Intensification of mass transfer processes in gas-liquid media by discrete – pulse energy input method

Oleksandr Bessarab[1], Oleksandr Obodovich[2], Vitalii Sydorenko[2]

1 – National University of Food Technologies, Kyiv, Ukraine
2 – Institute of Technical thermophysics National Academy of Science of Ukraine, Kyiv, Ukraine

Keywords:

Mass transfer
Absorption
Microorganisms
Intensification

Article history:

Received 03.03.2016
Received in revised form 26.04.2016
Accepted 30.06.2016

Corresponding author:

Vitalii Sydorenko
E-mail:
tdsittf@ukr.net

Abstract

Introduction. The aim of this study was the intensification of the aeration of culture media in a fermenter by the method of discrete – pulse input of energy, which is being implemented in a rotor – pulsating apparatus.

Materials and methods. The process of aeration of culture media in the technology of yeast Saccharomyces cerevisiae growing by discrete – pulse energy input. The mass transfer rate of oxygen was determined by the number of yeast biomass grown for cultivation period.

Results and discussion. During the experiments on cultivation of yeast on molasses solutions the mass transfer rate of oxygen dependence on the angular rate of the rotor unit in the culture medium with a solids content of 3 – 10% was determined. With the reduction of the solids content from 10 to 5% by treatment with an angular rate of rotor of 48 rps, the mass transfer rate is increased by 1.9 times. As the frequency of the flow pulsations increases from 2 to 3.85 kHz, mass transfer increases from 4 to 6.3 g / l per h at solids content – 3% and from 2,2 to 4 g / l per h at solids content – 10%. A further increase of the frequency of pulsations leads to inactivation of the yeast cells. It was also found that the optimal value of the flow shear rate is 90 – $100 \cdot 10^3$ s^{-1}.

Conclusions. The results of this study suggest that the use of the DPIE method in absorption technologies can significantly intensify the processes of mass transfer.

Introduction

The dissolution of sparingly soluble gases in technological liquids is an essential process in a number of food industry plants. Thus, the process of oxidation of technological water with oxygen contained in the air during water treatment of alcohol, brewing and other industries allows to remove from the water undesirable impurities such as iron, manganese, hydrogen sulfide. Wastewater treatment alcohol and brewing industries, causing biological pollution, also occured by chemical and biological oxidation of waste. Aeration of the culture media used in biological productions during culturing aerobic microorganisms. Oxygen breathing of organisms, being an order of magnitude more energetically favorable than the alcoholic fermentation, is at the heart of the process of growing biomass of yeast for bakery, alcohol industry, brewing, etc [1]. The main problem to be solved in the process of yeast growing is to provide a sufficient number of cells of dissolved oxygen during the entire culture period. The low equilibrium concentration of dissolved oxygen in water and nutrient media at a temperature of the process (30 °C) with a high rate of oxygen consumption by yeast cells is a constant need for supplying oxygen in the air into the culture medium.

Literary analysis

By the process of aeration of culture media continued interest displayed by the scientific community. It focuses on two aspects – the study of the impact of aeration on the growth or production of target metabolites by microorganisms, as well as ways to change the characteristics of mass transfer operation of the aeration devices [2–4].

Air flow rate passing through the culture medium in the bubble machines, mainly used for process of yeast growing an achieve significant volumes [5]. This is related to the fact that occurring during the bubbling air bubbles coalesce quickly, substantially reducing the surface contact between the phases. In addition, the terms of flow aeration process such that the mass of yeast unevenly distributed over the volume of the apparatus, which has a negative impact on results of process. The process of dissolving oxygen in the culture media is generally dependent upon the difference of oxygen concentration in the gas and liquid phases, the contact area of the phases, as well as hydrodynamic conditions at the interface. It should be noted that the main resistance to the mass transfer of oxygen has liquid. The mass transfer resistance inside the gas phase, as well as resistance at the liquid – cell interface is usually neglected.

Thus, the intensification of the mass transfer process is directed action on each of these parameters.

One method of providing directional effect on the treated liquid medium in the dispersion process, dissolving, emulsifying, mixing, catalysis, etc., is a method of discretely – pulsed power input [6]. The principle of the method consists in that previously entered stationary and randomly distributed in the working volume energy to accumulate (concentrate) in the local discrete points of system to achieve the desired effects. The aim of the method is the intensification of heat and mass transfer and hydrodynamic processes in technological media, as well as the creation of methods of optimization and control methods. Realization of the method involves the creation of a large number of uniformly distributed in a dispersion medium working elements or working elements which transform the fixed thermal, mechanical or other types of energy in the energy-power pulses, discrete in time and space. Accompanying these phenomena shock waves, interfacial turbulence, cavitation, penetrating cumulative microjet, vortices caused at interfaces such as Rayleigh –

Taylor and Kelvin-Helmholtz instability, which leads a significant increase in the total surface of phase contact and improve mass and heat transfer processes [7]. The discrete pulse energy input method is realized in a variety of devices. The most common are the impulse pulsator, rotary – disk and rotary – pulsation apparatus. The use of each of these types of devices, as well as the design features of the working parts and processing modes defined treatment goals, physical – chemical properties of the media, energy consumption. The use of certain apparatus allows you to boost the role of cavitation, or the role of shear stress, and so on. This allows to effectively solve technological problems in each particular case. The discrete pulse energy input method as a method of intensifying mass transfer processes at the gas – liquid has been applied in biotechnology in aquaculture ponds aeration processes, the activation of yeast in alcohol production [8–9].

The aim of this work is the intensification of the process of mass transfer of oxygen by discrete – pulse input energy in a rotary – pulsating apparatus in the fermentation unit at the aeration of culture media, as well as the effect of this treatment on the process of yeast growing .

Materials and methods

During the work the process of aeration of culture medium during the process of growing Saccharomyces cerevisiae yeast growing on molasses solutions in the fermentation unit with discrete – pulse energy input was studied.

The fermentation unit consists of the following units: the tank – storage, rotor – pulsation apparatus, loop recycling, the refrigerant circuit, the control and monitoring unit.

Capacity storage tank is a useful volume of 50 liters and serves for the culture medium processing.

In order to maintain a constant temperature process, the tank is provided cooling (heating) jacket, containing the inlet and outlet port for connection to the water mains. To determine the filling of the tank was a level gauge. Inside the tank storage removable inner glass can be provided, which serves for receiving the treated culture fluid of the recirculation system.

In the upper part of the tank – storage is welded pipe for the connection of the recirculation pipe. The cover of a tank – storage provides technologies connections for input into the workspace seed yeast, nutrients and defoamer, the pressure valve. The cover is provided with a viewing window. At the bottom of the tank valve drive is provided for the change of the volume flow.

Rotary – pulsating apparatus is intended for transforming electric energy input by method DPIE to the physical, hydrodynamic, acoustic impact on the culture medium.

Fully assembled apparatus consist of a disc mounted on a shaft with blades – the centrifugal pump impeller, a rotary – pulsating unit representing a settling down in the housing two fixed stator and rotor mounted on the motor shaft. The stator and rotor are in the form of shells with rectangular slits. Work RPA volume was $1.5 \cdot 10^{-3}$ m^3. The air in the aeration is supplied through a filter self-priming. The air supply is due to local discharge in the discharge line. Multiple processing is carried out at the expense of recycling of the culture medium along the contour of tank-storage – rotary – pulsating apparatus – tank – storage.

Control and monitoring unit is designed for controlling, monitoring and control of electrical equipment. The unit consists of a magnetic starter, frequency inverter, ammeter, electricity meter.

Oxygen mass transfer rate was determined by equating the rate of oxygen dissolution rate to its consumption by yeast cells. Taking the position that all the oxygen is consumed by the cell, it is spent on the process of division of cells the consumption rate is calculated based on the amount of growth of yeast mass.

This condition allowed to determine the oxygen absorption rate by determining the amount of biomass of yeast growed during cultivation period.

Methods of obtaining initial data for determining the mass flow rate was as follows.

The tank-storage supplied pre-prepared culture medium. Clarification of molasses made of acid – cold method. The resulting solution (1: 1, solids content – 37%) diluted with artesian water to a content of solids content provided program of experiment and was adjusted to 30 °C temperature.

The solids content was determined by the saccharometer. Preparation nutrient medium acidified with phosphoric acid to pH 5.0. The solutions of nutrient salts, growth substances prepared separately.

The tank – storage was filled with mixture of molasses solution and nutrient. Capacity was determined by the height of the filling level gauge.

Frequency converter sets the frequency of the output shaft speed. After switching on the device temperature of the medium was adjusted to 30^{o}C. The air valve opened. Prepared seed yeast was diluted with water to the yeast concentration, provided research program, and then fed into a tank – storage. After 5 minutes after seeding a sample the culture medium was taken, which was the control. A determination of yeast biomass, determination of the number of dead cells was made. Samples were collected during the period of cultivation for each hour. Temperature of cultivation was maintained by the start of cold water into the jacket.

Foam height was determined visually through the viewing window. When exceeding the critical level the oleic acid emulsion into the tank – storage supplied. The concentrated culture medium (1:1), nutrient growth substances and salt solutions were calculated by the method based on the intended specific growth rate. Supply of nutrients and growth substances carried out every half hour throughout the entire period of cultivation.

Obtained mass of yeast was determined by weighing on an analytical balance according to standard procedure.

The number of dead cells was determined by direct counting in Goryaev chamber.

The main parameters that have changed in the course of processing the culture media, was the frequency of the flow pulsations and flow shear rate. The first parameter is determined by the number of slots in the shell and characterizes the frequency of exposure to the culture medium pulses of pressure generated when slots of the rotor and stator are at overlapping. The second parameter takes into account the impact of gap between rotor and stator on processing the culture medium.

Results and discussion

The initial concentration of yeast cells in the culture fluid volume of 30 liters was 20 g / l. Yeast was cultured for 8 hours. The magnitude of biomass growth per hour was determined depending on the concentration of yeast biomass at different processing modes. In Figure 1–3 shows the dependence of the concentration of yeast and quantities of hourly biomass growth in the processing method DPIE with a variety of flow shear rates.

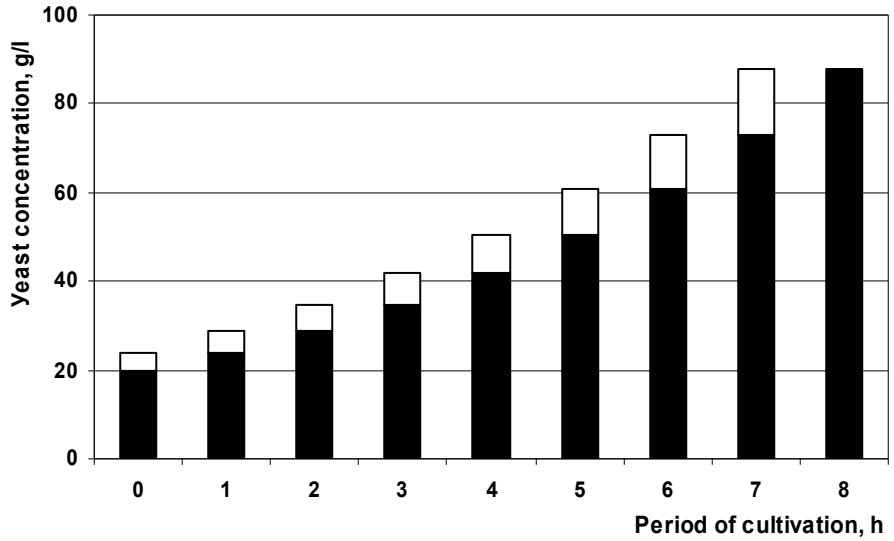

Fig.1. Yeast concentration dependence of the duration of culturing at a shear rate of flow of $85{,}46 \cdot 10^3$ s^{-1}

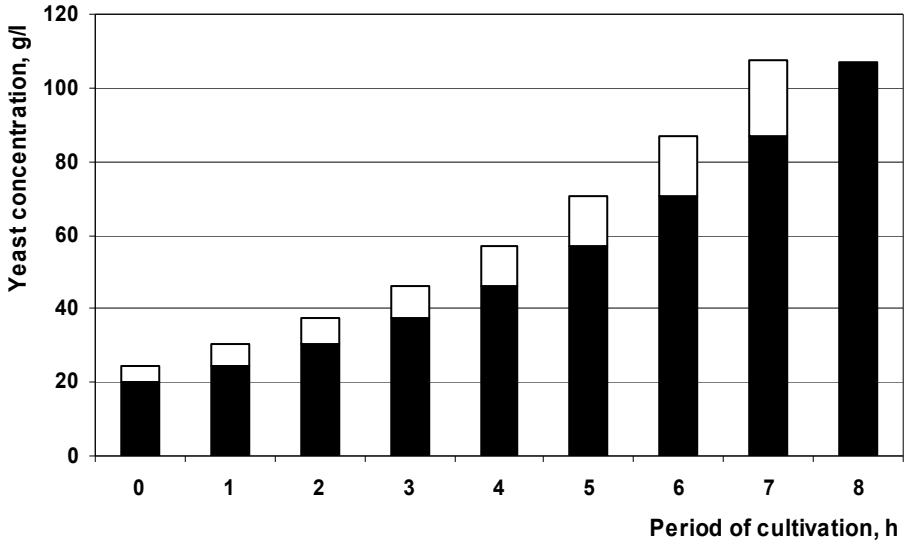

Fig.2. Yeast concentration dependence of the duration of culturing at a shear rate of flow of $114 \cdot 10^3$ s^{-1}

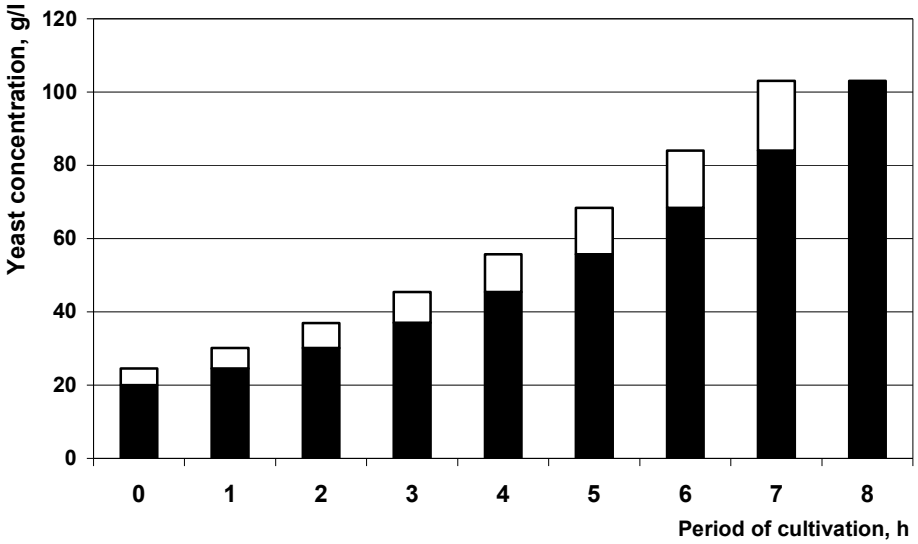

Fig. 3. Yeast concentration dependence of the duration of culturing at a shear rate of flow of 125,3 ·10^3 s^{-1}

Based on the obtained data of biomass growth for the last hour the mass transfer rate of oxygen into the culture media was determined.

Table 1 shows the dependence of the mass flow rate of the angular speed of the rotor at different solids content in culture medium

Table 1

Dependence of the rate of mass transfer on an angular rate of the rotor at different solids content

Solids content	Angular rate of the rotor, rps			
	38,2	**43**	**47,75**	**52,52**
10%	3,4	3,8	4,065	3,82
5%	4,15	4,7	4,88	4,59
3%	5,4	6	6,33	5,9

It should be noted that with increasing angular rate of the rotor from about 38.2 to 47.75 rps rate of mass transfer is increased. It is found that the mass transfer rate depends on the concentration of solids content in the medium. With decreasing solids content from 10 to 5% by treatment with an angular rate of 47.75 rps the mass transfer rate increases 1.9 times.

In conducting research of interest is the effect on the rate of mass transfer rate the frequency of flow pulsations at the different solids content (Table 2).

The table shows that the increase frequency flow pulsations from 2 to 3.85 kHz mass transfer leads to an increase from 4 to 6.3 g / l per h at 3% of solids content, from 3,0 to 4,88 g / l per h at 5% of solids content and of 2,2 to 4 g / l per h at 10% of solids content. A marked increase in the frequency of pulsation leads to a "tightening" mode of operation, which negatively affects the dynamics of the growth of yeast.

Table 2

Dependence of the rate of mass transfer on frequency flow pulsations at different solids content

Solids content	Frequency of the flow pulsations, kHz			
	2	**2,483**	**2,865**	**3,15**
10%	2,2	3,6	4,065	3,82
5%	3,0	4,5	4,88	4,59
3%	4	5,8	6,33	5,9

When determining the effect of DPIE mechanisms on the rate of mass transfer is an important factor a gap between rotor and stator , which takes into account the influence of an indicator such as the flow rate of the shift, which is defined as the ratio of flow rate radially to the thickness gap between rotor and stator.

Experimental data showing the dependence of the flow shear rate on the rate of mass transfer at different solids contents in medium shown in Table 3.

Table 3

Dependence of the rate of mass transfer on flow shear rate at different solids content

Solids content	Flow shear rate, $\cdot 10^3$ s^{-1}			
	57	**85,46**	**114**	**125,3**
10%	1,6	3,4	4,065	3,82
5%	2,5	4,35	4,88	4,59
3%	3,4	5,4	6,33	5,9

As in previous studies have shown that an increase in the flow shear rate of mass transfer rate increases, but the increase in value of this magnitude leads to a need for small (less than 100 micron) gap, which is technically difficult to implement. The optimum range is the shear rate of flow is within $90 – 114 \cdot 10^3$ s^{-1}. The table also shows that an increase in solids content of the medium the mass transfer rate decreases.

High values of the growth rate on the dilute media suggests that the oxygen in such media dissolves better, however, the rapid uptake of yeast weight carbonaceous nutrient forced feeding fresh medium practically continuously, which creates a certain difficulty in maintaining a stable growth dynamics, thus the initial concentration of solids in the culture medium should not be below 10%.

Reduced oxygen consumption rate by increasing the frequency of flow pulsations and flow shear rate associated with increasing numbers of dead cells, which is confirmed by data obtained by microscopy.

Conclusions

DPIE mechanisms controlling and changing the design features of the rotary – pulsating apparatus, it is possible to influence the rate of mass transfer of oxygen into the culture medium. This can be explained with decrease by the mean diameter of the air bubbles in the space between the working parts of apparatus that greatly increases the contact area of the interface.

Increasing the mass flow rate of 4.1 g / l·h allows to intensify the process of cultivation of yeasts, namely to reduce the process time duration from 12 to 8 hours and to

increase the final concentration in the yeast in 2 times compared to the conventional technology.

Increasing the degree of exposure on culture medium a flow shear rate higher then $114 \cdot 10^3$ s^{-1} leads to decrease in the yield of finished product. This may be due to the fact that increased physical and hydrodynamic effects in the apparatus leads to the inactivation of some cells.

References

1. Ian.L. Pepper, Charles. P. Gerba (2015), *Environmental Microbiology (Third edition),* Elsevier, Amsterdam.
2. Jihane Rahbani Mounsef, Dominique Salameh, Nicolas Louka, Cedric Brandam, Roger Lteif (2015), The effect of aeration conditions, characterized by the volumetric mass transfer coefficient K_La, on the fermentation kinetics of Bacillus thuringiensis kurstaki, *Chemical Engineering Science*, 210, pp. 100–106.
3. Chun-Ping Xu, Jong Won Yun (2004), Influence of aeration on the production and the quality of the exopolysaccharides from Paecilomyces tenuipes C240 in a stirred-tank fermenter, *Enzyme and Microbial Technology,* 210, pp. 33–39.
4. Damir Druzinec, Denise Salzig, Matthias Kraume, Peter Czermak (2015), Micro-bubble aeration in turbulent stirred bioreactors: Coalescence behavior in Pluronic F68 containing cell culture media, *Chemical Engineering Science*, 126, pp. 160–168.
5. Ghasem D. Najafpour (2007), *Biochemical engineering and biotechnology*, Elsevier, Amsterdam.
6. Dolinskiy, G. Ivanitskiy (2008*), Heat and mass transfer and hydrodynamics in the vapor-liquid media. Thermal basics of discrete input pulse energy*, Naukova dumka, Kyiv (in Russian).
7. Grabova T. (2007), Dispersion of heterogeneous systems in a rotary – pulsation apparatus of disc – cylindrical type, *PhD dissertation (Engineering).* Institute of engineering thermophysics, Kyiv (in Russian).
8. Dolinskii A. (2015), *Micro – and nano leveled processes DPIE technologies*, Akademperiodika, Kyiv (in Russian) .
9. Dolinskii A. Obodovich A., Borhalenko Yu. (2012), The method of discrete pulse energy input and its implementation, Apostrof, Kharkiv (in Russian).
10. Theodore L. Bergman, Adrienne S. Lavine, Frank P. Incropera, David P. DeWitt (2011), *Fundamentals of Heat and Mass Transfer*, John Wiley & Sons, Inc.
11. Pauline M. Doran (2013), *Bioprocess Engineering Principles (Second Edition)*, Elsevier, pp. 761–852.