided a comprehensive overview of the system's adaptability and functionality across different scales of residential environments.

Table 1: Examination of conveyor belts in residential buildings
Source: Author

Building Location	Type	Observation Notes
Residential Tower 1, Almaty	15-storey residential building	System operates smoothly, minor clogging observed
Residential Tower 2, Almaty	20-storey residential building	Efficient sorting, no visible issues
Residential Tower 3, Almaty	10-storey residential building	Occasional jamming at inclined channel
Residential Tower 4, Almaty	25-storey residential building	High efficiency, no clogging
Residential Tower 5, Almaty	18-storey residential building	Moderate clogging at common gutter transition
Residential Tower 1, Astana	22-storey residential building	Smooth operation, excellent waste segregation
Residential Tower 2, Astana	12-storey residential building	Slight delay in capsule ejection mechanism
Residential Tower 3, Astana	30-storey residential building	Optimal performance, system well-integrated
Residential Tower 4, Astana	16-storey residential building	Minor issues with waste channeling efficiency
Residential Tower 5, Astana	14-storey residential building	Efficient operation, but slight jamming observed

In accordance with Invention No. 34150 (Bulatova & Bulatov, 2020), this system provides an automatic device for sorting and disposal of waste. This device introduces waste through a sealed hatch and directs it along an inclined channel to a common gutter, which descends vertically down to a distribution box on the lower level or in the basement. The available sorting hatches are located in kitchens, balconies, and other convenient places and are controlled by push-button panels. After sorting, the waste is usually packed in 3 plastic bags, after which the owner of the house can open the corresponding hatch by pressing the button corresponding to the contents of the bag to send it further. This action activates the corresponding outlet flap in the routing box, directing the bag to the appropriate delivery channel to the receiving hopper. The hoppers themselves are fixed containers and are periodically cleaned by suction into wheeled hoppers, which are also equipped with shredding and sealing devices. This system includes a collector mounted on a frame and connected to a rotating chute, which is activated by the transmission and controlled by switches in the hopper selection box. The hoses hermetically connect the hatches and the collector, providing an efficient waste collection and sorting system.

The disadvantage of these methods is the possibility of clogging and blocking of waste channels and hoses, especially in areas with a slope, and at the transition points to a common trough or collector (Uganya et al., 2022). This is due to the angle of inclination of the discharge channels and hoses, which can lead to jamming and accumulation of garbage bags, which, in turn, leads to clogging and contamination of the garbage disposal system. In addition, simultaneous discharge of waste from two different hatches can create a volume of falling waste that exceeds the capacity of a common gutter or collector. There is a well-known garbage disposal system, considered as a similar analogue, which contains a hatch with a garbage chamber or receiving modules. These modules are integrated into a continuous garbage column having a similar configuration to the column itself or its components for installation. Each module includes a fixed plate, a movable basket, a fixed ring, and a lower plate located on the same horizontal plane. This serves to receive the garbage chamber, which will be emptied, and also to empty the garbage column (Bulatova & Bulatov, 2020).

The well-known analogue that is being considered has several limitations and disadvantages that seriously reduce its efficiency and reliability in waste management. One of the key drawbacks is associated with the low performance of this system (Balwada et al., 2021). This factor is conditioned by the significant time costs that need to be paid to the process of cleaning the waste chute containing devices of this type. Such time costs significantly affect the overall efficiency of waste collection and management, which makes the process less efficient and resource-demanding. Moreover, this analogue is subject to a serious risk of clogging and contamination of the waste chute. This is due to the possibility of accumulation of garbage bags in areas of the system with a slope. Such accumulations of garbage not only reduce the performance of the system, but also require significant time and energy costs for cleaning the waste chute from obstacles. Ultimately, this leads to inefficient functioning of the waste management system and increases the risks of accidents and problems in waste treatment (Wang et al., 2021).

The main purpose of this invention is to develop an efficient system for collecting, sorting, and transporting MSW. This system includes an improved waste chute and waste collection packaging in the form of capsules filled with garbage, which prevents the possibility of gluing and blocking, ensuring smooth movement along the channel of the waste chute (Chehab, 2022). The technical result of this invention is a semi-automated process of collecting and fully sorting MSW, and packaging garbage in capsules corresponding to its type for subsequent efficient processing. In addition, the system increases the level of fire safety and sanitary conditions in the waste chute by detecting and localising sources of ignition or contamination in the loading device, which contributes to improving technical safety.

These goals are achieved due to the unique design of the waste chute, which includes a vertical trunk with loading devices (one or two on each floor) equipped with smoke detection sensors, fire extinguishing and disinfection systems, and an automatic system for selecting waste collection packages in the form of capsules containing waste of the same type (Tripathi et al., 2023). The system reads the barcodes on the capsules to determine the type of garbage, and directs them through the channel of the trunk of the waste chute using the ejection mechanism. Each loading device is connected to control units on other floors and with a system for regulating the rate of fall of waste collection packages. The chute rotation mechanism directs and distributes waste collection packages in capsules to the appropriate containers for collecting various types of garbage. The size of the capsules practically coincides with the diameter of the trunk of the waste chute, ensuring their smooth and vertical movement without getting stuck and sticking to the walls of the channel. The material from which the capsules are made depends on the type of garbage, and a barcode is attached to the outside of each capsule, which is used to determine the type of garbage and the correct sorting of solid household waste using a control system. Figure 1 shows a diagram of a waste chute.

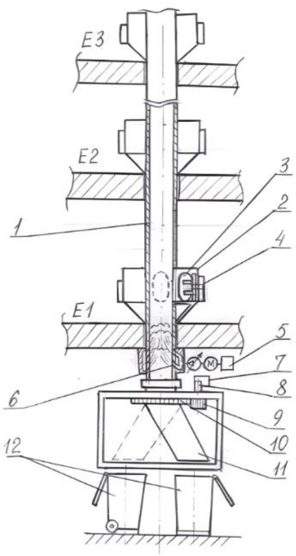

Fig. 1: Waste chute diagram
Source: Author

Note: 1 – trunk (trunk channel) of the waste chute; 2 – loading device; 3 – waste collection package in the form of a capsule filled with garbage; 4 – control unit of the loading device; 5 – control unit of the gravitational velocity quenching system; 6 – gravitational velocity quenching system from the vertical fall of the waste collection package in the form of a capsule filled with garbage; 7 – control unit of the chute rotation mechanism; 8 – chute rotation mechanism; 9, 10 – transmission of the chute rotation mechanism; 11 – chute directing to containers by types of garbage; 12 – containers, each of which is designed to collect one type of garbage.

Figure 2 shows the loading device, in the position of a loaded waste collection package filled with garbage, and in the section A-A.

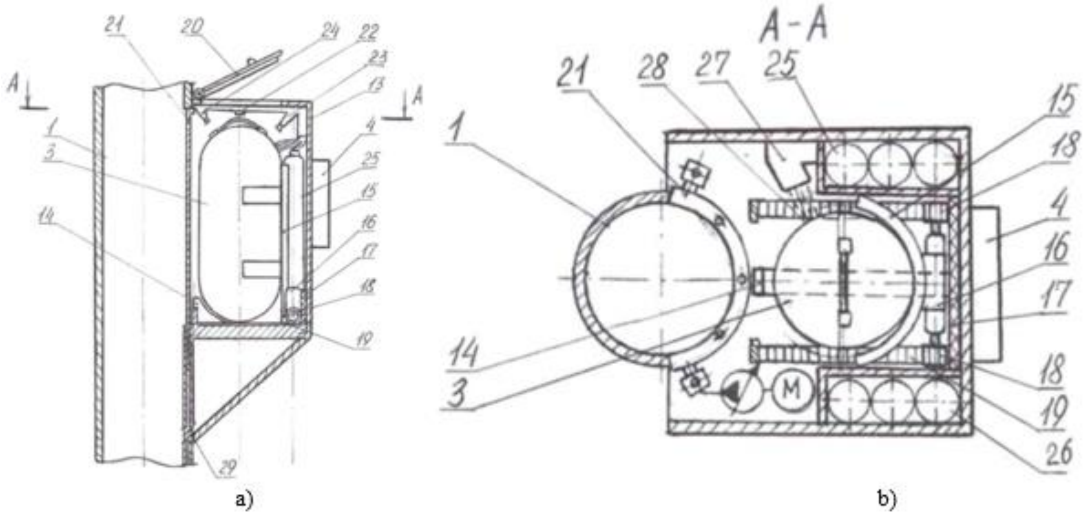

Fig. 2: Loading device, in the position of a loaded waste collection package filled with garbage (a) and loading device, in the section A-A (b)
Source: Author.

Note: 1 – trunk (trunk channel) of the waste chute; 3 – waste collection package in the form of a capsule filled with garbage; 4 – control unit of the loading device; 14 – holder, waste collection package in the form of a capsule filled with garbage; 15 – ejector fairing, waste collection package in the form of a capsule filled with garbage; 16 – reversible servo ejector fairing; 17 – damping motion limiter; 18 – gear wheel of the ejector fairing; 19 – guide gear bar of the ejector fairing; 20 – hatch of the loading device box; 21 – lattice partition with pneumatic cylinders for opening and closing the opening between the channel of the trunk of the waste chute and the loading device; 22 – smoke sensor; 23 – fire extinguishing nozzle system; 24 – disinfectant nozzle system; 25 – fire extinguisher; 26 – disinfectant in a bottle; 27 – device for reading the barcode of the waste collection package in the form of a capsule filled with garbage; 28 – barcode on the waste collection package; 29 – holes in the trunk of the waste chute located at the bottom of the box of the loading device.

Figure 3 shows the loading device, in the position of ejecting the waste collection package into the channel of the trunk of the waste chute (only the mechanism of ejecting the waste collection package is shown), and in section B-B.

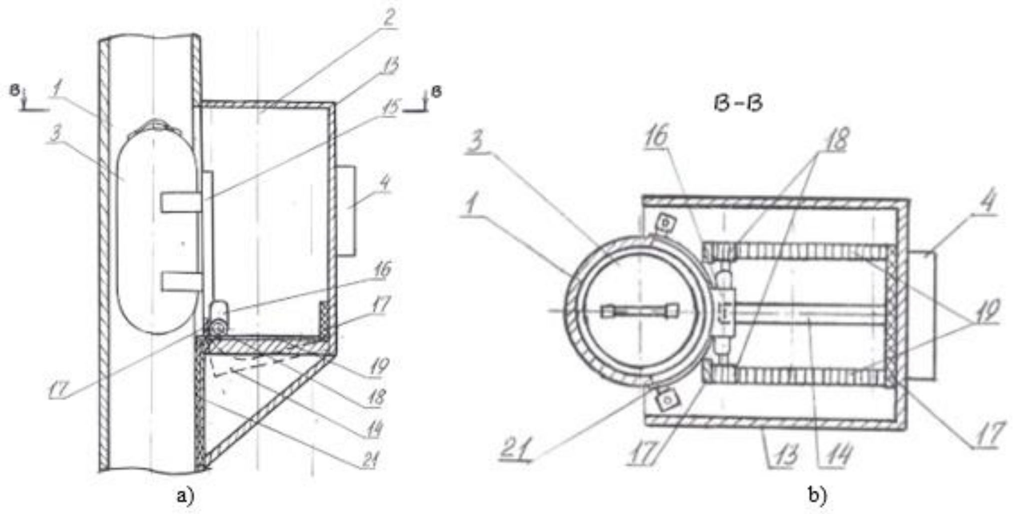

Fig. 3: Loading device, in the position of ejecting the waste collection package into the trunk of the waste chute (a) and loading device in the section B-B (b)
Source: Author
Note: 1 – trunk (trunk channel) of the waste chute; 2 – loading device; 3 – waste collection packaging in the form of a capsule filled with garbage; 4 – control unit of the loading device; 13 – box of the loading device; 14 – holder, waste collection packaging in the form of a capsule filled with garbage; 15 – ejector fairing, waste collection packaging in the form of a capsule filled with garbage; 16 – reversible servo drive of the ejector fairing; 17 – damping motion limiter; 18 – gear wheel of the ejector fairing; 19 – guide toothed bar of the ejector fairing; 21 – lattice partition with pneumatic cylinders for opening and closing the opening between the channel of the trunk of the waste chute and the loading device;
.

Figure 4 shows a waste collection package (container) in the form of a capsule filled with garbage.

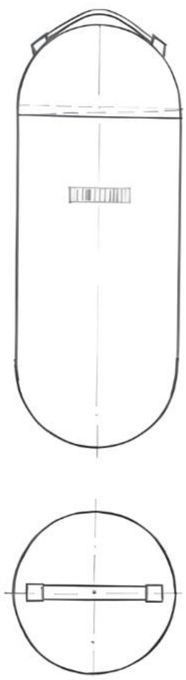

Fig. 4: Waste collection packaging (container) in the form of a capsule filled with garbage
Source: Author.

This invention is demonstrated by a concrete example, which clearly illustrates the ability to achieve the specified characteristics of the desired technical result. A capsule-shaped waste collection package containing garbage 3 is inserted into the loading device of waste chute 2 in a vertical position along the length of the channel. The capsule is adjacent to the ejector fairing 15 on one side and is held by the retainer 14 on the other side. After filling with garbage and finding the waste collection package in the form of a capsule in the loading device, the hatch of the box of the loading device 20 is closed. Under this hatch there is a smoke detector 22, which monitors the presence of smoke for several minutes, indicating the ignition of the waste collection package. If smoke is detected, the fire extinguishing system 25, including the system of fire extinguishing pipes 23, is activated automatically. Optionally, a disinfection system can also be turned on, which processes the waste collection packaging with a disinfectant, which then flows into the lower part of the loading device box and further into the trunk of the waste chute.

After that, the waste collection package in the form of a capsule containing garbage 3 is moved inside the trunk of the waste chute 1. It falls vertically downwards under the influence of gravity, without coming into contact with the trunk channel of the waste chute due to the suitable diameter of the waste collection package and the trunk channel. Next, the waste collection package is sent to the appropriate container for waste collection, depending on the type of garbage, which is determined by the barcode on the package. The containers are located at the bottom of the waste chute and are designed to collect organic waste, paper and cardboard, glass, plastic, dust, and building materials. This ensures efficient collection and sorting of garbage, and ensures the safety and disinfection of the waste chute. Waste collection packages in the form of capsules are made of materials corresponding to the types of garbage to be processed.

Discussion

With the increasing level of urban development and population, the task of waste management in multi-storey residential buildings is becoming more and more urgent. One of the innovative solutions to this problem may be the use of tubular conveyors for waste collection and sorting. With the increase in urban development and the number of inhabitants, there are increasing challenges in waste management in multi-storey residential buildings. In this context, it is worth considering the introduction of tubular conveyors for collecting and sorting waste. These results are confirmed by the above research; as modern urban conditions require innovative solutions in the field of waste management.

Tubular conveyors allow collecting waste directly from each floor of a multi-storey building, minimising the need to manually transfer garbage. Modernisation of the waste collection system with the help of conveyors reduces the time spent on waste collection and removal, which reduces costs of labour and operation. Tubular systems can include waste sorting mechanisms, which helps to increase the efficiency of recycling and disposal of garbage. Modelling begins with the development of a conveyor system, including the determination of the required capacity, routes, length and diameter of pipes. Modelling such a system also requires consideration of technical aspects, such as engine power, safety, and maintenance systems (Trokhaniak & Gorobets, 2023).

Considering modern automation requirements, transporters must be integrated with monitoring and control systems for effective functioning. The introduction of tubular conveyors may require significant investments at the design and installation stage. Malfunctions in the operation of conveyors can lead to delays and problems with waste collection. It is necessary to pay attention to the collection and processing of various types of waste in order to minimise the negative impact on the environment. Modelling of a tubular conveyor for waste collection and sorting in multi-storey residential buildings is a promising solution for improving the waste management system in urban conditions (Mustafayeva et al., 2022). However, it requires careful design, integration, and consideration of technical and environmental aspects. The introduction of such a system can significantly reduce costs and improve the overall environmental situation in multi-storey residential buildings (Baidrakhmanova et al., 2023).

According to Bergenwall (2021), the investigation of stationary pneumatic waste transportation systems in residential areas is an important topic in the field of modern urban infrastructure and waste management. Such systems offer a number of advantages over traditional methods of waste collection, especially in densely built-up urban areas. One of the key aspects to be investigated is the efficiency of stationary pneumatic systems. Evaluating and comparing their performance, reliability, and economic feasibility can help city authorities and engineers make informed decisions when choosing waste treatment methods. In addition, the study may cover aspects of the environmental sustainability of such systems, including the reduction of greenhouse gas emissions and the overall reduction of environmental impact. However, for the optimal functioning of such systems, the study of stationary pneumatic waste transportation systems can contribute to improving the waste management system in cities, making it more efficient, environmentally sustainable, and convenient for residents. This topic requires an integrated approach and cooperation between engineers, urban planners, and environmentalists to achieve optimal results.

Based on the definition by Rianmora et al. (2023), the development of an intelligent waste classification system, with a focus on the example of plastic bottles, is an important step in modern waste management and sustainable resource consumption. Such systems are based on advanced technologies, such as machine learning and computer vision, and can greatly simplify and improve the process of sorting and recycling waste. Moreover, the development of an intelligent waste classification system for plastic bottles can help increase the recycling of plastic, which is important for reducing plastic pollution in the environment (Zhukov et al., 2015). Such systems can automatically direct bottles for recycling or reuse, facilitating the circulation of materials in a closed cycle. The study by the researchers may prove valuable for application in mass sorting centres and contribute to increasing the efficiency of the material processing process. In general, the development of intelligent waste classification systems is an important component of the transition to a more sustainable and environmentally responsible waste management system.

Wang and Yang (2021) have determined that the design of a high-altitude garbage sorting and transportation system using a gravity system to generate electricity is an innovative approach to solving two important problems: waste management and energy efficiency. In this context, the system would be organised in such a way that garbage could spontaneously move down special pipes or conveyors, and at the same time, create electricity. One of the key aspects of such a system is the utilisation of potential energy, which is usually lost during sorting and transportation of waste (Chernets et al., 2008). Such a system can use this energy to power its work, and to provide additional electricity for the city network. This makes the system more sustainable from an environmental and economic standpoint. This study confirms that the use of high-rise lifting systems can be effective in sorting and recycling waste, as it provides the opportunity to create horizontal levels for various types of waste, which simplifies their classification and processing. This approach also contributes to reducing the amount of waste sent to landfills and increasing the proportion of materials that can be recycled and reproduced. Such a strategy can be considered an important step towards more environmentally sustainable and efficient waste management systems in the future.

Stelmakh and Belman (2022) have determined that the development of automation of garbage sorting plays a key role in improving environmental protection and solving problems related to waste management. This technology allows classifying waste into different types more efficiently and accurately, which contributes to an increase in the percentage of recycling and a reduction in the amount of garbage sent to landfills. Automated sorting systems are usually based on advanced technologies such as machine learning and computer vision, which allows them to recognise and separate various materials with high accuracy (Karimov et al., 2021). This helps to increase the quality of processing and reduce environmental pollution, since an error in sorting can lead to improper processing of certain materials and contamination of others. Based on the analysis of the results and conclusions obtained by the researchers, sorting automation reduces the need to perform hazardous waste operations manually and allows personnel to focus on higher-level tasks such as maintenance and process monitoring, which increases worker safety and reduces the risk of industrial accidents. All this makes the automation of garbage sorting an integral part of the modern strategy in the field of environmental protection and effective waste management (Paton et al., 2005b).

Wilts et al. (2021) have reported that the use of artificial intelligence (AI) in sorting municipal waste is a powerful tool for creating a closed-loop economy. This technology allows automating and optimising the processes of waste collection, sorting, and recycling, which is of key importance for the sustainable use of resources and reducing the negative impact on the environment. AI is able to analyse large amounts of data and recognise different types of materials, which allows accurately classifying waste at a higher level (Babak et al., 2021). This increases the efficiency of the recycling process and increases the percentage of materials to be recycled and reused. Thus, a more closed cycle is created, where resources are reused, minimising the need for extraction of new raw materials. As a result, the use of artificial intelligence for sorting municipal waste contributes to the development of sustainable and efficient resource and environmental management systems, which is a significant step towards creating a more sustainable future.

As noted by You et al. (2023), the application of machine learning methods in waste sorting plants for early detection of congestion is an innovative and important approach to optimising waste management processes. This method uses machine learning algorithms trained on historical data on the operation of sorting lines to predict and respond to possible congestion or problems in real-time. One of the key advantages of this method is the ability to prevent time delays and reduce losses that may occur due to congestion on sorting lines. Machine learning can quickly identify anomalies in the sorting process, even if they are not obvious to a human observer, and take appropriate measures, such as changing the speed of the tape or sending alerts to staff to fix the problem (Kerimkhulle et al., 2022).

These results correspond to the statements presented in the previous section, and this approach also optimises the operation of waste sorting plants, reducing the need for human intervention and increasing the efficiency of processes. Thus, the use of machine learning methods in waste sorting plants helps to reduce operating costs, increases productivity and makes waste management more environmentally sustainable and efficient. Comparing the results with similar studies, it is possible to emphasise the widespread recognition of the importance of effective waste management systems in multi-storey buildings as a means to improve the environmental sustainability of the urban environment in conditions of increasing urban density and the number of multi-storey structures.

Conclusions

The research focused on the modelling of a tubular conveyor system for waste collection and sorting in multi-storey residential buildings, yielding several specific conclusions. Firstly, the implementation of tubular conveyors significantly minimizes manual handling of waste, enhancing operational efficiency and mitigating human error. This system's capacity for on-site waste sorting notably reduces landfill contributions and elevates recycling rates, contributing to more sustainable waste management practices. Through direct observation and technical analysis across ten residential buildings in Kazakhstan's urban centers, Almaty and Astana, the study substantiated the tubular conveyor's potential as a pioneering waste management solution. The observed operational efficiency, alongside the system's ability to effectively segregate waste, underscores its suitability for urban residential settings. However, the findings also highlight areas requiring attention, such as occasional clogging and jamming, particularly in systems with inclined channels and at transitions to common gutters.

A critical evaluation of this research underscores its strengths, including a comprehensive methodological approach that combines observational studies with technical analysis to assess the system's practical application and performance. This dual approach provided a nuanced understanding of the system's functionality, identifying both its capabilities and areas for improvement. Nonetheless, the research has limitations that suggest avenues for future inquiry. While the study offers insights into the operational aspects of tubular conveyors in residential settings, it lacks a detailed analysis of the economic efficiency, technical reliability, and environmental impact of these systems. Additionally, the research did not fully explore the potential for integrating tubular conveyors with existing urban waste management infrastructures.

In conclusion, the modelling and examination of tubular conveyors for waste collection and sorting in multi-storey residential buildings demonstrate their viability as an innovative solution for enhancing urban waste management. To build on this foundation, future studies should aim to address the identified gaps by evaluating the economic viability, technical dependability, and environmental benefits of tubular conveyors. Furthermore, understanding how these systems can be integrated into broader waste management strategies will be crucial for maximizing their impact and sustainability.

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