Selection of Efficient Product for Sludge Disposal Based on the Pairwise Comparison Method

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Abstract: In the light of increasing global consumption, there has been an increase in the amount of waste generated, but the issues of recycling and recycling remain under-reported. In this situation, it is necessary to actively seek effective approaches to waste management. The work presents a comparative analysis of modern methods of wastewater sludge utilization, considers the use of one of the methods of pair comparisons for choosing the most effective product of waste treatment. More specifically, the algorithm used is considered in the context of the selection of the optimal treatment of sludge from wastewater according to the main criteria, and an example of the application of this method to the problem is given. The study revealed that fuel briquettes, within the accepted criteria, are an economically profitable product.

1 INTRODUCTION

The urgency of the work is due to the aggravation of the environmental situation in the world and the strict requirements imposed on industrial enterprises that use biological treatment of water in their composition. In world practice about 95% of wastewater is treated biologically (Nikolaeva, Iskhakova, 2021). The main, most effective stage of the process of cleaning household sewage is biological cleaning in aerotenics (Stepanov, Strelkov, Shvetsov, Morozova, 2017). More than 2.3 bln m3 of wastewater is annually treated at modern aeration plants, forming more than 11 million m3 of precipitation (Patrakova, 2017). In this case, an excess amount of sludge (active sludge) is formed, which is stored in the deposit areas, with further adverse effects on the environment and human (Burenkov, Grachev, Zabelkin, 2016).

One of the most acute is the issue of efficient disposal of excess sludge industrial and household waste with a humidity of no more than 80%. The modern landfill is a complex system equipped to prevent contact with the environment, which makes it difficult to decompose the waste and it poses a serious environmental threat (Klinkov, A. S., Belyaev, P. S., Odnolko, Sokolov, Makeev, Shashkov, 2015).

In the absence of oxygen, the organic waste is subjected to anaerobic fermentation, resulting in the formation of combustible gas. A very toxic liquid (leachate) is also formed in the interior of the landfill, the entry of which into water bodies or groundwater is extremely undesirable (Nikolaeva, Iskhakova, 2021).

Silt sludge from cleaning city sewage contains pathogenic microflora, parasitic agents, pathogenic viruses, intestinal sticks and Koch sticks, as well as smelling substances. All this threatens the penetration into soil, ground and surface waters of toxic organic compounds and heavy metal compounds, pathogenic microflora and helminth eggs (Burenkov, Grachev, Zabelkin, 2016).

So, obviously, That sludge storage should be recognized as not an effective way of waste management and there is an urgent need to develop new technical methods and means of preparing deposit sites for the effective management of sludge.

The aim of the work is to substantiate the efficiency of the disposal of sludge sewage by processing it into fuel briquettes.

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2 RESEARCH MATERIALS AND METHODS

The urgency of the work is due to the aggravation of the environmental situation in the world and the strict requirements imposed on industrial enterprises that use biological treatment of water in their composition. In world practice about 95% of wastewater is treated biologically (Nikolaeva, Iskhakova, 2021).. The main, most effective stage of the process of cleaning household sewage is biological cleaning in aerotenics (Stepanov, Strelkov, Shvetsov, Morozova, 2017). More than 2.3 bln m3 of wastewater is annually treated at modern aeration plants, forming more than 11 million m3 of precipitation (Patrakova, 2017). In this case, an excess amount of sludge (active sludge) is formed, which is stored in the deposit areas, with further adverse effects on the environment and human (Burenkov, Grachev, Zabelkin, 2016).

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3 RESULTS OF THE RESEARCH

At present, the main method of sludge disposal is its storage and insulation at deposit stands (Burenkov, Grachev, Zabelkin, 2016). In order to increase the efficiency of the use of landfill volumes available for storage, direct incineration is used.

However, direct incineration of waste is also economically unsustainable, as in this case the actual destruction of the material and energy potential possessed by sludge (Lovtsova, Pidenko, 2023). As a result, the state loses huge funds of the so-called «lost economic profit» from non-use of these wastes and spends money on elimination of consequences of environmental pollution.

Therefore, as part of the study, the term «recycling» was not meant to isolate the sediment from the outside environment or its destruction (for example, by burning), but processing with the production of valuable, marketable products.

In order to ensure the consistency of the approach, a classification of methods of sludge utilization based on its properties and the resulting products (fig. 1) has been developed.

Sludge of municipal wastewater is rich in the basic elements of organic, total nitrogen, phosphorus and potassium, as well as trace elements - S, Cu, Zn, Mn, therefore it can be the raw material for obtaining highly effective, complex organominary fertilizer. And the presence of a large volume of organic substances in the precipitate implies its use as energy raw material .

Thus, it is clear that sewage sludge, if properly treated, is not a hazardous waste but a valuable raw material.

From this diagram (fig. 1), it can be seen that the existing solutions can be divided into two large groups: products to improve the fertile or other properties of the soil (or to create an artificial soil layer where it is needed) and energy carriers.

To ensure the reliability of the choice of the most effective product of disposal, we consider in more detail the methods presented in the classification.

The first direction - by heat treatment (also in combination with pressure and chemical reagents) pre-dried (up to 85-90% humidity) sludge.

Another well-developed approach is sludge treatment using mainly chemical reagents (often flocculants or coagulants), which in some cases are secondary products of other waste treatment.

A third approach is the use of biological effects on sediments (e.g., the use of micro-organisms to treat active silt mixed with waste).

The application of residue recovery techniques with the production of humic substances or organominary compositions could help to solve the problem of transferring sediment from toxic waste to a safe product intended for land reclamation, urban use, road construction and organominary fertilizer production, but the heavy metal salt content in the initial sludge significantly limits their use.

In addition to the production of humic substances, the methods of soil improvement also include backfill materials, which are also called technogrunts. The production process of technogenic fortified (GRP) soils is based on the formation of mechanically resistant structures (also called blocks), with specified strength characteristics.

To ensure the environmental safety of the finished product, hazardous components (heavy metal salts and others) contained in the sludge are bound into stable compounds. This approach also blocks the natural fermentation of the sediment with the release of combustible gas.

The main method for preparing GUTs from sediments is to mix pre-dried sediments with binders such as liquid glass and inorganic acid. The units produced from the mixture shall be rigid after a certain time.

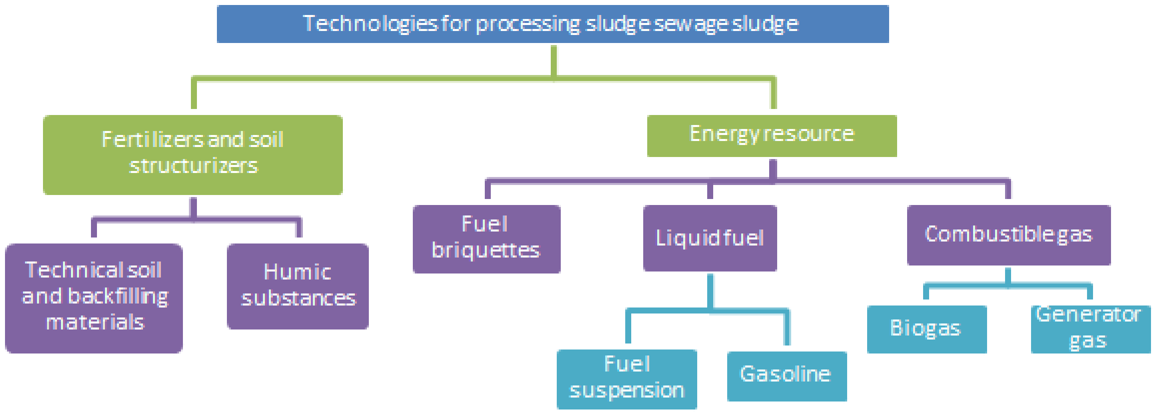

Figure 1: Classification of sludge disposal methods.

The resulting product may be disposed of, deposited, or used in the future not only in the above applications of humic substances, but also for the production of backfill and insulation materials, and for the recovery of solid domestic waste (SDW) landfills.

The disadvantages of these methods include discretionary and limited consumption (only during the period of new construction or landscape recultivation of territories), as well as a lack of study of the processes of aging technogrunt, its change over time, Migration processes of hazardous substances related in the State Customs Inspectorate as a result of long-term environmental impact.

When considering energy carriers, we will identify two main directions in this group of methods. The first involves grinding, completely drying the sludge (up to 10% humidity) and subsequent pelletizing (forming) of fuel briquettes. The second direction is partial drying of the original sediment (up to ~60%-80%), mixing and grinding with some SDW species and subsequent pelletizing (formation) of fuel briquettes.

The advantage of the second approach is that there is less energy loss associated with thermal sludge drying or that there is no need to apply large amounts of flocculants to mechanical sludge drying. The addition of SDW and some energy additives reduces the moisture and calorific content of the fuel.

Finished briquettes may contain pulp-containing materials, powder crumbs, clean wood sawdust, tobacco dust, grain husks, traces of straw, peat, coal waste and others as energy additives.

The disadvantages of the second approach are the inclusion of a waste sorting line and the additional cost of energy additives (coal dust, heating oil and others).

In both cases, the final step is compression in the form of fuel cells (briquettes or granulates) at a specific pressure between 30.0 and 40.0 MPa.

These methods allow to solve the issues of ecology, saving of natural resources, utilization of sludge and to obtain fuel materials that can be used in homes, boiler houses, thermal power plants, railway wagon furnaces.

In addition to the use of sludge for the production of solid fuel, it is necessary to consider its use as a raw material for producing energy carriers in the liquid and gaseous state.

Both fuel sludge and gasoline are produced from sewage sludge. There are generally two ways to obtain fuel suspension from sludge. In the first case, the suspension is made directly from the sludge, without pre-drying, by mixing it with additional energy additives. The resultant mixture is heated to 90°C and homogenized in a mixing agent, a rotary pulsation apparatus, a colloid mill or a disintegrator.

The advantage of this approach is the monostage and relative simplicity of the process. The disadvantage is energy consumption and the need for external energy additives to increase the calorific value of the working fuel.

The second approach involves the production of a fuel slurry based on a pre-extracted combustible gas sludge. This process is carried out under low temperature pyrolysis. Because pyrolysis takes place at a low temperature, the risk of toxic heavy metal salts evaporating is eliminated. The main output product is a fuel slurry. All other products are either secondary (hot air) or by-products (semi-coke).

The disadvantages of this approach include the multi-stage and complexity of the technological process, which entails an increase in capital and labour costs.

The method for producing gasoline from silt sludge consists of two stages: the first is the production of synthesis gas from silt sludge and natural or associated petroleum gas, and the second is the conversion of the resultant synthesis gas into petrol with octane number 80-92. Experimental plants can process raw materials with a humidity of 80%. Capacity on silt - about 180-200 thousand t/year.

The main advantage of the technology could be the demand for the output product, however, due to the significant amount of antidote and octane-enhancing additives, the resulting product is undesirable for use in modern internal combustion engines (ICE).

The disadvantages of this technology include the high cost of gasoline (almost double the cost of oil), the need to apply anti-detoponic and octane-boosting additives (up to 70% of the base amount of gasoline) and the complexity of the technology.

Thus, this method of disposal is recommended for use in hard-to-reach regions and in the operation of obsolete equipment.

In order to produce biogas, the sludge is placed in a tank isolated from the external environment (completely sealed), then, when exposed to methane-binding bacteria, a biological process begins, at which a combustible gas is formed.

To date, more than 50 different biogas technologies are known. The most common method is anaerobic fermentation in methants.

The advantages of this group of methods include refinement and relative simplicity (the basic principle of operation has long been known).

The drawbacks are the complexity of technical implementation in the conditions of landfills of deposited silt sediments, the need to track the optimal composition of raw material and temperature (these parameters have the most significant impact on the productivity of the line);

The generator gas generation method is universal and can be used for both initial sludge and briquettes. For the gasification of sediments (or briquettes), a straight-line or vortex gas generator is loaded into the hopper. The technology is based on pyrolysis - thermal decomposition under conditions of oxygen deficiency. As a result, the main combustible constituents of the CO and H_2 generator gas are formed.

The use of generator gas in the internal combustion engine (ICE) is similar to the use of natural gas, including the concentration of harmful emissions, which meet the norms of «Euro-5». Table 1 contains experimental tests of the ICE operation on generator gas.

Table 1: Toxic substances contained in the exhaust of internal combustion engines running on generator gas.

Substance	Actual, mg/m^3	Norms «Euro-5», mg/m^3
CO	34-41	50
NOx	64-93	200
SOx	25-32	50
HCl	5-9	25
HF	0,73-0,9	1
Dioxins, dibenzofurans according to DE	0,015-0,02	0,1
dust	7-9	10

Sludge or briquette gasification ash refers to wastes in classes 4 and 5, i.e. is a low-risk waste and potentially can be used as a binder in road construction.

Because it is difficult and expensive to transport gas to the final consumer (road transport is expensive and there are no gas pipelines from the deposit sites), this method of sludge disposal will not be feasible in most cases.

In order to make an informed choice of the most effective method of sludge disposal, it is necessary to consider several competing solutions: there is a problem of their comparison, which is solved by the method of pair comparison (MPC).

The method consists of comparing several sludge recovery products (call them a1a2...an; n is the number of estimated products) in pairs. For each pair, it is necessary to determine which product from this pair is preferable within the criteria considered.

The resulting data (0 and 1) are summarized in a square matrix. The number of rows and columns that equals the number of objects to consider. The elements of the matrix are obtained as follows: at the intersection of the i-th row of the j-ro column of such a matrix, the j-product is 1 if the j-th is preferable to the i-th product and is 0 if, on the contrary, the i-th product is preferable to the j-i. Let's call it a matrix of pair comparisons.

The first step was to collect data on paired comparisons of all products (table 2).

The obtained information is then combined into matrices of paired comparisons (table 3).

According to the results of the first two stages the final matrix is built (table 4).

Table 2: Data on the preference of products within the selected criteria.

	Liquid fuel	Briquettes	Gas	Briquettes	Gasoline	Briquettes
Transportation	0	1	0	1	0	1
Keeping	0	1	0	1	0	1
Sales	0	1	0	1	0	1
Exploitation	0	1	1	0	0	1

	Liquid fuel	Gasoline	Liquid fuel	Gas
Transportation	1	0	1	0
Keeping	1	0	1	0
Sales	1	0	1	0
Exploitation	1	0	0	1

	Gas	Gasoline
Transportation	0	1
Keeping	0	1
Sales	0	1
Exploitation	1	0

Table 3: Matrices of paired comparisons.

Transportation				
	Briquettes	Liquid fuel	Gas	Gasoline
Briquettes	×	0	0	0
Liquid fuel	1	×	0	0
Gas	1	1	×	1
Gasoline	1	1	0	×
Keeping				
	Briquettes	Liquid fuel	Gas	Gasoline
Briquettes	×	0	0	0
Liquid fuel	1	×	0	0
Gas	1	1	×	1
Gasoline	1	1	0	×
Sales				
	Briquettes	Liquid fuel	Gas	Gasoline
Briquettes	×	0	0	0
Liquid fuel	1	×	0	0
Gas	1	1	×	1
Gasoline	1	1	0	×
Exploitation				
	Briquettes	Liquid fuel	Gas	Gasoline
Briquettes	×	0	1	0
Liquid fuel	1	×	1	0
Gas	0	0	×	0

Gasoline	1	1	1	×

Table 4: Summary matrix.

	Briquettes	Liquid fuel	Gas	Gasoline
Transportation	3	2	0	
Keeping	3	2	0	1
Sales	3	2	0	1
Exploitation	2	1	3	0
Total	11	7	3	3

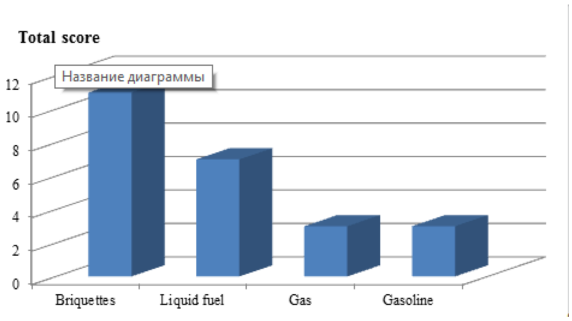

Figure 2: The results of comparing different products.

The results of the comparison are presented in fig. 2, we interpret them for each of the criteria:

- Transportation - the most inconvenient product for transportation is combustible gas, due to the fact that separate gas pipelines are not built to the landfills, and transport by road implies the presence of compressor stations and other special equipment, including for fire safety. Gasoline under this criterion is inferior to fuel suspension because of the high fire risk, which must be compensated with special equipment and a high degree of control of the loading and unloading and transport operations performed. Fuel briquettes do not require special transport trucks, which means, among other things, the possibility of transporting briquettes from the firing range to deliver consumables to the firing range;

- Storage - the most convenient to store are fuel briquettes, they require specially equipped premises for this purpose, for storage of fuel slurry will need sealed storage tanks. Such receptacles will be needed to organize the storage of petrol, only more complex, given the explosion, stored in them product. And the most difficult thing is to equip a gas storage area, gas holders, compressors for denser gas packaging, leak control equipment and more;

- Fuel briquettes are the most attractive potential market - a relatively large number of large consumers (boilers and solid fuel boilers) can be exported. Fuel slurry also has a large potential sales volume among industrial enterprises.

Sludge-based gas consumers are gas users who are not connected to a centralized gas supply line (due to the lack of pipelines at deposit stands, gas is actually delivered either in packaged form or in tankers for small gas filling stations). Sludge-based gasoline contains a large number of antidepressant and octane-enhancing additives, which does not allow its use in modern ICE. As a result, marketing is limited to consumers using obsolete equipment;

- Use - the most convenient to use is combustible gas (there is no need to change the equipment installed by consumers and working at the present time on natural gas). Fuel briquettes are worse than most of their analogues due to their relatively high ash content. During use, -12% of ash belonging to hazard class 4-5 (low-hazard) is formed, which must be disposed of.

The consequences of using fuel suspension and sediment-based gasoline have not been sufficiently studied. There is a possibility that when using these types of fuels, the contamination (or wear) of the nozzles of boilers (suspension) and carburettors of internal combustion engines (gasoline) will increase in comparison with the use of traditional fuels.

Thus, the most effective product, within the accepted criteria, are fuel briquettes. We believe that technical solutions for the disposal of sludge at landfills should be based on this product.

4 CONCLUSIONS

The classification of methods and means of utilization of sludge into fuel and organomineral products developed within the framework of the study is based on the physico-chemical properties of sludge and allows us to systematize the methods known to date in a visual form.

Based on these studies, a system of criteria combined with the method of paired comparisons allowed us to scientifically substantiate the choice of the most effective sludge disposal product - fuel briquettes.

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