REALITIES AND PROSPECTS FOR INTENSIFICATION OF BIOETHANOL PRODUCTION DUE TO THE USE OF DISCRETE-PULSE ENERGY INPUT

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Abstract. The development of the biofuel industry and the production of bioethanol and using it as a fuel in the world in general and in Ukraine in particular are analyzed in the paper. Bioethanol is mostly produced from sugar- and starch-containing raw materials. It is noted that bioethanol is obtained mainly from molasses in Ukraine. Molasses is a by-product of sugar beet production. The prospects of second-generation bioethanol production made from unfit for human consumption lignocellulosic biomass such as agricultural by-products, forestry residues, municipal waste are considered. Pretreatment of lignocellulosic biomass is the main task in bioethanol production from such raw materials. Partial or complete hydrolysis of hemicellulose and the conversion of crystalline cellulose into an amorphous state are required to destroy the strong structure of the lignocellulosic complex and remove lignin for further processing. The method of Discrete-Pulse Energy Input was used to intensify the production of bioethanol from lignocellulosic biomass. The method allows shortening the duration of pretreatment, hydrolysis and fermentation, increasing the amount of reducing substances in the wort, reducing energy consumption and generally making this technology more economically attractive. The universal heat and mass exchange installation in order to reduce energy and resource consumption in bioethanol production from lignocellulosic biomass is developed at the Institute of Engineering Thermophysics of the NAS of Ukraine. The Installation allows carrying out the processes of dispersion, dissolution, heating, hydrolysis at the same time in one apparatus.

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1. Introduction

There are global changes in the structure of energy production all over the world now. These trends have already led to the fact that today the share of various types of biofuels in the total energy consumption is about 14% as shown in Figure 1. In agriculture, 17% of the corn crop, 19% of the sugarcane and 13% of the produced vegetable oil are used for biofuel production. Biofuel is a high added value product. Biofuel production solves several problems before agricultural producers at once:

– allows to increase the overall profitability of production;

– expands the sales market;

– makes it possible to process substandard products and agricultural waste efficiently.

Biofuel producers are an effective channel for the implementation of advanced scientific developments and an important part of the overall support system for research in the field of biotechnology and energy.

The main advantage of biofuels is that it is a renewable resource of energy from the point of view of global sustainable development. In addition, the use of biofuels is CO_2 neutral. Also, the additional infrastructure required for producing and use of biofuels is minimal compare to wind energy.

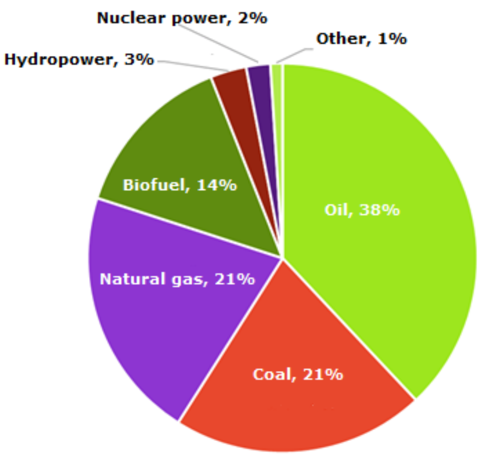

Figure 1. Structure of energy consumption in the world (according to the World Bioenergy Association, 2016)

The production of biofuels from renewable raw materials has received significant scientific attention as it can be used as a source of energy and alternative fuels. The support of this trend in many countries has provided the rapid growth of the production of motor biofuels such as bioethanol and biodiesel in the world since 2000.

2. World bioethanol production

Bioethanol is one of the most interesting biofuels due to its eco-friendly effectiveness, widespread production and use as a fuel or fuel additive. In Figure 2, the production of bioethanol is more promising than biodiesel.

The United States of America is the world leader in the production of motor biofuels. With a production of almost 15,800 million gallons (2017), the United States is more than twice ahead of its closest competitor Brazil as given in Figure 3. In Brazil, 90% of the cars produced in the country are equipped with engines designed to run on ethanol; 3 million vehicles run on ethanol alone, and another 16 million use a mixture of ethanol and gasoline. In the USA, 12% of cars run or can run on alternative fuels including ethanol. The so-called gasohol – gasoline containing 10% alcohol is widespread in the USA. The use of gasohol is allowed by all major car manufacturers without any engine adaptation.

As already mentioned, the share of biofuels in total world energy consumption is 14%, but only 4% from them is modern types of biofuels –

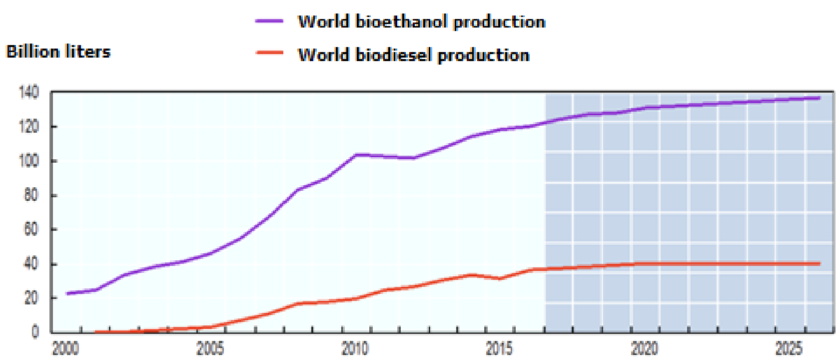

Figure 2. Dynamics and forecast of world production of bioethanol and biodiesel

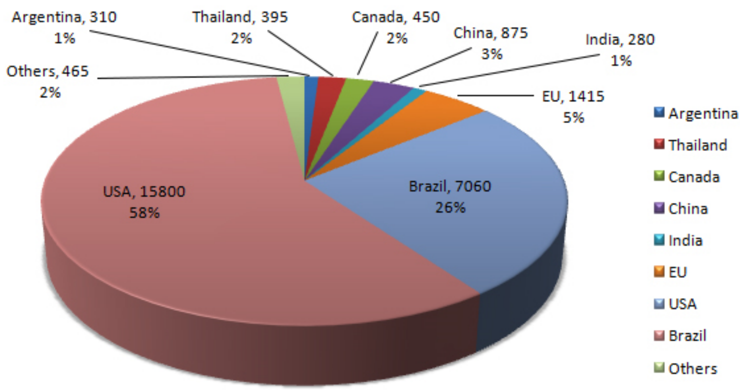

Figure 3. World production of motor biofuels (according to Renewable Fuels Association, 2017), million gallons

bioethanol and biodiesel, and the rest is traditional firewood, charcoal, etc. In some regions of the world, for example, in Central Africa, the share of traditional biofuels in the total energy balance exceeds 60%, while in Southeast Asia it remains at the level of 20-25%. For comparison, the share of such energy sources in Europe is only 0.3%, while in the USA it is close to zero. Sweden is the world leader in the use of biological energy sources. The share of various types of biofuels in the total volume of energy production is about 35%, more than a third of which is for industrial consumption.

Bioenergy is a large scale production. A key factor of bioenergy is arable land. Ukraine has a strong competitive position in this regards. An important role is also played by the development of technologies related to bioenergy, such as microbiological production of bioethanol, co-combustion technologies for using agricultural waste in energy production, etc. It is an effective instrument for the development of a whole cluster of innovative technologies focused on both domestic and global markets.

The main direction of bioethanol use is associated with the production of mixed fuels (ethanol + gasoline) with a high energy content. Table 1 compares the energy content of various fuels.

Special designations are used for bioethanol and mixed gasoline based on it, such as E5, E10, E85 (where E – from English, ethanol, digital

Table 1

Specific energy content of various fuels

Fuel	Specific energy, MJ/l
E100	23,5
E85	25,2
E10	33,7
Automobile gasoline	34,8
Aviation gasoline	33,5
Diesel fuel	38,6
LPG	26,8

indices the percentage in volume fractions of bioethanol in fuel). The most widespread fuel mixtures are E5, E10 and E85 in the world, also pure bioethanol E100 is produced and used as a motor fuel in Brazil. Common brands of ethanol – gasoline fuel mixtures are presented in Table 2.

Table 2

Common brands of ethanol-gasoline fuel mixtures [2]

Country	Brand	Comment
USA	E10	Gasohol (10% – ethanol-gasoline mixture)
Brazil	E70-E85	The ratio of ethanol to gasoline varies from region to region. Blends with a high ethanol content are used for refueling flexible fuel vehicles
	E25-E75	
	E100	
Europe	E5	Mixed with unleaded gasoline
	E85	It is not very common now

Fuel ethanol is the most popular gasoline additive. Bioethanol as a fuel has both advantages and a number of serious disadvantages.

The low toxicity, almost complete absence of CO in combustion and biodegradation products, the possibility of increasing the efficiency of the use of agricultural resources, reducing dependence on mineral oil, reducing the greenhouse effect are the undoubted advantages of bioethanol.

The main disadvantages of bioethanol are the use of food raw materials, unstable yields of some plants as sources of biomass, low efficiency of fermentative microbes, hygroscopicity, increased costs and low heat of combustion of ethanol fuel compared to petroleum [1]. As known, the research is currently underway to overcome the listed disadvantages of using ethyl alcohol as a fuel in many scientific centers around the world, and therefore one can hope that this problem will be solved in the near future.

The raw material for the production of bioethanol is starch-containing, sugar-containing and lignocellulose-containing raw materials.

It is necessary to destroy the starch macromolecular chain first of all in the process of bioethanol production from starch-containing raw materials. Thus, a large number of glucose units are obtained, which are a solution of sugars and can be converted into ethanol using yeast. Corn and wheat are predominantly used as starch-containing raw materials in North America and Europe. In addition, the raw materials for ethanol production can be sugar cane, beets, potato, Jerusalem artichoke, sugar production waste, etc. [3, p. 32].

The use of lignocellulose waste from agriculture and woodworking is one of the most attractive directions for bioethanol production. The main task in the process of converting raw materials into bioethanol is pretreatment for fermentation [4, p. 17]. Partial or complete hydrolysis of hemicellulose and transformation of crystalline cellulose into an amorphous state suitable for further processing are required to destroy the strong structure of the lignocelliolous complex and remove lignin.

Pretreatment of lignocellulose is carried out at the first stage of hydrolysis in order to destroy the structure of the cell wall of wood to extract hemicellulose and facilitate the access of hydrolytic enzymes, and, consequently, increase the reactivity of cellulose. Various physical methods can be used for pretreatment such as treatment with y-rays, electron flow, microwave radiation, heating, cooling, treatment with high or low pressure, ultrasonic vibrations, etc. [5, p. 322; 6, p. 167].

All known methods of plant waste recycling can be divided into three groups: mechanical (grinding), chemical (conversion), biological (bioconversion). These methods are usually combined in biotechnology.

Bioethanol from lignocellulosic raw materials is uncompetitive as the liquid fuel due to its high cost today. The improvement of the hydrolysis process and the creation of an economically efficient and environmentally friendly production can reduce the cost of such bioethanol.

The economic efficiency of bioethanol production depends primarily on the type of raw material and its preparation technologies for bioconversion.

The comparative economic calculations of the cost of bioethanol from grain and wood are known. The cost of raw materials and enzyme preparations is 62-70%, in the costs of ethanol from grain. The cost of raw materials is about 12% in the hydrolysis production of ethanol from wood processing waste. The large share of raw material costs in the first case can be explained by high prices for enzyme preparations.The costs for them is 5% of the total production cost. However, the process of bioethanol obtaining from grain is characterized by low consumption of heat and energy resources. Heat and energy resources about 40% and fixed expenses about 40% are the largest costs in the production of bioethanol from wood [7, p. 65].

3. Bioethanol production in Ukraine

The development of bioethanol in Ukraine is of current interest, but it is rather slow. Own production of raw materials (oil and gas condensates) provides the possibility of producing only 20% of the required amount of gasoline, the rest of the petrol is produced from imported oil or imported fuel from neighboring countries.

Ukraine's petrol dependence can be significantly reduced by developing production and expanding the use of alternative fuels, in particular bioethanol.

Approximate location of operating bioethanol production facilities is shown in Figure 4. There are 12 bioethanol producers in Ukraine. 9 state-owned plants are leased by private companies, and 3 plants are private. Investors became interested in this type of activity only when the price of a liter of gasoline reached the level of USD 1.25-1.35 per liter at filling stations. The cost price of ethanol-containing additives is USD 0.7-0.8 per liter at the above mentioned enterprises. Ethanol-containing additives mixed with cheap straight-run or gas condensate gasoline makes it possible to produce A-95 gasoline with a low content of sulfur and aromatic hydrocarbons. The names of ethanol-containing additives produced by these enterprises are mainly the abbreviation for the term "alternative motor fuel component" (AMFC).

According to the Deputy Director of the Institute of Food Biotechnology and Genomics of the National Academy of Sciences of Ukraine, D. Sc. in Engineering Sergii P. Tsygankov, the term "bioethanol" should not be used for the following reasons. The national standard since January 1, 2011, states that bioethanol must contain at least 98.3% (vol.) of ethanol and not

Figure 4. Bioethanol producers on the territory of Ukraine

more than 0.2% (vol.) of water. At the same time, although bioethanol is an excisable product with a zero rate, but it is followed all the requirements and rules for regulating its production and circulation such as:

– production license;
– tax post at the enterprise;
– transportation support;
– special requirements for storage;
– registration of a bank bill in the amount of excise duty on food alcohol (approximately USD 5 thousand per cubic meter) in case shipment to the consumer with a maturity of bill up to 90 days and using bioethanol for its intended purpose.

All manufacturers of ethanol-containing fuel additives avoid producing bioethanol in accordance with the national standard because of these conditions. They produce ethanol products that do not formally fall under the trade name «bioethanol». The composition differs from the requirements of the standard. Four of the above producers sell their products to oil traders with their own network of filling stations. Some gasolines A-95 sold at Ukrainian filling stations contain up to 15% ethanol replacing the more expensive methyl tertiary butyl ether. There are also types of fuels containing up to 40% of ethanol, under their own trade marks, such as "Pulsar-95", "A-95ek", "Ultimate-95". BioChemGroup enterprise has organized its own production of biofuel A-95a with a content of more than 30% ethanol and successfully sells it.

The raw material for fuel ethanol is almost entirely molasses, a by-product of sugar beet production, in Ukraine. Molasses is still the cheapest raw material for ethanol-containing additives despite periodic price surges. About 100 thousand tons of molasses are used for the production of 30 thousand tons of ethanol-containing components annually. Unfortunately, this source of raw materials is more and more exhausted every year. About 192 sugar factories operated in Ukraine in 1991. They produced 5.3 million tons of sugar and almost 2 million tons of molasses per year. 42 operating factories produced 1,820,000 tons of sugar last year. The potential for the production of bioethanol from molasses is unlikely to exceed 100 thousand tons per year considering that molasses is a raw material for the production of many types of products such as baker's yeast, food components, etc.

So, the development of innovative energy and resource-saving equipment and technologies for processing lignocellulosic raw materials such as waste from the agricultural and forestry industry is urgent task for domestic and for the global production of bioethanol.

The problems and difficulties associated with the process of lignocellulosic raw materials transformation into bioethanol are described above. Scientists from different countries of the world, including scientists from the National Academy of Sciences of Ukraine are trying to find the ways to solve them. In particular, the specialists of the Institute of Food Biotechnology and Genomics of the National Academy of Sciences of Ukraine under the leadership of D. Sc. in Engineering S.P. Tsygankov developed an installation for dehydration of alcohol steam in the production of bioethanol. There are two installations with a capacity of 3000 and 6000 decaliters per day for dehydrated product in Ukraine.

As has been noted above, one of the most technically and technologically difficult issue in the production of bioethanol from lignocellulose-containing raw materials is the preparation of raw materials for hydrolysis, that is, the wort preparation process. Different types of conversion such as chemical, physical, biological and combined methods, which are implemented using a variety of equipment and technologies, are used for this reason.

Scientists of the National Academy of Sciences of Ukraine set the goal of developing a universal, multifunctional heat and mass transfer equipment, with the help of which it is possible to simultaneously carry out various conversion processes of lignocellulosic raw materials, such as dispersion, mixing, heating, dissolution, hydrolysis, fermentation, etc. The use of Discrete-Pulse Energy Input (DPEI) method as a generalizing method of directed, local and intensive use of concentrated energy in liquid dispersed media is the solution of this problem [8, p. 39].

4. DPEI Method

The specialists of the Department of heat and mass transfer in dispersed systems of the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine search for new and improve known technologies for processing liquid heterogeneous systems in the food industry, pharmaceutical industry, energy using heat and mass transfer equipment and Discrete-Pulse Energy Input (DPEI) method.

The principle of DPEI method was first proposed in the work [9, p. 3], as a generalizing method for directed, local and intensive use of concentrated energy in liquid dispersed systems. The idea of the DPEI method is to accumulate stationary and arbitrarily distributed energy at local discrete points of the system in the working volume and then impulsely use it to achieve the necessary thermophysical effects. The purpose of the DPEI method is to intensify heat and mass transfer and hydrodynamic processes in technological media, as well as to create a methodology for their optimization and ways to control them.

The implementation of DPEI method provides the creation of a large number of working elements distributed evenly in a dispersed medium. They transform stationary thermal, mechanical or other types of energy into energetically powerful pulses that are discrete in time and space. Shock waves, interphase turbulence, microcavitation, penetrating cumulative micro-blasts, vortices cause the Rayleigh-Taylor instabilities or the Kelvin-Helmholtz instabilities on the interphase surfaces. It leads to intensive fragmentation of dispersed inclusions, a significant increase in the common phase contact surface and an increase in the processes of mass and heat transfer. Such effects are often unapproachable when using traditional methods for processing dispersed media, even at a significantly higher level of specific energy consumption.

Two-phase heterogeneous systems with several components that do not dissolve in each other under normal conditions or systems with low intensity of heat exchange processes are usually chosen as working systems where the use of DPEI method is effective. The processes of mixing, crushing, emulsification or homogenization of the dispersed component or dispersed phase are used as the working processes of the method. The phenomena of a decrease in the size of inclusions, an increase in their homogeneity, a significant increase in the common contact surface of components or phases are technologically necessary in a number of industrial processes.

The principle of DPEI method, as mentioned above, is to provide the energy into the technological medium, its concentration, discrete and local distribution in space and impulse influence in time [10, p. 3; 11, p. 13; 12, p. 208; 13, p. 58]. Ultrahigh fluxes and energy densities are realized in the processes of DPEI method. This makes it possible to obtain a high physical efficiency of the beneficial effects of heat and mass transfer at the interfacial surface, which is difficult to achieve using traditional methods such as in mixing devices. The introduced energy can be pre-concentrated in various thermal, mechanical, electrical, electromagnetic forms etc.

DPEI method consists in the distribution of the phase of the technological medium, which is compressed over a certain number of points of its volume in the sense of discreteness. In the sense of impulse, DPEI method consists in the conditions under which significant gradients of pressure, velocity, temperature, concentration, density, chemical potentials, potentials of electric or magnetic fields or discontinuities in the values of these technological parameters occur in the locality of these points. So, the DPEI technology can be implemented in multiphase systems or single-phase systems, which are transformed into multiphase systems under the influence of DPEI method. Moreover, one of the output, or initiated phases should be significantly compressed in comparison with the others [14, p. 59].

The DPEI method usually is implemented in media the main phase of which is in a liquid state. The concept of dispersion of the system should be understood as the presence or potential of the occurrence and distribution of vapor phase formations in the liquid or as the presence and distribution of inclusions of another liquid or solid insoluble component, for example, emulsion or suspension. In the case of emulsions the system is liquid single-phase, but heterogeneous, since the discontinuities of some physical parameters, such as density, chemical potential, heat and electrical conductivity are realized at the interface between two liquids.

5. Rotary Pulsation Apparatus

The different types of mixing equipment to organize the processes of dispersion, dissolution, mixing, emulsification and homogenization of various systems such as powder, liquid, multicomponent, high- and low-viscosity media are used in many industries. The classification of mixing equipment is given in Table 3. The rotary pulsation apparatuses (RPA) are the most energy-efficient and multifunctional among the variety of devices for mixing multicomponent media, dispersion and homogenization of emulsions. The principles of work of rotary mixers, disintegrators and dismembrators, centrifugal and vortex pumps, colloid mills and others are considered.

Table 3

Types of mixing devices

For powdered mixtures	For mixing dispersed components	For mixing with simultaneous fine dispersion	To form a processed media	For mixing multi-component media, dispersing and homogenizing
disintegrators	agitators	colloid mills: millstone, roller, rotary-beater	stamping (squeezing)	Rotary pulsating apparatus: disc, cylindrical
dismembrators	screw mixers	valve homogenizers	extruders	homogenizers: electromechanical (electromagnetic, piezoelectric), hydrodynamic (rotary, vortex)
mills: hammer, ball, colloidal		valve homogenizers	rounding, rolling	rotary cavitation apparatus

The factors such as the number, shape of the working parts and the state of their surface play the main role in the process of hydrodynamic action on the media in the classification of RPA.

RPA are classified according:

– to the way of passage;
– to the method of action;
– to the direction of the components movement;
– to the type of shaft location;
– to the method of supplying the components;
– to the geometry of the slots;
– to the number of stages;
– to the presence of additional work items;
– to the condition of the surface of the working elements;
– to the form of working parts;
– to the presence of additional displacements.

The rotary pulsation apparatuses are divided into apparatuses of disc and cylindrical types according to the shape of the working parts. The work on the study and creation of these types of rotary-pulsating apparatuses began in the early 40s of the last century. The way was passed from an idea and an experimental model to their widespread implementation in various industries over the past period. Disc-type apparatuses are similar to cylindrical ones but with some specific differences in terms of the principle of operation and the main characteristics. As a rule, slotted channels of rectangular cross-section are characteristic for a cylindrical apparatus, and it is advisable to use channels of a circular cross-section along with rectangular ones in a disc apparatus. Moreover, the length of the channels can differ significantly from each other. There is no pumping effect in disc-type apparatuses unlike cylindrical RPA and the movement of liquid occurs only due to the pressure drop.

Cylindrical-type RPA have become more widespread according to the approach method. They can be divided into two groups: submersible apparatuses with the working parts of which are located directly in the processed volume and flow apparatuses with their working parts are enclosed in a special casing having a centroaxial inlet branch pipe and radial or tangential processed medium outlet branch pipe.

The processed medium is sucked into the rotor cavity. It passes through the slots of the rotor and stator grids sequentially and then is unloaded into the working volume. These mixers are simple in design, but they have one common disadvantage, which is the uneven processing of the total mass of the product, since the frequency of passage of various particles through the working parts is not the same.

The use cylindrical type of RPA allows reducing the duration of the processes and the number of technological cycles in comparison with devices of a similar purpose.

A number of advantages were revealed comparing the operation of the RPA and the extruder when processing high-viscosity media:

– a flow with a linear stress distribution from $\sigma = 0$ (on the axis) to σw (on the wall) is realized in the extruder, which leads to a piston flow in its central zone; but in the RPA, the entire flow of the medium is subjected to shear deformation because throughout the intercylinder gap $\sigma = \sigma_w = const$;

– the flow is subjected to high-frequency dynamic processing up to 3000 Hz in RPA, leading to disintegration of the mass to micron sizes, which is not observed in extruders;

– the nature of the stress distribution in the RPA allows restricted low shear rates γ_{min}. It is necessary to significantly increase the value of the shear stress to reduce the size of the piston core in extruders. Thus, the energy consumption in RPA is lower.

RPA can be used in a variety of technological processes occurring both in heterogeneous media with a liquid continuous phase and in the processing of highly viscous media of plant origin. They are most widely used in technologies and industries for the preparation and processing of high-viscosity carbohydrate-containing heterogeneous media such as:

– fermentation and bakery industries to intensify the processes of dispersion and heat and mass transfer;

– food and processing industry when receiving mayonnaise, creams, pastes; for the processing of soybeans and the production of new types of food;

– technology of processing cellulose-containing wastes of agriculture and forestry industry in order to improve the process of hydrolysis of carbohydrates;

– to obtain medical emulsions in the pharmaceutical industry;

– for the preparation of emulsion thickeners in the paint and varnish industry.

6. Installation for wort obtaining

The specialists of the Institute of Engineering Thermophysics (IET) of the National Academy of Sciences of Ukraine have accumulated a great experience in the manufacture of various types of energy-saving heat and mass transfer equipment where the DPEI method is realized. It is most often implemented in rotary pulsating apparatuses, which are widely used in various industries such as food, pharmaceutical, chemical, microbiological, agro-industrial complex, etc. [15].

According to experts, the use of such equipment in the preparation of wort from lignocellulosic raw materials allows intensifying the technological process. It can reduce the duration of preliminary preparation, hydrolysis and fermentation, increase the amount of reducing substances in the wort, reduce energy consumption and, in general, make this technology more economically attractive. The specialists of the IET NAS of Ukraine have developed a universal rotary pulsating apparatus (RPA) designed for the preparation of wort in the production of bioethanol. The technological scheme is shown in Figure 5.

The wort preparation for bioethanol production according to the proposed scheme is as follows. The water is supplied to the receiving tank 1 and acid, alkali, enzyme preparations and other ingredients can be added depending on the type of raw material if necessary. Then two-way valve 2 is opened and the prepared solution is fed into the rotary pulsating apparatus 5, which is also a pump. Then three-way valve 7 is opened to return the solution to the receiving tank 1. All ingredients of the solution are well mixed for 2-3 pumping cycles through the RPA. The dispenser is turned on the 3-4th cycle of pumping. It supplies the feedstock to the solution flow in the established proportions. The solid feedstock mixing with the flow is fed to the RPA working parts (rotor and stator), where the processes of dispersion, dissolution, heating, and hydrolysis take place simultaneously. These processes occur simultaneously due to the influence of shock waves, interphase turbulence, cavitation and vortices. This makes it possible to destroy the structure of not only the weak starch complex (amylase and amylopectin), but also the strong structure of lignocellulose with the removal of lignin and the transformation of crystalline cellulose into an amorphous state suitable for further processing.

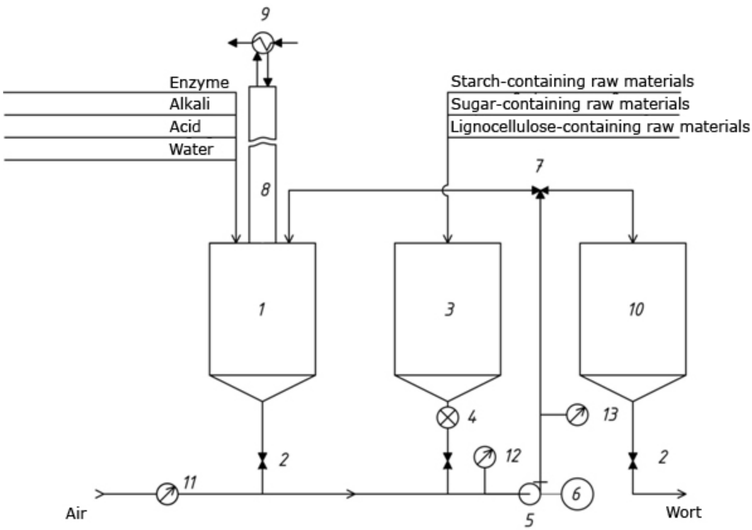

Figure 5. Apparatus and technological scheme for the preparation of wort in bioethanol production technology: 1 – receiving tank; 2 – two-way valve; 3 – tank for raw materials supply; 4 – dispenser; 5 – rotary pulsating apparatus; 6 – electric motor; 7 – three-way valve; 8 – rectification column; 9 – difflegmator; 10 – tank for wort; 11 – rotameter; 12 – vacuum meter; 13 – manometer

A mixture of liquid solution and processed raw materials circulates along the contour of the receiving tank 1 to RPA 5 from several minutes to several hours. The processes of dispersion, mixing, dissolution, heating take place in the mixture during this time. A complex of such operations prepares plant materials for hydrolysis. After that, enzyme preparations are fed into the receiving tank 1 and, again, the process of hydrolysis of polysaccharides to fermented carbohydrates is carried out in the recirculation mode. The ready wort is fed to the tank for wort 10 after hydrolysis. Then, bioethanol is obtained according to the classical scheme: fermentation, distillation, dehydration.

The proposed installation is universal and allows you to get wort for the production of bioethanol from sugar-, starch- and cellulose-containing raw materials The installation is given in Figure 6.

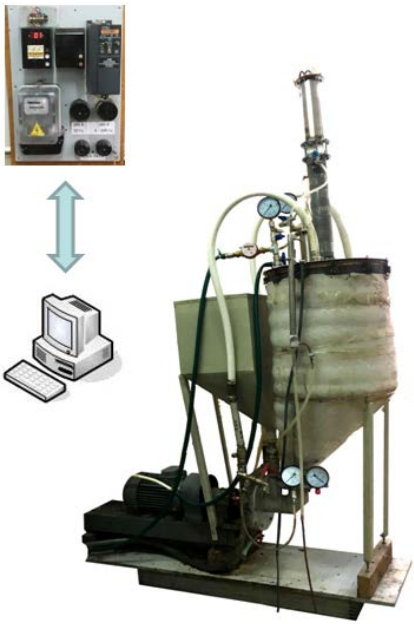

Figure 6. The view of the experimental universal installation for the production of bioethanol with the DPEI method

The technological, energy and economic attractiveness of this method consist in the fact that the processes of dispersing, mixing, dissolving, heating and hydrolysis take place simultaneously with the use of one type of equipment.

7. Conclusions

Bioethanol production is still the most dynamic sector of the biofuel industry. It accounts for 85% of the world's biofuel production. The United States and Brazil are the largest producing countries of bioethanol that provide 89% of global production. There are about 50 bioethanol enterprises with 10-15% of world production in the EU.

The main direction of bioethanol use is the production of fuel mixtures (ethanol + gasoline) with high energy content.

Bioethanol is obtained from molasses in Ukraine. Its annual production is about 30 thousand tons, that is approximately 0.7% of world production. First-generation bioethanol produced from food raw materials is used for the production of AMFC (alternative motor fuel component) in 99.85% of cases. This creates a tension between promoting biofuels and ensuring food security. This problem is especially actual in Asia and Africa.

The world science and industry aim is to develop an economically beneficial technology and equipment for the production of second generation bioethanol, which is made from not suitable for food consumption raw materials such as lignocellulosic biomass (agricultural by-products, forestry residues, perennial grasses, municipal waste, etc). The production of bioethanol of the second generation in comparison with bioethanol from starch-containing raw materials is still more energy and resource-intensive due to the features of the structure of cellulose-containing raw materials. The combination of several methods of processing cellulose-containing raw materials in the pretreatment for hydrolysis (acidic or enzymatic) makes it possible to increase the degree of biomass conversion and the yield of the bioethanol because of a decrease in the degree of crystallinity of the cellulose matrix, separation of the main component of the raw material, providing better access of hydrolytic enzymes (by enzymatic hydrolysis) to the surface of the material. Improving the technology due to the use of energy-efficient equipment and DPEI method is the solution to make it possible to intensify the processes of pretreatment of raw materials for hydrolysis without increasing energy and resource consumption. The specialists of the IET NAS of Ukraine have developed a universal heat exchange installation to reduce energy and resource consumption in the production of bioethanol. The processes of dispersion, dissolution, heating and hydrolysis occur simultaneously in one apparatus.

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