

Technology of Utilization of Polypropylene Waste and Wastewater Sediments by Production of Building Blocks

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ABSTRACT

Plastic waste and wastewater sediment stored on sludge lagoons are generated in almost every city in Ukraine. Their disposal is an urgent issue nowadays. The paper shows the ways of polypropylene utilization as one of the most widely used thermoplastics in everyday life, as well as the problem of formation and storage of wastewater sediments. The proposed technological scheme of complex processing of the resulted waste by production of building blocks is based on the property of polypropylene as a thermoplastic to soften and melt at above 160 °C, while exhibiting adhesive properties to a number of materials. For the implementation of technological solutions for manufacturing of construction products, the adhesion properties of polypropylene to wastewater sediments were substantiated, heating modes of the raw material mixture of wastewater sediments and polypropylene waste were specified, and the ratio of raw materials in the mixture for thermal treatment was determined. The samples of building blocks with a mass content of wastewater sediment from 5 to 95% (dry weight sediments) were made in the laboratory. In these samples, the polypropylene content was reduced from 95 to 5%, respectively. It was experimentally determined that for the samples of construction materials with a mass content of wastewater sediment 40–50% (dry weight), a uniform distribution of raw materials that would ensure their high strength, was observed. The comparison of the qualitative characteristics of the samples of building blocks with the regulatory requirements for construction products revealed that the experimental samples met the current requirements and were not inferior to the counterparts from traditional raw materials. However, the construction materials made from waste are recommended for application in building of industrial warehouses and storage facilities, non-food storage chambers, garages or other structures that do not provide permanent storage of food or living place for humans or animals.

Keywords: polypropylene, wastewater sediment, treatment facilities, melting, blocks-forming.

INTRODUCTION

The waste utilization for the production of building materials is a modern eco-efficient solution in order to solve the environmental problems of environmental pollution and to reduce the cost of raw materials in construction mixtures, which will lead to the cost reduction of final products (Trus I.M. et al. 2017, Ivanenko et al. 2021, Trus

I. et al. 2020). It is very important to explore new methods and procedures to use less energy intensive, cost effective and eco-friendly agricultural waste products for the utilization in the cement composites (Ahmad et al. 2015, Abdul Rahim et al. 2015, Halysh^a et al. 2020, Halysh^b et al. 2020). Nowadays, scientists consider the option of construction waste utilization, including the waste from the buildings dismantling, in

the manufacturing of building ceramics, heat-resistant materials based on liquid glass and materials based on natural reinforcing cement binder (Maslennikova et al. 2019, Awoyera et al. 2016, Akhtar and Sarmah 2018). The authors (Heriyanto et al. 2018, Adaway et al. 2015, Lee et al. 2008, Manikandan et al. 2021, Bagheri et al. 2021) recommend using glass waste (without remelting) as a raw material in the building materials manufacturing. The building materials from fly ash, sawdust and waste paper are light, strong and have good insulating properties (Aigbomian and Fan 2013, Rutkowska and Iwaszko 2015, Rutkowska and Małuszyńska 2014, Hausstein 2018). Cement-free building blocks of steel and blast furnace slag were studied in terms of density, water absorption, compression strength, resistance to freezing and thawing (Mahoutian et al. 2016, Tan et al. 2021, Mahoutian and Shao 2016). They show better mechanical properties than commercial cement blocks, and the cost of slag blocks manufacturing in mass production will be lower (Srivastava et al. 2021, Ghoulah et al. 2015, Mahoutian et al. 2018).

Nowadays, scientific research allows introducing new and promising methods of waste disposal (Trus I. et al. 2021, Paris et al. 2016, Trus I.M. and Gomelya 2021.). In particular, polypropylene is a fairly versatile material used for the manufacturing of various products: fabrics, films, bottles, automotive products etc. (Maddah 2016, Dhawan et al. 2019, Białasz 2018).

The papers (Awoyera et al. 2020, Arulrajah et al. 2017, Hameed et al. 2019, Hama et al. 2017, Singh et al. 2017) point to the possibility of applying recycled plastic waste as a component in cement composites, and it can be used to replace all solid components of the composite. Nowadays, research is being conducted regarding the manufacturing of composite materials with a polypropylene matrix (homogenization of composite samples is carried out in a twin-screw extruder), the processes of adhesion between the filler and the matrix are studied (Singh et al. 2013, Hashem et al. 2019).

Both low-organic wastewater sediments and plastic waste can be used together as a feedstock for the manufacturing of building materials. In this case, polypropylene heated to the melting point, as well as other thermoplastics, exhibits adhesive properties to a number of materials. In particular, such properties were used by the authors (Levitskaya 2012, Levytska et

al. 2020) in the production of composite building materials from wastewater sediments and low-pressure polyethylene.

MATERIALS AND METHODS

Materials

The waste from wastewater treatment plants and secondary polypropylene were used to make the samples of construction materials.

Production of the samples of building blocks using wastewater sediments and polypropylene waste

In a building composite consisting of two components, i.e. wastewater sediment and polypropylene, the matrix is polypropylene, since this thermoplastic exhibits adhesive properties during melting.

In the initial production of polypropylene, stabilizers are usually added to its composition: UV stabilizers or light stabilizers that filter out radiation and convert it into thermal energy, antioxidants that prevent thermal oxidative destruction of the polymer due to the action of heat and oxygen. As a result, application of waste as a secondary raw material does not require the re-addition of necessary stabilizers as they are present in the polymer.

In order to determine the ratio of wastewater sediment to polypropylene in the feedstock mixture, the samples of building blocks with a mass content of wastewater sediment (dry weight) from 10 to 95% were prepared. Thus, for each subsequent sample, the sediment content increased by 5% and the thermoplastic content decreased by 5%.

The samples of building blocks were used (two samples for each experiment – the obtained values of qualitative characteristics were averaged) in order to carry out experimental work to determine the mass ratio of wastewater sediment to polypropylene.

The manufacturing process of building block samples includes several stages:

1. Grinding of polypropylene to 2–4 mm fractions.
2. Dewatering of wastewater sediment. In the laboratory, an electronic mixer was used to destroy microorganisms and simplify the mechanical processes of dewatering; a filter, made

in the laboratory, with a horizontal press; and the processes of thermal finish drying of waste in drying ovens.

3. Mixing of raw materials in a given ratio. Pre-mixing of sediment and polypropylene increased the area of contact of the components that improved the binding processes.
4. Heating the feedstock mixture to the melting point of polypropylene – 176 °C. The feedstock mixture was loaded into a laboratory muffle furnace. Heating processes went faster and more efficient under constant stirring of the mixture during heating.
5. Formation and hardening of building block samples. The homogeneous liquid mixture was formed in wooden molds that were made experimentally and had the form of an open cube with a face size of 70 mm.

The samples hardening took 28 days, after which the strength and density of the experimental samples with different ratios of raw materials were measured. The feedstock composition of the samples, for which the highest values of strength were determined, were recommended for the implementation in production with a given chemical composition of sediments.

Methods for the assessment of the qualitative characteristics of building blocks samples made from wastewater sediment and polypropylene waste

In order to determine the qualitative characteristics of building blocks samples with a specific mass ratio of components, the following 3 parallel studies were conducted and, correspondingly, 3 samples were made for each analysis. The sediments formed 10–15 years ago, 5–10 years ago and at present time were used.

The average density was determined (DSTU B V.2.7-42-97), the strength – (DSTU B V.2.7-248:2011).

In order to calculate the average density, the building block samples were dried to constant weight, and the volume was determined by the geometric dimensions of the blocks. The average density in kg/m³ was determined by dividing the mass of the sample by its volume.

In order to determine the strength of the building blocks, they were placed in the center of the bottom plate of the press and pressed by the upper plate. The load was increased continuously

and evenly with a speed that ensured the increase of the estimated stress in a sample to its complete destruction within 0.6 MPa/s (DSTU B V.2.7-248:2011).

The ultimate compression strength for the building blocks samples was determined in kg/cm² by dividing the maximum load measured when compressing the sample by the cross-sectional area of the sample (Sviderskyi et al. 2018).

The strength values of the building blocks samples calculated from experimental data were compared with the regulatory requirements for construction products.

RESULTS AND DISCUSSION

The determination of time dependences of thermal processes on polypropylene fractionality

A vital task for the introduction of wastewater sediment and polypropylene disposal technology is the determination of the criteria according to which the time that went on heating, melting of the feedstock mixture and binding of its components would be the shortest.

Time reduction for thermal processes can be achieved by selecting the optimal size of the polypropylene fractions. Therefore, for the experiments, the polypropylene waste was crushed into fractions from 2 to 14 mm with an increase of the sample fraction by 2 mm for each following sample. For all groups of raw materials, the mass fraction of wastewater sediment by dry weight was the same –50%. Feedstock mixtures of 1 kg each were heated in a laboratory dryer. The processes of polypropylene softening began at 171–176 °C, the change in the physical state was observed at 176 °C. Along with the process of thermoplastic melting under periodic stirring of the feedstock mixture, the binding processes of wastewater sediment with polypropylene took place.

The dependences of the time that was needed for melting of polypropylene in the raw material mixture and the binding of raw components were built using the obtained experimental data (Fig. 1).

For the raw material mixtures containing wastewater sediments of different years of production, the time required for melting of polypropylene and for binding of raw materials will decrease with decreasing of polypropylene fraction size. Therefore, grinding of polypropylene to 2 mm for

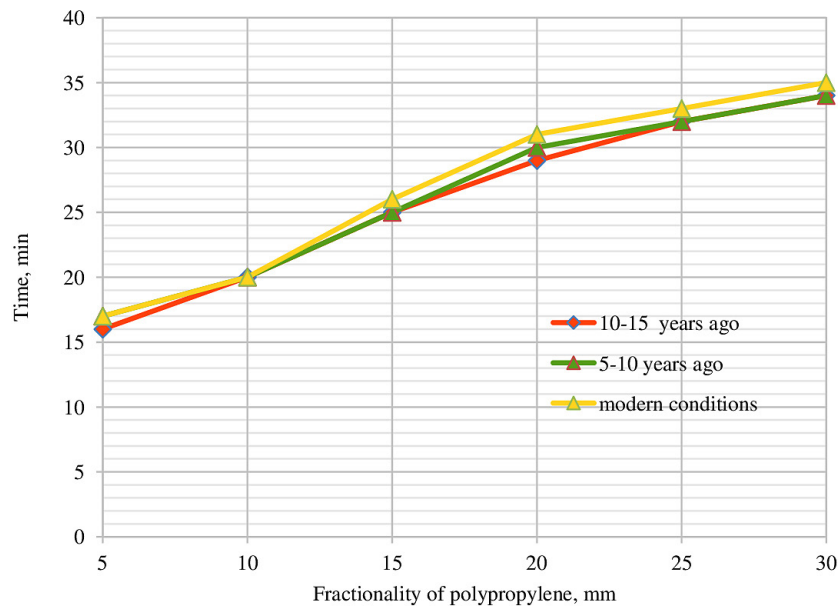


Figure 1. Dependence of the time of processes of melting of polypropylene and binding of raw materials in the raw material mixture from fractionality of polypropylene for the manufacturing of building blocks

the preparation of raw materials mixture for further research would be optimal (Fig. 1).

The determination of the optimal ratios of raw materials by the strength of construction products

The samples of building materials with different ratios of raw materials firstly were evaluated by appearance. Sludge was formed when the content of wastewater sediment was 70–95% (dry weight). Increasing the share of thermoplastic from 5 to 30% promoted the increase of the factionalism of the samples. If the content of wastewater sediment was 60–65%, the formed materials were capable of keeping the shape, but after compression by hand they were destroyed. In this case, it was visually clear that the materials were brittle, had low strength and could not be used in construction.

In the case the sediment content was 30–60% (dry weight), the formed sample had no external defects. The strength of the samples began to decrease significantly at the sediment content of 30–40%. With further decrease in the proportion of wastewater sediment in the raw material mixture, the formed samples had smooth faces (it would complicate the adhesion with grouts during construction works).

Figure 2 shows the dependence of the strength of building material samples on the mass fraction of wastewater sediment in the feedstock mixture (dry weight sediments).

The increase of mass share of wastewater sediment from 60 to 95% led to sludge formation with a fraction size 0.05–38 mm, because the sediment particles were bound to polypropylene, creating granules with polymer in the center surrounded by sediment. However, the amount of polypropylene in the feedstock mixture was not enough to bind these granules to form a homogeneous mixture.

The graph of the dependence of the strength of construction samples on the mass fraction of wastewater sediment displayed the highest strength of the samples with the wastewater sediment content of 40–50%. In this case, a uniform distribution of the components of the mixture was observed. The strength of the product was high, because the wastewater sediment used in the experiments (Livoberezhni treatment facilities in Kamyanske, Dnipropetrovsk region) contained large concentrations of compounds of high-strength metals, such as iron and aluminum. Both a decrease and an increase in the share of sediment led to the decrease in the main qualitative characteristic – the strength of the construction product. In the former case, the strength decreased due to the increased amount of polymer and uneven distribution of raw materials with a predominance of the areas consisting exclusively of thermoplastic, in the latter one – there was also an uneven distribution of the components, but with a predominance of the areas with insufficient content of a binder.

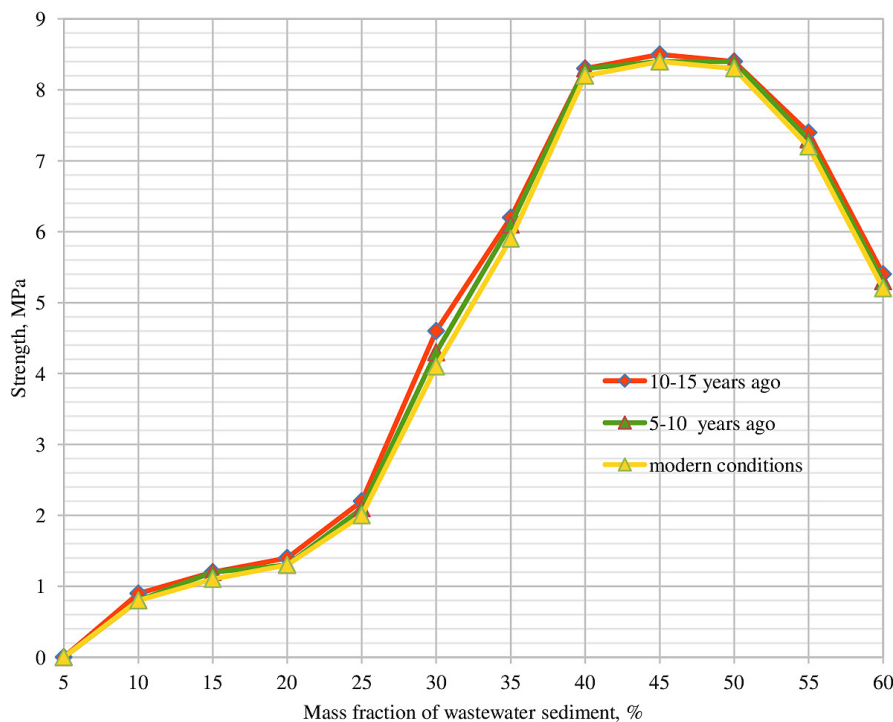


Figure 2. Dependence of the strength of building material samples on the mass fraction of wastewater sediment (in terms of dry matter) in the raw material mixture

Kinetics of polypropylene melting processes in feedstock mixtures

The production technology of building blocks using wastewater sediments and polypropylene waste involved the processes of heating the raw material mixture. This led to the softening of the thermoplastic and gradual transition of the material from solid to liquid.

The kinetics of thermal processes in the polypropylene-wastewater sediment mixture when using the sediments of different years of formation is shown in Figure 3.

Both wastewater sediment and polypropylene were heated simultaneously – the reliable adhesion requires all components of the raw material mixture to be hot. The addition of unheated sediment to the molten polypropylene resulted in the decrease of temperature of the binder, which would promote premature crystallization of the thermoplastic. The use of sediments of different years of formation practically did not change the kinetic curve of temperature dependence of the feedstock mixtures during thermal processes on the time of their heating.

The heating of the raw material mixtures was gradual – all graphs showed a steady increase in temperature over time. The softening of the thermoplastic began at the tenth minute

at 157 °C with the use of sediments formed 10–15 years ago, 156 °C with the use of sediments formed 5–10 years ago, 158 °C with the use of sediments formed at present time. During the softening of the polymer, the temperature of the feedstock mixture kept growing. Residual moisture from the precipitate evaporated.

The melting of the polymer for all cases began at 194 °C. The temperature remained constant until the end of the melting process and the binding of the sediment to the polypropylene. The mixing of the components was mandatory as the polypropylene started melting. If the mixing processes were delayed, the temperature started to grow and the polypropylene evaporated. The heat source was turned off after melting of the polymer in the mixture and its binding to the wastewater sediment in order to exclude the evaporation of polypropylene and the release of toxic volatile compounds into the environment.

The experimental results and development of the process flow diagram of the building blocks production and qualitative characteristics of building blocks samples

On the basis of the conducted experimental research and the obtained values, a process chart of utilization of two types of waste,

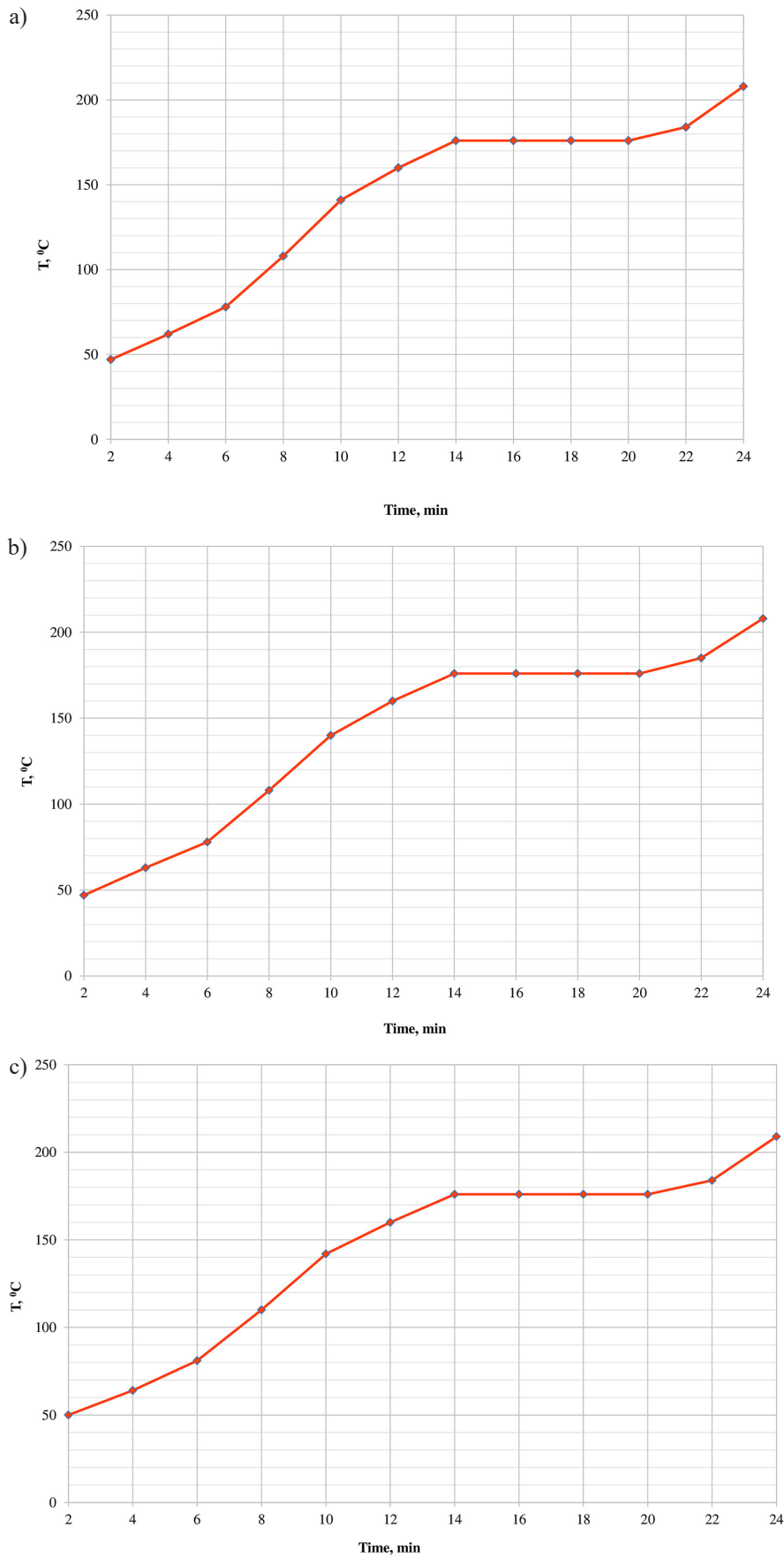


Figure 3. Kinetics of thermal processes in the raw material mixture of polypropylene – wastewater sediment when using: a) wastewater sediment formed 10–15 years ago; b) wastewater sediment formed 5–10 years ago; c) wastewater sediment formed in modern production conditions

generated in almost any city in the world, was developed. The process flow diagram of utilization of wastewater sediments and polypropylene waste is shown in Figure 4.

Waste is preliminary prepared for heat treatment: wastewater sediment is subjected to high-speed mixing 2 with the destruction of microorganisms, the body of which accumulates water, facilitating dehydration in the following stage – in the filter press 4. The sediment is dried in a dryer 10, water is pumped to the head of water treatment cycle at wastewater treatment facilities. That is why it would be reasonable from an economic and practical point of view to locate the facilities for the production of building materials near wastewater treatment plants. It is known that at 136–156 °C the chemical bonds in polypropylene are not destroyed and the only emission in the process of such heating is water vapor, which enters the steam collector 16 and can be used as a heat resource. Polypropylene is crushed to 2 mm fractions in a grinder 8.

Dehydrated and cooled sediment with crushed polypropylene enters the melting-heating unit 12, where a system of constant mixing of the mixture should be provided for effective interaction of the binder (polypropylene) with the filler (wastewater sediment). The resulting homogeneous mixture is fed to the vibropress 14, where building blocks are formed. The materials for the blocks-forming equipment have to be resistant to high temperature.

Qualitative characteristics of the building material samples are compared with regulatory values (Tables 1, 2).

According to the regulatory requirements for construction products, building blocks made of wastewater sediment and polypropylene were not inferior to analogues of traditional raw materials (Tables 1, 2).

Taking into consideration the raw materials utilized to make building materials, the latter are recommended to be used in the manufacturing of construction materials for the application

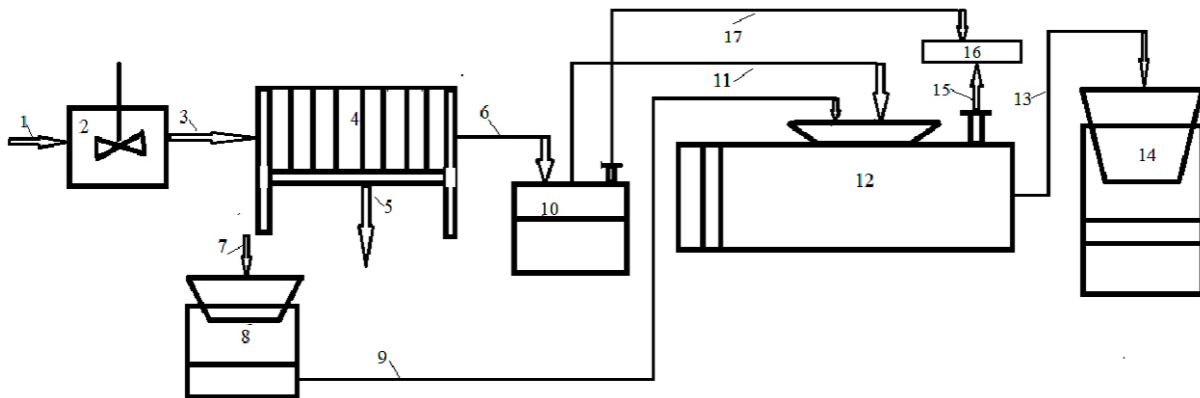


Figure 4. Schematic technological scheme of wastewater sediment and polypropylene waste utilization: 1 – wastewater sediment; 2 – electronic mixer; 3 – wastewater sediment after an electronic mixer; 4 – filter press; 5 – water for purification; 6 – wastewater sediment after filter press; 7 – polypropylene waste; 8 – chopper; 9 – crushed polypropylene; 10 – dryer; 11 – sediment after dehydration; 12 – melting and heating apparatus; 13 – raw material mixture for the formation of blocks; 14 – vibropress; 15, 17 – steam; 16 – steam collector

Table 1. Densities of the samples of building blocks made of wastewater sediment and polypropylene waste, kg/m³

The mass ratio of sediment to polypropylene is 40:60, sediments formed		
10–15 years ago	5–10 years ago	at present time
1191	1192	1189
The mass ratio of sediment to polypropylene is 45:55, sediments formed		
10–15 years ago	5–10 years ago	at present time
1194	1195	1193
The mass ratio of sediment to polypropylene is 50:50, sediments formed		
10–15 years ago	5–10 years ago	at present time
1198	1201	1196

Table 2. Strengths of the samples of building blocks made of wastewater sediment and polypropylene waste, MPa

The mass ratio of sediment to polypropylene is 40:60, sediments formed			DSTU B V.2.7-248:2011
10–15 years ago	5–10 years ago	at present time	2.5–10
8.3	8.3	8.2	
The mass ratio of sediment to polypropylene is 45:55, sediments formed			
10–15 years ago	5–10 years ago	at present time	
8.5	8.4	8.4	
The mass ratio of sediment to polypropylene is 50:50, sediments formed			
10–15 years ago	5–10 years ago	at present time	
8.4	8.4	8.3	

in building of industrial warehouses and storage facilities, non-food storage chambers, garages or other structures that do not provide permanent storage of food or living place for humans or animals.

CONCLUSIONS

The ratios of raw components for the production of building materials were determined experimentally. The building blocks had the highest strength with a mass content of wastewater sediment 40–50% (dry weight) in the raw material mixtures.

In the laboratory, dewatering of wastewater sediment was carried out using high-speed mixing to destroy microorganisms, pressing and thermal treatment. On the basis on the conducted experiments, industrial sludge dewatering equipment was recommended and included in the process flow diagram.

The dependence of the time of complete melting of polypropylene and the interaction of raw materials on the fractionality of the binder was evaluated in order to implement an effective process of heat treatment of raw materials. It was recommended to use polypropylene in a fraction of 2 mm.

The process flow diagram of utilization of polypropylene waste and wastewater sediments for the production of building blocks was developed. It included the technological units of wastewater sediment dewatering and polypropylene grinding. The re-treatment of wastewater after sediment dewatering was recommended. The diagram displayed the output and collection of water vapor formed in the processes of thermal dehydration of sediments in the dryer and heating of raw materials in the melting-heating equipment.

Qualitative characteristics, in particular the density and strength of the building blocks

samples from wastewater sediment and polypropylene waste were determined. It was shown that they met the regulatory values. Recommendations for the application of the construction materials made from waste were offered.

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