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LIMITING FACTORS IN PROCESSES OF ANEAROBIC FERMENTATION OF SUGAR CONTENT MEDIA

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Abstract: *A quantitative assessment of the quality of the process of kneading the dough in the dough machines, of both periodic and continuous this is the total and specific energy expenditure. Determination of energy expenditure is necessary for the calculation of the dough machine as well as the energy analysis of specific stages of the process. Studies were conducted on a laboratory kneading machine of periodic action. To measure the energy expenditure used wattmeter. An analysis of the experimental data showed how energy expenditure varied throughout the experiment and confirmed three stages of the kneading wheat dough process. Comparing the calculated theoretical values with the obtained experimental values, they were found to be different. Studies of the process of kneading wheat dough prove the need for changes in the method of calculating energy expenditure for kneading, eliminating the formal approach to this process and taking into account the energy expenditure of structural transformations.*
Keywords: *dough, mixing machine, energy expenditure, kneading, qualities.*

INTRODUCTION

Due to the background of the overall success in the use of anaerobic fermentation processes in sugar-containing media, a disadvantage has emerged associated with the limitations of microbiological transformations in terms of ethyl alcohol concentration. If their limit is 6% by mass by this indicator is almost satisfying the technology of production and consumption of beer, then the technology of secondary winemaking, champagne wines and especially ethyl alcohol is definitely not. The barrier by 8 ... 10% of C_2H_5OH concentration is a consequence of critical values of the osmotic pressure of solutes, because as the result of transformations and destruction of sugar molecules to the level of endogenous synthesis of alcohol and carbon dioxide, they increase to bacteriostatic effects [1 -3]. Modern views on the latter phenomenon [4, 5] relate its causes to osmotic pressure balances on semipermeable cytoplasmic membranes of yeast cells and disturbances of mass transfer processes, followed by their termination. However, such an explanation has a markedly simplified argument, but there is a set of factors such as temperature, viscosity, pH of the medium, nutrient concentration, the level of adaptation of microorganisms, hydrodynamic mode of the medium and even the geometry of the fermenter. Impacts of these factors are regularly reflected, including current studies [6-8], but an important component of interactions between microorganisms and the medium is almost ignored. Such component is the presence of dissolved CO_2 gas phase. It is important that the latter exists in continuous dynamics due to the same continuous synthesis. The consequences of such processes have at least two forms of reflection. The latter include the formation of a dispersed gas phase and the achievement of states of saturation of the liquid phase of media by CO_2.

The first is responsible for the hydrodynamics of the gas-liquid medium, and the second concerns the complications of CO_2 mass transfer.

In connection with this, the deepening of information on the peculiarities of energy and mass exchange processes in gas-liquid media creates the perspectives of their improvement and intensification, increase of productivity of technological devices and so on.

The relevance of the topic and the set of disadvantages in the processes of anaerobic fermentation of sugar-containing media led to the possibility of formulating the purpose of the study in such form: to generalize the limiting factors in the processes of anaerobic fermentation and search for reducing their effects.

Materials and methods

Materials and methods refer to the phenomenological generalizations of the processes of energy-efficient transformations of dissolved sugars under the action of yeast-saccharomycetes at the levels of Gay-Lussac, Vant-Goff, Archimedes laws, energy-exchange laws, gas solubility, and so on.

RESULTS AND DISCUSSION

It is known that the processes of alcoholic fermentation are limited by the accumulation in the culture media of the products of their life activity. First of all, these restrictions are associated with endogenous synthesis of ethyl alcohol [6-8] at concentrations of 8 ... 10% vol. and there are significantly fewer references to the negative effects of dissolved carbon dioxide [3], for which limited concentrations are in most cases not indicated. Alcohol concentration of 12% vol. leads to bacteriostatic effects against yeast cultures, and lethal effects are achieved from 16% or more. In this regard, there are subcritical values for parameters under which microbiological synthesis is possible. The latter include ambient temperature and C_2H_5OH concentration, but more complete generalization of the negative effects on fermentation dynamics relates to the osmotic pressures of solutions of various substances.

Alcohol limit of 8 ... 10% vol. correspond to the native capabilities of the yeast-saccharomycetes and the specified range is fully suited to the requirements of brewing technology of beer mash. In the production of champagne wines using osmophilic yeast, it is possible to increase the alcohol concentration to 12%. However, the main requirement is not the concentration of alcohol, but the concentration of carbon dioxide of 10 g / l. Fermentation occurs at a temperature of 6 ... 10 ° C for an extended time. The latter is determined by the choice of technology and in the classical scheme the fermentation period lasts 2-3 years, while fermentation in uninterrupted schemes ends in 25 ... 30 days.

In the technologies of production of beer fermentation requires 15 ... 28 days. The above-mentioned provisions indicate that the accumulation of predetermined concentrations of CO_2 at the maximum achievable depth of sugar utilization limits the speed of fermentation, including limited temperatures of the culture media.

Differences in the fermentation technologies of the alcohol industry are determined by their main task, namely the maximum accumulation of alcohol. The latter is related to the productivity of process equipment and energy costs for the next distillation process. In this regard, the field of industrial and scientific interests includes the task of leaving the accumulation of alcohol beyond 8 ... 10%. However, the search for more promising races of osmophilic yeast-saccharomycetes has not succeeded yet, and a limited solution on this path may be considered to be a limited subcritical concentration of alcohol in the medium with a corresponding limitation of the osmotic pressure of this component. This solution should be considered as half because it can only provide an extension of the fermentation time due to the extraction of C_2H_5OH from the medium by the use of special technologies [5].

Phenomenological scientific analysis of the flow of energy-mass transfer processes of fermentation of sugar-containing media allows to note the following list of conclusions:

– transformations of media are associated with the conversion of the input potentials of chemical energy of sugar solutions into the potentials of chemical energy of alcohol and thermal energy in classical perception, for which exact ratios are determined;

– fermentation is accompanied by the formation of the potential of dissolved CO_2, the parameters of which are determined by Henry's law, and the output beyond it leads to the formation of a dispersed gas phase. This means the appearance and essence of the energy potential of the newly formed surface of phase separation and the potential energy of a swollen gas-liquid medium;

– force manifestations in accordance with Archimedes law lead to the emergence of kinetic energy of vertical circulating circuits, which are enhanced by the presence of convective mixing in the interaction of media with cooling surfaces of the apparatus;

– the potential of the dissolved gas in the presence of hydrostatic pressure leads to a concentration gradient by CO_2 and to the corresponding energy potential of the latter;

– the compressed gas phase in the ingenious volume influences the potentials of the dissolved CO_2, the force manifestations, which are related to the Archimedes law, and the concentration gradients;

– issipative effects are accompanied by the reverse transformation of the kinetic energy of the circulating circuits into thermal energy;

– circulating circuits in gas-liquid media ensure the presence in them of local zones of saturation and desaturation, respectively, on the lower sections due to the increase in hydrostatic pressures and the decrease in temperatures and at the upstream sections due to the decrease in hydrostatic pressure;

– the use of deterministic changes in pressure leads to the possibility of creating desaturation and saturation modes in a full volume of the medium with a limitation of the duration of the desaturation and the extension of the saturation time;

– limiting factor in the accumulation of alcohol is its osmotic pressure as a component of the solution. Its stabilization at subcritical concentration means subcritical osmotic pressures. Subcritical stabilization means the technical ability to remove alcohol during fermentation by:

- vacuum distillation;

- evaporation of alcohol by the CO_2 gas phase with the use of circulating circuits in conditions of increasing temperature of the medium;

– subcritical stabilization of concentration and osmotic pressure of alcohol allows to continue fermentation beyond 72 hours. This is possible if the initial concentration of sugar is increased or when the continuous flow of its solution is organized. Both of these directions can be applied due to the limited osmotic pressure of the solution of $C_6H_{12}O_6$. The condensed evaporation of C_2H_5OH from the gas phase must be counted in the estimation of productivity of the fermenter;

– evaporation with the gas phase in the enhanced mode is carried out for the purpose of the biological fermentation heat transfer, including the transformed by heat pump. In the long run, this will limit energy consumption for temperature stabilization of the medium:

- evaporation consists of the amount of water and alcohol vapor, the ratio of which means energy costs. As a result, energy consumption for distillation is expected to decrease;

- evaporation condensation heat must be used.

Exposure factors include sugars as nutrients, alcohol and carbon dioxide as products of their microbiological transformations that comply with the Gay-Lussac law:

$$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2 \uparrow . \quad (1)$$

Obviously, this condition is consistent with the law of conservation of substances, and therefore the mass of dissolved glucose, alcohol and carbon dioxide at the stage of incomplete saturation of the liquid phase by CO_2 remains stabilized. However, the osmotic pressure of each of these components is determined by the dependence:

$$\pi = \frac{mRT}{MV}, \text{Pa} \quad (2)$$

where m is mass of the solute, kg; R – universal gas constant, J/(kg·K); T is absolute ambient temperature, K; M is molecular weight of the substance; V is volume of the mediun, m^3.

The molecular weights of glucose, alcohol and carbon dioxide are respectively 180, 46 and 44 units. Theoretically, this means that the osmotic pressure in the transformation of each glucose unit is increased by 4 times. It would be as if all the carbon dioxide remained in the dissolved state. However, the latter is limited by a physical feature in the form of Henry's law, according to which the content of CO_2 in the liquid phase is limited by its maximum solubility. The latter, as is known, depends on the physical and chemical properties of the gas and liquid phases and pressure in the system. The transition through the boundary solubility means the beginning of the formation of the dispersed gas phase and its separation from the medium. However, under conditions of the impermeable fermenter, the material balance under condition (1) continues to be fulfilled, and in the presence of liquid and gas phases in its volume, the change of pressure in the latter can determine the dynamics of fermentation [9].

Obviously, the latter applies to the technologies of secondary fermentation of wine in acratophores or in impermeable bottles, while reducing the pressure in the fermentation apparatus of the brewery breaks the condition with the creation of a powerful energy impulse with a sharp increase in the amount of dispersed gas phase. However, the transition to the mode of saturation of the liquid phase with CO_2 is not solved. It continues to be saturated and even oversaturated for some time due to the inertial properties of the transition processes. However, these features of beer wort fermentation technologies can not be considered to be negative, as the medium continues to remain in a predetermined saturation state. This is one of the reasons for the prolongation of fermentation in the alcohol industry. This is an important disadvantage that can be eliminated by rapidly increasing system pressure. The above analysis of the features of technologies of fermentation of sugar-containing media leads to the conclusion about the expediency of obtaining information on the influence of their saturation states on CO_2 and the course of mass exchange processes.

This provision does not claim to be scientific and technical novelty [5], since the mass transfer support between microbial cells and the medium remains beyond the scope of general attention. Note that the liquid phase necessarily reaches a state of saturation with CO_2. This is what creates the second carbon dioxide exposure factor compared to its osmotic pressure. The latter can be considered as hypothesis that needs experimental verification.

A method of fermentation of sugar-containing media is proposed for use (patent of Ukraine 124158). The proposal is based on the task of limiting the impact on endogenous synthesis of alcohol and carbon dioxide due to the discrete elimination of states of saturation of the media with carbon dioxide, increasing fermentation activity of yeast, productivity, concentration of ethyl alcohol and reducing energy costs for the process of distillation.

Self-generation of carbon dioxide in fermentation processes is accompanied by its mass transfer at the boundary of the phase separation of "yeast cells - medium" and the gradual increase of its concentration to the level of saturation. In accordance with Henry's law, by which saturation is proportional to the partial pressure of the gas phase, the medium can be converted from the saturated state to unsaturated and, conversely, by changing the pressure in the medium, for example, by changing the pressure in the gas ingenious volume. Reducing the pressure in the system reduces the solubility of the gas and translates the medium into a supersaturated state, through which its degassing is actively taking place.

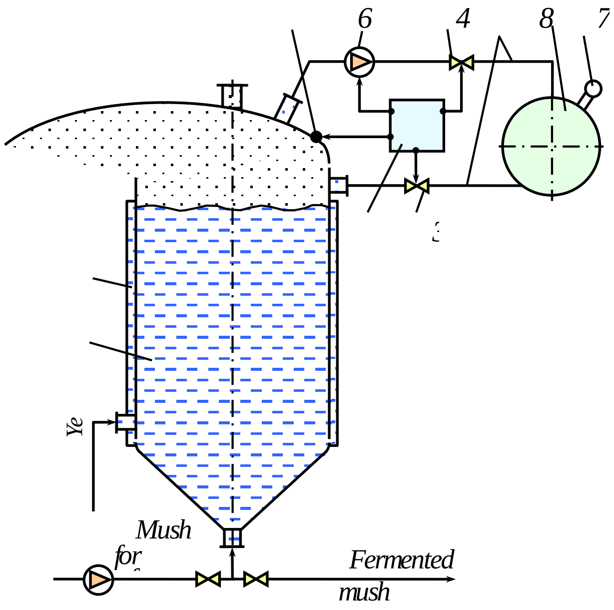

Fig. 1. System of fermentation of mash in ethanol production (patent of Ukraine No. 124159)

The subsequent increase in system pressure puts the medium to the unsaturated state with activation of mass transfer at the interface.

The implementation of this method can be carried out on the basis of the patent of Ukraine 124159 with the claims: system of fermentation of wort in ethanol production, consisting of a grain crusher, a mixer of grinding and water, apparatus of thermo-enzymatic processing, a succulent, which are connected by their exits, and the outlet of the succulent by a pipeline, with a pump mounted on it, with a fermenter with the cooling shirt, and the lower part of the apparatus is connected to a bumper distillation column, characterized by that the ingenious gas volume of the fermenter is impermeable with a closed loop of variable adjustable pressures consisting of the controller, compressor, receiver, sensor of pressure, pipelines and valves.

The system (Fig. 1) consists of a fermenter 1 with a shirt of thermal stabilization 2 and a closed circuit of variable adjustable pressures in the controller 3, the compressor 4, the receiver 5, the pressure sensor 6, the pipelines 7, the shut-off valves 8 and 9 and the relief valve 10.

The system works as follows. The medium enters the fermentation apparatus 1 with a shirt of heat stabilization 2, and with it the yeast is fed to the fold. From the beginning of the fermentation generated CO_2 increases concentration in the liquid phase of the medium to a state of saturation, the index of which depends on the pressure in the supernatural volume of the apparatus and on the hydrostatic pressure. Due to the influence of the latter in the medium, concentration gradient by CO_2 is formed and the filling of the ingenious volume with carbon dioxide begins when the saturation state is reached with the maximum pressure controlled by the relief valve 10 when the valves 8 and 9 on the pipeline 7 are opened. Achieving the maximum pressure of the gas phase means the presence of maximum indicators of saturation of the medium with CO_2, which limits the processes of its transition from cells to the medium. By the signal of the pressure sensor 6 and the corresponding command of the controller 3, the valve 9 is closed and the compressor 4 is switched on, the pressure in the gas volume of the apparatus is reduced, and in the receiver 5 is increased. Reducing the pressure in the ingenious volume is accompanied by an equivalent reduction in the pressure in the full volume of the liquid phase, resulting in the medium goes into a supersaturated state with the active release of CO_2 in the form of bubbles of the dispersed gas phase. The medium continues to remain in the supersaturated state. When the programmable minimum pressure is reached in the ingenious volume of the fermenter, the compressor 4 is switched off by the command of the controller, the shut-off valve 8 is closed and the there is a brief pause for pressure. Upon its completion, the controller issues a command to abruptly opening the valve 9 and the gas phase from the receiver is quickly transmitted to the entire volume of the system. The increase in pressure above the medium causes the collapse of the foam fraction and creates a cavitation analogue with respect to the dispersed gas phase. Increased pressure translates the liquid phase of the medium into an unsaturated state of CO_2, which activates the fermentation process with corresponding consequences. The excess of CO_2 pressure in the system is governed by the relief valve 10. After a new increase in pressure in system and holding time, the cycle repeats.

Implementation of fermentation regimes with restrictions on the state of saturation of the liquid phase with carbon dioxide is possible on the basis of the patent of Ukraine 129124 [11] with the formula of the invention: a system of fermentation of mash in the production of ethanol, consisting of a grain crusher, a mixer of grinding and water, the apparatus of thermo-enzymatic processing, apparatus, characterized in that the two paired fermenters with synchronized fermentation cycles are equipped with a system of combining their gas volumes consisting of the pipelines, gas compressor, valve, controller and pressure sensors.

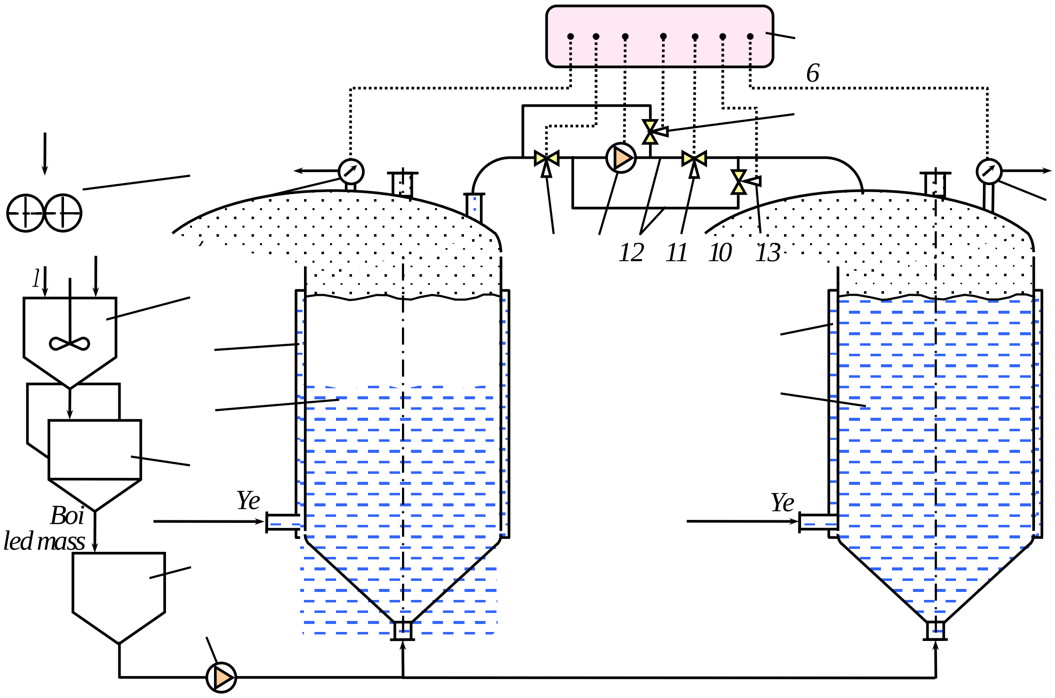

Fig. 2. Sytem of fermentation of mash in ethanol production (patent of Ukraine 129124)

Equipping two paired fermenters with time-synchronized fermentation cycles with a system of combining their gas volumes consisting of the pipelines, gas compressor, valves, controller and pressure sensors enables regulatory changes in the pressures in the gas ingenious volumes (increase in the first and simultaneous changes in the second) to ensure transitions of gaseous media to unsaturated CO_2 states with saturation and activated mass transfer modes and saturated modes with desaturation modes.

Fig. 2 shows the system of fermentation of the mash in the production of ethanol, which consists of a crusher 1, mixer 2 of milling and water, apparatus 3 thermo-enzymatic processing, saccharifier 4, pump 5, fermenters 6 and 7 with shirts of thermal stabilization 8 and 9, pipelines 10, gas compressor 11 , latches 12, 13, 14 and 15, controller 16 and pressure sensors 17. The mash digestion system in ethanol production works as follows. The processed cereal mass is fed to the crusher 1, from which the milling enters the mixer 2, where the mixture is prepared with water and enzymes. The prepared batch is transferred to the apparatus 3 for thermo-enzymatic processing, and then to the saccharifier 4, from which the medium enters the fermentation apparatus 6 and 7 with shirts 8 and 9 by the pump 5. The fermentation apparatus is fed with the yeast. From the beginning of the fermentation of closed valves 12, 13, 14 and 15, the synthesis of carbon dioxide and saturation of the liquid phase is followed by the formation of a dispersed gas phase, the ebbation of which is completed by the transition to the gas ingenious volumes and the pressure increase in the latter. When the pressure is reached by switching the compressor 11 for closed valves 12 and 13 and opened valves 14 and 15, the redistribution of pressure in the gas volumes begins with increasing pressure in the fermentation apparatus 6 and decrease in the apparatus 7.

This leads to increased saturation mode in the apparatus 6 and desaturation in the fermentation apparatus 7 with the intensification of mass transfer processes and to the activation of microorganisms. Changing the direction of the flow of CO_2 at closed latches 14 and 15 and opened latches 12 and 13 provides a decrease in pressure in the apparatus 6 and increase in the apparatus 7, which changes the modes of desaturation in the first and saturation in the second with similar technological consequences. The control of the system is provided by the controller 16 with the bypass of gas streams by pipelines 10. Monitoring and limit regulation of the pressure is carried out by the sensors 17.

The implementation of modes of subcritical fermentation of sugar-containing media reflects another important area of improvement of anaerobic fermentation technologies, which is possible on the basis of the patent of Ukraine 134316 (Fig. 3) with the following formula of the utility model: fermenter, which consists of the cylindrical hull with cooling shirt, safety valve, sanitary valve, conical bottom and system of alcohol pickup-absorber, characterized in that the system of alcohol pickup is made of the composition of the condensed gate-locked cameras and recuperation with the circuit of the heat pump and the circuit of the bubbling of the fermented medium with carbon dioxide consisting of the pipelines, compressor and gas distributor.

Equipping the fermenter with a system of alcohol pickup in the composition of the condensation and recuperation chambers combined with the gate valve with the contour of the heat pump and the contour of bubbling of the digestive medium with carbon dioxide in the composition of pipelines, the compressor and the gas distributor allows to increase the levels of separation alcohol from the liquid phase, to separate osmotic pressure in solutions at critical values, provides activation of fermentation processes and increase the performance of the device.

The essence of the utility model is explained by the figure showing the fermenter. It consists of a cylindrical hull 1 with cooling shirt 2, safety 3 and sanitary 4 valves, conical bottom 5, lock gate 6, condensation chamber 7 of a gas-gas mixture of CO_2 and C_2H_5OH, chamber 8 for heat recovery, heat pump circuit 10 with evaporator 9 , the condenser 11 and the control valve 12, the contour of the bubbling of the fermentation medium with carbon dioxide in the pipeline 13, the compressor 14 and the distributor 15. The device works as follows. From the beginning of fermentation, the synthesized carbon dioxide and alcohol dissolve in the liquid fraction of the cylindrical body 1 and the conical bottom 5 by thermal stabilization of the medium due to the cooling shirt 2 and control the operation of valves 3 and 4. After saturation of the fermented medium with CO_2, the formation of dispersed gas fraction is formed which due to Archimedes' law floats and passes into the gas ingenious volume of the apparatus. The formed gas bubbles are both carriers of water vapor and ethyl alcohol vapor. This mode continues until the critical concentration of alcohol in the solution and, accordingly, the critical osmotic pressure created by it in the medium. The nominal pressure at this stage is maintained by the relief valve 3. The stabilization of critical concentrations of alcohol and osmotic pressure is possible due to the material balance of synthesis of alcohol by yeast and its removal by the alcohol capture system due to the interaction of increased gas and gas-liquid

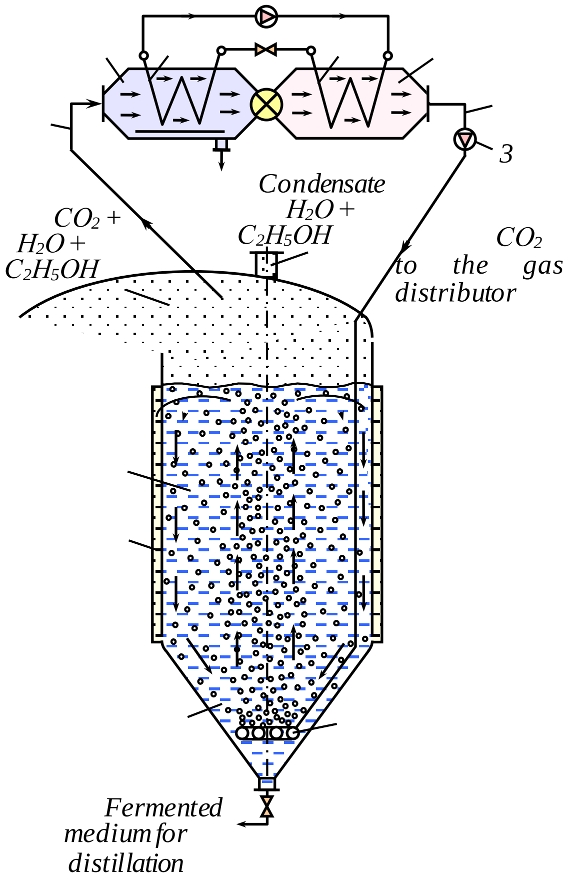

Fig. 3. Fermenter (patent of Ukraine 134316)

flows in the circuit of bubbling with pipeline 13, compressor 14, distributor 15 combined in operation with the condensation chamber 7, the lock gate 6, the regeneration chamber 8 with the participation of the heat pump in the evaporator 4, compressr 10, condenser 11 of the heat pump. In the condenser 7 there is the extraction and separation of the condensate of H_2O and C_2H_5OH with the participation of the evaporator 9 and the return of thermal energy in the gas fraction by its interaction with the condenser 11 in the regeneration chamber 8. The control valve 12 provides the corresponding temperature modes in the chambers 7 and 8. Gas phase of CO_2 by the compressor 14 goes into the gas distributor and the cycle is repeated until the fermentation process is completed, after which the medium is transferred to distillation. Excess of CO_2 is discharged through the relief valve 3.

The technical result is to increase the amount of extracted ethyl alcohol from the liquid fraction, to limit the osmotic pressure in solutions at certain subcritical levels, to ensure the activation of fermentation processes with increasing productivity of the apparatus.

CONCLUSIONS

The following list of estimations and impacts of intensification processes of anaerobic fermentation is proposed for use:

- transition to sub-critical modes of osmotic pressure of fermentation;
- variable pressures in the gas ingenious fraction to convert the liquid fraction to ununsaturated CO_2 state;
- organization of deterministic circulation circuits using the potential of CO_2 concentration gradient (due to hydrostatic pressures);
- the energy potential of the circulation circuits is estimated by the magnitude of the gas-holding capacity based on Archimedes' law and Newton's third law.

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