Energy transformations in processes of anaerobic fermentation

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Abstract

Introduction. The course of energy transformations in the processes of anaerobic fermentation refers to the indices of chemical energy as a result of biochemical reactions. This part of transformations is deeply studied and recognized, however, the synthesis of carbon dioxide in culture media is accompanied by the creation of energetic potentials in gas and liquid phases, is seriously understudied as of today.

Materials and methods. The object of this research is the gas-liquid medium in the processes of anaerobic fermentation. Evaluation has been carried out for their energy potentials created on the basis of carbon dioxide synthesis. The theoretical study was carried out on the basis of the Henry's, Pascal and Archimedes laws.

Results and discussion. Synthesized in anaerobic processes, carbon dioxide passes two stages of transformation. On the first stage, during the mass transfer between yeast cells and the medium, the concentration of CO_2 increases to the saturation index in accordance with Henry's law, and on the second stage the formation of the dispersed gas phase is carried out. The endogenous process of carbon dioxide synthesis, the processes of saturation of the liquid phase and the formation of the dispersed phase are self-loading and those in which the corresponding energetic potentials are created, resulting in a circulating mixing of the media. In cases of using sealed fermentation vehicles, the gas phase is characterized by an appropriate energy potential due to the increased pressure. The levels of energy potentials of the compressed gas medium and dissolved CO_2 are thermodynamically determinable and their ratios are interconnected due to the geometric volumes of the liquid and gas phases.

The possibility of creating local zones of desaturation and saturation of the liquid phase in the total volume of the gas-liquid medium is shown. The presence of such zones means the possibility of regulatory influences on osmotic pressure and the removal of media from saturated and supersaturated states.

Conclusions. The energy potential, associated with the saturation gradient of the media on CO_2, provides a fast and continuous implementation of restoration in the saturation possibilities of the liquid phase and the activation of fermentation in the case of the saturation circuit restoration.

Introduction

Processes of anaerobic fermentation of the wine-making, alcohol and brewing branches are similar in their essence and finish with the transformations of sugars of input materials into alcohol and carbon dioxide as a result of the life of the yeast- saccharomycetes. The course of these processes corresponds to the Gay-Lussac equation in accordance with the laws of conservation of mass and energy in the form:

$$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2 + 169\ \text{kJ} \qquad (1)$$

The chemical energy of glucose which is 2870 kJ transforms into 2640 kJ of alcohol and 230 kJ of free energy. The latter consists of energies of two molecules of ATP in the amount of 61 kJ and 169 kJ of thermal energy, and two molecules of synthesized CO_2 have no chemical energy potential. However, for the explicit awareness of the energy balance relative to condition (1), the analysis of the situation can not be considered to be complete, since the excited cultural medium has features of a system with an increased hydrodynamic state [1, 9, 10]. The latter is characterized by active upward and downstream streams of the circular circuits of gas-liquid mixtures and relatively independent upstream streams of the dispersed gas phase etc. These circumstances have at least two reasons. The first one concerns the process of generation and removal of heat stream generated during the fermentation process. It is obvious that there is a prerequisite to consider the process of generation of heat energy to be distributed sufficiently even in the full volume of the medium. However, the necessity to stabilize the temperature requires the presence of cooling surfaces, often in the form of external shirts of fermentation devices. This means the presence of volumetric temperature fields in the media, which results in the creation of circulating circuits [4, 5]. For cases of fermentation vehicles of cylindrical or cylindrical-conical geometry, the central part of the volume of media that are the most equidistant from the cooling surfaces correspond to relatively higher temperatures. Due to this, the conditions for the ascending flows of circulation circuits are created in the central zone and, conversely, the downstream flows adjacent to the surfaces of the occupation.

The intensity of such circulation circuits is proportional to the generated heat energy flow and depends on both the geometry of the fermentation apparatus and the total volume of the medium [6, 7].

The second reason for the creation of circulating circuits in fermentable media is the response of the system to the presence of dissolved CO_2 and its dispersed gas phase. The formation of these two forms is connected, firstly, with the gravitational field of the Earth and, secondly, with the manifestation of the gravitational field in the form of hydrostatic pressure, which is reflected by the Henry's law of solubility of gases. Transient processes of solubility of CO_2 are completed by the state of saturation, and they transit to the regime of creating the dispersed gas phase [8]. Under the action of the motive factor in the form of the Archimedes law, the dispersed gas phase fades from the formation of the gas phase in the ingenious volumes. In cases of sealed volumes of fermentation vehicles, the pressure in the ingenious volumes increases, creating the energy potential. At the feedback level, this increase of pressure leads to an increase of the solubility of CO_2 in the liquid phase and to the creation of additional energy potential of the dissolved gas. The latter can be transformed into the mechanical energy of the circulating circuit in case of a sharp decrease of pressure in the gas phase. The energy potential of circulating circuits is gaining due to

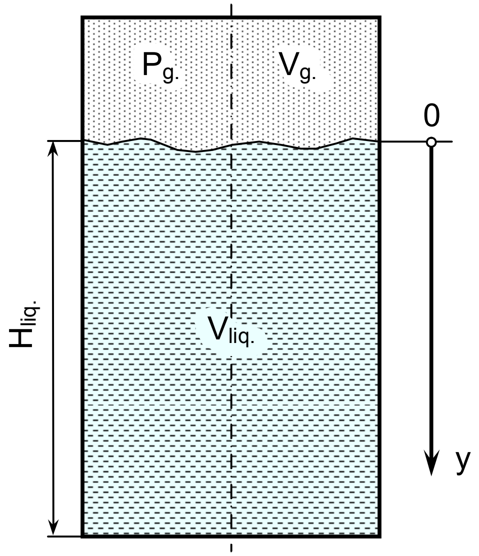

Figure 1. Scheme to determine the parameters

the presence of a gradient of saturation of the liquid phase on CO_2 due to hydrostatic pressures. It is obvious that the presence of circulation circuits leads to the creation of zones of desaturation of media in ascending streams by reducing hydrostatic pressures and saturation zones in downstream streams. In connection with the latter it is possible to conclude that the depth of desaturation and saturation processes, and even the manifestations of energy impulses, depends on the geometry of apparatus in the form of hydrostatic pressures [10].

The given analysis of energy potentials of systems of anaerobic digestion of sugar-containing media is executed on the basis of phenomenological generalizations, which it is expedient to supply by quantitative ratios of energy parameters.

The purpose of the study is to create mathematical formalizations for the establishment of energy potentials in anaerobic fermentation systems.

Materials and methods

The object of the study is the gas-liquid medium [1, 4] in the processes of anaerobic fermentation in the direction of evaluation of their energy potential.

The theoretical basis of the study relates to the laws of Henry [2], Pascal [11, 12], Archimedes [11], the laws and the provisions of thermodynamics.

Results and discussion

To establish quantitative estimates of the relations of energy parameters let's turn to the calculation scheme on Figure 1, which corresponds to the case of fermentation of the medium in a sealed apparatus. The pressure in the gas phase increases in the process of fermentation. The list of parameters for the calculation scheme includes: $V_{g.}$ - the volume of the gas phase in the ingenious volume, m^3; $P_{g.}$ - pressure of the gas phase, Pa; $\rho_{g.}$ - specific mass of the initial gas phase, kg/(m^3*Pa); $V_{liq.}$ - liquid phase volume, m^3; ρ - specific mass of the liquid phase, kg/m^3; g - acceleration of free fall, m/s^2; H - height of the liquid phase, m; R - gas constant, J/(kg*K); T - absolute temperature of the medium, K.

The following relationships are established for these parameters:

$$P_{g.}=\frac{\left(\rho_{g.}V_{g.}+0,489M_{s.}-kV_{liq.}\rho g\frac{H}{2}\right)RT}{V_{g.}+kV_{liq.}RT}; \qquad (2)$$

$$grad\left(CO_2\right)=\frac{c_s\left(y=H\right)-c_s\left(y=0\right)}{H},\qquad(3)$$

where $c_s\left(y\right)$ - the saturation constant of the medium on CO$_2$.

$$c_s=kP_{g.},\qquad(4)$$

The results of calculations are given in the table 1 for the parameter values and on the Figure 2-6:

$$R=189\,J/(kg\cdot K);\quad V_{g.}=0{,}1;1{,}0\,m^3;$$
$$M_{s.}=10...130\,kg\quad R=189\,J/(kg\cdot K);$$
$$V_{g.}=0{,}1;1{,}0\,m^3;\quad M_{s.}=10...130\,kg$$

Table 1

Estimated parameter values

Parameters	**Weight of fermented sugar, kg**						
	10	**30**	**50**	**70**	**90**	**110**	**130**
When							
P_gP_g , MPa	0,303	0,894	1,473	2,076	2,26	3,2	3,75
$c_s, kg/m^3$	4,48	13,22	21,8	30,72	39	47,8	62,2
$E_{(0,1)}$, kJ	30,3	89,4	147,3	207,6	260	325,5	401
$E'_{(0,1)}$, kJ	256,6	757,1	1248,4	1759,2	2213	2736,5	3255
$E_{equal(0,1)}$, kJ	286,9	846,5	1395,7	1966,8	2500,6	3062	3720,2
When							
P_gP_g , MPa	0,21	0,513	0,81	1,12	1,4	1,73	2,05
$c_s, kg/m^3$	3,11	7,59	11,91	16,56	21,01	25,5	32,3
$E_{(0,1)}$, kJ	210	513	810	1119	1422	1725	2040
$E'_{(0,1)}$, kJ	178	434,7	682	948,3	1203,2	1465,5	1745
$E_{equal(0,1)}$, kJ	388	947,7	1492	2067,3	2625,2	3185	3890

The potential energy of the gas medium was estimated by dependencies:

$$E_{(0,1)}=P_{g.}V_{g.(0,1)},\ \text{J};\qquad(5)$$
$$E_{(1,0)}=P_{g.}V_{g.(1,0)},\ \text{J};\qquad(6)$$

Comparison of values $E_{(0,10)}$ and $E_{(1,0)}$ shows an advantage $E_{(1,0)}>E_{(0,1)}$ with multiplicity of more than 5, which is the result of increased solubility of carbon dioxide in connection with pressures. The potential of dissolved CO$_2$ is determined by referring to the Mendeleyev-Clapeyron equation with the assumption that it is transferred to the gas state and, under the condition $V_{liq.}=1{,}0\,\text{m}^3$, we have:

$$E'_{(0,1)} = c_{s(0,1)}RT; \quad E'_{(1,0)} = c_{s(1,0)}RT \,. \tag{7}$$

In these dependencies, the saturation constants $c_{s(0,1)}$ and $c_{s(1,0)}$ reflect the mass of carbon dioxide M_{CO_2} in the liquid phase.

As examples we will make calculations for cases with masses of fermented sugars 10 and 120 kg.

When $V_{g.} = 0{,}1$ m^3 we have:

for the gas phase:

$E_{(0,1)} = 0{,}303 \cdot 10^6 \cdot 0{,}1 = 30300\,J = 30{,}3$ kJ;

$E_{(0,1)} = 3{,}55 \cdot 10^6 \cdot 0{,}1 = 355000\,J = 355$ kJ;

for dissolved gas:

$E'_{(0,1)} = 4{,}48 \cdot 189 \cdot 303 = 256556\,J = 256{,}556$ kJ;

$E'_{(0,1)} = 52{,}6 \cdot 189 \cdot 303 = 3012244\,J = 3012{,}244$ kJ;

total energy values are:

$E_{equal(0,1)} = 30{,}3 + 256{,}556 = 286{,}856$ kJ;

$E_{equal(0,1)} = 355 + 3012{,}244 = 3367{,}2$ kJ.

For the case $V_{g.} = 1{,}0$ m^3, we obtain respectively:

for the gas phase:

$E_{(1,0)} = 0{,}21 \cdot 10^6 \cdot 1{,}0 = 210000\,J = 210$ kJ;

$E_{(1,0)} = 1{,}88 \cdot 10^6 \cdot 1{,}0 = 1880000\,J = 1880$ kJ;

for dissolved gas:

$E'_{(1,0)} = 3{,}108 \cdot 189 \cdot 303 = 177985{,}8\,J = 177{,}99$ kJ;

$E'_{(1,0)} = 27{,}78 \cdot 189 \cdot 303 = 1590877\,J = 1590{,}88$ kJ;

total energy values are:

$E_{equal(1,0)} = 210 + 177{,}99 = 387{,}99$ kJ;

$E_{equal(1,0)} = 180 + 1590{,}88 = 3470{,}88$ kJ.

From the calculation data and their geometric interpretation, the importance of influencing on the pressure system in the gas phase, which is created in self-propelled processes such as fermentation, takes place. The technical implementation of the pressure parameters is provided by sealing the fermentation apparatus with the corresponding ratio of the regulator of the boundary pressure.

The presence of energy potentials in the gas and liquid phases is subject to an assessment of the possibilities of their use in the directions of fermentation intensity and its efficiency. Phenomenological analysis leads to the conclusion about the special possibilities of using the potential of compressed CO_2 in the volume of the gas phase, since the regulatory pressure changes allow the liquid phase to be removed from the state of saturation in the desaturation mode or to return it to the saturation regime, including in the form of collapse (cavitation) of the dispersed gas phase.

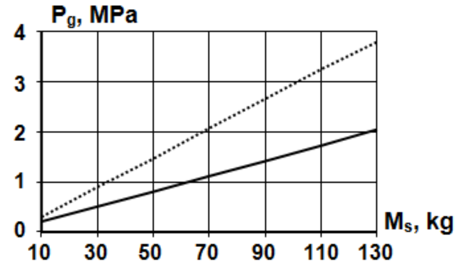

Figure 2. Graphs of dependence of pressure in gas ingenious volume on the amount of fermented sugar

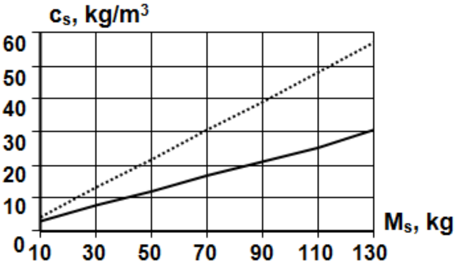

Figure 3. Graphs of the concentration of dissolved carbon dioxide in the liquid phase on the amount of fermented sugar

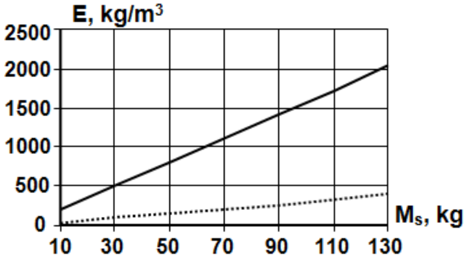

Figure 4. Graph of the dependence of the gas phase energy on the amount of fermented sugar

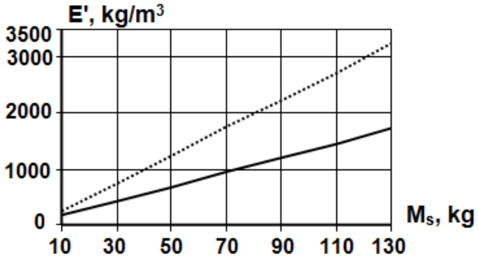

Figure 5. Graph of the dependence of dissolved CO_2 in the liquid phase on the amount of fermented sugar

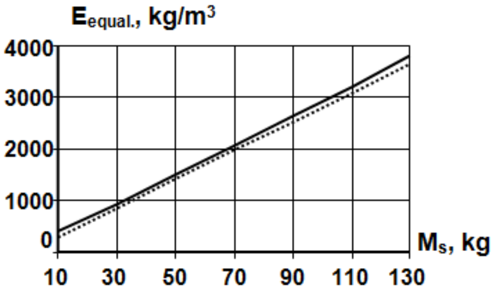

Figure 6. Graph of the dependence of the total amount of CO_2 energy in the liquid and gas phases on the amount of fermented sugar

It is obvious that the expansion of the range of energy influences, including impulse, on the gas-liquid medium is determined by its potential E'. From this point of view, limiting the volume of the gas phase in the ingenious volume is accompanied by extremely high efficiency when such conditions are reached:

$$E'_{0,1} >> E'_{1,0}$$

In our case, the multiplicity of the ratio when $V_{g.} = 0{,}1\ \mathrm{m}^3$ was

$$E'_{0,1}/E_{0,1} \approx 8{,}5\ ,$$

Whereas in the case $V_{g.} = V_{liq} = 1\ \mathrm{m}^3$ this ratio is:

$$E'_{1,0}/E_{1,0} \approx 0{,}85$$

The dependences shown on Figure 2–6, indicate the expediency of limiting the volumes of the gas phase due to the increased rate of saturation of the medium with the redistribution of energy potentials. It is important in the anaerobic technologies of digestion of secondary wine materials, beer, cider, etc., that is, in cases where saturation of the media with carbon dioxide is a composition of the technological task.

It is important to note that the indicated volume ratios do not almost affect the values of total potentials.

At the same time, in the technologies of alcohol fermentation, the transition to the limited volumes of the gas phase remains promising both for the intensification of mass-exchange processes, and for the creation desaturation and saturation periods and zones in gas-liquid media. The sharp reduction of pressure in the gas phase simultaneously and rapidly converts the full volume of the liquid phase into a supersaturated state, which is accompanied by an additional formation of the dispersed gas phase and increase of the volume of that part of the dispersed phase, which existed before the moment of decrease of pressure. The consequence of these two phenomena is an increase of the volume of the gas-liquid medium, which reflects its energy impulse, the intensification of mass-exchange processes and the level of desaturation. Complex of transition processes, associated with the reduction of pressure in the gas phase, is characterized by their self-determination until the new state of equilibrium. Saturation of the liquid phase on CO_2 corresponds to the latter but at a lower level with a corresponding decrease of the osmotic pressure.

The forced increase of pressure in the gas phase of the fermentation apparatus means the presence of a new transitional process of another direction, which transfers the liquid phase to the unsaturated state and to a new mode of saturation with the activation of yeast in the process of fermentation.

Conclusions

The energy potentials of synthesized in the processes of anaerobic fermentation carbon dioxide are divided into two parts. One of them relates to the gas phase, which transits into the ingenious volume, while the second is the potential of dissolved CO_2. An influential parameter for this redistribution is the ratio of volumes of liquid and gas phases. The convergence of these volumes in other existing conditions converges energy potentials, and the restriction of volumes of the gas phase is accompanied by a noticeable redistribution of energy potentials at the edge of the liquid phase.

The energy potentials of gas volumes do not find practical application in processes of fermentation, but the reduction of pressures in them provides the modes of desaturation of liquid volumes, the use of energy potentials of soluble gases, the intensification of mass-exchange processes.

The energy potential associated with the saturation gradient of the media on CO_2, provides fast and continuous implementation of the restoration of the saturation possibilities of the liquid phase and the activation of fermentation due to the condition of realization the deterministic circulatory circuit.

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