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FEASIBILITY OF USING PRODUCTION WASTE AT A MACHINE-BUILDING ENTERPRISE FOR ENERGY PRODUCTION

The article provides an analysis of the need and prospects for introducing elements of the zero-waste production concept to ensure sustainability of mechanical engineering enterprises and reduce the negative impact on the environment through waste recycling for energy production. The main types of waste in the mechanical engineering industry of Kostanay region enterprises, methods of their disposal and management are studied using the example of JSC Agromashholding KZ. Using the developed algorithm by the method of statistical sequential analysis, an assessment of the possibility of using mechanical engineering waste as secondary raw materials for generating electricity with the installation of its own mini-CHP is carried out. Analytical and experimental studies are carried out using the sequential analysis method, which allows in practice to take into account the capabilities of an engineering organization in handling production waste and reduce the labor intensity of production by several times. The prospects of using sequential analysis in assessing the possibility of using waste to generate energy are confirmed with satisfactory accuracy. An integrated approach to waste management is proposed, taking into account environmental, economic and social factors, which *allows using waste as fuel and reducing energy costs. The obtained results can be used by mechanical engineering enterprises to form an effective abandoned production cycle.*

Key words: combined heat and power plant, waste, electric power, mechanical engineering, secondary energy resources, boiler, steam turbine, turbogenerator

Introduction

The problem of using production waste at enterprises in the mechanical engineering industry is becoming increasingly important in several key areas, each of which plays an important role in modern production and management. Production waste is a valuable resource that can be recycled and reused in its various forms [1, p. 18-23].

The mechanical engineering industry is currently one of the major sources of industrial waste. As of October 1, 2024, there are 32 enterprises operating in the mechanical engineering industry in the Kostanay region, including 29 small and medium-sized production facilities (a branch of «Rostselmash» LLC, Kostanay «Agromekhanichesky Zavod» LLC (production of spare parts for agricultural machinery), «Kostanay Tractor Plant» LLC, «Kompozit Group Kazakhstan» LLC (production of tractors), «Don Mar» LLC (production of trailed shaft reapers)), and 3 large enterprises («SaryarkaAvtoProm» LLC (car production), «AgromashHolding KZ» JSC (production of engine components, assembly of combines and tractors, production of spare parts for agricultural machinery) and «KamLitKZ» LLC (production of components for trucks)), employing more than 3.5 thousand people.

Thus, the problem of using production waste at mechanical engineering enterprises is relevant. It affects economic, environmental, legislative, social and technological aspects. The introduction of innovative waste recycling methods and compliance with environmental standards are key factors for the successful operation of modern mechanical engineering enterprises [1, P.124–136]. The purpose of the study is to analyze and develop a method for an integrated approach to using production waste at mechanical engineering enterprises in Kostanay region by converting waste into energy.

Materials and methods

To study the problem, the method of statistical sequential analysis was used, which involves a sequential selection of factors for studying the problem of mechanical engineering waste, the choice of a method for efficient waste processing and subsequent technical and economic analysis [1, p. 202-218].

The algorithm of the method for the efficient use of mini-CHP involves the following sequential actions:

1 Determining the energy needs of a mechanical engineering enterprise (or site).

2 Selecting an energy source.

3 Designing a thermal mini-power plant.

4 Operation and maintenance of the power plant, integration with the power supply network.

5 Using waste.

6 Feasibility study.

An analysis of the composition of waste was carried out using the example of the mechanical engineering enterprise JSC "Agromashholding KZ" (Fig.1):

1.829 tons of waste are generated in the form of various oils.

0.906 tons of waste are packaging waste, absorbents, wiping cloths, filter materials and protective clothing not otherwise specified.

0.138 tons of waste are generated as a result of the production, processing, distribution and use (pores) of coatings (paints, varnishes and enamels), printing inks, adhesives and sealants.

0.098 tons of waste are generated as a result of dismantling decommissioned vehicles and their maintenance.

127 tons of waste are municipal waste.

3.5 tons of metal waste.

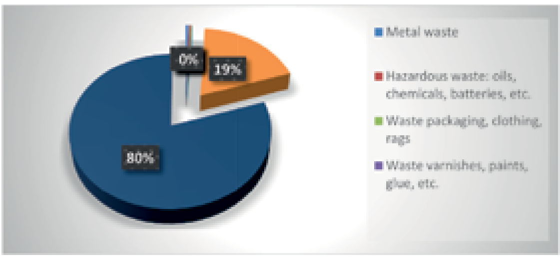

Figure 1 – Annual share of waste produced by JSC «Agromashholding KZ»

The total amount of metal waste is generated during mechanical processing and varies depending on the volume of metals and alloys to be processed. About 25 % of the metal becomes an irretrievable loss due to corrosion or friction. The rest is used in foundry production. It is also necessary to take into account the presence of wood waste that does not undergo the disposal or recycling procedure at the enterprise. In 2023, their volume at JSC «Agromashholding KZ» amounted to 535 tons.

In 2023, hazardous waste in the amount of 6.28 tons, excluding municipal waste, was transferred to a specialized enterprise TOO «Waste Recycling Factory» for the purpose of processing. Municipal waste in the amount of 127 tons was transferred to TOO «TAZALYK-2012» for the purpose of disposal. Figure 2 shows the proportion of waste content depending on the method of their disposal. Thus, it is clear that 95 % of waste is not recycled and is sent to the Kostanay landfill, which entails negative consequences for both the environment and the life and health of people, and 5% of waste is transferred to TOO "Waste Recycling Factory" for recycling.

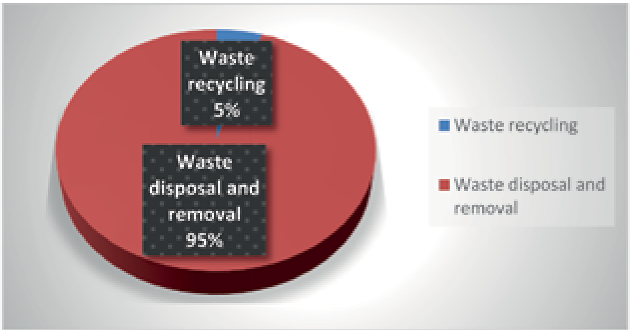

Figure 2 – Distribution of waste of JSC «Agromashholding KZ» by method of disposal

To reduce the negative impact on the environment, it is advisable to increase the share of waste that can be recycled directly at the enterprise, and one of the promising methods for increasing sustainability is the reuse of waste as raw material for energy production [2, P. 242–250].

Modern scientific research and technology seek to create production models that minimize production waste and maximize the use of available resources, improving the environmental and social situation of business and stimulating economic and sustainable development. The main principles of creating waste-free production include the integrated use of raw materials, the development of fundamentally new and improvement of existing technologies, the creation of closed water and gas cycles, cooperation of enterprises and the formation of territorial production complexes [3, P. 151–157; 4, P. 106–108]. Many scientific and technological approaches are aimed at minimizing production waste and increasing the efficiency of natural resource use [4, p. 18–36].

To date, three methods of utilization and thermal disposal of industrial waste have become the most widespread in world practice and in Kazakhstan:

layered combustion of unprepared, initial waste in waste incineration boilers [5, P. 106–108];

chamber or layered combustion of enriched waste, purified from ballast components and having a stable fractional composition in cement kilns or in boiler furnaces [6, P. 12–18] ;pyrolysis of waste, both enriched (pre-treated) and unprepared [7, P. 129–134].

In Kazakhstan, the method of recycling and processing industrial waste using pyrolysis remains little known due to its high cost. However, enterprises specializing in the processing of industrial waste using pyrolysis successfully operate in developed countries such as the United States, Denmark, Japan, Germany and others [8, P. 347]. During this time, the process of obtaining energy and heat by pyrolysis from rubber, plastic and other combustible waste has acquired great importance as an important source of energy resources [9, P. 394–397].

Taking into account all of the above, it is proposed to implement mini-CHP technology, which allows for the disposal of waste and the conversion of combustion energy to generate electricity and heat. In addition, to ensure the environmental safety of the facility, it is necessary to implement a multi-stage system for cleaning flue gas and disposing of unburned waste, since stations operating on gas and coal are required to pay quotas for CO2 emissions, [10, P. 89–92; 11, P. 1–2] while for mini-CHPs on solid household or industrial waste, this is not required.

Results and discussion

To implement the introduction of mini-CHP at mechanical engineering enterprises, an algorithm has been developed using the method of statistical sequential analysis for the creation and use of an in-house thermal power plant for converting waste into energy.

To determine the amount of energy released during the combustion of 127 tons of various household waste at the enterprise, including paper, plastic, cardboard and other materials, average values of the heat of combustion for these materials were used, with the assumption that the actual amount of energy may vary depending on the exact composition of the waste and its degree of moisture. With known average values of the heat of combustion of waste materials, and the proportion of waste from 127 tons: paper – 40 %; textile – 40% and cardboard –20 % and wood 100 %, calculated by the expression:

$$Q = (m_{paper} \cdot q_{paper}) + (m_{\text{Textile}} \cdot q_{\text{Textil}\ cardboard}) + (m_{wood} \cdot q_{wood}) \quad (1)$$

where: Q – amount of energy, MJ,

m– mass of the primary fuel source, kg,

q – heat of combustion of the fuel source, kW·h/t.

Approximately 127 tons of various municipal waste and 535 tons of wood waste, burned with high efficiency, can release approximately 3,395,560 kWh (or (12,228,040 MJ) of energy, which will allow the generation of up to 68,000 kW of electrical energy. The results of the analysis performed are shown in Table 1.

To implement the next stage of the algorithm for studying the efficiency of implementing a mini-CHP using the method of statistical sequential analysis, the operating principle of the power plant was considered and a technological scheme of the installation was developed.

Table 1 – Amount of thermal energy released during pyrolysis of enterprise waste

№	Type of waste	q	m	Q
		kW·h/ton	ton	kW·h/ton
1	Paper	8700	50.8	441960
2	Textile	6400	50.8	325120
3	Cardboard and other household waste	8700	25.4	220980
4	Wood	4500	535	2407500
Total:			662	3395560

The developed structural and technological scheme of the mini-CHP assumes the presence of basic elements and blocks, their functions, principles of operation of the units and interaction with each other [12, P. 356–358]. The technological scheme of the mini-CHP is provided in Fig. 3.

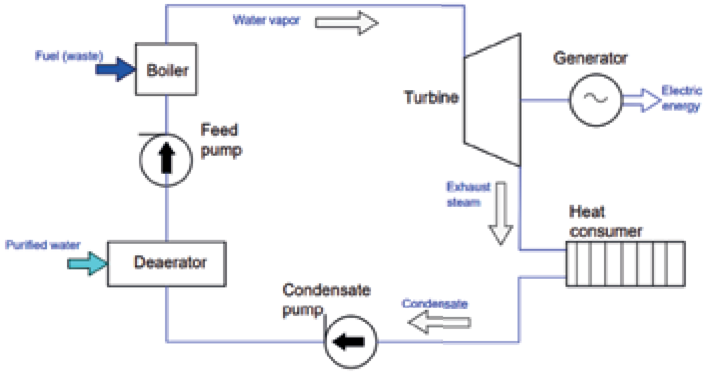

Figure 3 – Structural and technological scheme of a mini-CHP

The main elements of a thermal mini-CHP are:

Boiler unit (boilers): a device where pyrolysis of fuel (waste) occurs to heat water and then convert it into steam.

Turbines: steam obtained from boilers hits turbine blades, which rotate under its influence and sets the generator in motion.

Generators: convert mechanical energy obtained from the rotation of turbines into electrical energy.

Condensers: after leaving the turbine, the temperature of the steam in the condenser unit is reduced, after which it condenses back into a liquid state.

Emitted gas purification system. Allows for the purification of gases emitted during the waste pyrolysis process.

To justify the selected equipment, it is necessary to conduct a number of studies in the future:

Analysis of the thermal balance of the mini-CHP with the determination of the thermal power that will be generated and consumed during operation.

Selection of electrical equipment according to the relevant required characteristics.

Analysis and selection of boiler equipment, including boilers, turbines and other components for steam production.

Research of energy efficiency and environmental friendliness of the elements of the mini-CHP system.

With the known data on the annual volume of waste (solid municipal and wood), which is 662 tons, the amount of waste that can be used only on working days during the year was determined. It was assumed that there are about 260-

261 working days in a year, and calculations were made using the expression (tons / day).

$$Vd = \frac{Ngeneral}{Nwork},$$
$$Vd = \frac{662}{260} \approx 2{,}54 \quad (2)$$

Where: $N_{general}$ – number of working days per year, days

N_{work} – total amount of waste per year, tons

Assuming an annual waste supply of 662 tons, approximately 2.54 tons of waste can be used per day during a working year. The formula (kg/hour) is used to determine the amount of waste that can be used per hour, assuming an 8-hour working day.

$$Vhour = \frac{Vd}{Nwd} \quad (3)$$

$$Vhour = \frac{2{,}54}{8} = 0{,}3175tons/hour = 317{,}5\ kg/hour$$

where: V_{hour} – amount of waste per hour, tons

N_{wd} – Number of hours in a working day, hour

Research shows that for every hour of operation, approximately 317.5 kilograms of waste can be effectively used, which is approximately 1680 kWh (6048 MJ).

Based on the provided data, the proposed boiler model "KE 2.5-14O" for operation on wood and solid waste is capable of burning up to 360 kg of waste per hour with the required volumes of 317.5 kg of waste combustion per hour. Thus, one boiler will allow burning about 2540 kilograms of waste during an eight-hour working day, which is approximately equal to 13439 kW h (48380 MJ) of thermal energy daily. At the same time, the technological characteristics of the coolant are observed: Steam pressure - up to 1.3 MPa, steam temperature - 1940C.

The selection of a turbogenerator unit is carried out according to the calculated capacity of the turbogenerator based on the calculated mass of steam, reliability conditions, efficiency, rotation speed, permissible temperature and steam pressure.

The calculated mass of the released m_{steam} is determined by:

$$m_{steam} = \frac{Qhr}{Lwater}$$
$$m_{steam} = \frac{6048\ MJ}{2,3} = 2,63\ tons/hour \qquad (4)$$

where: Q_{hr} – energy released during 1 hour, MJ
L_{water} – specific heat of water transformation, MJ/kg.

Based on the estimated steam mass, a steam turbogenerator model "DTEC NO.15-1.25" was selected, which consumes up to 2.7 tons of steam per hour, which in turn allows generating about 170 kW of electric power with a voltage of 380 V. This, in turn, will allow producing about 1360 kW of electric power during an eight-hour working day, and will provide uninterruptible power supply to the compressor unit "DEN-160SHM" (consumer) at the enterprise JSC "AgromashholdingKZ". When selecting a steam turbogenerator, the required steam pressure at the inlet was taken into account, equal to 1.25 MPa, the steam pressure at the turbine outlet was 0.05 MPa, and the temperature of this steam was at least 1900C, while the previously proposed boiler "KE 2.5-14O" emits up to 1.3 MPa and 1940C, respectively, which in turn meets our requirements.

The condenser unit of the scheme in Figure 3 allows for the efficient use of steam leaving the steam turbine with subsequent condensation of the exhaust steam back into liquid form. The optimal solution, according to preliminary calculation data, would be the use of a condenser that allows condensation of 5 to 800 liters of steam per minute with subsequent introduction of heat exchangers into this system.

To select a system for cleaning emitted gases, which must be installed in the mini-CHP scheme to reduce the negative impact of industrial processes on the ecosystem, the volume of Msp gross emissions of solid particles in flue gases for solid and liquid fuels is calculated using the formula, tons/year

$$Msp = B \cdot Ar \cdot f \cdot (1-\eta)$$
$$Msp = 662 \cdot 0,6 \cdot 0,005 \cdot (1-0) = 1,986 \qquad (5)$$

where: B – fuel consumption per year, t/year,
A_r – fuel ash content per working mass, %,
η – proportion of solid particles captured in ash collectors,
f – a_{un}/(100-Gun) – ash content coefficient,
a_{ca} – proportion of fuel ash in fly ash,
G_{ca} – content of combustibles in fly ash (%).

The maximum one-time emission of solid particles is determined by the formula:

$$M = \frac{Мут \cdot 1000000}{(t \cdot 3600)}$$
$$M = \frac{1{,}986 \cdot 1000000}{(2080 \cdot 3600)} = 0{,}2652\ grams/sec \quad (6)$$

where: t – operating time of the boiler plant per year, equal to, t =260 · 8 = 2080 hour/year

The gross emission of carbon monoxide and nitrogen oxide for solid, liquid and gaseous fuels was calculated in a similar manner. The obtained values and the comparison result before and after filtration are presented in Fig. 4.

The studies show that the main pollutant in terms of concentration and total emission is carbon monoxide (CO), whose concentration and total emission significantly exceed the indicators of other substances. With the estimated volumes of harmful emissions and combustion of 317,0 kg. the volume of gas released during pyrolysis will be approximately 317,0 m3. As a result, the optimal solution was chosen to use the smoke filter «DGRH-K-3500,0 (U)», which combines several methods of cleaning smoke from pollutants, and allows to reduce the level of pollution by 93-98%. The total volume of emissions will be 2.0298 tons, which is 26.96592 tons less than in the absence of these filters.

The final stage is the analysis of the technical and economic feasibility of the project implementation based on the criteria for detertmining the costs of annual energy consumption, the costs of waste removal and disposal, the payback period and the amount of tax for the negative impact on the environment.

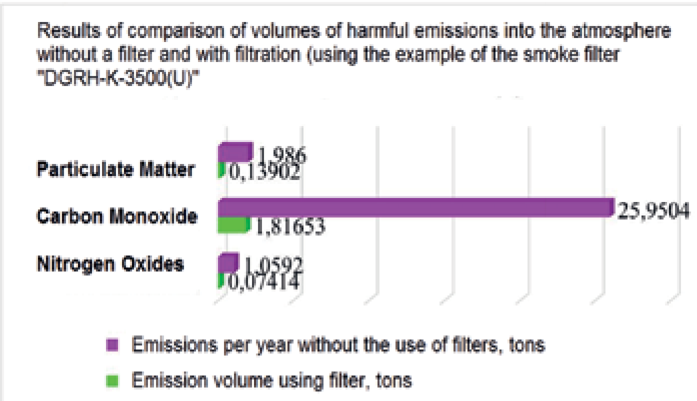

Figure 4 – Comparative analysis of the levels of harmful emissions into the atmosphere using a smoke filter

The assessment of the costs of energy consumption per day of consumers connected to the mini-CHP is formed with an assessment of the characteristics of a consumer with a capacity of 160,0 kW/hour, determined in kW:

$$P_{day} = P_{hr} \cdot T_{wd}$$
$$P_{day} = 160{,}0 \cdot 8 = 1280{,}0 \quad (7)$$

where: P_{day} – power consumption during the working day, kW

P_{hr} – power consumption per hour, kW/hour;

T_{wd} – number of hours per shift, hour

With the estimated output of the mini-CHP of 1360 kW/h, the condition , P_{day}=1280 *k*Wsatisfies the estimated one.

The volume of consumed electricity per year is calculated similarly, which will be 332,800 kW. With the cost of one kilowatt of electricity (in the Kostanay region, the electricity tariff is 33.14 KZT / kW·h), the enterprise annually spends 12,352,471 KZT /year on power supply of the compressor unit, taking into account VAT.

The assessment of the costs of waste removal and disposal by a waste disposal company consists of the analysis of the cost of waste removal per 1m3, which amounted to 2424.612 KZT, and the cost of disposal of the same 1m3 at a landfill, which is 1775.771 KZT, including VAT. When removing 127 tons of various solid municipal waste, their approximate volume is 635 m3. The cost of waste removal for 2023 amounted to 635 2424.612 = 1 539 627,35 KZT. The cost of waste disposal at the landfill for 2023 amounted to 635 1775.,77 = 1 127 613,95 KZT. The total cost of waste removal and disposal at the landfill in 2023 amounted to 2 667 241,3 KZT.

An assessment of the costs of purchasing and installing mini-CHP equipment was carried out, the results of which are shown in Fig. 5.

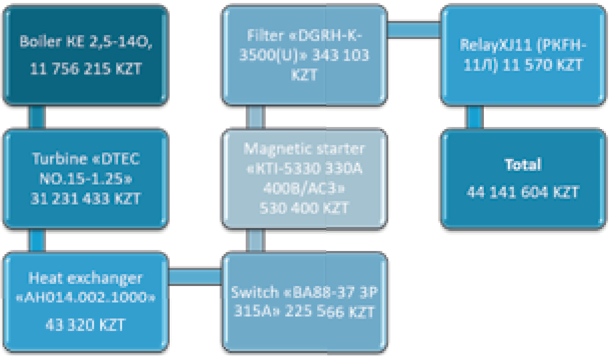

Figure 5 – Estimated cost of equipment and types of work for the installation of a mini-CHP

The payback period of the investment was determined taking into account the annual costs of waste removal and disposal, as well as energy supply for the compressor unit, and as a result, the amount of annual financial costs (net profit PP), compensated by the installation of a mini-CHP, was:

$$PP = 2\ 667\ 241 + \ 12\ 352\ 471 = 15\ 059\ 712\ KZT$$

The cost of purchasing the equipment described earlier will be, or otherwise, the investment costs of IC, amounted to 44 141 607KZT. The estimated payback period of the project was:

$$PBP = \frac{IC}{PP}$$
$$\mathrm{PBP} = \frac{44\ 141\ 607}{15\ 059\ 712} = 2{,}93\ \text{year} \qquad (8)$$

where: PBP – Pay-Back period,

IC – Investment Costs,

PP – Project Profit,

Conclusions

The results of the research demonstrate that the proposed technical solutions are not only environmentally sound, but also have significant financial attractiveness with a payback period of less than 3 years. The generation of electricity by a mini-CHP on waste met the needs of a machine-building plant, using the example of JSC Agromashholding KZ, by 45-50 %, and an energy survey showed that the boiler units «KE 2.5-14O» and «DTEC NO.15-1.25» have a reserve for further efficiency improvement, reduction of carbon monoxide emissions by additional adjustment of the automatic control system of the filtration device. The energy use of waste in boiler units as part of a mini-CHP is a relevant and promising area for both the Kostanay region and the Republic of Kazakhstan.

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ЭНЕРГИЯ ӨНДІРУ ҮШІН МАШИНА ҚҰРАСТЫРУ КӘСІПОРЫНДА ӨНДІРІС ҚАЛДЫҚТАРЫН ПАЙДАЛАНУ МҮМКІНДІГІ

Мақалада машина жасау кәсіпорындарының тұрақтылығын қамтамасыз ету және энергия өндіру мақсатында қалдықтарды қайта өңдеу арқылы қоршаған ортаға теріс әсерді азайту үшін қалдықсыз өндіріс концепциясының элементтерін енгізу қажеттілігі мен перспективаларына талдау жасалған. Қостанай облысындағы кәсіпорындардың машина жасау өнеркәсібіндегі қалдықтардың негізгі түрлері, оларды кәдеге жарату және басқару әдістері «Агромашхолдинг KZ» АҚ мысалында зерттелген. Әзірленген алгоритмді және статистикалық дәйекті талдау әдісін қолдана отырып, жеке шағын ЖЭО орнату арқылы машина жасау қалдықтарын электр энергиясын өндіру үшін қайталама шикізат ретінде пайдалану мүмкіндігіне баға берілді. Аналитикалық және тәжірибелік зерттеулер тізбекті талдау әдісін қолдану арқылы жүргізілді, бұл тәжірибеде өндіріс қалдықтарымен жұмыс істеуде машина жасау ұйымының мүмкіндіктерін есепке алуға және өндірістің еңбек сыйымдылығын бірнеше есе төмендетуге мүмкіндік береді. Қалдықтарды энергия өндіру үшін пайдалану мүмкіндігін бағалауда дәйекті талдауды қолданудың әлеуеті қанағаттанарлық дәлдікпен расталды. Экологиялық, экономикалық және әлеуметтік факторларды ескере отырып, өндіріс қалдықтарын басқарудың кешенді тәсілі ұсынылады, бұл қалдықтарды отын ретінде пайдалануға мүмкіндік береді және энергия шығындарын азайтады. Алынған нәтижелерді машина жасау кәсіпорындары тиімді қалдырылған өндірістік циклды қалыптастыру үшін пайдалана алады.

Кілтті сөздер: жылу электр станциясы, қалдықтар, электр энергиясы, машина жасау, екінші энергия ресурстары, қазандық, бу турбинасы, турбогенератор.

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ЦЕЛЕСООБРАЗНОСТЬ ИСПОЛЬЗОВАНИЯ ОТХОДОВ ПРОИЗВОДСТВА НА МАШИНОСТРОИТЕЛЬНОМ ПРЕДПРИЯТИИ ДЛЯ ПРОИЗВОДСТВА ЭНЕРГИИ

В статье приведен анализ необходимости и перспектив внедрения элементов концепции безотходного производства для обеспечения устойчивости предприятий машиностроения, и снижения негативного воздействия на окружающую среду за счет вторичной переработки отходов с целью получения энергии. Исследованы основные виды отходов в отрасли машиностроении предприятий Костанайской области, способы их утилизации и управления на примере АО «Агромашхолдинг KZ». С использованием разработанного алгоритма методом статистического последовательного анализа, проведена оценка возможности использования отходов машиностроения в качестве вторичного сырья для выработки электроэнергии с установкой собственной мини-ТЭЦ. Проведены аналитические и экспериментальные исследования с помощью метода последовательного анализа, который позволяет на практике учитывать возможности машиностроительной организации в обращении с отходами производства и сокращать трудоемкость выпуска продукции в несколько раз. Перспективность применения последовательного анализа в оценке возможности использования отходов для выработки энергии, подтверждается с удовлетворительной точностью. Предложен комплексный подход *к управлению отходами производства с учетом экологических, экономических и социальных факторов, что позволяет использовать отходы в качестве топлива и снизить затраты на энергоносители. Полученные результаты могут быть использованы предприятиями машиностроения для формирования эффективного закинутого цикла производства.*

Ключевые слова: теплоэлектроцентраль, отходы, электроэнергия, машиностроение, вторичные энергоресурсы, котел, паровая турбина, турбогенератор.

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