



DESATURATION OF CULTURAL MEDIA IN PROCESSES OF ANAEROBIC FERMENTATION

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Abstract: *The article deals with the analysis of transients in gas-liquid media with the self-synthesis of the gas phase. It is shown that the restriction of the mass transfer intensity in the culture media of the alcoholic and brewing industries is accompanied by the presence of transients in the state of saturation on CO₂. It is determined that the level of carbon dioxide accumulation increases due to physical and hydrostatic pressures and the latter one is determined by the geometrical parameters of fermentation vehicles, but the quantitative desaturation per unit volume of the medium does not depend on hydrostatic pressure. Quantitative desaturation of CO₂ depends on the pressure differences in the ingenious volume. It is shown that the restoration of the sorption properties of the liquid phase is possible due to combinations of reduction and subsequent increase of physical pressure. The analytical dependences on determination of interconnections of physical parameters in digestible media are given.*

Keywords: *desaturation, gas-liquid medium, gas-retaining ability, mass transfer, hydrostatic pressure, solubility.*

1. Introduction

Formulation of the problem. Anaerobic fermentation of sugar-bearing media under the action of yeast cells is accompanied by the formation of a new cellular substance, the acceptance and assimilation of substances from the external medium, the splitting and removal of unnecessary and harmful compounds and the transport of substances within the cell.

The energy supply of the processes is achieved thanks to the breath that begins with the splitting of glucose. The result of such transformation is the accumulation of ethanol and carbon dioxide in the medium. The presence of ethanol and carbon dioxide is accompanied by an increasing osmotic pressure, which ultimately limits

the concentration of ethanol in the range of 8 ... 10% and a maximum of 12% with the use of osmophilic yeast [1-3].

Traditionally, these restrictions are associated with ethanol and its osmotic pressure, and the presence of dissolved CO₂ in the fermented medium is an additive part [4]. In accordance with the Van-Hoff law and based on the principle of superposition [5], the total osmotic pressure of dissolved substances in the medium is determined by the dependence:

$$\pi_{osm} = \left(\frac{m_s(t)}{M_s} + \frac{m_{al}(t)}{M_{al}} + \frac{m_{CO_2}(t)}{M_{CO_2}} \right) \frac{RT}{V},$$

where $m_s(t)$, $m_{al}(t)$ and $m_{CO_2}(t)$, - mass of sugar, alcohol and carbon dioxide respectively as a function of time t ; M_s ,

M_{al} and M_{CO_2} - the molecular masses of substances respectively in volume V of the solution; R - universal gas constant, $J / (mol \cdot K)$; T - absolute temperature, K
At the end of fermentation when $m_i(t_e) = 0$, we have:

$$\pi_{osm} = \left(\frac{m_{al}(t_e)}{M_{al}} + \frac{M_{CO_2}(t_e)}{M_{CO_2}} \right) \frac{RT}{V},$$

where t_e is the final time of the process;
 $M_{CO_2}(t_e)$ - the final mean of the solution of carbon dioxide, due to the presence of hydrostatic pressure.

Calculations show that for alcoholic fermentation, 12% alcohol solution at a temperature $T = 303 K$ creates an osmotic pressure of $6.58 MPa$, while 2% solution of carbon dioxide leads to a similar index of $1.07 MPa$. For the close values of the molecular weights (46 and 44, respectively), the final difference in osmotic pressure is explained by the limited solubility of CO_2 in accordance with Henry's law, which is reflected by the equation of the material balance:

$$m_s = m_{al} + m_{CO_2} \uparrow,$$

by which the main part of carbon dioxide is removed in the form of a dispersed gas phase.

The formation of the latter begins when the concentration of CO_2 reaches saturation constant c_s :

$$c_s = kP$$

where k is the Henry's constant, depending on the nature of the gas and liquid phases and the temperature of the medium; P - partial pressure of the gas phase.

Under the condition of anaerobic fermentation, the partial pressure is equal to the physical pressure. The latter means the presence of a concentration gradient in connection with hydrostatic pressure.

By endogenous processes of synthesis of ethanol and carbon dioxide there are opposite transport flows on the interfacial

surface of microorganisms and fluid medium. When there is unbounded solubility of C_2H_5OH in water, the saturation of the medium on CO_2 creates a barrier to mass return and the preconditions for the formation of gas microbubbles.

The resistance to the mass transfer in a liquid film at the interface between the liquid and gas phases for the limited soluble gases is the main component [6, 10], and this hypothesis is hypothetically transferred to the surface "cell-medium". Transport of CO_2 through the cytoplasmic and external shell has its own peculiarities and is carried out at the molecular level. At the same level, the penetration through the liquid film into the liquid phase is carried out. At the same time, the state of saturation of the medium is the reason of the resistance to mass transfer and its termination under certain conditions.

The course of processes of anaerobic fermentation leads to the conclusion that the state of the liquid phase of the medium is noticeably close to the full saturation and depends on its hydrodynamic state due to the interaction of the dispersed gas and liquid phases.

In this case, there is the effect of pressure in the volume of the gas phase, the geometry of the equipment, the hydrostatic pressure, the gas-holding capacity and the intensity of the circulating contours.

The purpose of this study is related to the theoretical search for the mutual influence of these parameters for the restoration of sorption properties of culture media due to their forced desaturation.

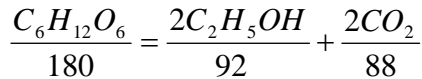
2. Materials and methods

Theoretical studies and phenomenological conclusions are performed on the basis of laws and principles that are involved in the interaction of chemical and biological processes of gas and liquid phases during

anaerobic fermentation. They include material and energy balances, Pascal and Archimedes laws, laws of the continuity of flows, Henry, Van-Hoff [5], Gay-Lussac laws and Le Chatelier principle, principles of superposition and the most probable state [7]. The solution of the problem of restoring the sorption properties of culture media in CO₂ is proposed on the basis of variable pressures [8–9].

3. Results and discussion

It is known that the ratio of material flows in the processes of fermentation is determined on the basis of the Gay-Lussac equation in the form:



Let the concentration of dissolved glucose be 160 kg / m³ at the initial fermentation condition, then the total cycle of synthesized CO₂ is 78.2 kg and ethyl – 81.8 kg. In recalculation on the number of moles of CO₂ we receive:

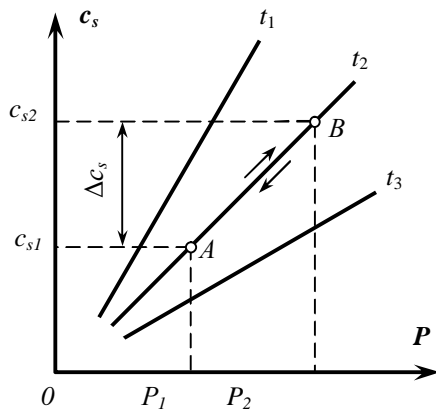


Fig. 1. Schedule of dependencies $c_s = c_s(P)$ in isothermal processes

$$M_{CO_2} = \frac{78200}{44} = 1777.3 \text{ mol}$$

under normal conditions, the volume of gas is:

$$V = \frac{M_{CO_2} RT}{P} = \frac{1777.3 \cdot 8.314 \cdot 293}{10^5} = 43.3 \text{ m}^3,$$

and the average rate of synthesis of CO₂ is:

$$\frac{dM_{CO_2}}{dt} = \frac{78.2}{t_e} = \frac{78.2}{72} = 1.086 \text{ kg}/(\text{hour} \cdot \text{m}.$$

It is obvious that in the regimes of the lag phase and the digestion, the rate of synthesis is considerably smaller and the state of saturation on CO₂ is initially achieved on areas with lower hydrostatic pressure with a gradual transition to the full volume. From the beginning of the formation of the dispersed gas phase, it begins transition into a superficial volume of the gas phase with increasing pressure. Let's assume that this pressure in the sealed volume increases from 0.1 to 0.2 MPa, and the increase of saturation constant Δc_s at a temperature of the culture medium of 30 ° C is 1.48 kg / m³ or in moles is 1480 : 44 = 33.64 This process is responsible for the areas A-B on the isotherm (Fig. 1). Forced pressure decrease from 0.2 to 0.1 MPa is accompanied by the release of 1.48 kg of CO₂ from each cubic metric of the liquid phase, regardless of the value of hydrostatic pressure, since the dependence $c_s = c_s(P)$ is linear.

To achieve the desired level of desaturation of the medium in the ingenious gas phase, a pressure of 0.1 MPa is maintained, and it means that the desaturated CO₂ is taken back from the apparatus (under normal conditions) in volume:

$$V_{CO_2} = \frac{33.64 \cdot 3.14 \cdot 293}{10^5} = 0.309 \text{ m}^3/(\text{m}^3 \text{ of the medium}).$$

The transition from c_{s2} to c_{s1} occurs without going beyond the saturation state, but its positive effect relates to a sharp increase in gas-holding capacity, an increase in the volume of the gas-liquid system and an increase in the dynamics of the hydrodynamic regime.

The short-term flow of such transient processes with intensive mass transfer leads the media to the indicator c_{s1} . At the same time, in an ingenious volume at a pressure of 0.1 MPa the amount of carbon dioxide that remains will be:

$$M_{CO_2} = \rho V_{ingenious} ,$$

where ρ is the specific mass of CO₂, kg / m³, which is in moles

$$M'_{CO_2(n)} = \frac{10^3 \rho V_{ingenious}}{44} = 22.73 \rho V_{ingenious}$$

At the average rate of synthesis of CO₂ $\dot{M}_{CO_2} = 1.086 \text{ kg/m}^3$, the recovery of the pressure at 0.2 MPa in the gravity process is achieved in time:

$$t_e = \frac{1.48}{1.086} = 1.363 \text{ hours}$$

In this mode, the liquid phase is in saturation, and the dynamics of increase in pressure is reflected by the dependence:

$$P_i(t) = \frac{\left(\frac{M_{CO_2}(t)}{44} + 22.73 \rho V_{ingenious} \right) RT}{V_{ingenious}}$$

where $M_{CO_2}(t)$ is the amount of synthesized CO₂ in the function of time.

At the same time with the pressure the constant of saturation increases from c_{s1} to c_{s2} :

$$c_{iv} = kP_i(t) = k \left(\frac{\left(\frac{M_{CO_2}(t)}{44} + 22.73 \rho V_{ingenious} \right) RT}{V_{ingenious}} + \rho g H \right)$$

where H is the fluid value of the altitude coordinate in terms of the liquid phase.

At constant rate of formation of CO₂

$$\frac{dM_{CO_2}}{dt} = const$$

we have a linear accumulation law:

$$M_{CO_2} = \frac{dM_{CO_2}}{dt} t .$$

Under these conditions, the pressure change is reflected by the linear law (Fig. 2). It is important that at the same time, the liquid phase both for the reduction of pressure and its growth is in a state of saturation, which limits the intensity of mass transfer and the final level of accumulation of alcohol.

The solution of the problem will be restoring the sorption possibilities of the culture medium due to the rapid increase in pressure in the ingenious volume after the

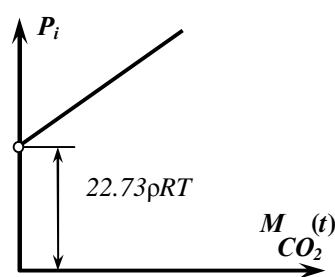


Fig.2. Graphic dependence of the pressure change in the ingenious volume

completion of the desaturation phase.

Such transition leads the system to a state when the fluid concentration of dissolved carbon dioxide is c_i ($c_i < c_{s2}$). It is obvious that the fluid concentration is a function of time $c_i = c_i(t)$ and during the second phase it is reaching the value $c_i = c_{s2}$. The fulfillment of this condition means the necessity of another reduction of pressure in the system to a magnitude P_1 . The control over phases is monitored by the values of pressure P_1 and P_2 with the phase at the point A at the pressure P_1 to complete degassing.

4. Conclusion

The analysis of the transition processes in the gas-liquid media with the self-synthesis of the gas phase allows drawing the following conclusions:

1. Modern technologies of anaerobic fermentation of alcohol and brewing fields are accompanied by the presence of digestible media in conditions which are close to their saturation states on CO₂. The latter limits the intensity of the mass transfer of carbon dioxide on the surfaces of the phase separation and the final result of the accumulation of ethyl alcohol in the alcohol industry.
2. Hydrodynamic modes in the media depend on the gas-holding ability, which in other equal conditions is determined by the ratios of the geometric parameters of the apparatus and media respectively.
3. The levels of CO₂ accumulation increase due to hydrostatic pressures, but the quantitative desaturation from the unit of the volume does not depend on hydrostatic pressure, but it depends on pressure differences (P₂ to P₁).
4. Restoration of the sorption properties of the culture media is possible only with combinations of sharp reduction in pressure and subsequent increases in pressures in the gas ingenious volume.

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