DOI: https://doi.org/10.30932/1992-3252-2020-18-38-57

Development of an Energy-Efficient Rotary Inertia Device for Briquetting Household Solid Waste (HSW)



Vitaly V. SAVINKIN **Victoria N. KUZNETSOVA** **Aigul S. ABILMAZHINOVA**

Savinkin, Vitaly V., *North Kazakhstan State University named after M. Kozybayev, Petropavlovsk, Kazakhstan.*
Kuznetsova, Victoria N., *Siberian State Automobile and Highway University, Omsk, Russia.*
Abilmazhinova, Aigul S., *North Kazakhstan State University named after M. Kozybayev, Petropavlovsk, Kazakhstan*.*

ABSTRACT

Today, increasing volumes of household solid waste (HSW) pose a serious problem throughout the world. The solution to this problem is involvement of secondary raw materials and waste in production. The disposal of HSW includes laborious stages of its collection and transportation. Aggregates of the garbage truck work inefficiently, only pressing HSW into a shapeless mass, not subject to sorting and processing. The suggested re-equipment of a special vehicle with aggregates with the combined functions of «loading–forwarding–grinding–pressing–briquetting» will significantly reduce the energy consumption of the transportation process by providing simultaneous processing and briquetting of garbage at the time of its transportation. A scientific and technical problem arises in development of a technique for technical re-equipment of high-performance special equipment with given nominal energy and power characteristics of the machines. It was proposed to solve this problem by combining recuperative systems with reuse of the energy of gravity of the own mass of garbage. Thus, the objective of the work is to develop a rotor-inertial device with reduced energy intensity. Methods of analytical and statistical research of the model range of special equipment with an analysis of its technical characteristics have been applied. To solve the problem of developing a kinematic diagram of a briquetting device, a calculation was performed based on the method of modeling the structure of composite aggregates. Modeling was performed in SolidWorks program in Simulation application package.

The developed kinematic diagrams of units and aggregates for briquetting and pressing garbage operate at rated power characteristics of hydraulic equipment achieved due to distribution of drive power among the most energy-loaded operations.

The article presents the rationale for effectiveness of the developed rotary-inertia device for briquetting HSW. The originality of the design lies in the structural arrangement of the briquetting unit and the grinding mechanism. The use of the principles of inertial moments and gravity of own mass of garbage allowed us to significantly (by 25 %) reduce the energy consumption of the pressing process and formation of the finished briquette. The use of mechanical energy of the conveyor belt tensioners and of the mass of the roll increased with briquetting under its own weight, allowed to reduce the work spent to form compacted HSW from 48000 kJ to 11970 kJ, to reduce the volume of the pressed roll, to increase the utilization rate of load carrying capacity, to reduce the energy intensity of the process.

Keywords: *household solid waste, municipal solid waste, HSW disposal, briquetting, rotary device, transportation energy efficiency.*

*Information about the authors:
Savinkin, Vitaly V. – D.Sc. (Eng), Associate Professor, Head of the Department of Transport Construction and Mechanical Engineering of North Kazakhstan State University named after M. Kozybayev, Petropavlovsk, Kazakhstan, cavinkin7@mail.ru.
Kuznetsova, Victoria N. – D.Sc. (Eng), Professor, Dean of the Department of Oil and Gas and Construction Engineering of Siberian State Automobile and Highway University, Omsk, Russia, dissovetsibadi@bk.ru.
Abilmazhinova, Aigul S. – master in engineering, Senior Lecturer at the Department of Transport Construction and Mechanical Engineering of North Kazakhstan State University named after Kozybayev, Petropavlovsk, Kazakhstan, aika_89__89@mail.ru.

Article received 16.01.2020, accepted 28.02.2020.

For the original Russian text of the article please see p. 38.

The rational use of the resource potential of the economies of developed and developing countries (Russia, Kazakhstan, Belgium, Great Britain, Germany, China, Japan, etc.) based on reduction of material consumption for goods manufacturing, careful consumption of raw materials, fuel, energy, and involvement of production waste and secondary resources in the economy turnover is becoming one of the urgent problems under modern conditions [1]. The rapid development of scientific and technological progress over the past century has brought many benefits to society that have contributed to raising the level and comfort of life, improving the well-being of people.

There are annual norms for accumulation of household (or municipal) solid waste (HSW) per person, in Russia it is approximately 225–250 kg per year. For comparison, in developed European countries, such as Belgium, Great Britain, Germany, Denmark, Italy, the Netherlands, Sweden, Switzerland, and Japan, this figure reached 340–440 kg already in 1995–1996; in Austria and Finland this figure is higher than 620 kg, and in the USA it has long exceeded 720 kg per person per year [1, p. 91; 4, p. 134].

For industrialized countries, increasing volumes (up to 200 million m^3) of HSW pose a serious problem [6, pp. 188–189]. Based on this, the mass of HSW accumulated, even in selected cities [4–6], not to mention the country as a whole, reaches gigantic quantities, therefore, disposal and neutralization of waste is a serious practical problem.

The involvement of secondary raw materials and waste in production also provides a significant environmental and social effect: the damage from environmental pollution by various types of waste is reduced, land occupied by dumps is freed up, and there is the possibility of creating additional jobs. In this regard, there is a need to study the problems of environmental, technical and economic efficiency of use and processing of household solid waste in modern conditions. The main technological difficulties are associated with high energy intensity of waste processing and its harmful effects on the environment, with ensuring necessary purity of the final products [6–8].

Therefore, *the objective* of the study is to increase productivity of garbage complexes by synchronizing basic operations and developing an energy-efficient rotor-inertia device for briquetting household solid waste.

Scientific sources [9; 10] comprise research and promising technological developments of A. A. Butko, V. M. Lebedev, B. I. Levin, M. S. Sherstobitov, implemented from the standpoint of solving individual issues of this multifaceted problem. However, the characteristics of the qualitative and quantitative composition of HSW, technological equipment, specific regional factors, in particular, the climatic and socio-economic situation, which excludes their direct replication, are not fully taken into account.

Technical solutions for waste management form a significant part of costs. When planning a waste management system, two main issues need to be considered:

1. What methods of processing or landfill will be used?

2. What is the population density and dominant types of houses (multi-storey buildings or private houses)?

The answers to these questions will determine the technological solutions for waste collection, types of containers and machines, transport logistics, etc.

To ensure appropriate sanitary conditions, as well as collection, transportation and processing of waste as secondary resources, household waste is regularly collected from sites of its generation.

The household waste collection system must meet several basic conditions [11; 12]:

• should ensure in a certain administrative territory respect of goals and objectives set at the state and regional levels, environmental and health requirements, as well as other local norms and rules related to the waste management system;

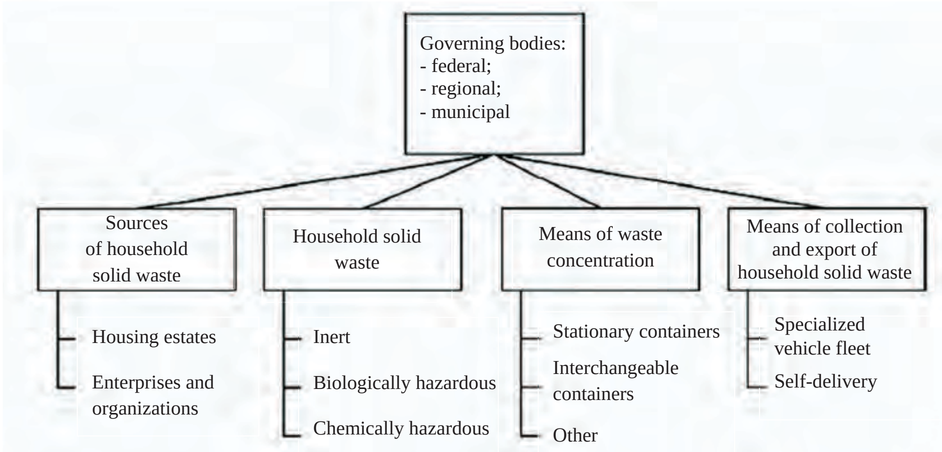
• should guarantee compliance with advanced service requirements at the lowest cost;

• should ensure close cooperation between the state, local government and the private sector to ensure achievement of the set goals;

• should be quite flexible to change and able to meet the requirements of further periods of use;

• should contribute to reduction of waste and to its use as of a recycled resource.

There are several types of waste collection [11; 12]. However, two main ones dominate: the so-called «bring and lay» (stationary container



Pic. 1. Range of collection systems [13].

Pic. 2. EMBED PBrush sorted waste transporting vehicles [14].

Pic. 3. Multisectional transport for waste transportation [14].

systems) and «leave at the edge of the sidewalk» (collection of packed waste according to the schedule at a certain time). These systems are distinguished by density of the collection sites, their location with respect to the user and the degree of transport use (Pic. 1).

Depending on the type and volume of collected and sorted waste, various types of containers and transportation machines are used.

For direct collection of waste and its transportation over short distances, densely

Pic. 4. Vehicle for collection of waste of medium capacity with rear loading [14].

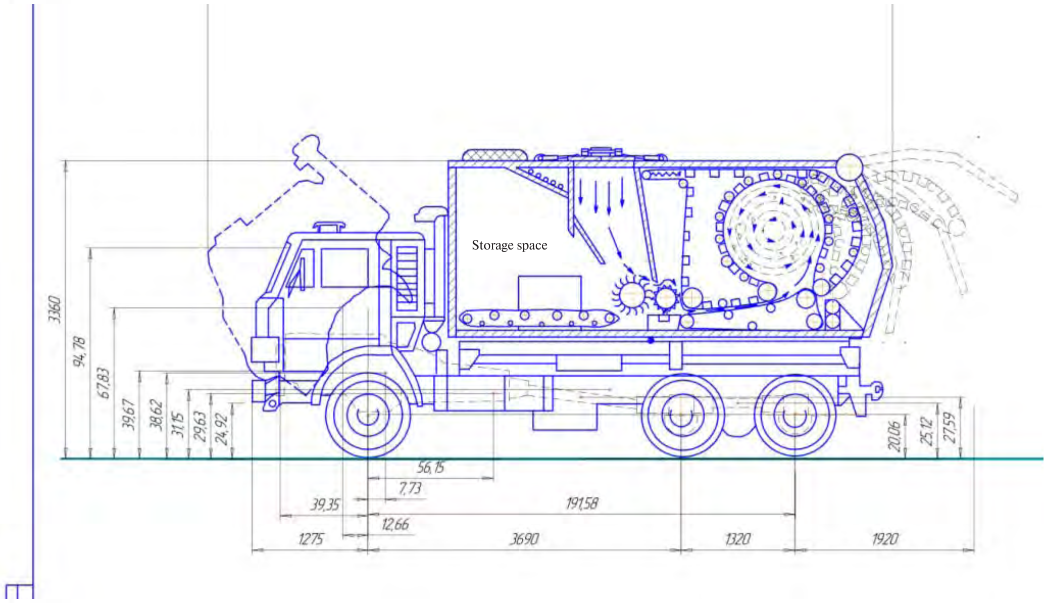
Pic. 5. Garbage truck model MKM-2 BK [14].

Pic. 6. Garbage truck MKM-35 BK [14].

Table 1

Analysis of the technical characteristics of the developed device

Name	Advantages	Disadvantages
1. The developed rotary-inertial device for briquetting household waste before disposal at the landfill	Allows for the initial processing of HSW, i.e. grinding and pressing	Recycling unsorted waste can damage the device
	The mass of special equipment for the garbage truck is reduced due to removal of the pushing (pressing) plate and disintegrator	It is necessary to make a complete re-equipment of the body
2. Variant round baler, model 385-360	Allows collecting hay with formation of rolls of densely compressed hay	Not suitable for processing other materials
3. Rollant baler, model 355	Allows compaction and wrapping of crops	High labor input in maintenance and large metal consumption



Pic. 7. General view of a briquetting rotary inertial device based on the chassis of KamAZ KO-415 [authors' model].

populated areas use medium-capacity garbage trucks with an optimal volume of 15–20 m³ and a compression ratio of 1:3 (Pic. 4). In turn, sparsely populated rural areas use more economical small cars with a volume of 7,5–10 m³.

The choice of a garbage truck depends on the type of waste and collection conditions. Garbage machines are distinguished by the type of chassis, design, as well as by a lift and a pressing device. Garbage machines (Pic. 5) mainly consist of two parts: a tractor (driver's cab and chassis), as well as a compactor and a waste collector, the size of which for different types of garbage machines varies from 5 m³ to 23 m³.

Specifications example 1: base chassis – ZiL-433362; body capacity – 9,5 m³; the mass of special equipment – 2,4 tons; mass of exported cargo – 4,350 t; the coefficient of compaction of garbage – 2–3; manipulator loading capacity – 500 kg; pressure in the hydraulic system – 18 MPa; dimensions – 7200 x 2422 x 3300 mm; model – ZiL-508.10.

Specifications example 2: type of base chassis – MAZ-5337; body capacity – 18,0 m³; the mass of special equipment – 3,7 tons; manipulator loading capacity – 0,7 t; the mass of exported garbage – 7,6 tons; pressure in the hydraulic system – 18,0 MPa; the coefficient of compaction of garbage is 2–3.

The density of waste and the degree of compaction determine the size and type of garbage machines. To reduce transport costs, the waste collection technique should be equipped with a pressing device. Containers, garbage trucks and other infrastructure that is designed for areas with a low degree of waste density may not be suitable for heavier waste. The availability of waste collection sites also affects the choice of garbage machines. Thus, HSW collection and transportation is an important stage of its disposal.

Pic. 8. Rubber-fabric belts with crossbars [17].

The energy and material costs associated with transportation of garbage are unreasonably high. The existing special equipment for transportation of solid waste spends about 65 % of the energy (from the power plant and hydraulic drive) on moving its own mass [13]. In order to efficiently transport garbage, it is necessary to solve the technical problem of the systemic use of power units of special equipment in the process of its movement from the container to the landfill. A justified choice of the structural and technological characteristics of the working equipment of the garbage truck, characterizing assessment of the device's operating efficiency and identification of design flaws, is implemented by the method of comparative analysis of existing patents.

To solve this problem, a patent search of existing mechanisms for processing raw materials and their briquetting at the stage of collection and transportation was carried out. A device for briquetting organic household waste, including a chamber and a hydraulic press with a pressing plate, the hydraulic cylinder of the press is installed vertically in the lower part of the device under the pressing plate (RU67507 U1, IPC6 C25C122, published on October 27, 2007) [15]. A known press for briquetting feed contains a hopper, a housing with an unloading window and a rotor with blades mounted on its surface, placed in the housing with formation of an annular cavity between them (RU2347679 C1, IPC B30B11/14, published on March 27, 2009) [16; 17]. The disadvantage of the above similar devices is the inability to use them for briquetting solid household waste, the complexity and high metal consumption of their design. The presence of a press plate significantly reduces the coefficient of utilization of capacity.

The study of key factors affecting performance of the machine and energy intensity of the processes revealed the shortcomings in the claims of patent RU67507 «Device for briquetting solid household waste» (published on October 27, 2007). The development of a rotor-inertial device for solid waste briquetting is based on a combination of a complex of aggregates for crushing and pressing garbage. The cutting and grinding device is based on a functional prototype used in agriculture which is VARIANT 385-360 round baler. The device is designed to collect hay from rolls with formation of bales of pressed hay.

The general view of the rotary inertial device developed with Simulation application of SolidWorks software is shown in Pic. 7. When developing a structural briquetting system, the tasks of functionality of special equipment and its equipment were taken into account. The optimal limits for varying the technical characteristics of the device are determined by the method of force calculation in the study of forces and moments created by the tensioner, feed rotor and pressing belt.

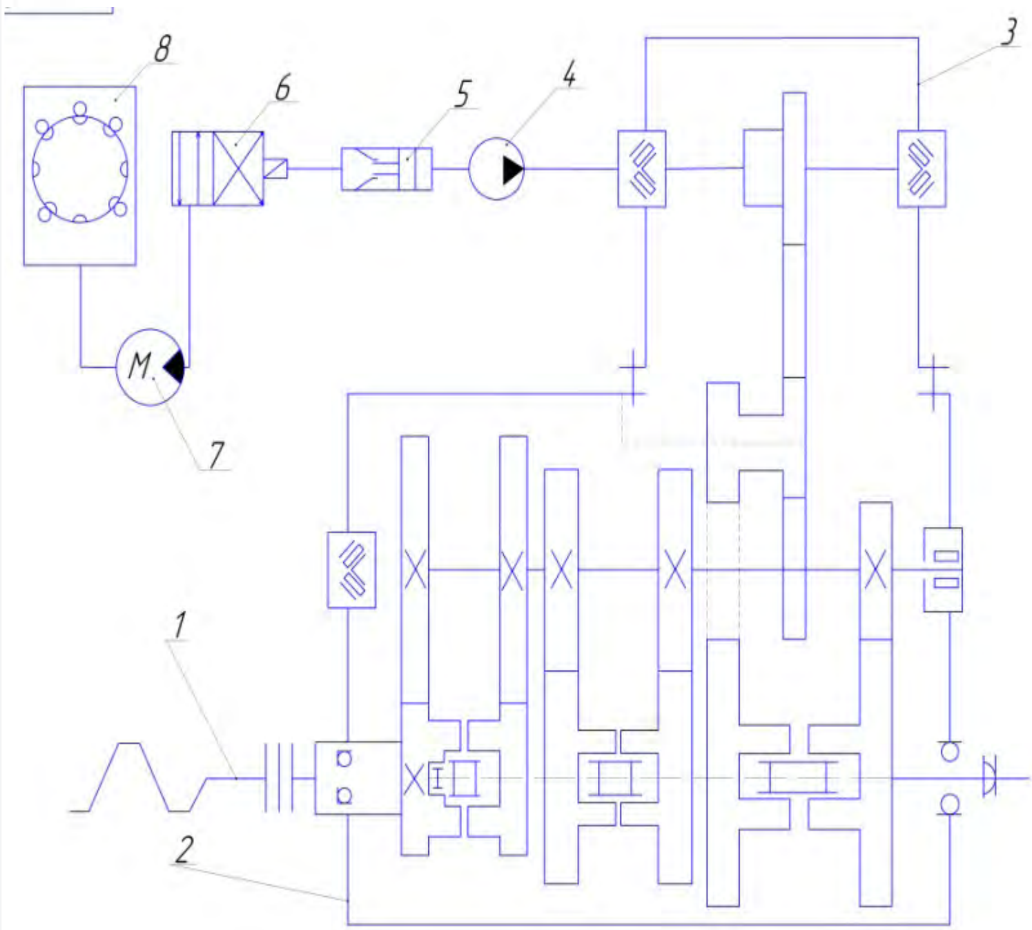
The developed rotor-inertial device relates to devices intended for collection, grinding and pressing of HSW. The press system with fabric-reinforced belts (Pic. 8) and cross bars provides higher pressing density and throughput, a smoother stroke, reduced wear and maintenance costs.

The combination of rubber-fabric belts and crossbars is ideal for the highest pressing density [18]. Thanks to high tension of the belts, reliable dynamic transmission of the drive force is ensured. A high degree of permissible loads is provided by layers of rubber and fabric: first, they are woven into a continuous belt without

Pic. 9. Cutting rotor of the briquetting device [17].

connecting elements, and then they are vulcanized. The resulted structure consists of high-strength fabric layers of polyester fiber and polyamide with rubber layers welded on both sides. The double-sided profiling of the belts makes them extremely flexible and durable, guaranteeing a very long service life. This technology provides the ability to withstand high loads anywhere.

The rotor-inertial device consists of a pressing drum, a lower conveyor, a working loop, an upper tension roller with a single loop and a sensor for turning on the knitting device, a rotor with four rows of teeth made of eight-millimeter boron-containing steel for optimal capture of HSW, a cutting rotor designed for high loads, with 30 knives made of double hardened steel and double-sided knife protection.



Pic. 10. The kinematic scheme of the briquetting device:
1 – engine, 2 – gearbox, 3 – power take-off, 4 – pump 310.256.04U1, 5 – oil filter, 6 – valve, 7 – hydraulic motor, 8 – rotary inertial device [authors' scheme].

The cutting and feed rotor with a diameter of 550 mm has a particularly high «absorption capacity» (Pic. 9). The V-shaped teeth smoothly stretch HSW through the knives. Cutting with a pull reduces energy consumption and improves smoothness. The wave-like shape of the knife blade ensures sharpness of the knife for a long period of time. The double teeth of the rotor continuously pull the loaded garbage through a series of cutting knives. Due to the insignificant distance between the knives and double teeth, material deviation is excluded. Also, the rotor-inertial device consists of a knitting device, a hydraulic motor, a guiding funnel and additional shafts, which create an additional pressing effect.

After development of the individual elements of the device, it is important to develop of the kinematic scheme of this complex, which takes into account the power and force characteristics of drive units. The rotary inertial device consists of a hydraulic motor that drives a continuous slat conveyor with rubberized belts that rotates and forms a briquetted roll of a stable shape. Household solid waste is loaded into the body using the manipulator through the hatch (the control panel of the working bodies is located in the right side of the car), then the gripping rotor brings the HSW to the cutting rotor with knives.

When the hydraulic motor (7) is turned on, the gripping and cutting rotors begin to rotate, feeding the crushed garbage to the lower conveyor (8). On the bottom conveyor, HSW is pre-pressed with a pressing drum and fed into the working loop along the conveyor belt. The working loop is made of fabric-reinforced belts with crossbars. This material provides higher compaction density and throughput. After grinding, HSW is transferred to the gap between the pressing drum and the lower conveyor. Here, HSW is pressed, enters the working loop, where it is twisted into a roll and finally pressed due to the twisting effect. When the roll reaches a diameter of about 1,4 meters, and the working loop increases so that the idle loop becomes minimal, its sensor activates the knitting machine. The knitting machine will bind the roll with the selected binding material (twine, film, net). Upon delivery of the compressed roll to the landfill, the driver, using the control panel, will lift the body, open the tailgate and the finished roll will fall to the ground. Then it is necessary to lower the body, close the tailgate, then the working loop returns to its original position and the pressing process can be repeated [18].

To assess the effectiveness of the proposed measures, we will calculate the operational and technical indicators. The mass of HSW transported on KO-440-7 garbage truck of standard design in the form of unsorted garbage is two tons. The actual mass of the total volume of transported garbage in the classic version of KO-440-7 is 1,38 tons. The mass of the roll compressed by the device under development is 1,87 tons.

The mass of compressed HSW is determined by the formula [18]:

$$m = V \cdot q_{comp}, \qquad (1)$$

where V is volume of compressed HSW (for standard equipment it is 16 m^3 [18, p. 26]);

q_{comp}^{stand} – HSW compaction coefficient on standard equipment is 0,136 t/m^3 [18, p. 27];

q_{comp}^{devel} – HSW compaction coefficient on the developed device is 0,25 t/m^3 [18, p. 27].

The volume of the roll pressed by the equipment under development is equal to:

$$V = \pi \cdot R^2 \cdot H, \qquad (2)$$

where R is radius of the compacted roll of HSW;

H – height of the roll.

Due to installation of new equipment, the mass of HSW transported increases by 490 kg.

The initial data for selection of the hydraulic motor is the load moment M_s and the limits of the change in frequency of rotation of the shaft of the hydraulic motor. Depending on the set parameters and specification data, the type of hydraulic motor is selected. Moreover, it is necessary that the moment M_h developed by the hydraulic motor is by about 5–10 % more than the load moment, and that the rotational speed of the hydraulic motor shaft provides the specified values. After choosing the size of the hydraulic motor by the maximum rotation speed criterion, it is possible to calculate the flow rate of the working fluid Q_h consumed by the hydraulic motor, according to the dependence [20]:

$$Q_h = q_h \cdot \frac{n_{hmax}}{\eta_{0h}}, \qquad (3)$$

where q_h – working volume of the hydraulic motor, m^3;

$n_{h\,max}$ – maximum speed of the hydraulic motor, min;

η_{0h} – efficiency of the hydraulic motor.

Table 2

Comparative development effectiveness indicators

Parameter name	Standard option		Developed option		Calculation formula
Mass of pressed HSW, t	m_{equip}^{stand}	2,176	m_{comp}^{devel}	3,077	$m = V \cdot q_{comp}$
Volume of pressed roll, m^3	V_{stand}	16	V_{devel}	12,31	$V = \pi \cdot R^2 \cdot H$
Work spent for formation of pressed HSW, kJ	A_{stand}	48000	A_{devel}	11970	$A = F \cdot b$
Service time for one container site with five containers, min	$t_{maneuver}$	3–4	– // –	3–4	Σt_i
	$t_{loading}$	10–12	– // –	15–18	

The pressure drop in the hydraulic motor at a load moment M_s is determined by the formula:

$$\Delta p_h = \frac{2 \cdot \pi \cdot M_s \cdot \eta_{0h}}{q_h \cdot \eta_{total}}. \qquad (4)$$

The pressure in front of the hydraulic motor can be represented as the sum of the differential pressure on the hydraulic motor and the pressure loss in the drain hydraulic line:

$$p_h = \Delta p_h + \Delta p_s. \qquad (5)$$

Pressure losses in the discharge hydraulic line Δp_s usually do not exceed 0,2–0,3 MPa.

Based on the obtained values of Q_h and p_h, we choose a hydraulic motor. The choice of the hydraulic motor for the developed rotary inertia device was carried out taking into account the initial data: the load moment on the shaft of the hydraulic motor M_s is 8000 N • m; the rotation frequency varies within n_h = 10–80 min^{-1}.

From the Table 2 [18] we select a MP-6,3/10 type radial-piston hydraulic motor with a rated developed moment M_h = 9520 N • m, with a pressure drop Δp_h = 10 MPa, with a working volume q_h = 6300 cm^3/rot and η_{0h} = 0,93.

The flow rate of the working fluid consumed by the hydraulic motor will be $Q_h \approx 9{,}02 \cdot 10^{-3}$ m^3/s, the pressure drop Δp_h at M_s = 8000 N • m will be 8,35 MPa, taking into account the discharge pressure Δp_s = 0,2 MPa, the pressure in front of the hydraulic motor p_h = 8,55 MPa.

Thus, the flow rate of the hydraulic motor is $9{,}02 \cdot 10^{-3}$ m^3/s and the pressure in front of the hydraulic motor is p_h = 8,55 MPa.

As can be seen from the calculations, for operation of the hydraulic motor and the entire device, a pressure of 8,55 MPa is required, and the pressure necessary for operation of the pressing plate should be at least 12 MPa [19]. Therefore, when installing the developed device on a garbage truck, the pressure in the hydraulic system can be reduced by 1,5 times and the load on the working bodies of special equipment can be significantly reduced.

The work spent for formation of pressed HSW is equal to:

$$A_i = F \cdot b, \qquad (6)$$

where F – force necessary for pressing, F = P;

b – length of the pressed HSW.

The work spent on formation of the roll with the designed equipment is four times less, therefore, wear of the pressing and hydraulic equipment is significantly reduced.

The total service time for one container site with five containers when working with standard equipment is 18 minutes:

Before introduction:

- time spent on maneuver $t_{maneuver}$ = 3–4 min;
- time spent on loading $t_{loading}$ = 12–14 min.

After introduction of the briquetting device:

- time spent on maneuver $t_{maneuver}$ = 3–4 min;
- time spent on loading, is reduced by 5 minutes, and so is equal to $t_{loading}$ = 9 min.

Thus, the total service time for one container site with five containers when working with the developed rotary-inertial device is decreased to 13 minutes.

Thus, by analyzing the results of the initial calculation and comparing the operational and technological indicators of the considered and proposed model of transport equipment, we can indirectly evaluate the effectiveness of the proposed measures. For example, in the classical layout scheme (Pic. 6) of the pressing mechanism in MKM-35 BK, the unit compresses the waste volume V_{stand} = 16 m^3 to the pressing mass m_{equip}^{stand} = 2,176 t. In this case, the technical capabilities of MKM-35 BK are limited. Low values of pressing do not allow to compress the volume of garbage to maximum values, providing 100 % use of the load capacity of special equipment. As a result, with the volume of the garbage truck fully filled, its carrying capacity was used only by 70 %. Applying the proposed scheme of rotary inertial pressing, it was possible to reduce the volume of the pressed roll from 16 to 12,3 m^3. This approach made it possible to form more dense garbage briquettes, increasing the pressing mass m_{comp}^{devel} from 2 to 3 tons and increasing the load utilization coefficient γ_h from 0,69 to 0,93. The load utilization coefficient γ_h is defined as the ratio of the nominal load capacity 2 t to the value of 1,87 obtained after modernization of the structure. That indicates an increase in productivity of one machine by 26,3 %.

The originality of the design lies in the structural arrangement of the briquetting unit and the grinding mechanism. The use of the principles of inertial moments of M_i and gravity of own mass of garbage made it possible to significantly (by 25 %) reduce the energy intensity of the process. So application of the principle of using the mechanical energy of the conveyor belt tensioners and the mass of the bale that increases when briquetting under its own weight allowed us to reduce the work required to form pressed HSW from A_{stand} = 48000 kJ to A_{devel} = 11970 kJ.

REFERENCES

1. Mubarakshina, F. D., Guseva, A. A. Current problems and technologies for garbage processing in Russia and abroad [*Sovremennie problemy i tekhnologii pererabotki musora v Rossii i za rubezhom*]. *Izvestia KGASU*, Iss. 4 (18), 2011, pp. 91–99.

2. Characterization of Municipal Solid Waste in the United States: 1998 Update. U.S. Environmental Protection Agency, EPA 530-R-99–021, July 1999.

3. The Role of Recycling in Integrated Solid Waste Management to the Year 2000. Keep America Beautiful, Inc. 1994.72. «Trends and Forecasts: Retail Sales», U.S. Industrial Outlook 1994, U.S. Department of Commerce.

4. Pashali, A. M., Abdrakhmanova, A. Z. A comparative analysis of Russian and foreign experience in disposal of household solid waste and development of means to improve environmental culture [*Sravnitelniy analiz rossiiskogo i zarubezhnogo opyta utilizatsii tverdykh bytovykh otkhodov i razrabotka sredstv povysheniya ekologicheskoi kultury*]. *Yuniy ucheniy*, 2019, Iss. 8, pp. 131–135. [Electronic resource]: https://moluch.ru/young/archive/28/1751/. Last accessed 02.02.2020.

5. Pushkareva, A. S. Effective garbage recycling methods: Sweden [*Effektivnie metody pererabotki musora*]. *Molodoi ucheniy*, 2019, Iss. 2, pp. 77–78.

6. Pavlenkov, M. N., Voronin, P. M. Organizational and economic problems and directions of waste disposal [*Organizatsionno-ekonomichenie problemy i napravleniya utilizatsii otkhodov*]. *Bulletin of Nizhny Novgorod University n.a. N.I. Lobachevsky*, 2013, Iss. 3 (3), pp. 188–192.

7. Mbuligwe, S. E. Institutional solid waste management practices in developing countries: A case study of three academic institutions in Tanzania, Resources, Conservation and Recycling, 2002, Vol. 35, No. 3, pp. 131–146.

8. Slack, R. J., Gronow, J. R., Hall, D. H., Voulvoulis, N. Household hazardous waste disposal to landfill: using LandSim to model leachate migration. *Environmental Pollution*, 2007, Vol. 146, No. 2, pp. 501–509.

9. Sherstobitov, M. S., Lebedev, V. M. Methods of disposal of household solid waste [*Sposoby utilizatsii tverdykh bytovykh otkhodov*]. *Izvestiya Transsiba*, 2011, Iss. 3 (7), pp. 79–84.

10. Levin, B. I., Butko, A. A. The use of waste as fuel through environmentally friendly neutralization with energy production (in relation to the urban economy of Moscow) [*Ispolzovanie otkhodov v kachestve topliva putem ekologicheski chistogo obezvrezhivaniya s vyrabotkoi energii (primenitelno k gorodskomu khozyaistvu Moskvy)*]. Moscow, Prima-Press, 2005, 128 p.

11. Malygin, A. S. Development of an integrated HSW management system in a residential environment [*Razrabotka kompleksnoi sistemy upravleniya TBO v zhiloi srede*]. *Vestnik AltGTU im. I. I. Polzunova*, 2010, Iss. 1–2, pp. 140–145.

12. Nikogosov, Kh., Bochkova, M., Maltseva, C. Separate collection of household solid waste [*Razdelniy sbor tverdykh bytovykh otkhodov*]. *Kommunalshchik*, 2010, Iss. 11, pp. 20–21.

13. Manaev, K. I., Melnikov, A. N. Optimization of the automobile and container fleet during collection and removal of household solid waste [*Optimizatsiya avtomobilnogo i konteinernogo parka pri sbore i vyvoze tverdykh bytovykh otkhodov*]. *Vestnik OGU*, 2014, Iss. 10 (171), pp. 130–134.

14. Garbage trucks of increased productivity with side loading. Center «Kommash» [*Musorovozy povyshennoi proizvoditelnosti s bokovoi zagruzkoi. Tsentr «Kommash»*]. [Electronic resource]: http://www.sweeper.ru/musorovozy_s_bokovoy_zagruzkoj/rarz_enhanced_perform/. Last accessed 02.02.2020.

15. Galkin, G. L., Sluzov, V. F., Pautov, E. K., Nazarov, V. Yu., Ivanov, S. A., Tonkov, S. M. Patent SU No. 1814618 A3 «Briquetting device». Patent holder: State Ivanovo Research and Production Center «Kardateks». Bull. No 17 on 07.05.1993.

16. Starshikh, V. V., Maksimov, E. A. Patent RU No. 2507242 C1 «Method for briquetting animal and bird wastes and a device for its implementation». Patent holder: Federal State Budgetary Educational Institution of Higher Professional Education «Chelyabinsk State Agroengineering Academy». Bull. No 5 on 20.02.2014.

17. Yunchik, A. P. Patent RU No. 2528376 C2 of the Russian Federation «Method for manufacture of briquettes from chopped straw and a device for manufacture of briquettes». Patent holder: A. P. Yunchik. Bull. No 26 on 20.09.2014.

18. Rizaeva, Yu. N., Korchagina, T. V., Paponova, A. I. Search model for effective functioning of the motor transport socio-natural economic system [*Model poiska effektivnogo funktsionirovaniya avtotransportnoi sotsioprirodnoekonomicheskoi sistemy*]. *Mir transporta i tekhnologicheskikh mashin*, 2011, Iss. 2, pp. 25–33.

19. Friction, wear, and lubrication: A Guide. Book 2 [Trenie, iznashivanie i smazka: Spravochnik. Kn. 2]. Ed. by I. V. Kragelsky and V. V. Alisin. Moscow, Mashinostroenie, 1978.

20. OJSC «Arzamas plant of municipal engineering». Garbage truck KO-440-7. Operation manual for special equipment, 2006.