**Study of Influence of Air Ions on the Growth Rate of Yeast Saccharomyces cerevisiae Based on Analytical Growth Model**

Maxim Yanko 1, Evgeniy Zayats1, a), Utkirbek Sulaymonov2, Usan Berdiyev2

1 Belarusian State Agrarian Technical University, Minsk, Belarus

2Tashkent state transport university, Tashkent, Uzbekistan

a) Corresponding author: [zayatsem@mail.ru](mailto:zayatsem@mail.ru)

**Abstract.** The effect of the concentration of ions in a nutrient medium on the surface charge and potential of a yeast cell as well as diffusion of nutrients across its membrane and the productivity of baking yeast were investigated theoretically. It was demonstrated that the concentration of ions in the medium, the surface charge and potential of the yeast cell are influenced by ionized molecules of the air components (first of all, of oxygen and nitrogen). This characteristic influences the process of diffusion of the nutrient through the membrane into the cell. The rate of growth of the yeast mass is determined by the level of electricity, which is carried by the air ions in the nutrient media and is restricted by its definite value. This is why the equation of mass growth of the yeast cells considers the quantity of the electricity introduced into the medium of nutrition by the air ions. It is a priori computation that the yeast of the baker may have an increased productivity of 12...17 percent.

**INTRODUCTION**

Saccharomyces cerevisiae or brewer or bread yeast is useful in some biotechnological applications[1]. The yeasts have received considerable attention because of the potentiality of cells. They are applied as starter in fermented beverage industries, as probiotic yeast, etc. The yeasts are also used to produce cellular components (proteins, polysaccharides) which are as functional ingredients in the food industry [2,3]. To this end, this would mean getting yeast in huge volumes instead of ethanol, as is the case in other instances. [3].

It is known that the yeast growth rate depends on a lot of factors (the oxygen concentration in the medium, the nutrient concentration, the nutrient solution composition, the medium temperature, and the diffusion of nutrient ions through the pores of the cell membrane, etc.) [3]. As an illustration, Saccharomyces cerevisiae has to be cultivated in a medium where oxygen is accessible as well as low initial sugar concentration [4,5]. The problem of baker's yeast production is low cell productivity and incomplete use of the nutrient medium potential. This problem can be solved by thermal, chemical, mechanical, electrophysical and other methods [6-12]. The most promising for development are electrophysical methods, one of which is the treatment of a nutrient medium with yeast using air ions.

Biofuels and bioenergy applications Electromagnetic fields can be used as biofuels, and possible mechanisms behind this extensive discussed in [7]. The latter implies that not only ionic redistribution occurs due to the low-frequency electric fields effects at, but also elevated potential difference occurs in the cellular suspension. The hypothesis is also that the pulsed electric fields induce modifications of cytoplasmic membrane due to temporary electroporation [13]. Regarding this, it is also stated in [14] that the external electric field enhances the transfer of nutrients with the altered cell membrane through the formation of pores.

The effect of negatively charged oxygen and nitrogen ions in the air on the nutrient medium of yeast Saccharomyces cerevisiae is studied [4,5,7,15]. It is known that hydrogen peroxide is the main active factor of air ions on the nutrient medium of yeast [16]. This factor changes the concentration of ions in the nutrient medium, activates the formation of new substances and the growth of yeast cells [17]. The surface charge and potential of a living cell are modified and, therefore, influence the diffusion of nutrients across its membrane and, thus, its growth [18,19].

The objectives of the present study were to demonstrate theoretically the influence of the concentration of ions in a nutrient media on the surface charge and potential of a yeast cell and diffusion of nutrients across the membrane of the cell.

**MATERIALS AND METHODS**

Kinetic models This is a method to investigate the yeast behaviour, metabolism, growth. The structured and unstructured models of description of the microbial cell growth are several [20-23]. Typically, the unstructured ones characterize the growth kinetics of cells and can be applied to characterize such a process under different working conditions (temperature, pH, and other parameters, which are adjustable). Structured models tend to be complicated to estimate kinetic parameters, primarily due to nonlinearities, the large count of parameters in comparison with the unstructured kinetic models. In the given case, we will consider the growth of the yeast Saccharomyces cerevisiae under the influence of air ions as per the model adapted to it [24-31].

**CONCENTRATION OF CHARGED PARTICLES IN THE NUTRIENT MEDIUM, CELL SURFACE CHARGE AND POTENTIAL**

The change in the molar volume concentration of substance (mol/m3) for an infinitely small time di in a medium volume where there occurs a current generated by the flow of air ions is:

(1)

here is the volume of a processed medium, m3; is the instantaneous strength of the current flowing through the medium for a time, А; F=96485 C/mol is Faraday’s number; is the instantaneous number of transfer of the ith cation k or the jth anion a for a time .

Transform (1) using the amount of electricity:

, (2)

here is the quantity of the electricity which is carried away by the air ions passing through the medium, C/m3.

Allowing for Faraday’s law, the molar volume concentration of negative ions (mol/m3) is obtained as a result of air ion processing of the medium:

=, . (3)

here is the initial molar volume concentration of negative ions, mol/m3, and is the current output of negatively charged particles.

The total yeast cell surface density (C/m2), generated, for example, by the cations of kind [4], is:

, (4)

where is the surface density of the charge of acid and basic groups, respectively, C/m2; are the mol/m3 of the dissociation constant of acid/basic groups of the water respectively.

At the same time,

 (5)

 is the concentration of positively charged ions, mol/m3;  is the concentration of ions of hydrogen and hydroxide, respectively, mol/m3; , ,  is the concentration of acid/basic groups and water, respectively, mol/m3.

Assume that the yeast cell is shaped as a sphere covered with negative-sign ions with a surface density ρS. The potential of the sphere surface is governed by the known equation:

. . (6)

where  F/m is the electric constant;  is the relative dielectric constant of the nutrient medium;  is the cell surface area, m2;  m is the cell radius [5].

Therefore, the diffusion rate and direction of substances through the cell membrane depends on the presence of charged particles in the nutrient medium (3), cell surface charge (4) and potential (6) changed by the current flowing through the form of air ions.

The concentration of ions within a living cell can be ten times different from their concentration in the ambient medium, the concentration gradients of different-sign ions being observed. This is attributed to transport dynamics of ions through the membrane and depends on the properties of a specific cell. The concentration difference of ions outside and inside the cell under normal conditions gives rise to voltage between citoplasma and ambient nutrient medium. It ranges from 50 to 70 mV [6, 7]. When air ions are applied, this potential difference can be larger than the membrane voltage breakdown (100…200 mV) [8].

Calculate the concentration gradient of ions at the cell edge, during the creation of which there arises a potential difference enough for membrane breakdown.

The diffusion equation for ions inside the cell pore is of the form [9]

 (7)

at the boundary conditions: , m;  is the concentration of ions at the cell surface, mol/m3; ,  is the concentration of ions in a region far from the cell surface, mol/m3; here  is the concentration of ions at a distance  from the center of the cell, mol/m3.

The solution to (7) assumes the form:

. (8)

The diffusion flow of ions Ф (mol/s) through the surface of the cell with allowance for its spherical symmetry is:

, (9)

or

, (10)

where  m2/s is the diffusion coefficient of substance in the medium [4];  is the surface element of the cell, m2.

From (10), one obtains

, (11)

at 

, (12)

i.e.

. (13)

On the other hand-side, by definition

, (14)

where  is the average ion velocity, m/s.

Taking into account (6) and (12) yields the average ion velocity in a pore:

, (15)

or

, (16)

where  is the concentration gradient of ions on the cell membrane.

In turn, the drift velocity of an ion is associated with the potential difference φ (V):

, (17)

where  is the ion mobility in the medium, m2/(s·V);  is the distance between different-potential regions, m.

Assume that , where  is the membrane thickness, m.

From (16) and (17), one obtains

, (18)

. (19)

Relation (19) permits calculating the concentration gradient of ions outside and inside the cell. It provides a required potential difference φ.

Bearing in mind the known gradient С/С1, relation (19) may be used to calculate a resulting potential difference. In this case, the concentration gradient can be directed to both sides, i.e., varying the ion composition of the medium makes it possible to change electric charge and cell behavior.

Relation (19) has been obtained while assuming the transport of one-kind ions only through the membrane. In the general case, relation (19) takes the form:

, (20)

where  is the gradient of ith kind-ions that participate in transport through the membrane.

Assume that the potential breakdown difference for the membrane  mV. Then based on (20), the concentration gradient of corresponding ions is obtained:

; ; ; ; ; ; .

Using Nernst’s equation

, (21)

 mV, i.e., the results are practically identical. Here  is the universal gas constant, J/(mol·K);  is the absolute temperature, К, at a total concentration gradient with regard to the ion mobility .

It can then be assumed that the diffusion of ions, providing a normal function of a cell, depends on the electric field generated by the charge of ions around the cell and in the cell itself.

According to Fick’s law, the diffusion rate of substance inside the cell is:

 (22)

where  is the diffusion time, s;  is the coefficient of diffusion of ions into the cell through the membrane pore, m2/s;  is the specific volume of cells in the medium, m3/m3;  is the diffusion layer thickness, m;  is the substance concentration in the cell, kg/m3;  is the substance concentration in the medium, kg/m3;  is the cell surface area, m2;  is the volume of one cell, m3.

Diffusion of ions into the cell through the membrane pore in the presence of the cell surface potential, m2/s, [9] is:

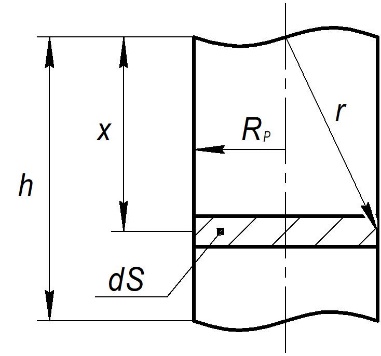
, (23)

where  is the empirical coefficient and  is the cell surface potential, V.

Assume that the cell membrane pore represents a tube with a radius RP and a length h (Fig. 1). Upon transformations, with the consideration of pore sizes formula (6) takes the form:

, (24)

where  is the distance along the tube axis from the pore entrance to the section plane passing through the middle of a strip , m, pictured in Fig. 1 and  m is the cell pore radius [5].



**FIGURE. 1.** Potential calculation inside the membrane pore

Solution to (24) can be written as:

, (25)

From (25), the potential at the pore entrance is:

, (26)

With (22) taken into account, according to Michaelis–Menten’s equation, biosynthesis can be described by the system of differential equations [10, 11]:

 (27)

where  is the substrate constant, kg/m3;  is the chemical activity the medium and  is the yeast specific growth rate, s–1.

Based on the time-independent solution to (27), one has:

,

.

Upon solution, the substance mass in the cell is

, (28)

where the factor

 (29)

where .

Substituting (29) into the first equation of system (28) yields the yeast growth rate equation:

, (30)

or

, (31)

Integrating (31) within given ranges provides the equation for the biomass specific growth under the influence of air ion processing:

 (32)

Equation (32) confirms that the yeast biomass growth depends on the cell surface potential  that determines the diffusion of ions into the cell (29). Mathematically, it describes the change in the productivity of the baker’s yeast and the medium when acted upon by air ions.

**YEAST BIOMASS GROWTH RESULTS**

The proposed analytical model allows computing: the concentration of negative ions with the consideration of the amount of electricity flowing through the medium when (3) undergoes transformation; the total density of the surface charge of the yeast cell (4); the potential at the cell pore entrance (26); the simplification factor А (29); the yeast biomass growth (32) per m3 of the nutrient medium. The results are depicted in Fig. 2.

Fig. 2 illustrates that the yeast biomass can increase per 15.2 kg/m3 of the nutrient medium when processed by the amount of electricity ranging from 380 to 430 C/m3 (m3 of the nutrient medium contains 90…110 kg yeast).



**FIGURE. 2.** Change in the yeast biomass growth when acted upon by air ions according to (31)

**CONCLUSION**

The yeast Saccharomyces cerevisiae taken in the present study could grow with high yield and product under the electric field conditions applied. The ionic redistribution and potential difference across the cell is also available on the cell due to the electric field effects at enable. Electric field is also assumed to enhance the nutrient transport across the cell membrane through pore formation.

Resolution of the equations that were used to model the kinetics of the yeast growth determined that mass production of the yeast was related to the following mechanisms. The concentration of the ions in the medium is altered by introducing the ionized air (the first to be introduced is oxygen and nitrogen). The ions influence the potential and charge of the cell of the yeast. This affects diffusion of nutrients through cell membrane as well. The mass growth rate of the yeast mass is proportional to the amount of electricity that is consumed, and that is introduced into the nutrient media by the ions of the air, and this is limited by the value of its 7. Consequently, the growth equation of yeast biomass was also dependent on the quantity of the electricity carried by the air ions in the nutrient medium. The a priori calculation indicates that the productivity of the baker yeast can be improved by up to 12 -17 percent given the conditions used in the case at hand. 8.

**REFERENCES**

1. Parapouli M, Vasileiadis A, Afendra AS, Hatziloukas E. Saccharomyces cerevisiae and its industrial applications. AIMS Microbiology. 2020; 6(1): 1-31.
2. Bertrand E, Vandenberghe LPS, Soccol CR, Sigoillot JC, Faulds C. First Generation Bioethanol, in Soccol CR, Brar SK, Faulds C, Ramos LP. (Eds.), Green Fuels Technology, Biofuels. Springer International Publishing, Cham. 2016:175-212.
3. Arevalo-Villena M, Briones-Perez A, Corbo MR, Sinigaglia M, Bevilacqua A. Biotechnological application of yeasts in food science: starter cultures, probiotics and enzyme production. J. Appl. Microbiol. 2017;123:1360-1372.
4. Rintala E, Toivari M, Pitkanen JP, Wiebe MG, Ruohonen L, Penttila M. Low oxygen levels as a trigger for enhancement of respiratory metabolism in Saccharomyces cerevisiae. ВМС Genomics. 2009;10:461.
5. Ginovart M, Carbo R, Blanco M, Portell X. Digital image analysis of yeast single cells growing in two different oxygen concentrations to analyze the population 15. growth and to assist individual-based modeling. Front. Microbiol. 2018;8:2628.
6. Alkhadra MA, Su X, Suss ME, Tian H, Guyes EN, Shocron AN, Conforti KM, de Souza JP, Kim N, Tedesco M, Khoiruddin Kh, Wenten IG, Santiago JG, Hatton TA, Bazant MZ. Electrochemical methods for water purification, ion separations, and energy conversion. Chem. Rev. 2022;122(16):13547-13635.
7. Hunt RW, Zavalin A, Bhatnagar A, Chinnasamy S, Das КС. Electromagnetic biostimulation of living cultures for biotechnology, biofuel and bioenergy applications. Int. J. Mol. Sci. 2009;10(10): 4515-4558.
8. Gavahian M, Tiwari BK. Moderate electric fields and ohmic heating as promising fermentation tools. Innovative Food Science and Emerging Technologies. 2020;64:102422.
9. Jan B, Shams R, Rizvi QEH, Manzoor A. Ohmic heating technology for food processing: A review of recent developments. Journal of Postharvest Technology. 2021 ;9(1 ):20-34.
10. Yanko MV, Zayats EM. Analysis of ways to activate the productivity of baker's yeast. Overview. Bui. BRFFI. 2022;100(2): 171-176.
11. Bertrand E, Pasquier C, Duchez G, Pons B, Creuly D. High-frequency, high-intensity electromagnetic field effects on Saccharomyces cerevisiae conversion yields and growth rates in a reverberant environment. Bioresource Technology. 2018;260:264-272.
12. Jimenez-Islas D, Paez-Lerma J, Soto-Cruz NJ, Gracida J. Modelling of ethanol production from red beet juice by Saccharomyces cerevisiae under thermal and acid stress conditions. Food Technol. Biotechnol. 2014;52(1):93-100.
13. Mattar JR, Turk MF, Nonus M, Lebovka Nl, El Zakhem H, Vorobiev E. S. cerevisiae fermentation activity after moderate pulsed electric field pre-treatments. Bioelectrochemistry. 2015;103:92-97.
14. Castro I, Oliveira C, Domingues L, Teixeira J A, Vicente AA. The effect of the electric field on lag phase, p-Galactosidase production and plasmid stability of a recombinant Saccharomyces cerevisiae strain growing on lactose. Food Bioprocess Technol. 2012;5:3014-3020.
15. Portero Barahona P, Martin-Gil J, Martin-Ramos P, Briones Perez A, Carvajal Barriga EJ. Assessment of the effect of nitrogen concentration on fermentation and selection of a highly competitive Saccharomyces cerevisiae strain for efficient ethanol production. Energies. 2019;12:2614.
16. Zayats EM, Yanko MV. Influence of negatively charged air ions of the nutrient medium of Saccharomyces cerevisiae. Bui. BRFFI. 2022;101(3):62-68.
17. Godon C, Lagniel G, Lee J, Buhler JM, Kieffer S, Perrot M, Boucheriei H, Toledano MB, Labarre J. The H2O2 stimulon in Saccharomyces cerevisiae. Journal of Biological Chemistry. 1998;273(35):22480-22489.
18. Lin YH, Chien WS, Duan KJ. Correlations between reduction-oxidation potential profiles and growth patterns of Saccharomyces cerevisiae during very-high-gravity fermentation. Process Biochem. 2020;45(5):765-770.
19. Meledina TV, Manshin DV, Golovinskaia OV, Harbah K, Ivanova VA, Morozov AA. Factors affecting the electric charge of Saccharomyces cerevisiae cells. Storage and Processing of Agricultural Raw Materials. 2020;2:73-84.
20. Sultana S, Mohd Jamil N, Saleh EAM, Yousuf A, Faizal Che Ku M. A mathematical model for ethanol fermentation from oil palm trunk sap using Saccharomyces cerevisiae. IOP Conf. Series: Journal of Physics: Conf. Series. 2017; 890: 012050
21. Paciello L, Landia C, de Alteriisb Palma Parascandolaa E. Mathematical modeling as a tool to describe and optimize heterologous protein production by yeast cells in aerated fed-batch reactor. Chem. Eng. Trans. 2012;27:79-84.
22. Konopacka A, Konopacki M, Kordas M, Rakoczy R. Mathematical modeling of ethanol production by Saccharomyces cerevisiae in batch culture with non-structured model. Chemical and Process Engineering. 2019;40(3):281-291.
23. Manjarres-Pinzon K, Barrios Ziolo L, Arias Zabala ME, Correa Londono G, Rodriguez Sandoval E. Kinetic study and modeling of xylitol production using Candida tropicalis in different culture media using unstructured models. Rev. Fac. Nac. Agron. Medellin. 2021;74:9583-9592.
24. Meledina TV, Davydenko SG. Yeast Saccharomyces cerevisiae. Morphology, chemical composition, metabolism. Textbook, Saint-Petersburg University of Fine Mechanics and Optics. 2015.
25. Oktyabrskii ON, Smirnova GV. Redox potential changes in bacterial cultures under stress conditions. Microbiol. 2012;81:131-142.
26. Lee KL, Singh AK, Heo L, Seok C, Roe JH. Factors affecting redox potential and differential sensitivity of SoxR to redox-active compounds. Molecular Microbiol. 2015;97(5):808-821.
27. Martinovich GG, Cherenkevich SN. Redox processes in cells. Monograph. Minsk: BSU Press; 2008.
28. Beckman IN. Mathematics of diffusion: A textbook. Moscow: OntoPrint Publishing House. 2016:400.
29. Yanko MV, Zayats EM. Air ion activation of some microbiological processes. Argopanorama. 2019;131(1):28-29.
30. Liu CG, Lin YH, Bai FW. A kinetic growth model for Saccharomyces cerevisiae grown under redox potential-controlled very-high-gravity environment. Biochem. Eng. J. 2011;56(1-2):63-68.
31. Riznichenko GYu. Mathematical modeling of biological processes. Models in biophysics and ecology. Textbook for Universities, 2nd edition. Moscow: Yrayt Publishing House; 2019.
32. U. T. Berdiyev, U. N. Berdiyorov, U. B. Sulaymonov, L. U. Khalikova; Ways to improve the energy performance of asynchronous electric motors of rolling stock. AIP Conf. Proc. 15 March 2023; 2612 (1): 050017. <https://doi.org/10.1063/5.0117784>
33. Research of energy-saving composite materials for electric motors Utkirbek Sulaymonov, Aleksandr Jelutkevich, Malika Nabiyevna, Oybek Sayfullayev and Ulug’bek Berdiyorov E3S Web Conf., 461 (2023) 01054 DOI: https://doi.org/10.1051/e3sconf/202346101054
34. S. F. Amirov, Sh.A. Sharapov, A.Kh. Sulliev, O.T. Boltaev. Biparametric resonant transformer sensor of large linear movements. AIP Conf. Proc. 26 December 2023; 2624 (1): 030007. DOI: 10.1063/5.0132847
35. Pirmatov N.B., Berdiyev U.T., Usmonov K.K., Nazirkhanov T.M., Berdiyorov U.N. Device for measuring the magnetic scattering field of the frontal part of the stator winding of a traction asynchronous electric motor of an electric rolling stock. (2023) E3S Web of Conferences, 401, art. no. 03021, DOI: 10.1051/e3sconf/202340103021
36. Yusupov D.T., Ismoilov I.K., Berdiev U.T., Kutbidinov O.M. Development of a simulation model for assessing the technical condition of the cooling system of oil power transformers by measuring the temperature of the tank and the external environment 15th International Conference on Thermal Engineering: Theory and Applications, ICTEA 2024. No. 1, vol. 12024.
37. Berdiyev, U., Berdiyorov, U., Toshpulatova, M. «[Problems and Tasks of Creating Energy-Saving Electric Machines](https://www.scopus.com/pages/publications/85132979260)». [Aip Conference ProceedingsOpen source preview](https://www.scopus.com/authid/detail.uri?authorId=57219315612), 2022, 2432, 020002.
38. Berdiev, U.T., Kolesnikov, I.K., Tuychieva, M.N., Khasanov, F.F., Sulaymonov, U.B., Methods of new technological developments of electric motors based on soft magnetic materials. E3s Web of ConferencesOpen source preview, 2023, 401, 03038
39. Sauchuk HK, Yurkevich NP, Akhmedov AP, Kolesnikov IK, Berdiyev UT, Khudoyberganov SB, Khakimov SH Physical and thermal properties of binary (Bi-Ti-O)-TiO2 UHF-ceramics (2024) https://www.scopus.com/ inward/record. uri?eid=2-s2.0-85199155227&partnerID=40&md5=ccbd0010d5 ffcfaa5e 077619c15e6149