Technological and constructor solutions for the design of silage trenches using CAD

S N Kostarev\textsuperscript{1,2,4}, T G Sereda\textsuperscript{3}, O V Kochetova\textsuperscript{4} and K A Sidorova\textsuperscript{5}

\textsuperscript{1}Perm Military Institute of National Guard Troops of the Russian Federation, 1, Gremjachij log St., Perm, 614030, Russia
\textsuperscript{2}Perm National Research Polytechnic University, 29, Komsomolski Avenue, Perm, 614990, Russia
\textsuperscript{3}Perm State Agrarian-Technological University named after academician D N Prianishnikov, 23, Petropavlovskaja St., Perm, 614990, Russia
\textsuperscript{4}Perm Institute of the FPS of Russia, 125, Karpinskogo St., Perm, 614012, Russia
\textsuperscript{5}Northern Trans-Ural SAU, 7, Republic St., Tyumen, 625003, Russia

E-mail: iums@dom.raid.ru

Abstract. The features of the technological process of silage formation are described. A kinetic model of biochemical reactions in the preparation of silage juice was developed and investigated. The kinetic model was the ratio of the growth rate of the silage mass under the influence of a complex of factors on it: specific growth rate, concentration of microorganisms, the use of various additives. The models of emission processes occurring with the synthesis of methane and carbon dioxide are studied. A system of automated monitoring and control of the technological process of silage has been developed. The accounting and monitoring of greenhouse gases generated during silage decomposition is also an important environmental challenge. The design of silage trenches included calculations of the bearing capacity of the base and the stability of clay slopes. For the computer-aided design system, the AutoLISP software module of the AutoCAD environment was used. The developed computer-aided design system allows speeding up the construction of outline drawings with various geometric parameters of the silage trench.

1. Introduction
Silage is an important food in the ration of animals. The scientific substantiation and mathematical modeling of chemical and biological processes taking place in silage trenches will make it possible to obtain a better silage product and optimize process parameters.

2. Equipment and devices used in studies
In the work methods of mathematical modeling and data from laboratory experiments were used to develop technological design. In the design section, the AutoLISP module of the AutoCAD system was used. The automated monitoring and control system was built using the Omron complex.
3. The results of the study and their discussion

3.1. Studies of the technological process of silage formation

The following conditions are necessary for the production of silage: energy and carbon sources; nutrients; lack of inhibitors; appropriate physical and chemical conditions [1]. During biodegradation of the grass mass, an acid silage solution (pH 3.9 – 5.4) is formed during fermentation, containing 20 – 90 g/l of dry matter, 18 – 87 g/l of organic matter, 30 – 50 g/l of water-soluble carbohydrates, acids and others substances. Leakage of the silage solution is detrimental to the environment, which is why it is important to calculate the coefficient of infiltration of the protective screen of the silage trench. The process of biodegradation of hay and the formation of silage proceeds in two phases: the first is acidic, and then, with a decrease in the mass of atmospheric oxygen spent on chemical reactions, the second phase begins – methanogenesis. Available atmospheric oxygen in the feed is used by plant enzymes. With a lack of oxygen, fermentation occurs under anaerobic conditions. Lactic acid bacteria present in small quantities begin to multiply to a concentration of $10^9$ cells/g, using sugars formed during the destruction of plant cells.

Various silage additives are proposed to accelerate silage processes. Silage additives are divided into two main groups: inhibitors and stimulators of fermentation. Inhibitors are acid supplements, stimulants are sources of carbohydrates. Currently, suspensions consisting of anaerobic microbial cultures containing propionic acid bacteria (PCB), lactic streptococcus (AMS), pentose-protecting lactic acid bacteria (PMB) and other micronutrient solutions are used as silage additives [2,3].

3.1.1. Kinetics studies of substrate utilization models. The simplest model of an ideal first-order reactor describing the growth of silage mass is determined by the differential equation [4]

$$\frac{dc}{dt} = \mu c,$$

where $c$ – is the concentration of bacterial biomass, mol/l.

Models of mixing reactors representing mixers for obtaining biologically active feed additive are known [5,6]. The theoretical basis of bacterial cultivation was described in Mono's works [7]. The improved Jerusalem-Mono Model included a nutrient substrate saturation coefficient

$$\frac{dc}{dt} = \nu \frac{c}{k_s + c} + k_p,$$

where $cP$ – is the concentration of the metabolic product; $k_s$ – is the saturation coefficient of the nutrient substrate, mol/l; $k_p$ – is the saturation coefficient of the metabolic product, mol/l.

Theoretical bases of continuous cultivation of bacteria were stated in Malek’s works. When taking into account the enzyme reactions are based on the following scheme

$$f + s \xrightarrow{k_s} [fs] \xrightarrow{k_p} f + p$$

where $f$ – enzyme, $s$ – substrate, $[fs]$ – enzyme-substrate complex, $p$ – reaction product.

3.1.2. Material balance of substances. The substance balance equation for the total substrate is following [8]:

$$V \frac{dS_1}{dt} = F(S_0 - S_1) - \frac{\mu X_1}{Y_{ss}} V$$

where $F$ – volumetric flow rate of the liquid phase, l/day; $S_0$ – substrate concentration at the input; $S_1$ – substrate concentration at the output; $\mu$ – growth rate, day$^{-1}$; $V$ – volume of the silage juice, l;
X1 – concentration of bacteria produced; Yx/s – produced by bacteria mol/mol substrate consumed.

The balance of the biomass of bacteria, taking into account the loss of organisms due to poisoning with toxic substances, is described by the equation

\[ V \frac{dX_1}{dt} = F(X_0 - X_1) + \mu X_1 V - KT_X V \]

where KT – coefficient of toxicity, mol of bacteria biodegradation / mol of toxic substance per day; TX – concentration of toxic substance, mol/l.

The formation of carbon dioxide in the gas phase is described by the equation

\[ \frac{dP_{CO_2}}{dt} = -P_D V T_0 - \frac{P_{CO_2} Q}{V_g} \]

where D – volume of 1 mole of gas; V – volume of liquid in the reactor, l; PT – total pressure of CO2 and CH4 in the gas phase, \( P_{CO_2} \) – partial pressure of CO2 in the gas phase, Q – total volume flow of gases, \( Q_{CH_4} + Q_{CO_2} \), 1/day.

The developed generalized model of anaerobic silage bioreactor based on the considered dependences is shown in figure 1.

Figure 1. Silage production bioreactor model: \( Q_m(t) \) – input flows; \( Q_p(t) \) – output flow of products; \( D(x,t) \) – distribution of substance inside the silage trench.
3.1.3. Development of automated monitoring system. During the ensiling process, complex biochemical and microbiological changes occur. Operational monitoring and control of the technological ensiling process will allow to achieve a better raw product [9]. Biochemical processes are closely related to the physical parameters of the silage. The speed and direction of biochemical reactions strongly depend on the temperature, humidity and density of silage, which, in turn, due to isothermal reactions of transformation of substances affect physical processes [10]. Software and hardware with Omron controller is developed for monitoring and control of ensiling process [11]. The operator panel is shown in figure 2.

![Operator panel](image)

**Figure 2.** Operator-technologist’s panel.

3.2. Automation of design solutions

3.2.1. Calculations of the bearing capacity of the base of the silage trench with a natural clay screen. When modeling mechanical processes in the design of the silage trench, the calculation of the possible movement of the soil of the silage storage bases, its sediment and deformation, both in normal operation, and as a result of the application of various control procedures (compaction, layer-by-layer laying of the silage) is presented (table 1).

| Methods of calculation                  | Implementation                  |
|----------------------------------------|----------------------------------|
| Linear-deformed layer                  | Homogeneous ground base          |
| Equivalent layer                       | Water-saturated soils            |
| Layer-by-layer summation               | Trench                           |
| Cylindrical sliding surfaces           | Calculation of slope stability   |
| Leaning slope                          |                                  |
As the mechanical processes investigated in the design and exploitation of the silage storage, the possible movement of the soil of the silo base, its sediment and deformation, also as a result of the application of various sealing procedures, layer-by-layer laying of the silo.

The calculation of soil bases of silo storage consisting of three blocks: calculation of stability of lateral slopes, strength calculation of bearing capacity of the basis and calculation on deformations (Soil bases of buildings and structures – 22.13330.2011) is executed in work. The choice of the deformation calculation method depends on the geological conditions and the method of silage. Calculation of silage sediment is presented by methods of calculation of linearly deformed layer, equivalent layer and layer-by-layer summation. In applying the method of calculation linear-deformed layer deals with the formulation and solution of the problem of compacting of a layer of silage from one-dimensional model models that take into account only the linear sediment, or three-dimensional, considering the lateral expansion.

3.2.2. Calculation of slope stability. In the course of development of silos of horizontal type at planning of platforms stability of arrays of soils in slopes is calculated. The device of gentle slopes will sharply increase the cost of construction. Steep slopes can lead to an accident, and therefore it is necessary to determine the maximum optimal steepness of storage slopes. When modeling is considered perfectly dry ground (the force of cohesion \( c = 0 \), the angle of internal friction \( \varphi \neq 0 \)) and perfectly viscous soil (with \( c \neq 0, \varphi = 0 \)). In the first case, the slope angle calculation model is expressed by the functional dependence \( \alpha = f (\varphi, \beta, Yn) \), where \( \varphi \) is the angle of internal friction, \( \beta \) angle of deviation from the vertical, \( Yn \) the reliability coefficient. In the second-the calculation of the slope height \( h = f (c, Y, Yn) \), where \( Y \) is the relative coordinate.

According to the theory of limit equilibrium, the maximum pressure on a horizontal surface of the soil in which the slope of the shape remains in equilibrium, and define the form equally stable slope steepness limit. The horizontal surface of the equidistant slope carries a uniformly distributed load.

3.2.3. Design of silo trench in AutoCAD. The program of automatic construction of a silo trench in AutoLISP language is developed. The initial data for the design were: depth, width, length of the trench and the slope angle of the slopes. The program builds a sketch drawing of the silo trench (figure 3: side view and top view), on which the dimensions are marked.

![Figure 3. Sketch drawing of the silage trench.](image-url)
4. Conclusion
Technological parameters of the silage juice bioreactor were investigated, chemical and biological processes during irrigation of the silage pit with bio-solution were investigated. The program of automated monitoring of technological processes and conceptual design of silo trenches is developed.

References
[1] Wang Y et al. 2019 The bacterial community and fermentation quality of mulberry (Morus alba) leaf silage with or without Lactobacillus casei and sucrose Bioresource Technology 293 122059
[2] Wang D et al. 2019 Effects of Piromyces sp. CN6 CGMCC 14449 on fermentation quality, nutrient composition and the in vitro degradation rate of whole crop maize silage AMB Express 9(1) 121
[3] Comino L et al. 2014 Effects of an inoculant containing a Lactobacillus buchneri that produces ferulate-esterase on fermentation products, aerobic stability, and fibre digestibility of maize silage harvested at different stages of maturity Animal Feed Science and Technology 198 94–106
[4] Veluchamy C, Gilroyed, B H, Kalamdhad A S 2019 Process performance and biogas production optimizing of mesophilic plug flow anaerobic digestion of corn silage Fuel 253 1097–103
[5] Ramm P et al. 2019 Optimized production of biomethane as an energy vector from low-solids biomass using novel magnetic biofilm carriers Applied Energy 251 113389
[6] Skinner C 2019 The impact of long-term organic farming on soil-derived greenhouse gas emissions Scientific Reports 9(1) 1702
[7] Benchaar C, Hassanat F 2019 Methane emissions of stored manure from dairy cows fed conventional or brown midrib corn silage Journal of Dairy Science 102(11) 10632-38
[8] Sereda T G, Kostarev S N, Elancheva E N 2014 Study Safety Environmental Protection Landfills Using Models Anaerobic Digesters Applied Mechanics and Materials 682 339-345
[9] Shan G et al. 2019 An automatic smart measurement system with signal decomposition to partition dual-source CO2 flux from maize silage Sensors and Actuators, B: Chemical 300 127053
[10] [Krzeminska I, Oleszek M, Wiacek D 2019 Liquid anaerobic digestate as a source of nutrients for lipid and fatty acid accumulation by auxenochlorella protothecoides Molecules 24(19) 3582
[11] Kostarev S N and Sereda T G 2017 Development of software and hardware models of monitoring, control, and data transfer to improve safety of downhole motor during drilling IOP Conference Series: Earth and Environmental Science 87(3) 032016