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# Controlled Glycolysis as the Basis of Beer Technology with Specified Consumer Properties

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ABSTRACT
The paper presents the aspects of beer production with a specified ethanol content and different taste and aromatic properties. The necessity of changing the classical brewing technology at the main fermentation stage is stated. The technical and technological decisions on division of the main fermentation into the stages of breeding of beer yeast and glycolysis are presented. A new generation intelligent neural network (INN) is offered, which ensures the performance of the set quality standards for the finished product. Corrective measures are proposed. It is grounded that the choice of beer yeast family should be determined by the optimal combination of cultures with amylotic and proteolytic properties. The requirements for yeast growth conditions are formulated. It is justified that obtaining the specified ethanol content during glycolysis should be ensured by anaerobic content of the culture medium and dosed addition of digestible sugars. It is shown that the necessary flavour bouquet at the given beer strength can be provided by adding the additives - carriers of hop bitterness and malt flavour, introduced in certain ratios. To meet the consumer preferences, groups of beers with different flavour and aromatic properties are offered.

**Keywords:** beer, intellectual neural network, main fermentation, glycolysis, flavour bouquet of beer.

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## INTRODUCTION

1. Problems with automatization of main fermentation technology.

Modern "smart" automation of the brewing industry comprises all stages of brewing: from the acceptance of malt to the bottling of the finished beverage. This system allows remote control of the brewing process and timely analysis of all incoming information [1]. However, existing automation systems do not allow controlling the parameters of biotechnological processes of the main fermentation. In the opinion of the Chinese specialists [2] it is possible to control the fermentation process automatically. Automation principles are aimed at improving the quality of beer and reducing costs for its production. The disadvantages of modern automated control systems include the missing connection of technological parameters with the quality of semi-products and the final brewing product.

To solve this problem, the authors of the article developed a methodological basis for evaluation and management of beer quality with specified consumer properties and technology for its production in conditions of information uncertainty, proposed a number of technical and technological solutions [3-11]. The introduction of original author's developments should be considered as a serious breakthrough in the technology of beer with the given taste and aromatic properties.

2. Problems of controlling the taste-aromatic bouquet of beer.

A German researcher, Dr. Morten Meilgaard, should be considered the founder of the quantitative evaluation of the taste and aromatic properties of beer. M.C. Meilgaard proposed to classify flavor-aromatic substances of a finished product into four groups taking into account the predominance of concentrations of these substances over their sensory thresholds [12, P.119-128]. However, the complex quantitative estimation of taste-aromatic parameters of beer was not carried out by him.

We have proposed [3; 13, pp. 13-23; 14, pp. 30-35] a complex assessment indicator - "taste dose", recommended as a criterion for assessing the taste and aromatic properties of a beer brand. It is suggested to determine the taste dose as a ratio of the actual concentration of a taste-aromatic component present in 1 liter of beer to its concentration which determines the " identification threshold" of this component. It is suggested to determine the taste and aroma of the beer brand by the sum of doses of taste components - the main carriers of taste and aroma.

On the basis of statistical data and our own research [13, 14] we have established that the taste and aroma bouquet of traditional (widespread) beer brands varies from 9.7 to 56.6 flavour units. It was offered "to prevent the sale of beer varieties with a total dose of taste less than 28 units and to provide tax preferences for beer varieties with a taste-aromatic bouquet over 100 taste units [14, P. 30-35]. Using of the proposed complex index allows to manage the contribution of the main flavor and aroma components in the "bouquet of taste and aroma" of beer and to model the required flavor and aroma profile of the finished product. In addition, it is possible to target beer as a beverage with predetermined properties, which is preferred by the consumer according to the set of flavour and aroma properties.

The authors of the article [15] tested the possibilities of chromatographic analysis to determine the actual concentrations of basic substances - flavouring carriers of ready beer and beer drinks. The received results of complex assessment testify to the possibility of differentiated assessment of taste-aromatic properties of beer and beer drinks. This fact is important for assessing the authenticity of beer.

To this day, the technological methods of changing the taste-aromatic set of beer have been widely spread, and the beginning of this trend was established in the USA in the 70s of the 20th century (information is taken from websites: https://culture.pl/ru/article/kraftovoe-pivo-pivnaya-revolyuciya; "Anchor Brewing Company" https://www.facebook.com/anchorbrewing/posts/1061016713982510)

3. Consumer preferences of beer drinkers.

It is known that beer producers are aware of consumers' opinions. At the same time, beer producers will change the ethanol content rather than focusing on the taste-aromatic bouquet of the finished beverage. For example, brewers in Scotland have mastered the cold distillation method to produce beer with over 60% alcohol content. [16]. However, the danger of 'beer alcoholism' requires a reduction in ethanol concentration even in 'strong beers'. It is known that one of the ways of struggle against "beer alcoholism" is the decisions of the World Health Organization (WHO) on daily rationing of beer drinking.

Many countries where brewers have learned to change the color properties of the drink for advertising purposes without fundamentally changing its taste and aromatic bouquet. Traditionally, "green" beer is brewed in Ireland and the Czech Republic. In addition, "coloured" beer is also brewed in Germany, Japan, Australia, China and even Russia (see information at https://kraspivo.ru/zelenoe-pivo/).

The Bavarian brewers take an original position, calling on technologists to return to the "Bavarian Beer Standards of 1516 year". [17]. However, in brewing technologies of that time beer yeast was not used and brewers had no information about the effect of yeast on taste and toxicity of the finished beverage.

Special studies of the authors of this article based on the fuzzy sets theory have shown that in Russia, more than 50% of consumers prefer varieties of "normal" beer, regardless of the regions of the country. To " normal " beer we classify beer of balanced taste and aroma by strength of no more than 5 %. Strong beer varieties are preferred by about 15% of consumers, while 79.8% of them are oriented to beer consumption with strength up to 5.0% [3, p. 38].

4. Necessity to change brewing technology

Brewers have always aimed to improve their technology. For example, the E.B. Nielsen [18, P. 149-157] and C.W. Bamforth [19, P. 26-29] suggested using enzymes to intensify barley germination. The use of specialized amino acid-carbohydrate compositions allowed reducing the brewing stages and improving the quality of the end product, making the brewing process manageable. Proposals by E.B. Nielsen and C.W. Bamforth were the basis for studying the possibility of using enzymes that stimulate biochemical processes in brewing. Detailed consideration of these methods is given in the studies of I.A. Debur [20, P.14-17] and C.W. Bamforth [21].

Special studies [22, P. 39-48] established the influence of main fermentation modes on beer taste and aroma: saturation of beer wort with oxygen during fermentation violates anaerobic glycolysis processes, deteriorating the properties of fresh beer. This fact required a change in the technology. In particular, at foreign breweries (Czech Republic, Germany, etc.) it has been shown that it is necessary to replace barbotage of fermenting wort with sterile air with carbon dioxide [23]. At the same time, it is reasonably stated that washing the fermenting wort with carbon dioxide allows to significantly reduce the concentrations of dimethyl sulphate, sulfur compounds and other volatile fermentation by-products (VBP). It is known that PPBs have a significant effect on the organoleptic properties of fresh beer. The research of M.M. Manasseina, E. Buchner and A.N. Lebedev substantiates the enzymatic nature of fermentation, which served as an inspiration for further study of the biochemical nature of fermentation.

However, in the brewing technology (main fermentation stage) two biotechnological processes that require different conditions are still combined: yeast growth and glycolysis. It is known that yeast growth requires oxygen (in concentrations of at least 12.0 $mgO_2/l$), while glycolysis (process of ethanol production), on the contrary, requires anaerobic conditions (oxygen content not exceeding 0.015-0.03 $mgO_2/l$).

Moreover, both processes are carried out in the same container, which contradicts the basic biotechnological principles. This is due to the difference in temperature regimes of both processes: for the growth of yeast biomass a temperature optimum of +32 0C is required, while for glycolysis of high-density wort lower temperatures are required: from +5.0 to +12.0 0C. V. Kunze believes that for reproduction of low fermentation yeast the temperature optimum in the range from +27 to +30 0C is recommended, and from +30 to +35 0C for top fermentation yeast [24, P. 102]. Russian brewers give preference to low fermentation yeast. In addition, a full set of amino acids, minerals and vitamins is also required for yeast biomass growth.

We propose to divide the main fermentation into two stages: yeast growth and fermentative controlled glycolysis process of prepared biomass yeast by using appropriate technical solutions (patent of RF № 2423417 "Method of beer production") [8].

5. New directions in beer production with reduced toxicological properties.

The "beer alcoholism" pandemic has led to the development in the most advanced beer-producing countries (Germany, Scotland) of a phytopharmaceutical direction. Its main point is the legislative correction of brewing technology, where brewers are obliged to introduce B vitamins or protector pharmacological substances into the finished product.

Thus, despite the differences in brewing technology, they cannot be considered as optimal: it is required to optimize the process management and flexible systems to ensure the quality of the finished product, taking into account the consumer preferences of the majority of consumers.

Purpose: to create conditions for obtaining beer with the specified content of ethanol and flavour-aromatic components by applying the INS, which provides correction of actual quality indicators from those specified by standards.

Objectives of the study

1) To substantiate the standard parameters of the beer yeast spreading tank;
2) to develop optimal conditions for ensuring beer yeast dilution;
3) to develop optimal conditions for glycolysis.
4) to substantiate the quality parameters of set properties of fresh beer.

## METHODS OF RESEARCH

Functional analysis of the above mentioned problems of brewing technology, method of structural matrixes and systematic diagrams for analysis of technical solutions; methods of quality indicators control; method of semi-product quality management by deviation from the set parameters.

## RESULTS

General principles of organization of a new type of intellectual neural network (INN) are described in the monograph [25]. For process control a fundamentally new model of the intellectual neural network (ANN) is proposed [6], the main difference of which is the new structure of the formal lower level neuron (Fig. 1). The organization of automated control of the brewing process in the form of a two-level neural network uniting step-by-step control centers in the form of modified formal neurons with the function of feedback and the ability to regulate the quality of a particular semi-product by corrective measures should be considered optimal. In this case, the formal lower level neuron of the INN receives measurement information about the real medium parameters.

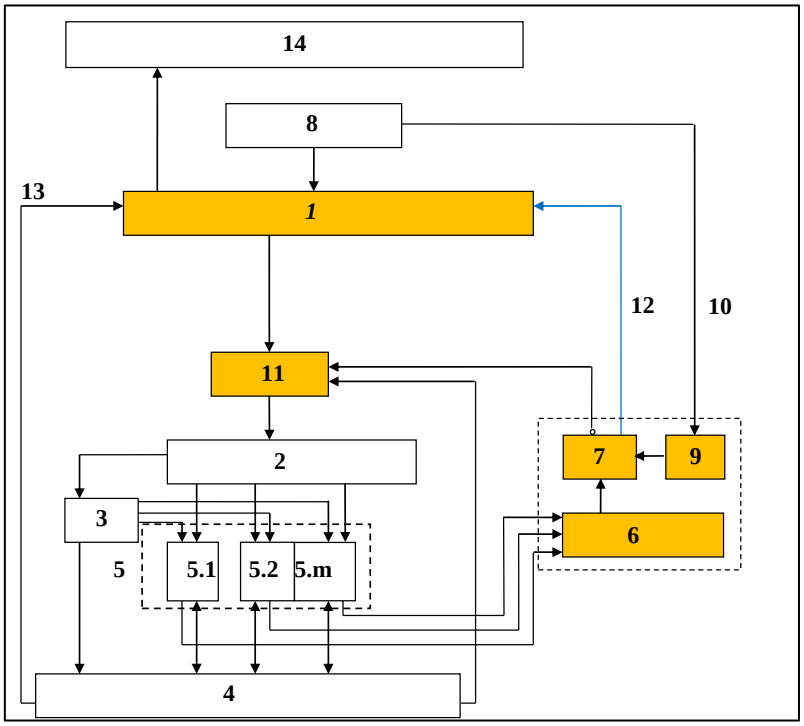



Figure 1: Proposed control structure for the main fermentation process

1: Control processor; 2: Control unit of the main process equipment; 3: Control unit of auxiliary equipment; 4: Unit for monitoring the technical condition of the equipment; 5. (5.1, 5.2, 5. m): The basic technological equipment of the given stage of the brewing process; 6: The block of quality monitoring; 7: The block of comparison of actual parameters of OU with the parameters set by the model (9); 8: The on-duty technologist-operator; 9: The standard of quality and safety of a semiproduct; 10: The special communication channel (correction of the standard); 11: The correction block; 12: The output signal of deviation of quality of an intermediate product for critical parameters (an alarm signal of a mismatch); 13: An emergency signal of a condition of the process equipment (an alarm signal of a condition of the process equipment).

The quantitative parameters of the information received are compared with standard criteria. Depending on the results of the comparison, a command is sent out for corrective actions necessary to achieve compliance between the required and real parameters.

The set process parameters are automatically supported by the monitoring unit (4). Any deviations are corrected via the communication line with the correction unit (11) through commands received by the main process equipment control unit (2). In addition, the INN provides for a more accurate control line: the semi-product quality monitoring block (6) provides information to the comparison block of actual semi-product parameters (7) with the established quality standard (9); if there is a mismatch, the system turns on the principle of "deviation from the standard", ie the information comes to the control processor (1) and the correction block (11), and then - to the control block of the main process equipment (2). If more subtle corrective actions are necessary, the auxiliary equipment control block (3) is activated. In special cases, the control of this process is corrected by the operator (8).

To develop the management system, specific versions of the INN have been developed: a single breeder tank of beer yeast

(RF patent No 98001) [9] and a fermentation tank for glycolysis (RF patent No 97130) [10].

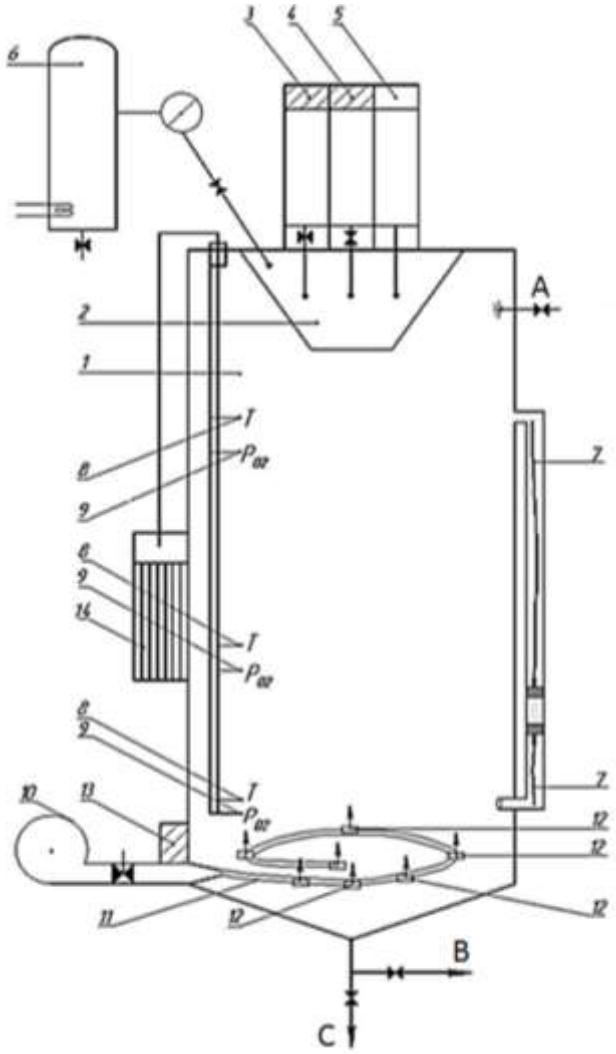
Standard parameters of the beer yeast spreading tank.
The offered design of the disintegration tank (propagator) represents a metal heated container of 5,0 m3 with a necessary set of the auxiliary equipment applied to reproduction of yeast (fig. 2). Our offered tank of disintegration [9] (the patent for useful model of the Russian Federation №98001) is equipped by the microprocessor functionally connected with feeders of vitamin and mineral additives to a wort, and also with automation tools of maintenance of composition of the reproduction medium, air temperature and speed required to optimize the biomass growth of the yeast to the "residual volume" for the main fermentation and to keep the yeast suspended, with the aeration nozzle placed at the bottom of the tank and designed as a series of nozzles. In the control processor of the INN, each volume of added wort is to be diluted with one volume of warmed water. When calculating the balance of nitrogen, carbon and mineral sources required for biomass production in the thinning tank, the following ratios are taken for dosing adjustment: one volume of plasmolizate and three volumes of wort per three volumes of water (Fig. 2).

Requirements for yeast reproduction conditions.
In order to ensure optimal conditions for yeast reproduction in the beer yeast biomass breeding tank, the following environmental quality parameters must be followed:

- Sufficient concentration of pure yeast culture from the Carlsberg flask (at least 50.0*106 cells/cm3);
- Concentration of dissolved oxygen (at least 8.0 mgO2/l);
- Maintaining the temperature optimum of the breeding medium (at least +32 0C):
- Active stirring to maintain suspended biomass of all breeding yeast;
- Necessary concentrations of nutritional elements of the growing medium required for reproduction of pure yeast culture.

For this purpose, feed of the culture medium in fractional portions is provided through the INN batchers: for each three volumes of wort three volumes of water and one volume of plasmolizate are added. From the experience of the microbiological industry it is known that in order to optimize the main fermentation process, the biomass of beer yeast required for glycolysis of wort can be obtained in a modified single fermentation tank in an optimized culture medium and under appropriate cultivation conditions. If the volume of the disintegration tank is not less than 5.0 m3, it is possible to obtain the concentration of yeast cells not less than 100.0*106 cells/cm3 on the third day of reproduction of usual portions of sown yeast (for classical reproduction conditions). Reproduction is considered to be complete (production of yeast biomass in the volume of "final quantity" has been achieved) at detection of cell concentration not less than 150,0*106 cells/cm3 from the tank of yeast culture in the sample. Achievement of this parameter is the basis for pumping the whole mass of yeast into the tank for glycolysis.

Development of a cultural medium for yeast reproduction.
There are various ways to enrich the culture medium with minerals, amine nitrogen and enzymes that accelerate the growth of yeast biomass. The English expert in the field of beer yeast farming wrote [26, P.193] that "yeast farming refers primarily to their simple reproduction and not to beer production". For accelerated biomass production of yeast the formulations of culture media have been suggested. Earlier it was proved [27; 28] that besides carbon and nitrogen the optimal composition of mineral additives is required. The optimal conditions have been obtained: at solution temperature +30°C and pH medium (equal to 3.8) the cell concentration was 30 g/kg with productivity 2 g/kg/h. For the qualitative fermentation of wort and the production of finished beer the volume of sown yeast is necessary, equal to 0.7-0.8 liters, which are added to the cylindrical fermenter for each hectolitre of wort.
The aim of the original technical solution we proposed was to develop a method for breeding beer yeast in a culture medium optimally adapted to the conditions required for breeding beer yeast.
In developing this method, we intended to use the biological resources of used beer yeast to the maximum in order to cultivate a new batch of sown beer yeast. In doing so, we preferred to use only plasmolysate of the yeast cell.




Symbols:
1 - Dispersion tank body;
2 - mixer of ingredients of culture liquid;
3 - beer yeast plasmolyzate dispenser;
4 - wort dosing unit; 5 - Carlsberg flask (seed yeast preserver);
6 - boiler (flowing water heater);
7 - remote float level meter; 8 - temperature sensors; 9 - meters of dissolved oxygen;
10 - blower;
11 - spiral distributor of air supply; 12 - air nozzles; 13 - control device of air nozzles;
14 - microprocessor (A - a washing water supply line; B - a yeast supply line in technological capacity (cylindrical-conical tank); C - discharge of the spent yeast into the sewerage system)

Figure 2: Scheme of a unified beer yeast spreading tank (Patent of the Russian Federation for utility model No. 98001) [9].

Ultrasound was used to destroy yeast cells. The shells of the destroyed cells were removed from the solution by centrifugation (rotational speed not less than 3000 rpm). We recommend to add proteolytic enzymes to the obtained plasmolysisate. The enzymes are needed to break down proteins into amino acids and nitrogen-containing components. These elementary structures provide the growth of biomass of the yeast. The lack of sugars in the plasmolysate crop mixture required for the biomass growth of yeast, the authors propose to compensate by carbohydrates of beer wort. For example, in the initial extractivity of 11.0% wort sugar concentration is 20.0 g/dm$^3$. Shortage of sugars in plasmolysate served as a basis to apply the wort as a source of carbon in a cultural liquid composed of yeast plasmolysate. That's why we recommended programming the output norms in the INN control processor: to add three volumes of wort per one volume of plasmolizate. Such approach allows to consider plasmolysate of yeast cell as an ideal culture medium for yeast reproduction.

The choice of yeast culture

It should be noted that the selection of the optimal yeast family in terms of its ability to form fermentation by-products (FPB) affecting the taste and aroma of the finished beer requires special attention. Methods of beer yeast selection considering their strain peculiarities are offered in special research by one of the authors of the article [3]. When choosing optimal combinations of beer yeast races, we consider the following features to be decisive: at least one race should combine the ability to produce the smallest amount of PPB and high flocculation capacity, along with a high degree of digestion and fermentation activity. The final conclusion about the possibility of application of the selected races should be made taking into account their physiological state: fermentation activity, flocculation capacity and degree of digestion.

At the same time it is necessary to take into account the well-known fact in brewing [22]: increase of the norm of yeast task leads to decrease of yeast growth and undesirable taste change due to decrease of higher alcohols content, increase of ethyl acetate content and decrease of isoamyl acetate concentration.

Proposed methods of control of medium parameters in yeast reproduction tank

1) It is recommended to count the number of yeast cells in the Goryayev chamber using a densitometer;
2) When monitoring the concentration of dissolved oxygen for the result it is recommended to take the average of three definitions (from the top, in the middle and at the bottom of the tank), carried out every hour by an automatic analyzer, for example, thermooximeter ANKAT-7655-05 (-06);
3) it is recommended to control the temperature parameter of the medium near the wall on three levels by temperature sensors;
4) It is recommended to supply sterile air to the duct system located near the bottom of the tank through the nozzles providing circular air supply to maintain suspended biomass of yeast (Figure 2). The operation mode of the blower shall be adjusted according to the concentration of dissolved oxygen;
5) for dilution of plasmolizate and wort portions a batch supply of heated drinking quality water from the boiler is supplied. In addition, the temperature of the supplied water must be regulated until the optimum temperature for yeast reproduction.
In this way, optimal conditions must be created for yeast reproduction (sufficient volume for complete glycolysis): correct selection of yeast races, availability of a complete culture medium, ensuring optimal oxygen concentration and maintaining the required temperature conditions.

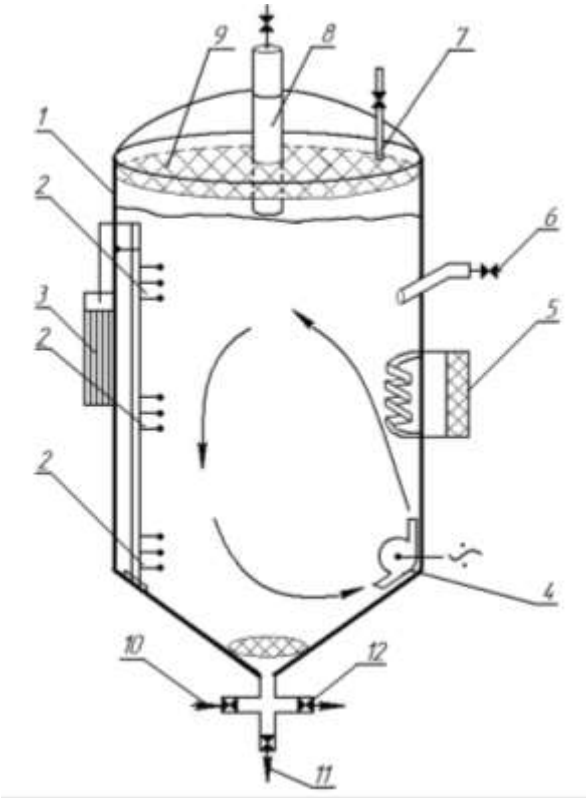
Justification of standard tank parameters for glycolysis.
We offer to carry out the obtained glycolysis in a conventional cylindrical-conical tank (CCT). However its construction should be upgraded with an integrated refrigeration unit 5, a submersible pump 4 providing weighted state of yeast biomass, a processor with a set of sensors 2 (Fig. 3). Yeast biomass addition is provided in the form of suspension in proportion to wort volume required for CCT filling. To significantly increase the ethanol concentration, an equivalent dose of maltose (ratio 180/92) should be introduced simultaneously with the beginning of yeast pumping into CCT. It is known that beer yeast is used for glycolysis of maltose in the first place, i.e. earlier than glucose or other sugars.

Increased yeast biomass will dramatically increase ethanol content. And it will happen before the degradation of beer yeast starts due to the absence of carbon sources and the phenomenon of polyauccession (use of other carbon sources with formation of higher alcohols by yeast). For glycolysis of yeast multiplied to the volume of "final quantity", except for providing the necessary amount of sugars, it is necessary to create low-temperature anaerobic conditions and to keep the whole biomass in the suspended state (temperature optimum from +2.0 to +4.0 0 0C in the oxygen mode providing tissue respiration - oxygen content not more than 0.015-0.03 mg/l).

Corrective measures to ensure optimum glycolysis conditions in the fermentation tank
For carrying out corrective actions we assume the technological solution of the following problems:

- Cooling of beer wort to temperatures optimal for glycolysis;
- removal of excessive oxygen concentrations from the fermentation tank;
- preventing osmotic shock of yeast biomass due to abundance of digestible sugars.

Cooling the medium as a way to reduce concentrations of by-products of fermentation.
It is technologically reasonable to reduce the wort temperature and automatically maintain a certain fermentation temperature by using the coils installed inside the fermenting machines (Fig. 3). As a cooling agent we recommend polypropylene glycol. For optimal glycolysis process the temperature interval from +5,0 to +8,0 0 C is required. The wort temperature should be reduced by no more than 1.0 C per day. At the end of glycolysis the temperature of fresh beer should be reduced to +2,0 ... +1,0 C.Such glycolysis regime will allow, in our opinion, to prevent secondary biochemical interactions of PPB (formation of ethyl acetate, methyl acetate and other secondary products).




Symbols:
1 - vat housing; 2 - bracket with temperature, density and pH sensors for wort;
3 - controller;
4 - submersible pump;
5 - refrigeration unit; 6 - sampling device;
7 - carbon dioxide discharge line;
8 - dosing unit input channel;
9 - foam extinguisher; 10 - wort and yeast introduction channel; 11 - draining into the sewerage; 12 - fresh beer diversion channel for filtration.

Figure 3: Fermentation vat for glycolysis

The difference in temperature conditions which are optimal for metabolism of beer yeast and formation of volatile (flavouring) substances contributed to unification of problems of fermentation temperature control and regulation of beer taste and aroma. It is known that high temperatures have a favourable stimulating effect on metabolism and yeast growth. However, higher fermentation temperatures promote more intensive formation of acetohydroxy acids and vicinal dicytones. The formation of higher alcohols and phenylacetate increases in the temperature range from +10.0 to +20.0 °C, while the formation of isoamyl acetate and ethyl acetate has a temperature optimum of about +1.05 °C. In the guidelines for the production of a number of Bavarian beers, the main fermentation is carried out at high temperatures and then fermentation at low temperatures for a short period of time. Experiments on alcohol control in experimental units with immobilized yeast also confirmed [20] the importance of temperature as a critical variable: the process at low temperatures and high retention times was the best compromise between a low alcohol content and the threshold value of toxic carbonyl compounds.

Thus, the temperature factor should be considered as a defining regulatory indicator of the efficiency of homogenization of the entire volume of fermented wort. In this connection, the precise control of the optimal temperature of the medium in the fermentation apparatus by the processor of the intellectual neural network should be controlled by an automatic system of temperature sensors installed over the entire volume of the fermented wort (Fig. 3).

Removal of excessive oxygen content.

It is known that oxygen saturation of wort during fermentation violates anaerobic glycolysis processes [22, P. 39-48]. The experience of foreign breweries (Czech Republic, Germany, etc.) shows the necessity to replace barbotage of roaming wort with sterile air with carbon dioxide [23, P. 17-21]. In this case it is fairly stated that washing the roaming wort with carbon dioxide leads to the removal of dimethyl sulphate, sulfur compounds and other volatile fermentation by-products that can negatively affect organoleptic properties of fresh beer. We offer carbon dioxide or nitrogen barbotage as an optimal solution for the removal of unwanted excess oxygen concentrations from the roaming wort.

Keeping all fermented yeast biomass suspended by periodic carbon dioxide barbotage (but not air) at 0.5$m^3$ $CO_2$ /hour per cubic metre of fermented wort is only permissible in the first hours after fermentation begins.

By command of the control processor of the intellectual neural network, the barbotage of the roaming wort with carbon dioxide should be stopped when the concentration of dissolved oxygen reaches 0.03 mg/l. Further mixing of yeast biomass and its maintenance in suspended state is carried out using a submersible circulation pump. In the developed device the line of carbon dioxide removal, formed during glycolysis, through the lid of fermentation vat is designed (fig. 3).

Batch supply of yeast with sugar for glycolysis.

We determined that in order to get beer with a given ethanol concentration it is necessary to get a norm of sowing yeast at the rate of 0.5 liters of liquid yeast for each hectolitre of wort. To produce beer with the required concentration of ethanol

the biomass of yeast should be supplied with carbohydrates in the volume required for production of the required amount of ethanol: for each 92,0 g of ethanol it is required to add 180,0 g of glucose. However adding the total volume of digestible sugars will inevitably lead to osmotic shock of beer yeast. Brewers long- ago conceded the need for fractional addition of sugars. It is important to note how sugars are added to the fermented wort under control of the dynamics of wort extractivity: if it remains the same, it means that the yeast is in osmotic shock and does not absorb sugar.

In order to ensure controlled glycolysis, we offer to add sugar to the fermenting wort continuously with sugar batchers. And for the control of the sugar/ethanol ratio in on-line mode we offer to use our developed flow ionometric analyzer [30].

The technological separation of the main fermentation into stages of reproduction of yeast and glycolysis that we propose will make it possible to control not only the amount of ethanol produced by yeast but also the flavour-aromatic bouquet. If for the breeding biomass of yeast the presence of ethanol is lethal for young cells (Grabtree effect), then for the mass of grown-ups prepared for glycolysis of yeast, ethanol, in the absence of sugars, becomes the carbon source from which the higher alcohols are formed (polyauxia effect, i.e. use of other carbon sources by yeast with release of higher alcohols). In this case, there is no need to introduce proteolytic enzymes or amine nitrogen portions necessary for the biomass growth phase of yeast. The control of glycolysis process can be organized by tracking the dynamics of ethanol concentration ratio to the amount of digestible sugars (according to the alcohol meter and saccharimeter): in case of insufficient ethanol concentration additional maltose intake is required. The required ethanol concentration should be a criterion of the main fermentation process completion. The process of glycolysis may take 36-50 hours. When the required concentration is reached, the INN processor sends a command for pumping fresh beer for filtration.

Thus, the division of main fermentation into the " fermentation" and "glycolysis" stages allows to manage glycolysis and to obtain a given ethanol concentration, while reducing the fermentation time and the content of fermentation by-products. Moreover, the process control is provided by the INN according to saccharimeter and alcohol meter readings.

Production of beer with specified properties.

The offered technology of glycolysis regulation allows to receive four basic groups of beer: "strong" (string beer), "bitter", "fragrant" and with "protector" properties. The groups of beer possess different flavor-aromatic properties and, as the research has shown, are most demanded in different consumer groups [25].

Upon completion of the main fermentation for fresh beer with a specified ethanol content we offer the following technological methods of giving different flavour and aromatic properties to the finished beer:

- to produce strong beer, it is enough to extend the fermentation time for the formation of excessive concentrations of higher alcohols, aldehydes and esters. The flavours of strong-alcoholic beer are characterised by a predominance of wine and alcoholic flavours.
- For the production of the bitter beer we suggest adding hop bitterness (in the form of iso-α-acids or xanthogumol in concentrations not less than 5.0 mg/dm3) at the given ethanol concentration not exceeding 4%m;
- To produce "fragrant" beer it is required to introduce 2% crystalline malt extract (malt flavor carrier), xantogumol (hop bitterness carrier) in concentration not less than 5.0 mg/dm3 and not less than 10.0 g/dm3 of glycyrrhizic acid (licorice root sweetness carrier naked) in concentration not more than 3%m of ethanol.
- Protective beer can be produced by adding vegetable additives with protective properties to any of the above mentioned beer groups. To ensure protective properties, additives are added to the finished beer before bottling.

The antioxidant properties of beer are given by non-toxic compound of divalent selenium (from 100 to 150 mg/dm3); hepatoprotective properties - by solution of standardized extract "Rastoropshi" (from 50 to 75 mg/dm3), adaptogenic properties - by eleuterococcus (from 8 to 10 ml/dm3). To ensure anti-allergic properties of beer it is suggested to add glycyrrhizic acid (less than 10 g/dm3) before bottling, and for anticarcinogenic properties - xanthogumol solution (concentration not less than 5.0 mg/dm3). The concentrations of plant supplements offered by us correspond to 30% of the adequate consumption level for an adult, which is in compliance with WHO international requirements.

## CONCLUSION

1) It is substantiated that the main (basic) fermentation stage in modern brewing technology is represented by an unacceptable combination of two biotechnological processes requiring different optimisation conditions.

2) The necessity of dividing the main fermentation stage into a stage "reproduction of yeast" up to the level of their "final quantity" and "wort glycolysis" by the biomass of yeast up to a given ethanol concentration has been substantiated.

3) The volume of "final quantity" of the required biomass of the yeast for the anaerobic stage of the main process (glycolysis) is proposed to be the volume of biomass of the yeast, approximately equal to four times of the biomass of the traditional seeded yeast norm. For full anaerobic glycolysis in the main fermentation tank it is necessary to create optimal conditions for keeping the biomass of the yeast suspended by a submersible recirculation pump.

4) It is recommended to control the main fermentation parameters in on-line mode by automated tools integrated in the smart neural network. The dynamics of ethanol and digestible sugar concentration ratios should be used as a basis for monitoring. In this case the main fermentation can be stopped when the specified ethanol concentration is reached or it can be continued until the specified ethanol concentration is reached by fraction addition of digestible sugars.

5) The original technological measures are offered to manage the ethanol content in the fresh beer and the taste-aromatic bouquet of the finished product. To control the taste and aromatic properties of the beer it is recommended to use

flavour-aromatic additives of plant origin. Focusing on the consumers' demands, it is proposed to create the main groups of beer with different flavour and aromatic properties: "strong", "bitter", "aromatic" and "protector".

6) To reduce the negative consequences of beer consumption, herbal supplements with hepatoprotective, antioxidant, anticarcinogenic, adaptogenic and anti-allergenic properties have been proposed. Our suggested concentrations of herbal supplements correspond to 30% of the adequate consumption level for an adult, which is harmonized with the international requirements of the World Health Organization.

## REFERENCES


1. Beer production control system. Access mode: https://allics.ru/articles/asutp-beer-production/ - 23.07.2019.
1. 2 Automation in brewing / EVOC GROUP [Electronic resource] - Access mode:
2. http://www.evocipc.ru/solutionssolutiondetail.aspx?id =AutomaticControlofBeerProduction - 23.07.2019. 2. Automation in Brewing / EVOC GROUP [Electronic resource] - Access mode: http://www.evocipc.ru/solutionssolutiondetail.aspx?id =AutomaticControlofBeerProduction - 23.07.2019.
3. Tretiak L.N. Methodological bases of an estimation and management of beer quality with the given consumer properties and technology of its production in the conditions of information uncertainty: Abstract of thesis... Doctor of Technical Sciences. - Moscow, 2013, 51 p.
4. Patent 2383587 Russian Federation. Beer production method. Tretyak L.N., Gerasimov E. - publ. 10.03.2010, Bul. № 7 - 11 p.
5. Patent 2391388 Russian Federation. Method of obtaining beer must. L.N. Tretyak, E.M. Gerasimov; - publ. 10.06.2010, Bul. № 16 - 10 p.
6. Patent 2396101 Russian Federation. Method of management of the brewing process. Tretyak L.N., E.M. Gerasimov, M.S. Zobkov; - publ. 10.08.2010, Bul. № 22 - 11 p.
7. Patent 2405812 Russian Federation. Filtration automatic machine. Treyak L.N., Gerasimov E.M., Zobkov M.S. - publ. 10.12.2010, Bul. № 34 - 10 p.
8. Patent 2423417 Russian Federation. Method of beer production. Tretyak L.N., Gerasimov E.M. - publ. 10.07.2011, Bul. №19 - 29 p.
9. Patent 98001 Russian Federation. Device for propagation of beer yeast seeds. Trettyak L.N., Gerasimov E.M. - publ. 27.09.2010, Bul. №27 - 2 p.
10. Patent 97130 Russian Federation. Low-temperature drying boiler. Tretyak L.N., E.M. Gerasimov - publ. 27.08.2010, Bul. № 24 - 2 p.
11. Patent 98091 Russian Federation. Device for drying and sterilizing grain products. OGU/Tretyak L.N., Gerasimov E.M. - publ. 10.10.2010, Bul. №28 - 2 p.
12. Meilgaard, M.C. Reference standards for beer flavor terminology system. Journal of the American Society Brewing Chemistets, 1982. - – №40/ – P.119-128.
13. Gerasimov, E.M. New Approaches to Assessment of Taste and Aromatic Properties and Toxicity of Beer Microalcohols / E.M. Gerasimov, L.N. Tretyak // Brauwelt - The World of Beer and Drinks. 2010, №3. - – C. 13-23.
14. Oganesiants, L.A. Beer quality standard. Requirements for biological value and safety / L.A. Oganesiants, M.V. Gernet, L.N. Tretiak // Food industry. - – 2014. - – №5. - – C.30-35.
15. Tretiak, L.N. Complex estimation of beer flavour-aromatic properties on the basis of chromatographic determination of concentration of fermentation by-products (in Russian) / L.N. Tretiak, D.M. Muslumova // Polzunovsky vestnik. - – 2019. - – № 1. - – pp. 119-127.
16. The strongest beer in the world contains 67.5% alcohol and is called "Snake poison". Access mode: https://www.syl.ru/article/322190/samoe-krepkoe-v-mire-pivo-soderjit-spirta-i-nazyivaetsya-zmeinyiy-yad-shotlandskie-pivovaryi-levish-shend-i-djon-makkenzi. - – 29.04.2020.
17. German law on purity of brewing [Electronic resource] // "Law on purity of brewing" / Beer. - [B.M.], 2019. - Access mode: http://bote.com.ua/content/rubric/zakon. - – 30.04.2020
18. Nielsen E.B. Brewing with barley and enzymes: A review / Nielsen E.B. // Proc.Congr. Eur. Brew. Conv. Estoril. 1971.Vol. 13. – P. 149-157.
19. Bamforth C.W. Beer: A proud past and promising future / Bamforth C.W. // Brewer Internationnal. 2001. Vol. 1. №2. – P. 26-29.
20. Debur, I.A. Improvement of fermentation in brewing: new technologies. / I.A. Debur // Beer and drinks - 2000 - № 4. - – pp. 14-17.
21. Bamforth, Ch. New in Brewing / Ch. Bamforth (ed.); per. from English E.S. Borovikova, I.S. Gorozhankina - St. Petersburg. Profession, 2007. - – 520 p.
22. Kruger, Lin. Yeast metabolism and its influence on beer taste and aroma / Lin Kruger // Brewery's companion: Vesna, 1999. - – pp. 39-48.
23. G. Millar et al. CCT of "Velke Popovice" brewery: yeast propagator, double-sided filling, washing and homogenization of yeast with CO2 // Beer and Life, P.17-21 // www.propivo.ru Beer @ Life magazine.
24. Kunze, V. Technology of malt and beer. SPb.: Profession. - – 2009. - 1064 p., P. 102.
25. Tretiak, L.N. Beer production technology with specified properties: monograph. - St. Petersburg. Profession, 2012. - – 463 c.
26. Quain, D.E. Yeast Introduction and Breeding // New in Brewing / edited by C.U. Bamfort. - St. Petersburg. Profession, 2007. - – C.193.
27. Author's certificate of the USSR №484696 C12C 11/18 (2000.01) Method of biomass production. /Jean-Amadrick du Chaffot and Claude Raymond Magnaud // The British Petroleum Company Limited. - publ. 15.09.1975; Bulletin No. 34. - – 3 p.
28. Author's certificate of the USSR №554281, C12C 11/18 Method of biomass production. All-Union Scientific

Research Institute of Protein Biosynthesis / Richter Klaus et al. 28.05.1974; publ. 15.04.1975. - – 3 p.

29. Kosminskiy, G.I. Features of beer wort digestion by multistage combinations of yeast (in Russian) / Kosminskiy, G.I.; Morgunova, E.M. // Izvestia vuzov. Food technology 2005. - – №1, pp. 53-55.
30. Patent 106379 RF, IPC 7 G01 N 33/14, G01 N 27/26. In-line ionometric express-analyzer. Tretyak L.N., Gerasimov E.M., declared. publ. 10.07.2011, Bul. № 19 - 2 p.