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ENERGY EFFICIENT TECHNOLOGIES

Collective monograph

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Energy-efficient electricity generation technologies used in the world are reviewed and analyzed. Developments in the field of alternative energy and resource-saving technologies are described. Issues of energy-saving technologies, energy-efficient equipment and technological solutions are considered, the implementation of which provides the increasing of efficiency of use of fuel and energy resources.

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INTRODUCTION

The development of scientific and technological progress, the growth of the Earth's population and the improvement of its well-being have led to a dramatic increase in global consumption of resources. The significance and severity of this problem is increasing every year. Therefore, in a market economy, it is necessary to organize production on the basis of the principles of resource conservation and energy efficient technologies, which in turn will increase the efficiency of industries as a whole.

Expert analysts have found that the effective and full use of resources in the XXI century can be achieved by evaluating the entire technological chain from the point of view of resource conservation, which includes both the process of preparation and processing of raw materials and technological processes.

A comprehensive analysis of the processes of intensification, resource conservation, innovation and modernization shows that in order to implement them into real production conditions of enterprises it is necessary to create certain prerequisites, which in the majority are aimed at the organization of effective quality management of finished products and 100% use of resource potential.

Today, in almost every industrialized country, manufacturers and scientific organizations carry out exploratory work to create the most optimal options for waste-free production in terms of environmental friendliness, financial efficiency, low production costs for raw materials.

But the problems of efficiency of use of traditional energy sources in Ukraine are more acute than in the EU countries. The reasons for this are outdated technologies, depletion of the resource of use of fixed assets of generation of electricity and heat, which together with low efficiency of fuel use leads to considerable volumes of harmful emissions. The significant losses while the transportation, distribution and use of electricity and heat, as well as the monopoly dependence on the import of energy carriers, further complicate the situation in the country's energy markets.

Practice and world experience have shown that the technological factor of high-performance, resource-saving production is the most effective resource for the growth of the country's economy, the factor of improving the environment, the path to energy independence.

Therefore, resource conservation, comprehensive and full use of raw material potential, recycling of secondary raw materials and production cycle waste are the key to Ukraine's successful development in the near future.

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GEOTHERMAL ENERGY

Serohin O. O.

1. General concepts and characteristics

Geothermal energy is the energy of the Earth's subsoil, which is found in solid rocks and groundwater of the Earth. The temperature of the Earth's crust increases by 2.5…3 °C every 100 m. So, at a depth of 20 km the temperature is about 500 °C, at a depth of 50 km it is about 700…800 °C. In certain places, especially at the edges of continental tectonic plates, as well as in so-called "hot spots", the temperature gradient is almost 10 times higher, and then at a depth of 500...1000 meters the rock temperature reaches 300 °C.

Geothermal reserves are divided into hydrothermal and petrothermal. Hydrothermal reserves are water, vapors or vapor-water mixtures which project through the cracks of rocks and have a temperature of 200…300 °C, water streams or aquifers of 80…95 °C. The method of using geothermal resources depends on the temperature of the coolant. At temperatures above 120…150 °C, it is advisable to use the electricity in the production. At lower temperatures the geothermal reserves are used for heating systems, air conditioning, water heating of urban and industrial hot water supply systems, for heating of greenhouses, fisheries, for recreational purposes.

Geothermal energy sources are divided by the physical state of the heat carrier and by temperature into the following groups:

- soils and rocks up to a depth of 2500 m, from which heat for heating using heat pumps is obtained by means of special heat probes;
- groundwater directly used as a heat source for heat pumps;
- water vapor obtained by wells supplying water, which is used in geothermal power plants for electricity production;
- salt deposits, the energy of which is derived by brine or inert liquids, such as isobutane;
- hot rocks from which the energy is produced by high pressure water circulating through a system of artificial or natural cracks in rock

complexes at considerable depth. This energy is used in geothermal power plants to produce electricity as well as for heating.

The use of geothermal energy can make a significant contribution to solving the following urgent problems:

- ensuring sustainable heat and power supply to the population in the areas of our planet where centralized energy supply is absent or too expensive (for example, in Russia in Kamchatka, in the regions of the Far North, etc.);
- ensuring a guaranteed minimum of energy supply to the population in the areas of unstable centralized energy supply due to electricity shortages in the power systems, preventing damage from emergency and restrictive shutdowns, etc.;
- reduction of harmful emissions from power plants in selected regions with complex environmental conditions.

2. World geothermal energy potential and prospects for its use

A group of experts from the International Geothermal Association, which has evaluated the low- and high-temperature geothermal energy reserves for each continent, according to the potential of different types of geothermal Earth sources, obtained the data listed in Table 1.

Table 1

The Earth's geothermal energy reserves

The name of the continent	The type of geothermal source		
	high temperature used for electricity production, TJ/year		low temperature used in the form of heat, TJ/year (lower limit)
	traditional technologies	traditional and binary technologies	
Europe	1830	3700	>370
Asia	2970	5900	>320
Africa	1220	2400	>240
North America	1330	2700	>120
Latin America	2800	5600	>240
Oceania	1050	2100	>110
World potential	11200	22400	>1400

As can be seen from the table 1, the potential of geothermal energy sources is enormous. However, it is used to a small extent: the capacity of geothermal thermal power plants (GeoTPP) in the world in the early 1990s was about 5000 MW, and in the early 2000s – about 6000 MW, substantially inferior by this indicator to most power plants operating on other renewable energy sources. And electricity production at GeoTTP was negligible during this period.

It is known that geothermal resources have been explored in 80 countries and are actively used in 58 of them. The most powerful producer of geothermal power is the USA, where geothermal energy, as one of alternative forms of energy, has special government support. In the United States in 2005, about 16 billion kWh of electricity was generated at GeoTTP in major industrial areas such as the Great Geysers Zone, located 100 km north of San Francisco (1360 MW of installed capacity), the northern Salt Sea in the central California (570 MW of installed capacity), Nevada (235 MW of installed capacity), and more.

In the table 2. the comparative characteristics of the use of geothermal resources in different countries for the years 2000–2019 are given.

Table 2

The direct use of geothermal resources in different countries of the world

Country	Capacity, MW		Annual production				Capacity factor (the share of maximum capacity per year)	
			TJ/year		GWh/year			
	2000	2019	2000	2019	2000	2019	2000	2019
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Algeria	100,0	152,3	1586	2417	441	671,4	0,50	0,50
Argentina	25,7	149,9	449	609,1	125	169,2	0,55	0,13
Australia	10,4	109,5	294	2968	82	824,5	0,90	0,86
Austria	255,3	352,0	1609	8027,64	447	2229,9	0,20	0,20
Belgium	3,9	63,9	107	431,2	30	119,8	0,87	0,21
Bulgaria	107,2	109,6	1637	1671,5	455	464,3	0,48	0,48
The United Kingdom	2,9	10,2	21	45,6	6	12,7	0,23	0,14
Venezuela	0,7	0,7	14	14	4	3,9	0,63	0,63

Table 2 (continuance)

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Greece	57,1	74,8	385	567,2	107	157,6	0,24	0,24
Georgia	250,0	250,0	6307	6307	1752	1752,1	0,80	0,80
Denmark	7,4	821,2	75	4360	21	1211,2	0,32	0,17
Israel	63,3	82,4	1713	2193	476	609,2	0,86	0,84
India	80,0	203,0	2517	1606,3	699	446,2	1,00	0,25
Indonesia	7,3	2,3	43	42,6	12	11,8	0,19	0,59
Iceland	1469,0	1791,0	20170	23813	5603	6615,3	0,44	0,42
Italy	325,8	606,6	3774	7554	1048	2098,5	0,37	0,39
Jordan	153,3	153,3	1540	1540	428	427,8	032	0,32
Canada	377,6	461,0	1023	2546	284	707,3	0,09	0,18
Caribbean	0,1	0,1	1	2,8	0	0,8	0,62	0,89
Kenya	1,3	10,0	10	79,1	3	22	0,25	0,25
China	2814,0	3687,0	31403	45373	8724	12604,6	0,35	0,39
Colombia	13,3	14,4	266	287	74	79,7	0,63	0,63
South Korea	51,0	16,9	1077	75,2	299	48,7	0,67	0,33
Lithuania	21,0	21,3	599	458	166	127,2	0,90	0,68
Macedonia	81,2	62,3	510	598,6	142	166,3		0,30
Mexico	164,2	164,7	3919	1931,8	1089	536,7	0,76	0,37
Nepal	1,1	2,1	22	51,4	6	14,3	0,66	0,78
The Netherlands	10,8	253,5	57	685	16	190,3	0,17	0,09
Germany	397,0	504,6	1568	2909,8	436	808,3	0,13	0,18
New Zealand	307,9	308,1	7081	7086	1967	1968,5	0,73	0,73
Norway	6,0	450,0	32	2314	9	642,8	0,17	0,16
Peru	2,4	2,4	49	49	14	13,6	0,65	0,65
Poland	68,5	170,9	275	838,3	76	232,9	0,13	0,16
Portugal	5,5	30,6	35	385,3	10	107	0,20	0,40
Russia	307,0	308,2	6132	6143,5	1703	1706,7	0,63	0,63
Romania	152,4	145,1	2871	2841	797	789,2	0,60	0,62
Serbia	80,0	88,8	2375	2375	660	659,8	0,94	0,85
Slovakia	132,3		187,7	2118	3034	588	842,8	0,51 0,51
Slovenia	42,0		48,6	705	712,5	196	197,9	0,53 0,46
The USA	5366,0		7817,4	20302	31239	5640	8678,2	0,12 0,13
Thailand	0,7		1,7	15	28,7	4	8	0,68 0,54

Table 2 (ending)

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Tunisia	19,7	25,4	174	219,1	48	60,9	0,28	0,27
Turkey	820,0	1177,0	15756	19623,1	4377	5451,3	0,61	0,53
Hungary	328,3	694,2	2825	7939,8	785	2205,7	0,27	0,36
Ukraine	45,5	6,3	495,8	68,7		0,4		0,35
Philippines	1,0	3,3	25	39,5	7	11	0,79	0,38
Finland	80,5	260,0	484	1950	134	541,7	0,19	0,24
France	326,0	308,0	4895	5195,7	1360	1443,4	0,48	0,53
Croatia	113,9	114,0	555	681,7	154	189,4	0,15	0,19
The Czech Republic	12,5	204,5	128	1220	36	338,9	0,33	0,19
Chile	0,4	8,7	7	131,1	2	36,4	0,55	0,48
Switzeland	547,3	581,6	2386	4229,3	663	1174,9	0,14	0,23
Sweden	377,0	3840,0	4128	36000	1147	10000,8	0,35	0,30
Japan	257,5	413,4	5836	5161,1	1621	1433,8	0,72	0,40
Total	162563	273293	162504,8	258839,7	45008	71868,9	27,41	24,09

Describing the development of the world geothermal energy as an integral part of renewable energy in the longer term, we note the following. The share of renewable energy in the global energy production is projected to decline in 2030 (down to 12,5% comparing to 13,8% in 2000). The energy of the sun, wind and geothermal waters will develop at an accelerated rate, increasing annually by an average of 4,1%.

3. Ukraine geothermal energy potential

Regarding the prospects for the development of Ukrainian geothermal energy, it should be noted that Ukraine has identified six priority areas for the development of geothermal energy:

- the creation of geothermal stations for heat supply of cities, settlements and industrial facilities;
- the creation of geothermal power plants;
- the creation of heat supply systems with underground heat accumulators;
- the creation of drying installations;
- the creation of freezing installations;
- the creation of schemes of geothermal heat supply of greenhouses.

Geothermal resources of Ukraine are primarily thermal waters and the heat of heated dry rocks. In addition, the prospects resources for industrial use include heated groundwater resources that are extracted with oil and gas by existing oil and gas wells[1,2,3,4,5].

One of the promising directions for the development of geothermal energy is the creation of combined energy technology units for obtaining electricity, heat and valuable components contained in geothermal heat carriers.

See below in Table 1.3. the potential of working wells for geothermal energy production in Ukraine is presented.

Table 3

The potential of geothermal resources of existing wells in Ukraine

Regions	Theoretically possible potential of geothermal energy, thousand tons of c. f.	Technically achievable potential of thermal water, thousand tons of c. f.	Economically feasible potential of thermal waters, thousand tons of c. f.
1	*2*	*3*	*4*
The Autonomous Republic of Crimea	804,0	67,0	53,6
Vynnytsia Region	–	–	–
Volyn Region	–	–	–
Dnipropetrovsk Region	–	–	–
Donetsk Region	–	–	–
Zhytomyr Region	–	–	–
Zakarpattia Region	236,0	19,8	17,82
Zaporizhzhia Region	–	–	–
Ivano-Frankivsk Region	79,0	4,9	3,92
Kyiv Region	–	–	–
Kirovohrad Region	–	–	–

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Table 3 (ending)

1	*2*	*3*	*4*
Luhansk Region	–	–	–
Lviv Region	262,0	30,5	24,4
Mykolayiv Region	–	–	–
Odesa Region	47,0	5,5	4,4
Poltava Region	271,0	27,1	18,97
Rivne Region	–	–	–
Sumy Region	674,0	67,4	47,18
Ternopil Region	–	–	–
Kharkiv Region	230,0	23,0	16,1
Kherson Region	312,0	26,0	20,8
Khmelnytsk Region	–	–	–
Cherkasy Region	–	–	–
Chernivtsi Region	–	–	–
Chernihiv Region	864,0	86,4	60,48
Total	*3779,0*	*357,6*	*267,67*

On the example of geothermal circulation system (GCS) in the village Illinka it was found that the operation of the GCS for three heating periods showed the possibility of implementing a method of extracting geothermal heat with back-pumping of spent geothermal coolant for the hydrological conditions of Crimea. Thus, a virtually closed cycle of filtration of the geothermal coolant is implemented, which provides environmental protection from pollution.

The list of geothermal objects on which exploration and development works were carried out at various times is given in Table 4.

Table 4

Geothermal power plants in Crimea on the basis of GCS

Settlement	Capacity, MW	Water temperature, °C	Well flow rate, m^3/hour	Objects of heat supply	Annual fuel economy, tons of c. f.
1	*2*	*3*	*4*	*5*	*6*
village Ilyinka	3,2	57	72	residential settlement	1574
village Syzovka	3,5	61	72	residential settlement	1722
village Novo-Oleksiivka	8,4	53	205	dairy farm, residential settlement	4133
village Kotelnykovo	3,5	65	67	residential settlement	1722
village Trudove	4,5	59	96	greenhouses, hot water supply	2214
village Zernove	2,7	50	72	hot water supply	1328

Table 4 (ending)

1	2	3	4	5	6
village Rivne	6,9	62	139	residential settlement	3395
village Yantarne	4,8	85	65	agro-industrial complex	2361
village P'yatykhatky	6,5	51	167	hot water supply	3198
village Medvedivka	1,5	67	28	kindergarten, residential settlement	738
Total	*45,5*				*22385*

It is known that geothermal power plants require very small land plots, much smaller than those required for power plants of other types. They can be placed on almost any land, including farmland. If only 1% of geothermal energy of Earth's crust (depth of 10 km) could be used, we would have at our disposal an amount of energy that is 500 times greater than all the world's oil and gas reserves.

4. Advantages and disadvantages of using geothermal energy

The main advantage of geothermal energy is the possibility of its use in the form of geothermal water or a mixture of water and vapor (depending on their temperature) for the needs of hot water and heat supply, for generating electricity or for all three purposes simultaneously; its practical inexhaustibility; complete independence from environmental conditions, time of day and year.

Recommended applications for geothermal waters depending on their temperature

Temperature, °C	Applications
more than 140	Electricity generation
less than 100	Heating systems of buildings and constructions
about 60	Hot water supply systems
less than 60	Geothermal heat supply systems for greenhouses, geothermal freezing installations, etc.

Note that, taking into account the advancement of geothermal technologies, these recommendations are being revised toward the use of geothermal waters with increasingly low temperatures for electricity generation. Thus, the developed modern combined schemes of geothermal sources application allow to use for the electricity production the coolants with initial temperatures of 70… 80 °C, which is much lower than the recommended ones (150 °C and above). In particular, the St. Petersburg Polytechnic Institute has created hydrosteam turbines, the use of which at GeoTPP allows to increase the useful capacity of systems by an average of 22%.

The efficiency of thermal water in their complex use significantly increases. At the same time in various technological processes it is possible to achieve the most complete realization of the thermal potential of water, including residual, as well as to obtain valuable components contained in thermal water (iodine, bromine, lithium, cesium, table salt, boric acid and many others) for their industrial use.

One of the biggest disadvantages of geothermal energy is the need to return the wastewater to the underground aquifer. Another disadvantage of using this type of energy is the high mineralization of thermal water of most deposits and the presence of toxic compounds and metals in water, which in most cases eliminates the possibility of discharge of this water into the on-surface natural water systems. The aforementioned disadvantages of the use of geothermal energy lead to the fact that for the practical use of the heat of geothermal water requires considerable investment for well drilling, back injection of waste geothermal water, creating corrosion-resistant thermal equipment.

5. Geothermal energy conversion equipment

5.1 Geothermal power plants

There are two types of geothermal power plants: the first group uses water vapor to generate electricity, the second one uses superheated geothermal water. In the first dry vapor from the well enters the turbine or generator to generate electricity. At other plants, geothermal water with a temperature of more than 190 °C is used. Water naturally rises up the well, comes into the separator, where as a result of the decrease in pressure, a part of it boils and turns into steam. The steam goes to a generator or turbine and generates electricity. This is the most common type of geothermal power plant.

Even more striking is the new GeoTPP revolutionary construction technology Hot-Dry-Rock, developed by Australian GeodynamicsLtd several years ago, which significantly improves the energy conversion of geothermal water into electricity. To confirm the forecasts, wells were drilled at a depth of 4.5 km each, which showed that at this depth the temperature reached the required 270… 300 °C. Work is currently underway to estimate the total geothermal energy reserves at this anomalous point in southern Australia, which is estimated to have a capacity of more than 1 GW, with the cost of that energy being half the cost of wind power and 8…10 times cheaper than solar power.

It is becoming clear today that the considerable scale of development of geothermal energy in the future is possible only in case of obtaining thermal energy directly from the rocks. In this case, in places where dry hot rocks are found, parallel wells are drilled, between which a system of cracks is formed. That is, an artificial geothermal tank is actually formed, where cold water comes with the subsequent obtaining of steam or steam mixture.

5.2 Heat pumps

Heat pumps are environmentally friendly compact and economical heating system installations that produce heat for hot water supply and heating systems for buildings using natural and free soil heat, artesian water, seas, lakes, rivers, air heat, process emissions, etc. by transferring it to a coolant with a higher temperature.

In heat pumps, as well as in freezing instalations, the so-called reverse cycle of heat transfer from a low temperature source to a higher temperature source is carried out. It is necessary to spend some amount of mechanical energy.

Heat pumps can be classified by the following features: operating principle; sources of low-potential heat; the combination of low-potential heat used with the environment heated in heat pumps; types of energy consumed.

6. The technological aspects of the exploration of geothermal resources

Physical capabilities of heat power generation by geological environment (GE) within the territory of Ukraine are evaluated using information on the distribution of thermophysical parameters of GE.

The heat flux density is the amount of heat transferred from the bowels to the surface per unit of time per unit of area. It is measured in mW/m^2 and is determined as the result of the multiplication of a geothermal gradient in a certain depth range by the thermal conductivity of the rocks of that interval. In Ukraine, the heat flux density varies from 25…30 mW/m^2 to 100…110 mW/m^2. Temperatures at a depth of 1 km vary from 20 to 70 °C, and at a depth of 3 km – from 40 to 135 °C. The distribution of heat flows is closely related to the peculiarities of the geological development of the regions and their tectonics. Deep heat flux (DHF) is defined as the observed heat flux, adjusted for numerous close to the surface effects: paleoclimate, groundwater movement with a vertical component, geological structures that cause non-horizontal occurrence of the surfaces of the rock section with different thermal conductivity, young sediments, the accumulation of young sediments, etc. The DHF map shows the distribution of its background (35…50 mW/m^2) and anomalous (60…130 mW/m^2) values in Ukraine.

Utilization of thermal energy from GTPP to generate electricity also has a real socio-economic perspective, despite the small efficiency of thermoelectric elements (3…5% for temperatures up to 120 °C and 6…8% for temperatures up to 250 °C), since during the warm season geothermal energy can switch to maximum electricity generation.

7. The formulas for calculating geothermal heating systems

7.1 The calculation of the efficiency coefficient for different geothermal heat supply systems

A. Open two-pipe geothermal heat supply system with connection of hot water supply systems to the falling pipeline (i.e parallel supply of geothermal coolant for heating and hot water supply).

1. The specific consumption of geothermal water, which comes to 1 MW of estimated heat load, is determined by the formula:

$$G_{\text{Т}}^{\text{пит}} = \frac{10^3}{c} \cdot \left(\frac{Q'_{\text{оп}}}{\delta \cdot t'_{\text{оп}}} + \frac{Q'_{\text{г.в}}}{\delta \cdot t_{\text{г.в}}} \right), \quad (1)$$

where: $Q'_{\text{оп}}$, $Q'_{\text{г.в}}$ denote estimated loads of heating, ventilation and hot water supply, W;

c denotes specific heat of the coolant, J/(kg· °C);

$\delta \cdot t'_{\text{оп}}$, $\delta \cdot t'_{\text{г.в.}}$ denote estimated fluctuations in coolant temperatures in heating, ventilation and hot water systems, °C,

$G_{\text{Т}}^{\text{пит}}$ denote specific geothermal water flow per unit of calculated heat load of the object, kg/J.

2. The share of estimated flow of geothermal water consumed for heating is determined by the formula:

$$\alpha = \frac{Q'_{\text{оп}}}{c \cdot G_{\text{Т}}^{\text{пит}} \cdot \delta \cdot t'_{\text{оп}}}. \quad (2)$$

The same thing, for hot water we get from the formula:

$$\alpha + \beta + \gamma = 1, \quad (3)$$

where $\gamma = 1 - \alpha$.

3. The degree of relative use of the maximum load for heating is determined by the formula:

$$Z_{\text{оп}} = \frac{T_{\text{сез}} \cdot \varphi_{\text{ср.відп}}}{8500}, \quad (4)$$

where: $\varphi_{\text{ср.відп}}$ – average heat release coefficient

The average heat release coefficient is determined by the formula:

$$\varphi_{\text{ср}} = \frac{\left(t_n - t_{\text{з.ср}}\right)}{\left(t_n - t'_{\text{з}}\right)}, \quad (5)$$

where: t_n – air temperature in the serviced premises, °C;

$t'_{\text{з}}$- estimated outside air temperature for the design of heating or ventilation systems, °C;

$t, t_{\text{з.ср}}$ – average outside air temperature for the period of operation of heating or ventilation systems, °C.

4. The degree of relative use of the maximum load for heating is determined by the formula:

$$Z_{\text{г.в}} = \frac{5500 \cdot 0{,}35 \cdot T_{\text{сез}}}{8500}. \quad (6)$$

5. Well exploitation coefficient is determined by the following formulas:

- for heating:

$$\tau_{\text{сверд.оп}} = z_{\text{оп}} \cdot \frac{\left(t_{\text{Т}}^{'} - t_{\text{о}}^{'}\right)}{\left(t_{\text{Т}}^{'} - t_{\text{Т}} - 5\right) - \varphi_{\text{ср.оп}} \cdot \left(t_{\text{о}}^{'} - t_{n} - 5\right)}, \quad (7)$$

- for hot water supply:

$$\tau_{\text{сверд.г.в}} = z_{\text{оп}} \cdot \frac{6800 + 0,2 \cdot T_{\text{сез}}}{8500}, \quad (8)$$

6. The weighted average value of the well exploitation coefficient is determined as follows:

$$\tau_{\text{сверд.об}} = \alpha \cdot \tau_{\text{сверд.оп}} + \gamma \cdot \tau_{\text{сверд.г.в}}, \quad (9)$$

7. The degree of relative increase in the estimated flow rate of the well in general for the object is determined with the known $\tau_{\text{сверд.об}} = 0,23$ for for a semi-bounded layer with $I_{n} = 4,9 - \xi_{\text{об}} = 1,6$.

8. The degree of relative triggering of the temperature difference is determined according to the condition $t_{\text{Г}}^{'} = t_{\text{Т}}^{'} = 100$ °C by the formulas:

- for heating:

$$I_{\text{оп}} = \frac{t_{\text{г}}^{'} - t_{\text{о}}^{'}}{t_{\text{г}}^{'} - 5}, \quad (10)$$

- for hot water supply $I_{\text{г.в}} = 1$ since $t_{\text{г.в}}^{'} = t_{\text{т}}^{'}$.

9. The coefficient of efficiency of geothermal heat supply for this scheme is determined by the formula:

$$\eta_{\text{геот}}^{\text{об}} = (\alpha \cdot I_{\text{оп}} \cdot z_{\text{оп}} + \gamma \cdot I_{\text{г.в}} \cdot Z_{\text{г.в}}) \cdot \xi_{\text{об}} . \quad (11)$$

B. Dependent heating system with peak heating of geothermal coolant:

1. The specific consumption of geothermal water, which comes for 1 MW of estimated heat load, is determined by the formula:

$$G_{\text{Т}}^{\text{пит}} = \frac{10^{3}}{c} \cdot \left(\frac{Q_{\text{оп}}^{'}}{\delta \cdot t_{т.г}^{'}} + \frac{Q_{\text{г.в}}^{'}}{\delta \cdot t_{\text{г.в}}^{'}} \right). \quad (12)$$

1. The share of the estimated flow rate of geothermal water will be:

$$\alpha = \frac{Q'_{\text{оп}} \cdot 10^2}{c \cdot G_{\text{Т}}^{\text{пит}} \cdot \delta \cdot t'_{\text{т.г}}}. \qquad (13)$$

for hot water supply:

$$\gamma = 1 - \alpha .$$

2. The coefficient of heat release corresponding to the moment of shutdown of the peak heating, is determined by the formula:

$$\varphi_{\text{п.відп}} = \frac{\left(t'_{\text{Т}} - t_{\text{в}} - 5\right)}{(t'_{\text{т.г}} - t_{\text{в}} - 5)}. \qquad (14)$$

3. The approximate duration of peak heating T_n is determined by the formula:

$$T_{\text{п}} = \frac{\left(1 - \varphi_{\text{п.відп}}\right)^1 / \text{B}}{\text{A}}, \qquad (15)$$

where: A and B are empirical coefficients.

4. The average heat release coefficient is determined by the formula:

$$\varphi_{\text{відп}} = \frac{\left(\varphi_{\text{п.відп}} + \varphi_{\text{к}}\right)}{2 \cdot \varphi_{\text{п.відп}}}. \qquad (16)$$

5. The temperature of the waste water corresponding to the moment of shutdown of the peak heating, is determined by the formula:

$$t_{\text{сп}} = \varphi_{\text{п}} \cdot (t'_{\text{о}} - t_{\text{в}} - 5) + (t_{\text{в}} - 5), \qquad (17)$$

Well exploitation coefficient while heating is determined by the formula:

$$\tau_{\text{сверд.оп}} = \frac{T_{\text{п}} \cdot 24}{8500} + \frac{(T_{\text{сез}} - T_{\text{п}}) \cdot 24}{8500} \cdot \frac{\varphi_{\text{відп}} \cdot (t'_{\text{т}} - t_{\text{сп}})}{(t'_{\text{т}} - t_{\text{в}} - 5) - \varphi_{\text{відп}} \cdot (t_{\text{сп}} - t_{\text{в}} - 5)}. \qquad (18)$$

6. The share of peak heating for heating is determined according to the graphs of Fig. 1.

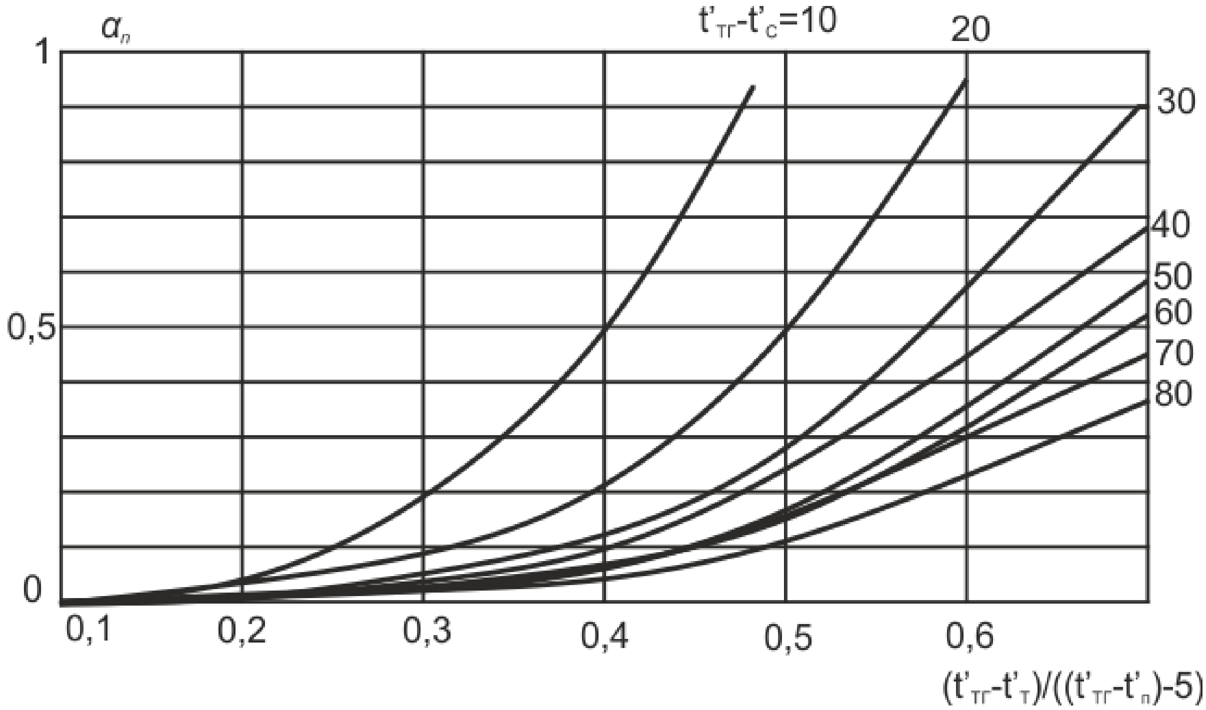

Fig. 1. Graphs for determining the proportion of peak heating during heating

$$\frac{t'_{\text{т.г}} - t'_{\text{т}}}{t'_{\text{т.г}} - t_{\text{п}} - 5}, \tag{19}$$

$$t'_{\text{т.г}} - t'_{\text{о}}, {}^{\circ}C,$$

$$d_{\text{н}} = 0,05.$$

7. The degree of relative triggering of the temperature difference is determined by the formulas:

- for heating systems:

$$\frac{t'_{\text{т.г}} - t'_{\text{о}}}{t'_{\text{т}} - 5} \tag{20}$$

- for hot water supply: $I_{\text{г.в}} = 1$.

9. The weighted average value of the well exploitation coefficient is determined as follows:

$$\tau_{\text{сверд.об}} = \alpha \cdot \tau_{\text{сверд.оп}} + \gamma \cdot \tau_{\text{сверд.г.в}}, \tag{21}$$

10. According to the graph of Fig. 2. we determine the value of the index $\xi_{об}$.τ

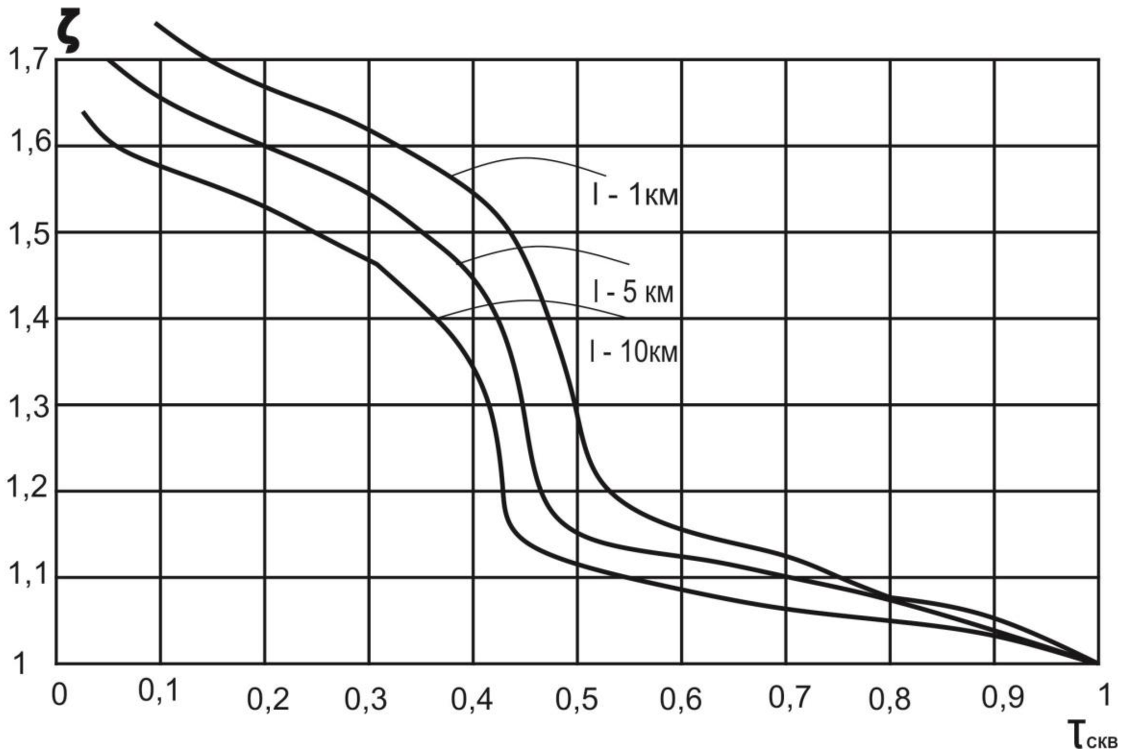

Fig. 2. Graph for determining the degree of relative increase in the calculated flow rate of the heat collection

11. The coefficient of efficiency of geothermal heat supply of the object by the formula is:

$$\mu_{геот}^{об} = (\alpha \cdot I_{оп} \cdot z_{оп} \cdot (1 - d_{н}) + \gamma \cdot I_{г.в} \cdot z_{г.в}) \cdot \xi_{об}. \qquad (22)$$

7.2 The selection of heating devices and the construction of geothermal heating systems' regulation graphs

Below we have an example of calculating the required nominal heat flow of a geothermal heating system device installed in a premise.

1. The calculated degree of triggering of the heat potential of the coolant is determined by the formula:

$$\tau' = \frac{\tau_{г}'' - \tau_{о}''}{\tau_{г}'' - \tau_{п}}. \qquad (23)$$

If τ > 0,4, the calculation should be made according to the following formula:

$$\varepsilon = \frac{\tau_{\text{г}}^{"} - \tau_{\text{о}}^{"}}{\tau_{\text{о}}^{"} - \tau_{\text{п}}}. \tag{24}$$

2. Let us determine the estimated flow use of coolant through the heating device:

$$G_{\text{в}} = \frac{Q}{c \cdot (\tau_{\text{т}}^{"} - \tau_{\text{о}}^{"})}.$$

3. Taking into account the calculated values, choose the type of heating device and by the formula (1.24) we have calculated loads:

$$\varphi_{\text{відп}} = \frac{t_{\text{п}} - t_{\text{н.ср}}}{t_{\text{п}} - t_{\text{н}}}. \tag{25}$$

4. The calculation of the calculated average temperature head is made by the formula:

$$\Delta t_{\text{ср}} = \left\{ \frac{n \cdot \left[(t_{г}^{"} - t_{\text{в}}) - (t_{\text{о}}^{"} - t_{\text{в}}) \right]}{(t_{\text{о}}^{"} - t_{\text{в}})^{-n} - (t_{\text{г}}^{"} - t_{\text{в}})^{-n}} \right\}^{\frac{1}{1,35}}, {}^{\circ}C. \tag{26}$$

5. Determine the values of $\overline{G_n}$ and $\overline{\Delta t_{\text{ст}}}$ by the formulas:

$$\overline{G_n} = \frac{G_{\text{в}}}{0,1}, \tag{27}$$

$$\overline{\Delta t_{\text{ст}}} = \frac{\Delta t_{\text{ст}}}{70}. \tag{28}$$

The nominal heat flow of a heating device to be installed in a premise is determined by the formula:

$$Q_{\text{н}} = \frac{Q}{\overline{\Delta t_{\text{ст}}}^{1,35} \cdot \overline{G_n}^{\text{р}}}, Bm. \tag{29}$$

To construct a graph of quantitative regulation of the heating load, first determine the value χ.

In the next step, we define an indicator characterizing the regulation of the heating load:

$$\overline{G} = \frac{G}{G^{'}} = \varphi \cdot \frac{t_{г}^{"} - t_{в}^{"}}{(t_{г}^{"} - t_{в}) - (t_{о}^{"} - t_{в}) \cdot \varphi}, \quad (30)$$

where: φ – coefficient of heat release for heating; G and $G^{'}$ are current and estimated coolant costs.

The current temperature of the return water is determined by the formula:

$$t_{о} = t_{в} + (t_{о}^{"} - t_{в}) \cdot \varphi, \quad (31)$$

where: $t_{г}^{"}$, $t_{о}^{"}$ - the calculated temperatures of hot and return water in the heat network, °C.

7.3 The calculation of a complex system of geothermal heat supply

Let us define the main technical indicators of a complex system of geothermal heat supply, which provides heating of greenhouses and hot water supply of buildings, which are necessary for technical and economic calculations.

1. Let us set the calculated temperature of tap water after the heat exchanger:

$$t_{г.в}^{р} = t_{о}^{'} - 5, ^{\circ}C. \quad (32)$$

2. The necessary efficiency coefficient of heat exchanger is determined by the formula:

$$\varepsilon = \frac{t_{г.в}^{р} - t_{вод}}{t_{о}^{'} - t_{вод}}. \quad (33)$$

3. KF work, which characterizes the design and size of the heat exchanger is determined by the formula:

$$KF = \frac{c \cdot 10^{3} \cdot G_{г.в}}{\frac{G_{г.в}}{G_{т}^{'}} - 1} \cdot \ln \frac{1 - \varepsilon}{1 - \varepsilon \cdot \frac{G_{г.в}}{G_{т}^{'}}}. \quad (34)$$

4. Installed thermal power of peak heat source:

$$Q_{\text{п}}^{'} = c \cdot 10^{3} \cdot G_{\text{г.в}} \cdot \left[t_{\text{г.в}}^{'} - t_{\text{вод}} - \varepsilon \cdot (t_{\text{о}}^{'} - t_{\text{вод}}) \right], MBm. \qquad (35)$$

The value of the heat release coefficient, according to the activation (shutdown) of peak heating, is determined according to the formula:

$$\varphi_{\text{п}} = 1 - \frac{Q_{\text{п}}^{'}}{\varepsilon \cdot c \cdot 10^{3} \cdot G_{\text{г.в}} \cdot (t_{\text{т}}^{'} - t_{\text{о}}^{'})} \qquad (36)$$

5. Outside air temperature $t_{\text{ç.ї}}$ is determined by the formula:

$$t_{\text{з.п}} = t_{\text{н}}^{'} + \frac{Q_{\text{п}}^{'} \cdot \left[t_{\text{в}} - t_{\text{н}}^{'} \right]}{\varepsilon \cdot c \cdot 10^{3} \cdot G_{\text{г.в}} \cdot (t_{\text{т}}^{'} - t_{\text{о}}^{'})}, \ {}^{\circ}\text{C}. \qquad (37)$$

The annual flow rate of a geothermal coolant can be determined by defining the area constructed on the basis of the adjustment graph $G_T(\varphi)$ by the formula (25).

7.4 The number of extraction and absorption wells

The number of extraction and absorption wells is determined by the amount of geothermal water required and the productivity of one well:

$$n = \frac{Q}{Q_c}, \qquad (38)$$

where n is the number of extraction or absorption wells; Q – volume of required production of geothermal water; Q_c – estimated productivity of extraction well.

$$Q_c = \frac{4\pi kmS}{\ln \dfrac{2.25at}{r_c^2}}, \qquad (39)$$

where S – reduction in the well (defined as the difference between the pressure at the outlet of the well and the pressure at its intake); k – filter coefficient; m – reservoir power; a – coefficient of piezoconductivity; t – operation time of the geotherm; r_c – well radius.

During the calculations, it must be borne in mind that the extraction wells should be located as close as possible to the consumer, and the absorption wells should be at a distance so as not to affect the temperature regime of the former.

7.5 The calculation of pump power for pumping the coolant into absorption well

Pump capacity is:

$$N = \frac{\gamma QP}{102\eta} \tag{40}$$

where γ is the density of thermal water; Q – geothermal water consumption;

η – Pump efficiency; P – pressure at the inlet of the absorption well.

$$P = \frac{Q_{доб}}{2\pi km} \ln \frac{1.5\sqrt{at}}{r_c}, \tag{41}$$

where Q_{daily} – daily flow of water pumped into the reservoir; k – filter coefficient; m – reservoir power; a – coefficient of piezoconductivity of the collector; t – operating time of the well; r_c – well radius.

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HYDROPOWER AND WIND ENERGY

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1. Hydropower

1.1 General characteritics

Hydropower is energy, concentrated in streams of water masses in river watercourses and tidal movements.

The hydropower plant operates on "free fuel": solar energy evaporates water (mainly from the surface of the oceans), air flows transfer steam to the continents, where it condenses and falls in the form of rain and snow. Moisture falling to the surface of the earth partially evaporates again, partially collects into rivers and flows back into the oceans. The river flow of Ukraine is 46 km^3 water per year (about 20 thousand m^3 per capita).

Hydropower plants mainly operate in the variable peak part of the load graph, and only while flood – in basic mode.

1.2 Types of hydropower plant devices and hydro turbines

They distinguish between derivative hydropower plants, the buildings of which are installed on the channel diverted from the reservoir (the upper buffer of the hydroelectric hub), and the dams, in which the hydro turbines and generators are placed directly in the dam. The low-pressure hydropower plants widely used in the northwest are of the crest type. Their structures typically include a soil barrier blocking the bed and a small concrete dam and the hydropower plant building adjacent to it.

the orifice of the hydropower plant increases with increase in water consumption and the speed of flow of turbine blades.. It is determined by the formula:

$$N = \eta_m \cdot \eta_{ег} \cdot \rho \cdot g \cdot Q \cdot H_{під} \,. \quad (1)$$

where ρ is the density of water, kg/m^3

g – acceleration of gravity, m/s^2

Q – water consumption through the turbine, m^3/s,

$H_{під}$ – water head supplied to the turbine, m,

$\eta_{т}$ – Hydraulic turbine efficiency,

$\eta_{ег}$ – Power Generator Efficiency.

Supplied to the turbine head $H_{під}$ is equal to the difference in levels in the upper and lower reservoir (buffer), excluding hydraulic losses.

The hydropower plant project is being developed on the basis of topographic-geodetic and engineering-geological studies. Long-term observations of the hydrological regime of the river are used: costs, levels, ice regime. The pressure at the hydroelectric unit H_{HPP} is equal to the difference in the water levels of the upper and lower buffers. At H_{HPP} <25 m the plant is referred to as low pressure. The head of the unit (hydraulic unit) is the difference of the specific potential energies at the inlet and outlet of the hydro turbine and is determined from the formula:

$$H_{бл} = H_{ГЕС} - \Delta h_{кін}, \tag{2}$$

where $\Delta h_{кін}$ – loss of kinetic energy in water and drainage structures of the dam. According to hydraulics, these losses are proportional to the square of the water velocity (and therefore the square of the consumption rate). At low-pressure dams with H_{HPP} = 6...8 m the head pressure of the block can be reduced by 10...15% only due to the lattices that hold the garbage.

The water consumption in the reservoir (upper buffer) depend not only on the flow through the dam, but also on the water intake for the needs of water supply, precipitation, evaporation, filtration, ice formation. The consumption in the lower buffer depends on the consumption through the turbines, blank discharges, filtration.

1.2.1 Hydraulic turbines

The conversion of the potential energy of water of a hydro power station into mechanical energy transmitted to electric generators occurs in hydraulic turbines. While turbine operating energy losses occur. Hydraulic losses are associated with viscous friction and vortex formation as water moves through the turbine. Volumetric losses are caused by the flow of some volume of fluid through the intervals between the turbine blades and the walls of the stator unit. Mechanical losses are due to friction in the bearings. The total power loss is taken into account by the efficiency of the turbine η_m. Modern turbines are characterized by values of $\eta_m = 0,85...0,9$.

For low pressure, including small, hydropower plants turbines of a propeller type with a horizontal shaft are optimal. In Fig. 2.1. a hydroelectric unit for microHPP with a capacity of 7 to 50 kW, head – from 3 to 10 m, water consumption – from 0.3 to 0.9 m^3/s is schematically presented. Hydroelectric units of this type are placed in the body of the dam without recess, which reduces the cost of construction of hydropower plants. Dimensions of horizontal turbines are smaller than vertical.

With the increase in the pressure on the dam, the advantages are the hydraulic units with a vertical axis: rotary blade axial, diagonal, radial axial. At very high pressures (hundreds of meters) bucket turbines with a horizontal axis are used.

Capsule reversible hydro-aggregates for hydro-accumulating and tidal power plants are being distributed. In these units, the impeller of the hydraulic machine is located outside the capsule (gondola), and the electric machine is inside it. When the gondola is being flown with the water flow, the unit operates in turbine mode, the electric machine generates current in generator mode. If it is necessary to pump water, the current is supplied to the unit from the energy system, the electric machine operates in the mode of electric motors and rotates the shaft in the opposite direction. In this case, the impeller functions as a pump. For the turbine mode of operation of such units we have values of efficiency at the level of 85%, for the pump mode – at the level of 75%.

1.2.2 The impact of hydroelectric power plant operation on the energy system

An important advantage of hydropower is the high agility of the hydropower units – they can be started at full capacity in a very short time (40...50 seconds). Thermal and nuclear power plants do not have this capability. According to the law of thermodynamics, the efficiency of thermodynamic cycles increases with the increase of the parameters of the coolant – pressure and temperature.

Transition modes (power ups and downs) also pass at low speeds and vary in small ranges. However, energy consumption can vary widely.

At night time there is a "failure" of loading, in the daytime and in the evening – "peaks". If only the thermal and nuclear power plants were to be supplied, they would waste fuel during the load failure.

The uneven schedule causes the thermal power plants to stop at night. The process of starting the boilers and turbines of the TPP is the most difficult in their operation. The greatest danger is caused by the start-ups of the units from the non-cooled state, since the individual elements of the equipment, cooling at different speeds, have different temperatures. There are thermal stresses, changes in the gaps in the connected nodes and parts. Therefore, start-ups and stops of steam turbine units are characterized by the highest accidence and high wear of the equipment. Downtime for boilers and turbines in emergency repairs, overhaul and overhaul costs increase. As a result, the cost of energy at the TPP increases.

Hydraulic power plants are ideal for removing peaks. For this reason, hydroelectric power plants are designed and built at a capacity exceeding the average drainage capacity. They work mainly in the variable part of the load schedule, accumulating water in the upper buffer during periods of load failure and triggering it during the peak.

1.2.3 Pumped hydroelectric energy storages

Increasingly, Pumped hydroelectric energy storages (PHES) that operate in alternating mode are increasingly used in the world energy: energy accumulation (charge) is replaced by energy recovery (discharge).

A charge is the lifting of water by hydromachines from the lower to the upper reservoir (at night, on weekends and holidays when there is a load failure in the energy system). This generates excess capacity of thermal and nuclear power plants. Discharge – in hours of maximum load or in case of accidents at other power plants; the potential energy of the raised water is converted into electrical energy in the turbine and generator. Thus, when charging, the PHES operates as a pumping station and at discharge – as a conventional HPP. Having spent four units of electricity on the charge, we return three units at discharge. The power consumed by the charge when the PHES is operating in pumping mode is determined by the formula:

$$N_н = \eta_н \cdot \rho \cdot g \cdot Q \cdot h_н / 1000, кВт, \quad (3)$$

where $h_н$ is the given head (sum of static head and loss),

$\eta_н$ – pump mode efficiency.

In the plain part of Ukraine, the head of possible PHES do not exceed 120 m, in the Carpathians, the construction of PHES with a head of 400 m is possible.

Semi-peak PHES are also being developed, designed to operate in a 10...12 hour zone. Semi-peak PHES require the construction of larger storage tanks and higher pumping capacity comparing to turbines. Powerful pumps have to be installed in addition to reversible hydraulic units.

1.2.4 Tidal power plants

The attraction of the moon and the sun generate a tidal wave in the oceans. The height of this wave is maximum when the Earth, the Moon and the Sun are on the same line, and it is minimum when the directions to the Moon and the Sun make a right angle. As a result of the daily rotation of the Earth, the wave is accumulated on the shores of the continents. The amplitude of the tidal fluctuations of the level on the shores depends on the bottom relief and the shape of the shoreline. For example, the maximum height of tidal fluctuations in the Bay of Fundy (Atlantic coast of Canada) is 19.6 m.

1.2.5 Wave Energy

From the energy point of view, sea waves are a concentrated form of wind energy. Winds that blow over the ocean are wreaking waves, the strength of which depends on the speed of the wind and the length of the run. In the waves water particles make circular motions. The wave height is equal to the diameter of the circular orbit of a particle on the surface.

The mechanical energy of the wave is proportional to the length and the square of the height. The energy of a wave of six meters in height exceeds 100 kW per 1 linear meter of wave front. Average for ocean waves energy is estimated at 50 kW/m. Experts have estimated that taking into account the inevitable losses of wave energy use on the coast of England would give 120 GW, which is more than the total power of the country's power plants. The total wave power of the oceans is estimated at 2700 GW.

1.3 Basic indicators of hydrological calculations

The drainage rate is the ratio of the average long-term value of river costs (over 40… 50 years) to the intake area.

The drainage module expresses the rate of runoff in specific units, i.e the ratio of the amount of water (in l/s) flowing from one square kilometer of the intake area:

$$M_0 = \frac{1000 \cdot Q_0}{F}, л/с \text{ with } 1км^2 \quad (4)$$

where Q_0 – average long-term costs, m^3/s; F – water intake area in km^2.

Stock volume:

$$W = Q_0 \cdot T, \quad (5)$$

where T is the number of seconds in the period over which the drainage is measured.

Annual height of water (drainage layer):

$$h_0 = \frac{W_0 \cdot 10^3}{F \cdot 10^{12}} = M_0 T. \quad (6)$$

Modular coefficient is the ratio of drainage value to average multi-year drainage value over the same periods:

$$k_i = M_i / M_0 = W_i / W_0. \quad (7)$$

It can be annual, seasonal, monthly, maximum and minimum.

Drainage coefficient is the ratio of the height of the drainage layer (h) to the amount of precipitation (χ), which fell in the drainage basin:

$$\eta = h / \chi. \quad (8)$$

The calculation of the percentage of availability of annual drainage for each year of observations is calculated by the formula:

$$P = \frac{m - 0,5}{n} \cdot 100, \%, \quad (9)$$

where P is the percentage of availability of annual drainage for each year of observations;

m is the ordinal number of a member of a row when positioning them in the direction of decrease;

n -is the number of all members in a row.

To determine the ordinates of the availability curve, you need to know three numerical parameters: drainage rate (Y_0); the coefficient of variation (c_v) is the ratio of the root-mean-square deviation to the arithmetic mean of the series *Y*; c_s – asymmetry coefficient, which characterizes the amplitude of fluctuations in drainage values in a number of observations:

$$c_v = \sqrt{\frac{\sum(k-1)^2}{n-1}}, \tag{10}$$

where $k = Y_i / Y_0$ – modular coefficient;

$$c_s = \frac{\sum(k-1)^3}{(n-1)c_v^3}. \tag{11}$$

In short-term observations, the following value is assumed: $c_s = 2c_v$.

To move from table values to others, use the ratio:

$$k = \Phi \cdot c_v + 1, \tag{11}$$

where Φ is the deviation of the ordinates of the availability curve (Annex 1); c_v – calculated coefficient of variation for a given series.

In the absence of these observations of the drainage or their short duration (less than 10 years), the value of the coefficient of variation is determined by the approximate expression:

$$c_v = 0.723 - 0.213\lg M_0 - 0.063\lg(F+1), \tag{13}$$

where M_0 – drainage rate; *F* – intake area.

The intra-annual drainage distribution depends on climatic conditions and is given in annex 2 for the country's macro-regions. It serves while calculations when there is no information for a specific object. In annex 3 the approximate magnitude of the specific maximum consumption of spring floods is given. To obtain the estimated value, the table data must be multiplied by the intake square. Maximum summer and autumn rainfall floods are much lower than spring ones.

1.4 The calculation of low power hydropower plant

To carry out the calculations we set the following symbols: set by marks natural water levels – V (m); flow length – L_j (km); water consumption – Q_j (m^3/s); j is the number of the gate (j = 1,..., 10), where the numbering of the objects goes from top to bottom according to the river flow; restriction on the maximum raising of the water level – Z_{max}; $Д_1$(m) – impeller diameter; $h_{доп}$(m) – minimum permissible depth of flow for installation of free-flow units for set values $Д_1$ and V_p (m/s) – flow velocity; L_{min}(m) is the minimum permissible distance between free-flowing units, placed in a raw along the river.

The calculation of the main categories of winter non-freezing potential of the flow is done for hydrological conditions that correspond to an availability of 50%. Flow consumption in each gate is considered constant throughout the year, Q_i = const.

Only HPP that do not alter the natural hydrological flow regime are considered. For these hydropower plants, a constant time level of water in the reservoir or upper buffer (UB) is assumed to be any hydropower station $(Z_{ВБ})$ and equal to the NSL (m) – the normal supporting level, i.e

$$Z_{ВБ}(t) = НПР = const \tag{14}$$

Accordingly, all natural flow consumption is skipped without redistribution in time to the lower buffer (LB) of the HPP:

$$Q_{НБ}(t) = Q(t). \tag{15}$$

The installed power of the HPP dams $N_{вст1}{}^{ГЕС}$ (kW) is determined in each 1st calculated gate of the HPP by the formula:

$$N_{вст1}{}^{ГЕС} = 9{,}81 \cdot \eta_{ГЕС} \cdot Q_{розр} \cdot Ha_i = K_n \cdot Q_{розр} \cdot Ha_i \tag{16}$$

where $\eta_{ГЕС}$ (0.e.) – HPP efficiency, and K_n = 9.81 n_{HPP} – power coefficient;

It is accepted that

$$Q_{розр} = 0{,}6 \cdot Q_i, \tag{17}$$

where Q_i (m^3/s) is the flow consumption in the i-th calculated gate; Ha_i (m) is the head of the HPP unit, defined by the formula:

$$Ha_i = НПР_i - Z_{НБi}, \tag{18}$$

where $НПР_i$ (m) is the normal supporting level of the upper buffer (UB) of the HPP in the 1st gate.

$Z_{НБi}$ (m) is the estimated level of the lower buffer (LB) of the HPP in the 1st gate, which is differently determined depending on the type of cascade and restrictions on the level of the LB.

For the lowest one down the flow (HPP1):

$$Z_{НБi} = Z^{\min доп} = 102м = const. \tag{19}$$

For a closed cascade of the HPP dams "down the flow" (except HPP at the mouth of the flow):

$$Z_{НБi} = НПУ_{i+1}. \tag{20}$$

For the open cascade of the HPP dams "down the flow":

$$Z_{НБi} = V_i + \Delta Z_{НБi} = V_i + 0.256 \cdot Q_{роз}, \tag{21}$$

where V_i(m) – the mark of the water level in the i-th gate

The number of hours of use of the HPP installed capacity "down the flow" – h (hours) is taken to be equal to 3000 hours.

The 1st supply of hydroelectric power from HPP is considered efficient (expedient) if the distance from the consumer to the flow or location of the HPP (L_l) is less than the economic radius (R_l), i.e L_l<R_l.

The calculation of the water-energy cadastre of the flow is carried out using the method of "linear accounting".

The length of the flow between the j and j-1, ie $l_{1,\ j-1}$ is determined by the formula:

$$I_{1,j-1} = L_j - I_{j-1}, м. \tag{22}$$

Head of the same section:

$$H_{j,j-1} = V_{j-1} - V_j, м. \tag{23}$$

Average cost per division:

$$Q_{j,j-1} = 0.5 \cdot (Q_j + Q_{j-1}), м^3 / с. \tag{24}$$

Potential flow capacity at the same division:

$$N_{j,j-1} = 9.81 \cdot H_{j,j-1} + Q_{j,j-1}, кВт. \tag{25}$$

Specific flow power:

$$iN_{j,j-1} = N_{j,j-1} / I_{j,j-1}, кВт / км. \quad (26)$$

Gross flow potential

$$N_{вал} = \sum_{j=2}^{10} N_{j,j-1}. \quad (27)$$

2. Wind energy

2.1 Wind energy resources

Winds are the currents of atmospheric air generated by the uneven heating of the Earth's surface by solar radiation. Wind energy has been used by humankind since time immemorial, mostly in sailing shipping and windmills. For example, in the Netherlands, windmills have been pumping water from polders, land bonings lying below sea level, for more than 500 years. Multi-bladed windmills in the United States have been widely used to pump water from wells; in the 30s of the twentieth century, there were more than 6 million units.

The European wind farms are located mainly on the coasts of the Baltic, North Seas and Atlantic Ocean. Offshore wind turbines are popular when installed away from the shore, problems of land alienation for construction are eliminated, and noise loads are reduced.

According to the Interdepartamental Scientific and Technical Center of Wind Energy of the National Academy of Sciences of Ukraine, the territory of our country has considerable wind energy resources, which are estimated at 30 TWh/y.

Today, 13 wind power plants have been built in Ukraine: 10 in the Autonomous Republic of Crimea (of which only 6 operate), one wind farm in the Donetsk and Mykolaiv regions, as well as one plant near Truskavets in the Carpathians.

Also today there is a number of opinions against the development of wind power. Windmills and power lines are thought to damage the landscape. You can hear noise, possible infrasound vibrations, possible interference with television, at a distance up to a kilometer. Therefore, in

Western Europe, wind farms are being built in shallow water, at some distance from the seashore. Birds can suffer from windmill blades.

2.2 Designs of wind motors and wind power plants

A wind stream passing through a square*F*flowing between the blades of the wind motor has energy

$$E = m \cdot w^2 / 2 Дж, \tag{28}$$

where *w*- wind speed, m/s,

m – mass of air.

Per second through the area *F* mass $m = \rho \cdot w \cdot F$ kg/s flows, where $\rho = p / RT$ – air density, kg/m, *p*- atmospheric pressure, Pa, *R* = *287* J/(kg·K) – gas constant, *T* – absolute temperature, K. For a blade wind wheel, the square*F* is determined through the length of the blade *L*: $F = \pi L^2$. Accordingly, the electrical power *N* increased by the wind turbine, is determined by the formula

$$N = \eta_в \cdot \eta_{ег} \cdot \rho \cdot \pi \cdot L^2 \cdot w^2, Вт, \tag{29}$$

where η_{in} – Wind turbine efficiency,

η_{er} – Electric efficiency of wind generator and transducer (within 0.70...0.85).

It has been experimentally established that windmills with a vertical rotor axis are less efficient than wind wheels with a horizontal axis and with two or three blades. Modern blades are made of fiberglass, designed using hydrodynamic methods taking into account a three-dimensional wrap. The width (chord) of the blade is reduced to its end, this is done to reduce noise. Noise level near full-capacity wind turbine does not exceed 100 dB. The length of the blade reaches 50 m, respectively, the height of the mast tower exceeds 50 m. The efficiency of modern windmills $\eta_в$ is at the level of 25…33%. The wind turbine operation is calculated at a wind speed of 3 to 25 m/s, the maximum estimated wind speed before the rotor is destroyed is 60 m/s.

2.3 Operation of wind power plant for the energy system

Wind speed varies throughout the day and is usually seasonal. Accordingly, the power of the energy produced by wind power plants changes, and excesses and failures of its share in the load of the energy system occur. Therefore, in order to maintain the frequency of the current, it is necessary to have a reserve capacity in the power system. The simplest solution is working together on the energy system of wind and hydraulic power stations, including HPP. Excess energy produced by wind farms during hours of minimum power consumption can be accumulated by pumping water into the pool above. It can be used by pumping compressed air into underground reservoirs or by producing hydrogen fuel by electrolysis of water.

In Ukraine, the production of wind power plants was established at Dnipropetrovsk "Southern Machine-Building Factory". Ukrainian power machinery engineering has sufficient experience for solving mechanical and electromechanical problems of wind turbine development and production. However, there are concerns about freezing the rotor in winter, especially in regions where cold air is adjacent to the non-freezing sea. According to literary data, in Denmark and northern Germany, operating wind turbines do not freeze in winter, as vibrations of fiberglass blades shake off stuck pieces of ice. However, when the wind turbine is stopped, the icing of rotor can cause destruction.

2.4 The calculation of wind power plant

2.4.1 Average monthly and average annual wind speed

Data on average monthly and annual wind speeds are presented for selected plants in Table 1.

Table 1. presents wind speeds for the height of the weather vane below the estimated wind turbine. Therefore, for further calculation we will need a correction coefficient of altitude k_h and wind speed at a height of 60 m *U*, which are determined by the formulas:

$$k_h = \left(\frac{H}{h_ф}\right)^m, \qquad (30)$$

$$U_н = U_ф \cdot k_h. \qquad (31)$$

where k_h is the height correction coefficient (Hellmann exponent);

H – the height at which you want to know the wind speed *U*;

$h_ф$ – weather vane height;

m = 0,14 – indicator of degree function, varying depending on wind speed and meteorological conditions;

$U_н$ – wind speeds at height H = 60 m;

$U_ф$ – wind speed at the height of the weather vane.

Table 1

Average monthly and average annual wind speed

Plant	The height of the weather vane $h_ф$, m	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	$Uph_ф$	Up H = 60m
Wind speed at the height of the weather vane	16	7,5	6,5	5,9	5,0	4,7	4,9	5,1	5,7	6,2	6,8	6,8	7,6	6,1	
Wind speed at the height of the wind turbine tower		9,0	7,8	7,1	6,0	5,7	5,9	6,1	6,9	7,5	8,2	8,2	9,1	–	7,3

2.4.2 The repeatability of wind directions and calms

Repeatability of wind and calm directions is presented in Table 2.

Table 2

The repeatability of wind directions and calms

Plant	Rhumb	North	North-East	East	South-East	South	South-West	West	North-West	Calm
Baltiysk	ΔΦ,%	11	8	12	11	14	16	14	14	3
	K	10b	9b	9b	9b	9b	10b	10b	10b	

The data presented in table 2.2, allow you to determine the class of openness weather stations. The general openness class of the station $K_{заг}$ is determined by the formula:

$$K_{заг} = \sum_{1}^{8} K_{табл} \cdot \Delta\Phi, \tag{32}$$

where $K_{табл}$ is a table class of openness for each rhumb of the wind direction (in this case $K_{табл}$ is the same for all directions);

$\Delta\Phi$ – table value of the wind frequency of a given rhumb per year,%.

It should be borne in mind that $\sum_{1}^{8} \Delta\Phi = 100\%$, excluding the calm. However, many, and often most, weather stations are not representative. Therefore, in wind energy calculations, the data of all weather stations are processed.

Since wind energy resources are determined for open-area conditions, which may involve the construction of wind turbines and wind farms, a correction coefficient of openness $\hat{E}_{î}$ is introduced, which can be determined by the formula:

$$K_o = \sum \frac{K_{\max}}{K_{табл}} \cdot \Delta\Phi, \tag{33}$$

where $K_{\max}$ is the maximum openness coefficient accepted:

$K_{\max} = 9$ – for areas situated on the coast of the sea or ocean, and for islands;

$K_{\max} = 8$ – for coastal areas

$K_{\max} = 7$ – for areas farther from the shoreline.

If the maximum value of the table coefficient of openness is $K_{табл.\max}$ greater than the above values of $K_{макс}$, then it should be accepted: $K_{\max} = K_{табл.\max}$.

Station openness class $C_{total} = 9.55$.

2.4.3 The probability of wind speed by gradation

Probability of wind speed by gradation is the most important characteristic of the wind cadastre. This distribution characterizes the frequency or probability of the values of the set wind speeds (gradation) in% of the total number of cases over the considered period of time (month, year).

The probability of wind speed on gradients for all stations is presented in Table 3.

Table 4. presents the differential repetition of the mean induced wind speed by months in gradations in % of the total number of cases. The values of the differential frequency of wind speed by months are determined by the known values of the average monthly wind speed calculated in table 1., for the first type of velocity distribution (open sea coast).

Table 3

The probability of wind speed by gradation Baltiysk (% of total cases)

Graduation of speed	U_{gr}	0-1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-20	21-24	25-28	29-34
Average graduation value	U	0,5	2,5	4,5	6,5	8,5	10,5	12,5	14,5	16,5	19	22,5	26,5	31,5
Differential repeatability	dF = f(U)	4,2	10,5	13,0	13,8	13,3	11,7	9,7	7,7	5,7	5,5	4,9		
Integral repeatability	F(U)	4,2	14,7	27,7	41,5	54,8	66,5	76,2	83,9	89,6	95,1	100,0		

Table 4

The differential repetition of the wind speed by months in gradations in % of the total number of cases

Month U_{pr}, m/s	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0,5	0,8	1,1	1,3	1,6	1,8	1,7	1,6	1,3	1,2	1	1	0,8
1	4,15	5,1	5,9	7,5	8,1	7,7	7,3	6,2	5,4	4,7	4,8	4
2	5,7	7	8,1	10,1	10,8	10,3	9,8	8,4	7,4	6,5	6,6	5,6
3	6,75	8,2	9,3	11,4	12,1	11,6	11,1	9,7	8,6	7,7	7,8	6,6
4	7,35	8,8	9,9	11,7	12,3	11,9	11,5	10,2	9,2	8,3	8,4	7,2
5	7,7	9	9,9	11,2	11,6	11,3	11,1	10,1	9,4	8,5	8,6	7,5
6	7,75	8,8	9,5	10,2	10,3	10,2	10,1	9,6	9,1	8,4	8,5	7,7
7	7,6	8,4	8,7	8,8	8,7	8,8	8,9	8,8	8,5	8,1	8,2	7,5
8	7,3	7,7	7,8	7,3	7	7,3	7,4	7,7	7,7	7,6	7,6	7,2
9	6,8	6,9	6,7	5,9	5,4	5,7	6	6,6	6,8	6,9	6,9	6,8
10	6,2	6	5,6	4,5	4	4,3	4,6	5,4	5,9	6,1	6,1	6,2
11	5,6	5,1	4,5	3,3	2,8	3,1	3,4	4,3	4,9	5,3	5,3	5,6
12	4,9	4,2	3,6	2,3	1,9	2,2	2,5	3,4	4	4,5	4,5	4,9
13	4,25	3,4	2,7	1,6	1,3	1,5	1,7	2,5	3,2	3,8	3,7	4,3
14	3,6	2,7	2,1	1,1	0,8	1	1,2	1,9	2,5	3,1	3	3,7
15	3	2,1	1,5	0,7	0,5	0,6	0,7	1,3	1,8	2,4	2,4	3,1
16	2,45	1,6	1	0,4	0,3	0,4	0,5	0,9	1,4	1,9	1,8	2,5
17	1,95	1,2	0,7	0,2	0,2	0,2	0,3	0,6	1	1,5	1,4	2,1
18	1,55	0,9	0,5	0,1	0,1	0,1	0,2	0,4	0,7	1,1	1	1,7
19	1,2	0,6	0,3	0,1	-	0,1	0,1	0,3	0,5	0,8	0,8	1,3
20	0,95	0,4	0,2	-	-	-	-	0,2	0,3	0,6	0,5	1
21	2,45	0,8	0,2	-	-	-	-	0,2	0,5	1,2	1,1	2,7

2.4.4 The type and characteristics of wind power plant

The wind farm is planned to include wind farms of the Danish NEG MICON company of the NM 1500/64 type with a capacity of 1500 kW. This installation applies to high capacity wind turbines.

Main technical characteristics of MICON NM 1500/64:

- installed (nominal) capacity – $N_{wind\ turbines}$ = 1500 kW;
- wind wheel diameter – D = 64 m;
- tower height – H = 60 m (conical tower);
- area of the air flowing around the wind wheel – S = 3217 m^2;
- minimum wind speed – u = 4 m/s;
- nominal wind speed – u = 16 m/s;
- maximum wind speed – u = 25 m/s;
- the number of blades – 3 pcs.

Frequency of wind wheel rotation – of 17 t/m.

Asynchronous generator with two pairs of poles. Nominal frequency of electric current 50 Hz. Nominal voltage 690 V.

Weight of three blades – 16,5 t. Weight of one blade, respectively – 5,5 t.

Weight of the hub of a wind wheel of 14 t.

Weight of the tower – 83 t.

Weight of the gondola with a rotor and a shaft – 55 t.

Total weight of the structure: 170 t.

2.4.5 Capaciry return characteristic

The capacity return characteristic depending on wind speed of this wind turbine «Micon NM 1500/64» is presented in fig. 1.

The characteristics of wind turbines indicate the following characteristic values of wind speed:

u_0 = 4 m/s – the minimum wind speed at which the wind turbine starts to give capacity;

u_p = 16 m/s is the estimated wind speed at which the wind turbine power reaches a value equal to its installed capacity;

u_{max} = 25 m/s – maximum wind speed above which the wind turbine stops automatically.

Below the dependence of wind turbine capacity on wind speed is given (Table 5).

Table 5

Table of dependence of wind turbine capacity on wind speed

u	m/s	4	5	6	7	13,5	14	15	16	17	17,5	25	25	30
N	kW	0	50	125	250	1390	1450	1490	1500	1475	1450	1250	0	0

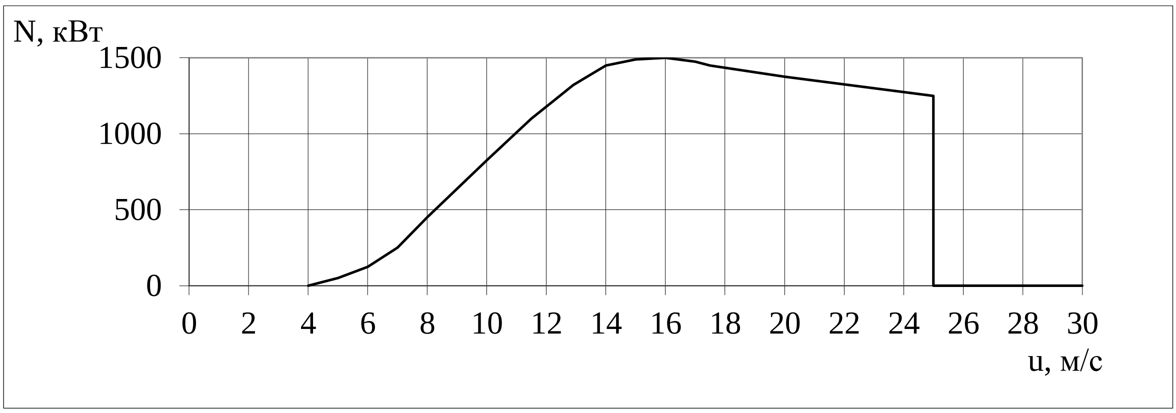

Fig. 1 Capaciry return characteristics of wind turbine MICON NM 1500/64

2.5. The description of the device of the wind power plant

Consider a longitudinal section of the gondola (Fig. 5).

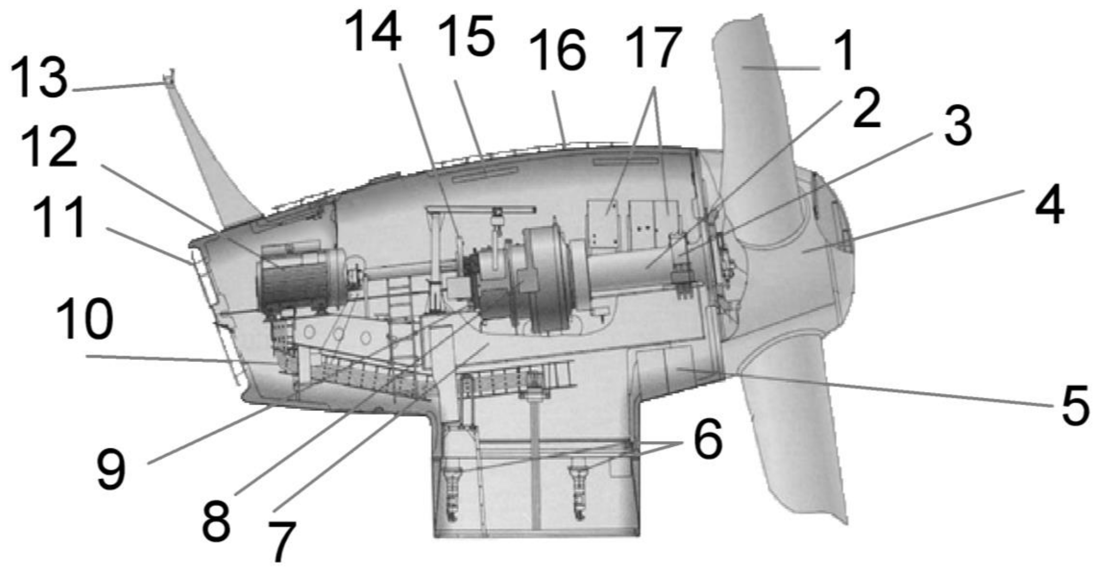

Fig. 2 Longitudinal section of the gondola:

1 – blade; 2 – main shaft; 3 – main bearing; 4 – hub; 5 – air insert; 6 – engine of deviation from the course (rotary device of the gondola); 7 – main construction of the gondola; 8 – reduction gear; 9 – collector rings; 10 – generator cables; 11 – lattice; 12 – generator; 13 – anemometer; 14 – crane (auxiliary equipment); 15 – brake disc; 16 – windows; 17 – remote control.

Wind turbines have three blades made of metal. The place where these blades converge is called the hub (4). In the hub the devices that rotate the blades around its axis are hidden. The hub is rigidly connected to the shaft (2).

The generator rotor is connected to the main shaft. The shaft leans by the main bearing (3) and reduction gear (8) on the main gondola structure (7). A reduction gear is required to convert the frequency of the generator shaft (18) rotation. Reduction gear with gear ratio 1:87,8. Generator (12) operates in a mode with a constant rotation speed of blades and variable speed. An asynchronous generator with two pairs of poles is located in the tail part of the gondola. The generator cables (10) are connected to the collector rings via the collector. The collector rings act as fixed tires.

The working space in the gondola allows two specialists to work freely.

An anemometer (13) and a wind direction picker are installed at the top of the gondola. As the wind direction changes, the rotary device (6) deploys the rotor downwind. If the speed of the wind exceeds the maximum, then the signal from the anemometer is transmitted to the rotating device of the blade and deploys the blade (stopping the wind wheel).

2.6 Wind power plant layout

2.6.1 The determination of the main technical and economic indicators of wind power plant

The location of wind turbines in the wind farm on the area is performed in accordance with the wind rose and the area relief of the given map. It should be borne in mind that the distance between wind units should be at least (5÷10) diameters of the WT.

This calculation assumes the installation of 16 wind installations at a distance of 7 WT diameters, i.e 450 m along the prevailing wind direction, and at a distance of 5 WT diameters, i.e 350 m, in a perpendicular direction. Thus, the total capacity of the wind farm will be 24 MW.

In order to ensure access to the facilities, it is necessary to provide access paths not less than 6 m wide and, in addition, a common road leading from the city to the wind plant.

2.7 Wind power plant and the environment. Environmental factors

Let us consider the main types of environmental impact of wind farms.

1) Land alienation.

The layout of the wind turbine in the wind farm is shown in the diagram. The area of land seizure is m^2. The area of exclusion for individual wind turbines, industrial buildings and structures is 20% of the total extraction area (km^2). Traditional economic activities may be conducted in the rest of the WPP territory, with certain restrictions.

2) Emergencies.

During operation of wind turbines there is a danger of destruction and flying away of moving parts of the WT. Depending on the $N_{wind\ turbine}$, D_{WT}, material, wind force, the danger zone while the destruction of wind turbines may be different:

at U<25 m/s L_{fl} = 9 D_{wt} = 576 m;

at U>25 m/s L_{fl} = 25 Dwt = 1600 m.

Positive factors for the use of wind energy: reduction of carbon dioxide emissions; slight alienation of land[6,7,8,9,10,11,12,13].

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SUN ENERGY

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1. Solar Energy Resources

The local values of the sun's radiation energy coming to the surface of the lithosphere or hydrosphere depend on the orientation to the sun (luminoity), cloudiness, air dust, altitude, seasons and daytime. In the mid-latitudes in the afternoon, the intensity of solar radiation reaches 800 W/m in summer and 200…350 W/m in winter, decreasing to zero with the sunset.

The radiant energy of the sun has been used by the biosphere since the advent of life on the planet. The transformation of solar energy into mechanical energy was first demonstrated at the World's Fair in Paris, when a solar collector set in motion a steam engine.

Radiation from the Sun's surface is characterized by a broad energy spectrum, which roughly corresponds to the energy spectrum of blackbody radiation at 5800K. The maximum of the intensity lies in the visible region of the spectrum (0.35–0.75 μm), in which almost half of all energy is concentrated. The rest of the solar radiation is distributed between the ultraviolet part of the spectrum with a wavelength of less than 0.3 μm (smaller part) and the infrared with a wavelength more than 0.75 μm (bigger part). The intensity of solar radiation near the Earth's atmosphere is 1360 W/m2 – known as the solar constant AM0. When passing through the Earth's atmosphere, the intensity of solar radiation decreases due to its absorption, scattering and reflection during interaction with dust particles, oxygen, ozone, carbon dioxide, water vapor. When interacting with ozone and oxygen, the absorption of solar radiation occurs mainly in the ultraviolet part of the spectrum, water vapor and carbon dioxide absorb mainly in the infrared part. Therefore, the solar radiation that reaches the Earth's surface has less energy and its spectrum changes. The method of direct conversion of solar radiation into electricity is, firstly, the most convenient for the consumer, as it produces the most consumed kind of energy, and secondly, this method is considered to be an environmentally friendly means of generating electricity unlike others that use organic fuel, nuclear raw materials or hydraulic resources[1].

The average annual amount of total energy from solar radiation that enters the territory of Ukraine annually is in the range from 1 070 kWh/sq.m. in the northern part of Ukraine up to 1 400 kWh/sq.m. and higher in the Autonomous Republic of Crimea.

Photovoltaic equipment can operate efficiently enough throughout the year, however, as effectively as possible – for 7 months a year (from April to October).

The transformation of solar energy into electric power in the conditions of Ukraine should be oriented in the first place on the use of photovoltaic devices. The availability of significant reserves of raw materials, industrial and scientific and technical basis for the production of photovoltaic devices can to the full provide not only the needs of domestic consumers, but also export of more than two-thirds of the produced capacity.

As of 01.01.15, 98 solar plants with a total installed capacity of 819 MW operated in Ukraine, having generated 485 million kWh of electricity in 2014.

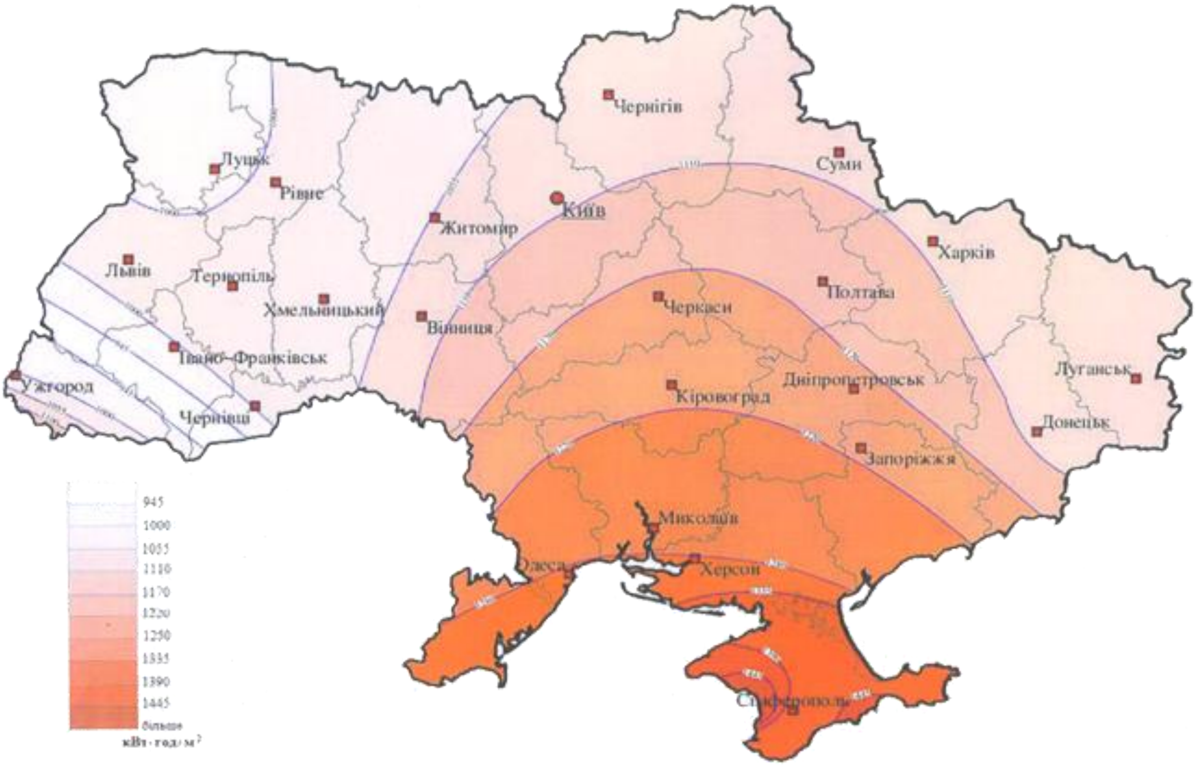
Taking into account the experience in the introduction of solar power plants (hereinafter – SPP) in European countries with similar levels of solar radiation, and also in view of the global tendencies of permanent decrease in the cost of construction of SPP due to technology development, in Ukraine due to the improvement of technology and commissioning of new facilities SPP electricity production can be significantly increased.

Roughly the territory of Ukraine can be divided into four zones depending on the intensity of solar radiation[2].

The experience of EU and North American countries shows that solar energy can be used on an industrial scale even at night. In Spain and the United States, there are businesses that, in the dark, generate electricity from the heat accumulated per day.

Solar-powered (solar) plants are completely silent. A significant drawback is that such stations occupy large areas. Each 1 MW of SPP capacity requires at least 1.5 ha of land. The disadvantage is that the energy output is inconstant. Today SPP accounts for about 4% of renewable electricity in the world. The transformation of solar energy into electrical energy is mainly due to the use of photovoltaic evements.

[1] URL: https://otherreferats.allbest.ru/physics/00097451_0.html
[2] URL: http://saee.gov.ua/uk/ae/sunenergy



Розподіл питомої сумарної сонячної радіації на території України протягом року
(Національний атлас України. – К.: ДНВП «Картографія», 2007)

With the help of the sun energy, it is possible to partially supply electricity to private sector residents (in parallel with the operation of the electricity grid). To do this, photovoltaic elements, located on the roof of the house, are used.

In private homes, solar collectors (SC) can be used to produce heat in a hot water supply system. Solar collectors are capable of heating water up to 70 °C. In the afternoon, the SC transforms the sun energy into heat, which heats the water that is accumulated in heat-insulated tanks (storage tanks). Water is supplied to the hot water supply system from the storage tanks. SC are installed on the roof of the house, and the storage tank and auxiliary equipment are installed in the technical room[3].

2. Solar-powered non-mechanical electrical installations

In non-machine solar power plants, the energy of the solar radiation is directly converted into electrical energy, without an intermediate transition into mechanical energy. Turbines and generators are not required for direct conversion.

[3] URL: http://saee.gov.ua/uk/ae/sunenergy

2.1 Thermoelectric transducers

The direct conversion of solar thermal energy into electricity is based on the Seebeck effect, which was discovered in 1821. If you connect two conductors of different chemical composition with the ends and place the solders in mediums with different temperatures, then thermoelectric power occurs between them:

$$E = \alpha \cdot (T_1 - T_2) \quad (1)$$

where T_1 – the absolute temperature of the hot junction,

T_2 – absolute cold junction temperature,

α- proportionality coefficient.

A current Joccurs in the conductor circuit, with hot junction absorbing heat from the heated source in the amount of $Q_1 = \alpha \cdot T_1 \cdot J$ per second, and cold junction giving heat to the low temperature body in the amount of $Q_1 = \alpha \cdot T_1 \cdot J$. The difference between the inlet and outlet heat is the instantaneous operation of the current

$$L = \alpha \cdot (T_1 - T_2) \cdot J, Bm. \quad (2)$$

The ratio of work to the inlet heat is the thermal efficiency of the conversion process

$$\eta_t = L / Q_1 = \alpha \cdot (T_1 - T_2) \cdot J / \alpha \cdot T_1 \cdot J = (T_1 - T_2) / T_1. \quad (3)$$

Thus, the efficiency of an ideal thermoelectric transducer coincides with the thermal efficiency of the Carnot cycle and is completely determined by the absolute temperatures of hot and cold junctions. In real transducers there are irreversible losses due to the electrical resistance of the conductors, their thermal conductivity and the thermal resistance of the heat transfer of the junctions with the environment. Therefore, the actual installation efficiency is equal to

$$\eta = \eta_{oe} \cdot (T_1 - T_2) / T_1, \quad (4)$$

where η_{oe} <1 is the relative electrical efficiency of the transducer (named so by analogy with the relative internal efficiency of the turbine, which takes into account the irreversible throttle losses).

When using metal thermoelectrodes the efficiency of thermoelectric transducers is very small – it does not exceed one hundredth of a percent.

2.2 Photoelectric transducers

The principles of this type of installations are based on the principle of electrons being knocked out of semiconductor materials by light quanta. Radiation energy is converted into electrical energy. In modern solar energy semiconductor transducers of pure crystalline silicon are widely used. Silicon is a widespread element in the Earth's crust; sand, quartz are silicon dioxide SiO_2 . The production of pure silicon at the end of the twentieth century made it possible to adjust the production of a number of semiconductor devices, in particular processors for modern computers.

The power of the SPP with photoelectric transducers is determined by the ratio

$$N_{фе} = \eta_{фе} \cdot F_{фе} \cdot I, Bm, \quad (5)$$

where $\eta_{фе}$ – efficiency of photoelectric transducers (varies in modern silicon elements within 0,12...0,17), $F_{фе}$ – their total square, m^2.

Industrial production of photovoltaic transducers, modules and solar power plants in Ukraine has quadrupled in the last three years. Solar energy is nowadays a serious alternative to traditional energy, since direct conversion of solar radiation to electricity is the most efficient use of solar energy carried out by means of semiconductor photoelectric transducers. Yes, the production cycle of Quasar OJSC is a positive example of the Ukrainian experience in forming a production chain, starting with the production of mono-multi-silicon and ending with the installation of systems. This enterprise is the largest industrial producer in Ukraine, which in its work covers the main part of the production cycle from growing semiconductor material to installation of finished photovoltaic systems of autonomous power supply. Also one of the largest participants in the market of "solar" silicon is the capital CJSC "Pillar" (more than 2500 tons per year), which supplies its products to many foreign manufacturers of solar elements.

The total amount of heat received by the solar energy steam generator is

$$Q = \eta_{в} \cdot n \cdot F \cdot I, Bm, \quad (6)$$

where $\eta_{в}$ – the coefficient of efficiency of the use of solar radiation (varies within 0.35...0.5), n – number of heliostats,

F – mirror square of one heliostat, m^2,

I – intensity of solar radiation, W/m^2.

The wwork of 1 kilogram of steam in a steam turbine unit in the Rankine cycle is equal to

$$I = h_1 - h_2, кДж / кг. \quad (7)$$

Thermal Efficiency:

$$\eta_t = (h_1 - h_2) / (h_1 - h_k), \quad (8)$$

where h_1 – enthalpy of hot steam,

h_2 – enthalpy of steam exhausted in the turbine (determined by h – s diagram of water vapor), h_k – enthalpy of condensate (determined by the tables of thermodynamic properties of water and water vapor).

The theoretical power of the steam turbine of ST will be:

$$N_{nm} = \eta_t \cdot \eta_{oi} \cdot \eta_e \cdot QBm, \quad (9)$$

where η_{0i} – relative internal efficiency of the turbine,

η_e – efficiency of the generator (within 0.92...0.96).

The actual capacity of the SPP is less than the theoretical capacity due to energy consumption for own use (pump drive, etc.).

3. Solar heat supply

Solar water heaters have been used for heating and hot water supply since the beginning of the twentieth century. Up to now, due to state-supported energy-saving programs in a number of countries (USA, Germany, Norway) solar collectors, installed on the roofs or glazed porches and made of polymeric plastics with glass, are widespread.

The device of the solar module-water heater is very simple. A flat screen with tubes welded from below is illuminated by sunlight. Tubeless screens are also used, in the form of two plates with a gap between them. The screen is connected by tubes to the top and bottom of the storage tank. The natural circulation is installed in the circuit: cold water enters the pipes from the bottom of the tank, the water heated in the pipes of the screen with lower density flows into the upper part of the tank. The top of the screen is painted with black matte paint to increase the coefficient of absorption of the radiant energy, and covered with glass or polymer membrane to protect from precipitation. In regions with negative temperatures, the circuit is filled with an aqueous antifreeze solution; solar-heated antifreeze gives heat to the water of the storage tank in a tubular heat exchanger.

Solar energy can be used to desalinate seawater and polluted water. The simplest solar distiller is a reservoir filled with a layer of salt water of small thickness; the sun's rays concentrated on the reservoir evaporate the water. The steam condenses on an inclined flat wall, and the condensate flows into the water desalination tank. Solar refrigeration units have also been developed, in which the refrigerant (ammonia) is evaporated by solar radiation and further participates in the operation of the absorption type refrigeration cycle.

4. Solar installations. General characteritics

Solar collectors are designed to convert solar energy into thermal to heat water for domestic use and to support the heating system. Thanks to design improvements and high absorption coefficient (95%), solar collectors are effectively running for almost 9 months a year. The collector glass is impact resistant and guarantees mechanical resistance to precipitation (hail) or solid objects' hits. The use of non-freezing liquid (glycol solution) ensures the operation of the collectors at low air temperatures up to minus 30 °C. Solar thermal systems, if properly designed and properly installed, are considered to be one of the most reliable and durable.

The main types of solar water heaters are flat and tubular vacuum collectors, thermosyphon solar systems.

Flat collectors are widely used all over the world; they are slightly cheaper than vacuum tubular collectors.

Thermosyphon solar systems are used seasonally – from spring to autumn. But there are already constructive modifications of thermosyphon systems for use throughout the year, but in the absence of heavy frosts.

The flat collector is a well-insulated glass panel that houses a solar heat absorber plate and tubes with circulating fluid to remove the heat generated.

This plate has a special highly selective coating that absorbs solar energy well. The lower plate and side walls of the collector are covered with heat insulating material. But despite this, the heat losses of the flat collectors on the glazed side are quite considerable, especially in winter with a considerable difference between the temperatures of the coolant in the collector and the outside air. The heat flux from the sun enters the plate, that heats up converting solar radiation into thermal energy, which is transmitted to the coolant. To improve the perception of solar radiation, absorbers are made with a selective coating. The selective coating consists of a thin membrane of filter (nickel, titanium) deposited on a metal substrate that conducts heat well (copper, aluminum) and is characterized by high absorption capacity in the visible region of the spectrum and low radiation coefficient in the infrared region.

The designs of vacuum **tubular collector**have different modifications but in principle are similar to the construction of a thermos: one glass tube is placed in another, of a larger diameter, and between them there is vacuum, the best heat insulator.

Thermosyphon solar systems are used to compensate for seasonal heat loads – work in the warm months of the year, for the preparation of hot water for heating water in outdoor pools, summer boarding houses and guest houses, etc.

This installation is installed on any sunlit area in the south direction, and is connected to a conventional pipeline system (like a regular electric boiler). The use of multilayer coated vacuum tubes and heat pipes more efficiently ensures the transfer of heat to the water and will ensure the continuity of operation of the device even in case of failure of several vacuum tubes.

Solar collectors are installed at an angle equal to the latitude angle on the south side. Mounting directly on the roof is possible. The angle of rotation of the collector towards the south orientation is also taken into account. There are many schemes for the implementation of solar systems, both separately functioning and those that are connected to the existing system of hot water supply and heating.

5. Technological aspects

The examples of circuit solutions and the composition of solar systems.

Solar collector converts solar energy into thermal energy. The heat is extracted by pumping through its channels the liquid coolant. The collectors must be oriented in the south direction (tolerance without significant reduction in efficiency is up to 60°).

Heat exchanger tank-battery. The peculiarity of solar heating systems is the need to accumulate solar thermal energy in order to use it at different times of the day. This can be done by using the tank-battery system.

In such systems, the circulation is carried out due to the difference in the densities of cold and heated water. As a consequence, the storage tank in such systems should always be located above the panels of the solar collectors. Such systems are made open. Open systems are systems in which water for hot water supply systems is directly heated in the solar collectors.

Advantages:

- simplicity of construction;
- easy installation, due to the modular construction, it is possible to install independently;
- reliability of work;
- low cost;
- possibility of heating water to high temperature;
- energy independence

Disadvantages:

- the need for water purification due to the possibility of formation of deposits in the collector tubes;
- limited use due to the possibility of system freezing in winter.

In open systems, the circulation is carried out by means of electric pumps.

Advantages:

- possibility of execution of HWS system of any capacity;
- possibility of arrangement of the storage tank in any convenient place (as a rule, basement);
- no risk of unfreezing of the storage tank;
- possibility of successive connection to the installation of the boiler unit or introduction of the electric heater directly into the storage tank for additional heating of water in the cold period.

Disadvantages:

- higher cost than of the previous scheme;
- more complex installation;

- energy dependence;
- the need for water purification due to the possibility of formation of deposits in the collector tubes;
- limited use due to the possibility of system freezing in winter.

Closed systems are systems in which the intermediate coolant is heated. As a coolant, as a rule, non-freezing liquids based on glycols are used, which allows to exploit the reservoirs in winter.

Advantages:

- possibility of execution of HWS system of any capacity;
- possibility of arrangement of HWS boiler in any convenient place;
- the possibility of full-fledged work throughout the year in case of the use of freezing coolant in the first circuit;
- possibility of combining the device with the boiler unit for hot water heating.

Disadvantages:

- high cost;
- lower energy efficiency due to additional heat exchanger;
- the need to involve qualified installers, due to the greater complexity of the system;
- energy dependence.

Initially, the most popular solar collectors in Ukraine are the ones for hot water supply needs in the private residential sector. Although, the scope of solar energy in our country is much wider.

The controller is a mandatory element of solar systems with forced circulation of coolant. It monitors the state and controls the solar heating process of the solar system, and can control other thermal processes in the general system. The controller receives information from the temperature sensors and selects the required operating mode. The efficiency and security of the solar system depend to a large extent on the controller, its algorithms, the reliability of the elements.

The pumping station is used in systems with forced circulation (such a system is 30% more efficient than a system with natural circulation) and is intended to ensure the circulation of coolant in the collector circuit. The hydraulic resistance of the collector circuit is quite small, which makes it possible to use low-power pumps whose power consumption is negligible compared to the received thermal energy from solar collectors.

Pipelines and thermal insulation. Metal pipelines need to be used, so all known plastic pipes do not withstand the possible operating temperatures (maximum steam temperature in the circuit, even in inefficient solar collectors can reach 150 °C, and the operating temperature of the coolant can reach 110 °C). For the same reason, the requirements for pipe insulation are increased, which must withstand high temperatures, as well as not absorb moisture or shrink. Thermal insulation of foamed rubber meets all requirements. To ensure a sufficient reduction of thermal losses in the pipeline, as well as for safety purposes, thermal insulation must be at least 19 mm thick. It is forbidden to use thermal insulation made of foamed polyethylene applied directly to the pipe without a temperature suppression layer. The pipe diameters are selected individually based on the required hydraulic resistance of the system and the flow rate of the coolant. Possible system parameters and pipe diameters must be consistent with the parameters of the pumping stations.

Expansion tanks. Due to the fact that the solar collector circuit is closed, expansion tanks with a working pressure of 6 atmospheres (max. 10 atm.) must be used to compensate for the change in the volume of the liquid during the temperature change. With nitrogen cushion to increase membrane life.

Support metal structures are made of corrosion-resistant materials (stainless steel or anodized aluminum) and are designed for a wind speed of 30 m/s.

6. Equipment and layout calculation methodology

Modern heating and HWS systems due to the uneven supply of solar energy in different periods of the year are not able to fully meet the demand for thermal energy, that is, at the right time of the right temperature in the required amount. To act in terms of fuel economy and environmental protection means that the use of a solar collector installation should be planned not only for hot water preparation but also for the heating system.

A solar installation can only work if the coolant temperature drops below the temperature of the solar collector adsorber. Therefore, the best option is to use it for heating devices with a large heating area and low temperatures in the system or for floor heating.

Solar collectors use total solar radiation, which consists of direct, scattered, and reflected, to heat the coolant. The density of direct solar radiation flux in the collector plane $H_{пр}$ to the surface inclined at an angle to the horizon is equal to:

$$H_{пр} = H_{sc} \cdot R_{пр} \cdot K_{ат}, \tag{10}$$

where $R_{пр}$ is the conversion coefficient of direct solar radiation arrival from the horizontal to the inclined surface;

$K_{ат}$ is a coefficient that takes into account the correction for the air mass the sun's radiation goes through.

The conversion coefficient of direct solar radiation arrival from the horizontal to the inclined surface is equal to:

$$R_{пр} = \frac{\cos\theta_{пох}}{\cos\theta_{гор}} \tag{11}$$

where $\theta_{пох}$ is the angle between the direction of direct sunlight and normal to the inclined surface;

$\theta_{гор}$ - the angle between the direct sunlight direction and the normal to the horizontal surface.

$$\begin{aligned}\cos\theta_{пох} &= \sin\delta\cdot\sin\varphi\cdot\sin S - \sin\delta\cdot\cos\varphi\cdot\sin S\cdot\cos\varphi + \\ &+ \cos\delta\cdot\cos\varphi\cdot\cos S\cdot\cos\omega + \cos\delta\cdot\sin\varphi\cdot\sin S\cdot\cos\gamma\cdot\cos\omega + \\ &+ \cos\delta\cdot\sin S\cdot\sin\gamma\cdot\sin\omega,\end{aligned} \tag{12}$$

$$\cos\theta_{гор} = \sin\delta\cdot\sin\varphi + \cos\delta\cdot\cos\varphi\cdot\cos\omega, \tag{13}$$

where *S* – angle of the solar collector incline to the horizon, deg;

γ is the azimuthal angle, that is, the deviation of the normal to the collector plane from the local meridian (the south direction is taken as the beginning of the reference, the deviation to the east is considered positive and the one to the west is negative);

ω is a time angle equal to zero at noon; each hour is equal to 15 ° longitude, with the value of time until noon is considered positive and the one after noon is negative;

δ is the Sun's inclination, that is, the angular position of the Sun at noon relative to the plane of the equator, deg;

φ – latitude (positive for the northern hemisphere).

The time angle ω is calculated by the formula

$$\omega = \frac{\pi}{12} \cdot (12 - t), \tag{14}$$

where t is the solar time for the area, h.

The Sun declination is calculated as follows:

$$\delta = 23 \cdot 45 \cdot \sin\left\{\frac{2\pi}{365}(284 + N)\right\}, \tag{15}$$

where N is the ordinal number of the day of the year (starting from 1, corresponding to January 1);

The coefficient K_{am}, which takes into account the correction for air mass, is given by the formula:

$$K_{am} = 1{,}1254 \cdot \frac{0{,}1366}{\sin h}, \tag{16}$$

where $h$is the angle that determines the height of the sun above the horizon at a given time, deg., the sinus of this angle is equal to:

$$\sin h = \cos\delta \cdot \cos\omega \cdot \cos\varphi + \sin\delta + \cos\varphi. \tag{17}$$

Formula (4.10) allows to calculate only the amount of direct solar radiation flux directed to a random surface. However, any solar collector also experiences the effect of scattered solar radiation. The exact calculation of this component of the energy supplied to the solar collector is quite complicated. However, with sufficient accuracy for a randomly located surface, this value can be approximated by empirical dependence:

$$H_{розс} = 137{,}1 - 14{,}82 \cdot \frac{1}{\sin h}. \tag{18}$$

The reflected solar radiation can be estimated from the expression:

$$H_{від} = 0{,}5 \cdot \rho \cdot (1 - \cos S) \cdot (H_{пр} + H_{розс}), \tag{19}$$

where ρ – reflective property of the Earth;

$\rho = 0{,}2$ in summer;

$\rho = 0{,}7$ in winter with snow.

Finally, the total energy flow brought by solar radiation to a randomly space-oriented inclined surface at latitude L is equal to:

$$H_{т} = H_{пр} + H_{розс} + H_{від}. \tag{20}$$

It should be borne in mind that all these values are given for a clear day, in practice, when calculating the so-called cloud factor should be taken into account. It should also be noted that the calculated flow values for different hours are almost exactly the same as those given in the tables in the regulatory documents (Building rules and regulations) and the climate atlas.

Solar systems that provide heat demand are divided into *active* and *passive*. Passive systems that use architectural elements that are designed to maximize the use of solar energy are less expensive and do not require additional equipment. The active ones are built on the basis of solar collectors (SC) with forced circulation of the coolant by means of pumps. Flat solar collectors capture both direct and scattered solar energy and allow you to obtain water at a temperature of 40…60 °C. The seasonal efficiency of simple passive solar systems may be no less effective compared to more sophisticated and expensive solar thermal supply systems.

The disadvantage of passive systems is the complexity of regulating indoor air temperature and the need to use self-regulating devices.

Active solar systems can use non-freezing air or liquid (antifreeze) as coolants. The advantage of active systems is the ease of integration with traditional heating systems, as well as the ability to automatically control the operation of the system, and the main disadvantage is the high cost. The choice, composition and layout of the elements of the active system is determined in each case by climatic factors, object type, heat supply regime, economic indicators. Due to the fact that it is difficult and expensive to maintain the surface of the solar collector perpendicular to the sun rays, the solar collectors are installed fixed or they change orientation twice a year. It is best to orient the collectors to the south. The optimal angle of inclination of the collector to the horizon is:

– $S = \varphi + 12°$, – for summer (seasonal) operation;

– $S = \varphi - 12°$, – for year-round operation.

where φ is the latitude.

Solar installations are of two types: of *seasonal* and *constant use*. In the solar collector of seasonal type, the water is heated directly in the solar collector, and in installations of constant use the water is heated in the tanks of indirect year, as an intermediate coolant uses antifreeze, which perceives the sun energy in the solar collector.

The mode of operation of the solar collector is described by the equation of energy balance, which divides the energy of solar radiation into useful accumulated energy and losses. The energy balance of the collector as a whole can be written in the following form:

$$A\{[H_R(\tau\alpha)]_b + [H_R(\tau\alpha)]_d\} = Q_u + Q_L + Q_S, \quad (21)$$

where H – the density of the flux of solar radiation (direct or scattered) incident per square unit of the horizontal surface;

R – coefficient of recalculation of direct or diffuse radiation density from horizontal to inclined surface;

τα is the absorbing property of the coating system with respect to direct or scattered radiation;

A – collector square;

Q_u – the heat flow that is transferred to the working fluid in the solar collector (useful heat);

Q_L – thermal losses of the collector to the environment by radiation and convection, as well as by thermal conductivity on the resistances of the absorbing plate, etc .;

Q_s – the heat flow accumulated by the collector.

An indicator of the efficiency of a solar collector is its efficiency – the ratio of useful thermal energy Q_u to incident solar energy.

For testing solar collectors they often use the methodology of the US National Bureau of Standards. According to this method, the test is carried out on an experimental bench in a stationary environment, when solar radiation, wind speed, ambient temperature for some time.

The tests are carried out either in the natural environment at about noon on sunny days, or using a solar simulator.

The useful energy from the collector is determined by the expression

$$Q_u = F_R \cdot A \cdot [I_T(\tau\alpha) - U_L(T_i - T_a)], \quad (22)$$

where *FR* – coefficient of heat removal from the collector;

IT – total solar radiation flux density in the collector square, W/m²;

τα – reduced absorption capacity (also takes into account that part of the radiation that passed through the glass coating, reached the adsorber, and returned to the glass again):

U_L – full heat loss coefficient of collector W/(m^{2}K);

T_i – fluid temperature at the inlet to the collector, °C;

T_a – environment temperature, °C;

The test results determine the efficiency of the collector

$$\eta = \frac{Q_u}{A \cdot I_T}. \qquad (23)$$

The collector heat capacity can be also determined by the temperatures of the coolant at the inlet and outlet of the collector by the formula:

$$Q_u = G \cdot C_p (T_o - T_i), \qquad (24)$$

where G is the mass flow rate of the coolant, kg/s;

C_p – specific mass heat capacity of the coolant, J/(kgK);

T_o, T_i – coolant temperatures at the outlet and inlet of the collector absorber, °C.

The efficiency coefficient can be also determined as follows:

$$\eta = F_R(\tau\alpha) - \frac{F_R \cdot U_L (T_i - T_a)}{I_T}, \qquad (25)$$

where *FR(τα)* is a component coefficient showing the maximum theoretical efficiency value for this solar collector structure;

$F_R U_L$ is the component coefficient characterizing the thermal losses of a particular collector srtucture.

The coefficient found by formula (3.26) largely characterizes the structural and thermal perfection of the flat solar collector structure. In the equilibrium state (no coolant circulation), the collector is heated to the maximum temperature when there are the intensity of sun radiation and environmental temperature. The equilibrium temperature is to some extent a characteristic of the collector thermal efficiency (collector heat losses).

The density of absorbed converted energy is calculated by the formula:

$$q = \frac{E}{A}, \qquad (26)$$

where $A$is the working square of the collector surface, m² [4,5,6,7,8].

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The coolant temperature at the inlet to the collector has a great influence on the value of the solar collector efficiency: the lower the temperature, the lower the heat losses and the higher the efficiency. According to the experience of operating flat solar collectors, increasing the flux density of solar radiation from 300 to 1000 W/m² leads to an increase in the efficiency from 32 to 59%, and when the environment temperature increases from 20 to 30 °C, the efficiency increases from 41 to 55%.

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SOLID BIO-FUEL

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1. The general characteristic of the granulation process and the bio-fuel potential of Ukraine

Granulation is a collection of physical and physicochemical processes that ensure the formation of particles of a certain range of sizes, shapes, required structure and physical properties.

A pellet is a cylinder of milled, pressed wood or other bioraw material. It is 10 to 30 millimeters in length and 6 to 10 millimeters in diameter.

Granulation is carried out in order to improve the quality of both intermediate and finished products. Quality indicators depend on the specifics of the product and its purpose. In the general case, granulation can significantly reduce the tendency of the product to caking, and therefore simplify storage, transportation and dosing; to increase flowability while eliminating dustiness, and thus to improve working conditions in various fields of production. Consider the use of fuel pellets in more detail, as the use of pellets in this area is the most rational and widespread.

Fuel pellets are the environmentally friendly fuel with an ash content of not more than 3%. Burning pellets releases as much CO_2into the atmosphere as was absorbed by the plant during growth. The pellets have a low moisture (8… 12%) and a high density. These qualities provide a high calorific value – while burning of a ton of pellets about 5 thousand kWh of heat is emitted, which is one and a half times more than while burnin of ordinary firewood. Low moisture is not only an advantage of pellets as a fuel, but also a problem of their production. Agricultural biomass used as fuel has a number of features that distinguish it from traditional energy resources used as an energy source. Some of the characteristics of solid biofuels, primarily external ones (density, particle size, surface specificity), can be modified by grinding and consolidating. At the same time, its main fuel and technological characteristics are considered as of steel.

Below there is the average calorific value of agricultural energy raw materials (previously referred to as agricultural waste) with an absolute moisture of 20%.

Calorific value of energy raw materials

Name of energy raw materials	Calorific value, MJ/kg
Grain straw	10,5
Corn stalks	12,5
Branches of fruit trees	10,5
Buckwheat husk	12,5
Sunflower husk	14,2

For many regions of Ukraine, using solid biofuels is more appropriate than using coal or petroleum products, since biofuels produced from local raw materials are 2 to 4 times cheaper and do not require significant transportation costs for its delivery. They use solid biofuels in the form of straw briquettes, pellets, logs and agricultural waste. Properties of various organic fuels are given in Table 1.

Table 1

Comparative characteristics of properties of different fuels

Fuel type	Material moisture,%	Calorific value, MJ/kg	Sulphur content	Ash content,%
Natural Gas	–	35…38	0	0
Coal	–	15…25	1...3	10…35
Motor fuel	–	42,5	0,2	1,0
Masut	–	42	1,2	1,5
Wood chips, sawdust	40…45	10.5… 12.0	0	2,0
Briquettes, pellets of wood	7...8	16.8… 21.0	0,1	1,0
Briquettes, pellets of straw	8...10	16,5…18,8	0,2	3,0

Granulated solid biofuels for boilers consisting of waste wood (bark remains, sawdust, logs, pieces of wood, etc.) must have a calorific value of dry weight higher than 5400 kWh/t; moisture less than 40%; an average particle size of 50 × 50 × 20 mm, with containing of particles of up to 150 × 60 × 20 mm not more than 10%; ash content up to 2% of its dry weight. In addition, it is not allowed to add to biofuels substances that can negatively affect its storage, transportation and use in heating equipment.

2. The production of pellets and briquettes in terms of quality characteristics

The rational use of waste of vegetable origin is a serious problem. Usually the direct use of waste for energy purposes is impossible due to their high moisture and inappropriate physical condition.

Difficulties arising from the use of biomass energy can be overcome by processing, which significantly increases their calorific value. These operations are expensive and energy consuming. However, the benefits of the new fuel (significant increase in density and calorific value, lack of CO_2emissions, reduction of NO_x and SO_2 emissions into the atmosphere which is EU legislation compliant) make it attractive for investment and promising.

Combustion heat and calorific value

Vegetable waste has a very high calorific value, being a good, environmentally friendly material for fuel.

As an example, the combustion heat and calorific value for sawdust, straw, paper, coal and bark (of oak, birch, alder, willow and pine bark) are given (Table 2).

Table 2

Combustion heat and calorific value of solid biofuels

Tested material	Combustion heat, MJ/kg	Caloric value, MJ/kg
Spruce sawdust	18,89	17,58
Straw:		
Rye	17,78	17,12
Rapeseed	19,14	17,82
Buckwheat husk	20,12	18,76
Paper (waste paper)	17,05	16,39
Charcoal	31,55	30,23
Bark:		
oak	19,05	17,51
birch	23,37	21,86
alder	21,73	20,31
willow	18,19	16,76
pine	21,08	19,66

Manufacturing of fuel briquettes and pellets

Fuel briquettes and pellets that are formed in the process of agglomeration under pressure (granulation, briquetting), when the consolidation of bulk materials under the action of external pressure of compression and internal (intermolecular forces and bonds) forces, are formed of geometrically correct and uniform shape.

The use of compressed vegetable waste (briquettes and pellets) has many advantages.

Waste of vegetable origin, such as sawdust or chips, is usually heterogeneous and has particles of different sizes. For example, pine sawdust has the following particle size distribution: 31.3% of particles are retained on a sieve with a mesh of 1.5 × 1.5 mm, 16% on a sieve of 1 x 1 mm, 13.5% on a sieve of 3 × 3 mm, and 15, 4% on a 2 × 2 mm sieve, and it is a good material for briquetting.

In industrial practice, the production of pellets can be conditionally divided depending on the type of equipment used (Fig. 1): a – in a closed chamber, a piston consolidation; b – in open chamber, a piston consolidation; c – in the open chamber, auger consolidation, and also depending on the type of matrix; d – a flat matrix; e – an annular matrix.

The closed chamber pressing equipment (Fig. 1. a) is characterized by low energy consumption per unit of received products and enables the use of various materials and mixtures of vegetable origin as raw materials for pressing. The disadvantage is the complex mechanism of closing and opening the consolidation chamber and low efficiency.

Systems using open camera devices (Fig. 1. b) have a simpler design and higher efficiency. The disadvantages of such devices include high energy consumption and the need to use different types of matrices for pressing, depending on the material being pressed. The increase in energy consumption that results from friction forces in the process of briquette formation is partly a positive factor (when converting mechanical energy into thermal, there is an effect of bonding particles of material, which contributes to the formation of a better briquette).

Pressing of sawdust (straw cuttings) on the briquetting equipment (Fig. 1. c) is carried out by means of the auger 1 and the matrix 2, the obtained briquettes have a strong structure and hardened outer and inner cylindrical surfaces.

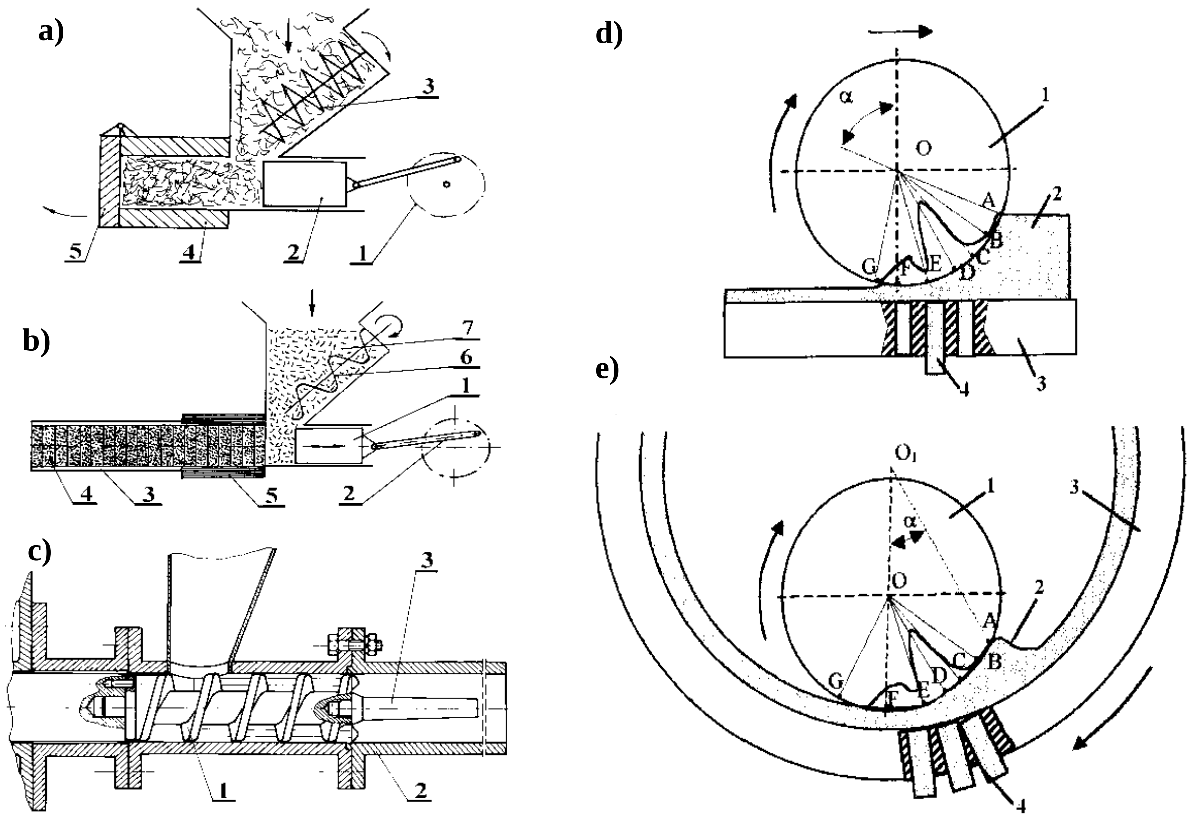

Fig. 1. Schemes of typical pressing equipment:

a) in a closed chamber, a piston consolidation: 1 – eccentric, 2 – piston, 3 – auger, 4 – consolidation chamber, 5 – movable plate; b) in open chamber, a piston consolidation: 1 – piston, 2 – connecting rod, 3 – consolidation chamber, 4 – briquettes, 5 – heater, 6 – auger, 7 – raw materials; c) in the open chamber, auger consolidation: 1 – pumping auger, 2 – matrix, 3 – shaft; d) on a flat matrix: 1 – consolidating roller, 2 – material, 3 – matrix, 4 – pellet; e) on the annular matrix: 1 – consolidating roller, 2 – material, 3 – matrix, 4 – pellet.

The granulation process is carried out in systems using a flat or annular pressing matrix (Fig. 1. d and 1. e). The process of pressing the crushed plant material in these systems is very similar. The material is first consolidated, getting into the wedge-shaped gap between the roller and the matrix, the final compression occurs in the holes of the matrix.

3. The technological schemes for the production of solid bio-fuels

In Fig. 2 and Fig. 3 there are technological schemes of biofuel production.

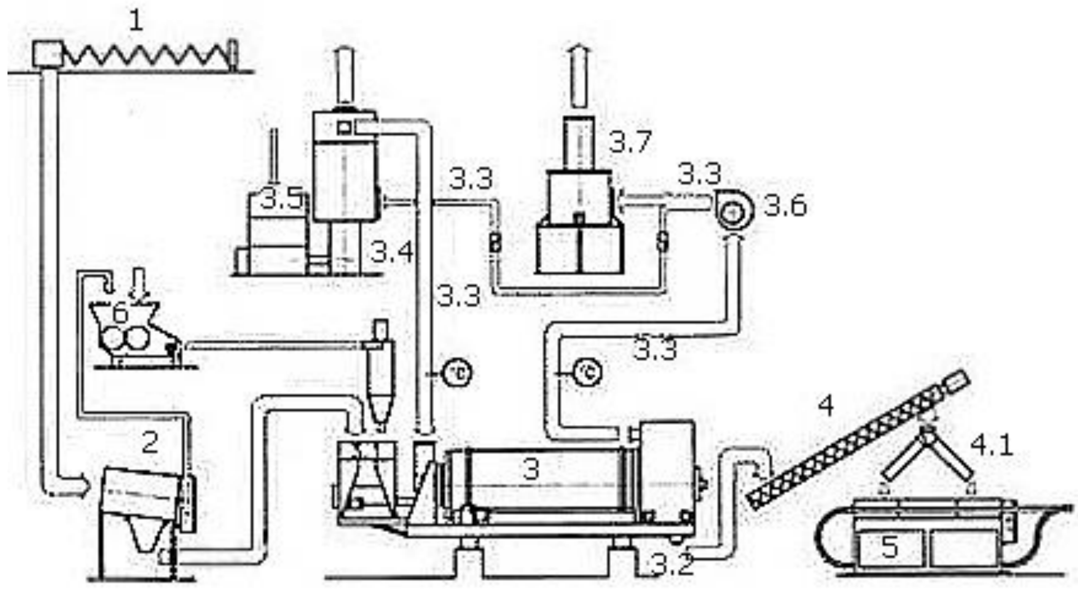

Fig. 2. Technological scheme of solid biofuel production

1 – Auger; 2 – Sieve; 3 – Drying chamber, 3.1 – Raw material bunker, 3.2 – A line for removing raw materials, 3.3 – Air pipelines, 3.4 – Boiler on raw material, 3.5 – Fuel bunker, 3.6 – Fan, 3.7 – Filter; 4. – Auger feed in the briquetter (granulator), 4.1 – Raw material distributor; 5. – Briquetting press (granulator); 6. – Waste crusher.

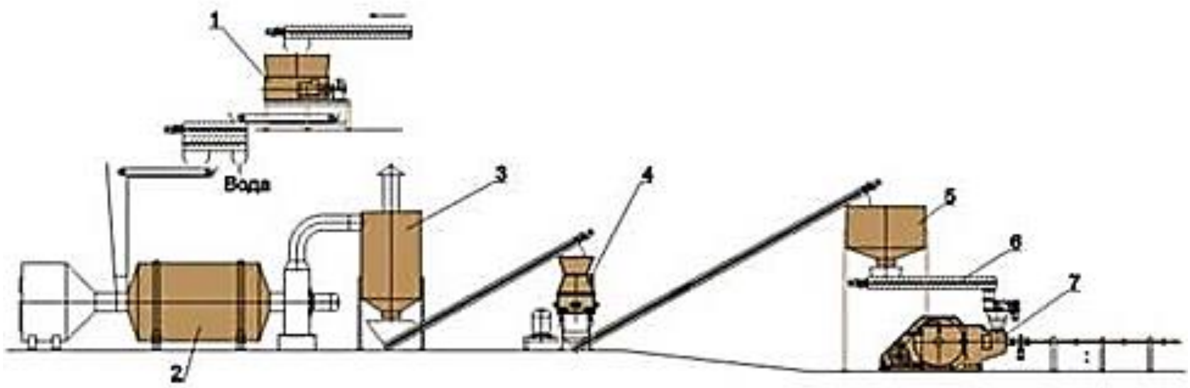

Fig. 3. Technological scheme of solid biofuel production

1 – a large fractional crusher; 2 – drying chamber; 3 – bunker; 4 – fine fractional crusher; 5 – bunker; 6 – auger; 7 – briquetting press (granulator)

4. The equipment for grinding of bio-raw materials

The process of mechanical grinding is widely used in technological schemes for the production of solid biofuels. Thus, in a number of technologies, mechanical grinding of solid materials is applied, with their subsequent separation by size. The grinding result is characterized by the degree of grinding, which is determined by the ratio of the average characteristic size D of a piece of material before grinding to the average characteristic size d of a piece of material after grinding.

$$i = \frac{D}{d}. \quad (1)$$

The characteristic linear size of a piece of spherical shape is the diameter, a piece of cubic shape – the length of the rib. The characteristic linear size of pieces of irregular geometric shape can be found as the average geometric value:

$$d_x = \sqrt[3]{lbh}, \quad (2)$$

where *l, b, h*are the maximum dimensions of a piece in three mutually perpendicular directions. The largest of these dimensions is *l* – length, the medium is *b* – width, and the smallest is *h* – thickness.

To calculate the average characteristic size of the pieces, the material is divided into several fractions. In each fraction, the medium characteristic size is found as a half-sum of the characteristic dimensions of the maximum d_{max} and the minimum d_{min} pieces:

$$d_{cep} = \frac{d_{\max} + d_{\min}}{2}. \quad (3)$$

The average characteristic size of a piece in the mixture is determined by the formula:

$$d = \frac{d_{cp1}a_1 + d_{cp2}a_2 + ... + d_{cpn}a_n}{a_1 + a_2 + ... + a_n}, \quad (4)$$

where d_{cp1}, d_{cp2},…, d_{cpn} – the average sizes of the pieces of each fraction; $a_1, a_2, \ldots, a_n$ – the amount of each fraction, weight%.

In the technology of production of solid biofuels from raw materials of plant origin, 2 stages of grinding are distinguished. The first stage is coarse grinding, before drying. The second stage is a fine grinding, just before pressing.

Coarse grinding. Crushers, for large grinding, grind raw materials for further drying. Grinding should reach a particle size of not more than 25 × 25 × 2 mm. Coarse grinding allows quickly and qualitatively dry the raw material and prepares it for further grinding in a crusher, for fine grinding.

Fine grinding. Raw materials should enter the press with a particle size of less than 4 mm. Therefore, the crusher, for fine grinding, crushes the raw materials to the required size. In a crusher for fine grinding the raw material should usually come with a maximum particle size of 25 × 25 × 2 mm.

Crushers of vertical and horizontal type are used for coarse grinding, depending on the method of raw material loading. Drum cutting machines and hammer crushers are most common.

For fine grinding hammer crushers and mills of different designs are used.

Drum cutting machines.

They are used for the production of technological and fuel wood chips, as well as "micro-chips" of round wood, balance, thin-hued humpback and other lumpy waste and substandard wood. Cutting units can have a capacity of 10 to 900 cubic meters of wood per hour (input).

Hammer crushers.

Hammer crushers have also become widely used in the production of briquettes and pellets (Fig. 4). Grinding of the material in them occurs under the influence of dynamic loads of mechanical hit. Effect on the body under concentrated load is similar to splitting, with distributed – crushing.

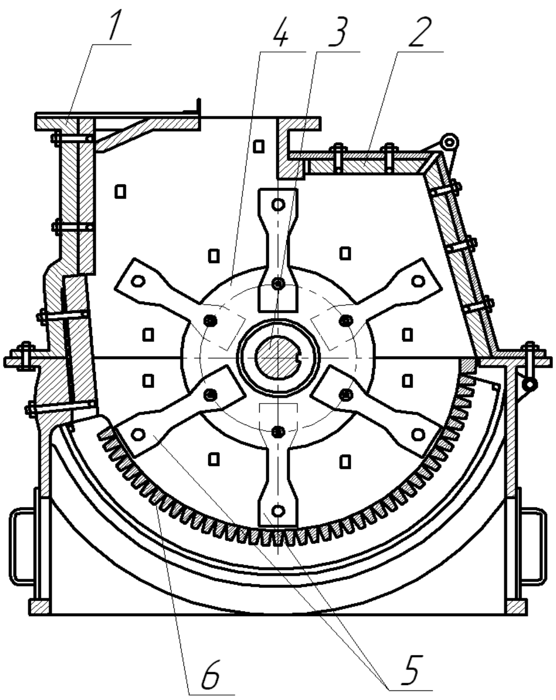

Fig. 4. scheme of a hammer crusher

1 – sieve; 2 – rod; 3 – hammer; 4 – branch pipe; 5 – feeder; 6 – shaft

The main element of the crusher is the rotor, which has a horizontal shaft 6 with disks fixed at a certain distance by means of remote rings. To the disks on the rods 2 steel plate hammers 3 are mounted. As the shaft rotates, the material passes through the feeder 5 and the branch pipe 4 is processed by repeated hammer hits, crushed, passed through a sieve 1 and unloaded. The sieve condition is controlled through the hatch. Crushers with cam type hammers are used. As the rotor rotates, its velocity and kinetic impact energy must be sufficient to destroy the material. The critical (minimum) impact velocity, m/s, which ensures the grinding of the material depends on the initial particle size and is determined by the formula:

$$v_{кр} = 175\left(\frac{\sigma_P}{\rho \cdot d_П}\right)^{2/3}, \qquad (5)$$

where σ_p is the ultimate tensile strength of the material, MPa; ρ is the material density, kg/m^3; $d_п$ – initial particle size of the material, m

Impact velocity (rotor speed) when crushing pieces of wood is 60…90 m/s. The performance of the hammer crushers, kg/h, it is recommended to calculate by the formula:

$$G = \frac{KlD^2n^2}{3{,}6(i-1)}, \qquad (6)$$

where K is the empirical coefficient (accept K = 4,0… 6.2); *l* – rotor length, m; D – rotor diameter, m; n – the rotor speed frequency, min^{-1}; i – the degree of grinding.

The peculiarity of the hammer crusher is the considerable load that arises when grinding hard-to-process fibrous materials, such as wood, so when designing it should be taken into account as a heavy-duty housing and a reinforced sieve construction. The mass of the crusher absorbs all the vibration and the rigid body allows a very small gap between the hammers and the sieve.

One of the most important characteristics of hammer crushers is the so-called linear speed of rotation of the hammers. High speed hammers are best suited for fine grinding. Coarser grinding can be performed at lower speeds.

5. The equipment for drying bio-raw materials

Drying is a must in the process of production of wood pellets.

By its physical nature, drying is a complex diffusion process, the speed of which is determined by the rate of diffusion of moisture from the surface of the material to be dried into the environment.

Material balance of air dryer.

If there is no loss of material, then the amount of completely dry matter in it before and after drying remains unchanged; if m_1 and m_2 – costs of wet material before and after drying, kg/s, and ω_1 and ω_2 – mass shares of moisture before and after drying,% to the total weight, the dry matter balance will be:

$$\frac{m_1(100-w_1)}{100}=\frac{m_2(100-w_2)}{100}, \qquad (7)$$

whence the weight of wet material:

$$m_1=m_2\frac{100-\omega_2}{100-\omega_1}, \qquad (8)$$

або маса висушеного матеріалу:

$$m_2=m_1\frac{100-\omega_1}{100-\omega_2}. \qquad (9)$$

The amount of moisture *W*, which is removed during drying, is equal to the difference in mass of wet and dried material:

$$W=m_1-m_2. \qquad (10)$$

Substituting into the last equation the expression for m_2 we get:

$$W=m_1-m_1\frac{100-\omega_1}{100-\omega_2} \quad \text{or} \quad W=m_1\frac{\omega_1-\omega_2}{100-\omega_2}. \qquad (11)$$

If we substitute instead of m_1 its expression from the equation, then

$$W=m_2\frac{\omega_1-\omega_2}{100-\omega_1}. \qquad (12)$$

The material balance of the dryer by moisture will be made if we equate the amount of moisture brought into the dryer with wet material and with air, to the amount of moisture in the dried material and the used air:

$$\frac{m_1\omega_1}{100}+Lx_1=\frac{m_2\omega_2}{100}+Lx_2, \qquad (13)$$

whence

$$\frac{m_1\omega_1}{100} - \frac{m_2\omega_2}{100} = (x_2 - x_1)L, \tag{14}$$

where L is the flow rate of absolutely dry air, kg/s.

The left side of the last equation is the amount of moisture that is removed during drying, that is:

$$W = (x_2 - x_1)L, \tag{15}$$

where the total flow rate of completely dry air for drying is:

$$L = \frac{W}{x_2 - x_1}. \tag{16}$$

The specific flow of air, that is, its consumption per 1 kg of moisture, which is removed from the material in the dryer:

$$l = \frac{L}{W} = \frac{1}{x_2 - x_1} = \frac{1000}{d_2 - d_1}, \tag{17}$$

where d_2, d_1 – moisture after and before the dryer, g/kg.

As air passing through the heat exchanger does not absorb or give off moisture, its moisture content when heated in the heat exchanger remains unchanged, therefore, $x_x = x_0$ *and* therefore:

$$l = \frac{1}{x_2 - x_0} = \frac{1000}{d_2 - d_0}. \tag{18}$$

This equation is the basic equation for determining the air flow rate in a dryer. From this equation it can be seen that the air flow increases with increasing x_0. Due to the fact that the moisture of the outside air in the summer is higher than in the winter, the fan is calculated for the summer working conditions of the dryer.

The thermal balance of the air dryer

For a steady process, the heat balance equation expresses the uniformity of the amount of heat entering the drying device and the heat exiting it.

Heat input:

a) with fresh air, heat is introduced into the heat exchanger LI_0, where I_0 – enthalpy of air at its temperature t_0;

b) from the heat source in the heater $Q_к$;

c) additional heat introduced into the drying chamber $Q_Д$;

d) with wet material $m_1 c_M \theta_1$, where m_1 – the mass of material submitted for drying per unit time, kg/s; $s_м$ – heat capacity of the material, J/(kg · K); θ_1 – temperature of the material before drying, °C.

Since by the equation $m_x = m_2 + W$, we can write

$$m_1 \cdot c_м \cdot \theta_1 = m_2 c_м \theta_1 + W c_в \theta_1, \quad (19)$$

where $c_в$ – heat capacity of water, J/(kg · K);

e) with transport devices $m_{т,}$ $c_{т,}$ $t_{т.п}$, де $m_т$, $c_т$, $t_{т.п}$, – accordingly, the mass, heat capacity of the material of the transport device and its temperature at the inlet of the dryer.

Heat output:

a) with the outgoing air LI_2, where I_2 – enthalpy of air at its temperature t_2;

b) with the dried material $m_2 c_M \theta_2$ where θ_2 – temperature of the material at the outlet of the dryer;

c) with transport devices $m_{T,} c_{T,}$ t_{tk}, where $m_т$, $c_т$, $t_{т.к}$, – the temperature of the material of the transport device at the outlet of dryers;

d) loss of heat in the environment $Q_н$.

The thermal balance of the dryer is expressed by the equation:

$$\begin{aligned} &LI_0 + Q_к + Q_Д + m_2 c_м \theta_1 + W c_в \theta_1 + m_T c_T t_{TП} = \\ &= LI_2 + m_2 c_M \theta_2 + m_T c_T t_{TK} + Q_н. \end{aligned} \quad (20)$$

The total flow rate of heat in the dryer consists of $Q_к$ and $Q_Д$, so the last equation looks like:

$$\begin{aligned} &Q_к + Q_Д = L(I_2 - I_0) + m_2 c_м (\theta_2 - \theta_1) + \\ &+ m_T c_T (t_{TK} - t_{TП}) + Q_н - W c_B \theta_1. \end{aligned} \quad (21)$$

Let us divide each component of the heat balance by W_i and obtain the specific heat consumption:

$$\frac{Q_к}{W} = q_к, \; \frac{Q_н}{W} = q_н, \; \frac{L}{W} = l, \; \frac{W c_B \theta_1}{W} = c_B \theta_1, \quad (22)$$

$$\frac{m_2 c_M(\theta_2-\theta_1)}{W}=q_M,\ \frac{m_T c_T(t_{TK}-t_{T\Pi})}{W}=q_T. \qquad (23)$$

Let us denote the total specific heat losses through the formula:

$$\sum q_{BTP}=q_M+q_E+q_B. \qquad (24)$$

According to these designations the specific heat consumption for drying will be:

$$q_K+q_Д=l(I_2-I_0)+\sum q_{BTP}-c_B\theta_1. \qquad (25)$$

The specific consumption of heat in the heater at a given $q_д$, we determine from the equation:

$$q_K=l(I_2-I_0)+\sum q_{BTP}-c_B\theta_1-q_Д. \qquad (26)$$

The specific heat consumption in the heat exchanger can also be determined from the equation:

$$q_K=l(I_2-I_1). \qquad (27)$$

Equating the right parts of these equations, we get:

$$l(I_2-I_1)=(q_Д+c_B\theta_1)-\sum q_{BTP}. \qquad (28)$$

Let us denote the right side of this equation by Δ:

$$\Delta=(q_Д+c_B\theta_1)-\sum q_{BTP}. \qquad (29)$$

Then

$$l(I_2-I_1)=\Delta. \qquad (30)$$

For the analysis and calculation of drying processes, it is advisable to introduce the concept of the so-called theoretical dryer, which operates without additional supply of heat in the drying chamber ($q_д = 0$), without heat losses ($\sum q_{втр} = 0$) and at $\theta_1 = 0$. According to the equation for such a dryer Δ = 0, then we get the equations $l(I_2-I_1)=0$ or $I_2=I_1=I=const$

The process in a theoretical dryer occurs at constant enthalpy of air. In this case, the heat released during the cooling of the air is spent only on the evaporation of moisture from the material, and therefore, together with the steam formed, is again returned to the air.

Based on the above considerations, the value of Δ is called the thermal characteristic of the dryer[1,2].

5.1 Drum dryers

For a number of reasons, in the biofuel industry, as well as in many other industries where the drying of large volumes of bulk materials is most widespread, the drying units of the drum type have become popular. These dryers are widely used for continuous drying at atmospheric pressure of lumpy, granular and bulk materials (Fig. 5).

The unit capacity of such a dryer can be up to 20 tons per hour or more. The advantages of drying technology in the drum are reasonable cost, proven, reliable, traditional technology, careful drying, that ensures the preservation of all material properties, high energy efficiency.

The scheme of the drum type drying unit with solid fuel heat generator is presented in Fig. 6.

Sometimes a biomass furnace may be included in the drying complex, which produces the hot gases required for drying.

When installing a drum dryer in the open air, it is necessary to additionally carry out thermal insulation of the main cyclone, the gate lock to avoid condensation of moisture at these nodes. The thermal insulation of the drum is necessary in any case.

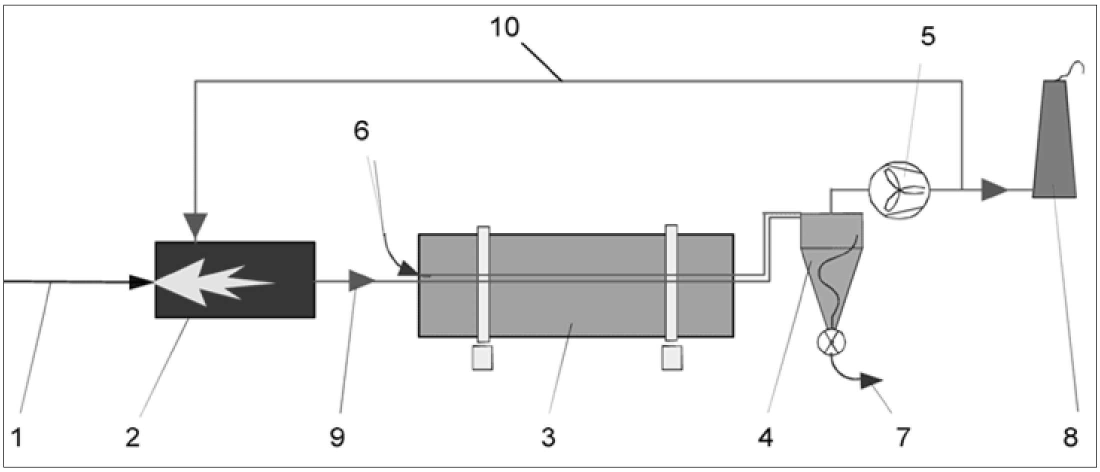

Fig. 5. Scheme of drying in the dryer of the drum type:

1 – fuel; 2 – heat-generating unit; 3 – drum; 4 – cyclone; 5 – fan; 6 – supply of wet material; 7 – gate valve; 8 – coolant eject pipe; 9 – coolant; 10 – reusable coolant.

[1] Bogdanovich V.P., Shevchenko N.V. Perspectives of alternative fuel use in agriculture. Machinery in agriculture. 2012. № 5. P. 38–40.

[2] Sukhenko Yu.G., Seryogin O.O., Sukhenko V.Yu., Ryabokon N.V. Resource-saving technologies in food and processing industries. Textbook. K. 2016.

Wet material is given into the drum 6. The coolant 9 (combustible gases in admixture with air) is heated in the heat generating unit 2 and comes into contact with the material inside the drum 3. The constant rotation of the drum and the partitions (blades) installed inside it ensure a constant finding of the material in the coolant flow, which leads to intensive evaporation of moisture. In addition, this interaction effectively separates the small and light particles of the material that dry quickly from larger, heavier, wetter particles. The small dry fraction quickly leaves the drum, caught by the coolant flow. The large fraction remains inside the drum for a longer time until leaves it with the proper moisture level. The coolant is transported from the heat generating unit via a drum to the main cyclone 4 of the drying unit by means of a powerful main fan 5. In the cyclone, the dried product is separated from the coolant stream. The used coolant (air saturated with water vapor) is released into the atmosphere through the coolant eject pipe 8. A large gate valve 7 is installed under the cyclone, which retains the coolant and releases the dried product for further processing.

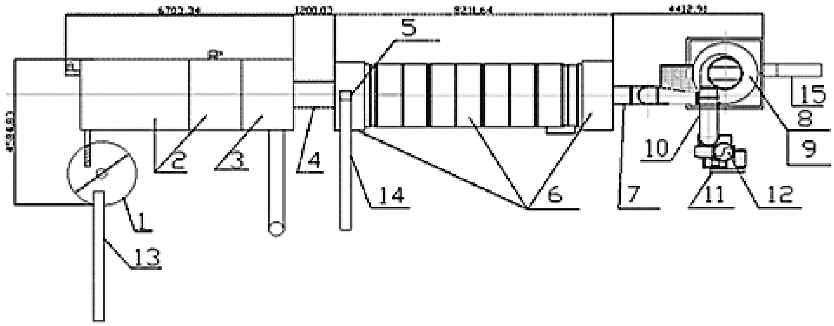

Fig. 6. Drying complex of drum type with solid fuel heat generator:

1 – fuel bunker; 2 – mixing chamber; 3 – sparking redemption system; 4 – gas pipeline; 5 – raw material loading feeder; 6 – loading bunker; drying drum; unloading bunker; 7 – coolant outlet pipeline; 8 – cyclone of purification of the coolant from a small fraction of dry raw material; 9 – cyclone feeder; 10 – gas pipeline to the smoke exhaust; 11 – the smoke exhaust; 12 – the smoke exhaust pipe; 12 – conveyor loading fuel into the fuel bunker; 14 – conveyor loading of raw material into the dryer feeder; 15 – conveyor of raw material feed for the following technological operations.

Items 1-3 can be replaced by a gas burner with a mixing chamber. Coolant: flue gases in admixture with air.

The temperature maintained at the inlet of the drum depends on the characteristics of the drying unit and its mode of operation – the required performance, the initial moisture of the product, etc. Most often it is maintained at 250...450 °C. As the material moves through the drum, its moisture decreases, but at the exit of the drum the temperature of the coolant and the material itself is much lower than the combustion temperature. The temperature of the coolant at the outlet of the drum should be above the dew point to avoid condensation of the steam. It is usually maintained at 70...110 °C.

5.2 Belt dryers

Belt drying complexes (Fig. 7) are used in conjunction with drum dryers for biomass drying.

Belt drying complexes for wood chips and sawdust have several advantages over drum dryers. Low-temperature belt-type drying unit, which uses hot water as a coolant, saves electricity, has a low level of harmful emissions (no additional measures are needed to clean up emissions), enables the use of low-temperature energy, provides gentle drying, which preserves all material properties, automates the production process.

The disadvantages of belt dryers include: high cost, very stringent requirements for uniformity of material in fractional composition and initial moisture, difficult to maintain (due to warps and stretching of the belts), has a large number of moving parts, specific productivity is low, and the specific flow rate is quite high.

It is ideal to use belt dryers in the presence of excess heat capacity of an existing boiler or process heat. The hot water is a coolant with a temperature of 90...110 °C.

Sometimes the belt dryer is equipped with a biomass boiler, through which the water will be heated to 105 °C in the amount required for drying.

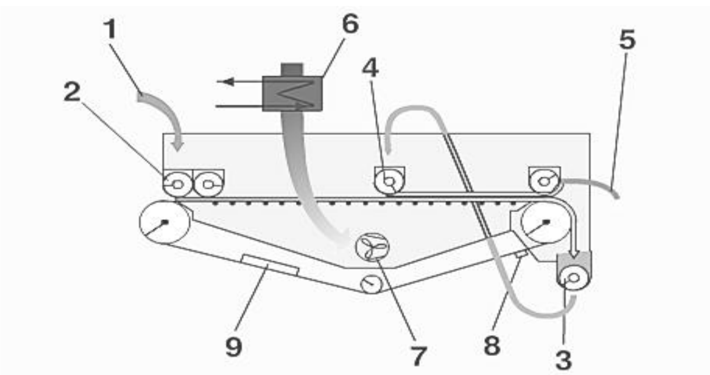

Fig. 7. The scheme of drying in a belt dryer:

1 – wet material; 2 – auger feeder I; 3 – unloading auger I; 4 – auger feeder II; 5 – unloading of dry material; 6 – heat exchanger; 7 – exhaust fan; 8 – cleaning brush; 9 – a device for washing the belt.

With the help of the conveyor wet material 1 is dosed fed into the auger feeder 2, which evenly distributes it throughout the width of the belt. The amount of fed material is regulated by changing the torque of the auger feeder 2, which allows a uniform filling of the auger. The product layer is transported through the drying chamber together with the belt to the unloading auger I. With the help of an additional auger feeder, the unloaded product is returned to the auger feeder II, which re-distributes the material on the belt over the first layer. After re-passing of the part of the length of the drying chamber, the material is unloaded for further processing. The use of such a dual system allows to achieve the maximum saturation of the drying agent (gas) with moisture and thus – the maximum energy efficiency of the process. At the outlet of the dryer 5 the moisture of the material is controlled. According to the results of this control, a signal is sent that regulates the speed of the belt and thus the bandwidth (performance) of the drying unit. Thus, the performance of the dryer depends on the amount of heat available. The exhaust fan 7 draws the outside air through the heat exchanger 6, where the air is heated before it enters the drying chamber and passes through the material layer and the perforated belt itself. As it passes through the drying chamber, the material on the belt dries. Moisture-rich air leaves the drying chamber through the coolant discharge pipe. The fan output is controlled by a frequency transducer, depending on the thermal power supplied to the heat exchanger. For optimum performance, the unit is equipped with a brush 8 and a washing system 9 that clean the belt during the dryer operation.

6. The presses for bio-fuel granulation

Methods of granulation by molding and extrusion are based on the ability of dispersed materials to form pellets of the desired shape and size as a result of the force action of the working bodies on the treated mass and pushing it through the holes.

Granulation by molding involves a number of steps:

- preparation of the initial product;
- molding or extrusion (forcing the mass through the perforated surface by force action);
- cooling, crushing, size classification of pellets.

Granulation presses are classified:

• on the principle of pressing – in presses with closed and open chambers, in which the pressure is created respectively by a blank wall and the force of friction against the side wall of the camera;

• on the type of workpieces that create the compression force, the following: auger, plunger, roller and combined.

6.1 Auger granulators

Screw granulators can be cylindrical and conical, single- and twin-auger, with horizontal and vertical arrangement of augers.

Fig. 8. depicts one of the possible designs of a auger granulator.

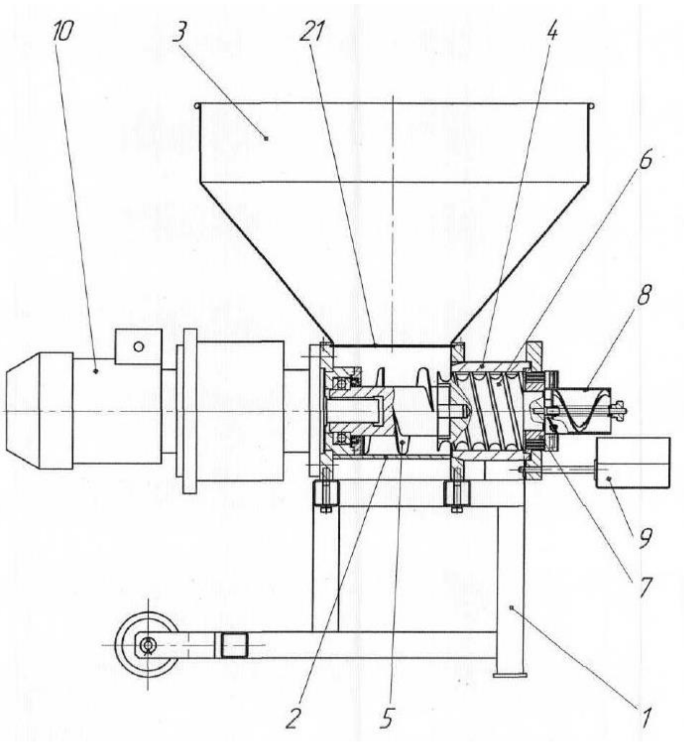

Fig. 8. Schematic diagram of the auger granulator:

1 – frame; 2 – receiving chamber; 3 – receiving bunker; 4 – working chamber; 5 – feeding auger; 6 – pressing auger; 7 – annular matrix; 8 – pelletizing device; 9 – tray; 10 – drive; 11 – hatch

The granulator consists of a frame 1 on which a receiving chamber with a receiving bunker 3 and a working chamber 4 are mounted, in which the feeding 5 and pressing augers 6 are located.

At the end of the working chamber the annular matrix 7 with die for extruded product is fixed. On the outside of the matrix 7 pelletizing device

8 and tray 9 for waste disposal are placed. The drive of the augers 5 and 6, as well as the pelletizing device 8 is carried out from the general power drive 10.

The granulator works in this way: the raw material is loaded into the receiving bunker 3 and when the power drive 10 is on, it is supplied by the feeding auger 5 to the pressing auger 6, which pushes the product through the die of the matrix 7. At the exit of the die of the matrix 7, the product bundles are cut into pellets with the blades of the main knives. The length of the pellets depends on the number of blades and the amount per unit time of product coming in and can be adjusted by the hatch 11 of the receiving chamber 2.

6.2 Plunger extruders

In plunger extruders widely used in the production of fluoroplasts, unlike auger ones, molding is the result of uniaxial compression. Typically, a large portion of material is loaded into the cylinder of the plunger extruder, which is substantially unmixed in the molding process. This complicates the warming of the molded material.

6.3 Roller granulators

Roller granulators are divided into:

1. According to the location of the axes of the pressing rolls:
- granulators with vertical arrangement of axes of the pressing rolls;
- granulators with horizontal arrangement of axes of pressing rolls.

2. By type of drive mechanism:
- the matrix is stationary, only the pressing rollers are driven;
- the matrix and the pressing rollers are driven;
- only the matrix is driven.

Granulators with vertical arrangement of axes of the pressing rolls.

The rolls can be conical and cylindrical with active and passive drive. In cylindrical roller presses, matrices and rolls wear out irregularly due to the difference in wheel speeds. Among disadvantages there is also certain circumferential velocity of the material attribution under the action of centrifugal forces to the periphery of the matrix and, as a consequence, an uneven load on its working surface.

When granulating on a flat matrix, the rollers are often driven, and the matrix is fixed permanently. The material comes from above, falling on the matrix, and then the roller rolls upon it, and it is forced through the holes in the matrix.

Granulators with horizontal arrangement of axes of pressing rolls.

In cylindrical matrix granulators, the rollers are most often fixed permanently and the matrix is driven and rotates around them vertically. The granular material is backfilled on the side of the end face of the matrix, entrained by it in rotational motion and, being in the wedge space between the matrix and the roller, which also rotates under the action of friction forces, is forced through the radial holes of the matrix. This method of granulation is more rational than the previous one in terms of machine design, process energy consumption and wear resistance of the matrix and rollers.

7. The calculation of the design of the press granulator

The design of the press-granulator is related to the calculation of the geometric dimensions of the matrix and the pressing roller. In practice, a press pair having from one to three rollers is used, and the rollers, like the matrix, can have a drive. Often rollers are placed inside the annular matrix, but there is an external installation of the pressing roller.

Let us consider the most typical case where the roller is located inside the annular matrix, where the radius of the matrix R is greater than the radius of the roller [3,4,5,6,7,8].

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BIO-GAS AND THE GAS GENERATION OF ORGANIC BIOMASS

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1. The history of bio-gas technology development

The first scientific substantiation of marsh gas combustion, the determination of the presence of methane in marsh gas and methane fermentation were discovered and investigated in 1776 by Volt. After discovering the chemical formula of methane by Dalton in 1804, European scientists took the first steps in the study of the practical application of biogas.

Biogas is formed as a result of anaerobic fermentation of organic materials. Being a product of metabolism and present in organic waste of methane bacteria which produces biogas. A prerequisite for biogas production is the productive activity of methane-forming bacteria.

Today it is known that this is a lack of oxygen, pH – from 6.5 to 7.5 and constant temperature from 15 to 55 °C. The fermentation period is from 10 to 120 days, depending on the conditions regulated by the above parameters, namely the pH factor and the temperature of the environment.

1.1 The main stages of methane fermentation

Methane fermantation is the process of decomposing organic matter to end products, mainly methane and carbon dioxide, due to the vital activity of a complex of microorganisms under anaerobic conditions. Under optimal conditions, these gases are formed in the amount of 90...95% of decomposed organic matter. The remaining 5… 10% are spent on bacterial cell renewal.

According to McCarthy's theory, the complete destruction of organic matter is as follows:

$$C_{10}H_{19}O_3N + 4,5H_2O \rightarrow 6,25CH_4 + 3,75CO_2 + NH_3 + HCO_3 \qquad (1)$$

According to modern concepts, anaerobic methane fermentation has four related stages:

1. Stage of enzymatic hydrolysis of insoluble complex organic substances with the formation of simple soluble substances;

2. Stage of acid-forming process with the release of volatile fatty acids (VFA), amino acids, alcohols, hydrogen and carbon dioxide (acidogenic stage);

3. Acetogenic stage of conversion of VFA, amino acids and alcohols to acetic acid;

4. The methanogenic stage is the formation of methane from acetic acid and the recovery of carbon dioxide by hydrogen.

Enzymatic hydrolysis takes place with the help of the enzymatic bacteria Bacillus, Micrococcus, Pseudomonas, Clostridium, etc., which convert organic complex compounds into simple ones by enzymatic hydrolysis and acid formation. These bacteria at pN = 6,5...7,6 quickly grow and release into the environment biological catalysts – exoenzymes, with the participation of which the hydrolysis and transition of soluble insoluble compounds into soluble state proceeds. The rate of hydrolysis depends on the nature of the organic matter and the conditions of its conduct: it is necessary to provide a sufficient number of enzymes, to create conditions for their contact with the organic substrate, to maintain optimal temperatures and pH values.

The acidogenic stage occurs with the help of heterogeneous microorganisms, for which carbon, which is converted into a solution of simple organic compounds, is a source of nutrition. Stages of acid formation occur quickly, because the acid-forming bacteria are unpretentious and multiply at high speed. The intense course of hydrolysis and acid formation (total duration of about 7 hours) leads to the accumulation of volatile acids and pH decrease, which suppresses the bacterial growth and stimulates methanogenesis.

In the third acetogenic stage, the first group of bacteria, for example from propionic and butyric acids, acetic acid and hydrogen are formed.

$$\begin{gathered} CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2 \\ CH_3CH_2CH_2COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2 \end{gathered} \quad (2)$$

The second group of acetogenic bacteria forms acetic acid by recovery of carbon dioxide with hydrogen.

$$4H_2 + 2CO_2 \rightarrow CH_3COOH + 2H_2O \quad (3)$$

In the fourth methanogenic stage, methane bacteria form methane in two ways – the splitting of acetate (acetic acid) and the recovery of carbonic acid by hydrogen.

$$CH_3COOH \rightarrow CH_4 + CO_2$$
$$CO_2 + H_2 \rightarrow CH_4 + H_2O \qquad (4)$$
$$CO_2 + H_2 \rightarrow CH_4 + H_2O$$

The simplest process of methane fermentation takes place in watertight tanks (digesters) with a side opening through which the enzymatic raw material is introduced. A gas container (metal or plastic) is installed above the digester to collect gas. Mounted over the fermenting biomass, dome container prevents air from entering the dome and provides anaerobic process conditions.

Lime is used as a stabilizer against acidification. Optimal "breathing" in the methane tank occurs under conditions close to neutral (pH = 6.0…8.0). The maximum temperature of the process depends on the mesophilicity or thermophilicity of the microorganisms (30… 40^{o}C or 50… 60^{o}C) sudden changes in temperature are undesirable.

In terms of the nutritional requirements of the bacteria, excess nitrogen (eg in the case of liquid manure) contributes to the accumulation of ammonia, which suppresses the bacterial growth. For optimal processing, the C/N ratio should be 30: 1 (by weight). This ratio can be varied by mixing nitrogen-enriched components with carbon-enriched components. So, the ratio of manure can be varied by the addition of straw or sugar beet pulp. Food and agricultural wastes have a significant amount of carbon, so they are best suited for methane fermentation, especially since some of them (pulp) are produced at the temperature most optimal for the process.

Biogas production through methane “fermentation” of waste is one of the ways to solve energy, economic, environmental, agrochemical problems in most countries of the world.

Biogas is a mixture of methane (60…85%) and carbon dioxide (15…40%). It is obtained in special installations of various constructive designs, depending on local conditions.

The heat of solid fuel combustion, such as coal, is 6…32 MJ/kg. Biogas has a combustion heat of 21…36 MJ/kg under normal conditions. From a ton of organic matter from 250 to 600 m^3 of biogas are released . After the methane process, compost residue. Different substances produce not the same amount of biogas. It should be noted that by adding up to 30% of cellulose to biomass, the biogas output increases by 2…3 times.

A kilo of manure gives: 0.18 kg of methane, 0.32 kg of carbon dioxide, 0.2 kg of water and 0.3 kg of humus. One kilogram of biogas gives heat that emits 0.6 kg of kerosene, 1.5 kg of coal, 2…3 kg of firewood. Today more than 70 types of biogas technologies have been developed.

1.3 The hardware realization of bio-gas production

The biogas plant produces biogas and biofertilizers from the biowaste of the agro-industrial complex of the food and processing industry through methane treatment.

According to temperature regimes, biogas production is divided into psychrophilic (15…20 °C), mesophilic (30…40 °C) and thermophilic (52… 56 °C). The average time of origin in mesophilic mode is 15…30 days, in thermophilic – 5…10 days.

Fig. 1 presents a schematic diagram of continuous anaerobic processing of organic waste.

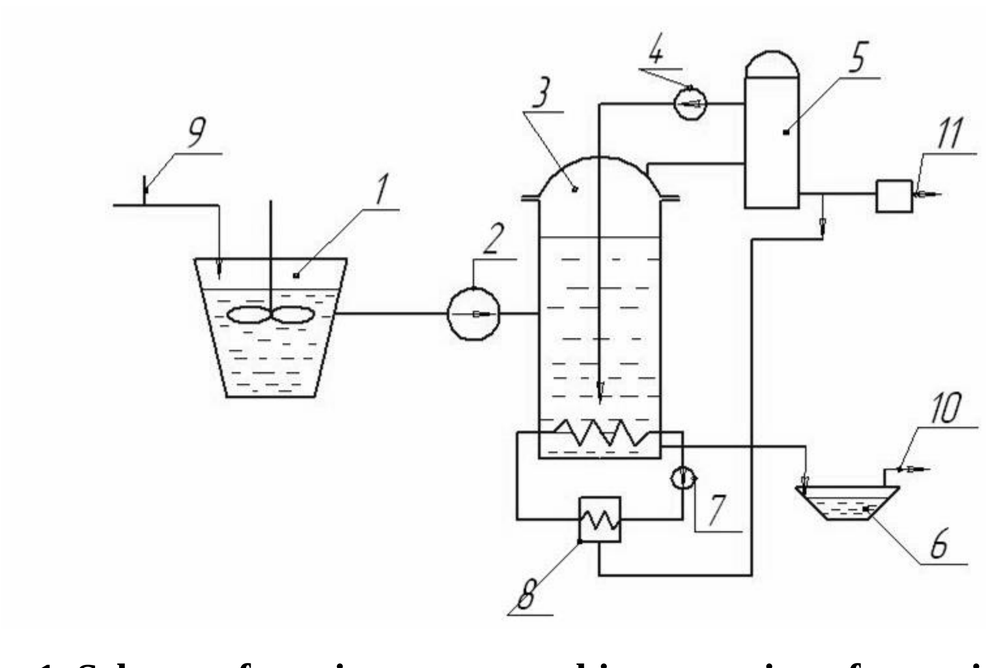

Fig. 1. Scheme of continuous anaerobic processing of organic waste:

1 – tank for the preparation of raw materials; 2 – metering pump; 3 – methane tank; 4 – compressor; 5 – gas holder; 6 – compost collector; 7 – circulation pump; 8 – a boiler for maintaining the temperature of methane tank; 9 – supply of raw materials; 10 – fertilizers for use; 11 – gas filter; 12 – biogas for use.

Organic waste is supplied into the raw material preparation tanks (1), in which grinding, mixing, removal of solids, mass moisture up to 88… 90% and other operations take place. The prepared raw material is supplied by metering pumps (2) to the methane tank (3), where the process of fermentation occurs under the action of methane-forming bacteria. The generated biogas is discharged from the upper part of the methane tank into the gas holder (5), from where it comes to the consumers. The residues of the fermented raw materials (decontaminated fertilizers) from the lower part are supplied into the waste collector (6) from which they are taken to the field.

In order to maintain the set temperature in the methane tanks, hot water heated in the boilers (8) is pumped through the coil pipes. Such heating consumes 20… 30% of the produced biogas. Depending on the time of fermentation of raw materials, the required volume of methane tanks and the amount of raw material supplied for dispensing by the pumps are determined.

To accelerate the fermentation process, part of the biogas is supplied back from the gas holder by compressor (4) to the methane tank.

The installation consists of two reactors, a heater, a fecal and screw pumps, a gas holder, a compressor, a boiler.

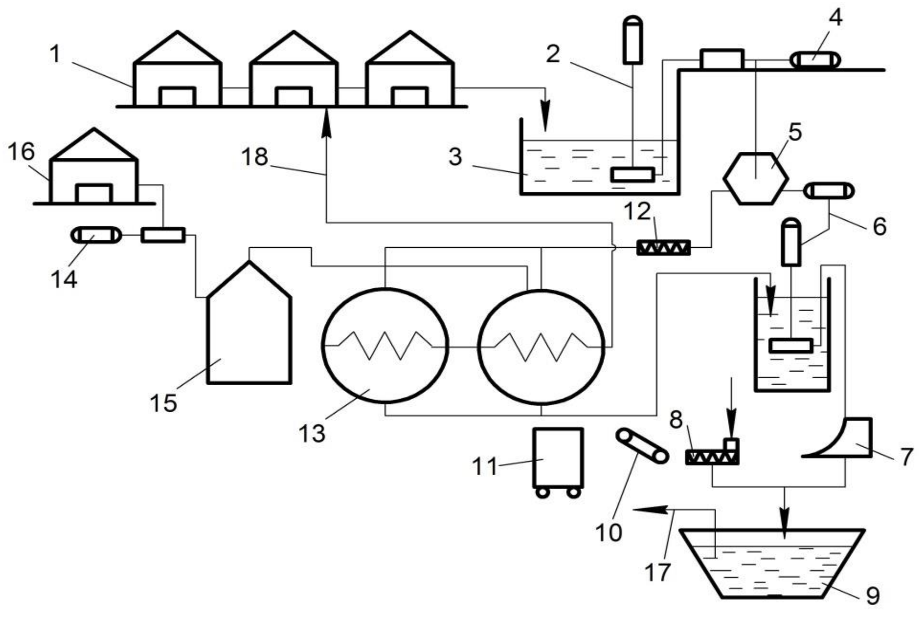

Fig. 2. Technological flowchart of biogas plant:

1 – farm; 2 – pump for liquid pulp; 3 – collector; 4 – granulator; 5 – heater-holder; 6 – pumps for liquid manure; 7 – arc sieves; 8 – press filter; 9 – manure storage; 10 – conveyor; 11 – tractor trailer; 12 – screw pump; 13 – methane tank reactor; 14 – compressor; 15 – gas holder; 16 – boiler; 17 – fertilizers for use.

The waste from the farm flows into the collector (3). Various organic wastes can be added to the collector. The mixture from the collector (3) is pumped into the granulator (4) and then into the heater-holder (5).

The heater-holder (5) is a 25 m^3 tank with a heat exchanger where the manure is heated to the required temperature. From the heater-holder (5), the mixture is pumped with a screw pump – dispenser (12) to the reactor (13), where biogas is released, which is pumped by the compressor for cleaning into the gas holder (15). The gas is then fed to the gas boiler (16) for use by a compressor (14) through a water valve and a non-return valve. Inloads can be regulated automatically.

In various designs of biogas plants, the process mixture is divided into solid and liquid parts. The thick mass is passed through a press filter for dewatering up to 75%, and water is used as a technical water for industrial purposes.

1.4 The formulas for the calculation of the parameters of biogas plant

Most biogas plants are based on the the streaming principle of action, that is, they have input raw materials that immediately displace waste. Fresh manure is supplied continuously (2…10 times a day), and biogas and sludge removal are done as needed.

The biogas plant consists of the following elements: receiving tanks, a fermentation chamber (methane tank, reactor), a heating device (heat exchanger), a device for mixing the substrate, a gas holder and a gas water heater.

Raw material from the loading bunker enters the methank, where it is fermented, resulting in biogas coming through the water gate into the gas holder. Part of the biogas is sent to the boiler to maintain the required temperature in the methane tank. The biomass is mixed by an electric motor stirrer. Used methane tank raw material is supplied into biofertilizer storage.

Calculations of structural and technological parameters.

The daily supply of biomass $m_{бм}$ is determined by the formula:

$$m_{бм} = \sum N_{mj} m_{nmj}, кг / добу, \tag{5}$$

where N_m – number of animals of the j-th species, heads; m_{nmj} – daily output of excrement from the j-th animal, kg/h.

The proportion of dry matter in biomass m_{CP} :

$$m_{CP} = m_{бм} \cdot \left(1 - \frac{\varphi_{бм}}{100}\right), \quad (6)$$

where $\varphi_{бм}$ – biomass moisture,%.

Let us determine the proportion of dry organic matter m_{COP} by the formula:

$$m_{COP} = m_{CP} \cdot \rho_{COP}, \quad (7)$$

where ρ_{COP} is the proportion of organic matter in the dry matter,%.

Let us determine the volume of methane tank $V_{мт}$ by the formula

$$V_{мт} = \frac{(0,7...0,9) m_{бм} t_{б}}{\rho_{бм}}, \quad (8)$$

where $t_б$ – duration of fermentation, *days*; $\rho_{бм}$ – density of the fermented biomass, *kg/m*^{3} .

Biogas output $V_{пов}$, m^3, with complete decomposition of dry organic matter (DOM):

$$V_{пов} = m_{COP} \cdot n_{ек}, \quad (9)$$

where $n_{ек}$ – biogas output from 1 kg of DOM.

let us determine the amount of biogas obtained $V_б$, m^3, with the selected duration of methane fermentation:

$$V_б = V_{пов} \frac{n_t}{100}, \quad (10)$$

where n_t is the fraction of biogas output at the given fermentation time.

Monthly volume of biogas produced:

$$V_{бг}^{м} = 30 \cdot V_б, м^3. \quad (11)$$

Annual volume of biogas produced

$$V_{бг}^{р} = 365 \cdot V_б, м^3. \quad (12)$$

Calculation of the dimensions of the methane tank

As a rule, the methane tanks have a cylindrical shape, the ratio of height to its inner diameter is assumed to be h/d = 0.9…1.3. We accept h/d = 1.

$$V_{мт} = \frac{\pi d_в^2}{4} \cdot h = \frac{\pi d_в^2}{4} \cdot d_в, \qquad (13)$$

$$d_в = \sqrt[3]{\frac{4V_{мт}}{\pi}}, м. \qquad (14)$$

Determination of the average monthly amount of biogas.

The amount of heat $Q_{під}$, is required to heat the loading mass to the temperature of the fertilization process:

$$Q_{під} = m_{бм} \cdot c_{бм} \cdot (t_{пр} - t_{зав}) \cdot 10^{-3} мДж, \qquad (15)$$

where $c_{бм}$ – average biomass heat capacity, $c_{бм}$ = 4.18 kJ/(kg · °C); $t_{пр}$ – fermentation process temperature, °C; $t_{зав}$ – loading biomass temperature °C. We assume equal to the average monthly environment temperature, if less than 5 °C, then 5 °C is accepted.

The monthly average amount of heat is determined by the expression:

$$Q^{м}_{під} = Q_{під} \cdot t^{м}_{доб}, \qquad (16)$$

where $t_{доб}^{м}$ – the number of days in a month, $t_{доб}^{м}$ we accept equal to 30 days.

The amount of heat $Q_{втр}$, that is lost in the process of heat transfer through the wall of the methane tank to the environment:

$$Q_{втр} = k \cdot f \cdot (t_{пр} - t_{ср}) Вт, \qquad (17)$$

where k – the heat transfer coefficient, W/(m^2·°C); f – the surface square of the methank, m^2; $t_{ср}$ – average monthly air temperature, °C.

The heat release coefficient is determined by the formula:

$$k = \frac{1}{\frac{1}{\alpha_1} + \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_2}} Вт/(м^2 \cdot {}^\circ C), \qquad (5.18)$$

where $1/\alpha_1$ – resistance of heat perception, $1/\alpha_1$ = 0,05 (m^2· °C)/W; $1/\alpha_2$ – heat transfer resistance, $1/\alpha_2$ = 0.05 (m^2· °C)/W; δ_{and} – the thickness of the i-th layer of the fence element, m; λ_i – coefficient of thermal conductivity of the i-th layer of the fence element, m·°C/W.

The surface area of the methane tank will be determined from the expression:

$$F = S_{біч} + 2 \cdot S_{осн}, м^2, \quad (19)$$

where $S_{біч}$ is the area of the lateral surface of the methank, m^2;
$S_{осн}$ – metanthanese base area, m^2.

$$S_{OCH} = \frac{\pi d^2{}_B}{4}, м^2. \quad (20)$$

$$S_{біч} = \pi \cdot d_в \cdot h = \pi \cdot d_в^2, м^2. \quad (21)$$

Transfer of the amount of heat, lost to the environment, into MJ/mo:

$$Q^м_{втр} = 3{,}6 \cdot 10^{-3} \cdot Q_{втр} \cdot t_{гм}. \quad (22)$$

where $t_{гм}$ is the number of hours in a month.

The total energy consumption for mechanical stirring of the substrate in the methane tank $Q_{мех}$ is determined by the formula

$$Q_{мех} = q_{норм} \cdot V_{мт} \cdot z, кВт \cdot год, \quad (23)$$

where $q_{норм}$ – specific load on the stirrer, $q_{норм} = 50\frac{Вт \cdot год}{м^3}$; $V_{мт}$ – methane tank volume, m^3; z – stirrer life, z = 8 hours a day.

We transfer the obtained values in MJ/month:

$$Q^м_{мех} = 3{,}6 \cdot Q_{мех} \cdot t^м_{доб}. \quad (24)$$

Total energy flow rates for support of the process per month:

$$Q_{заг} = Q^м_{під} + Q^м_{втр} + Q^м_{мех}, МДж / міс. \quad (25)$$

The amount of biogas required to support the process:

$$V_{бгз}^{\ м} = Q_{заг} / q_{бг}, м^3 / міс. \quad (26)$$

The product quantity of biogas $V_{бг\ тов}{}^{м}$, m^3/ month, will be equal to:

$$V_{бгтов}^{\ м} = V^м_{бг} - V_{бгз}^{\ м}. \quad (27)$$

Calculations of energy efficiency indicators of biogas plant.

The potential energy of biogas $Q_{отр}$produced in a year is determined by the formula:

$$Q_{отр} = V_{бг}^{рік} \cdot q_{бг}, мДж. \tag{28}$$

Energy effect of biogas plant $Э_б$ per year:

$$Э_б = V_{бгтов}^{рік} \cdot q_{бг}, мДж. \tag{29}$$

Venality ratio of biogas plant

$$K_{тов} = \frac{Э_б}{Q_{отр}} \cdot 100\%. \tag{30}$$

Annual savings of conventional fuel will be:

$$B_{уп} = \frac{Э_б}{29300}. \tag{31}$$

The theoretical basis of the process of gasification of plant biomass

Gasification is a process of intense exothermic oxidation, in which the reaction of carbon with carbon dioxide and water vapor with the formation of combustible gases (CO, H_2, CH_4, etc.) takes place. With excess oxygen, the gasification process goes into the combustion process, characterized by maximum heat release (endothermic reaction).

It is established that the whole process of gasification can be divided into three stages:

1 – heating and drying of plant biomass;

2 – thermal decomposition of raw materials into gaseous products and solid residue;

3 – gasification of the carbon residue.

In the first stage, the plant biomass is heated to a temperature of about 250 °C. At this temperature, at high heating rates, due to the increase in pressure, the walls of plant biomass cells break with the release of bound moisture from organic raw materials in the form of steam.

It is established that at 200 за 300 °C the biomass begins to react and at 400 °C the thermal decomposition ends. It should be noted that the main components because of thermal decomposition, of wood for example, are cellulose, lignin and hemicellulose.

It is noted that at high temperatures and small particle size of the raw material the process of gasification takes place, and at low temperatures and large particle size, and in the presence of moisture in the raw materials – the formation of carbonaceous matter, water and CO_2.

If the process of gasification is only due to the oxygen of the air, then the so-called air gas is formed, which mainly consists of carbon monoxide and nitrogen passing from the air, as well as a small amount of carbon dioxide. When used as a blast of water vapor these are formed: hydrogen, carbon monoxide and carbon dioxide, which are mixed with water vapor. This mixture is called – water gas. When simultaneously used as a blast of water vapor and air, carbon monoxide, hydrogen, carbon dioxide, nitrogen and water vapor are formed, this mixture is called mixed or vapor-water gas.

A prerequisite for the process of gasification of plant biomass is the prevention of combustion of the gases formed in the process.

Most of the dry distillation products are capable of burning with a significant amount of heat, which leads to an increase in its calorific value (Table 1).

Table 1

Characteristics of gases

Name of the substance	The chemical formula	Molecular Weight	Actual gas weight (kg/m^3)	Calorific value	
				higher	lower
				MJ/m^3	
Hydrogen	H_2	2,016	0,0898	12,8	10.8
Oxygen	O_2	32,0	1,4290	-	-
Nitrogen	N_2	28,016	1,2510	-	-
Carbon monoxide	CO	28,01	1,25	12,6	12,6
Carbonic acid	CO_2	44,01	1,977	-	-
Methane	CH_4	16,04	0,717	39,8	35,9
Ethylene	C_2H_4	28,05	1,26	62,7	58,7
Ethan	C_2H_6	30,06	1,356	69,7	63,8
Sulfuric anhydride	SO_2	64,07	2,927	4,3	4,3
Hydrogen sulfide*	H_2S	34,09	1,539	25,1	23,2
Water vapor	H_2O	18,016	0,804	-	-
Air	-	28,853	1,293	-	-

* during combustion H_2O and SO_2

Obtaining air gas is accompanied by the following reactions:

$$C + O_2 \rightarrow CO_2 + 399.8\ kJ \qquad (34)$$

$$2C + O_2 \rightarrow 2CO + 232.6\ kJ \qquad (35)$$

$$C + CO_2 \leftrightarrow 2CO - 167.2\ kJ \qquad (32)$$

$$2CO + O_2 \leftrightarrow 2CO_2 + 566{,}9\ кДж \qquad (33)$$

Thus, as a result of combustion at excess carbon, a carbon dioxide is formed in the carbon-oxygen system, which in the presence of excess oxygen can turn into CO_2. In turn, the combustion with excess oxygen ongoes with the formation of CO_2, which when heated decomposes into CO and O_2.

The reaction $C + O_2 = CO_2$ is instantaneous at temperatures of 982 °C, and at lower temperatures its relative velocity is expressed by the following values: 350 °C – 1, at 400 °C – 10 and at 500 °C – 200.

The reaction $2C + O_2 = 2CO$ is considered to be primary in carbon combustion. However, given that carbon burns directly into CO_2 with subsequent recovery, (5.2) is used to express the end result of the reactions:

$$C + O_2 = CO_2$$

$$C + CO_2 = 2CO$$

$$2C + O_2 = 2CO$$

The reaction $C + CO_2 = 2CO$ is essential in terms of the gas-generating process. The interaction of CO_2 and carbon with CO production proceeds with increasing volume and negative thermal effect. According to the Le Chatelier principle, in equilibrium, with increasing pressure, the reaction must proceed towards the formation of CO_2, and conversely, with decreasing pressure in the equilibrium mixture, the CO content should increase. Similarly, raising the temperature should cause the reaction to flow towards the formation of CO, and vice versa.

In the mixture of gases correlating by the composition with the generator gas, the reaction of CO formation takes place at temperatures above 700 °C, and the temperature below 700 °C leads to the decomposition of CO. It is found that the higher the temperature, the more complete the recovery of CO_2 is. It was found that at 1000 °C favorable conditions for complete recovery of CO_2 in CO occur, while the decrease in pressure contributes to obtaining more CO and less CO_2.

The transformation of carbon residues into gaseous products is due to the following reactions:

$$C + H_2O \rightarrow CO + H_2 - 11\ \text{MJ/(kg of carbon)}$$

$$C + CO_2 \rightarrow 2CO - 14.6\ \text{MJ/(kg of carbon)}$$

To accelerate the flow of gasification of plant biomass a temperature of 700 °C and heat supply in the amount of from 11 to 14.6 MJ per 1 kg of carbon in the carbon residues are required.

Depending on the method of heat supply, gasification of plant biomass can be classified into autothermal and allothermal.

Depending on the composition, oxidizing medium and moisture of the source fuel, the generator gas has a combustion heat of 4 to 15 MJ/m^3.

The allothermal method of producing combustible gases from solid fuels is based on bringing heat into the gasification zone of the solid carbon residue through the gas generator reactor vessel, or by heating the fuel particles inside the gas generator at the expense of an external coolant. Given the theoretical foundations and features of the allothermal method design, the production of gaseous fuels has not become widespread, unlike the autothermal gasification method.

Depending on the organization of the supply of oxidizer and particle size distribution of the source solid fuel they distinguish the following schemes of autothermal gasification method: in a dense layer; in a fluidized bed; in the dust stream.

Scheme of gasification in the dense layer. At gasification in a dense layer the source fuel in the form of small particles is supplied from above into the shaft of the gas generator, where the stages of drying, pyrolysis and, in fact, gasification take place. Depending on the type of fuel, its composition and moisture, a suitable drying, pyrolysis and gasification time is set, which is characterized by the height of the respective zones in the gas generator shaft.

Considering the place of supply and the type of blast (air, water vapor, oxygen) and the location of the output of the synthesis gas from the shaft they distinguish three types of gas generators with a dense layer:

- direct gasification process;
- reverse gasification process;
- horizontal gasification process.

In the direct process of gasification of raw materials, the generator gas exits from the upper part of the shaft, and the supply of air blast is carried out at the very bottom of the shaft gas generator, where the process of combustion of carbon residual fuel with heat and combustion products (CO_2, H_2O) takes place.

Moving from the bottom up, the products of combustion pass the entire layer of fuel in the shaft, and there is a consistent process of gasification of carbon residue and pyrolysis. Gasification products (CO, H_2, CH_4) form a cooled gas mixture that passes through the middle part of the fuel layer in a shaft where there is a process of thermal decomposition with the release of acids, resins, and gases. Further, the mixture of combustion products (generator gas) passing through the upper layer of fuel, dries it, cools down and exits at the top of the shaft of the gas generator.

The advantages of the reverse process on the purity of the generator gases are especially important in the gasification of "young" solid fuels, which emit resin and acid in large quantities during the pyrolysis.

Scheme of gasification in a fluidized bed. The characteristic difference between the method of gasification of solid fuel in the fluidized bed (Winkler's method and its modifications) in comparison with the method of gasification in the dense layer is that the fuel particles under the action of steam-air or steam-oxygen blast make continuous movement in the volume of the gas generator shaft. This movement intensifies significantly: the processes of heat and mass exchange between solid particles of fuel and the heated steam-gas environment; processes of thermochemical decomposition of solid fuels and unstable compounds formed in the process. This is favorably reflected in the uniformity of flow of the processes of gas generation gas, the increase of gas output per square unit of the cross section of the gas generator shaft, as well as the reduction of the amount of unwanted impurities in the gas and equalization of the composition of gases at the exit of the shaft.

In the case of autothermal gasification technology, the heating of the circulating solid coolant (as well as its presence) is optional, and the fluidization of the fuel particles can be carried out without recirculation, by the appropriate organization of the supply of steam-air or steam-oxygen blast.

Scheme of gasification in the dust stream. During the experimental studies of gas formation processes as a result of thermal effects on different particle sizes of fuel, a significant influence of particle size and heating rate on the intensity of gassing, composition and amount of gases formed is revealed. The smaller the particle size of the fuel, the faster and more gaseous products of thermal decomposition of plant biomass are formed.

There are several methods of gasification of powdered solid fuels for realization of the revealed positive effects: «Koppers-Totzek», «PRENFLO» and «Texaco». In all these methods, powdered fuel with a particle size of not more than 100 microns (0.1 mm) is used.

According to the "Koppers-Totzek" ("PRENFLO") method, the powdered fuel is supplied by counter flows along with the oxygen blast. In the Texaco method, the powdered fuel is supplied in the form of an aqueous suspension in a stream enriched with oxygen. These methods of gasification occur at excess pressure (1÷3.5 MPa) and temperature 1300÷1700 °C.

The advantage of the Koppers-Totzek method is the high level of conversion of the organic part of the fuel into a relatively pure resinless generator gas, as well as the ability to process almost any kind of solid fuels, regardless of their sintering.

2.2 The structure and principle of operation of gas generating power plant

The gas-generating energy complex (block A, figure 3) is the main component of the whole range of equipment for the disposal of disperse organic waste.

The scheme in fig. 5.1 is one of the technological options for the installation. The complex works as follows: from the receiving area the fuel (18) by grapple (3) with the help of the monorail (1) and electric hoist (2) is supplied into the buffer tank for waste (4), from where it is sent through the gateway dispenser (5) to the gas generator (6) for gasification. Then, the mineral residue in the form of ash through the hatch unloading ash (8) is shipped to the ash bunker (17), after which it is sent to consumers. In order to carry out the gasification process, the air is supplied from the blower (7) is supplied to the gas generator (6). The generated gas through the gas branch pipe (9) is sent to the cyclone (10) for cleaning of suspended particles, the cyclone is periodically unloaded through a special device in the bunker (17). Then the gas enters the radiator (11), where it is cooled. Then, the generator gas is sent to a fine gas filter (12) to remove fine dispersed solids and further cooling to a temperature below 45… 60 °C and the resin and water vapor are condensated. The generator gas thus prepared is supplied to the consumer via the additional purification device (14). In the role of the consumer, the manufacturer recommends the use of unit of heating modular AOM-02,5 in combination with a burner of DSGM-30 (15) type, or internal combustion engine of DGMA-75 (16) type or their analogs.

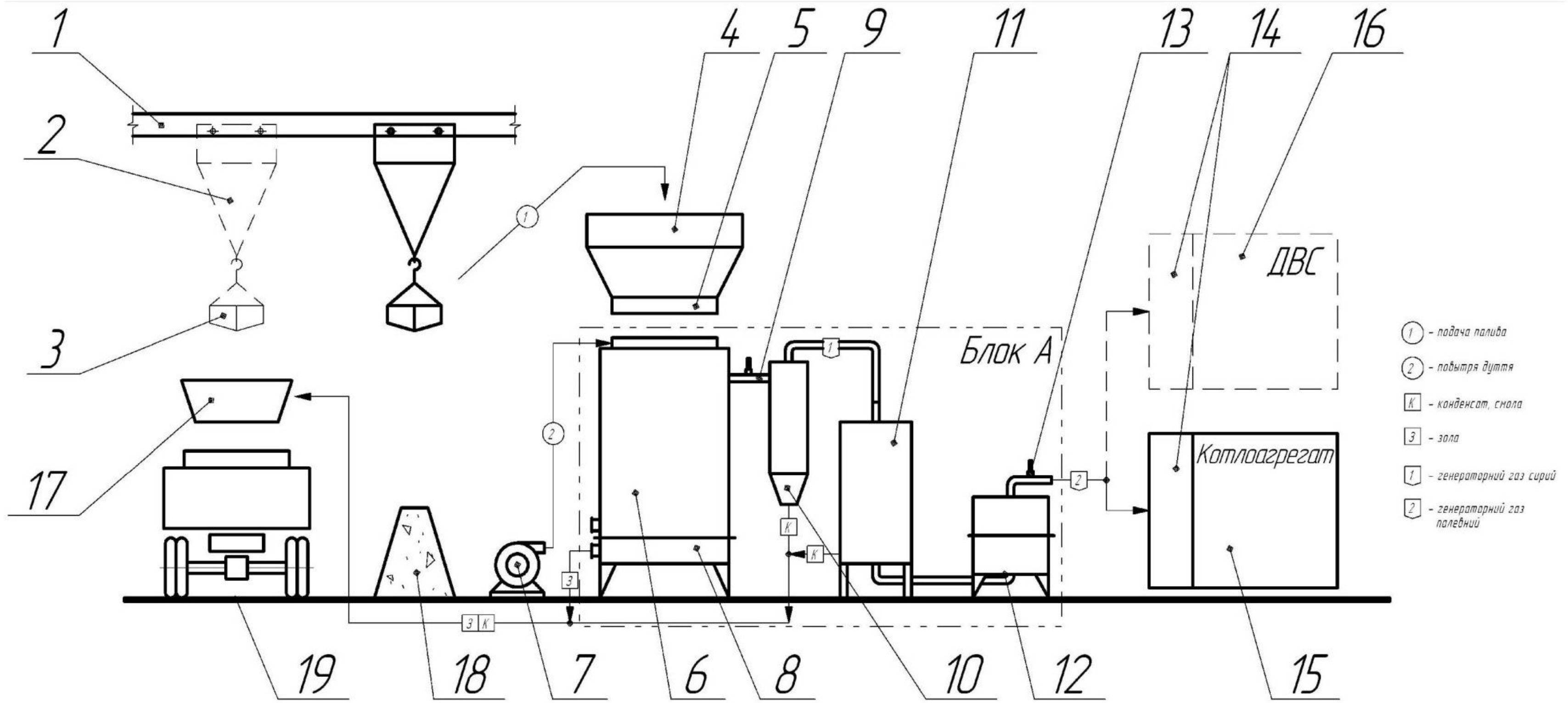

Fig. 1. The proposed technological scheme for the utilization of wastes of organic origin by means of the gas-generating energy complex GECA-3:

1 – monorail; 2 – electric tal; 3 – grapple; 4 – buffer tank for waste; 5 – gateway dispenser; 6 – gas generator; 7 – blower machine; 8 – ashbin; 9 – gas branch pipe; 10 – cyclone; 11 – radiator (cooler); 12 – fine gas filter; 13 – temperature measuring device; 14 – additional gas purification; 15 – boiler; 16 – ICE; 17 – condensate; ash bunker; 18 – fuel; 19 – frame.

2.4 The formulas for calculating the process of gasification of plant biomass using a gas generating power plant

To determine the basic parameters of the gasification process it is necessary to know the elemental composition of the fuel (table 2), on which the gas-generating power plant operates, and the approximate composition of the gas that may be obtained as a result of the gasification process.

Table 2

Elemental composition of fuel

Fuel	Content, %		Combustible mass,% by weight				
	moisture, W^p	ash, A^c	carbon, C^g	hydrogen, H^g	oxygen, O^g	nitrogen, N^g	sulfur, S^g
wood waste – technological chips	16…18	0,4…1,0	50,0	6,0	43,0	1,0	-
agricultural waste (sunflower husk)	10	3,5	47	6	45	1	1

The moisture content of the fuel W^p is given in % by weight relatively to the working mass of the fuel, ashes A^c – in % by weight relatively to the dry mass, other components – in % by weight relatively to the combustible mass of the fuel.

The combustible mass of the fuel consists of carbon C^g, hydrogen H^g, oxygen O^g, nitrogen N^g and sulfur S^g:

$$C^g + H^g + O^g + N^g + S^g = 100\% = \text{fuel mass} \quad (34)$$

The dry mass of the fuel consists of combustible and ash:

$$\text{fuel mass} + A^c = 100\% \quad (35)$$

To calculate the composition of the fuel from the combustible mass to dry we use the following formula (for any component):

$$x^c = \frac{x^г \cdot \left(100 - A^c\right)}{100}. \quad (36)$$

The working mass of the fuel consists of dry weight and moisture. The conversion from dry mass to working is performed by the formula (for any component):

$$x^p = \frac{x^c \cdot \left(100 - W^p\right)}{100}. \tag{37}$$

We convert the elemental composition of the fuel into working mass.

The conversion from combustible mass to working is performed by the formula:

$$x^p = \frac{x^г \cdot \left(100 - A^c\right) \cdot \left(100 - W^p\right)}{100 \cdot 100}. \tag{38}$$

Having converted the elements that make up the fuel by the formula (9) we get the composition of the working mass of the fuel.

The lower calorific value of the working mass of solid fuel is determined by the Mendeleev formula (10):

$$H_н^p = 81 \cdot C^p + 246 \cdot H^p - 26 \cdot \left(O^p - S_л^p\right) - 6 \cdot W^p ккал/кг, \tag{39}$$

where $S_л^p$ is the content of volatile (combustible) sulfur in the working fuel.

Dry gas outlet from 1 kg of working fuel.

Considering the loss of carbon of the fuel together with the ash, as well as in the form of dust, we obtain the amount of carbon of the fuel, which has passed into the gas, per 1 kg of fuel:

$$\frac{C^p - C_n}{100}, \tag{40}$$

where C_n – carbon losses in ash.

The carbon content of the gas is determined by the formula

$$C^г = \frac{12 \cdot (CO + CO_2 + CH_4)}{22{,}4 \cdot 100}, \frac{кг}{м^3 газу}, \tag{41}$$

where 12 is the molecular weight of carbon;

22,4 – volume of one mole of gas in m^3 at 0 °C and 760 mm Hg

Dividing the amount of carbon in the fuel (Formula 11) that has passed into the gas by a carbon content in 1 m^3 of gas (12), we obtain the output of dry gas (5.13) from a kg of working fuel:

$$V_g = \frac{22{,}4 \cdot \left(C^p - C_n\right) \cdot 100}{12 \cdot (CO + CO_2 + CH_4) \cdot 100} = \frac{1{,}867 \cdot \left(C^p - C_n\right)}{CO + CO_2 + CH_4}, \frac{м^3}{кг}. \tag{42}$$

Carbon losses in ash C_n are taken as 1.5…3%.

Specific weight of gas.

Specific weight of dry gas at 0 °C and 760 mm Hg:

$$\gamma_г = 0{,}0125 \cdot CO + 0{,}0009 \cdot H_2 + 0{,}0072 \cdot CH_4 + \\ +0{,}0198 \cdot CO_2 + 0{,}0125 \cdot N_2 + 0{,}0143 \cdot O_2, \frac{кг}{м^3}. \quad (43)$$

Moisture content in generator gas.

The amount of water vapor contained in the generator gas consists of hygroscopic moisture, moisture supplied from the outside, moisture formed from hydrogen of fuel, not taking into account the hydrogen consumed in the formation of methane. The amount of moisture contained in 1 m^3 of gas is determined by the formula:

$$f_г = \frac{W^p + 9 \cdot H^p}{100 \cdot V_g} - \frac{0{,}804 \cdot (H_2 + 2 \cdot CH_4)}{100}, \frac{кг}{м^3}, \quad (44)$$

where W^p and H^p – the percentage of moisture and hydrogen in 1 kg of fuel;

H_2 and CH_4 – percent of hydrogen and methane content in 1 m of gas;

0,804 – conditional specific weight, kg/m^3 of water vapor at 0 °C and 760 mm Hg, calculated by the formula: $\frac{m_{води}}{22{,}4} = \frac{18}{22{,}4} = 0{,}804$.

The total content of water vapor in the gas resulting from gasification of 1 kg of fuel can be calculated by the formula:

$$G_{вод} = f_г \cdot V_g \, \frac{кг}{кг_{палива}}. \quad (45)$$

The output of wet gas from 1 kg of fuel consists of the amount of dry gas V_g and the amount of water vapor $G_{вод.}$ expressed in units of volume:

$$V_g^{'} = V_g \cdot (1 + 1{,}24 \cdot f_г), \frac{м^3}{кг_{палива}}. \quad (46)$$

Air flow rates for gasification of 1 kg of fuel.

To calculate the cross-section of the tuyere through which the air enters the gasification chamber, it is necessary to know the amount of air required to gasify 1 kg of fuel.

The air flow rate is determined on the basis of the nitrogen balance, which changes from air to gas during the gasification of the fuel. Knowing that 1 m^3 of air contains 79% nitrogen (by volume), and 1 m^3 of gas contains N_2 % nitrogen, we conclude – the formation of 1 m^3 of gas consumes $\frac{N_2}{79}$ air. Then for gasification of 1 kg of fuels it is necessary to:

$$L = V_g \cdot \frac{N_2}{79} = 0{,}0127 \cdot V_g \cdot N_2, \frac{м^3}{кг}. \tag{47}$$

Material balance.

According to the law of conservation, the amount of substance used for gasification of 1 kg of fuel should be equal to the amount of substance obtained as a result of the gasification process of the fuel. Material balance of gasification process:

$$1{,}0 + 1{,}293 \cdot L = \gamma_г \cdot V_g + G_{вод} + 0{,}01 \cdot A^p + 0{,}01 \cdot C_n, \tag{48}$$

where 1.00 – weight of fuel in working condition;

1,293 – specific weight of air at 0 °C and 760 mm Hg;

1,293 L – weight of air consumed for gasification;

$\gamma_г \cdot V_g$ – weight of dry gas formed in the process of gasification of fuel;

$G_{вод.}$ – weight of water vapor resulting from the gasification process of the fuel;

$0.01 \cdot A^p$ – weight of ash;

$0.01 \cdot C_n$ – Carbon loss with ash and dust.

The amount of H_2 and O_2 is insignificant so it is not taken into account. Taking into account the possible variations in the composition of the generator gas with respect to the set fuel composition, as well as rounding in the calculations, it is possible to allow a difference in the material balance within ± 3%.

The efficiency of the gas generator.

Efficiency of gas-generating power plant is determined by the formula

$$\eta_г = \frac{V_g \cdot H_u}{H_н^p}, \tag{49}$$

where $\eta_г$ – gas generator efficiency; $H_н^p$ – calorific value of the working fuel in kcal/m^3; V_g – gas output from 1 kg of fuel m^3/ kg; H_u – lower calorific value of gas at 0 °C and 760 mm Hg in kcal/m^3.

Lower calorific value of gas is calculated by the formula:

$$H_u = 30{,}35 \cdot CO + 25{,}7 \cdot H_2 + 85{,}7 \cdot CH_4 \frac{ккал}{м^3}. \quad (50)$$

Thermal power of the gas generator.

Taking into account the data of the formulation of the task for the experimental design work, the thermal capacity of the gas-generating plant N_y should be in the range from 100 kW to 400 kW.

Knowing that 1 kW = 1 kJ/s = 3600 kJ/h and 1 kJ = 4.19 kcal from here

1 kW = 3600/4.19 = 860 kcal/h, we have

$$\begin{cases} N_y = 100 \text{ kW} = 86000 \text{ kcal/h.} \\ N_y = 250 \text{ kW} = 215000 \text{ kcal/h.} \\ N_y = 400 \text{ kW} = 344000 \text{ kcal/h.} \end{cases}$$

Having previously calculated by the formula (50) the lower calorific value of gas of a given fuel composition, we find the required power of the gas generator on the produced gas $N_г$:

$$N_г = \frac{N_у}{H_u}, \frac{м^3}{год}. \quad (51)$$

Fuel consumption.

Knowing the gas output V_g from 1 kg of fuel, we find the amount of gas required for gas production:

$$G_T = \frac{N_г}{V_g}, \frac{кг}{год}. \quad (52)$$

The amount of air required to burn 1 m^3 of synthesis gas.

When burning synthesis gas, air flow rate is determined by the ratio:

$$L_0 = \frac{1}{21} \cdot [0{,}5 \cdot (CO + H_2) + 2 \cdot CH_4 - O_2] \frac{м^3}{м^3_{газу}}. \quad (53)$$

The calorific value of the gas-air mixture is determined by the formula:

$$h_u = \frac{k \cdot H_u}{1 + \alpha \cdot L_0}, \frac{ккал}{м^3}, \quad (54)$$

where k = 0.92 and α = 1.

CONCLUSIONS

1. Ukraine has unique natural and climatic conditions and is a favorable region for energy efficient alternative energy technologies.

2. On the basis of modern methods and energy-efficient technologies, based on the techniques of biological intensification, technologies of increasing the efficiency of photosynthesis at the expense of prolonged use of solar energy have been developed.

3. The economically viable biomass potential that can be used for energy purposes in Ukraine is estimated at 30 million tonnes of conventional fuel per year. Its main constituents are agricultural waste and energy agroindustrial crops. By engaging them in energy production about 13 percent of Ukraine's primary energy needs can be met.

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