CRITERIAL ANALYSIS OF BIOCHAR PRODUCTION EQUIPMENT AND DETERMINATION OF THE OPTIMUM SOLUTION FOR A NEW TYPE OF INSTALLATION

ANALIZA CRITERIALĂ A UNOR ECHIPAMENTE PENTRU PRODUCȚIA DE BIOCHAR ȘI CONCEPEREA UNOR INSTALAȚII INOVATIVE

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Abstract.
The main objective of this study is the analysis of representative technical solutions described in invention patents, as well as the study of existing equipment in this field, for the development of an eco-innovative system for biochar production from plant waste under laboratory conditions (The Generalized Object Method of Technical Creation, Vitalie Belousov). Biochar is produced from biomass by burning it in the absence of oxygen or at low oxygen levels. Once in the soil, it activates its properties, such as carbon sequestration and water retention in the ground. The study utilized a technical creativity method through the criterial analysis of existing technical solutions and the development of a cylindrical matrix, which will determine the discovery of a new constructive-functional version that will be further developed through design and research activities. The research carried out has led to an original, patentable solution, which will be developed by designing and executing a prototype based on a research contract
Key words: biochar, reactor, biomass, plant waste, technical creation.

Rezumat.
Obiectivul principal al acestui studiu este analiza soluțiilor tehnice reprezentative descrise în brevetele de invenție, precum și studiul echipamentelor existente în acest domeniu, pentru dezvoltarea unui sistem eco-inovator de producere a biocharului din deșeuri vegetale în condiții de laborator (The Metoda obiectului generalizat de creație tehnică, Vitalie Belousov). [1] Biocharul este produs din biomasă prin piroliza cesteia în absența oxigenului sau la niveluri scăzute de oxigen. Odată ajuns în sol, își activează proprietățile, cum ar fi captarea

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carbonului și reținerea apei în sol. Studiul a utilizat o metodă de creativitate tehnică prin analiza criterială a soluțiilor tehnice existente și dezvoltarea unei matrice cilindrice, care va determina descoperirea unei noi versiuni constructiv-funcționale care va fi dezvoltată în continuare prin activități de proiectare și cercetare. Cercetările efectuate au condus la o soluție originală, brevetabilă, care va fi dezvoltată prin proiectarea și executarea unui prototip pe baza unui contract de cercetare.

Cuvinte cheie: biochar, reactor, biomasă, deșeuri vegetale, creație tehnică.

INTRODUCTION

Biochar is produced from biomass by burning it in the absence of oxygen or at low oxygen levels. Once in the soil, it activates its properties, such as carbon sequestration and water retention in the soil. This transformation process is known as pyrolysis, and the resulting "biochar" is a solid, coal-like substance. This proposed carbon dioxide removal (CDR) approach can utilize very large amounts of biomass, such as forest or agricultural products and waste, and high pyrolysis temperatures, e.g., up to 900 °C, to produce a carbon-rich residue that can be mixed into the soil, where the carbon is – theoretically – stored and absorbed by plants. Compared to other products, biochar has a value ten times higher in terms of increasing soil fertility. Once in the soil, it activates its properties, such as carbon sequestration and water retention in the soil. Under normal conditions, nitrogen in biomass is lost through decomposition, which is why the subsequent administration of nitrogen is necessary for agricultural crops. This issue is resolved by biochar, which retains nitrogen from biomass like a sponge. Biochar retains nitrogen, nutrients, and even *E. coli* bacteria in the soil, giving it extraordinary qualities [Ion *et al.*, 2021].

At the local or regional level, pyrolysis and gasification units can be operated by larger companies and can process up to 4.000 kg of biomass per hour qualities [Ion *et al.*, 2021]. Small-scale gasification and pyrolysis systems, which can be used on farms or in small industries, are commercially available with biomass inputs ranging from 50 kg/h to 1.000 kg/h. Biochar kilns are low-tech biochar production units with a primary design function of producing biochar, fig.2 [Ushakumary, 2022]. Dr. Brown highlights several specific goals for advanced biochar manufacturing: continuously-fed pyrolyzers to improve energy efficiency and reduce pollution emissions associated with batch kilns, exothermic operation without air infiltration to improve energy efficiency and biochar yields, recovery of by-products to reduce pollution emissions and improve process economics, control of operating conditions to enhance biochar properties and allow modifications to by-product yields, and feedstock flexibility, allowing both woody and grassy biomass (such as crop residues or grasses) to be converted into biochar [Menya, 2019].

The German demonstration model GO-GRASS converts lower-nutrient grass from wetland areas into biochar. By installing a complete processing line, the grass is converted into biochar through pyrolysis or hydrothermal carbonization

Globally, various biochar production equipment exists, which will be presented and analyzed in the following chapter.

Nationally, Professor Erol Murad from the University Politehnica of Bucharest has conducted numerous studies on biochar production equipment. ECOHORNET has designed and developed biochar and heat production equipment from agricultural waste for large production capacities (1-4 tons/hour) [Ion *et al.*, 2021].

MATERIAL AND METHOD

Research on technical creativity methods for biochar production equipment

For the analysis of known equipment, as well as for finding the optimal design solution for a laboratory biochar production device from plant waste, the "Generalized object method of technical creation" will be used (Belous and Boris, 2005).

The following classification criteria are used:

B - by type of equipment:

B1 - fixed equipment for biochar production:

B2 - mobile equipment for biochar production:

?- other solutions unknown at the time of the research.

Elaboration of the generalized object of technical creation (Belous and Boris, 2005).

The generalized object of creation is presented in the form of a cylindrical morphological matrix, visualized in Fig. 5, with each sector representing a solution (each sector represented by a tri-assembly BiCjDk, the total number of solutions being: N=2x3x4=24 solutions, some of which are known, while others are unknown).

Among these, incompatible solutions must be eliminated, while others must be analyzed, as their complete resolution may lead to highly efficient designs.

After eliminating clearly incompatible solutions and highlighting the apparently incompatible ones, the existing solutions need to be identified (Belous and Boris, 2005).

C - by the constructive solution of the equipment:

C1- retort equipment;

C2- horizontal screw conveyor equipment;

C3- inclined screw conveyor equipment;

?- other solutions unknown at the time of the research.

D- by the thermal agent used:

D1- with solid fuel;

D2- with gaseous fuel;

D3- with ignition resistance-electric current;

D4- with liquid fuel

?- other solutions unknown at the time of the research.

The following possible combinations are presented:

- B1C1D1 - Fixed equipment, with retort, using solid fuel;- B1C2D1 - Fixed equipment, with horizontal screw conveyor, using solid fuel; - B1C1D2 - Fixed equipment, with retort, using gaseous fuel; - B1C1D3 - Fixed equipment, with retort, using electric ignition resistance; - B2C1D1 - Mobile equipment, with retort, using solid fuel; - B2C1D2 - Mobile equipment, with retort, using gaseous fuel; - B2C1D3 - Mobile equipment, with retort, using electric ignition resistance;

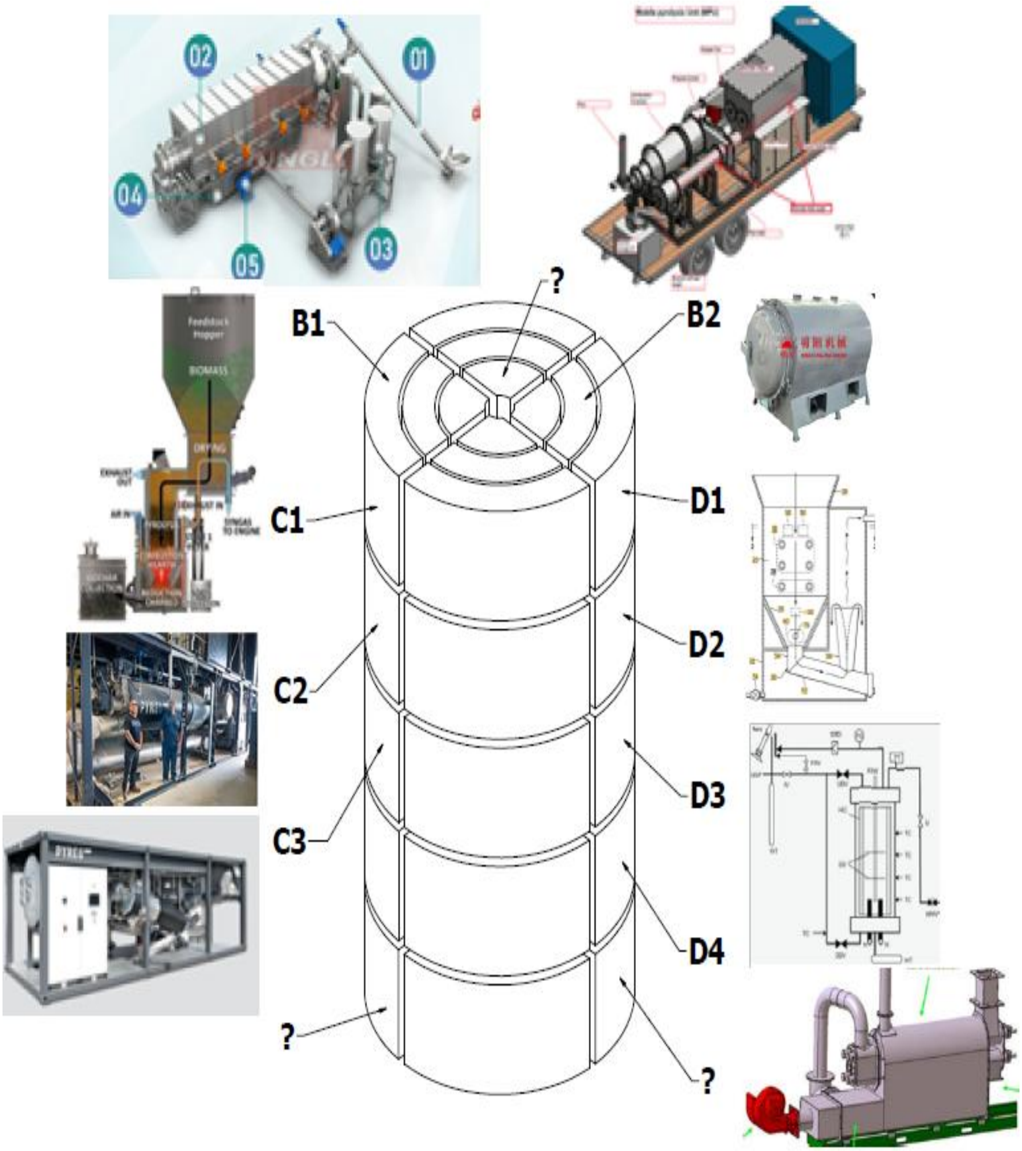

Fig. 5. The generalized object of technical creation in the field of biochar production equipment (Belous and Boris, 2005).

- B2C2D1 - Mobile equipment,with horizontal screw conveyor, using solid fuel; - B2C2D2 - Mobile equipment, with horizontal screw conveyor, using gaseous fuel; - B2C2D3 - Mobile equipment, with horizontal screw conveyor, using solid fuel; - B2C3D1 - Mobile equipment, with inclined screw conveyor, using solid fuel; - B2C1D1 - Mobile equipment, with retort, using solid fuel; - B2C1D2 - Mobile equipment, with retort, using gaseous fuel; - B2C1D3 - Mobile equipment, with retort, using electric ignition resistance; - B2C2D1 - Mobile equipment, with horizontal screw conveyor, using solid fuel; - B2C2D2 - Mobile equipment, with horizontal screw conveyor, using gaseous fuel; - B2C2D3 - Mobile equipment, with horizontal screw conveyor, using solid fuel; - B2C3D1 - Mobile equipment, with inclined screw conveyor, using solid fuel; - B2C3D2 - Mobile equipment, with inclined screw conveyor, using gaseous fuel; - B2C3D3 - Mobile equipment, with inclined screw conveyor, using electric ignition resistance; - B1C2D4 - Fixed equipment, with horizontal screw conveyor, using liquid fuel-tar; - B2C3D2 - Mobile equipment, with inclined screw conveyor, using gaseous fuel; - B2C3D3 - Mobile equipment, with inclined screw conveyor, using electric ignition resistance; - B1C2D4 - Fixed equipment, with horizontal screw conveyor, using liquid fuel-tar.

From the 15 possible combinations, 6 reliable solutions will be selected for analysis: B1C1D1; B1C2D1; B1C1D2; B1C1D3; B2C1D3; B1C2D4.

After eliminating the clearly incompatible solutions and highlighting the apparently incompatible ones, the existing solutions need to be identified (Belous and Boris, 2005).

Level	Ranking coefficient
B1C1D1	3
B1C1D2 BIC2D1 B2C1D1	4
B1C2D2 B2C2D1 B2C1D2 B1C3D1 B1C1D3	5
B2C2D2 B1C3D2 B1C2D3 B1C1D4 B2C1D3	6
B1C3D3 B2C2D3 B1C2D4 B2C1D4	7
B1C3D4 B2C2D4 B2C3D3	8
B2C3D4	9

- Highlighting, evaluating, and critiquing existing variants

Eight known solutions were identified at the time of drafting the generalized object from Fig. 5, and certain tri-assemblies remain unknown, potentially serving as the foundation for new inventions in the field (Belous and Boris, 2005).

For evaluating the existing variants, the "imposed decision" technique from value analysis is used, considering the following key evaluation criteria:

- maneuverability degree, noted as MD;
- automation degree, noted as AD;
- investment cost, noted as IC.
- moisture content of raw material, noted as M,
- duration of the technological process, noted as T.

The criteria marked as MD, AD, and IC are compared in pairs, resulting in D decisions in the form of 1-0; 0.5-0.5; 0.3-0.7; 0.6-0.4, etc., or 0-1 (see Tables 1, 2, 3). The number of decisions is given by the known formula:

D = C2e = 5 (5-1)/2 =10 decisions.

To determine the importance coefficient and reorder the five criteria, the imposed decision method is used (Belous and Boris, 2005) (Table 1).

Table 1

Reorder the five criteria

No.	Criterion	Decisions 1	2	3	4	5	6	7	8	9	10	No. of positive decisions N	Importance coefficient N/D
1	MD	0.6	0.7	0.6	0.5							2.4	0.24
2	AD	0.4				0.5	0.6	0.3				1.8	0.18
3	IC		0.3			0.5			1	0.5		2.3	0.23
4	M			0.4			0.4		0		0.6	1.4	0.14
5	T				0.5			0.7		0.5	0.4	2.2	0.22

The number of positive decisions N is divided by the total number of decisions D, obtaining the importance coefficient for each criterion, which leads to reordering these criteria according to Table 2.

Table 2

Reordering these criteria

No.	Criterion	Importance coefficient
1	Maneuverability degree - MD	0.24
2	Investment cost - IC	0.23
3	Duration of the technological process - T	0.22
4	Automation degree - AD	0.18
5	Moisture content of raw material - M	0.14

From the 15 possible combinations, the following constructive variants are representative:

B - Based on the degree of mobility:

- B1 - fixed equipment for biochar production:Fig.6.

- B2 - mobile equipment for biochar production:Fig.7.

C - Based on the constructive solution of the equipment:

- C1- Equipment with retort (US2013264831A1**;** US2014250784A1**;** *[2;3]*.

-C2- Equipment with horizontal screw conveyor:

D- Based on the thermal agent used:

-D1 - using solid fuel (CN215103026U-2021; **CN218002214U-2022**).

-D2 - Using using gaseous fuel (US2008014132A1-2008), fig.11.

-D3 -Using electric ignition resistance (US2013264831A1-2013; **US 6790317B2**).

For the comparison of the seven solutions, determining their numerical value, and reordering them to identify the optimal solution, Table 3; 4; 5; 6 and 7 is used, specific to value engineering [Ion *et. al.,* 2021].

Table 3

Decisions based on maneuverability degree

No	Solu-tion	Decisions based on the criterio – **Maneuverability degree - MD** 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	D_{MD}	0,24 DT/21
1	B1	0.5	0.3	0.4	0.5	0	0																1.9	0.01028
2	B2	0.5						1	0.5	0.6	0.3	0.5											3.4	**0.03886**
3	C1		0.7					0					0.6	0.5	1	0.5							3.3	0.03771
4	C2			0.6					0.5				0.4				0.5	0.3	1				3.3	0.03771

5	D1				0.5					0.4				0.5			0.5			0.5	0.3		2.2	0.02514
6	D2					1					0.7				0			0.7		0.5		0.4	3.3	0.03771
7	D3						1					0.5				0.5			0		1	0.6	3.6	**0.04114**

Table 4

Decisions based on criterion investement cost

No.	Solu-tion	Decisions based on the criterion																						
		Investment cost - IC																					D_{IC}	0,24 D_T/21
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
1	B1	0.3	0.5	0.7	0.4	0	0																1.9	0.02171
2	B2	0.7						1	0.7	0.6	0.7	0.5											4.2	**0.048**
3	C1		0.5					0					0.6	0.5	1	0.5							3.1	0.03542
4	C2			0.3					0.3				0.4				0.5	0.3	1				2.8	0.032
5	D1				0.6					0.4				0.5			0.5			0.5	0.3		2.8	0.032
6	D2					1					0.3				0			0.7		0.5		0.4	2.9	0.03314
7	D3						1					0.5				0.5			0		1	0.6	3.6	**0.04114**

Table 5

Decisions based on duration of the tehnological process

No.	Solu-tion	Decisions based on the criterion																						
		Duration of the technological process - T																					D_T	0,24 D_T/21
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
1	B1	0.4	0.3	0.4	0.5	0	0																1.6	0.01828
2	B2	0.6						1	0.7	0.6	0.6	0.5											4	**0.04571**
3	C1		0.7					0					0.6	0.5	1	0.3							3.8	0.04342
4	C2			0.6					0.3				0.4				0.5	0.3	0.4				2.5	0.02857
5	D1				0.5					0.4				0.5			0.5			0.5	0.3		2.7	0.03085
6	D2					1					0.4				0			0.7		0.5		0.4	3	0.03428
7	D3						1					0.5				0.7			0.6		0.7	0.6	4.1	**0.04686**

Table 6

Decisions based on automation degree

No.	Solu-tion	Decisions based on the criterion																						
		Automation degree - AD																					D_{AD}	0,24 D_T/21
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
1	B1	0.5	0.3	0.4	0.5	0	0																2	0.02286
2	B2	0.5						1	0.7	0.7	0.7	0.5											4.1	**0.04686**
3	C1		0.7					0					0.6	0.5	1	0.4							3.1	0.03543
4	C2			0.6					0.3				0.4				0.5	0.3	0				2.1	
5	D1																			0.5	0.3		2.7	
6	D2					1									0							0.4	2.9	

7	D3				0.5		1			0.3	0.3	0.5		0.5		0.5	0.5	0.7	1	0.5	1	0.6	4.6	0.024 0.03086 0.03314 **0.05257**

Table 7

Decisions based on moisture content of raw material

No.	Solu-tion	Decisions based on the criterion																						
		Moisture content of raw material – M																					D_M	0,24 D_T/21
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
1	B1	0.5	0.4	0.5	0.4	1	0																2.8	0.032
2	B2	0.5						1	0.5	0.6	0.3	0.5											3.4	**0.03886**
3	C1		0.6					0					0.6	0.7	0.5	0.5							2.9	0.03314
4	C2			0.5					0.5				0.4				0.4	0.3	0				2.1	0.024
5	D1				0.6					0.4				0.3			0.6			0.5	0.3		2.7	0.0308
6	D2					0					0.7				0.5			0.7		0.5		0.4	2.8	0.033
7	D3						1					0.5				0.5			1		1	0.6	4.6	**0.05257**

To calculate the numerical value of each technical solution, we use the following equation:

Nv=(0.24 x DMD + 0.23 x DIC + 0.22 x DT +0.22 x DAD +0.18 x DM) /10.

In accordance with the table, the numerical values of the seven representative solutions are:

NVB1=(0.24x1.9+0.23x1.9+0.22x1.6+0.18x2+0.14x2.8)/10=0.1997

NVB2=(0.24 x 3.4 + 0.23 x 4.2 + 0.22 x 4 +0.22 x 4.1 +0.18 x 3.4) /10=0.4129

NVB3=(0.24 x 3.3 + 0.23 x 3.1 + 0.22 x 3.8 +0.22 x 3.1 +0.18 x 2.9) /10=0.3545

NVB4=(0.24 x 3.3+ 0.23 x 2.8 + 0.22 x 2.5 +0.22 x 2.1 +0.18 x 2.1) /10=0.2826

NVB5=(0.24 x 2.2 + 0.23 x 2.8 + 0.22 x 2.7 +0.22 x 2.7 +0.18 x 2.7) /10=0.2846

NVB6=(0.24 x 3.3 + 0.23 x 2.9 + 0.22 x 3 +0.22 x 2.9 +0.18 x 2.8) /10=0.3261

NVB7=(0.24 x 3.6 + 0.23 x 3.6 + 0.22 x 4.1 +0.22 x 4.6 +0.18 x 4.6) /10=0.3656

The technical solutions with the highest numerical values are selected:

NVB2=0.4129 which corresponds to mobile equipment with a retort for biochar production,

NVB7=0.3656 which corresponds to equipment using electric resistance ignition with electric current.

Thus, the optimal variant results for the design of the Laboratory equipment for biochar production from plant residues - a mobile device, with a retort, and electric burner ignition of the raw material [Olan *et. al*., 2023].

RESULTS AND DISCUSSIONS

The final proposed variant for the design and patenting of laboratory equipment for biochar production from various plant residues, combining B2C1D3 — Mobile equipment, with a retort, and electric burner ignition of the material, will be developped.

The laboratory equipment for biochar production from plant residues [Olan *et. al.*, 2023], consists of a mobile support (1) that includes a platform (2) fitted with four self-locking wheels (3) and two side walls (4) where two weighing cells (5) and two rotating bearings (6) are mounted, fastened to the top plate of the weighing cells (5) with hexagonal head screws (7). The weighing cells measure the weight of the raw material introduced into the retort and the amount of biochar produced, fig.6

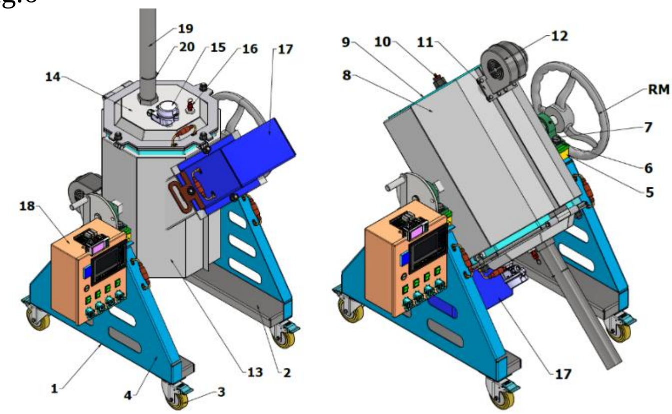

Fig.13. Biochar production equipment – Working position Biochar discharge

On the mobile support (1) is mounted a casing (8) with spindles that penetrate the rotating bearings (5). The casing (8) consists of two concentrically mounted octagonal chambers insulated between them with a layer of ceramic fiber and supports a lower cover (9) with an electric resistance (10) for igniting solid fuel and an air diffuser with holes (11) that supplies the necessary air for igniting the combustible material which is received from a fan (12). The rotation of the casing (8), which contains the retort (13) for burning the raw material to produce biochar, is done with a handwheel (RM). On the casing (8) is mounted an upper cover (14) that supports a thermocouple (15) for measuring temperature and a sensor (16) for pressure control inside the chamber. The casing (8) has a discharge outlet for the biochar, which is emptied into a sealed tray (17).

For programming the working parameters: temperature, pressure, electric ignition control, draft fan adjustment, vacuum pump, the equipment is equipped with a programmable logic controller (PLC) (18). Monitoring these parameters helps establish optimal values for obtaining high-quality biochar from various types of plant residues under laboratory conditions.

The exhaust gases at the start of raw material ignition are vented through a chimney (19), which is then closed off with the drawer (20).

CONCLUSIONS

The equipment for biochar production from plant residues has the following advantages:

-It does not require a biochar unloading system (conveyor screw, trays, etc.), as the produced material can be discharged by rotating the equipment with the help of a handwheel and emptied into a sealed tray;
-The equipment has a single chamber, eliminating the need for a separate retort for heating and drying material. The raw material is introduced into the reactor tray where the entire technological process takes place;
-Low energy consumption for starting and running the production cycle;
-Automated production cycle with a process computer;
-Short working time;
-Thermal insulation with ceramic fiber and a double jacket ensures low energy consumption;
-The equipment is mobile, compact, and recommended for laboratory tests, with automatic adjustment of working parameters;
-It can utilize plant residues with moisture content between 30-40%, compared to known solutions which can only handle residues with a maximum of 15% moisture.

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